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Recommended Performance-Related Specification for Hot-Mix Asphalt Construction: Results of the WesTrack Project

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Contractor's Supplemental Technical Reports for NCHRP Project 9-20
Submitted November 2000

National Cooperative Highway Research Program
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Driverless Vehicle Integration

U.S. Department of Transportation
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PROJECT DESCRIPTION

WesTrack was an experimental road test facility constructed in Nevada under a contract awarded by the Federal Highway Administration (FHWA) and entitled "Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction" (Contract No. DTFH61-94-C-00004). The WesTrack Project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for hot-mix asphalt (HMA) construction by evaluating the impact on performance of deviations in materials and construction properties (e.g., asphalt binder content, air void content, aggregate type, and aggregate gradation) from design values in a large scale, accelerated field test.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

The accomplishment of the above objectives was achieved through the construction, loading, monitoring, and performance evaluation of 26 experimental HMA pavement sections along a 2.9-km (1.8-mile) oval test track.

One of the subtasks of the WesTrack Project involved the use of autonomous (driverless) vehicle technology to meet the desired objectives. WesTrack utilized driverless vehicle technology to allow near-continuous vehicle operation in an otherwise monotonous driving environment. Four triple-trailer combinations were designed, developed, and certified to operate on the track up to 22 hours per day, 7 days per week to meet the loading goals.

The triple-trailer vehicle combinations were operated an average of 15 hours per day over the 2½-year period.

A team of truck and truck-component manufacturers was assembled to support the test and provide the best in advanced transportation technologies. The vehicle team members participating in the WesTrack Project included the following companies and specialities:

- Navistar: Class 8 vehicles (International tractors).
- Detroit Diesel: advanced engine control.
- Twin Disc: automatic transmissions for heavy power requirements.
- Goodyear: tires.
- Haldex Brake Systems: brake-by-wire and ABS technology.
- Alcoa: aluminum wheels.
- Disc-Lock: advanced fasteners for wheels.
- Shell Oil: vehicle lubricants.
- East Pennsylvania Manufacturing: batteries.

TRACK CONFIGURATION

The track consisted of two tangent sections connected by two spiral curves. All test sections were constructed on the straight tangents between the turnarounds. The tangent sections were 10.4-m (34-ft) wide, consisting of two 3.7-m (12-ft) lanes and a 1.2-m (4-ft) HMA shoulder outside the test lane. There was a 1.2-m (4-ft) gravel shoulder on the outside of the track and a 0.6-m (0.2-ft) gravel shoulder on the inside of the track. The outside lane served as the "test" lane, while the inside lane served as both a shoulder and "trial" HMA placement lane. Each of the experimental sections was 70 m (230 ft) in length: 25 m (82 ft) for transition, 40 m (131 ft) for performance monitoring, and 5 m (16 ft) for destructive sampling. Figure 1 shows the layout of the test track.

VEHICLE LOADING

The pavement loading was accomplished using four triple-trailer vehicle combinations (figure 2). Navistar supported the test with four similar conventional tandem-axle Class 8 tractors. This configuration provided a total of 10.48 80-kN (18,000-lb) equivalent single axle loads (ESALs) per truck/trailers pass. The truck configuration is common for the western States.

To aid in the electronic control of the trucks through the driverless vehicle system, the trucks were equipped with a Detroit Diesel Series 60, turbo charged, electronically controlled engine (figure 3). Twin Disc automatic transmissions in each truck allowed electronic control of the transmission. The trucks and trailers were equipped with a Haldex Brake Systems Antilock Brake System (ABS) and electronic brake valve for electronic control of the brake system. The trucks were equipped with 295/75R22.5 Goodyear tires. The cold inflation pressure of the tires was set at 690 kPa (100 lbf/in^2). Each axle of the vehicle train was loaded to 89 kN (20,000 lb), except for the front axle of the tractor, which was 53 kN (12,000 lb). The test speed around the track was 64 km/h (40 mi/h).

The following are the major features of the driverless trucks that aided in their proper operation. The block diagram in figure 4 shows the multiple computers and redundant control systems integrated into the truck/trailer combination for fail safe operation and continuous safety monitoring.

GUIDE-BY-WIRE SYSTEM

The driverless vehicle system utilized a guide-by-wire system for the lateral and longitudinal control of the trucks. Additionally, every system controlling the trucks was designed with a backup in the event of primary system failure. All track and control room systems were connected to uninterruptible power supplies in the event of power loss.

Primary and backup wires buried under the asphalt gave a continuous feedback signal to the steering controller that guided the trucks. Audio amplifiers powered the two continuous wire loops installed around the track. As shown in figure 5, each vehicle was equipped with guidance antennas mounted to the front bumper to acquire the guide tones emitted by the redundant wires. The vehicle antennas were capable of reading either primary or alternate wire paths. A

proportional integral differential (PID) control loop was used within the control system to guide the trucks. A robust stepper-motor was connected to the steering gearbox and controlled the steering based on feedback from the antenna and the error signal generated from displacements from the center of the wire (figure 6).

TRAFFIC CONTROL

The four trucks were controlled and monitored through a control room located beside the test track. Computers in the control room, shown in figure 7, were used to initiate the starting and stopping of the vehicles and to regulate vehicle spacing and speed for traffic control purposes.

The traffic control and longitudinal control utilized radio frequency (RF) serial modems to communicate with the four trucks. Each truck had an RF serial modem for sending/receiving information packets to the control room. The control room had four RF serial modems for sending and receiving information packets from each truck. Each modem was on a separate frequency. As a final judge of the vehicle spacing, a differential global positioning system (DGPS) independently monitored the position of the trucks and provided a fail-safe input to the traffic control computer.

Traffic was managed by referencing high-resolution odometer positions that the trucks reported twice per second to the control room. The trucks also reported their odometer positions once per lap when they passed over a radio beacon located on the track surface. Truck spacing control was maintained by adjusting the directed speed of the individual trucks so that they remained equally spaced around the track. This control system resided in the first of the two computers; it was backed up by the second, which used the DGPS data reported by the trucks once per second. The second computer compared the DGPS data to the odometer-generated positions and used both to continuously verify that the spacing tolerance between trucks had not been violated.

In addition to controlling the truck spacing, the traffic management computer periodically, or on manual request, commanded the vehicle equipped with strain gauges and accelerometers to take high-resolution dynamics data as it passed strain gauges in the pavement at specific locations along the track. This computer also provided a graphical display of the steering deviation of the trucks relative to the guide wire. For each truck, the positions of the tractor and the last trailer could be displayed so that the tracking performance of the triple-trailer combination could be examined as it circled the track.

The safety monitoring computer verified the truck spacing from the DGPS data and interfaced with a lock board that contained safety keys for all of the trucks. The truck control authority was passed to the control system only when the safety key had been inserted and locked. This provided a hardware method of removing a truck from automatic operation. When the truck was in maintenance, the safety key for that truck was removed from the lock board and commands could not be sent to that truck.

In addition to the traffic management and safety computers, vehicle monitoring computers were located in the control room. These computers continuously verified that all truck and control systems were operating properly. The screens of the vehicle monitoring computers were displayed in a "red-yellow-green" format. If a parameter display was green, it indicated that the system was operating well within the tolerances set for that system. If a parameter was yellow, the system was getting close to the upper or lower limit. If the parameter was red, all trucks were stopped automatically, and the control room operator got an instant, visual reading of the problem.

ON-BOARD CONTROL COMPUTERS

Each vehicle had two on-board computers, one for vehicle control and one for vehicle monitoring, as shown in figure 8. The computers were located in the sleeper section of the truck in a shock-mounted cabinet. The guidance and steering control activated the steering actuator connected to the steering system. The monitoring computer performed a check of truck health that included more than 160 parameters normally evaluated by a driver.

The control room operator had one computer for each truck that displayed the status of the truck in an easy-to-read format and had diagnostics to aid in monitoring and correcting critical control parameters. A vehicle monitoring computer checked the critical components and provided decisions to the control computer on the status of the vehicles. If a critical parameter was out of bounds, the vehicle monitoring computer would transmit a shutdown signal to the control computer.

SPEED CONTROL

The Nevada Automotive Test Center (NATC) staff had automated the control of the throttle, engine, and transmission by using advanced electronics on the engine and automatic transmission electronic control unit as shown in figure 9. The brake interface builds upon Haldex Brake Systems' electronic brake valve and controlling circuitry. Haldex's Antilock Brake System (ABS) was installed on the truck and all trailers to allow controlled stopping during normal and emergency braking.

BRAKE CONTROLS

The final set of truck controls (for the brakes) performed three separate functions. The first was for routine stops and was performed by computer control of a conventional air-brake system. A proportional valve provided an air pressure that was in proportion to an analog command from the control system. In addition to the proportional valve, a parallel solenoid valve conveyed the full-system air pressure to the brakes in the event of a detected failure. The secondary computer in the truck controlled this solenoid valve. The solenoid valve is normally open, and it must be continuously energized to keep the valve closed and to prevent the brakes from being applied. In the event of a loss of power to the control system, the solenoid valve opens and the brakes are applied. This system is also used for several emergency braking scenarios.

The second function of the braking interface was to control the whip of the triple-trailers. Steering adjustments, if severe and rapid, could be amplified through the length of the trailers and potentially result in a loss of control. Such adjustments might occur in the event of a steering-tire blowout. To control whip, the brakes on the last axle of the third trailer were applied by a solenoid valve located on the third trailer and were controlled by one of the computers in the truck.

The final function of the brake controls was antilock braking. An antilock braking system was included in the trucks to ensure stability of the trucks under emergency braking conditions. It operated on all of the truck axles, except the steering axles where the brakes had been disconnected. The antilock braking system performed well. The system was tested in many hard braking modes, including full air pressure to the service brakes through the backup solenoid valve. This last test produced a very short stop, but, as in all of the other tests, the tires did not lock.

PAVEMENT INSTRUMENTATION

WesTrack implemented a unique pavement measurement capability not available at any other pavement research facility. Through the driverless vehicle controls, the lateral and longitudinal location of the truck was precisely defined at all locations around the track. This allowed the longitudinal location of the trucks to be defined within 50 mm (2 in.) of any measurement sensor installed in the pavement. This exact alignment included all the phase delays associated with the data acquisition computers on the truck and data acquisition computers for the track.

VEHICLE INSTRUMENTATION

One of the triple-trailer vehicle combinations was instrumented at each axle end with accelerometers and shear strain gages. This instrumentation allowed investigation of vehicle dynamics with respect to stationing along the track and measurement of dynamic loading as each truck axle passed over the pavement strain gages. The alignment and correlation of pavement strains with dynamic forces on the vehicle provided a unique investigation and model validation tool for the ongoing WesTrack research.

TRUCK HEALTH DATA

To be sure that the trucks were operating safely and without mechanical or electrical problems, the health of the systems in each truck was checked and evaluated every half second. Data were acquired from four sources aboard the truck and then transmitted to the control room. The Detroit Diesel electronic control (DDEC) from the Series 60 engines provided engine data and some vehicle data over an SAE J1708 data bus. The system monitored this bus and extracted data of interest. Additional pressure, temperature, and voltage sensors were installed in the vehicle to measure truck parameters, such as cab temperature and power steering fluid temperature, that is not monitored by the DDEC III system. One of the trucks was equipped with a set of accelerometers and strain gauges to measure the forces on the axles of the truck. These accelerometers and strain gauges had very severe signal-processing requirements to maintain precise timing alignment with other pavement signals.

The data from the four sources were accumulated by the two computers in each truck, combined with the vehicle-control information, and sent back to the control room over the spread spectrum radio-frequency modem links. The data rate was 9,600 baud. In the control room, these data were captured by a data acquisition computer and were downloaded once a week to CD-ROMs for permanent storage.

The dual guidance antennae were mounted in a wooden housing attached to the front bumper of each of the four test vehicles.

LESSONS LEARNED FROM THE WESTRACK DRIVERLESS TRUCKS

Over a period of 2½ years, the driverless trucks accumulated 4.9 million ESALs (figure 10) and covered 1.31 million km (821,000 mi). WesTrack researchers learned much that will be useful in future driverless truck system design and presumably in automated highway development.

MULTIPLE FAILURES WILL OCCUR

Redundancy was designed into the WesTrack driverless vehicle system, and there were few potential sites for single-point failures within the system. Where single-point failures were possible – for example, the belt between the stepping motor and steering box – the system was significantly overdesigned. As a result, it was assumed throughout the design of the system that it was improbable that two different failures would occur at the same time.

However, we learned that multiple failures can occur at the same time. A steering motor failure and a brake system (airline) failure occurred at the same time on one of the WesTrack trucks, resulting in a "slow-speed track exit," and the truck was slightly damaged. A second incident resulted from a nearly simultaneous lockup of the main control computer and a brake system (regulator valve) failure. This resulted in the crash of one of the driverless vehicles into a second vehicle and caused significant damage. A lesson was learned: A driverless system must be able to control the vehicle in multiple failure scenarios.

VEHICLE WANDER IS CRITICAL

Both WesTrack and other driverless vehicle systems have proven that lateral position control is extremely repeatable. For example, without the wander control built into the driverless vehicle system, the precise repeatability of the truck paths (less than 2 mm of variation from center per pass) would reproduce the rain grooves of the tire tread in the asphalt.

The concentrated wheelpath loading accelerates pavement wear. One concept for an automated highway system dedicates vehicle lanes, similar to current, dedicated high-occupancy vehicle (HOV) lanes, for driverless vehicle operation. Given traffic with extremely repeatable guidance systems, this concentrated loading will accelerate the pavement wear and quickly establish rutting or fatigue cracking within the narrow wheel-loading area. Building in and controlling wander is a lesson learned and a consideration for future designs. WesTrack trucks were initially

designed to operate "on the wire," centered over the embedded guidewire, but, to reproduce driver variation, they were later programmed to operate up to 380 mm (15 in.) "off the wire." The new capability allowed the track operators to generate a distributed traffic pattern that approached the wander patterns found on typical open highways (figure 11). Truck wander and the establishment of a different wander algorithm in each truck may be an important consideration in future designs. A Gaussian wheelpath distribution with a standard deviation of 100 mm (4 in.) is the minimal recommendation for an automated highway scenario.

GUIDANCE SENSORS CAN MOVE

Two lessons were learned about the WesTrack "wire in the road" design. At the time of construction, the wire was installed in a conduit under the asphalt.

The first lesson learned was that it is nearly impossible to keep a conduit or any other sensor device perfectly aligned underneath an asphalt paving machine. Slight jogs were introduced in the wire during paving and the tightly controlled trucks followed the jogs. Instead of maintaining a straight path down a tangent section of the track, the trucks executed a series of extremely repeatable left and right steering variations. This was eventually corrected by cutting a groove in the top of the HMA layer and placing a new straight wire at the surface.

The second lesson learned was that the wire can, and does, move within the conduit. The direction of WesTrack traffic around the track is always in the same direction – counterclockwise. The wire in the conduit also moved counterclockwise and was displaced approximately 200 mm (8 in.) longitudinally within the first 120,000 km (75,000 mi) of vehicle operation. This tensioned the wire to the point that service loops were pulled tight and the wires broke. This problem was also corrected by moving the wire to the surface. The lesson learned was that asphalt is a flexible pavement, and given a constant direction of traffic – especially heavy truck traffic – subpavement items will migrate.

SLIGHT LATERAL POSITIONS MAKE A BIG DIFFERENCE

When the wire was installed in the spiral that transitions from the straight tangent section to the 18 percent superelevated curve, it sometimes was placed as much as 25 mm (1 in.) laterally from its design-targeted line. This created an undesirable lateral sway when the trucks exited the curve. The lesson learned was that alignment of a curve transition is critical, and the position of a guidance sensor 25 mm (1 in.) left or right of the theoretical path can establish undesirable lateral sway dynamics. Given that sensors can move in HMA, this sensitivity to exact curvature is critical to future intelligent transportation system (ITS) designs.

STANDARD TRUCK AIR-CONDITIONING SYSTEMS ARE NOT DESIGNED TO OPERATE 24 HOURS PER DAY

The control computers for the WesTrack trucks were located in the sleepers of the trucks and the air conditioning was directed through ducts to keep the computers operating as in an office environment. During the summer, this required the air-conditioning systems to operate up to 22 hours per day, and current, standard truck air-conditioning systems are not designed for such extended, continual operation.

STEERING LASH INCREASES WITH GEARBOX WEAR

By the time each truck had been driven some 200,000 km (125,000 mi), the track operators noted the steering lash, the amount of steering wheel play, had increased significantly as the steering gearboxes on the trucks wore. By design, truck steering gearboxes are designed with lash because overly responsive steering on a large truck is not desirable. Steering wear must be accounted for during steering control design.

ROBUST COMMUNICATIONS ARE NECESSARY

Stable communications systems for longitudinal control are critical. Telemetry communications need to be robust. Loss of communications for as little as one second can cause problems. Of all the redundant subsystems in the WesTrack design, longitudinal control was considered the most critical.

STEERING TIRE SELECTION IS IMPORTANT FOR LARGE TRUCKS

Radial tires have a natural tendency to go straight. This effect is called self-aligning torque. The higher is the self-aligning torque, the greater is the tendency to go straight.

Initially, steering tires with relatively high self-aligning torque were selected for the steering axles of the WesTrack trucks. As a result of the increased steering demands on the tires negotiating the curves of the track, the tires wore high on their shoulders. After the first 100,000 km (60,000 mi) on each truck, new tires with a lower self-aligning torque were put on trucks. This enabled the trucks to steer with less frequent correction through the curves and it reduced the demand on the steering motor. Steering tire selection is an important consideration for future ITS vehicle designs.

VEHICLE OPERATIONS

Four driverless vehicles were operated up to 22 hours per day with an average loading rate of 16 hours per day throughout the test duration. The average operating hours per day included delays caused by periodic rehabilitation of test sections, vehicle maintenance, and unfavorable weather conditions limiting the test.

Initially, plans were to load the test track up to 10 million ESALs. However, failure of some of the test sections at the early stage of the loading plan generated a modified plan that continued loading until the test sections were declared as failed based on pre-established criteria.

The primary objective for integrating driverless vehicles into the accelerated pavement testing program was to minimize the incidents resulting from driver fatigue and drowsiness as a result of monotonous operation of the vehicles for an extended period of time. The automation associated with integration of the driverless vehicles also ensured close monitoring of operating speed.

Two supervisors, a lead electronic technician and a lead mechanic, supervised the track loading operation, oversaw schedules, and maintained the vehicles. Three operators (8 hours per shift, 24 hours per day, 7 days per week) were assigned to the control room. These operators kept records pertinent to the traffic operation.

The vehicles were stopped once every 24 hours for refueling and routine inspections. The staging and launching of the trucks was closely monitored to ensure that the actual loading duration was recorded.

FUEL ECONOMY, MAINTENANCE, AND OPERATING COSTS

Although accelerated pavement testing facilities are designed to investigate the performance of pavement materials and structural designs, they also offer the opportunity to collect vehicle operation data under controlled conditions. The loading completed at the WesTrack facility in Nevada provided significant data on truck fuel and maintenance costs as a function of pavement smoothness. The reader is referred to several interim reports and articles for a detailed description of the WesTrack Project,[(1)] interim findings,[(2)] and the description of the driverless vehicle integration.[(3)]

During WesTrack's 2½-year loading period, pavement sections developed varying amounts of rutting and/or fatigue cracking, some eventually requiring minor or major rehabilitation. The last rehabilitation of WesTrack was conducted in March 1998. Prior to that rehabilitation, the track was in a very rough condition due to fatigue failures of various test sections and deterioration of patched areas (patches had been placed after previous core and slab samplings). The vehicle and pavement data taken before and after the rehabilitation were used to project the impact of pavement roughness on vehicle operating costs.

PAVEMENT ROUGHNESS AND ITS EFFECTS ON THE VEHICLES

The distinct differences in pavement roughness just before and just after rehabilitation presented a unique opportunity to investigate the effects of pavement roughness on fuel consumption, unscheduled maintenance, and other factors related to vehicle health. Relevant data were examined for a period of 8 weeks just before rehabilitation, and 7 weeks just after rehabilitation, to assess the effect of pavement roughness on vehicle health and fuel consumption rate. International Roughness Index (IRI) values for the tangents of the oval track[(2)] measured prerehabilitation and postrehabilitation were compared. The measured IRI values showed a 10 percent reduction in IRI after the rehabilitation compared to the IRI just before the rehabilitation.

Subjectively, the deterioration of the patched areas caused additional roughness in the form of a pothole-type discrete bump. To document this difference from a vehicle motion resistance perspective, an attempt was made to estimate the rolling resistance of the track using a coastdown test (SAE J1263).[4] The inside lane of the track (service lane) was relatively smooth compared to the outside lane (test lane). It was assumed that the difference in the rolling resistance between the two lanes could be used as an estimator of the relative difference. The coastdown test was conducted using a 160-kN (35,900-lb) tractor semitrailer. The coastdown speed range was 32 to 8 km/h (20 to 5 mi/h). The result of this limited observation showed that the rolling resistance of the test lane was higher than the inside lane (service lane) by approximately 3 percent.

Figure 12 shows a representative visual distress, i.e., cracks (highlighted here with white paint), of the fatigued pavement before rehabilitation. Figure 13 shows a representative deteriorated patch area. The fatigued sections were milled down 100 mm (4 in.) and resurfaced in March 1998. Additionally, most of the patches from previous slab and core removal areas were also milled to a depth of 100 mm (4 in.) and re-patched using a t-patch methodology for longer life.[5] The localized repairs resulted in approximately 6 percent of the total track length being milled and resurfaced.

FUEL ECONOMY AND PAVEMENT ROUGHNESS

The power a truck requires at a given time is a function of its speed, its weight, tire/road surface interaction, aerodynamic drag, and grade. The power requirements can be divided into three categories, overcoming:

- Wheel rolling resistance.
- Air drag.
- Pavement grade.

Rolling resistance is the sum of all resistance impeding the free rolling of the vehicle, so the power required to overcome rolling resistance includes the power required to overcome irregularities in the pavement, the flexing of tires, the deformation of the road surface, and friction, each of which in turn may depend on the vehicle's gross weight and/or speed. Given that vehicle gross weight and speed were fixed and that the vehicles were very well maintained throughout the WesTrack experiment, increases in fuel flow rate noted on vehicle performance/health monitoring computers could be directly attributed to increased pavement roughness (i.e., increased deterioration of the track led to increased motion resistance in the trucks).

Estimates of rolling resistance for different road conditions are available in the literature.[6] Table 1 shows typical road rolling resistance (RR) in N per kN (lb per 1,000 lb) of gross combined weight (GCW) for different surface conditions from one such source.[6] With all other factors held constant, an increase in road rolling resistance from 2.5 N per kN GCW to 5 N per kN (going from a good [smooth] asphalt concrete pavement to a poor [rough] one) results in a theoretical 100 percent increase in required rolling resistance power.[6,7]

To validate the effect of pavement quality changes on fuel economy, data from two identical WesTrack vehicles, WT-3 and WT-4, were examined for periods just before and after the March 1998 rehabilitation. The fuel rate, fuel temperature, engine torque, and engine speed from the DDEC units were analyzed, as were other vehicle parameter data. The WesTrack computers recorded vehicle data twice per second while the trucks were operating. Additionally, fuel use data from the daily inspections and refueling of the WesTrack trucks were analyzed.

The average fuel mileage over an 8-week period before rehabilitation was measured to be 1.79 km/L (4.2 mi/gal) for the two trucks. After the rehabilitation, the average fuel mileage over a 7-week period was 1.87 km/L (4.4 mi/gal). This indicates a 4.5 percent improvement in fuel economy as a direct result of the decrease in pavement roughness due to the rehabilitation.

Table 2 is a summary of environmental and engine parameter data for the periods just before and just after rehabilitation. The average engine torque was 913 N-m (674 ft-lb) before rehabilitation and 881 N-m (650 ft-lb) after. The average engine speed was 1,456 rev/min. This would correspond to a calculated power of 139 kW and 134 kW (187 and 180 hp) before and after rehabilitation, respectively. Other environmental influences on fuel consumption were evaluated. Temperature effects have been compensated for in this calculation, as the average air temperatures were lower for vehicle operation before the rehabilitation than after. The average wind speeds over the duration before and after the rehabilitation were 5.6 km/h (3.5 mi/h) and 7.9 km/h (4.9 mi/h), respectively, with consistent average wind direction (table 2). Given the oval track design (with the trucks traveling both with and against the wind during each circuit of the track), the effects of wind are at least partly negated. Because the average wind speed was higher after rehabilitation than before, the reported improvement in fuel consumption may be less than it would have been if the wind speeds did not differ. Overall, the improvement in fuel consumption would have been slightly greater than 4.5 percent if all of the environmental effects could have been eliminated (i.e., if wind speed, temperature, etc., were the same before and after the rehabilitation).

If the fuel consumption changes noted at WesTrack were extrapolated to a fleet operation of 1,600,000 vehicle km (1,000,000 vehicle mi), the savings would be 46,600 liters (10,260 gal) of fuel as a result of operating on “smooth” pavement rather than “rough.” From a fleet operator’s perspective and environmental protection standpoint, these savings are substantial.

MAINTENANCE COSTS

The increase in pavement roughness also increased the frequency of fatigue failures in the truck and trailer components. For example, trailer frames began to fracture (four occurrences) and required reinforcing welds during the time just before pavement rehabilitation. Steering motors and other components loosened more frequently. Figure 14 shows trailer spring failure rates during different time intervals in the track’s life. Eight of 17 spring failures during the 2½-year loading life occurred within 2 months prior to the March 1998 rehabilitation of the track, resulting in the large increase in the rate of spring failures. Although some 330,000 ESALs were applied to the track sections during the 7 weeks after rehabilitation, compared to the 265,000 ESALs in the 8 weeks before, the postrehabilitation trafficking yielded only a single spring failure.

Fatigue and exposure to varying degrees of stress over their lifetimes certainly contributed to the spring failures. Nevertheless, the fact that very few spring failures were observed after rehabilitation is an indicator of severe loading of the trucks by the rough pavement just before rehabilitation.

OPERATION COSTS

The graph in figure 15 shows the variation in vehicle operating costs over the 2½-year loading period. The average cost was approximately $0.86/km ($1.38/mi). The equivalent cost incurred during the AASHO Road Test some 40 years earlier is given below for comparison.

	WesTrack	AASHO
Average cost/km	$ 0.86	$ 0.20 (1960) 1.06 (1997)
Average cost/mile	1.38	0.32 (1960) 1.70 (1997)[1]

The above costs include drivers, administrative and supervisory staff, maintenance, fuel, oil, lubricants, tires, and repair costs. The average operating hours per day were approximately the same (16 hours per day). The speed of operation of WesTrack vehicles was 64 km/h (40 mi/h) and that of AASHO was 56 km/h (35 mi/h).

PAVEMENT STRAIN MEASUREMENT

As a loaded vehicle passed over a pavement section, strains in the pavement were measured using strain gages. Kyowa H-gages Model No. KM-120-120-H2-11-W1M3 strain gage was selected for this purpose. The following modifications were made by the University of Nevada, Reno (UNR), prior to the installation of the gages at WesTrack:

- Metal plates with 0.8-mm (0.03-in.) thickness were attached to the top and bottom of each strain gage to protect the strain gage strips from bending stresses.
- The strain gage strips attached to the metal plates were enclosed in watertight plastic to protect against moisture damage.
- Anchors were attached to the ends of the strips to allow the strain gages to be secured to the asphalt concrete layer.
- The lead wires on each gage were extended to allow for field installation and connection to the signal conditioning and data acquisition station alongside the track.

[1]Assumes average inflation rate of 4.5 percent over 38 years.

STRAIN GAGE CALIBRATION AND INSTALLATION

The strain gage calibration was done by UNR. The calibration values were incorporated into the data acquisition software so that the output was in microstrains. The field installation process involved the placement of the gages, their protection from construction equipment, and connection of the gage wires to the junction box. UNR installed 260 strain gages (10 gages per test section, see figure 16) and 26 NEMA-rated junction boxes (75 mm x 125 mm x 75 mm – 3 in. x 5 in. x 3 in.) .

On track sections 1, 2, 3, 4, 14, 15, 16, and 17, the outer strain gages were placed 150 mm (6 in.) to the right of the test lane centerline and 450 mm (18 in.) inward from the inside shoulder edge.

On track sections 5, 6, 7, 8, 9, 10, 11, 12, 13, 18, 19, 20, 21, 22, 23, 24, 25, and 26, the outer strain gages were placed 450 mm (18 in.) to the right of the centerline and 450 mm (18 in.) inward from the inside shoulder edge.

DATA STRUCTURE

For each truck/trailer pass, 4,096 data points were collected per strain gage. (Note: No strain gage data are included in this report but discussion of the installation and data structure have been included here for historical purposes.) These data were filtered through a moving average and reduced to 251 data points per pass. The selection of the moving average range is such that "peaks and valleys" were captured without losing resolution in the data.

Pavement strain data were recorded once per month in June, July, August, and September 1996. Five to six repeated measurements were taken per measurement. Temperature data were collected at depths of 12.7, 38.1, 88.9, 114.3, and 139.7 mm (0.5, 1.5, 3.5, 4.5, and 5.5 in.) within the asphalt-concrete layer. The temperature data are included in each data set.

NOMENCLATURE

The description of the file name is explained with the following example:

File name: 616716_01_05.xls

The first digit (left to right) denotes the year the data were taken (i.e., 6 → 1996). The next three digits (167) represent a Julian date for the date of data collection. The next two digits (16) represent the section number of the track from which the data were collected.

- _01 indicates the first pass over the sensor.
- _05 indicates the last replicate pass over the sensor. In general, numbers shown after underscore (_) are the first and last runs.

As indicated previously, pavement strain gage data were collected once each month during the months of June through September 1996. Although the strain gages responded well at the early stage of measurement, all gages may not have responded at all times. This could be due to truck

wander or failure of the gages. Because of the severe environment and rapid failure of the test track, some of the gages may have failed somewhat early. The database provided includes all the data collected without excluding responses from bad gages.

SKID RESISTANCE TEST

Skid resistance tests of the WesTrack pavement were conducted using the ASTM E274-97 test procedure (Standard Test Method for Skid Resistance of Paved Surfaces Using Full-Scale Tire). The skid tests were conducted nine times between March 1996 and September 1997. Typically, skid tests were performed as soon after repaving as they could be scheduled.

In accordance with ASTM E274-97, paragraph 7.3, at least five determinations of skid resistance were made on each surface. Since the test sections were not 0.8 km (0.5 mi) in length, multiple passes were made on each surface. An arithmetic mean skid number was reported.

In accordance with ASTM E274-97, paragraph 7.4, the test determinations were made in the left wheel track of the traffic lane. All tests were conducted for approximately 2 hours starting at daybreak. A standard rib tire for pavement skid-resistance tests (ASTM E501 specification) was used for the skid test. The test speed was 64 km/h (40 mi/h).

SUMMARY

The WesTrack driverless vehicle program was successful and provided an operational real-world example of heavy-vehicle driverless operation. It addressed the practical requirements for control system redundancy and for continuous vehicle safety and vehicle health monitoring that should be part of practical automated highway systems. WesTrack operated with four driverless triple-trailer combinations from June 1996 until early in 1999. The trucks recorded a total of 1.31 million vehicle-km (821,000 vehicle-mi) of operation over a 2½-year period. Fail-safe controls were implemented, and a practical level of reliability was achieved. A system of continuous vehicle safety monitoring also was demonstrated.

Pavement roughness had a significant impact on fuel consumption of trucks applying loads to WesTrack pavement test sections. Under otherwise identical conditions, trucks used 4.5 percent less fuel per unit distance on smooth (postrehabilitation) pavement than they did on rough (prerehabilitation) pavement. The increase in pavement roughness also significantly increased the frequency of fatigue failures of truck and trailer components during the WesTrack loading.

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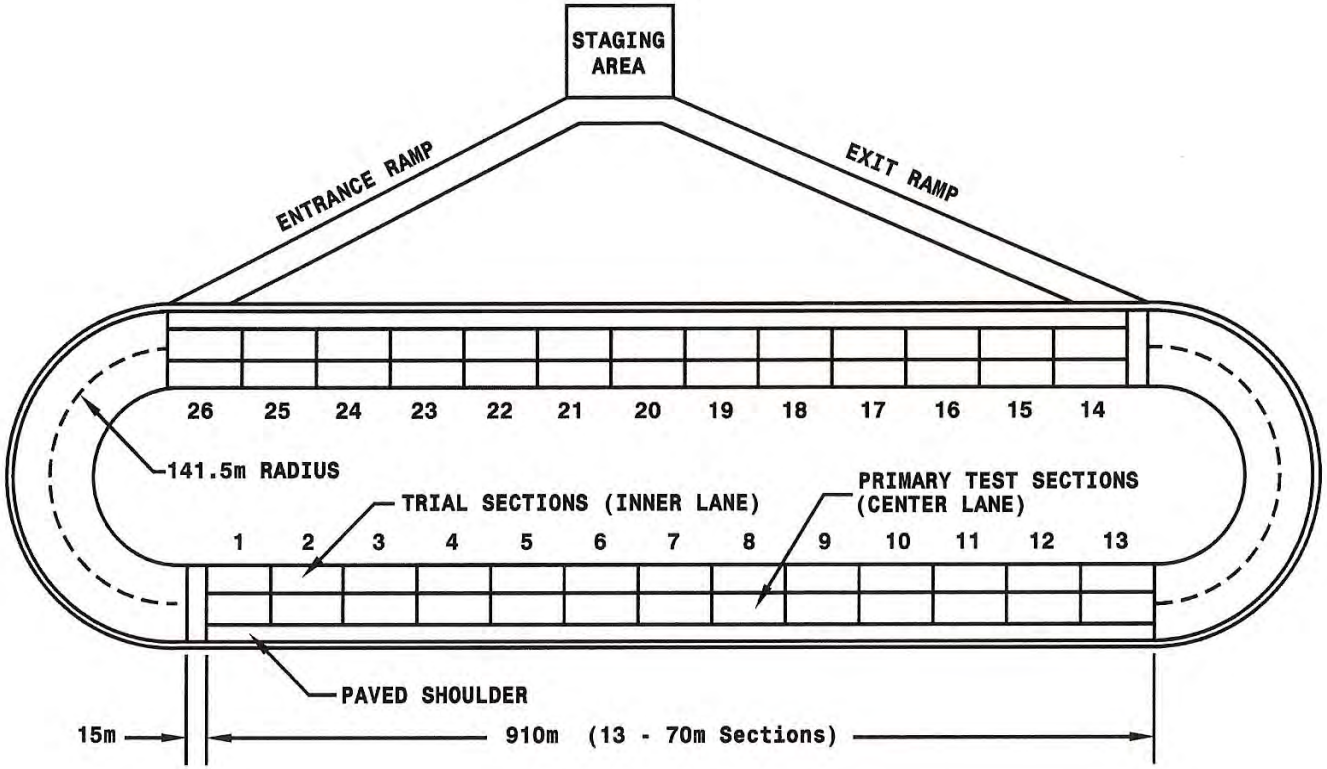
6. SAE Recommended Practice, "Commercial Truck and Bus SAE Recommended Procedure for Vehicle Performance Prediction and Charting," SAE J2188.

7. Fitch J., *Motor Truck Engineering Handbook*, Fourth Edition, Society of Automotive Engineers, Inc., Warrendale, PA, 1994.



1 ft = 0.3048 m

Figure 1. Track layout.

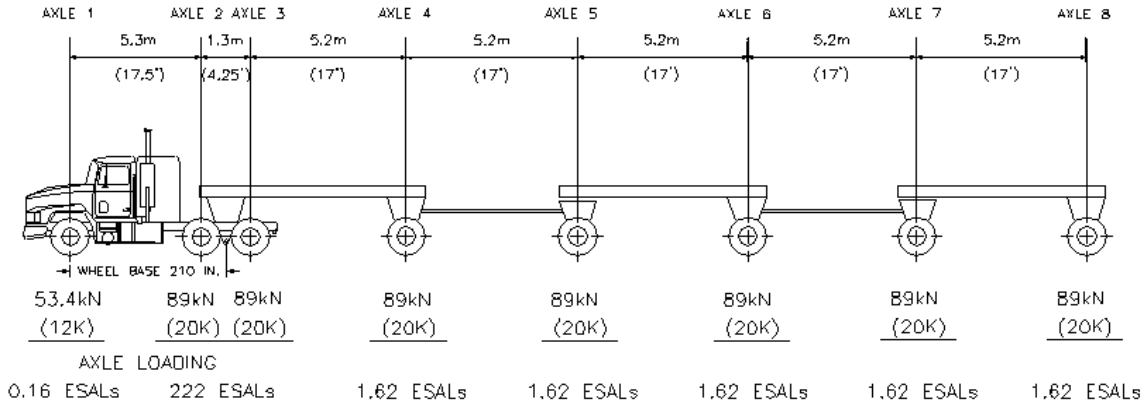


Figure 2. Tractor/trailer configuration.

Figure 3. Driverless triple-trailer test trucks.

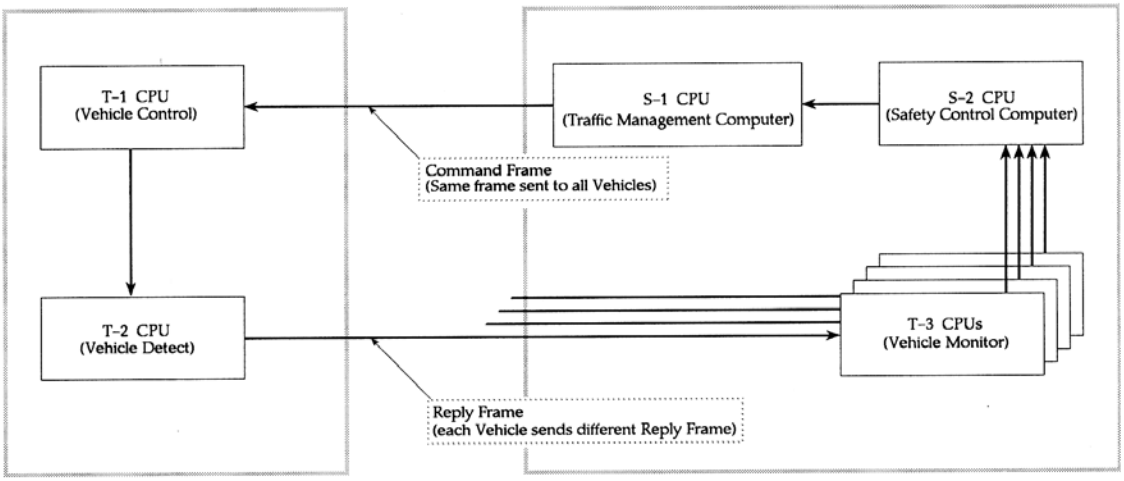


Figure 4. System block diagram.

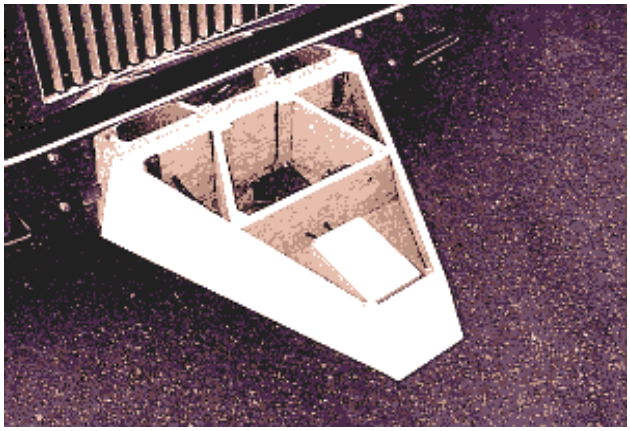


Figure 5. Antenna on truck senses lateral position.

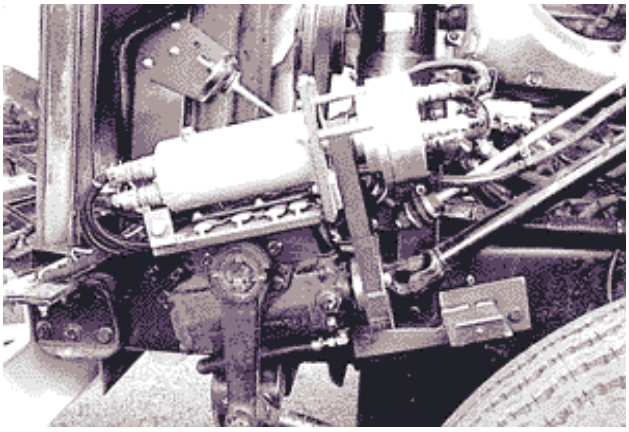


Figure 6. Stepper motor controls steering gearbox.

Figure 7. WesTrack control room computers.

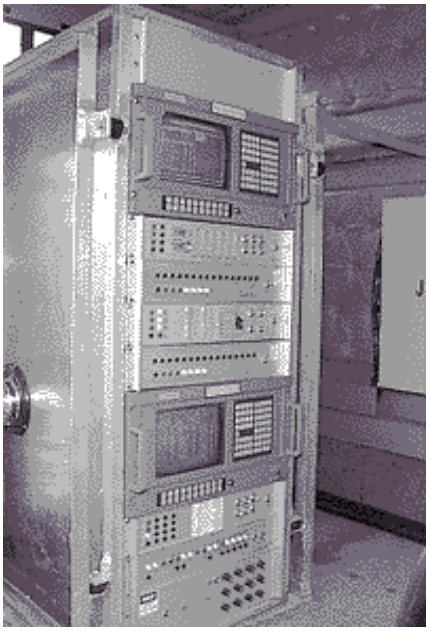


Figure 8. Two on-board computers used for vehicle control and real-time truck health monitoring.

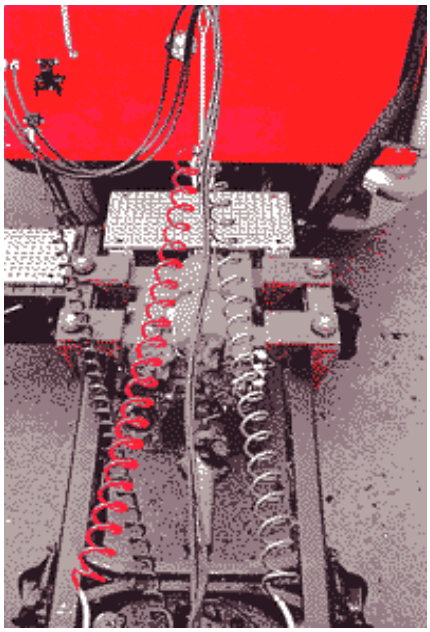


Figure 9. Electronically controlled automatic transmission.

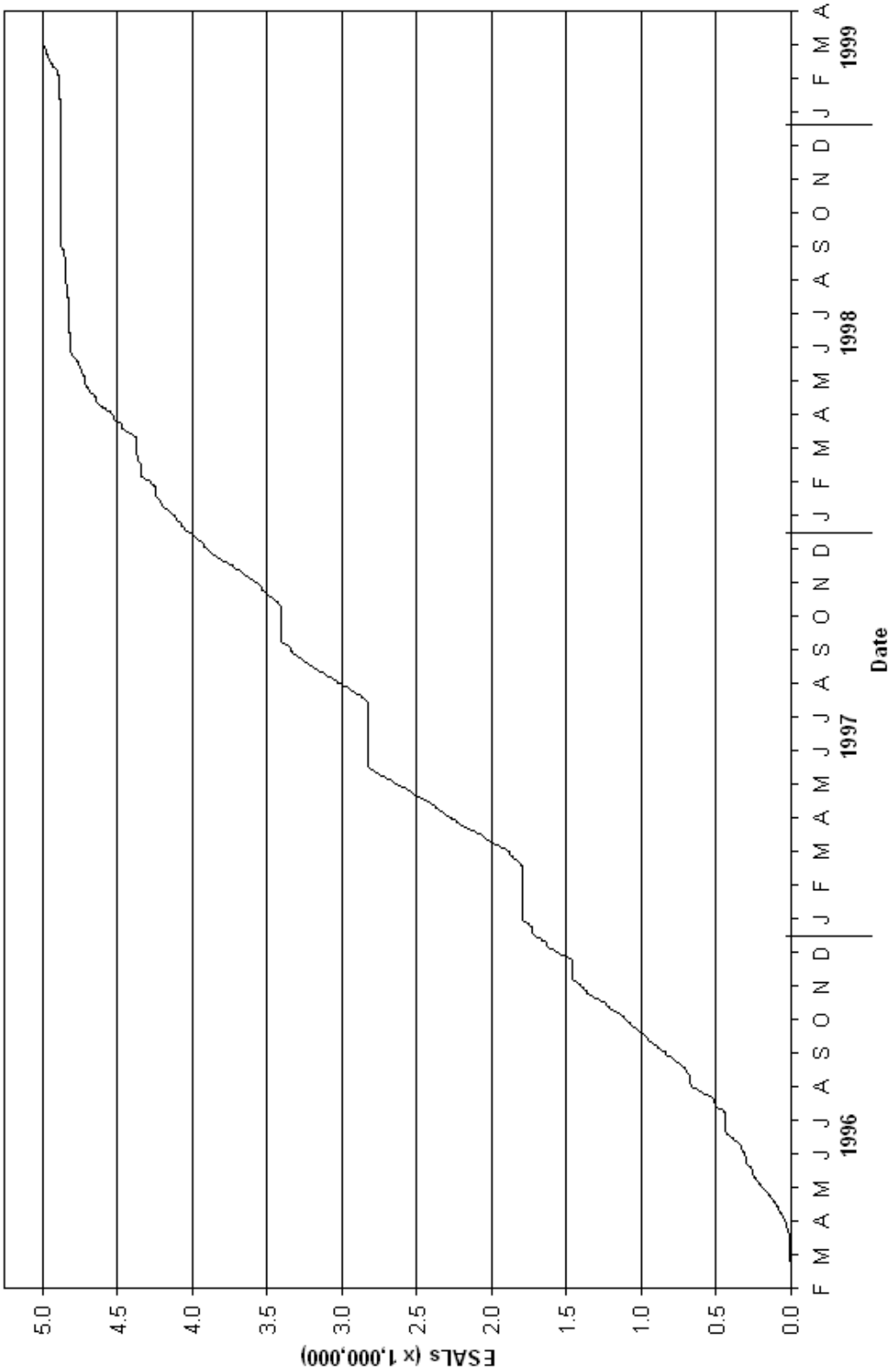
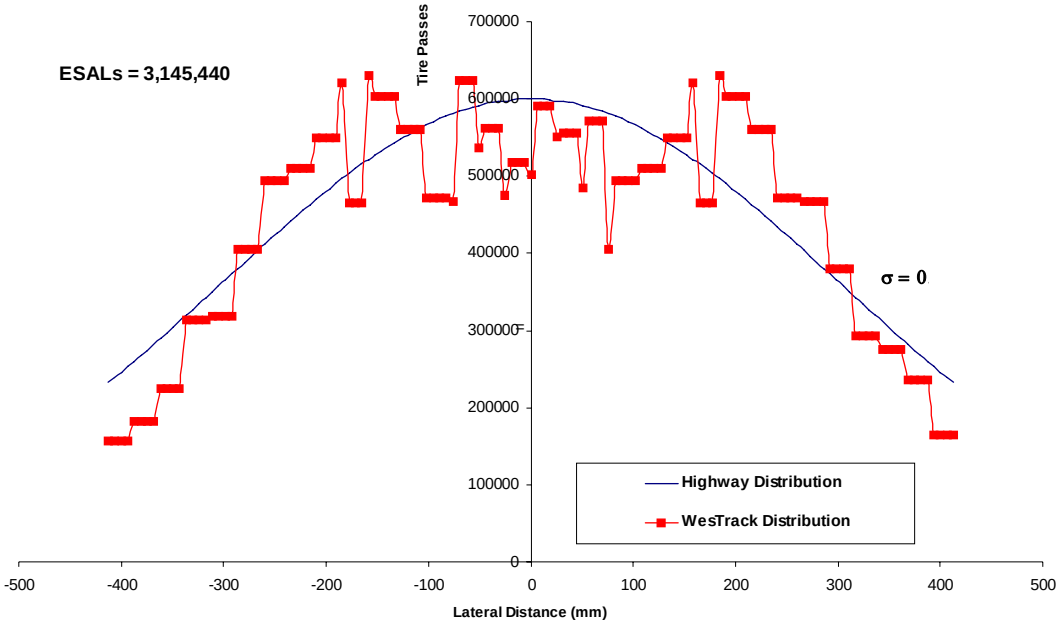


Figure 10. Accumulated ESALs.



1 in. = 25.4 mm

Figure 11. Distribution of tire passes for WesTrack at 3,145,440 ESALs.

Figure 12. Example of pavement roughness in fatigued test sections.

Figure 13. Example of deteriorated patch area.

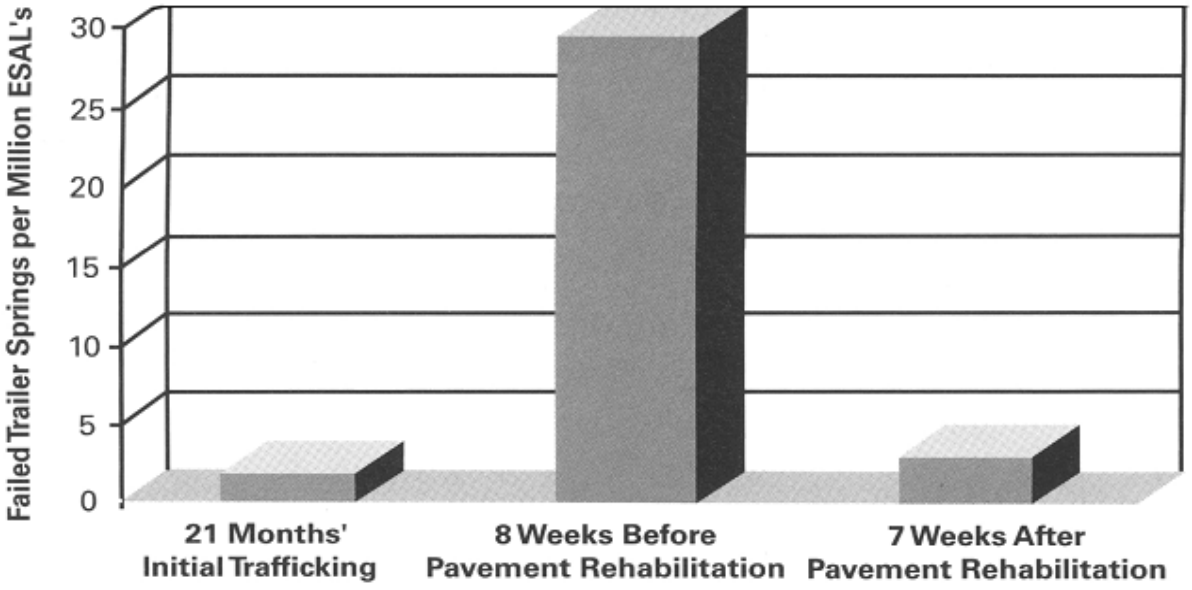


Figure 14. Example of the effect of pavement condition on truck health.

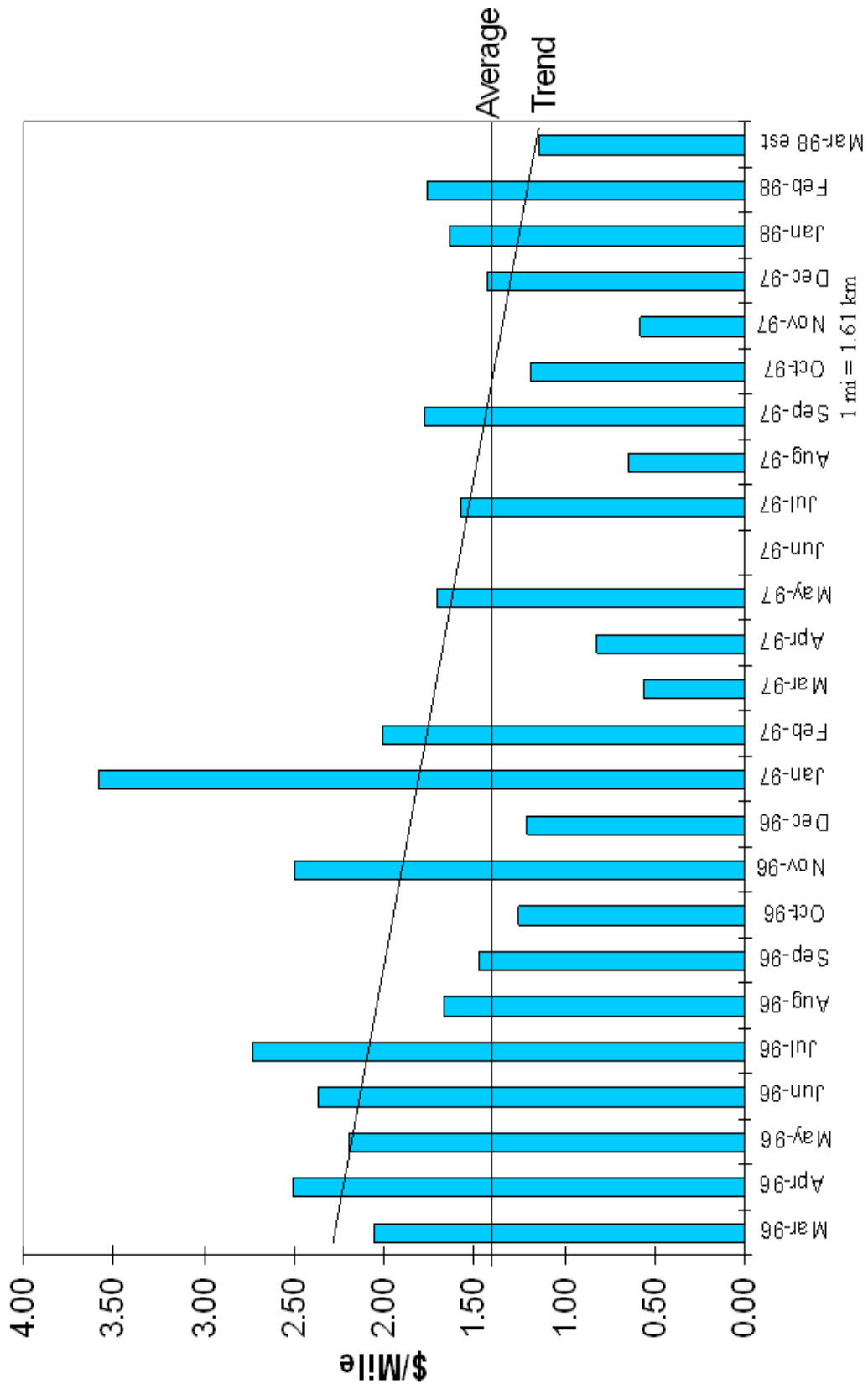


Figure 15. Cost per mile.

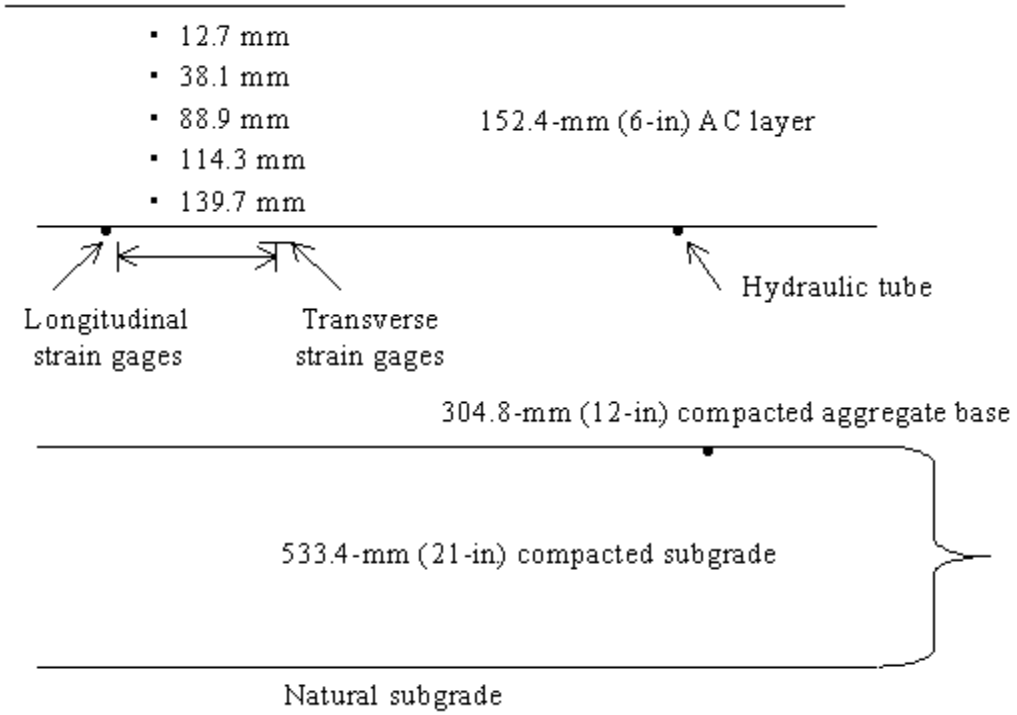


Figure 16. Thermocouple and strain gage location with depth.

Table 1. Typical values for asphalt concrete surface rolling resistance.[6]

Asphalt Road Condition	RR, N per kN GCW	RR, lb per 1,000 lb GCW
good (smooth)	2.7	12
fair	3.8	17
poor (rough)	5	22

Table 2. Summary of environmental and engine parameter data before and after rehabilitation.

	Before Rehab. 1/5/98 - 3/1/98		After Rehab. 3/13/98 - 5/6/98		
Number of kilometers	38,970		48,942		
Environmental	**Avg.**	**Std. Dev.**	**Avg.**	**Std. Dev.**	
Ambient temperature (°C)	2.3	5.2	6.5	5.6	
Maximum relative humidity (%)		75.8	20.7	64.8	22.4
Minimum relative humidity (%)		66.8	22.2	54.3	22.0
Wind speed (km/h)	5.6	5.5	7.9	6.1	
Engine parameters					
Fuel rate (liters/h)	32.2	4.5	31.0	4.2	
Output torque (N-m)	913.1	138.8	881.1	131.5	
Engine RPM	1456.1	6.4	1455.8	5.6	
Engine load (%)	51.6	6.5	50.0	6.2	
Throttle (%)	59.4	4.2	58.4	4.0	
Fuel temperature (°C)	35.6	0.8	40.2	0.6	
Calculated power (kW)	139.3	21.2	134.4	20.1	

Notes: °F = 1.8 x °C + 32; mi/h = 1.6 km/h; gal/h = 0.220 L/h;
ft-lb = 0.738 N-m; hp = 1.34 kW

Pavement Surface Distress Collection and Data Reduction

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report NCE-1
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

It is well understood that visual distress surveys are critical to understanding the failure mechanisms and performance of hot-mix asphalt (HMA) pavement structures. This technical report explains how the WesTrack Team summarized and reported fatigue cracking and other pavement surface distresses collected from the WesTrack experimental sections.

DATA COLLECTION

The distress data collection procedure for the WesTrack project was based on the Long-Term Pavement Performance (LTPP) project procedure for distress identification.[1] Pavement surface distress data were collected every 2 weeks; however, it was sometimes necessary to collect the data more frequently during periods when fatigue cracking was progressing quickly (i.e., during cold temperatures). The data were collected by a single surveyor, walking each section and recording the distresses according to the descriptions in the LTPP *Distress Identification Manual*. The distress data were recorded on custom-made survey sheets, as shown in appendix A. The sheets subdivided each test section into 0.5 m by 0.5 m (1.6 ft by 1.6 ft) increments. Additionally, the sheets referenced each section's layout (stationing), which simplified field data collection.

During data collection, the pavement surface temperature was recorded for each section during the distress survey. This was important, as surface temperature affected the observed distress in some cases. When pavement surface temperatures were above 20°C (60°F), determination of fatigue cracking was sometimes difficult.

The effect of high pavement surface temperatures was observed in the distress data for 1996 and 1997. During this time period, data were collected independently of the survey sheets from previous monitoring sessions, i.e., only blank sheets were taken to the field. The goal was to have the surveyor make an unbiased survey of what surface distresses were actually observed. However, this led to discrepancies in the measurement of percent fatigue cracking. The discrepancy was the result of fatigue cracks "closing" during high pavement temperatures, making them unobservable to the naked eye.

The data collection team was concerned with these fluctuations in the amount of fatigue cracking, and decided to allow the surveyor to use the previous distress survey sheets while collecting the data. This process produced a more uniform trend in observed surface distresses. Additionally, using the previous distress maps reduced the likelihood of missing past observed distresses. The surveyor used the previous maps as guidelines for identifying the progression of each type of distress. However, if a distress from a previous map could not be verified through a close inspection of the pavement surface, the distress was not recorded.

During the distress data collection, all distresses observed were recorded, regardless of their location within the test section. This is an important point, as two different distresses occurring in the same place in a wheelpath area would both be recorded. An example is the presence of both fatigue cracking and raveling.

DATA REDUCTION

Data reduction for surface distress identification was a time-consuming process. After the distress types were recorded to scale on the section maps, the correct summary values were determined. For example, fatigue cracking was summarized by total area of fatigue cracking and level of severity. Once the summary values were calculated, they were recorded on the distress summary sheet. Appendix B shows an example of a distress survey summary sheet. These sheets were modified LTPP sheets, but followed the same format and method of data summarization. After completing the summary sheet, the data were then incorporated into the WesTrack database. The pavement distress information for the 26 sections was added to the WesTrack Microsoft® Access database by an engineering technician familiar with distress survey collection. This process allowed an additional quality control check of each data sheet prior to input.

AREA ASSOCIATED WITH A SINGLE FATIGUE CRACK

It is generally accepted that fatigue cracking is reported in terms of area or percent of the wheelpath. At WesTrack, fatigue cracking began in one of two ways, either as a group of small transverse cracks in the wheelpath, which would appear like a ladder, or as small longitudinal cracks in the wheelpath. When fatigue cracking appeared in the form of longitudinal cracks, the following methods were used to assign an area to each crack.

PRELIMINARY METHOD OF ASSIGNING AN AREA TO A FATIGUE CRACK

The WesTrack Team initially tried to fit a rectangle over a single crack by increasing the length by 0.1 m (4 in.) at each end and assuming a width of 0.4 m (16 in.) (i.e., 0.2 m (8 in.) on either side of the crack). Therefore, the formula was as follows:

$$\text{Fatigue Cracking } (m^2) = (\text{Crack Length } (m) + 0.2) * 0.4 \quad (1)$$

Initially, this method appeared reasonable based on the underlying distress observed during the postmortem investigations. However, after plotting the data, this method was found to be overly conservative, i.e., the area assigned was excessive. This is illustrated by looking at the WesTrack theoretical wheelpath width of 0.83 m (33 in.) in comparison to the 0.4 m (16 in.) width of the superimposed rectangle. The superimposed width is about one-half the width of the wheelpath. From a maintenance standpoint, a single crack in the wheelpath would not necessarily require 50 percent of a wheelpath to be removed and replaced. Therefore, the team re-evaluated the area assigned to a single fatigue crack.

FINAL WESTRACK METHOD OF ASSIGNING AN AREA TO FATIGUE CRACK INITIATION

To understand better what was done in the past for assigning an area to a single fatigue crack, Mr. Fred Finn was contacted. The team wanted input from someone who had been a part of the

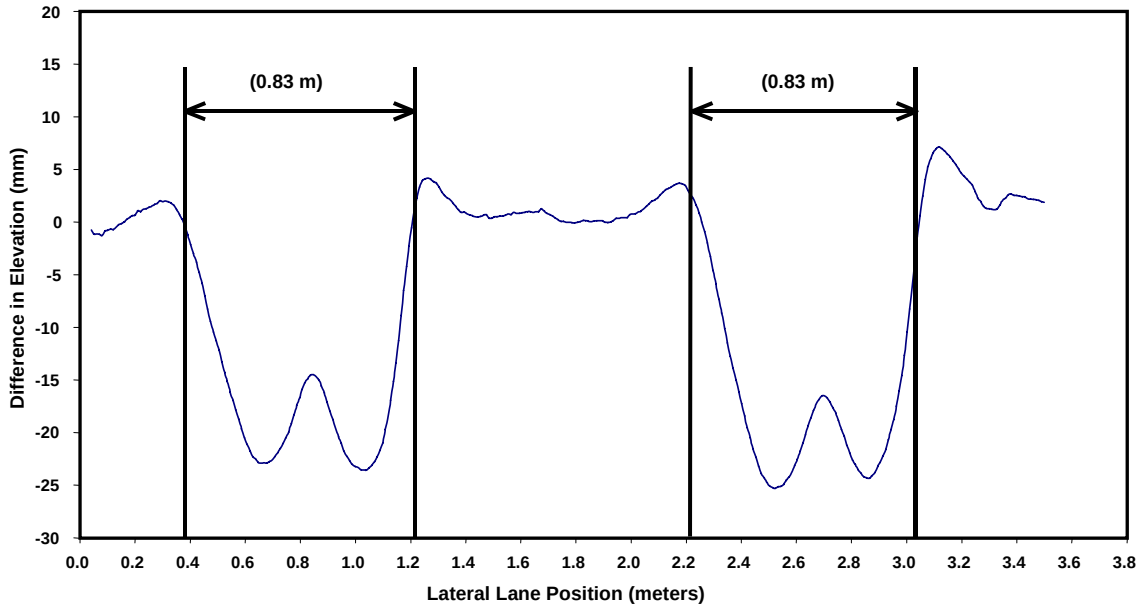
data collection of the American Association of State Highway Officials (AASHO) Road Test almost 40 years earlier. It became clear from the discussion with Mr. Finn that the initial area the WesTrack Team assigned to a single crack was excessive. Based on discussion with team members, a new procedure was developed, where a rectangle was fit around a single crack using the length of the crack as the length of the superimposed rectangle and the total width as 0.15 m (6 in.) (see equation 2 below).

$$\text{Fatigue Cracking } (m^2) = (\text{Crack Length } (m)) * 0.15 \quad (2)$$

This was more reasonable, as a single crack would be considered a damage of slightly less than 20 percent of the theoretical WesTrack wheelpath width. This procedure was adopted and the final summarized data reflect this procedure.

EFFECT OF WHEELPATH WIDTH ON DISTRESS CALCULATIONS

The WesTrack sections were loaded in a manner to produce a truncated normal highway wheelpath distribution. Theoretically, the width of each wheelpath was 0.83 m (33 in.), accounting for the width of the dual tires and the maximum lateral movement of the guide antenna of 0.127 m (5 in.) left and right. However, after trafficking, the distresses observed for some sections were 0.70 to 0.75 m (28 to 30 in.) in width. This was observed to be the direct result of rutting and the corresponding shear flow in the wheelpaths that reduced the lateral movement of the test vehicle trailers due to wheelpath channelization. Figure 1 illustrates this phenomenon.



1 in. = 25.4 mm

Figure 1. Wheelpath width before and after loading.

This phenomenon is important because the wheelpath width determines the percent of wheelpath distress. For example, if the final distress width is only 0.75 m (30 in.) due to severe pavement rutting, and the theoretical wheelpath of 0.83 m (38 in.) is used for the calculation of maximum wheelpath area, then the most distress observed would be reported as 90 percent (0.75/0.83) of the wheelpath area. Depending upon which wheelpath width is used, a bias could be introduced into the data reduction. Therefore, the actual measured wheelpath width was used for all data reduction.

DISTRESSES OBSERVED

The WesTrack test sections consisted of 150 mm (6 in.) of HMA on 300 mm (12 in.) of high-quality granular base. However, the majority of the sections were constructed off-target, with respect to asphalt content, air voids, and percent passing the 75-mm (No.200) sieve, as per the experiment design. Therefore, many distress types were observed in the test sections due to this off-target construction.

The test sections were loaded in an accelerated manner that caused some distress types to progress rapidly, namely rutting and fatigue cracking. Additionally, the trafficking occurred in a natural environment; therefore, the seasonal variations also affected the distress progression. It was found that, during the summer months when the ambient air temperature was very high, rutting took place in the top 75 mm (3 in.) of the off-target sections with high asphalt content. Fatigue cracking occurred during the winter months, and was observed in the off-target sections with low asphalt content and medium or high air voids. These observed distresses were consistent with the expected performance of these mixes.

Secondary distresses, such as asphalt bleeding (flushing) and raveling, were also observed in some test sections. As expected, asphalt bleeding occurred during the summer months in the off-target sections with high binder and low or medium air void content. Pavement surface raveling was also observed for the off-target sections with low binder content, especially at high air voids. However, it was difficult to determine if raveling was affected by environmental (seasonal) changes.

Additional information was gathered during destructive sampling and trenching of the test sections to supplement the surface distress measurements. Visual inspection of the cores and slab samples indicated that stripping of HMA did not occur (lime was added to the aggregate during construction to prevent stripping).

SUMMARY

The fatigue cracking data were reduced in a manner similar to the AASHO Road Test procedure for fatigue cracking data summary. All data collection was performed systematically by the same surveyor throughout the project. These data will be helpful in the development of the HMA performance-related specifications (PRS) and early validation of the Superpave mix design procedures.

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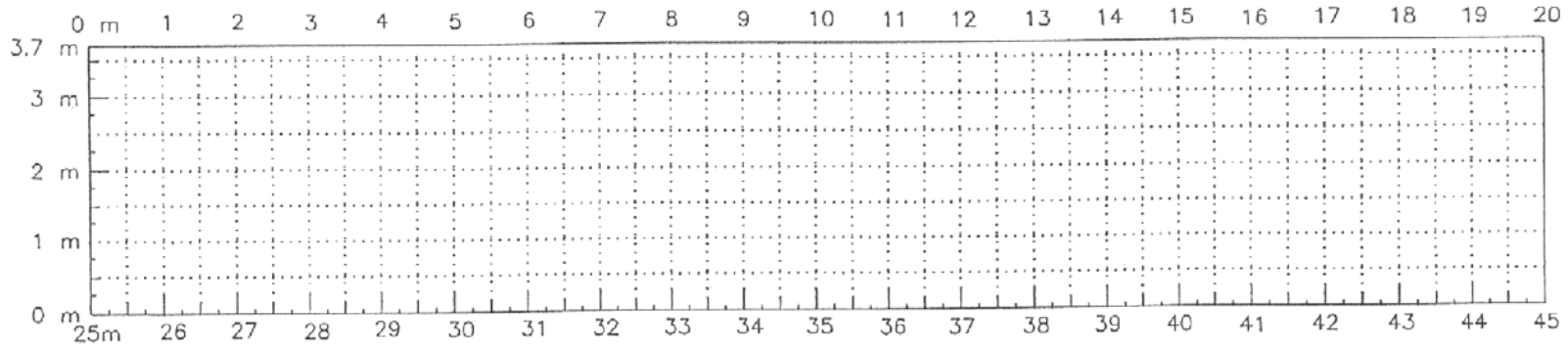
1. *Distress Identification Manual for the Long-Term Pavement Performance Project*, Report SHRP-P-338, Strategic Highway Research Program, National Research Council, Washington, D.C., 1993.

APPENDIX A

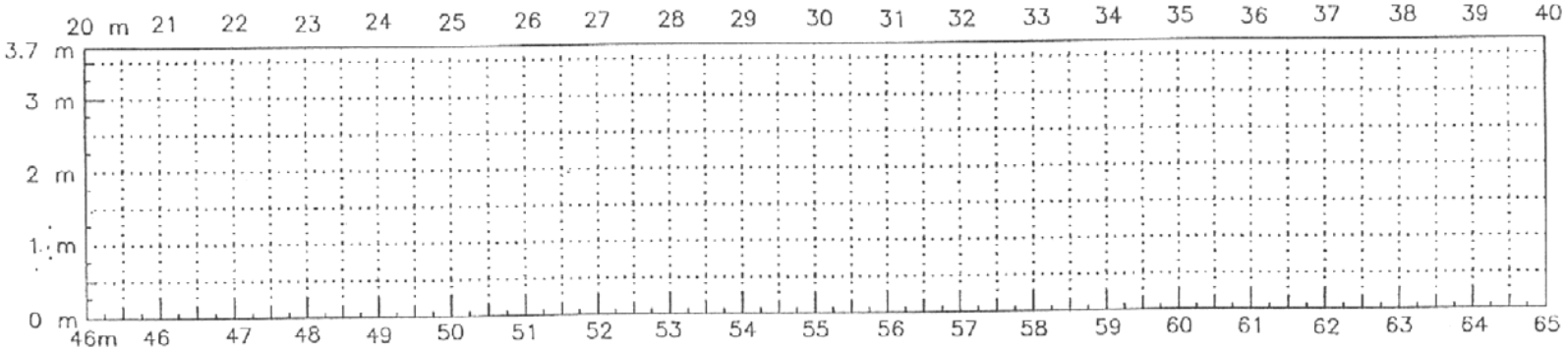
EXAMPLE OF DISTRESS SURVEY SHEET

WESTRACK DISTRESS SURVEY
Section 1

Date: _____ Surveyor: _____



Comments: _____



APPENDIX B

EXAMPLE OF DISTRESS SURVEY SUMMARY SHEETS

WESTRACK DISTRESS SURVEY SUMMARY

Section 01 Test Lane

DISTRESS SURVEY FOR PAVEMENTS WITH ASPHALT CONCRETE SURFACES

DATE OF DISTRESS SURVEY (Month/Day/Year) __ __/__ __/__ __

SURVEYOR: __ __ __ MONITORING SEQUENCE: __ __

PAVEMENT TEMPERATURE: Before __ __ __ °C ; After __ __ __ °C

DISTRESS TYPE	SEVERITY LEVEL LOW	MODERATE	HIGH
CRACKING			
1. FATIGUE CRACKING (m^2)	__ __ __.__	__ __ __.__	__ __ __.__
2. BLOCK CRACKING (m^2)	__ __ __.__	__ __ __.__	__ __ __.__
3. EDGE CRACKING (m)	__ __ __.__	__ __ __.__	__ __ __.__
4. LONGITUDINAL CRACKING (m)			
4a. Wheel Path	__ __ __.__	__ __ __.__	__ __ __.__
Length Sealed	__ __ __.__	__ __ __.__	__ __ __.__
4b. Non-Wheel Path	__ __ __.__	__ __ __.__	__ __ __.__
Length Sealed	__ __ __.__	__ __ __.__	__ __ __.__
6. TRANSVERSE CRACKING			
Number of Cracks	__ __ __ __	__ __ __ __	__ __ __ __
Length (m)	__ __ __.__	__ __ __.__	__ __ __.__
Length Sealed (m)	__ __ __.__	__ __ __.__	__ __ __.__
PATCHING AND POTHOLES			
7. PATCH/PATCH DETERIORATION			
(Number)	__ __ __ __	__ __ __ __	__ __ __ __
(m^2)	__ __ __.__	__ __ __.__	__ __ __.__
8. POTHOLES			
(Number)	__ __ __ __	__ __ __ __	__ __ __ __
(m^2)	__ __ __.__	__ __ __.__	__ __ __.__

DISTRESS SURVEY (Continued)

Section 01 Test Lane

DATE OF DISTRESS SURVEY (MONTH/DAY/YEAR) __/__/__

SURVEYOR: ___ MONITORING SEQUENCE: __

DISTRESS TYPE	SEVERITY LEVEL LOW	MODERATE	HIGH
SURFACE DEFORMATION			
10. SHOVING (Number)			____
(m^2)			____
SURFACE DEFECTS			
11. BLEEDING (m^2)	____	____	____
12. POLISHED AGGREGATE (m^2)			____
13. RAVELING (m^2)	____	____	____
MISCELLANEOUS DISTRESSES			
15. WATER BLEEDING AND PUMPING (Number)			____
Length of Affected Pavement (m)			____

16. OTHER(Describe)_____

Geometric Design

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report NCE-2
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GEOMETRIC DESIGN

The geometric design refers to the three-dimensional features of WesTrack. These features include the cross section (lanes, shoulders, roadside slopes, and clear area), intersections (off- and on-ramps for pit row), and the horizontal and vertical alignment of the test track.

A number of basic design controls and criteria governed the manner in which the test track was designed. Design speed was established as 64 km/h (40 mi/h) for the test vehicles. The horizontal alignment was dependent on the number and length of test sections, which were only placed within the tangents; and the radius of the horizontal curves was based on a maximum superelevation rate of 18 percent. Spiral curves were used to transition the track tangent sections to circular curved alignment and to develop the optimal superelevation. Figure 1 is the horizontal control plan.

The track length is summarized below:

Tangents: 2 x 13 sections x 70 m	=	1820 m (5971 ft)
Spiral transitions: 4 x 46 m	=	184 m (604 ft)
Alignment transitions out of curves: 2 x 15 m	=	30 m (98 ft)
Horizontal curves: 2 x 398.5 m	=	797 m (2615 ft)
		2831 m (9288 ft)

For all practical purposes, this is very flat terrain. The natural ground has less than 1 meter (3 ft) fall from south to north (<0.1 percent) and less than 0.5 meter (1.5 ft) fall from west to east (<0.2 percent). The design relied totally on the normal cross slope for drainage. Transitioning of the cross slope for development of superelevation warping was a factor in development of the infield drainage and drainage conveyance features. The test track was sited adjacent and parallel to the Carson River. The infield drainage outlet was equipped with a flap gate to prevent backwater from the river from entering the infield area during high flows.

A portion of the test track was within the Carson River 100-year flood plain as indicated by the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Map (FIRM) Panel 320029 0155C, dated September 30, 1992. This FIRM shows an approximate 100-year flood plain for this portion of the Carson River, which means that water surface elevations have not been established and a regulatory floodway has not been defined.

The profile of the track was set above existing ground, with the inside edge of shoulder top of subgrade set near existing ground elevation after stripping of vegetation (refer to construction cross section, figure 2). Adding a typical 2 percent cross slope across the track section resulted in an outside edge of pavement that ranged between 0.5 and 1 meter (1.5 and 3 ft) higher than adjacent natural ground. Fill for construction of the track subgrade was borrowed from the inside of the track. This borrow area provided for a vehicle safety area as well as for drainage collection and conveyance. Due to the flat profile of the track, there were no vertical curves.

The 11-meter (36-ft) test track transverse cross section consisted of the following elements: bypass/trial lane, test lane, paved shoulder adjacent to test lane, and aggregate base shoulders; roadside safety slopes were established beyond the 11 meters (36 ft). The bypass/trial lane was 3.7 meters (12 ft) in width and served as the asphalt production and laydown trial lane as well as a bypass lane for the track during test lane shutdown. The trial lane was bordered by a 0.6 meter (2 ft) aggregate base shoulder on the inside of the track. The test lane was 3.7 meters (12 ft) in width and lay outside of and adjacent to the trial lane and was bordered by a 1.2-meter (4-ft) asphalt shoulder that was bordered, in turn, by a 1.8-meter (6-ft) aggregate base shoulder. Beyond the outboard aggregate base shoulder was a 6:1 graded slope to catch at existing ground. The inside of the track had a 6:1 downslope hinging off the aggregate base shoulder for an approximate distance of 16 meters (50 ft) to hinge at a flowline and slope up at 6:1 to catch at existing ground (refer to figure 2).

In addition to the test track, along the northeast side of WesTrack was an off-ramp, vehicle staging area, and on-ramp.

ATTACHMENTS

Figure 1 – Horizontal control plan.
Figure 2 – Cross sections.

Longitudinal Profile Data Collection and Level 1 QC/QA Data Analysis

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report NCE-3
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

It is commonly recognized that the pavement characteristic of most concern to the roadway user is pavement roughness. The roughness as experienced by the user is due to the longitudinal profile of the pavement and is expressed in terms of a roughness index. The roughness index utilized by the WesTrack Project was the International Roughness Index (IRI) and is expressed in units of meters per kilometer (m/km).

IRI DATA COLLECTION PROCEDURE

Longitudinal profile data for the WesTrack Project was collected on average once per month using a K.J. Law Profilometer. During periods when the pavement was fatiguing more rapidly (i.e., cold temperatures) than usual, profiles were measured more frequently. This testing frequency resulted in 33 longitudinal profile data sets collected over the life of the project, approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs).

The Long-Term Pavement Performance (LTPP) longitudinal profile data collection guidelines were utilized as the basis for the longitudinal profile data collection at WesTrack. The criteria specified by the LTPP guidelines state that longitudinal profile runs (each run being one pass of the profilometer over the pavement) should be conducted until the average IRI for both wheelpaths meets the following criteria:

- The IRI of three runs are within 1 percent of the mean IRI.
- The standard deviation of all IRIs is within 2 percent of the mean.

It is only necessary for five runs to meet these criteria. If these criteria are not met, a maximum of nine runs should be conducted.

The above criteria were not directly applicable to the geometry of the WesTrack sections because the profilometer only computed the IRI for the entire track tangent while on the site. The longitudinal profiles were not subsectioned into the respective pavement sections until after the staff returned to the office. Therefore, it was quite possible for the runs to meet the LTPP criteria for the tangent as a whole and still fail the criteria for any given section. The WesTrack sections were profiled in this manner because the number of starts and stops necessary to profile each section individually would have made acquiring a full data set for each section too time-consuming to be feasible. Additionally, because the criteria applied to the average IRI of both wheelpaths, it was quite possible for the runs to meet LTPP criteria for the average IRI and still fail for the left wheelpath and/or the right wheelpath.

QC/QA DATA ANALYSIS

After data collection and subsectioning of the tangent profiles into individual section profiles, the profiles were visually examined using the LTPP Profilometer software (PROFSCAN) and the IRI values for the five closest matching profiles were used to compute the average IRI for the left and right wheelpaths (LWP and RWP) for each section. In cases where at least five closely matching longitudinal profiles could not be determined, as many closely matching profiles as could be determined were used (i.e., two, three, or four). If no profiles matched closely, a

decision was made on which longitudinal profile to use; typically the one judged to represent the average of all the profiles for that section was chosen.

Late in the project, a major problem was recognized with the longitudinal profile data during the level 1 quality assurance check (The level 1 check was the major quality assurance (QA) check applied to all data before entry into the database). There appeared to be a significant change in the "pattern" of the longitudinal profile of the left wheelpath for all sections beginning with monitoring session 30 (5/16/97; 2.8 million ESALs). The behavior of the left wheelpath longitudinal profile was typical of a profilometer experiencing a "lost lock." Figures 1 and 2 illustrate this phenomenon, before and after occurrence of the “lost lock,” respectively. There are two components to the measurement of the longitudinal profile of a wheelpath: An accelerometer records the vertical motion of the profilometer and another sensor records the displacement between the profilometer and the road using an incandescent light. Both are necessary to develop the longitudinal profile. The "lost lock" occurs when the sensor measuring the displacement between the profilometer and the road loses its "lock" on the road due to sensor malfunction or some impedance to the reflection of the incandescent light. Therefore, the longitudinal profiles recorded after monitoring session 30 only included the vehicle vertical motion component. After discussions with members of the Western Region LTPP team experienced with profilometer data, the WesTrack Team concluded that the left wheelpath data from monitoring session 31 on was invalid and should not be used. Therefore, the profilometer data contained in this report includes right wheelpath data for all sections over the entire life of the project (5 million ESALs) and left wheelpath data for only the first 30 monitoring sessions (2.8 million ESALs).

RESULTS

Longitudinal profile data were collected during 33 monitoring sessions over the life of the project. Over this life, several significant events occurred that may have had an effect on the pavement roughness and that must be kept in mind when utilizing these data. These events were:

- 0 ESALs – Initiation of traffic on sections 1 through 26.
- 1.5 million ESALs – Sections 7, 9, 13, 21, and 25 were rehabilitated to repair severe rutting.
- 1.8 million ESALs – The Carson River flooded its banks, submerging the entire track. Loading of the track was suspended for approximately 4 weeks.
- 2.8 million ESALs – Sections 5, 6, 7, 8, 9, 13, 21, 24, 25, and 26 were taken "out of service." These sections were replaced with sections 35, 36, 37, 38, 39, 43, 51, 54, 55, and 56.
- 3.4 million ESALs on original sections, 0.6 million ESALs on replacement sections – Rehabilitation performed to repair rutting and roughness on sections 23, 36, 37, 54, 55, and 56.
- 4.1 million ESALs on original sections, 1.3 million ESALs on replacement

sections – Rehabilitation performed to repair severe fatigue on sections 1, 2, 3, and 10.

- 5 million ESALs on original sections, 2.2 million ESALs on replacement sections – Traffic loading ceased on all sections.

Figures 3 through 38 illustrate the IRI values for all of the pavement sections for the life of the project. Tables 1 and 2 present these IRI values in tabular form. Note that the IRI values are expressed in units of meters per kilometer (m/km) (1 m/km = 63.0 in./mi).

ROUGHNESS MODELS FOR FLEXIBLE PAVEMENTS

Upon completion of the longitudinal profile date collection activities, attention was turned to the development of a relationship between roughness and pavement surface distress. A literature review of several roughness models is provided in this section. The next section, WesTrack Roughness Correlation, describes, based on the WesTrack data, the relationship between roughness and pavement surface distress.

Pavement roughness is defined as the deviation from a true planar surface with a characteristic dimension that affects vehicle dynamics, ride quality, and dynamic loads. Predicting the progression of roughness during pavement design life is very important for pavement management decision making. Several researchers have developed models for characterizing roughness progression in flexible pavements.

The American Association of State Highway Officials (AASHO) Road Test developed a model for predicting roughness progression as a function of traffic:[1]

$$g_t(P_o - P_t) / (P_o - P_r) = (N_t/\rho)^{\beta} \quad (1)$$

Where: g = Damage function,
P = Serviceability index,
N_t = Cumulative number of ESALs, and
ρ and β are functions.

The Transport and Road Research Laboratory (TRRL) developed a model for predicting roughness progression from a 4-year monitoring program of the road network in Kenya:[2]

$$R_t = R_o + s\,(S)\,N_t \quad (2)$$

Where: R = Roughness,
S = Pavement strength parameter, and
N_t = Cumulative number of ESALs.

Lytton et al. modified the AASHTO model to an S-shaped function of slope ρ and curvature β. The model is considered to apply to cases in which the contributing modes of distress stabilize over time, such as rutting due to densification or where defects are repaired by maintenance:[3]

$$g_t = \exp [-(\rho/N_t)^{\beta}] \quad (3)$$

Where: g = Damage function,
N_t = Cumulative number of ESALs, and
ρ and β are functions.

A study by the Arizona Department of Transportation found a significant influence of environment on the time-rate of progression of roughness. The rates ranged from 2 percent per year in arid nonfreezing areas to 8 percent per year in freezing areas:[4]

$$\Delta R_t = a\, R_t\, \Delta t - b \quad (4)$$

Where: a and b are constants, and
R = Roughness.

An Australian study developed a model for progression of roughness as a function of time and reported about 2 percent rate of progression per year for a semi-arid climate:[5]

$$R_t = R_o + a\, t^b \quad (5)$$

Where: a and b are constants, and
R = Roughness.

Queiroz developed a model to predict progression of roughness in Brazil as a function of age and traffic in a simple log-linear model:[6]

$$R_t = a + b\, t + c\, f\,(s, \log Nt) \quad (6)$$

Where: a, b, and c are constants,
t = Age of pavement since rehabilitated, and
R = Roughness.

A British study reported a strong link between the progression of roughness and the area of cracking:[7]

$$\delta R_t / R_t = \max (a\, CX^b, c)\, \Delta t \quad (7)$$

Where: a, b, and c are constants,
CX = Area of cracking, and
R = Roughness.

Uzan and Lytton developed a model to predict the progression of roughness as a function of rutting, cracking, and patching:[8]

$$t = f\,(P_o, \text{var RD}, RD^{2.5}, (c + p)^{0.5}) \quad (8)$$

Where: P = Serviceability index,

RD = Rut depth, and
c + p is the area of cracking and patching.

Patterson developed a general model for predicting the incremental progression of roughness as a function of strength, pavement condition, traffic, environment, and maintenance:[9]

$$\Delta RI_t = 134e^{0.023t}\, SNCK^{-5.0}\, \Delta NE_4 + 0.114\, \Delta RDS + 0.0066\, \Delta CRX + 0.010\, \Delta PAT + Z_{pot} + 0.023\, RI_t\, \Delta t \quad (9)$$

Where: ΔRI_t = Increase of roughness over time period t (m/km IRI),
SNCK = 1 + SNC - 0.0000758 H CRX,
ΔNE_4 = Incremental number of equivalent single-axle loads in period t (million ESAL/Lane),
ΔRDS = Increase in rut depth standard deviation of both wheelpaths (mm),
ΔCRX = Increase in area of indexed cracking (percent),
ΔPAT = Increase in area of surface patching (percent),
Z_{pot} = Dummy intercepts estimated for sections with pot holing,
RI_t = Roughness at time t (m/km IRI),
Δt = Incremental time period of analysis (years),
SNC = Modified structural number of pavement strength,
H = Thickness of cracked layer (mm),
CRX = Area of cracking (percent), and
t = Age of pavement or overlay (years).

Note: Indexed cracking is the weighed area given by CRX = (4 x area of class 4 + 3 x area of class 3 + 2 x area of class 2 + 1 x area of class 1 cracking)/10.

WESTRACK ROUGHNESS CORRELATION

Utilizing data collected from the WesTrack Project, a relationship was established between the roughness (IRI) and the initial roughness (IRI_{init}), percentage of fatigue cracking, and average rut depth. Documentation of this roughness relationship is provided in Transportation Research Record 1699:[10]

$$IRI = 0.6436(IRI_{init}) + 0.008684\ (\text{Fatigue \%}) + 0.007625\ (\text{Rut Depth}) + 0.3245 \quad (10)$$

Where: IRI = roughness (m/km),
IRI_{init} = the roughness of the pavement section measured just after construction (m/km),
Fatigue % = the fatigue cracking area divided by the total wheelpath area, and
Rut Depth = the average rut depth of both wheelpaths (mm).

SUMMARY

This report has provided a description of how the longitudinal profile data were collected and the quality control and quality assurance measures taken. Figures are presented illustrating the change in roughness for each section over the life of the project. A literature search was performed of the existing roughness models and a relationship between roughness and distress developed from the WesTrack data was presented.

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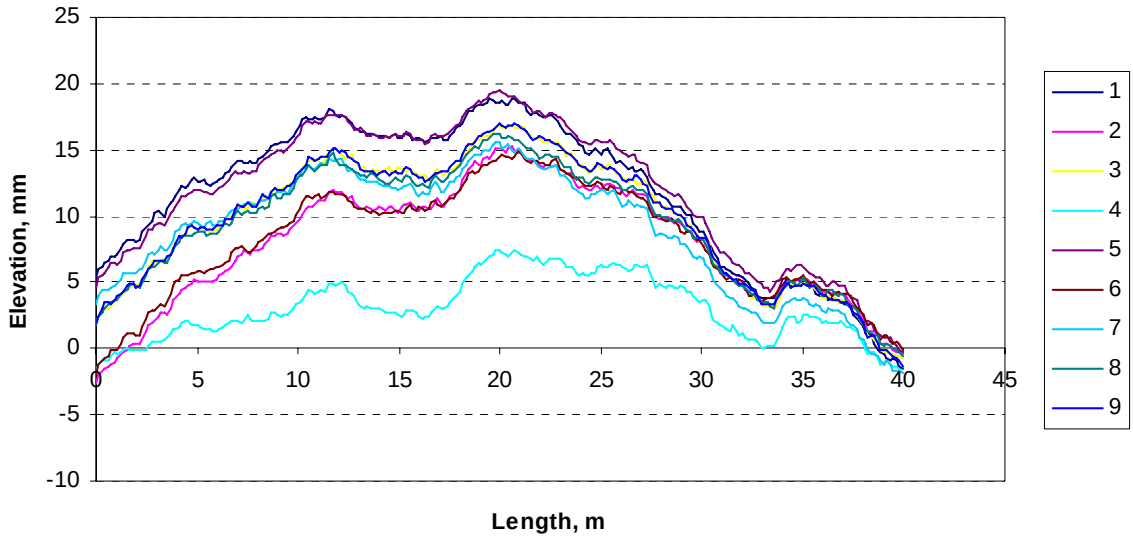

Figure 1. Left wheelpath longitudinal profiles, section 1, monitoring session 29.

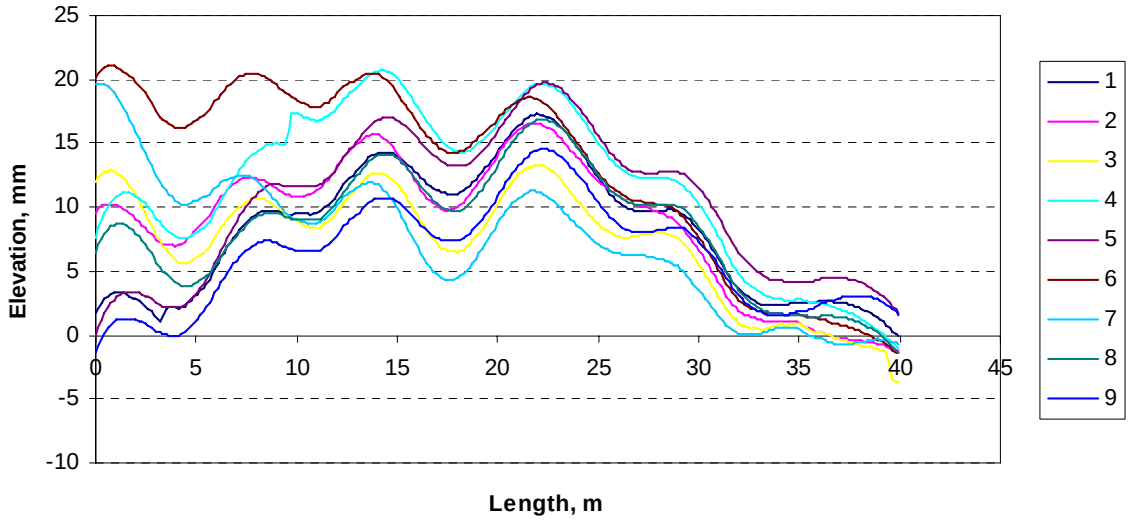

Figure 2. Left wheelpath longitudinal profiles, section 1, monitoring session 37.

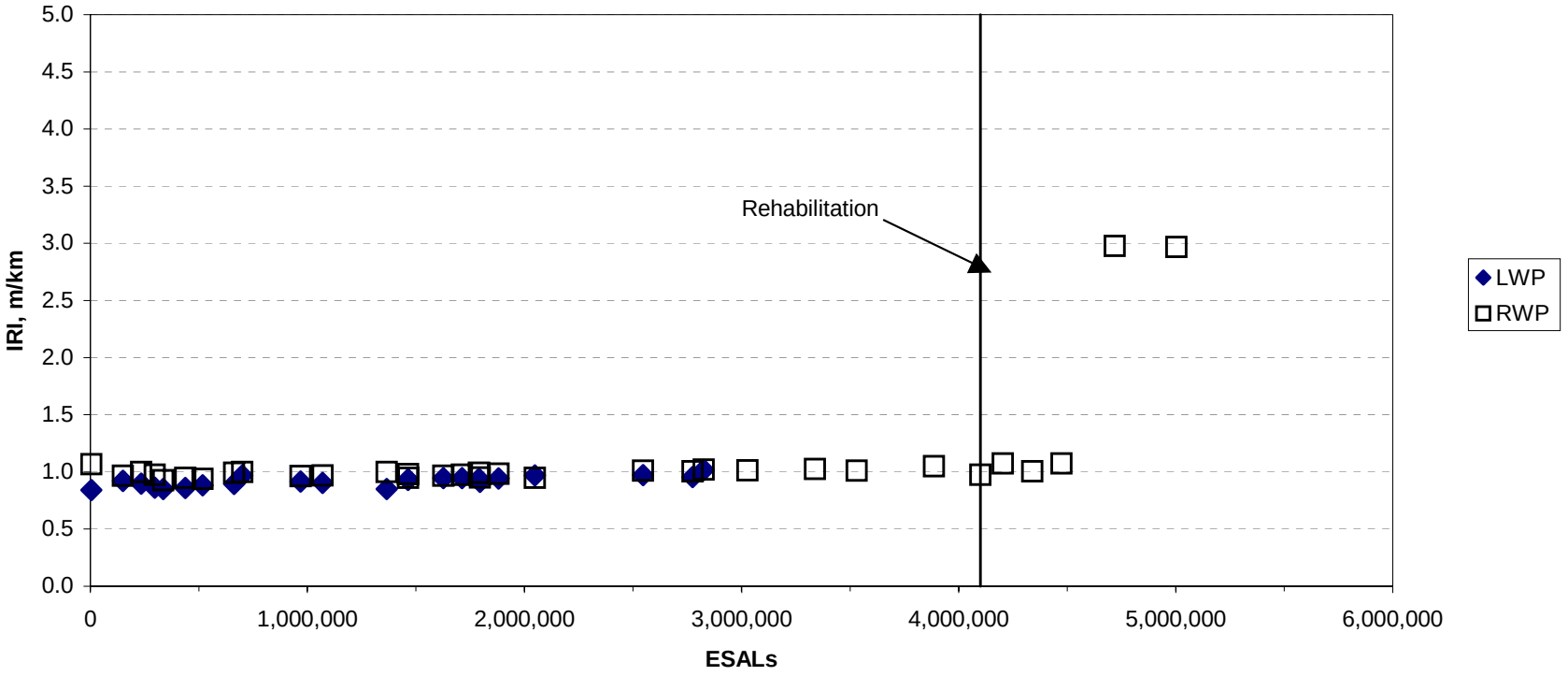

Figure 3. IRI versus time for section 1.

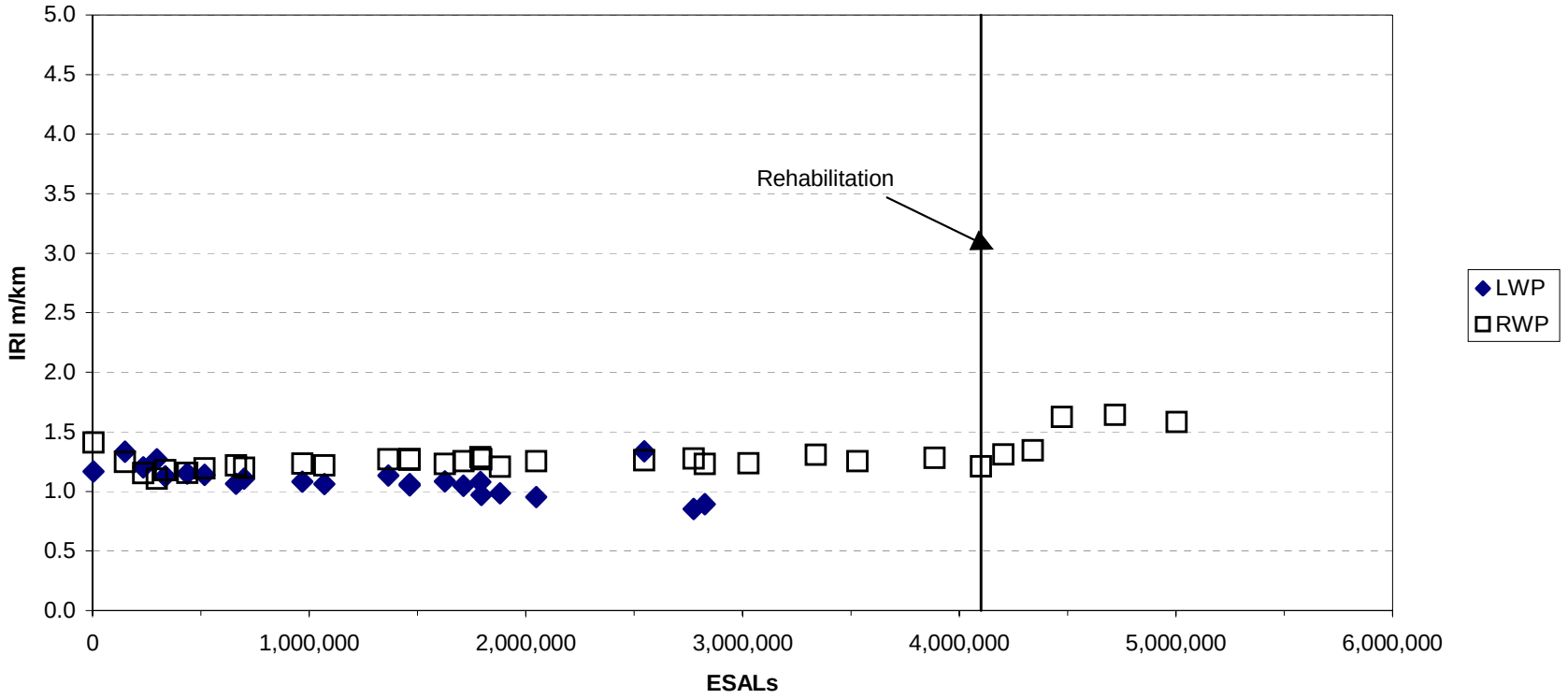

Figure 4. IRI versus time for section 2.

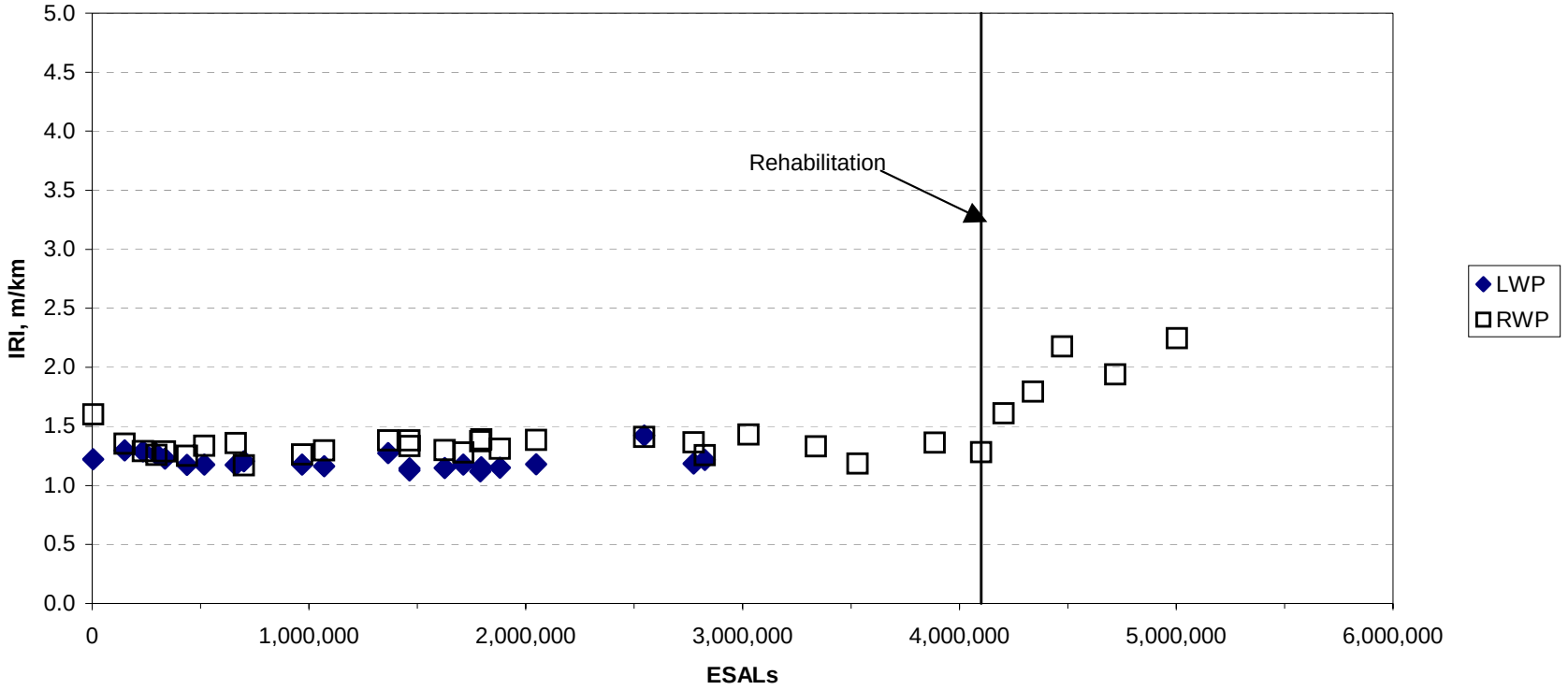

Figure 5. IRI versus time for section 3.

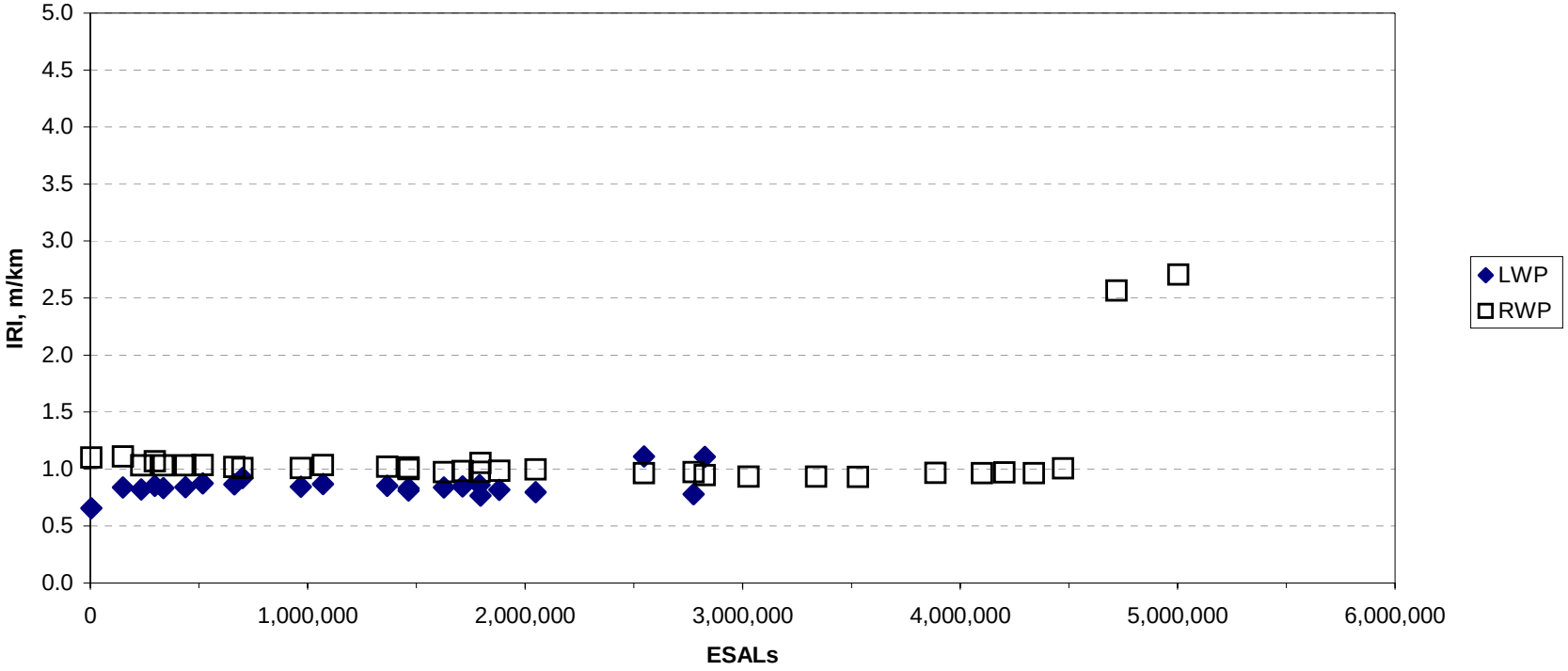

Figure 6. IRI versus time for section 4.

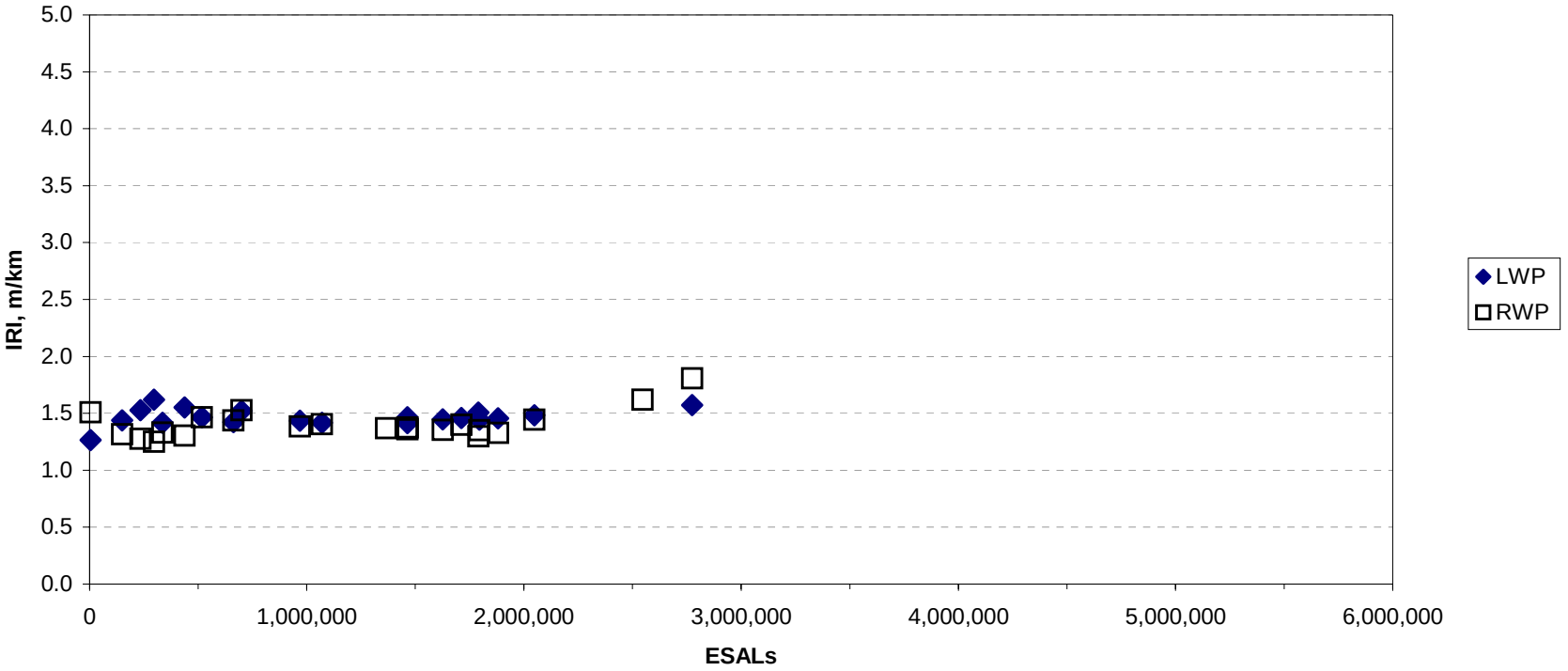

Figure 7. IRI versus time for section 5.

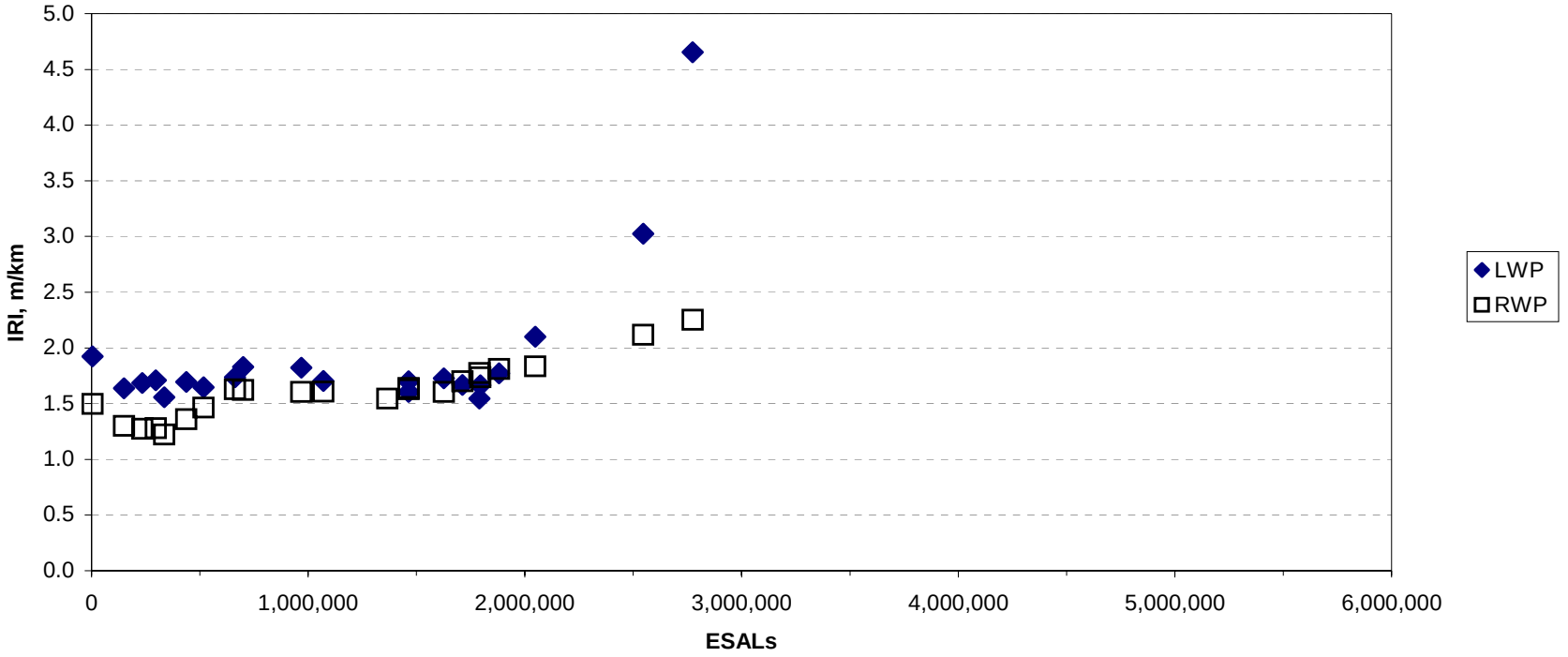

Figure 8. IRI versus time for section 6.

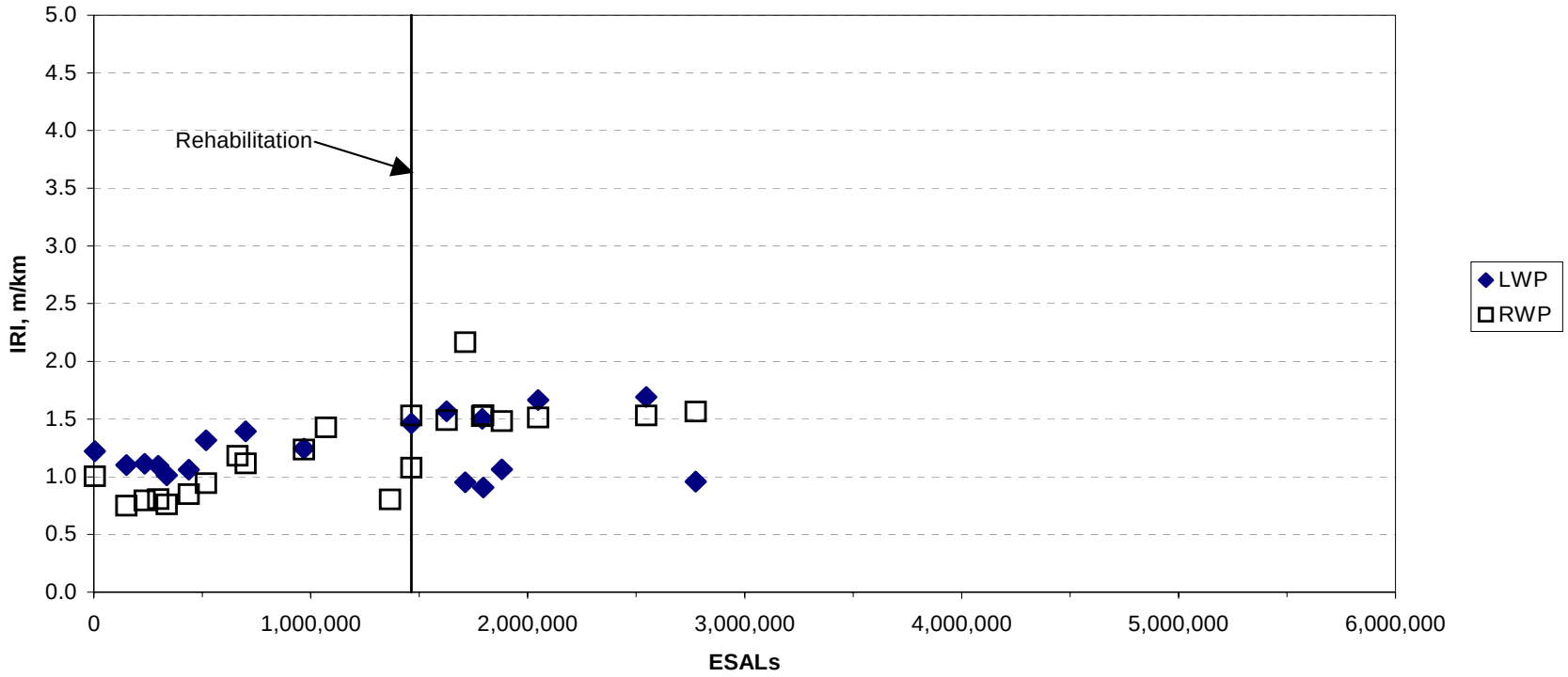

Figure 9. IRI versus time for section 7.

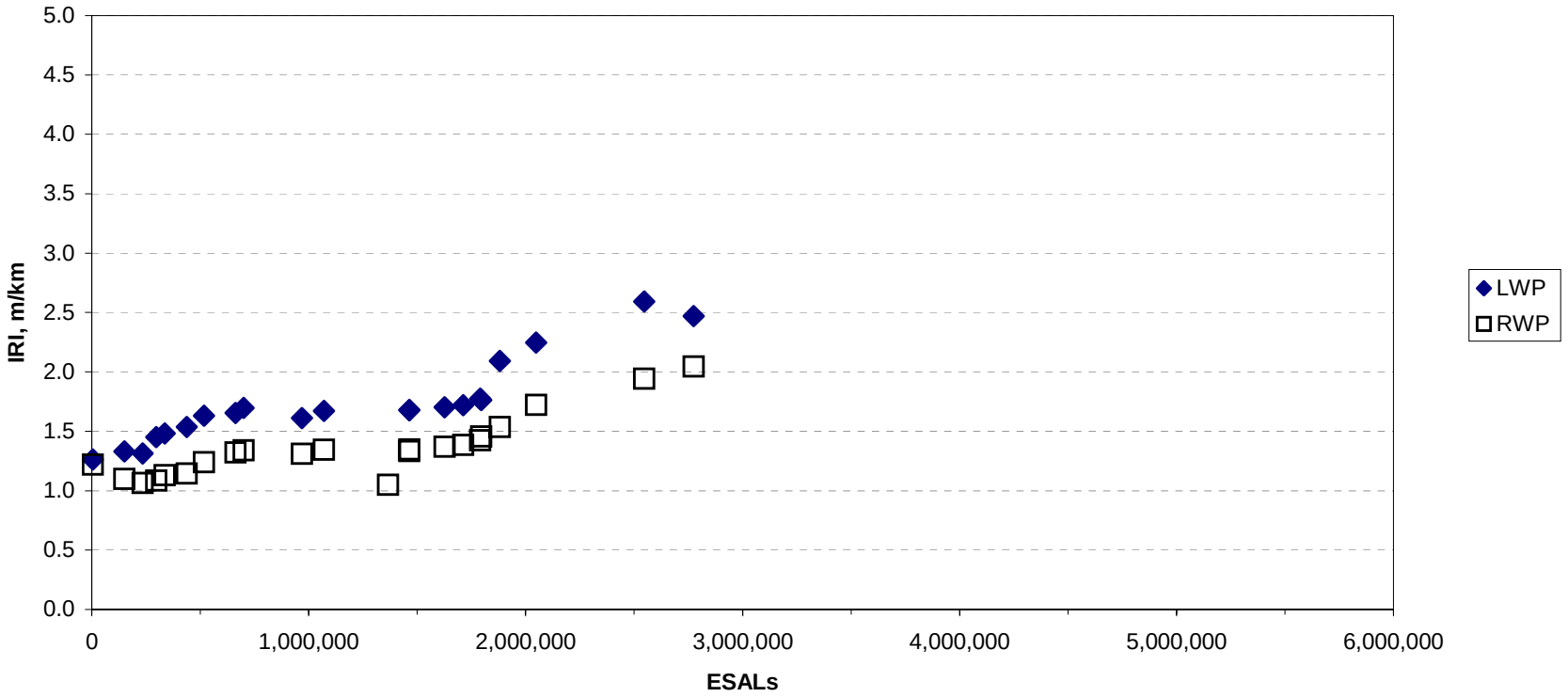

Figure 10. IRI versus time for section 8.

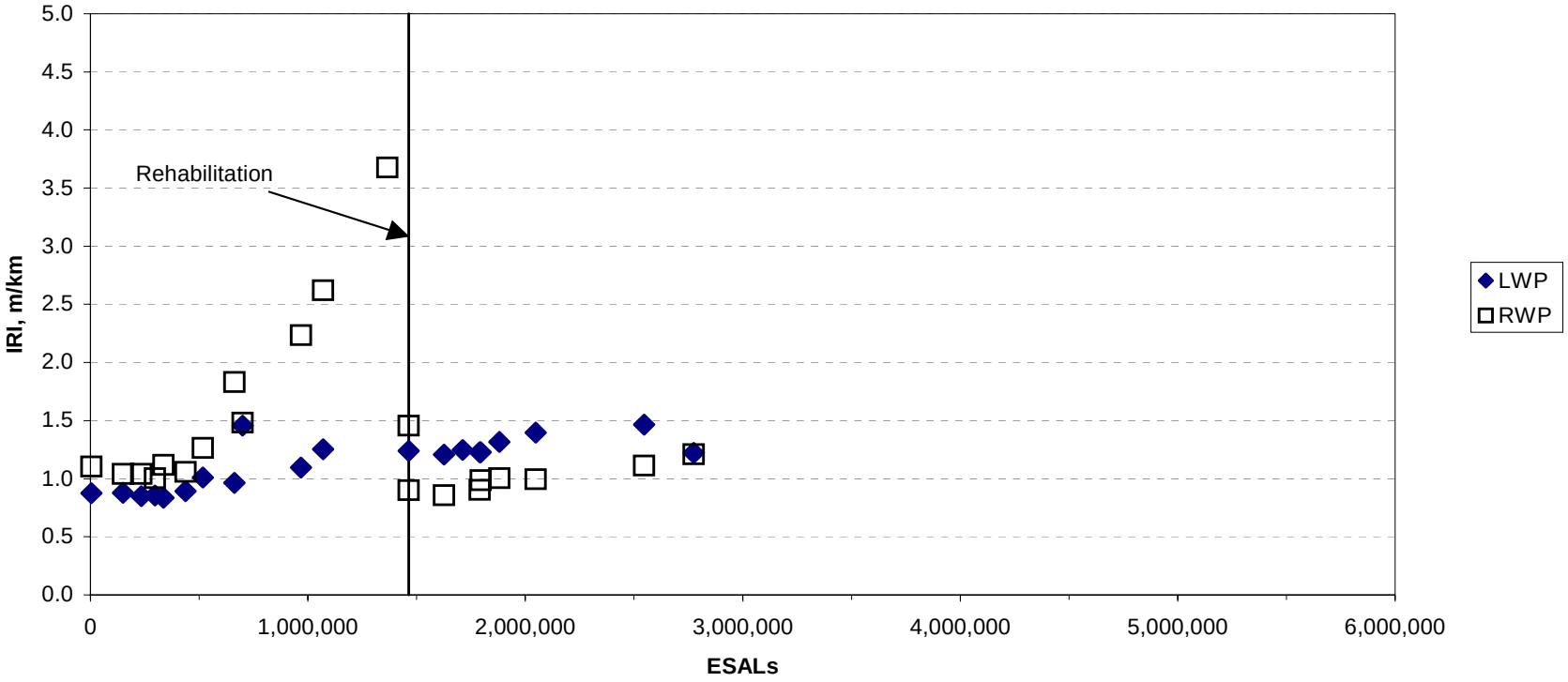

Figure 11. IRI versus time for section 9.

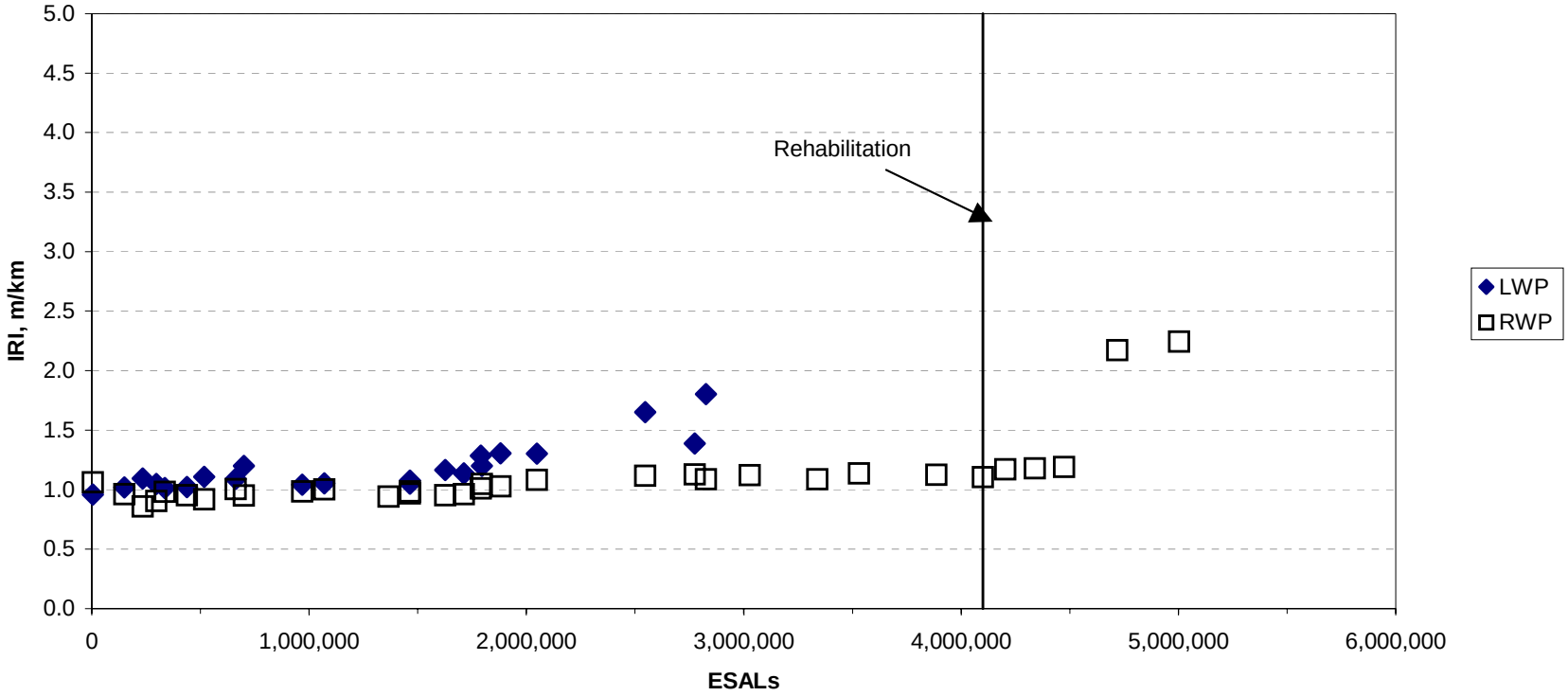

Figure 12. IRI versus time for section 10.

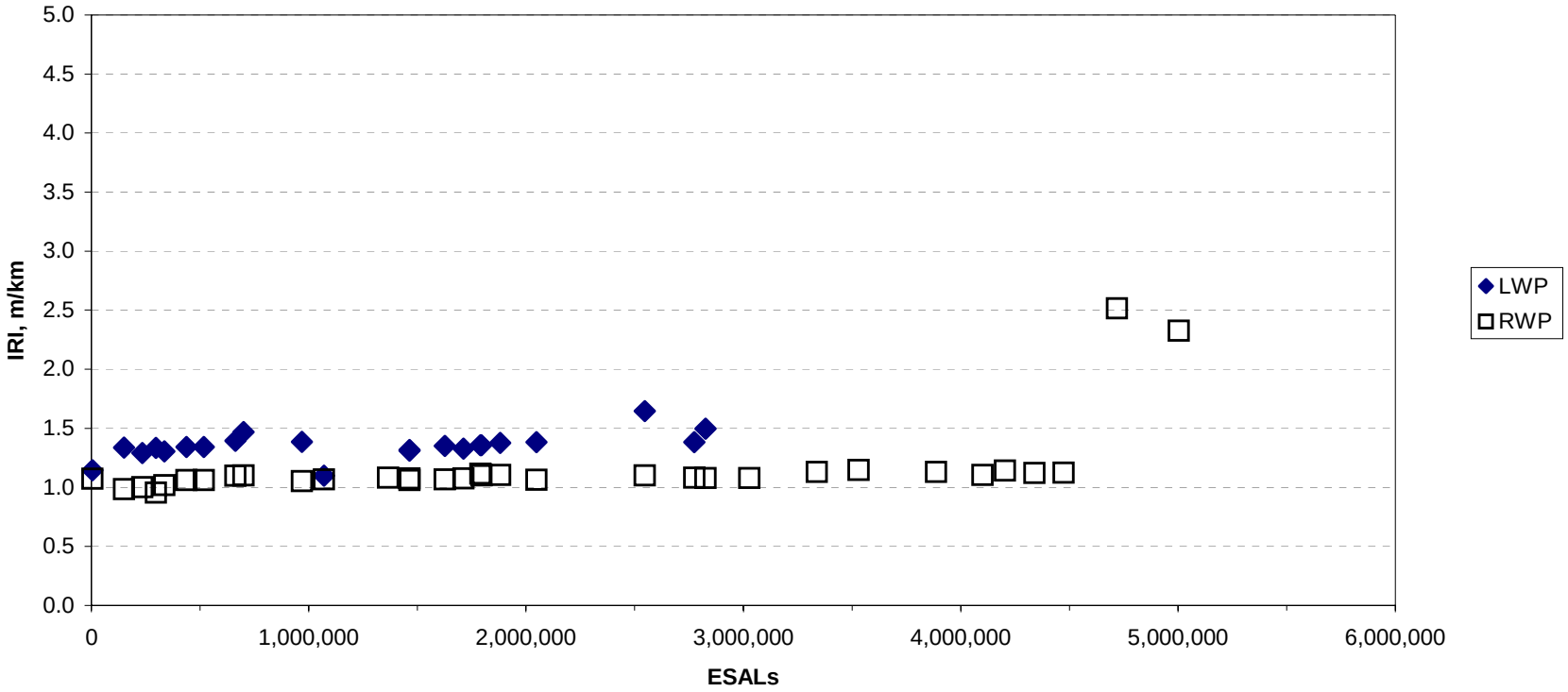

Figure 13. IRI versus time for section 11.

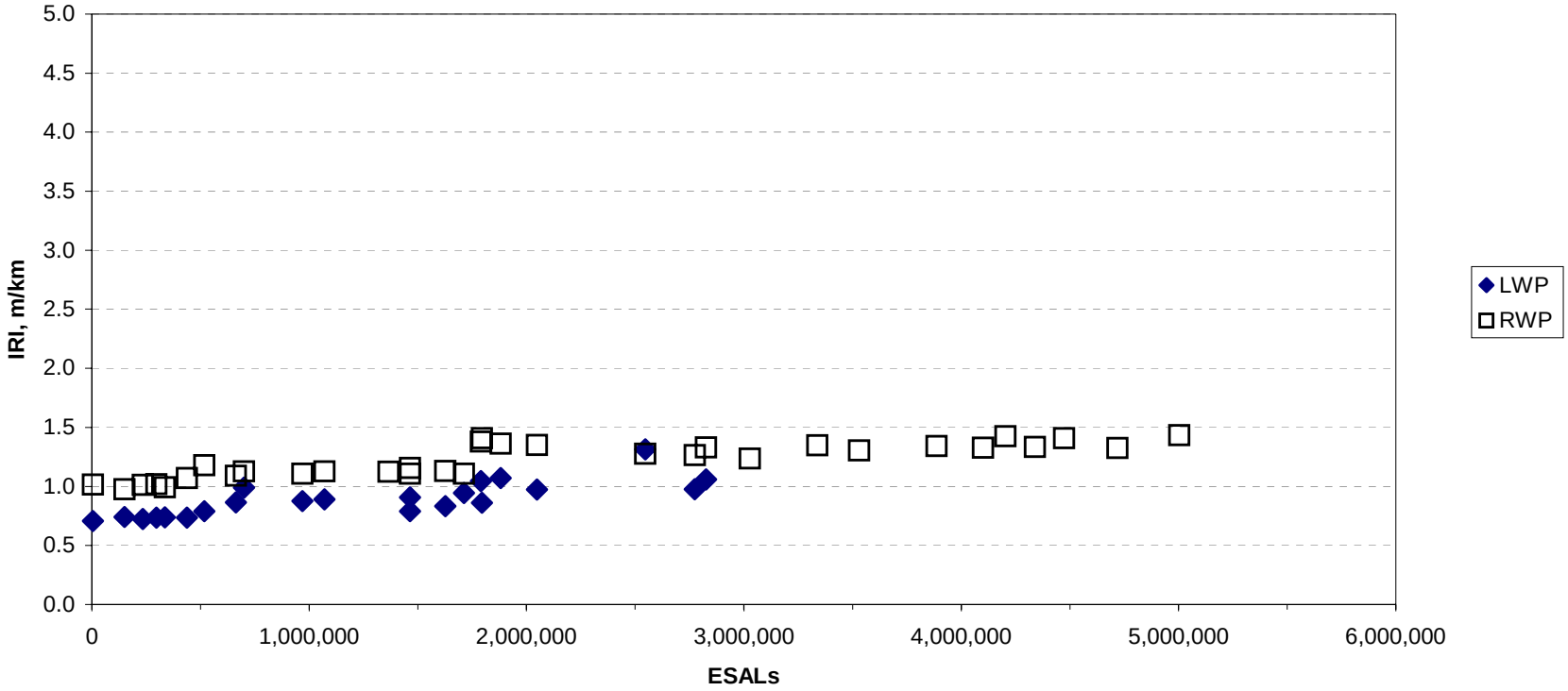

Figure 14. IRI versus time for section 12.

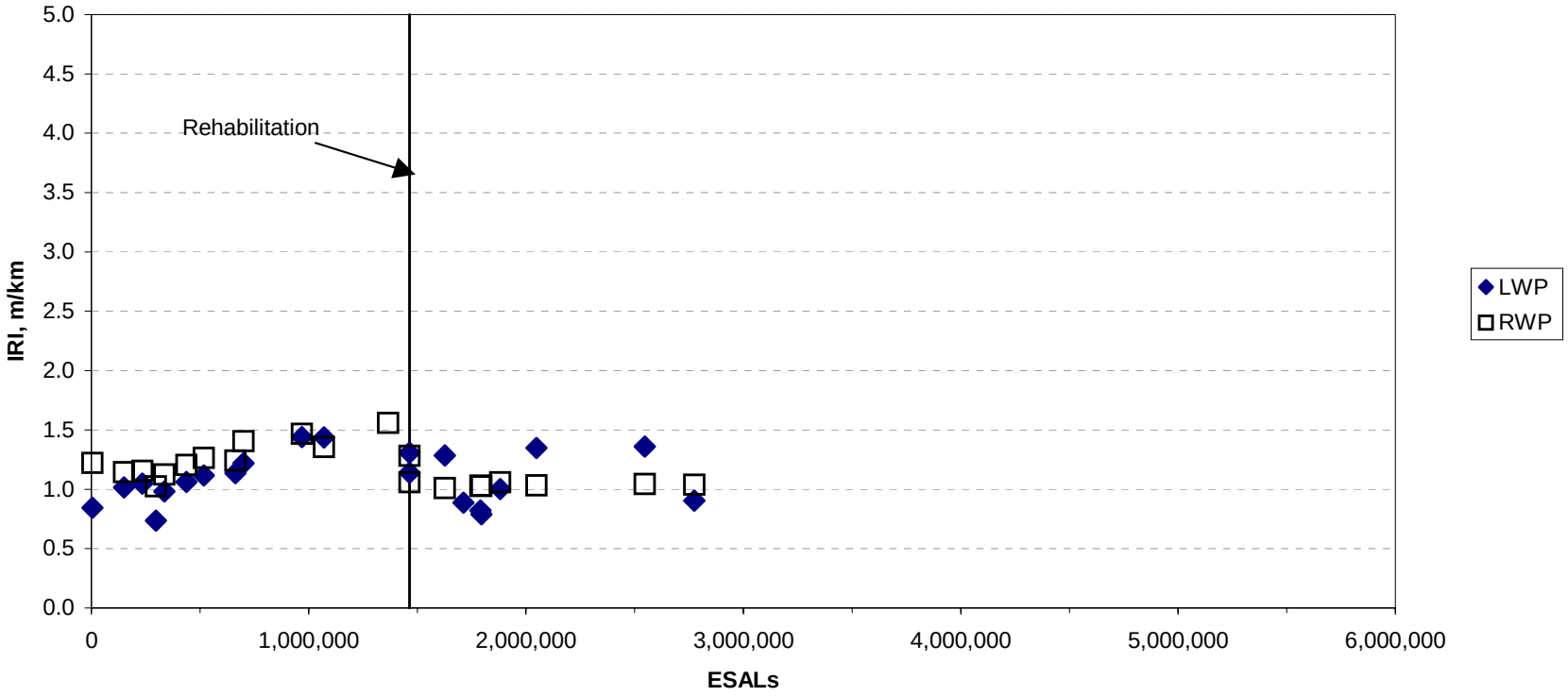

Figure 15. IRI versus time for section 13.

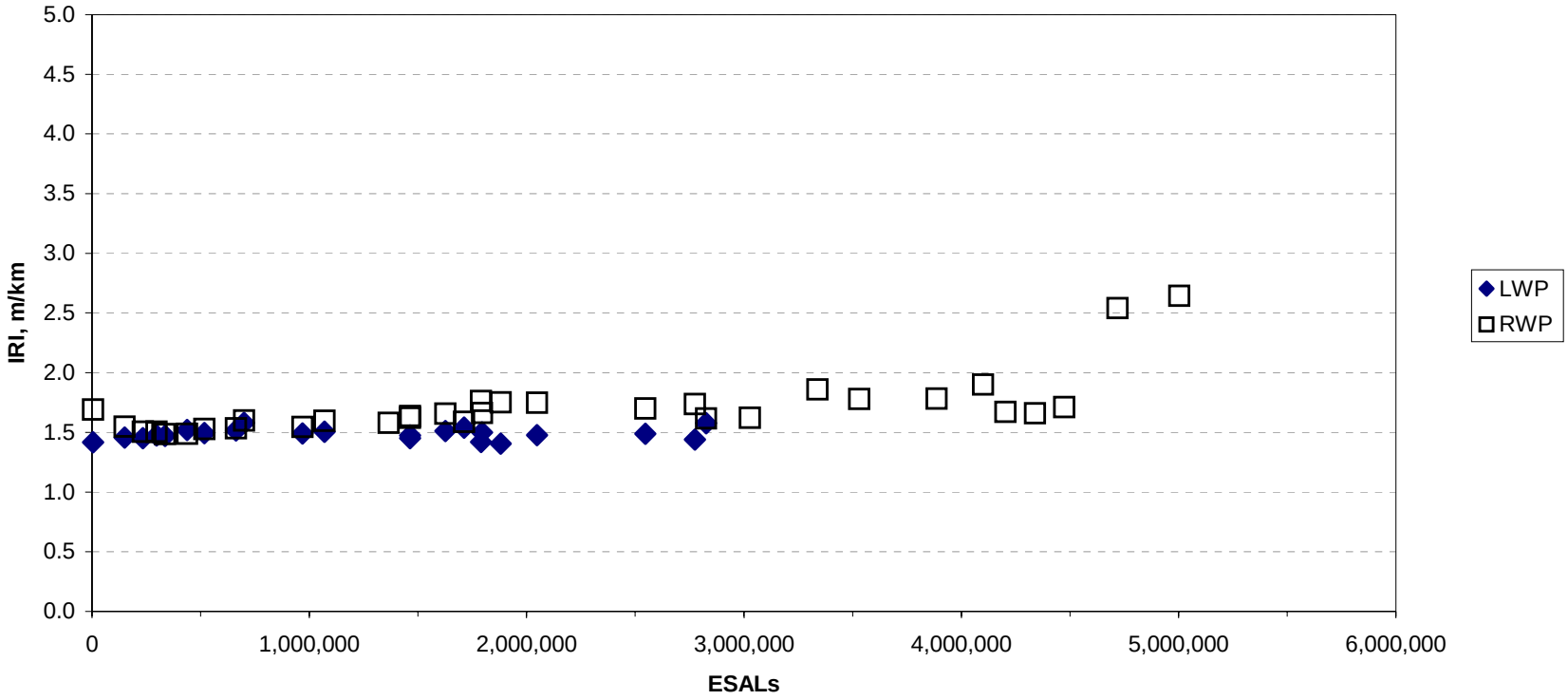

Figure 16. IRI versus time for section 14.

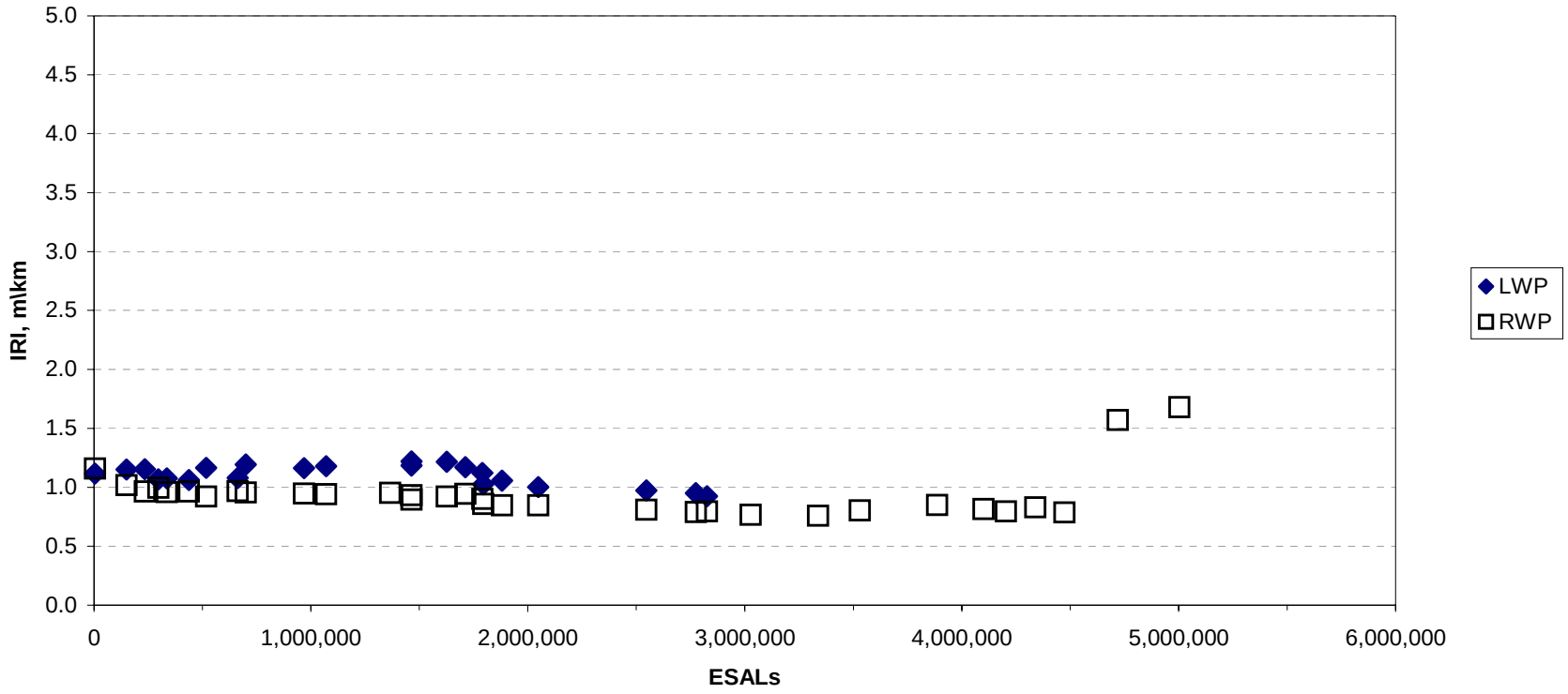

Figure 17. IRI versus time for section 15.

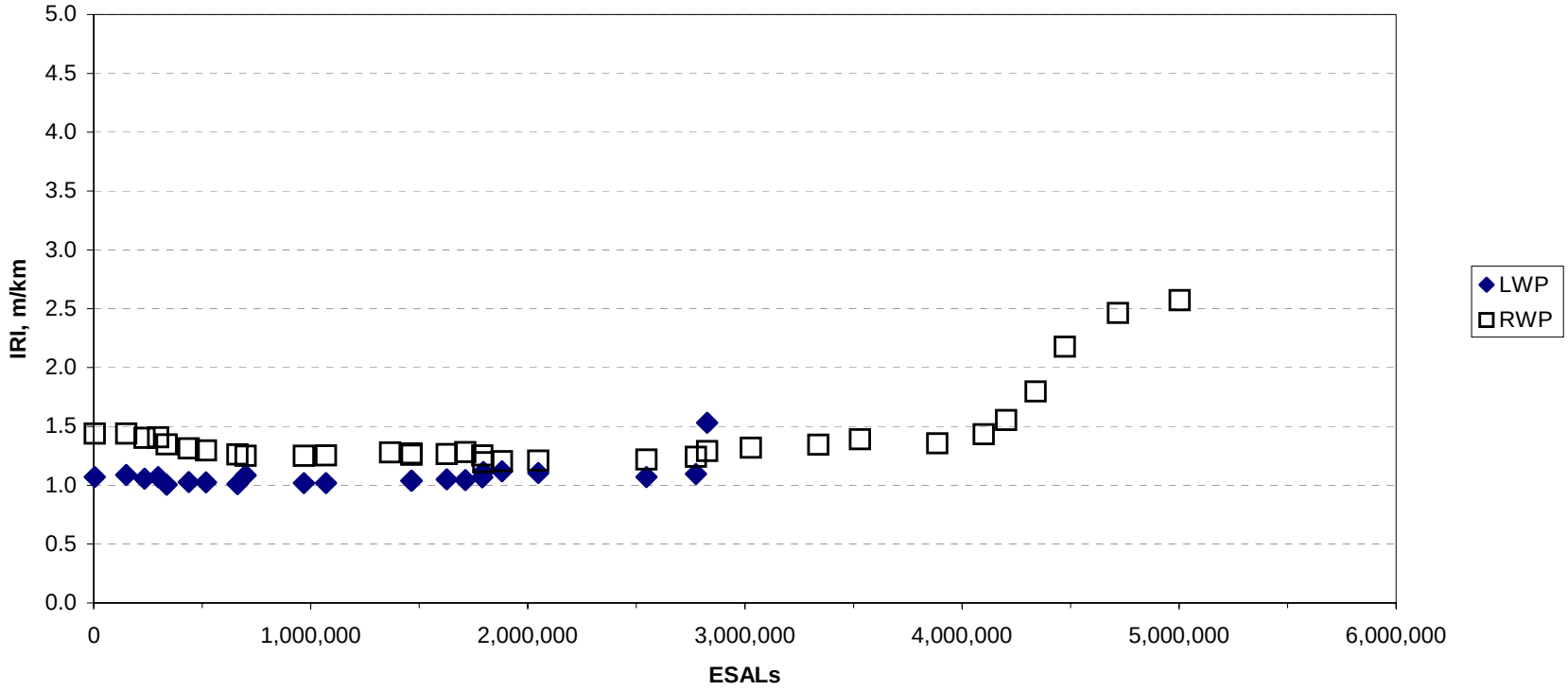

Figure 18. IRI versus time for section 16.

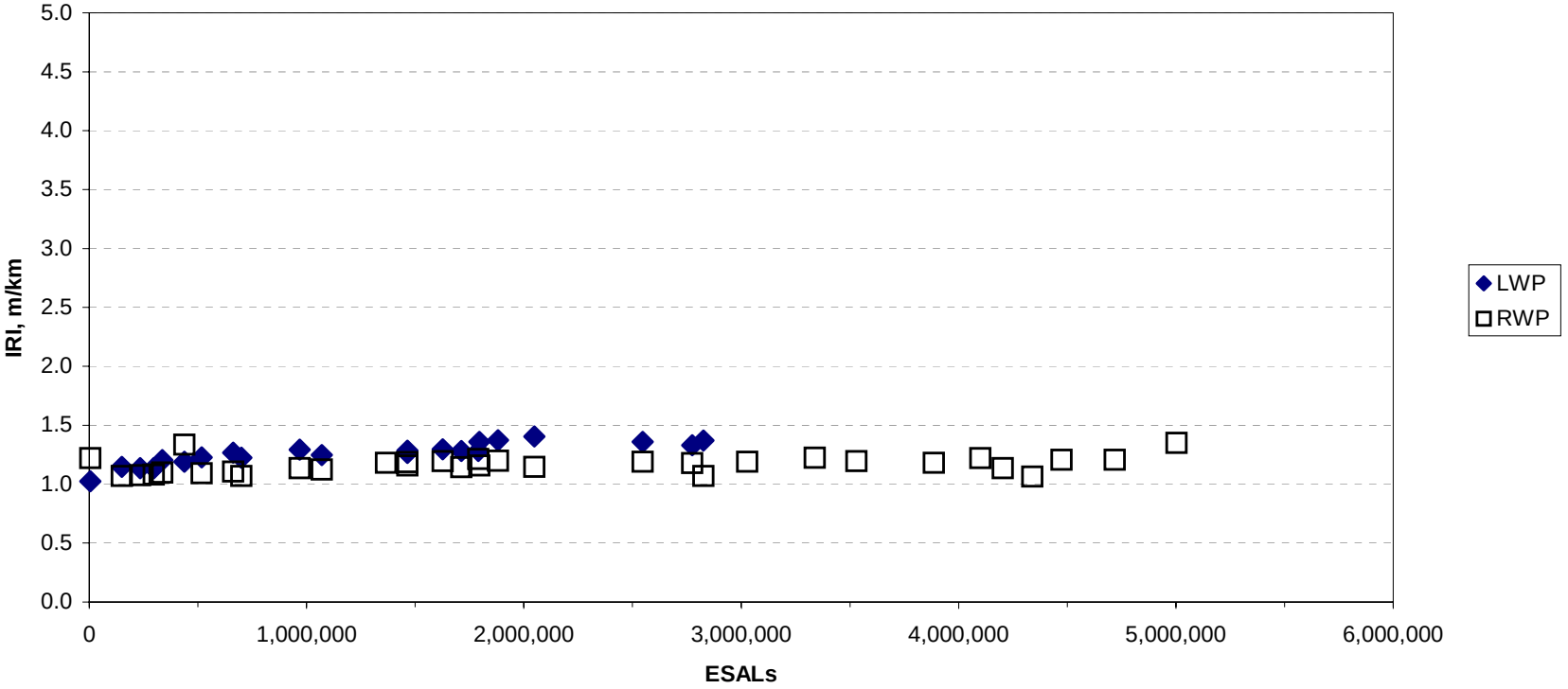

Figure 19. IRI versus time for section 17.

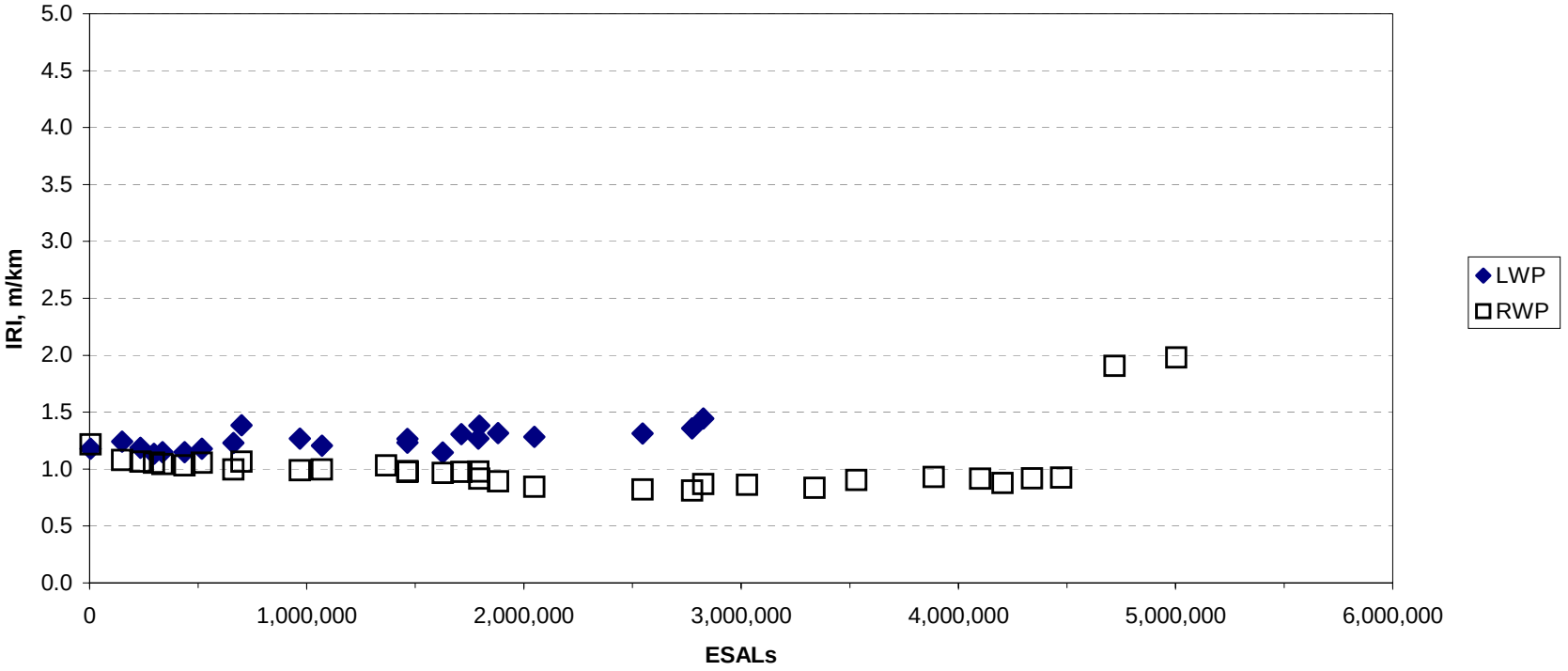

Figure 20. IRI versus time for section 18.

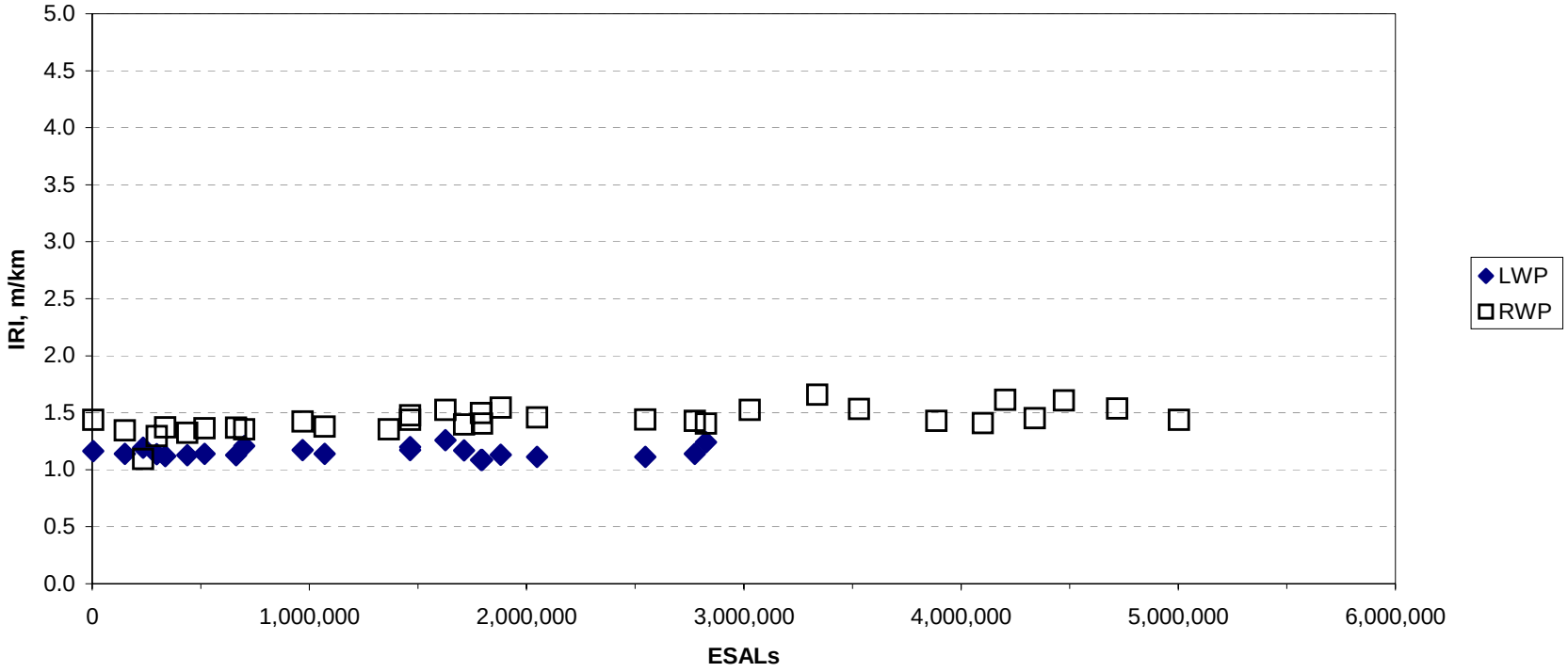

Figure 21. IRI versus time for section 19.

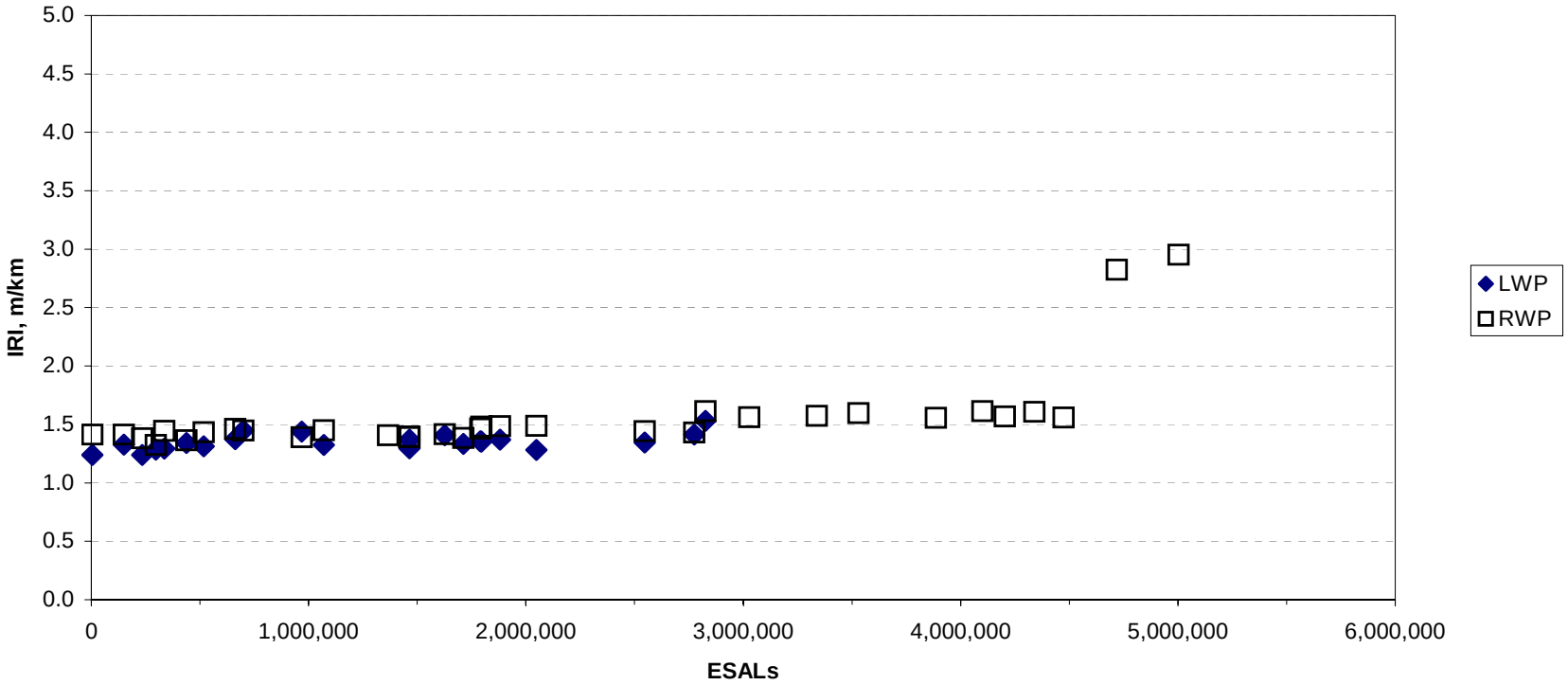

Figure 22. IRI versus time for section 20.

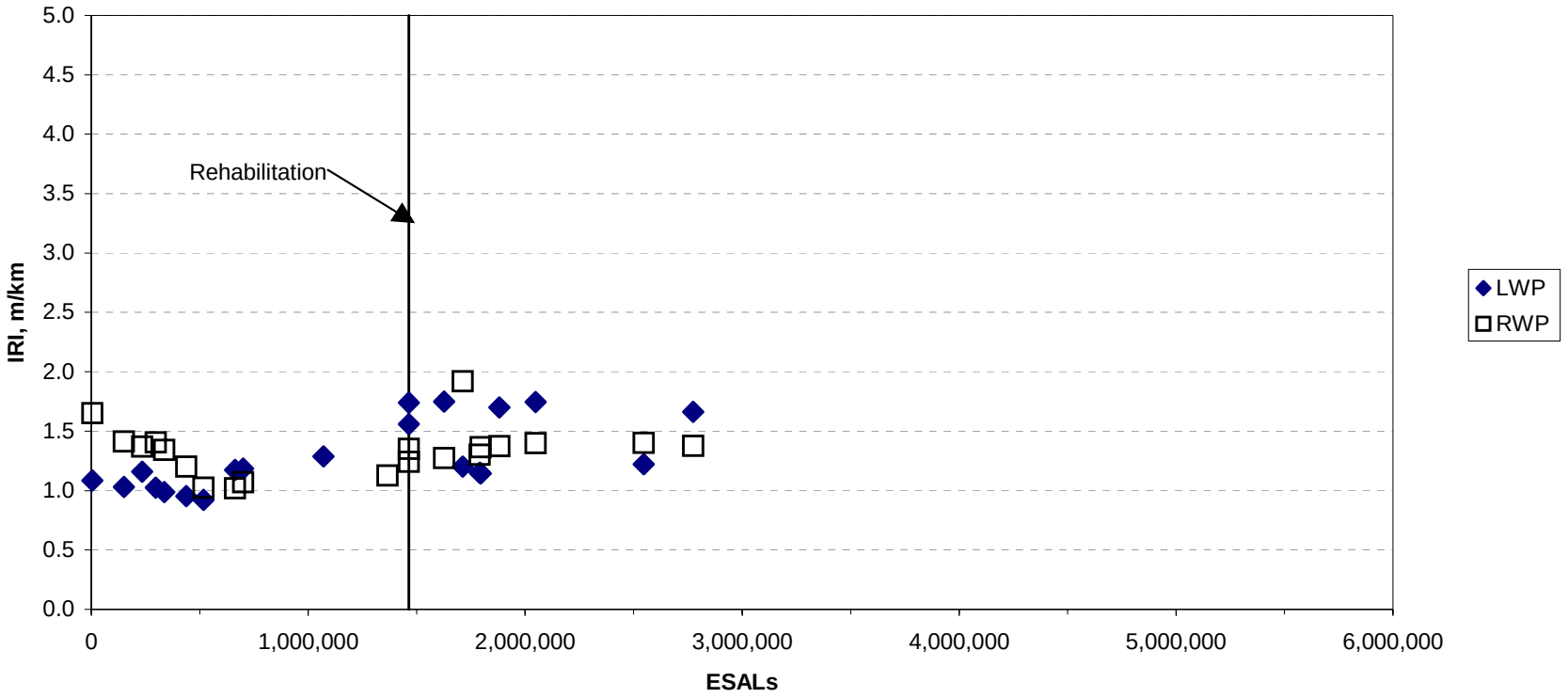

Figure 23. IRI versus time for section 21.

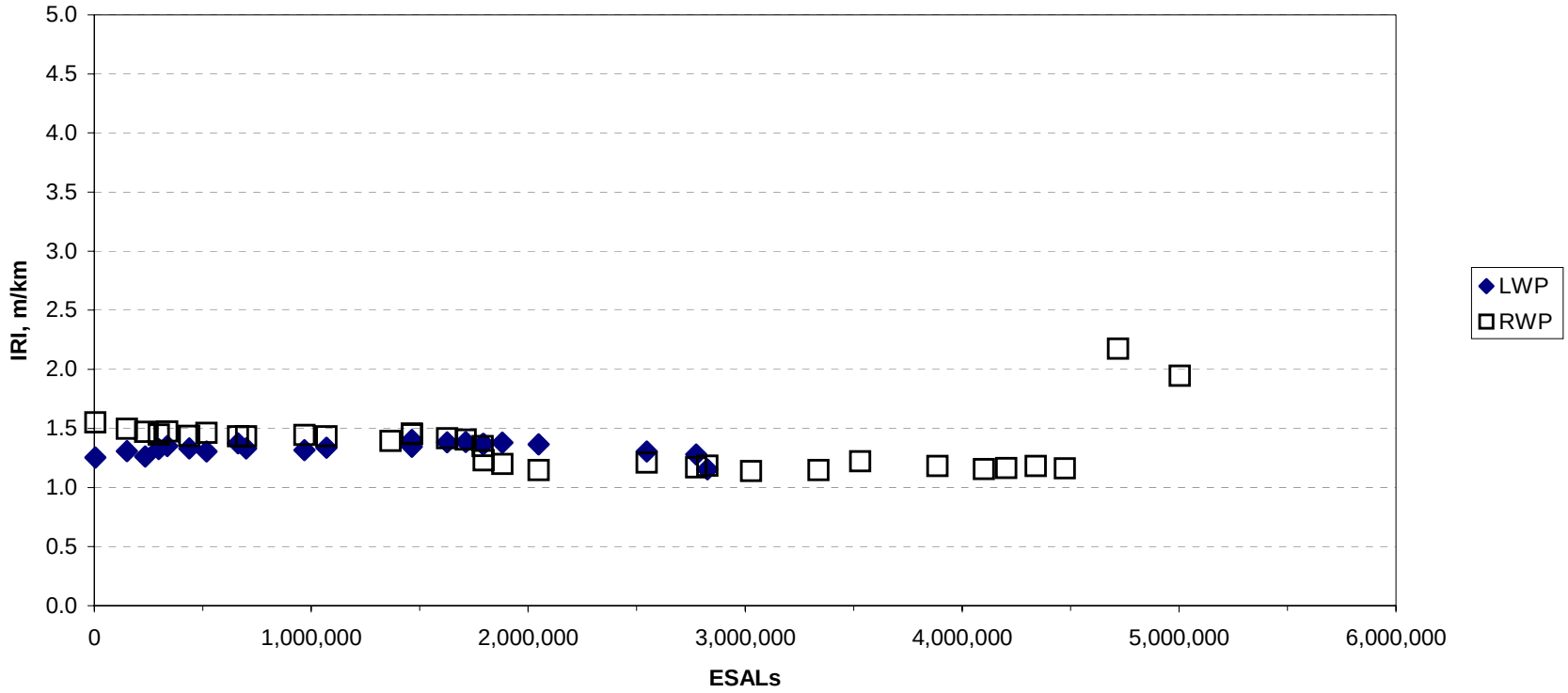

Figure 24. IRI versus time for section 22.

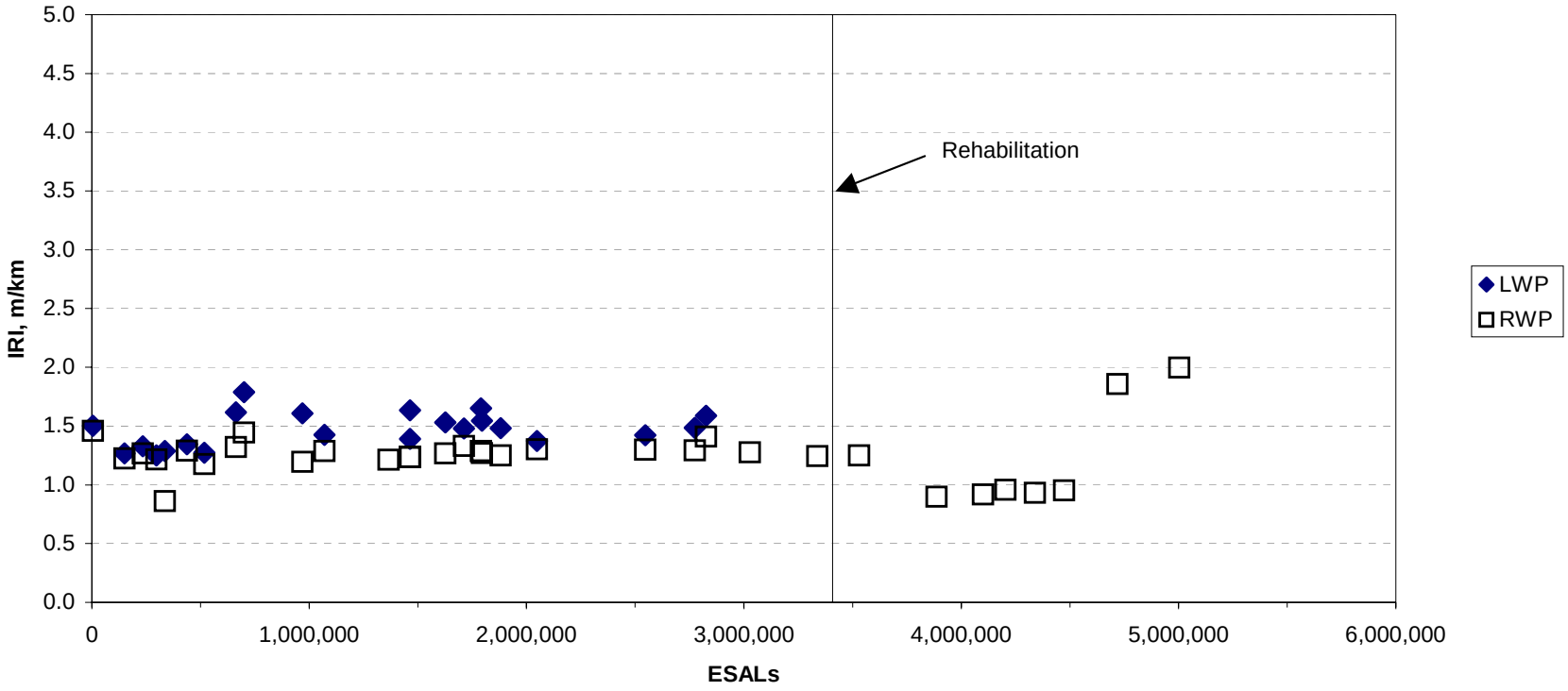

Figure 25. IRI versus time for section 23.

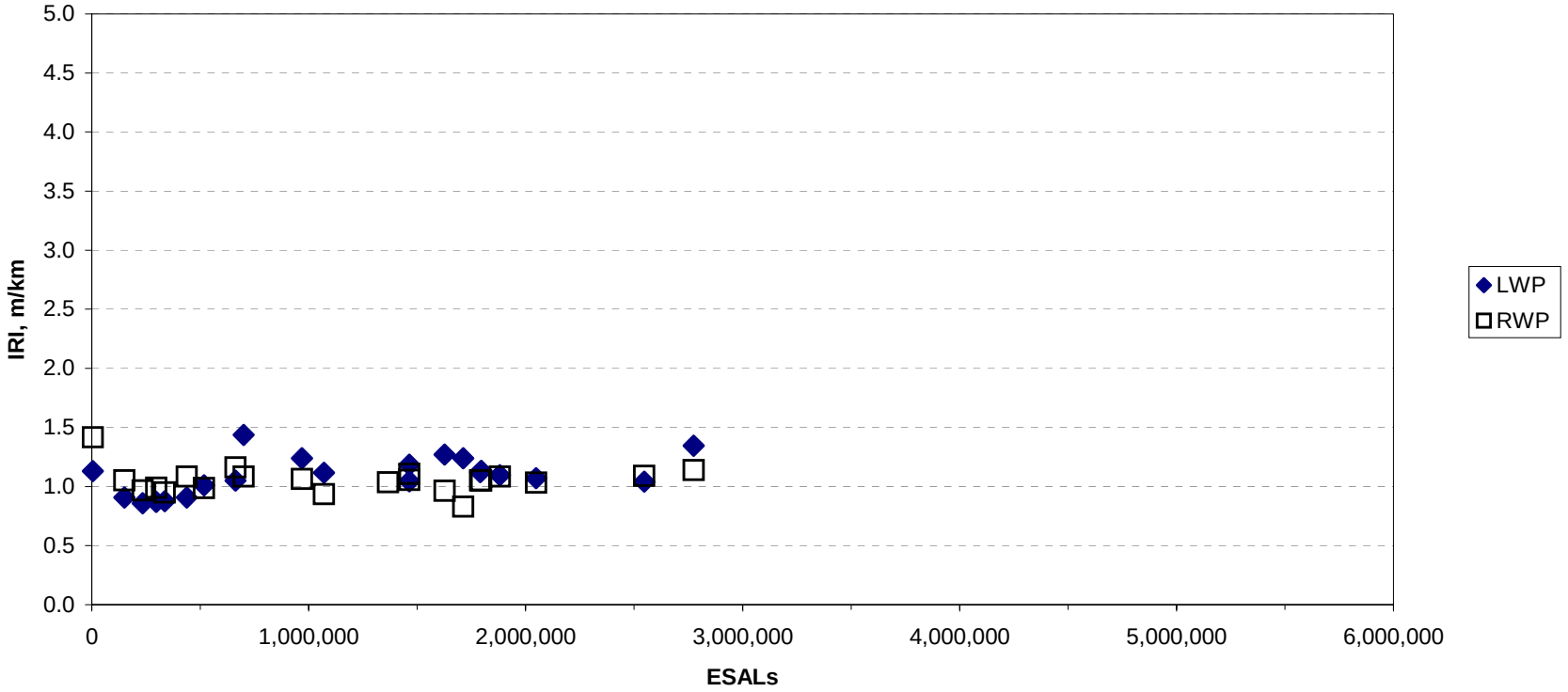

Figure 26. IRI versus time for section 24.

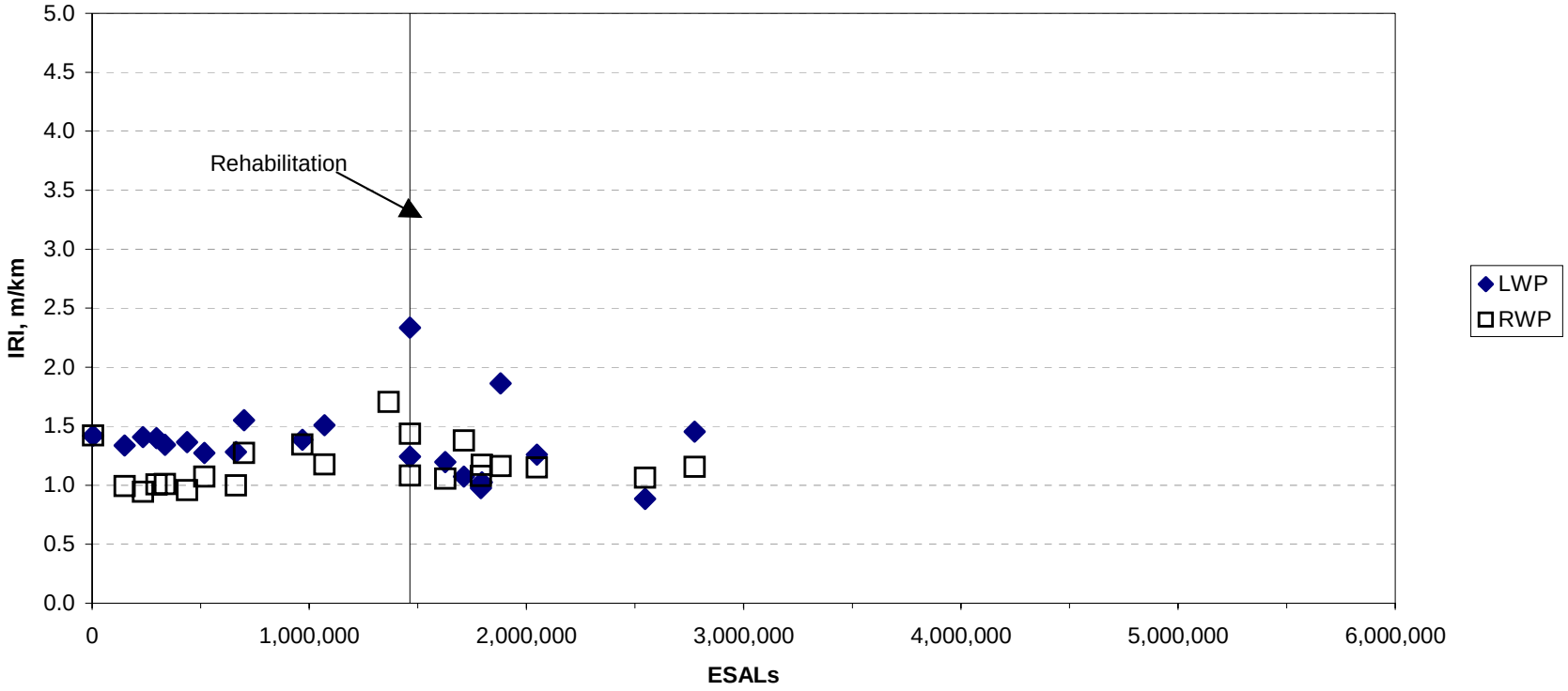

Figure 27. IRI versus time for section 25.

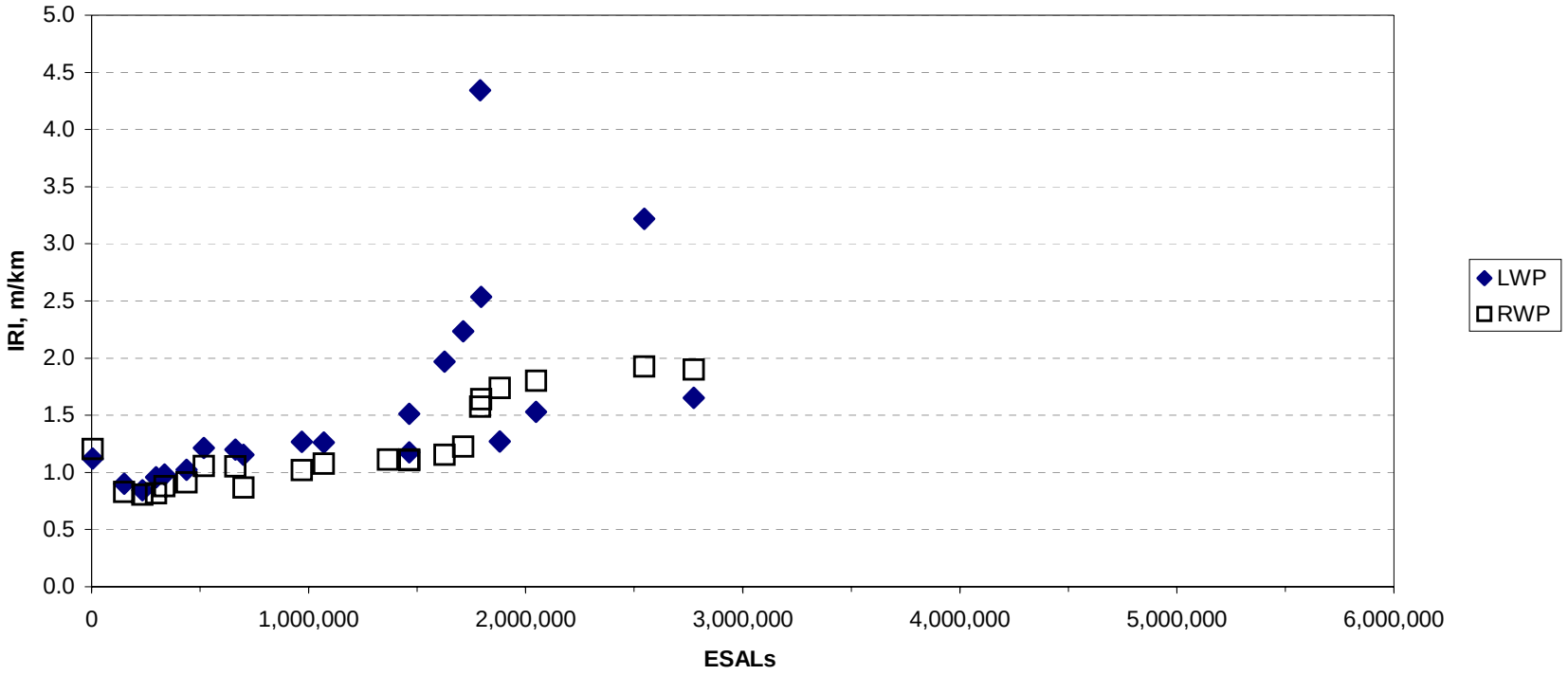

Figure 28. IRI versus time for section 26.

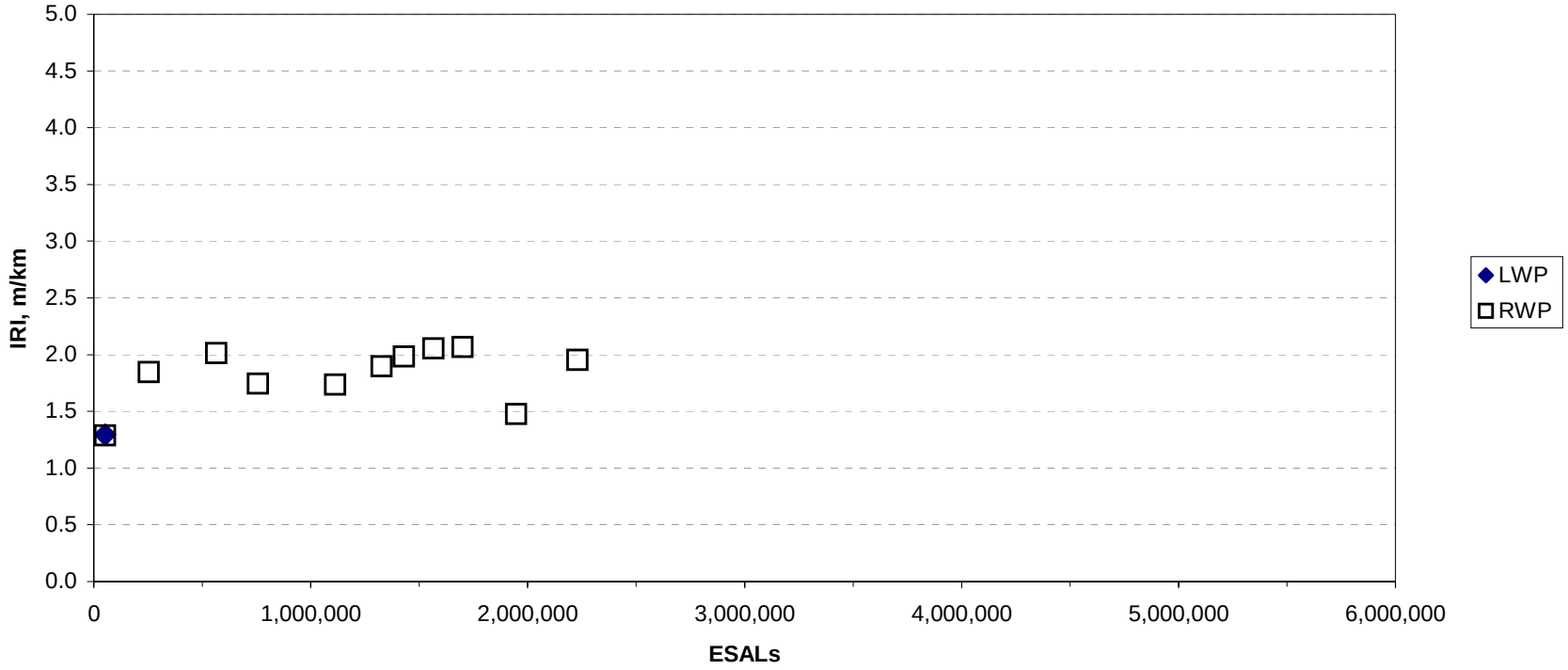

Figure 29. IRI versus time for section 35.

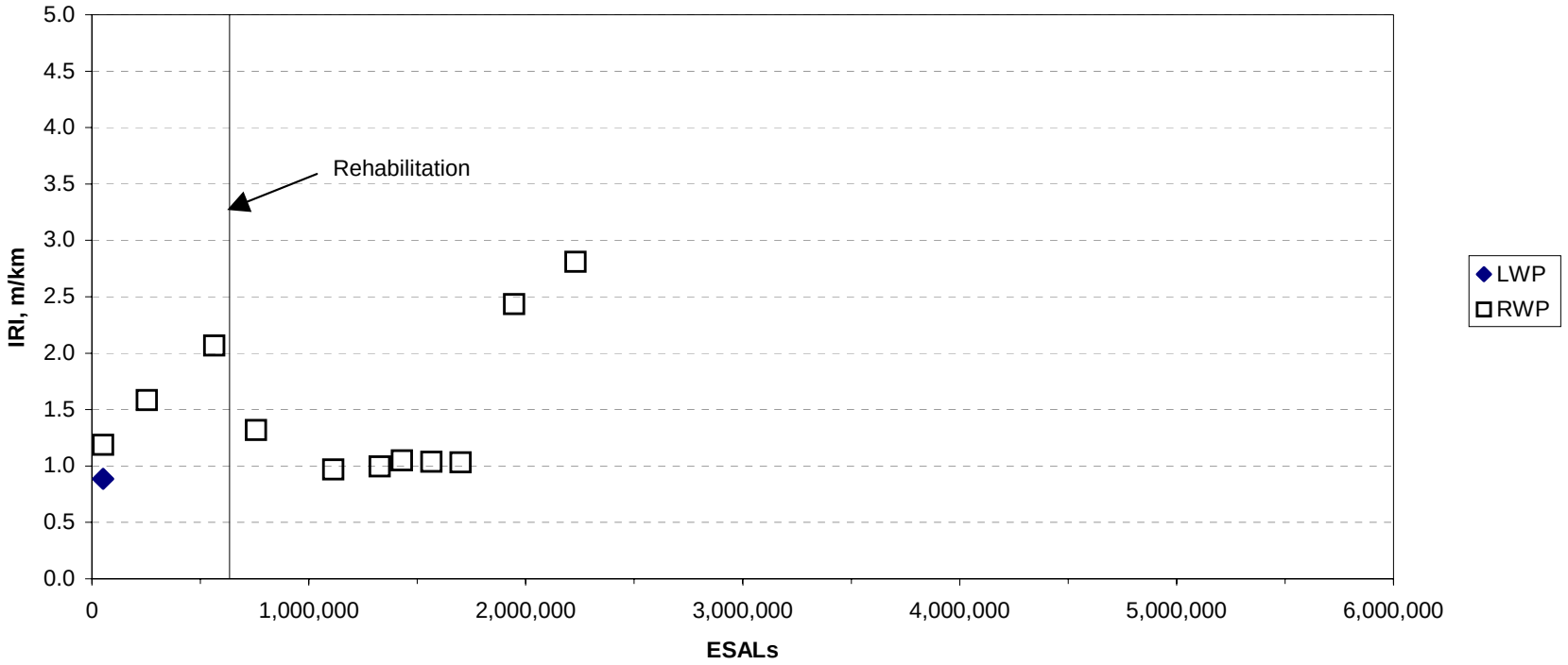

Figure 30. IRI versus time for section 36.

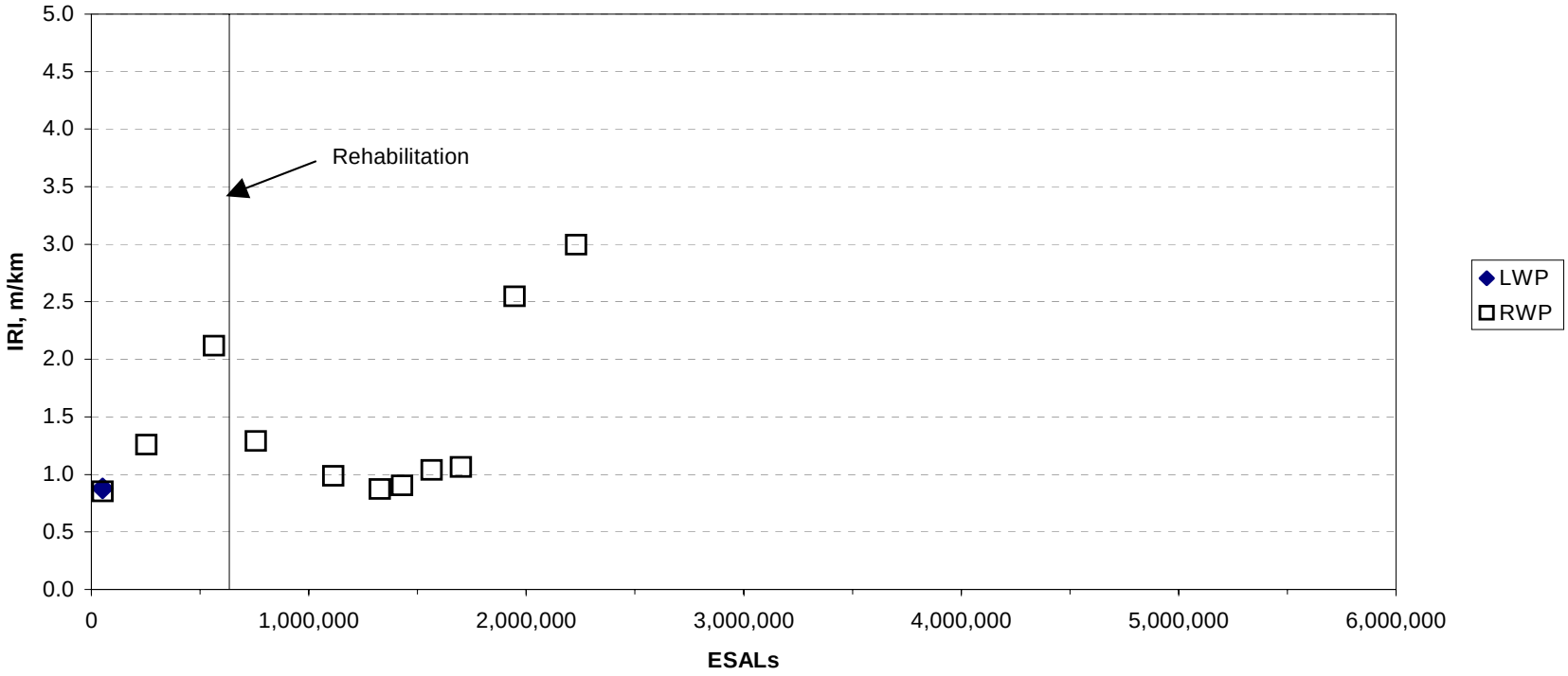

Figure 31. IRI versus time for section 37.

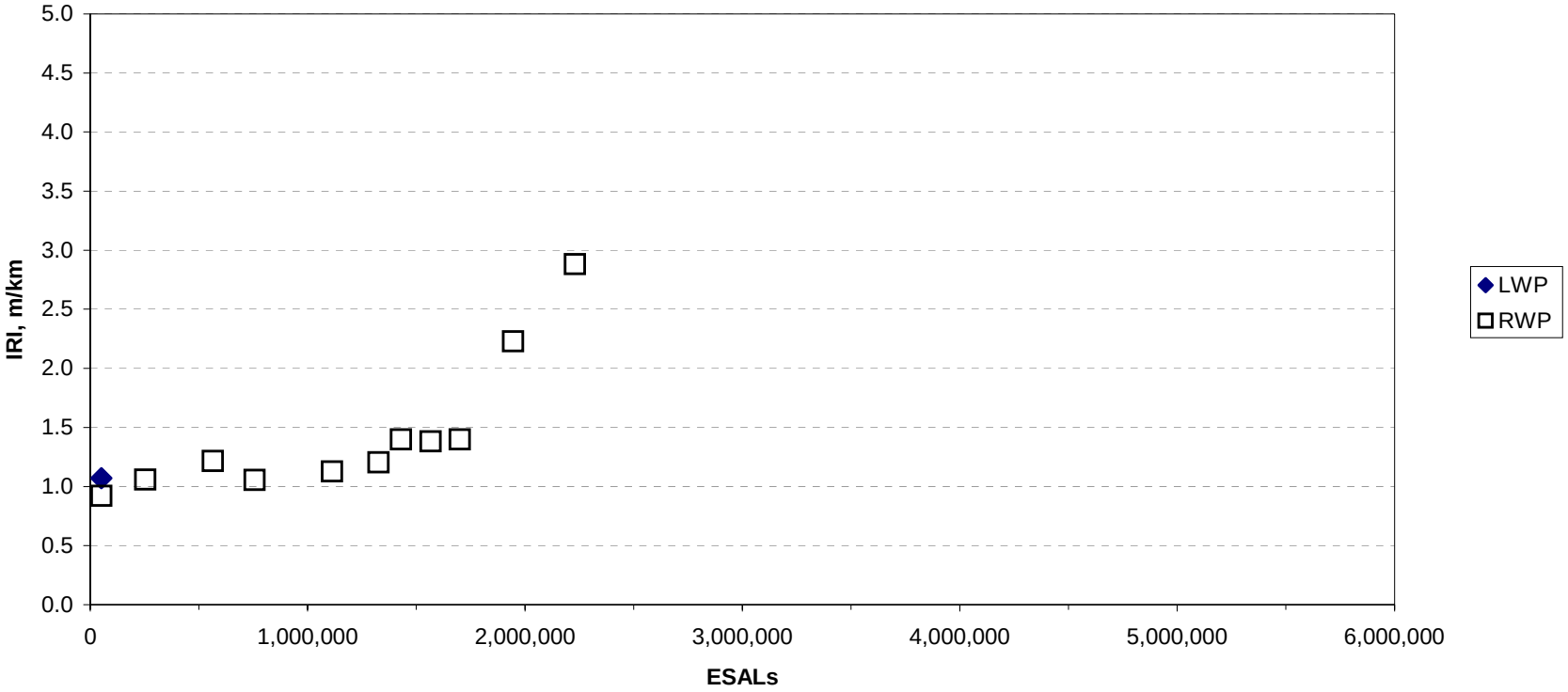

Figure 32. IRI versus time for section 38.

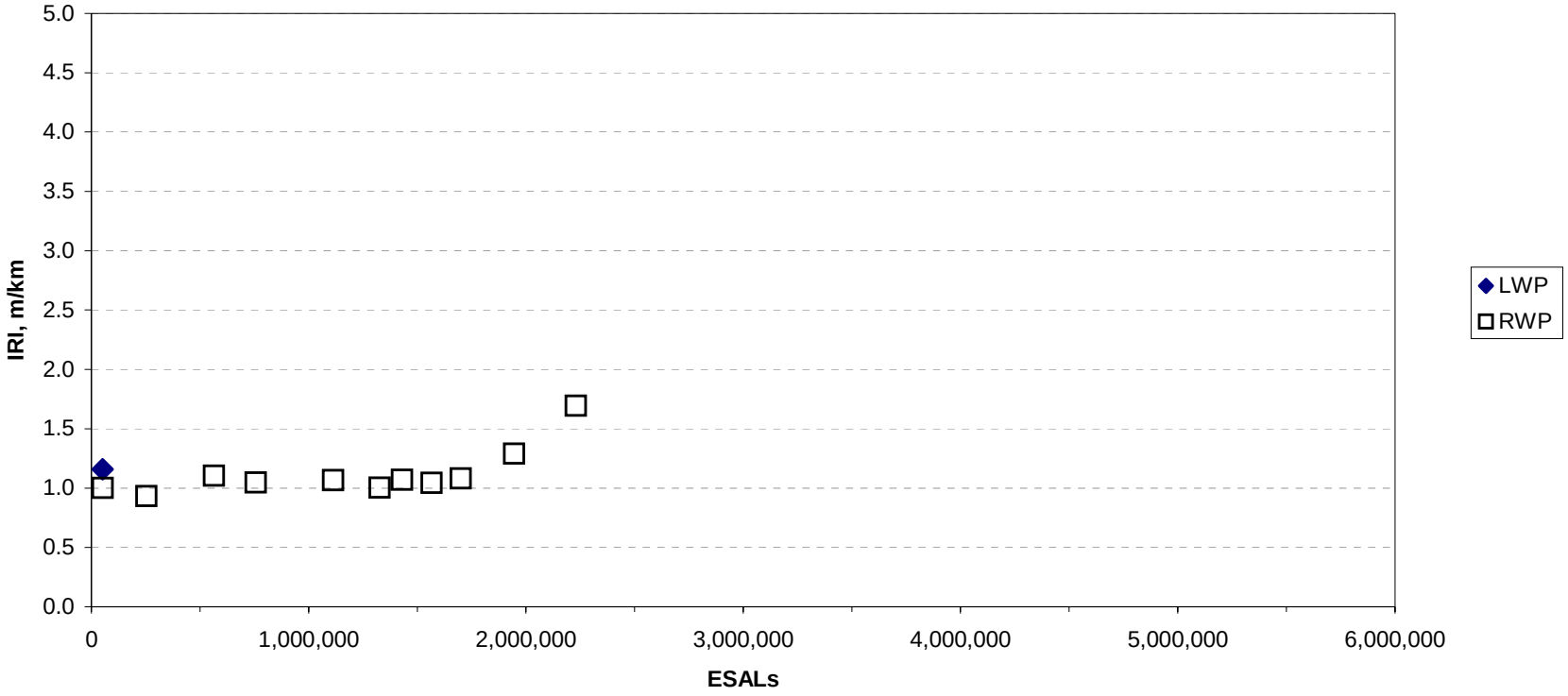

Figure 33. IRI versus time for section 39.

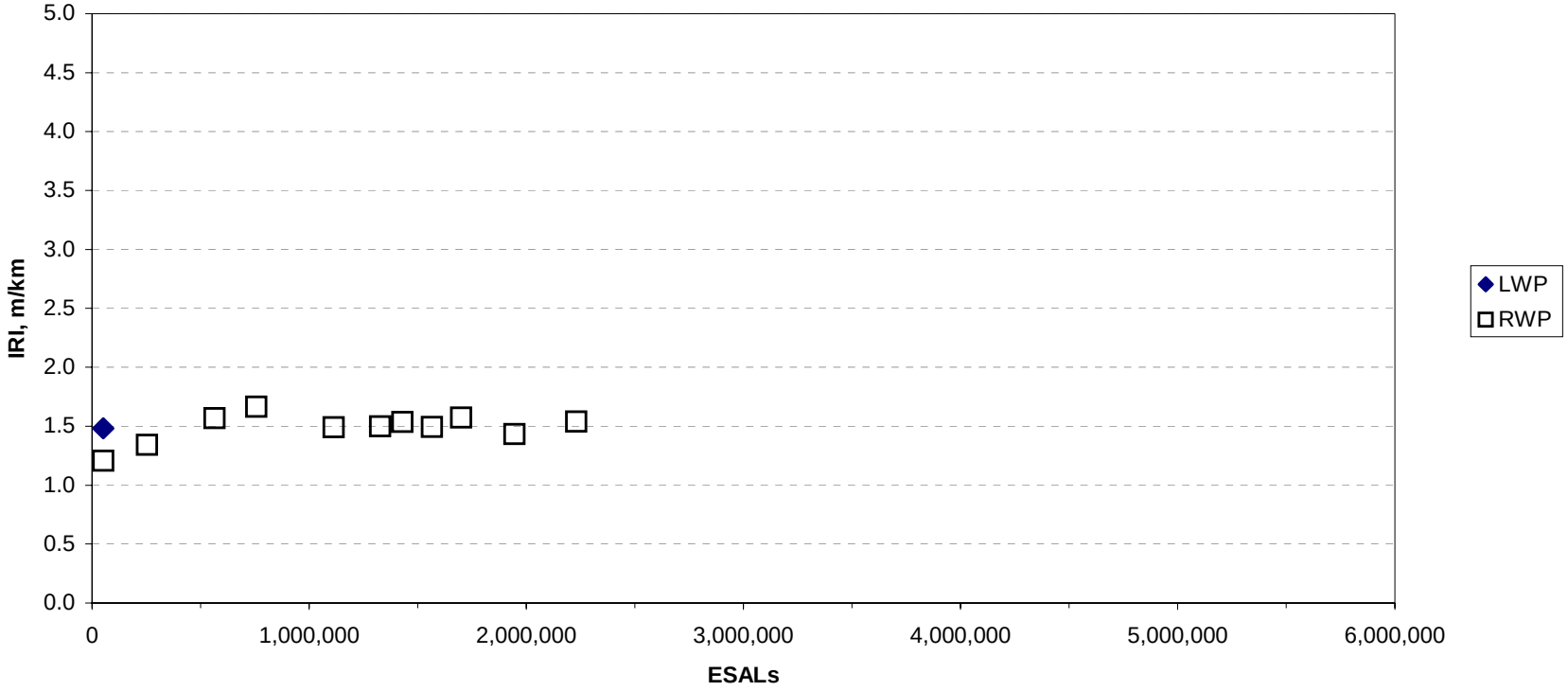

Figure 34. IRI versus time for section 43.

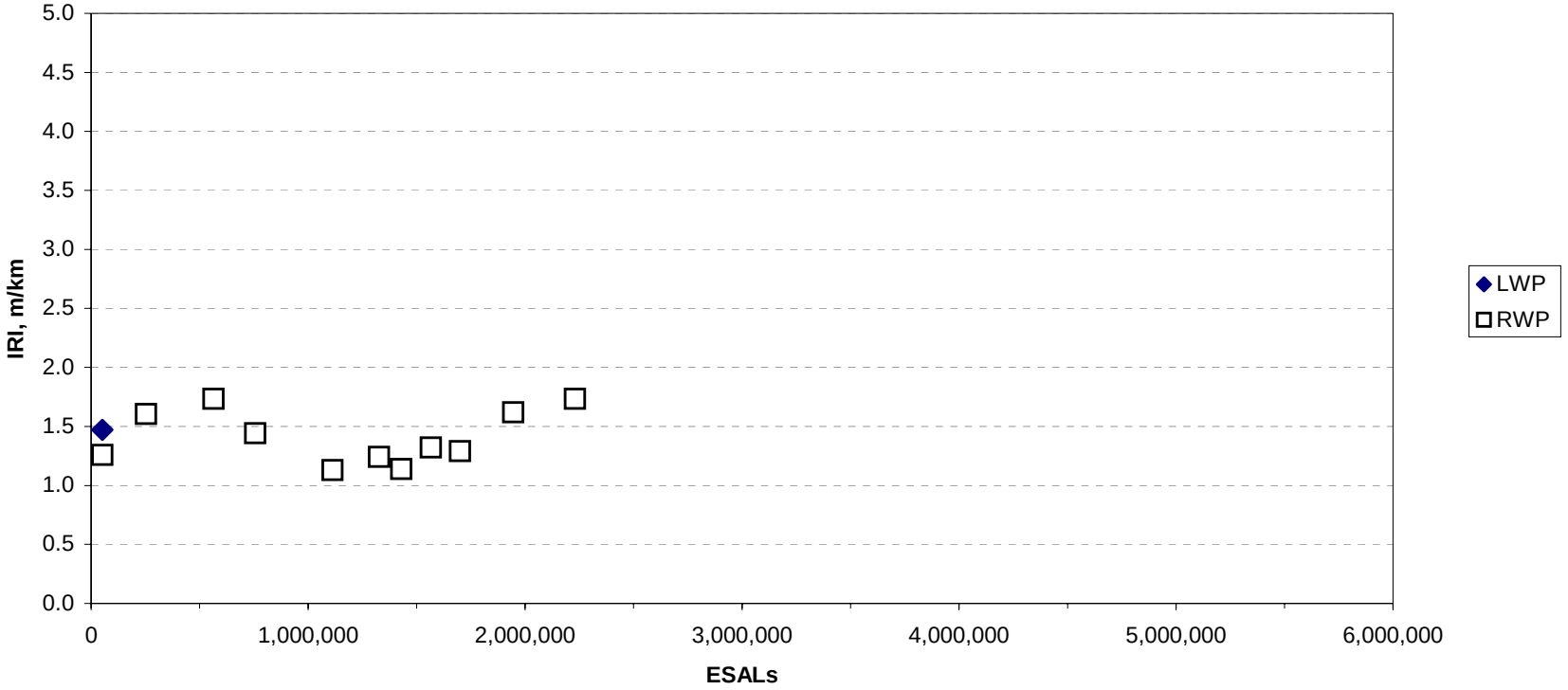

Figure 35. IRI versus time for section 51.

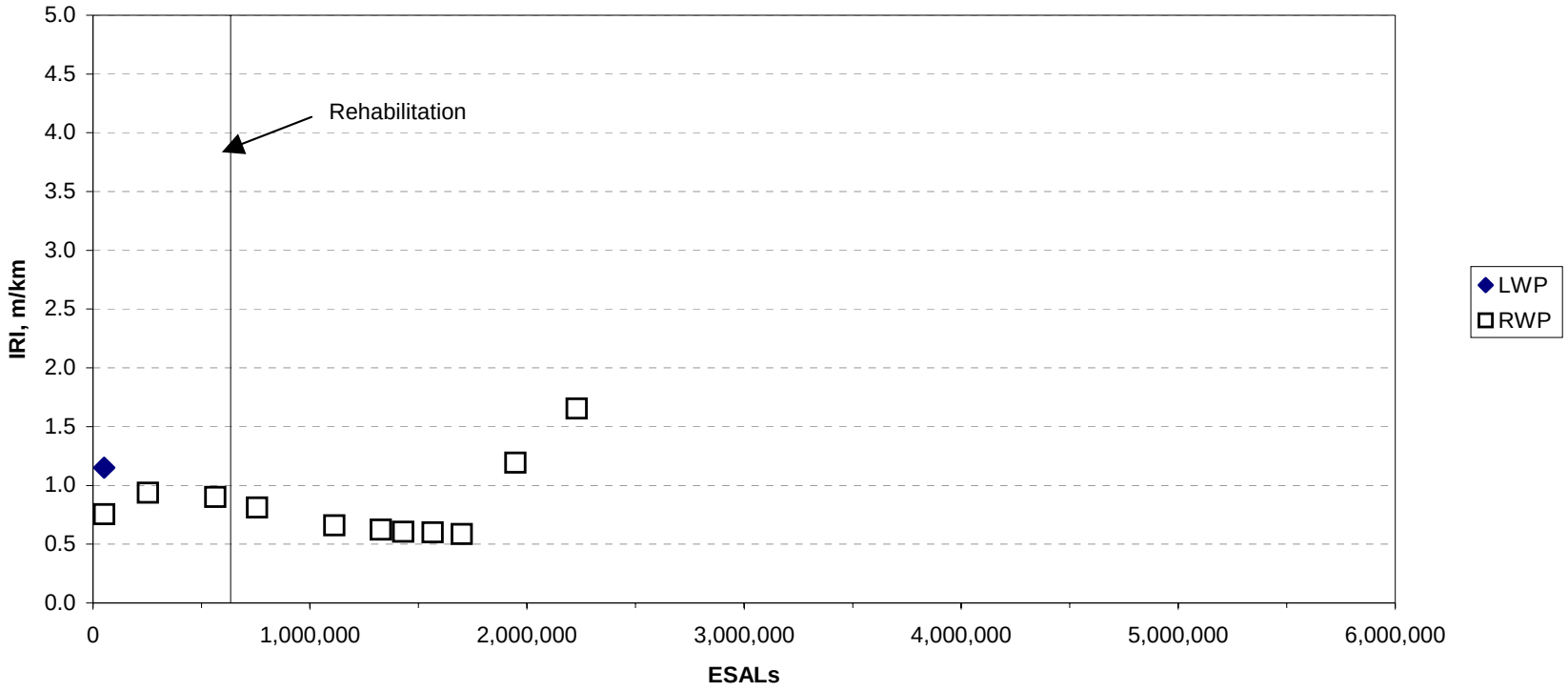

Figure 36. IRI versus time for section 54.

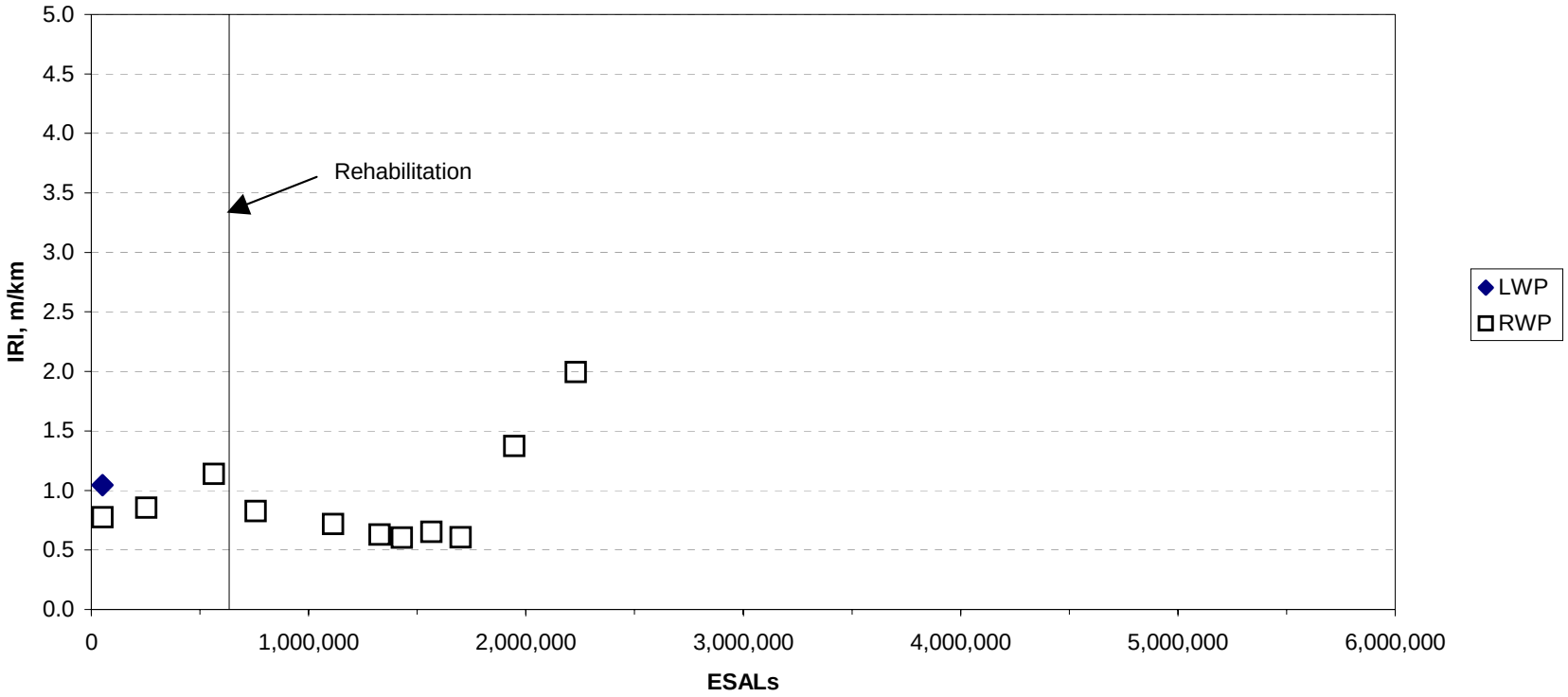

Figure 37. IRI versus time for section 55.

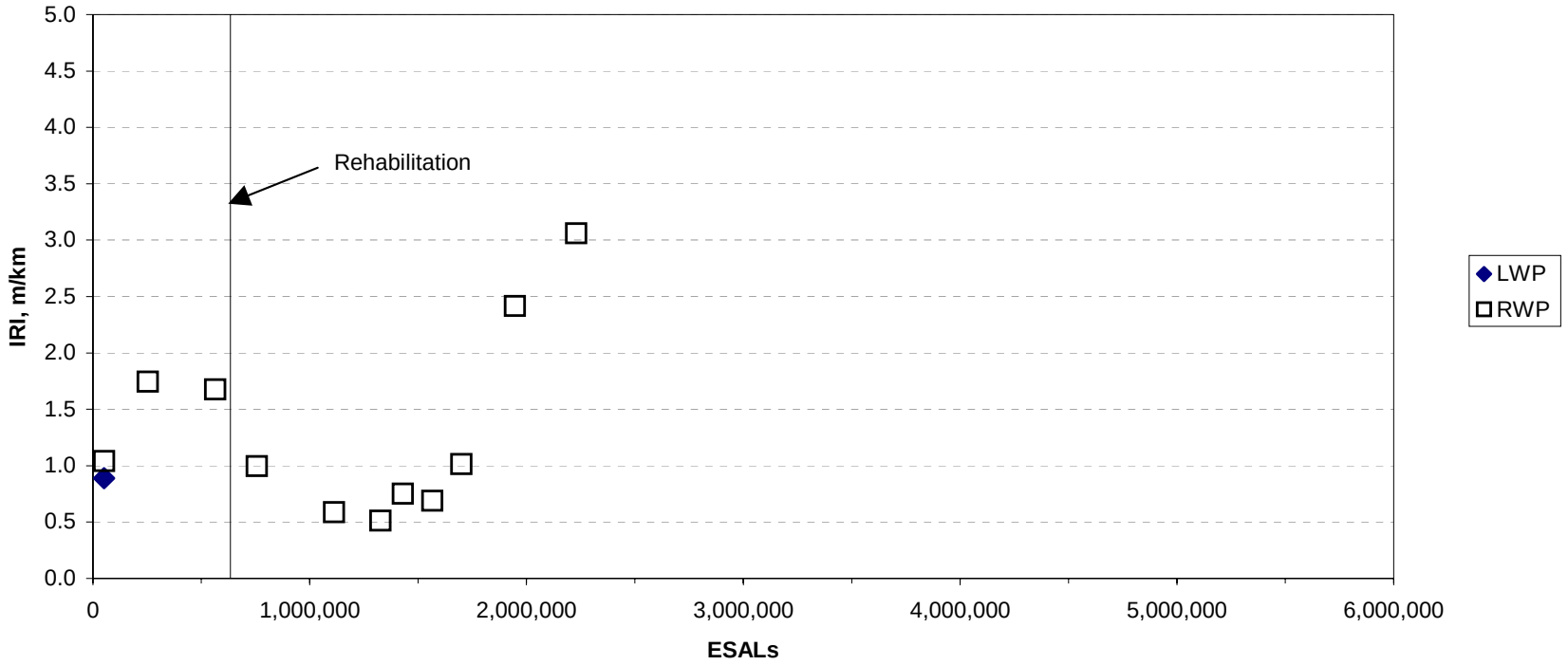

Figure 38. IRI versus time for section 56.

Table 1(a). Right wheelpath International Roughness Indices for the WesTrack original sections.

MONITORING SESSION #	DATE	CUMULATIVE ESALS	PAVEMENT SECTION #																									
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	3/15/1996	4,518	1.068	1.411	1.604	1.102	1.509	1.497	1.005	1.219	1.105	1.063	1.075	1.017	1.221	1.690	1.158	1.441	1.221	1.216	1.438	1.415	1.652	1.552	1.461	1.417	1.422	1.205
3	4/16/1996	150,644	0.966	1.249	1.353	1.110	1.316	1.301	0.749	1.098	1.041	0.963	0.985	0.976	1.146	1.549	1.019	1.440	1.070	1.080	1.345	1.414	1.413	1.498	1.224	1.053	0.993	0.829
4	5/13/1996	233,736	0.999	1.155	1.291	1.032	1.276	1.275	0.794	1.064	1.041	0.860	1.001	1.014	1.158	1.506	0.966	1.403	1.076	1.064	1.095	1.382	1.371	1.472	1.267	0.968	0.944	0.805
5	5/28/1996	296,504	0.976	1.106	1.259	1.067	1.250	1.279	0.806	1.085	1.005	0.905	0.957	1.020	1.025	1.505	0.997	1.407	1.083	1.057	1.296	1.324	1.405	1.447	1.216	0.991	1.008	0.818
6	6/10/1996	336,073	0.928	1.178	1.288	1.034	1.332	1.222	0.760	1.130	1.118	0.982	1.019	0.992	1.125	1.484	0.959	1.348	1.098	1.045	1.373	1.444	1.343	1.474	0.862	0.951	1.009	0.881
7	6/24/1996	436,966	0.949	1.157	1.250	1.031	1.304	1.360	0.849	1.146	1.058	0.952	1.061	1.072	1.205	1.489	0.966	1.313	1.336	1.032	1.324	1.364	1.203	1.436	1.292	1.085	0.960	0.912
9	7/22/1996	516,563	0.940	1.194	1.336	1.035	1.466	1.463	0.945	1.241	1.265	0.920	1.062	1.178	1.266	1.528	0.921	1.297	1.094	1.057	1.363	1.434	1.025	1.464	1.176	0.987	1.075	1.058
10	8/5/1996	662,883	0.994	1.220	1.359	1.017	1.437	1.628	1.181	1.323	1.831	1.004	1.099	1.092	1.242	1.534	0.968	1.263	1.108	0.996	1.370	1.462	1.020	1.435	1.322	1.163	0.999	1.055
11	8/20/1996	699,823	0.999	1.199	1.172	1.007	1.528	1.622	1.115	1.340	1.483	0.949	1.101	1.128	1.404	1.600	0.956	1.250	1.071	1.065	1.355	1.449	1.069	1.435	1.445	1.085	1.275	0.868
13	9/19/1996	967,780	0.963	1.235	1.261	1.009	1.385	1.607	1.238	1.311	2.235	0.985	1.052	1.108	1.468	1.547	0.947	1.250	1.137	0.991	1.424	1.391		1.447	1.195	1.066	1.345	1.020
14	9/30/1996	1,070,221	0.971	1.218	1.296	1.035	1.404	1.608	1.427	1.345	2.621	1.003	1.067	1.126	1.357	1.596	0.941	1.253	1.125	0.997	1.377	1.450		1.435	1.288	0.935	1.176	1.076
16	10/30/1996	1,365,970	1.000	1.270	1.382	1.020	1.368	1.544	0.803	1.051	3.677	0.942	1.083	1.125	1.560	1.579	0.952	1.281	1.183	1.033	1.354	1.407	1.127	1.395	1.215	1.037	1.705	1.113
17	11/11/1996	1,463,101	0.948	1.267	1.333	0.999	1.375	1.640	1.078	1.334	1.458	0.967	1.076	1.108	1.281	1.637	0.896	1.259	1.160	0.977	1.438	1.394	1.243	1.451	1.236	1.106	1.438	1.108
18	11/27/1996	1,463,163	0.981	1.271	1.381	1.015	1.359	1.629	1.531	1.349	0.900	0.985	1.061	1.155	1.058	1.622	0.933	1.272	1.186	0.983	1.478	1.394	1.352	1.457	1.235	1.056	1.082	1.112
19	12/9/1996	1,626,437	0.966	1.231	1.298	0.973	1.355	1.604	1.491	1.371	0.858	0.953	1.066	1.129	1.011	1.656	0.922	1.264	1.197	0.965	1.524	1.417	1.274	1.416	1.269	0.965	1.057	1.155
20	12/19/1996	1,711,938	0.975	1.253	1.281	0.982	1.398	1.700	2.168	1.384		0.962	1.075	1.107		1.588	0.943	1.283	1.145	0.977	1.397	1.385	1.921	1.406	1.332	0.830	1.379	1.225
21	1/17/1997	1,790,400	0.992	1.288	1.375	0.976	1.298	1.776	1.526	1.425	0.906	1.011	1.115	1.380	1.032	1.762	0.901	1.254	1.213	0.979	1.498	1.467	1.303	1.352	1.287	1.053	1.079	1.574
23	2/19/1997	1,794,199	0.952	1.272	1.390	1.052	1.351	1.737	1.535	1.456	0.987	1.047	1.102	1.407	1.027	1.663	0.858	1.196	1.158	0.915	1.404	1.483	1.364	1.230	1.270	1.051	1.172	1.640
24	3/3/1997	1,880,144	0.984	1.208	1.311	0.984	1.329	1.811	1.483	1.536	1.004	1.028	1.104	1.361	1.058	1.751	0.846	1.206	1.198	0.891	1.547	1.487	1.374	1.200	1.250	1.086	1.162	1.739
25	3/17/1997	2,047,631	0.950	1.254	1.386	0.997	1.445	1.834	1.513	1.724	0.997	1.081	1.065	1.350	1.034	1.747	0.848	1.210	1.147	0.846	1.460	1.489	1.399	1.147	1.303	1.033	1.151	1.803
28	4/25/1997	2,546,035	1.012	1.262	1.410	0.963	1.619	2.119	1.533	1.942	1.112	1.117	1.103	1.278	1.046	1.700	0.809	1.220	1.191	0.821	1.442	1.442	1.403	1.211	1.300	1.092	1.065	1.926
29	5/14/1997	2,774,052	1.004	1.275	1.365	0.971	1.809	2.253	1.566	2.045	1.211	1.126	1.082	1.264	1.038	1.739	0.790	1.243	1.180	0.811	1.430	1.430	1.376	1.171	1.294	1.138	1.156	1.901
30	7/15/1997	2,825,970	1.021	1.230	1.256	0.944						1.087	1.078	1.331		1.617	0.797	1.290	1.070	0.867	1.405	1.614		1.184	1.411			
31	8/5/1997	3,027,764	1.013	1.236	1.432	0.935						1.123	1.080	1.236		1.624	0.766	1.319	1.192	0.861	1.523	1.562		1.138	1.276			
33	9/2/1997	3,338,264	1.028	1.307	1.332	0.935						1.089	1.131	1.349		1.859	0.759	1.346	1.224	0.836	1.658	1.575		1.149	1.246			
35	10/29/1997	3,530,248	1.012	1.253	1.184	0.931						1.135	1.148	1.306		1.779	0.804	1.391	1.197	0.904	1.534	1.598		1.221	1.251			
37	12/2/1997	3,886,594	1.049	1.283	1.362	0.968						1.124	1.130	1.341		1.784	0.850	1.357	1.181	0.930	1.430	1.557		1.182	0.900			
39	12/30/1997	4,100,720	0.975	1.212	1.283	0.962						1.106	1.104	1.329		1.900	0.816	1.434	1.222	0.917	1.407	1.614		1.155	0.918			
40	1/13/1998	4,203,408	1.075	1.312	1.612	0.968						1.172	1.143	1.426		1.671	0.797	1.554	1.135	0.876	1.613	1.568		1.164	0.959			
42	2/10/1998	4,339,085	1.005	1.345	1.794	0.964						1.178	1.123	1.333		1.661	0.831	1.796	1.064	0.919	1.453	1.610		1.181	0.932			
44	3/27/1998	4,473,690	1.075	1.626	2.179	1.006						1.192	1.124	1.409		1.711	0.787	2.177	1.209	0.924	1.609	1.559		1.161	0.952			
46	5/7/1998	4,719,839	1.071	1.966	2.458	0.984						1.501	1.147	1.383		1.972	0.790	2.121	1.426	0.899	1.543	1.558		1.180	1.166			
49	1/13/1999	5,003,303	1.071	2.052	2.613	1.074						1.512	1.101	1.491		2.203	0.824	2.318	1.618	0.953	1.718	1.501		1.276	1.159			

Table 1(b). Right wheelpath International Roughness Indices for the WesTrack replacement sections.

MONITORING SESSION #	DATE	CUMULATIVE ESALS	PAVEMENT SECTION #									
			35	36	37	38	39	43	51	54	55	56
30	7/15/1997	51,918	1.288	1.188	0.853	0.921	1.000	1.207	1.259	0.757	0.777	1.042
31	8/5/1997	253,712	1.846	1.584	1.259	1.059	0.933	1.342	1.605	0.940	0.857	1.745
33	9/2/1997	564,212	2.014	2.067	2.119	1.216	1.104	1.568	1.735	0.902	1.140	1.676
35	10/29/1997	756,196	1.745	1.320	1.292	1.055	1.047	1.665	1.444	0.814	0.826	0.997
37	12/2/1997	1,112,542	1.736	0.970	0.988	1.129	1.069	1.490	1.131	0.660	0.719	0.587
39	12/30/1997	1,326,668	1.898	0.996	0.873	1.206	1.006	1.500	1.243	0.624	0.630	0.513
40	1/13/1998	1,429,356	1.984	1.049	0.905	1.399	1.071	1.536	1.138	0.607	0.603	0.752
42	2/10/1998	1,565,033	2.054	1.040	1.038	1.383	1.044	1.493	1.321	0.602	0.652	0.690
44	3/27/1998	1,699,638	2.067	1.031	1.064	1.400	1.081	1.575	1.290	0.587	0.605	1.014
46	5/7/1998	1,945,787	2.035	1.164	0.902	1.343	1.024	1.561	1.693	0.582	0.639	1.543
49	1/13/1999	2,229,251	1.972	1.887	1.118	1.529	1.313	1.578	2.139	0.698	0.802	3.077

NOTE: ALL INTERNATIONAL ROUGHNESS INDEX VALUES ARE EXPRESSED IN UNITS OF METERS PER KILOMETER.

Table 2(a). Left wheelpath International Roughness Indices for the WesTrack original sections.

MONITORING SESSION #	DATE	CUMULATIVE ESALS	PAVEMENT SECTION #																									
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	3/15/1996	4,518	0.841	1.168	1.223	0.657	1.265	1.925	1.221	1.261	0.877	0.959	1.146	0.707	0.844	1.417	1.116	1.071	1.025	1.178	1.165	1.238	1.085	1.255	1.502	1.131	1.421	1.121
3	4/16/1996	150,644	0.923	1.334	1.295	0.837	1.437	1.638	1.102	1.330	0.880	1.019	1.336	0.742	1.016	1.457	1.151	1.086	1.148	1.242	1.141	1.327	1.030	1.308	1.268	0.908	1.337	0.900
4	5/13/1996	233,736	0.898	1.201	1.287	0.820	1.528	1.686	1.113	1.314	0.850	1.093	1.290	0.725	1.047	1.452	1.153	1.056	1.135	1.188	1.193	1.239	1.159	1.261	1.328	0.858	1.408	0.846
5	5/28/1996	296,504	0.863	1.272	1.266	0.854	1.621	1.709	1.097	1.451	0.857	1.048	1.335	0.734	0.736	1.473	1.067	1.069	1.137	1.135	1.138	1.286	1.024	1.325	1.250	0.870	1.399	0.959
6	6/10/1996	336,073	0.850	1.127	1.229	0.831	1.417	1.559	1.012	1.483	0.836	1.014	1.305	0.739	0.981	1.470	1.077	1.004	1.204	1.150	1.119	1.294	0.987	1.352	1.289	0.876	1.342	0.981
7	6/24/1996	436,966	0.858	1.150	1.174	0.843	1.550	1.693	1.063	1.538	0.894	1.023	1.343	0.735	1.062	1.520	1.062	1.029	1.191	1.150	1.127	1.342	0.952	1.331	1.345	0.906	1.365	1.023
9	7/22/1996	516,563	0.882	1.138	1.178	0.874	1.464	1.646	1.317	1.632	1.012	1.107	1.342	0.790	1.116	1.493	1.164	1.024	1.229	1.177	1.140	1.314	0.920	1.306	1.273	1.010	1.275	1.213
10	8/5/1996	662,883	0.895	1.065	1.173	0.864	1.422	1.737		1.653	0.965	1.092	1.393	0.864	1.136	1.517	1.078	1.011	1.268	1.228	1.128	1.373	1.173	1.374	1.616	1.051	1.283	1.201
11	8/20/1996	699,823	0.968	1.108	1.204	0.921	1.522	1.829	1.394	1.698	1.458	1.200	1.468	0.991	1.221	1.579	1.195	1.084	1.224	1.385	1.209	1.447	1.185	1.332	1.789	1.437	1.551	1.155
13	9/19/1996	967,780	0.915	1.082	1.176	0.846	1.435	1.823	1.245	1.612	1.095	1.042	1.384	0.875	1.439	1.491	1.161	1.018	1.294	1.268	1.171	1.441		1.317	1.608	1.238	1.386	1.267
14	9/30/1996	1,070,221	0.904	1.061	1.162	0.869	1.417	1.704		1.672	1.254	1.054	1.098	0.891	1.438	1.505	1.180	1.019	1.248	1.207	1.141	1.325	1.287	1.335	1.424	1.116	1.508	1.262
16	10/30/1996	1,365,970	0.850	1.134	1.274	0.852																						
17	11/11/1996	1,463,101	0.933	1.062	1.127	0.830	1.414	1.605	1.462	1.678	1.240	1.078	1.310	0.907	1.139	1.450	1.219	1.038	1.286	1.266	1.200	1.298	1.561	1.344	1.390	1.045	2.334	1.176
18	11/27/1996	1,463,163	0.930	1.052	1.144	0.810	1.466	1.700		1.681		1.050	1.316	0.790	1.309	1.474	1.185	1.038	1.264	1.233	1.172	1.372	1.740	1.402	1.633	1.185	1.242	1.513
19	12/9/1996	1,626,437	0.946	1.085	1.147	0.839	1.447	1.728	1.568	1.703	1.209	1.164	1.352	0.833	1.285	1.510	1.216	1.051	1.297	1.147	1.259	1.408	1.749	1.383	1.531	1.272	1.198	1.968
20	12/19/1996	1,711,938	0.946	1.049	1.177	0.846	1.459	1.669	0.954	1.720	1.249	1.136	1.328	0.946	0.887	1.539	1.171	1.044	1.284	1.306	1.170	1.334	1.202	1.386	1.479	1.241	1.075	2.236
21	1/17/1997	1,790,400	0.941	1.079	1.120	0.859	1.506	1.547	1.501	1.774	1.227	1.286	1.357	1.044	0.821	1.418	1.121	1.069	1.281	1.267	1.085	1.356	1.149	1.369	1.650	1.122	0.977	4.345
23	2/19/1997	1,794,199	0.914	0.970	1.153	0.767	1.445	1.666	0.906	1.762	1.229	1.200	1.356	0.863	0.789	1.499	1.026	1.112	1.359	1.380	1.087	1.354	1.145	1.367	1.546	1.133	1.025	2.536
24	3/3/1997	1,880,144	0.943	0.984	1.150	0.817	1.456	1.772	1.065	2.092	1.315	1.305	1.376	1.071	1.003	1.406	1.056	1.120	1.373	1.316	1.130	1.370	1.699	1.380	1.484	1.097	1.864	1.270
25	3/17/1997	2,047,631	0.970	0.953	1.180	0.797	1.481	2.099	1.667	2.247	1.396	1.303	1.381	0.972	1.348	1.478	1.001	1.106	1.404	1.284	1.114	1.281	1.745	1.367	1.373	1.069	1.258	1.530
28	4/25/1997	2,546,035	0.972	1.335	1.423	1.110		3.024	1.691	2.592	1.466	1.652	1.646	1.314	1.359	1.489	0.972	1.070	1.360	1.312	1.114	1.344	1.223	1.304	1.421	1.043	0.884	3.220
29	5/14/1997	2,774,052	0.953	0.852	1.185	0.780	1.571	4.655	0.958	2.469	1.222	1.387	1.384	0.977	0.904	1.440	0.951	1.096	1.331	1.356	1.140	1.415	1.662	1.279	1.486	1.345	1.454	1.653
30	7/15/1997	2,825,970	1.016	0.894	1.216	1.107						1.803	1.496	1.059		1.576	0.924	1.532	1.370	1.444	1.243	1.530		1.152	1.589			
31	8/5/1997	3,027,764																										
33	9/2/1997	3,338,264																										
35	10/29/1997	3,530,248																										
37	12/2/1997	3,886,594																										
39	12/30/1997	4,100,720																										
40	1/13/1998	4,203,408	1.523		1.966	1.417							1.573	1.715			1.377											
42	2/10/1998	4,339,085																										
44	3/27/1998	4,473,690																										
46	5/7/1998	4,719,839		1.916		1.461							1.589				1.663	2.192							1.835			
49	1/13/1999	5,003,303																										

Table 2(b). Left wheelpath International Roughness Indices for the WesTrack replacement sections.

MONITORING SESSION #	DATE	CUMULATIVE ESALS	PAVEMENT SECTION #									
			35	36	37	38	39	43	51	54	55	56
30	7/15/1997	51,918	1.295	0.886	0.879	1.070	1.158	1.482	1.472	1.152	1.044	0.889
31	8/5/1997	253,712										
33	9/2/1997	564,212										
35	10/29/1997	756,196										
37	12/2/1997	1,112,542										
39	12/30/1997	1,326,668										
40	1/13/1998	1,429,356		1.960						0.989	0.763	1.087
42	2/10/1998	1,565,033										
44	3/27/1998	1,699,638										
46	5/7/1998	1,945,787	1.347								1.197	
49	1/13/1999	2,229,251										

NOTE: ALL INTERNATIONAL ROUGHNESS INDEX VALUES ARE EXPRESSED IN UNITS OF METERS PER KILOMETER.

Evaluation of Laboratory and Field Tests Used To Determine Pavement Structural Support From the WesTrack Experiment

U.S. Department of Transportation
Federal Highway Administration

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PURPOSE

Modern pavement rehabilitation and design methodologies require accurate characterization of underlying material strengths. Several tests are widely used to measure pavement surface and subsurface material strengths. The pavement test sections at the WesTrack Project near Reno, Nevada, have provided a unique opportunity to conduct several of these tests on 34 pavement sections and compare their results.

The purpose of this report is to discuss existing relationships between laboratory and field test data from information collected at WesTrack. This will be done using the data from dynamic core penetrometer (DCP), California bearing ratio (CBR), falling weight deflectometer (FWD), and laboratory resilient modulus tests. It is the goal of this report to determine if the different tests are interchangeable, within engineering reason.

INTRODUCTION

The understanding of material properties of each pavement structural layer is a key element in the design and analysis of a pavement's load-carrying capacity. The testing procedures for the material properties are done in both the field and laboratory using many different procedures and equipment. Often only limited testing or site evaluation is possible due to time and budget constraints. Therefore, correlation of results from testing of the same material by various procedures and equipment is a routine activity. This report uses testing results from WesTrack to compare various field and laboratory tests.

As noted above, the structural support of the pavements can be assessed with the DCP, CBR, FWD, or laboratory resilient modulus tests. The following sections provide descriptions of each of these tests.

BACKGROUND

DCP testing has been performed throughout the United States for some time. The test allows the determination of soil properties through empirical relationships. Figure 1 provides a diagram of the equipment. The DCP data are collected by using a slide hammer of known weight, dropped from a known height to drive a cone of known dimensions. During the driving of the cone, the depth-per-blow count is recorded. The data are then reduced to the DCP index. From the DCP index, a relationship found by Livneh et al.[(1)] can be used to convert the data to CBR values. The equation for the conversion is found below:

$$\text{Log CBR} = 2.46 - 1.12\ (\text{Log DCP}) \qquad (1)$$

where:

CBR = soil strength used for pavement design/evaluation
DCP = DCP index = average penetration caused by one drop.

A correlation of DCP to CBR becomes essential, because the American Association of State Highway and Transportation Officials (AASHTO) "Guide for the Design of Pavement Structures"[2] requires resilient modulus values of unbound material for pavement design. Figure 2 shows the correlation of different tests, including CBR, to resilient modulus; no direct correlation of DCP values to resilient modulus is available.

These correlations can be used as a guide if more reliable information is not available. However, these relationships are empirical and their dependence on local conditions should be understood. The correlations in Figure 2 may not be valid if the actual conditions are different from those under which the correlation were established.[3]

Work has been done to relate more simplistic laboratory and field tests to fundamental measurements of material properties, namely the resilient modulus of a pavement layer. The most accepted relation for CBR to modulus E, established by Huekelom and Foster,[4] is found in equation 2.

$$E = 1500\ (CBR) \tag{2}$$

This equation was found by correlation between modulus and CBR based upon dynamic (wave propagation) techniques.[5] Further, "it should be noted that the conditions of dynamic testing (load rate and stress magnitude) generally yield moduli in the linear elastic range."[5] Conventional CBR tests include deformations that are plastic and/or non-recoverable; therefore, the two tests are performed at different stress states. Also, equation 2 is restricted to fine grain materials with soaked CBR values of 10 or less.[6] Further, CBR values are a measure of shear strength while E is stiffness prior to shearing. The CBR correlation value does not recognize the materials' stress sensitivity.[6]

Work has been done to determine if general differences in CBR are a function of soil type. Table 1 contains typical CBR ranges based on the Unified Soil Classification System.[6] From Table 1, an engineer can get an estimate for the type of support that could be expected from the soil classification after a limited site investigation. This table becomes more valuable as CBR values are used by many highway agencies that do not perform resilient modulus testing.[6]

DYNAMIC CONE PENETROMETER

DCP tests were performed at WesTrack after pavement section failure, during the section postmortem investigations. DCP tests were conducted at three locations within each pavement section (each wheelpath and in the center of the lane). The testing layout was set up in this manner to determine if changes occurred in the unbound material between the wheelpaths in the center of the lane after trafficking.

The WesTrack DCP data were plotted as blow count versus depth. A typical plot of the data is found in Figure 3. It is immediately apparent from Figure 3 that a drastic difference in slope occurs when the penetrometer core reaches 300 mm (12 in.). This change in slope corresponds exactly to the change in material type within the layer structure, as the first 300 mm (12 in.) of unbound material is a high-quality base course sitting on engineered fill.

The DCP penetration rate (DCP-PR) was determined from the reduced field data. The DCP-PR was calculated by the Army Corps of Engineers' DCP software, which takes blow count versus depth data and converts it to CBR. The program allows the user to select the layers for calculation of CBR by selecting the depth of penetration corresponding to the desired layer structure. The Army Corps program provides both DCP-PR and CBR values. The CBR values for the base course and engineered fill/subgrade soil are found in Table 2, as calculated by the Army Corps software.

The same conversion to CBR was done using the Livneh et al. equation (equation 1). This allowed a quality control/quality assurance (QC/QA) check of CBR obtained from the Army Corps software. The data from the Livneh equation are found in Table 3.

FWD ANALYSIS

FWD testing was performed on all sections prior to the postmortem investigation. The data were then back-calculated using the Washington State Department of Transportation (WSDOT) Evercalc back-calculation software. The back-calculation was performed using a four-layer system, using the as-built HMA and base course thicknesses. However, the third and fourth layers were defined in two different manners, depending on their location.

For both back-calculation cases, a modulus was assigned to the fourth layer, since this layer was completely saturated and behaved like a stiff layer. From laboratory testing and the use of the Seismic Pavement Analyzer (SPA) data, it was determined that the stiff layer modulus value for the north tangent (pavement test sections 14 through 26) was 207 MPa and for the south tangent (pavement test sections 1 through 13) was 172 MPa. The third layer thickness was dependent on the depth-to-groundwater table. The back-calculation results for the rehabilitation sections are shown in Table 4.

LABORATORY DATA: RESILIENT MODULUS AND CBR

Testing of the unbound materials during the construction of the WesTrack Project was very extensive, well beyond what would normally be done for 1.8 mi (2.9 km) of two-lane flexible pavement construction. Among the many laboratory tests performed were those for determination of the resilient modulus (M_R) and of the CBR. Table 5 contains the results of the resilient modulus testing and Table 6 contains the results of the CBR testing. The resilient modulus was tested at different confining pressures and different applied loads. From the raw data, a modulus was determined for the data corresponding to the same state of stress as applied by the FWD under a 40-kN (9,000-lb) plate load.

DATA COMPARISON

From the data sets collected during the WesTrack Project's life, comparisons were made among tests to determine the possibility of using different tests to characterize the underlying pavement layer strength properties. The desired property for comparison was the resilient modulus;

however, comparisons of CBR are also included, since a correlation between CBR and resilient modulus for coarse-grained soils is not available.

CBR COMPARISON OF LABORATORY AND FIELD TESTS

Laboratory CBR testing was only performed during construction. The laboratory samples were tested in the usual manner and a CBR value was selected at the in-place density. Correlations between DCP data and CBR were used to calculate a "field" CBR. Table 7 shows the differences between the field-correlated CBR values (i.e., the CBR values calculated from the PCP data by the Livneh equation and by the Army Corps of Engineers' DCP software) and the laboratory CBR values. Note that the field DCP test correlation did an adequate job in replicating the laboratory CBR values. Nearly all tests produced a difference of 45 percent or less. However, it is also observed that all of the field correlation CBR values are lower than the laboratory CBR values. This suggests that either the soil properties changed or that the correlation was biased and produced slightly lower CBR values. It was not possible to resolve this issue from the data set available.

RESILIENT MODULUS COMPARISON OF LABORATORY AND FIELD TESTS

To determine how well the field and laboratory tests (DCP and CBR) predicted the laboratory resilient modulus and the back-calculated modulus, two tables were created. Table 8 shows the percent difference between the laboratory resilient modulus and the field (from DCP) and laboratory (from CBR) correlation modulus. Table 9 shows the percent difference between the back-calculated modulus and the field (from DCP) and laboratory (from CBR) correlation modulus.

It is apparent from Table 8 that predicting resilient modulus from field data is more difficult than predicting CBR. This may be because the differences between laboratory values and field predictions for resilient modulus can be affected by many variables. It is clear that for the testing during September 1996, two sections shared significant differences.

This difference of subgrade modulus was not the norm, as the majority of sections had a difference of less than 50 percent. The percent difference for subgrade soils is more critical, as the modulus is not a large number. Differences in subgrade modulus could significantly affect a pavement design.

It is apparent from table 9 that the percent difference between the field-correlated resilient modulus (from DCP) and the back-calculated modulus was considerable. (Note: testing was performed for both center of lane and the right wheelpath in the direction of traffic for the FWD and DCP.) Again, many variables could affect the results of both the field DCP correlation and the back-calculation results from the field-collected FWD data. However, the tests were performed at the same time and the materials were at the same in situ conditions.

It also was observed that the DCP-correlated data produced a consistently greater subgrade modulus than the back-calculated results. This is of concern, since using the DCP-correlated

values for pavement design could produce a less conservative pavement structure than using the back-calculated modulus values.

SUMMARY

It is often the case that pavement engineers have to substitute different methods for collecting information about underlying soil structural support. The WesTrack Project presented a unique opportunity to study the different procedures for determining soil properties within a pavement structure.

By using the DCP and corresponding correlation, the CBR for base course materials can be predicted reasonably. However, the results showed that the field DCP correlation data underestimated the laboratory CBR data in every case. This difference should be accounted for when using DCP-correlated CBR data.

The comparisons of resilient modulus of fine grain soils at WesTrack showed significant differences in the estimation ability of DCP tests through the use of a correlation to CBR and resilient modulus. It is shown that the DCP correlation could estimate the laboratory resilient modulus better than the FWD back-calculated value. Additionally, the DCP correlation procedure overestimated the back-calculated modulus in nearly every case.

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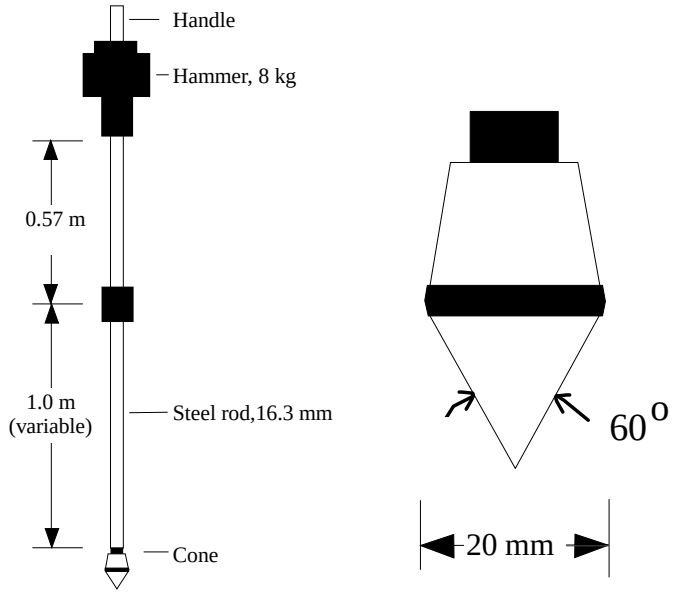
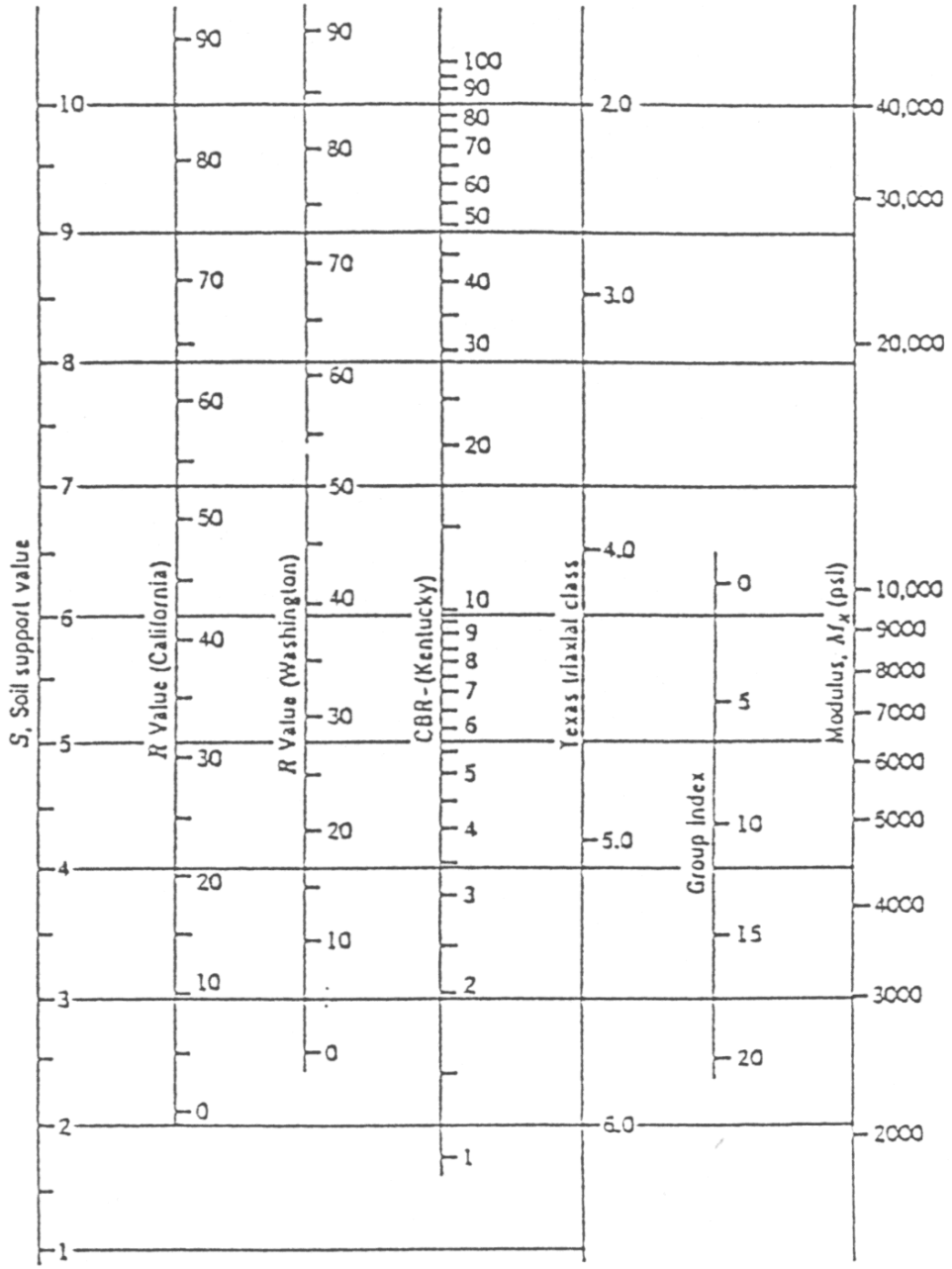


1 mm = 0.039 in.
1 m = 3.28 ft.
1 kg = 2.202 lb.

Figure 1. DCP cone detail.



1 psi = 6.9 kPa.

Figure 2. Correlation chart for estimation of resilient modulus of subgrade soils.[7]

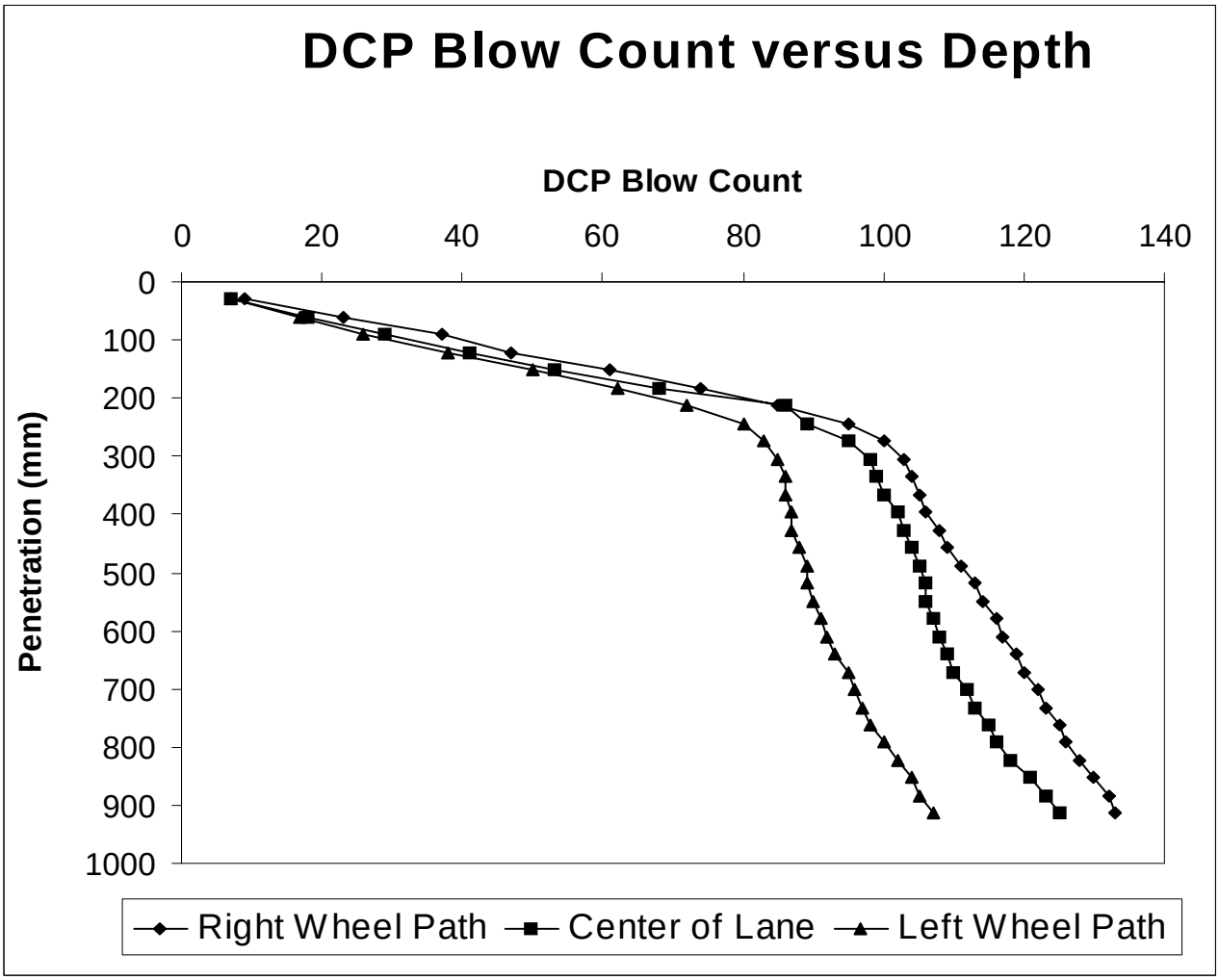


Figure 3. DCP blow count vs. depth for a typical WesTrack section.

Table 1. Typical CBR ranges using the Unified Soil Classification System.[5]

Soil Type	CBR Range
GW	40 – 80
GP	30 – 60
GM	20 – 60
GC	20 – 40
SW	20 – 40
SP	10 – 40
SM	10 – 40
SC	5 – 20
ML	15 or less
CL LL<50%	15 or less
OL	5 or less
MH	10 or less
CH LL>50%	15 or less
OH	5 or less

Table 2. Base course and subgrade soil CBR values from Army Corps of Engineers software.

Section	CBR Base Course			CBR Subgrade Soil		
	LTWP	CNTR	RTWP	LTWP	CNTR	RTWP
DCP Testing on November 11, 1996						
7	65	83	74	11	9	8
9	82	85	74	13	10	10
13	62	65	77	16	16	18
21	80	82	90	12	17	25
25	74	73	55	8	8	9
DCP Testing on May 23, 1997						
5	78	75	55	8	11	7
6	83	79	80	11	17	9
8	82	84	81	11	7	11
24	75	78	83	7	8	10
26	73	82	81	9	13	15
DCP Testing on September 24, 1997						
23	45	60	58	11	7	11
36	35	23	41	22	7	7
37	70	67	81	8	10	7
54	59	62	70	9	7	12
55	87	85	62	7	7	9
56	87	77	84	7	10	12
DCP Testing on April 22, 1999						
1	91	79	82	8	9	9
35	94	92	84	9	6	7
11	64	83	91	7	11	9
15	83	81	98	15	12	10
19	81	83	89	9	11	10
54	74	91	98	12	7	11

Note: RTWP = Right wheelpath.
CNTR = Center of lane.
LTWP = Left wheelpath.

Table 3. Base course and subgrade soil CBR values from Livneh equation.

Section	CBR Base Course			CBR Subgrade Soil		
	LTWP	CNTR	RTWP	LTWP	CNTR	RTWP
DCP Testing on November 11, 1996						
7	93	119	118	14	9	10
9	104	129	100	15	14	13
13	72	76	84	18	18	20
21	123	141	145	14	20	32
25	99	112	72	10	10	8
DCP Testing on May 23, 1997						
5	99	80	63	9	9	7
6	125	93	100	18	7	9
8	133	99	118	15	11	14
24	91	102	99	8	9	11
26	102	121	118	12	16	23
DCP Testing on September 24, 1997						
36	35	24	49	13	4	6
37	80	80	99	9	14	7
23	51	67	67	15	9	15
54	71	74	78	13	7	11
55	102	104	76	6	8	9
56	114	110	119	12	13	14
DCP Testing on April 22, 1999						
1	85	72	78	8	9	8
35	104	104	85	9	6	7
11	63	80	89	6	10	8
15	80	91	131	20	16	10
19	84	95	97	9	9	9
54	69	97	106	14	6	16

Note: RTWP = Right wheelpath.
CNTR = Center of lane.
LTWP = Left wheelpath.

Table 4. Results from back-calculation of layer moduli for the base course and subgrade soil.

Section	Base Course		Subgrade Soil	
	CNTR	RTWP	CNTR	RTWP
FWD Testing on October 28, 1996				
7	164	166	77	75
9	168	231	89	83
13	156	260	93	101
21	114	107	144	112
25	130	138	103	91
FWD Testing on May 16, 1997				
5	224	217	55	54
6	165	191	47	47
8	161	204	50	49
24	149	212	49	47
26	172	223	48	49
FWD Testing on September 16, 1997				
36	114	111	61	60
37	113	153	68	66
23	125	169	69	62
54	119	140	63	62
55	129	161	78	71
56	112	158	57	65
FWD Testing on March 10, 1999				
1	156	130	77	73
35	188	190	77	75
11	185	173	88	87
15	131	177	77	82
19	215	213	76	68
54	152	200	66	59

Note: Units in MPa.
RTWP = Right wheelpath.
CNTR = Center of lane.

Table 5. Results of laboratory resilient modulus testing for base and subgrade soil.

Section No.	Base Modulus	Subgrade Modulus
5	64	77
6	76	95
7	71	95
8	106	111
9	105	111
13	59	53
21	70	94
23	69	96
24	73	99
25	75	100
26	76	100

Note: Units in MPa.

Table 6. Laboratory-determined CBR for the base course and subgrade soil at in situ density.

Section No.	Average CBR
Base Course	
1	130
2	150
3	56
6	123
8	121
11	108
15	151
17	121
21	150
22	113
24	110
Subgrade Soil	
8	5
9	3
13	11
21	2
24	5
25	4
26	5

Table 7. Percent difference between laboratory- and field-correlated CBR data for center of lane.

Lane Center Data	Army Corps (DCP)	Livneh	Army Corps (DCP)	Livneh	Army Corps (DCP)	Livneh	Army Corps (DCP)
Testing Date	11/11/96	11/11/96	5/23/97	5/23/97	9/24/97	9/24/97	4/22/99
Section No.	Base Course						
1							39
6*			36	24	81	80	
8*			31	18			
11							23
15							35
21	45	6					
24			29	7	44	33	17

Table 8. Percent difference between laboratory resilient modulus and the field and laboratory correlation modulus for center of lane.

Section No.	Resilient Modulus from lab CBR	Army Corps (DCP)	Livneh	Army Corps (DCP)	Livneh	Army Corps (DCP)	Livneh
		11/11/96	11/11/96	5/23/97	5/23/97	9/24/97	9/24/97
5				-49	-21		
6				-86	24	24	57
7		2	2			24	-53
8	53			35	-3		
9	72	7	-31				
13	-113	-209	-248				
21	78	-88	-121				
23						-7	4
24	48			16	6	27	27
25	59	17	3			28	17
26	48			-35	-66	-3	-35

Table 9. Comparison of the back-calculated modulus to the field and laboratory correlation modulus.

	Percent Difference Army		Percent Difference Livneh	
Section	CNTR	RTWP	CNTR	RTWP
Testing on October 28, 1996				
7	-21	-10	-21	-38
9	-16	-25	-63	-62
13	-78	-84	-100	-105
21	-22	-131	-44	-196
25	20	-2	0	9
Testing on May 16, 1997				
5	-107	-34	-69	-34
6	-274	-98	-54	-98
8	-45	-132	-128	-196
24	-69	-120	-90	-142
26	-180	-217	-245	-385
Testing on September 16, 1997				
36	-19	-90	32	-3
37	-6	-10	-113	-10
23	-50	-17	-35	-150
54	-15	-100	-15	-83
55	7	-31	-6	-31
56	-81	-91	-136	-123
Testing on March 10, 1999				
1	-21	-28	-21	-13
35	19	3	19	3
11	-29	-7	-18	5
15	-61	-26	-115	-26
19	-50	-52	-22	-37
54	-10	-93	6	-180

Note: RTWP = Right wheelpath.
CNTR = Center of lane.

Post-Mortem Investigation of Sections: 05, 06, 08, 24, and 26 on May 23, 1997

U.S. Department of Transportation
Federal Highway Administration

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WesTrack Report NCE-5
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

The objective of the WesTrack experiment was to further the development of performance-related specifications (PRS) for hot-mix asphalt (HMA) pavements. This required that many of the asphalt pavement test sections at WesTrack be designed to fail prior to the optimum design section. This report describes an end-of-study, or "postmortem," investigation of five of these nonoptimum sections that were removed from testing in May 1997.

The postmortem investigation involved destructive and nondestructive tests to determine the following properties:

- Section properties.
- Section distresses.
- Section roughness.
- Dynamic cone penetrometer penetrations.
- Sand cone densities.
- Pavement lift thicknesses.
- Falling weight deflectometer (FWD) deflections.

The following sections describe each of these test programs.

AS-BUILT SECTION PROPERTIES

The five sections that underwent this postmortem investigation were sections 5, 6, 8, 24, and 26. These consisted of coarse-graded mixes that had low-to-medium asphalt content and low-to-high air void content. The as-built mix properties are found in Tables 1 and 2 for the bottom and top pavement lifts, respectively.

SECTION DISTRESSES

Even though the sections all had received the same loading at the time they were removed from testing, the ways in which the sections failed were quite different. Table 3 shows the types of distresses present in each of the five sections. None of the sections exhibited raveling, even though the mix for section 26 was built with a low asphalt content. Another interesting observation was that sections 5 and 6 exhibited both fatigue cracking and bleeding. This combination of distresses is not typical.

SECTION ROUGHNESS

The roughness of each test section was the determining factor in the decision to remove sections from WesTrack. The roughness for the removed sections was caused by fatigue cracking, rutting, and patching. The fatigue cracking for sections 6 and 8 had progressed to a point of complete structural failure. At this stage, damage to the test vehicles was observed in the form of broken leaf springs and cracks in the trailers of the test vehicles.

Figures 1 and 2 show the International Roughness Index (IRI) over time for sections 6 and 8. Note that there is a drastic increase in roughness near the end of the pavement life. This increase is mirrored by the

increase in wheelpath fatigue cracking. For more detail on the relationship between IRI and distress, see WesTrack Technical Report NCE-3.[1]

The ending IRI readings for section 6 were 4.655 m/km (295 in./mi) and 2.253 m/km (143 in./mi) for the left and right wheelpaths, respectively, and the ending IRIs for section 8 were 2.469 m/km (156 in./mi) and 2.045 m/km (130 in./mi) for the left and right wheelpaths, respectively. It is obvious that, as the fatigue cracking propagated and became more severe, the roughness increased.

DESTRUCTIVE SAMPLING METHODOLOGY

Destructive sampling was performed on all five sections. Twelve slab samples, with approximate dimensions of 460 mm x 510 mm (18 in. x 20 in.), were removed from each section. Each slab was brushed off and thoroughly inspected. This inspection included photos, section labeling, and marking the direction of traffic on the top and sides of the slabs. If the slab was delaminated, the section number and the direction of travel were marked on both lifts of the slab.

Additionally, 27 150-mm (6-in.) diameter cores were removed from each section. In cases where cores from the fatigue-cracked areas were cracked to such an extent that the top lift disintegrated, additional cores were taken so that a minimum of 27 intact cores were removed.

Each section was trenched to a depth of approximately 1.2 meters (4 ft) below the asphalt concrete surface. This allowed inspection of the engineered fill and the top of the natural soil. The trench locations are listed in Table 4.

VISUAL OBSERVATION OF SECTIONS FROM TRENCHING

Pavement thickness measurements were performed for all five sections. After the trenching, the pavement face was cleaned with water and the top and bottom of the pavement layer were marked. Then, after close inspection, the researchers were able to mark out the asphalt concrete (AC) lift interface. This allowed not only a visual observation of the overall AC thickness, but also thickness measurements of each lift.

Additionally, measurements were taken from a level bar to the interface of the base and engineered fill. These data allowed an investigation to determine if deformation of the subsurface layers occurred. For each section, thickness measurements were made at 50-mm (2-in.) intervals in the wheelpath regions and at 100-mm (4-in.) intervals in the center of the lane. This allowed the change in layer thickness to be observed across the lane. Appendix A contains the results of these measurements. The following descriptions detail the observations of the field engineer, which were recorded during the trenching operation.

Section 5

During the removal of core and slab samples from section 5, thickness changes were observed in both the top lift of the HMA and the base course. The bottom lift of the HMA deformed to fit the contour of the base layer. However, the thickness did not change. This lack of thickness change indicates that shear flow most likely did not occur. The engineered fill layer below the base layer showed no change, and no mixing of the base and engineered fill was observed.

Section 6

All slabs removed were intact. The wheelpath slabs showed no visual segregation. However, the top lift of the pavement showed signs of segregation in three areas (the center of the lane, near the fog line, and near the center stripe). Two slabs separated at the lift interface when they were pried from the test section. From examination of the bottom of the slabs, one transverse crack was observed.

Thickness changes were observed in both the top lift of the HMA and the base course. The bottom lift of the HMA deformed to fit the contour of the wheelpath. However, the thickness did not change. The engineered fill layer below the base layer showed no change, and no mixing of the base and engineered fill was observed.

Section 8

The fatigue cracking was very severe and nearly all of the slabs were delaminated. The only slabs that stayed together were those near the center stripe, fog line, and the center of the lane (i.e., nontrafficked areas). Some segregation was observed in the top lift near the fog line, in the top lift near the center stripe, and in the bottom lift at the center of the lane.

A significant amount of moisture was observed between the lifts of the delaminated slabs. The moisture was not the result of sawcutting, as dry sawcutting was used for all slab samples, nor from precipitation, as no precipitation occurred during the sawcutting operation.

Thickness changes were observed in both the top lift of the HMA and the base course. The bottom lift of the HMA deformed to fit the contour of the base. However, the thickness did not change. The engineered fill layer showed no change, and no mixing of the base and engineered fill was observed.

Section 24

The only layer in which a thickness change was observed was the top lift of the HMA. During the removal of the slab samples, delamination of the slabs was observed. It is interesting to note that when the two lifts were separated, fatigue cracking was observed at the bottom of the top lift and both sides of the bottom lift. However, during the prior monitoring periods, no fatigue cracking was observed on the surface of the monitoring section.

It bears mentioning that section 24 was a replicate of section 5. The observed surface distress was different. However, when the slabs were removed, the same underlying fatigue cracking was observed.

This may indicate that debonding of pavement lifts will affect the observed pavement surface performance with respect to fatigue cracking.

Section 26

At the time that this section was removed from service and postmortem investigation began, the left wheelpath had already been removed. The left wheelpath was removed previously, at the beginning of December 1996, due to excessive fatigue cracking. Unfortunately, no investigation was done prior to removal of the left wheelpath. Therefore, the following notes apply only to the right wheelpath and the center of the lane.

Thickness changes were observed in both the top lift of the HMA and the base course. The bottom lift of the HMA deformed to fit the contour of the base. However, the thickness did not change. The engineered fill layer below the base layer showed no change, and no mixing of the base and engineered fill was observed.

DYNAMIC CONE PENETROMETER

Dynamic cone penetrometer (DCP) tests were performed at three locations in each section (under each wheelpath and in the center of the lane). Figures 3 and 4 show the schematic of the equipment and cone.

The DCP data allow an empirical correlation with the California Bearing Ratio (CBR) to be made. The Army Corps of Engineers' DCP software was used for the analysis of the data. The calculated CBR values for the base course and engineered fill are provided in Tables 5 and 6.

The CBR values clearly show a difference in support of the two materials. Additionally, the data show that the CBR values for each type of pavement structural layer are very similar. The uniform material strength was later confirmed by falling weight deflectometer (FWD) testing.

SAND CONE TESTING

Sand cone tests were performed to determine the relative compaction of the base layer. The testing was performed at three locations in each section (under each wheelpath and in the center of the lane). Samples of the base course were taken during sand cone testing immediately after the slabs were removed to determine moisture content. Table 7 shows the resulting density values and Table 8 contains the in-place moisture content at the three locations.

From Table 7, it is apparent that the density of the left wheelpath is almost always greater than the density in the center of the lane or in the right wheelpath. The relative compaction values, shown in Table 9, clearly indicate that more densification has occurred in the left wheelpath. This increase in density is likely to be due to the observed difference in weight between the left and right side of the test vehicles. Additionally, the loading difference was exaggerated by the 2 percent cross-slope from right to left in the direction of travel.

From Table 8, it is apparent that the moisture beneath the pavement was generally uniform. In general, however, the south tangent (sections 5, 6, and 8) retained slightly more moisture than other areas of the

track. The moisture observed between the lifts for section 8 may have been caused by the severity and type of distresses unique to section 8.

FWD ANALYSIS

FWD analysis was performed on the base course after the AC was milled from the track. Figure 5 illustrates the stiffness values calculated from the FWD analysis. The testing on the base course also was performed on three additional sections that were removed at the same time. The relative stiffness values were found to be very similar for all sections. This is an indication of the uniform support of each of the sections.

SUMMARY

A postmortem investigation of five test sections was conducted in May 1997. This investigation consisted of various destructive and nondestructive tests. The results of this testing indicate that the support conditions and moisture content at the time of postmortem investigation were nearly the same for all pavement sections. This confirms that the different mix properties produced the different performance and modes of failure for sections with the same mix gradation subjected to the same loading conditions. This lends confidence to the observations that the mix performance was solely due to the mix properties of the 150 mm (6 in.) of HMA.

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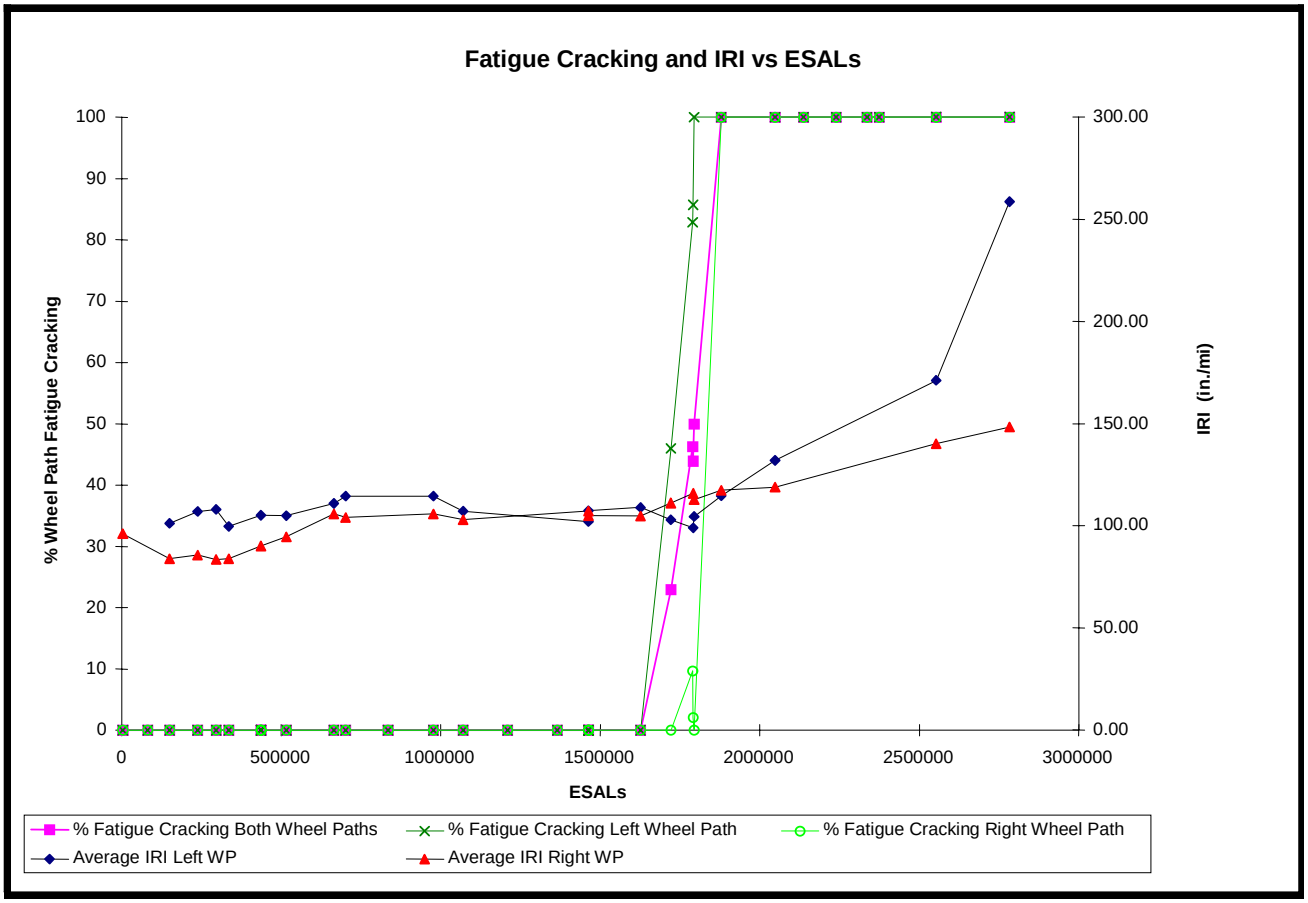
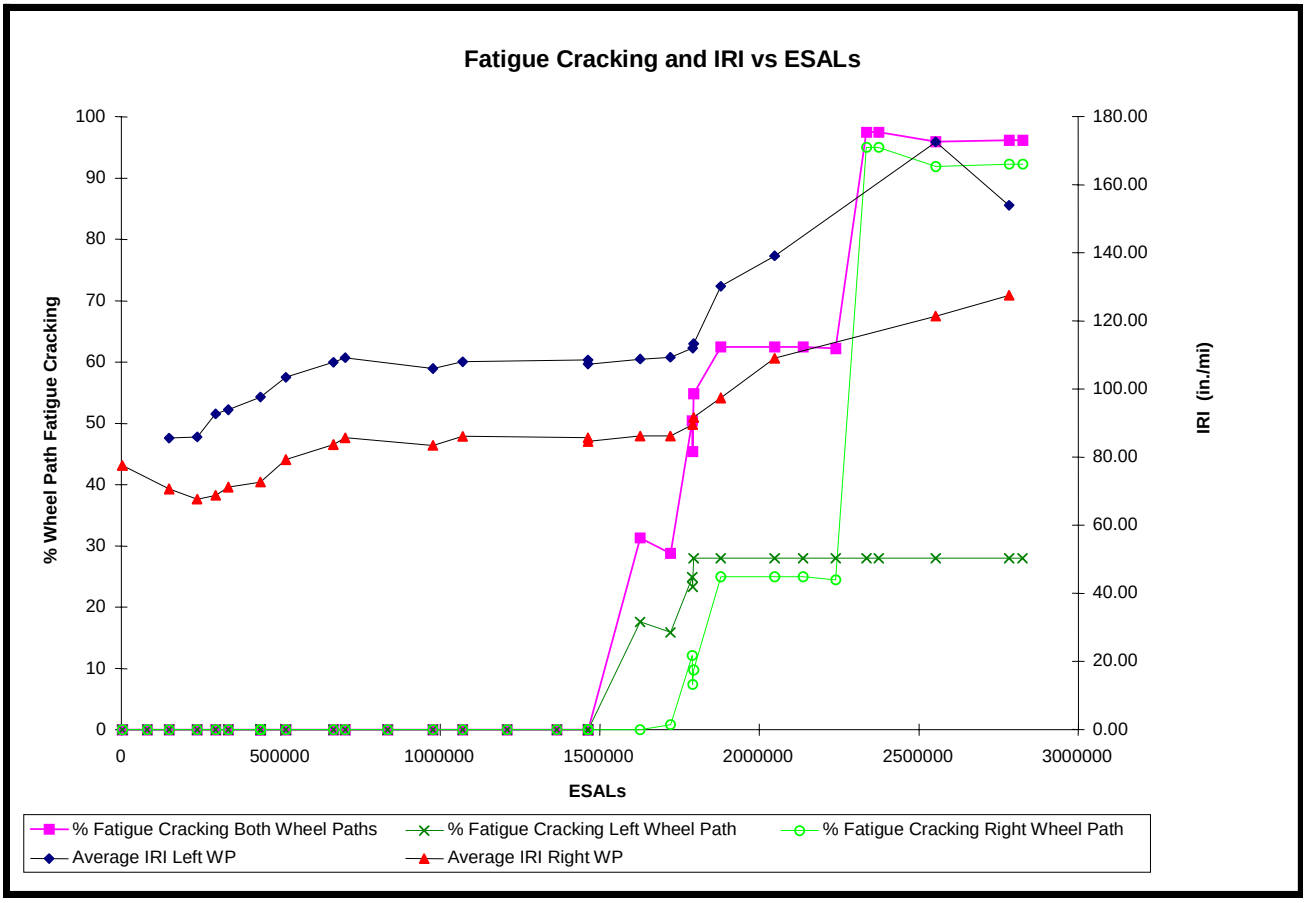


1 m/km = 63.4 in./mi

Figure 1. Percent wheelpath fatigue cracking and IRI as a function of ESALs for section 6.



1 m/km = 63.4 in./mi

Figure 2. Percent wheelpath fatigue cracking and IRI as a function of ESALs for section 8.

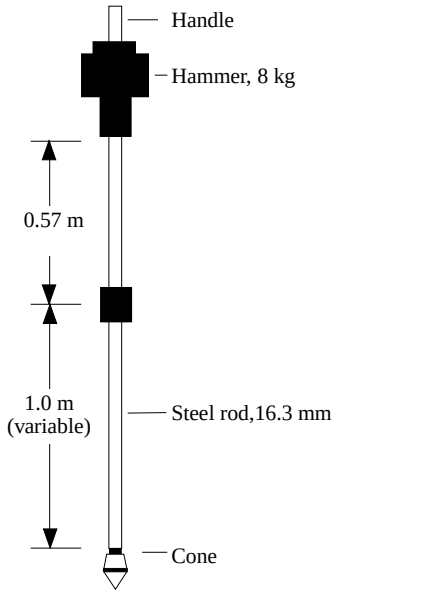


Figure 3. Dynamic cone penetrometer setup.[2]

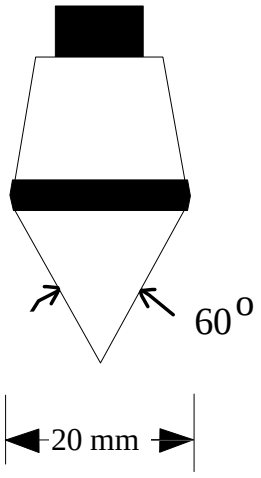
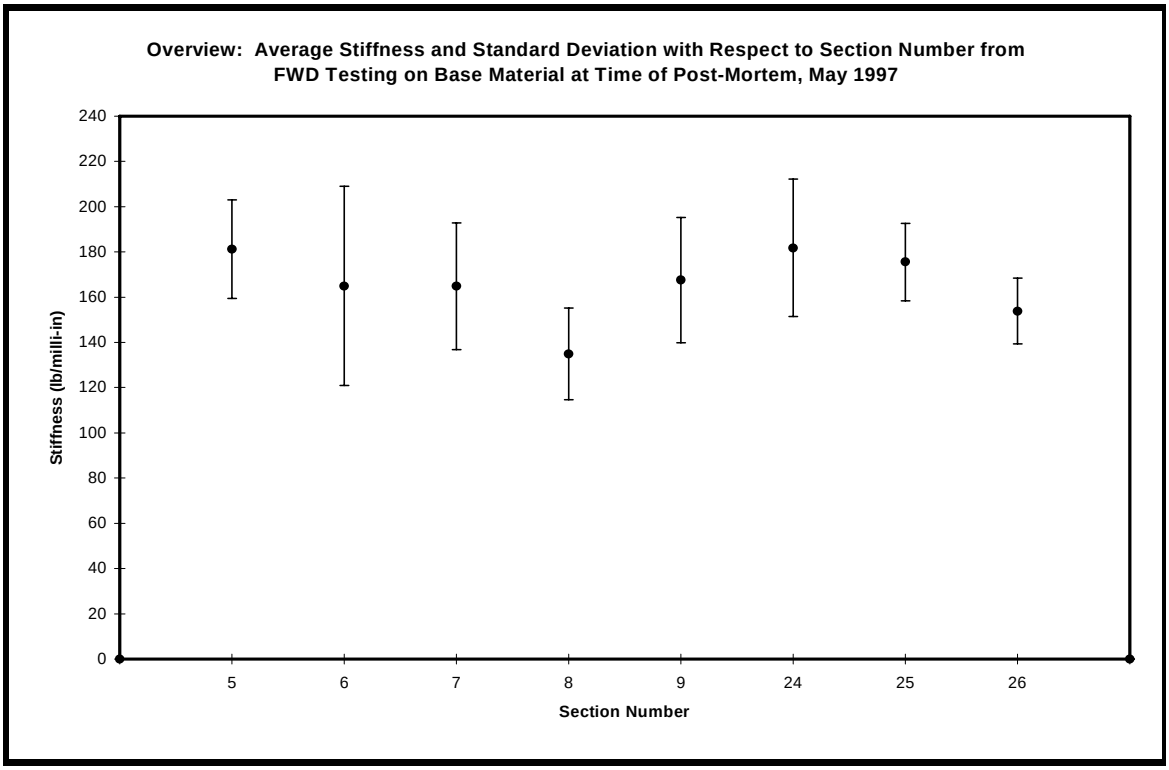


Figure 4. Cone detail.



Note: Error bars represent ± one standard deviation.

Figure 5. Average relative stiffness of each section.

Table 1. Bottom lift as-built section properties for sections 5, 6, 8, 24, and 26.

Section Number	Air Voids*	Asphalt Content**	% Passing the #200 Sieve***	Matrix Type
5	8.26	5.39	5.39	MM1
6	11.30	5.93	5.93	MH
8	8.89	5.44	5.44	ML
24	7.50	5.77	5.77	MM2
26	8.22	5.22	5.22	LH

* Average air voids after top lift placement, percent.
** Average asphalt content, percent.
*** Average percent passing the #200 (0.075-mm) sieve from ignition samples.

Table 2. Top lift as-built section properties for sections 5, 6, 8, 24, and 26.

Section Number	Air Voids*	Asphalt Content**	Percent Passing the #200 Sieve***	Matrix Type
5	8.07	5.63	5.63	MM1
6	10.78	5.71	5.71	MH
8	8.50	5.47	5.47	ML
24	6.78	5.94	5.94	MM2
26	10.97	5.31	5.31	LM

* Average air voids, percent.
** Average asphalt content, percent.
*** Average percent passing the #200 (0.075-mm) sieve from ignition samples.

Table 3. Summary of distresses for removed sections.

Section	Rut Depth*	Rut Depth*	Fatigue Cracking		Bleeding		Raveling	
Number	Total (mm)	Downward (mm)	Left WP %	Right WP %	Left WP %	Right WP %	Left WP %	Right WP %
5	22	21	81.0	18.4	100.0	100.0	0.0	0.0
6	30	29	89.8	80.9	31.9	0.0	0.0	0.0
8	23	22	100.0	93.4	0.0	0.0	0.0	0.0
24	26	23	0.0	0.0	100.0	100.0	0.0	0.0
26	21	22	100.0	32.2	0.0	0.0	0.0	0.0

1 mm = 0.039 in.

* The rut depth represents the average right wheelpath rut depth as measured at five locations in each section.

Table 4. Summary of trench locations.

Section Number	Trench Location	Nearest Monitoring Station
05	62+00 to 63+00	65+00
06	64+00 to 65+00	65+00
08	64+50 to 65+50	65+00
24	65+00 to 66+00	65+00
26	61+00 to 62+00	55+00

Table 5. CBR values for base course and engineered fill from Army Corps software.

	CBR of Base Course			CBR of Subgrade Soil		
Section	RTWP	CNTR	LTWP	RTWP	CNTR	LTWP
DCP Testing on May 23, 1997						
5	55	75	78	7	11	8
6	80	79	83	9	17	11
8	81	84	82	11	7	11
24	83	78	75	10	8	7
26	81	82	73	15	13	9

Note: RTWP = Right wheelpath.
CNTR = Center of lane.
LTWP = Left wheelpath.

Table 6. CBR values for base course and engineered fill from Livneh equation.

Section Number	CBR of Base Course			CBR of Subgrade Soil		
5	63	80	99	7	9	9
6	100	93	125	9	7	18
8	118	99	133	14	11	15
24	99	102	91	11	9	8
26	118	121	102	23	16	12

Note: RTWP = Right wheelpath.
CNTR = Center of lane.
LTWP = Left wheelpath.

Table 7. In-place density values for base course (units in lb/ft^3).

Section Number	Left Wheelpath	Center Lane	Right Wheelpath
05	135.1	130.6	126.7
06	141.3	133.3	131.9
08	144.5	134.3	132.7
24	131.3	131.0	131.9
26	135.6	140.1	133.7

$1\ lb/ft^3 = 16.0\ kg/m^3$

Table 8. In-place moisture values for base course (units in percent).

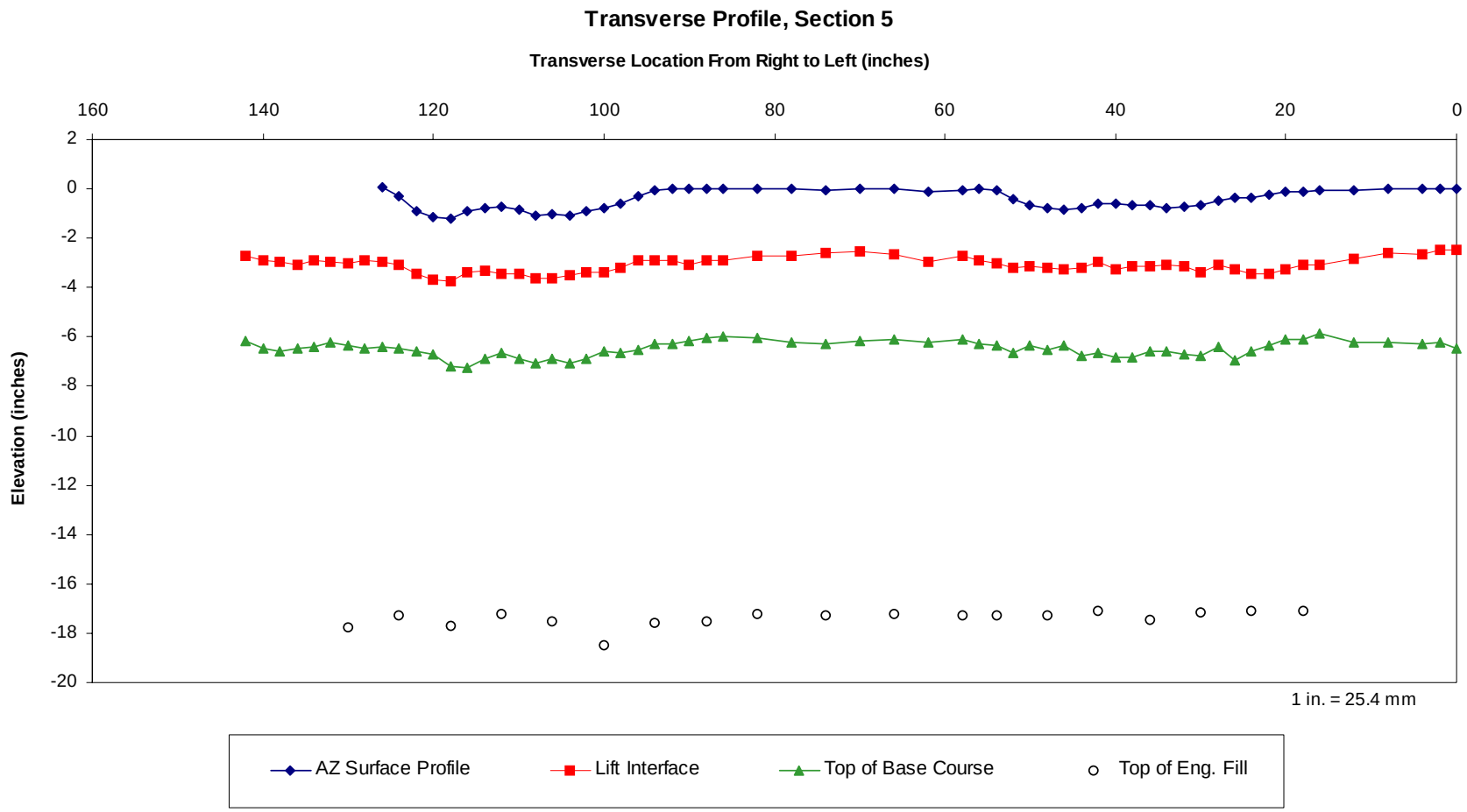
Section Number	Left Wheelpath	Center Lane	Right Wheelpath
05	7.5	7.1	7.1
06	7.1	6.8	7.4
08	7.0	7.5	6.6
24	6.5	6.3	6.4
26	6.3	6.9	4.3

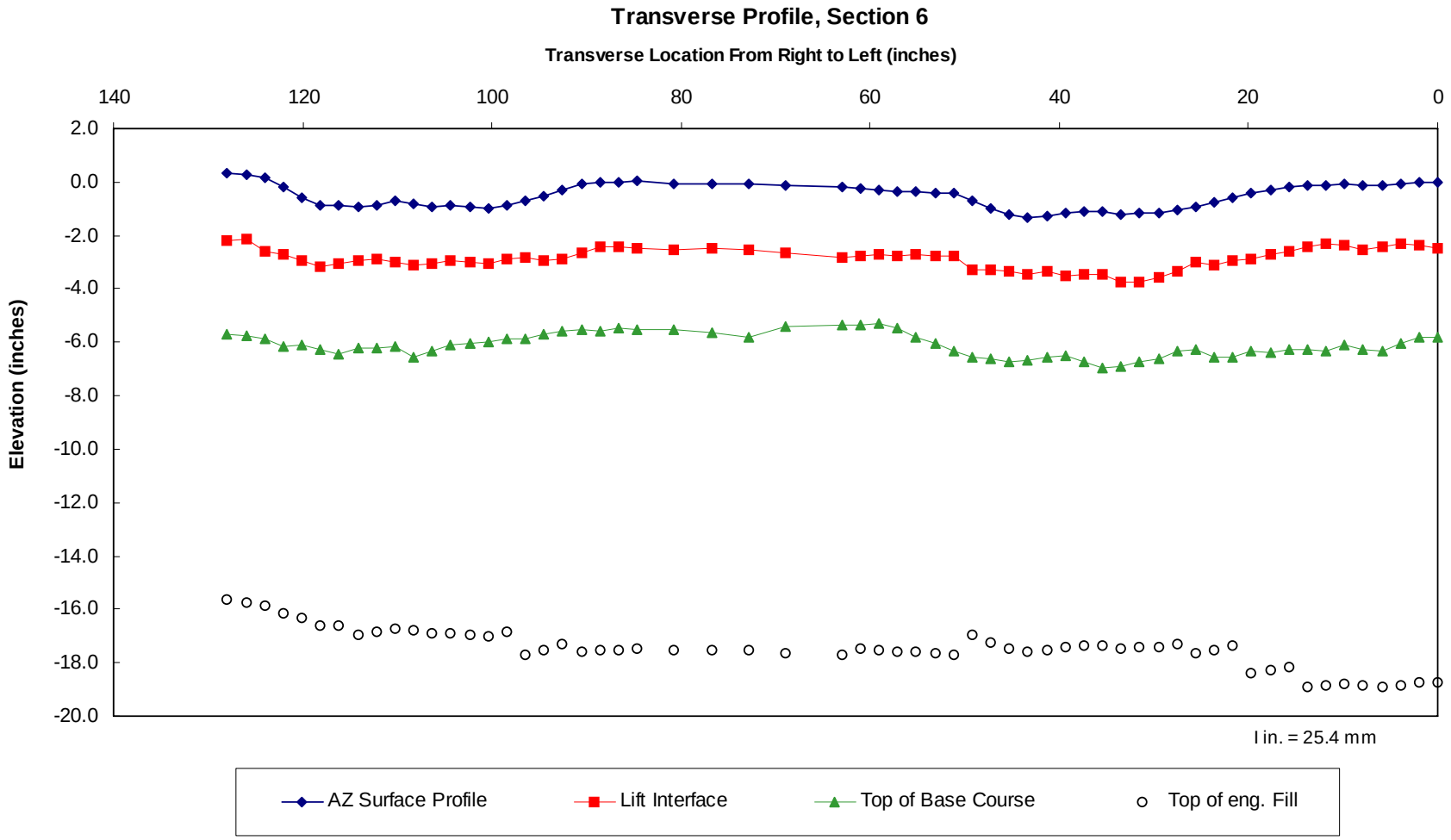
Table 9. Relative compaction (units in percent).

Section Number	Left Wheelpath	Center Lane	Right Wheelpath
05	100.5	97.1	94.2
06	105.1	99.1	98.1
08	107.4	99.9	98.7
24	97.3	97.0	97.7
26	100.4	103.8	99.0

APPENDIX A

PAVEMENT LIFT THICKNESSES


Transverse Profile, Section 5
Transverse Location From Right to Left (inches)
160
140
120
100
80
60
40
20
0
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Elevation (inches)
1 in. = 25.4 mm
AZ Surface Profile
Lift Interface
Top of Base Course
Top of Eng. Fill


Transverse Profile, Section 6
Transverse Location From Right to Left (inches)
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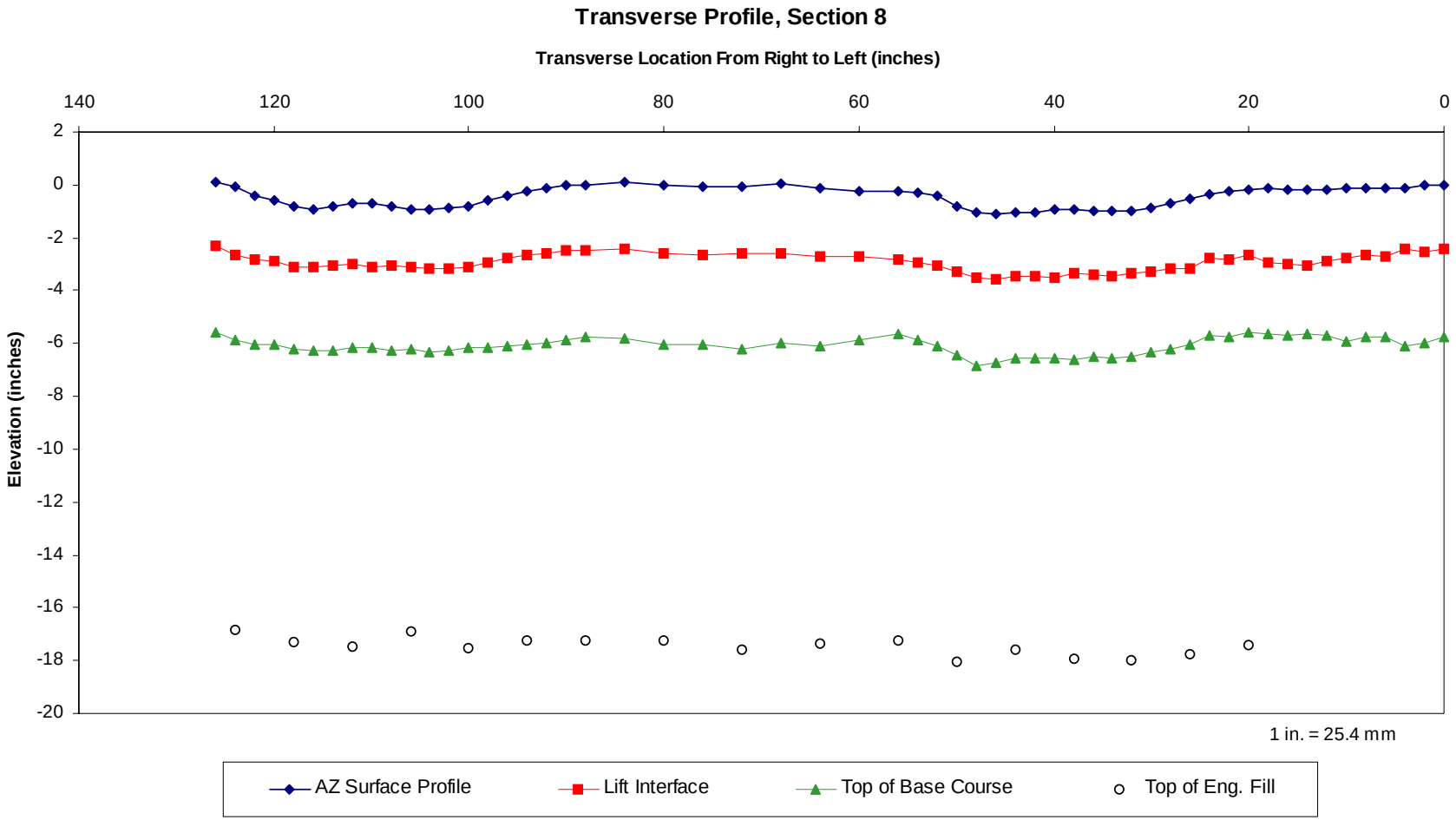
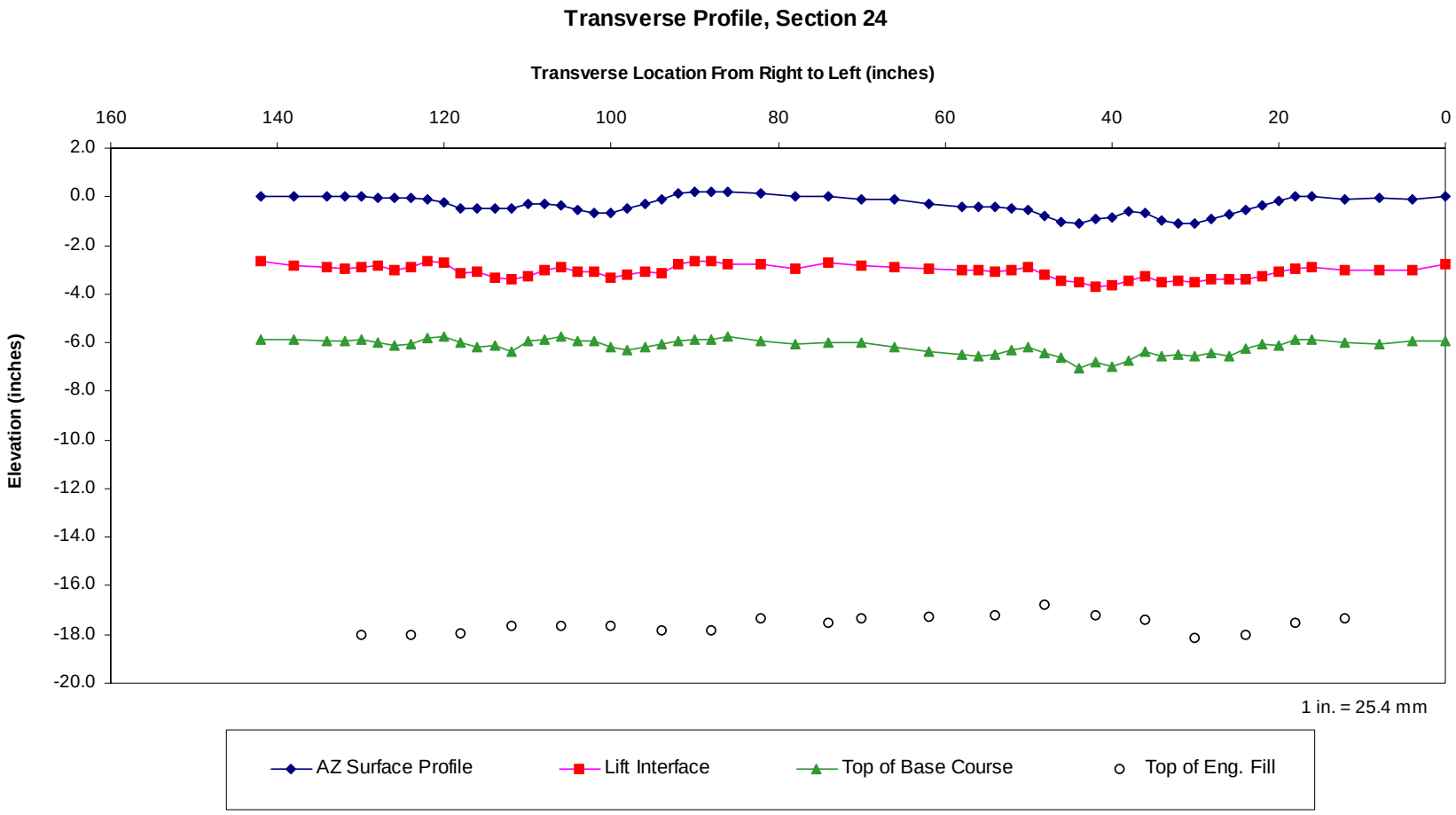
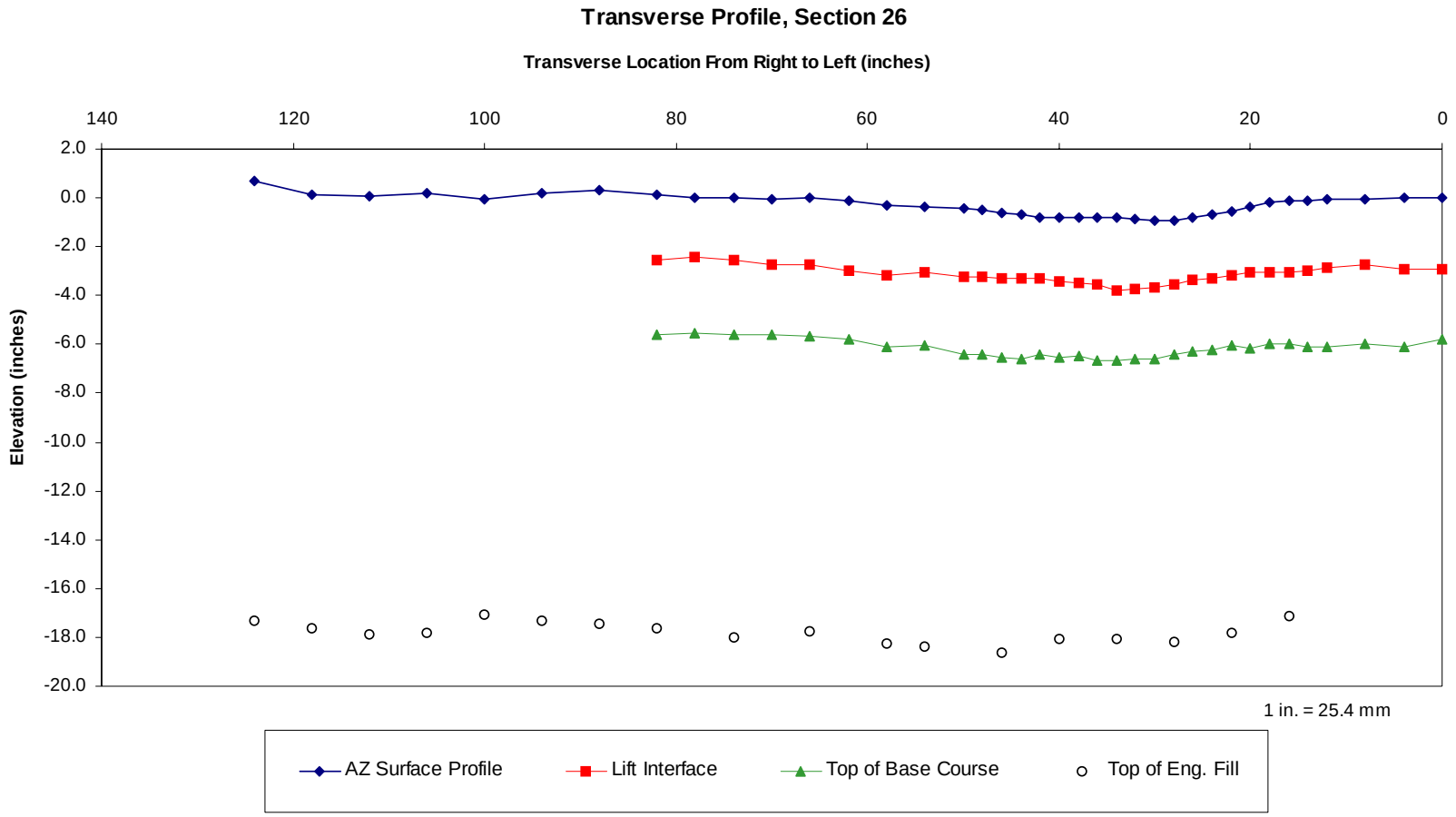
120
100
80
60
40
20
0
Elevation (inches)
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
-20.0
1 in. = 25.4 mm
AZ Surface Profile
Lift Interface
Top of Base Course
Top of eng. Fill


Transverse Profile, Section 8
Transverse Location From Right to Left (inches)
140
120
100
80
60
40
20
0
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Elevation (inches)
1 in. = 25.4 mm
AZ Surface Profile
Lift Interface
Top of Base Course
Top of Eng. Fill


Transverse Profile, Section 24
Transverse Location From Right to Left (inches)
160
140
120
100
80
60
40
20
0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
-20.0
Elevation (inches)
1 in. = 25.4 mm
AZ Surface Profile
Lift Interface
Top of Base Course
Top of Eng. Fill


Transverse Profile, Section 26
Transverse Location From Right to Left (inches)
140
120
100
80
60
40
20
0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
-20.0
Elevation (inches)
1 in. = 25.4 mm
AZ Surface Profile
Lift Interface
Top of Base Course
Top of Eng. Fill

Traffic Wander

U.S. Department of Transportation
Federal Highway Administration

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HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

The use of driverless technology at WesTrack made traffic wander a very important issue. The removal of the “human” element and the random wander associated with it and the subsequent replacement with what can be described as “developing” technology raised many questions about just what distribution of loading would be achieved. The additional influences of the configuration of the trucks, the geometry of the track, and a changing wind direction served to complicate matters further. Therefore, the traffic wander achieved at WesTrack as compared to the actual traffic wander on a real road presented an issue that was imperative to address. This report provides an account of the manner in which traffic wander was controlled at WesTrack, what the design wander was, and how it was calculated. This report also describes the determination of a "snapshot" of the actual traffic wander achieved at WesTrack and a comparison to typical traffic wander on an actual highway. A comparison of the actual wander to the theoretical wander is also discussed. Lastly, notes are provided on the time and computer requirements for performing this analysis.

WESTRACK IN REVIEW

The WesTrack Project was a full-scale flexible-pavement accelerated loading facility, located near Reno, Nevada. The WesTrack Project originally tested 26 different asphalt pavement sections to further the development of performance-related specifications for hot-mix asphalt (HMA) pavements and provide early validation of the Superpave mix design procedures. Figure 1 shows the layout of the WesTrack Project. An additional eight sections were constructed at a later date to replace failed sections. The pavement structure and binder grade were the same for all 34 pavement sections. The structure consisted of 150 mm (6 in.) of HMA on 300 mm (12 in.) of a high-quality granular base. The base was placed on 450 mm (18 in.) of an engineered fill of quality natural soil. During the construction and throughout the project, many laboratory and field tests were performed to quantify and monitor the bound and unbound material properties. Approximately 5 million 80-kN (18,000-lb) equivalent single axle loads (ESALs) were applied to the pavement sections over a period of 2.5 years. Loading was induced by four triple trailer trucks weighing approximately 70,000 kg (154,000 lb) each. Each truck pass imparted approximately 10.49 ESALs. Figure 2 shows the configuration of the trucks used for loading the pavement sections at WesTrack. Distress monitoring was performed every two weeks and roughness measurements were performed approximately once per month. During periods when the pavement was fatiguing more rapidly (i.e., in cold temperatures), monitoring was performed more often.

DRIVERLESS TECHNOLOGY

Driverless technology was used to guide the trucks that applied the loading at WesTrack. The trucks followed a guidewire embedded within the asphalt layer in the middle of the test lane. Each of the driverless trucks had antennas mounted to the front of the tractor and to the rear of the third trailer. The front antenna measured the lateral distance to the guidewire and the steering of the trucks was controlled to enable the trucks to follow the guidewire around the track. The front antenna also measured the longitudinal position of the truck on the track. The rear antenna also measured the lateral distance to the guidewire. The longitudinal position on

the track and the lateral distance of the front and rear antennas from the guidewire were recorded twice per second. By offsetting the front antenna to the left or right of the center of the truck, the lateral locations of the wheels were likewise offset and, therefore, traffic wander was simulated, providing a closer approximation to real traffic. The antenna was moved ±127 mm (±5 in.) from the centerline.

TRAFFIC WANDER IN THE REAL WORLD

In order to develop the design wander for the WesTrack Project, a literature search was conducted on the typical traffic wander of highway traffic.

The Road and Hydraulic Engineering Division of the Dutch Department of Public Works conducted a research project to study the influence of the width of traffic lane on the wheelpath distribution.[(1)] Field data were obtained from tests conducted with a specially developed measuring system. The core of the system was a sensing element, a thin mat of synthetic material, which was attached to the pavement surface. The mat contained 120 switch elements. As a tire crossed the sensor, several switches were activated and information was registered in a microcomputer. The study showed that the lateral wheel shift pattern could be represented by a normal distribution. The standard deviation of this distribution established the extent to which wheelpaths were spread out across the traffic lane. Measurements of lateral wheelpath shifts were made in the right-hand wheel track of the right-hand traffic lane of three motorways having three lanes in each direction, 15 motorways with two lanes in each direction, and three roads with one lane in each direction. The measurements were performed under similar conditions so that weather and pavement conditions would not affect the results. Table 1 shows a summary of the results. The results show that the standard deviation increases with the width of the traffic lane. A typical standard deviation for a 3.66 m (12 ft) lane on a freeway was about 0.3 m (11.8 in.). These standard deviations represent tire contact wander.

THEORETICAL TRAFFIC WANDER

Over their 3 years of traffic loading, the four driverless trucks ran approximately 450,000 laps at WesTrack. This amounted to a loading of approximately 5 million ESAL applications. The front antenna location was operated in 11 different transverse positions using 25.4-mm (1-in.) increments and ranging from 127 mm (5 in.) left of the truck center to 127 mm (5 in.) right of the truck center. Table 2 shows the final number of ESALs at the different antenna locations for the four trucks used at WesTrack.

Based upon the above antenna locations, histograms were developed for both the single (steering axle) and dual (all other axles) tire footprints. The tires were assumed to be 229 mm (9 in.) wide. A gap of approximately 11 mm (4.5 in.) was assumed between the dual tires. Figure 3 shows the distribution of tire passes for a dual tire axle at WesTrack. Figure 4 shows the distribution of tire passes for a single tire axle at WesTrack.

Each truck had seven axles with dual tires and one axle with single tires. Because of the geometry of the trucks (i.e., the center of the single tire footprint does not coincide with the center of the dual tire footprint), a different theoretical tire pass distribution was calculated for

the left and right wheelpaths. Figures 5 and 6 show the distribution of tire passes for WesTrack, which correspond to 5 million ESALs for the left and right wheelpaths, respectively. A typical highway distribution with standard deviation of 0.3 m (11.8 in.) also is included. The figures show that the theoretical distribution covers approximately 83 percent of a typical highway distribution truncated at 412.8 mm (16.25 in.).

DISCUSSION OF TRUCK BEHAVIOR

The investigation of the "theoretical" traffic wander only represents the beginning of an investigation into the "actual" wander achieved at WesTrack. As previously mentioned, other factors may have influenced the wander of the trucks used to the load the pavement. Although this report makes no attempt to identify and quantify these influences, it is important that the fact that they exist be established. Figure 7 shows a snapshot of the path that WesTrack truck 1 (WT-1), with its front antenna centered, followed down the south tangent on August 9, 1997. This illustration reveals that the truck had a tendency to weave rather than follow the guidewire in a straight line. Additionally, note that the rear antenna was always offset downslope, i.e., followed a path lower on the downslope than the path of the front antenna. (The WesTrack pavement was constructed with a 2 percent cross-slope, downward toward the interior of the track.) As shown in figure 7, this rear antenna offset, or "crossfall," can be estimated at between 200 and 250 mm (8 and 10 in.).

Figure 8 shows a snapshot of the path that WesTrack truck 3 (WT-3), with its front antenna set at 127 mm (5 in.) left, followed down the south tangent on July 31, 1997. Realizing that the front antenna is not at the center of the truck, the crossfall in this case can be estimated at between 150 and 200 mm (6 and 8 in).

Figure 9 shows a snapshot of the path that WesTrack truck 2 (WT-2), with its front antenna set at 127 mm (5 in.) right, followed down the south tangent on July 31, 1997. Realizing that the front antenna is not at the center of the truck, there appears to be little crossfall in this case.

Because the trucks were essentially identical, it was assumed that the difference in crossfall was due to differences in the front antenna setting rather than the trucks themselves. The influence of rutting and cross slope could influence trucks with different antenna offsets in different ways. Therefore, the need for an actual wander distribution was demonstrated. It is obvious that the WesTrack trucks did not behave "theoretically."

CALCULATION OF ACTUAL WANDER

Description of Data

As previously stated, the lateral distance from the front and rear antennas to the guidewire was recorded twice per second. Data files were generated containing:

- Time – A time stamp providing the exact time of the data acquisition to the nearest second.
- Lateral position of front antenna – A voltage value indicating the lateral position of the front antenna relative to the guidewire (0.5 volts corresponded

to 0.3048 m [1 ft] of lateral offset).

- Lateral position of rear antenna – A voltage value indicating the lateral position of the rear antenna relative to the guidewire (0.5 volts corresponded to 0.3048 m [1 ft] of lateral offset).
- Speed – The speed of the truck as measured by the Detroit Diesel on board computer in units of miles per hour.
- Position on track – The longitudinal position of the truck on the track in terms of a coordinate value ranging from 0 to 65535. The position was based on a signal from the front antenna box of each truck. One meter corresponded to 23.149064 longitudinal position units.

Ideally, the development of a traffic wander histogram would be tabulated along a transverse cross-section of negligible width. However, since lateral offset data were recorded twice every second, and the trucks moved at approximately 64 km/h (40 mi/h), a data point was recorded approximately every 9 m (30 ft). The maximum speed observed in the data used for this analysis was approximately 71.6 km/h (44.5 mi/h). This corresponds to a distance of almost 10 m (33 ft) between data point locations. This would not necessarily present a problem if the locations where the data points were recorded were different each time around the track. Unfortunately, the locations happened to be repeatable, resulting in a clustering of data points, as shown in figure 10. The unfeasibility of locating these clusters required that a horizontal cross-section of substantial length (i.e., at least 10 m) be used to generate a traffic wander histogram in order to collect at least one data point within the cross-section each time the truck made a pass. For the purpose of this analysis, a cross-sectional length of 10 m was used.

A cross-sectional length of 10 m had both benefits and drawbacks. It assured that the lateral position of the front antenna was recorded for every truck pass. The drawback was that the cross-section could potentially have been positioned such that half of the data from two different clusters was used to generate the histogram. This presented a problem if the truck was weaving substantially within the cross-section. Additionally, if the truck was traveling at slower speeds, two data points were recorded within the cross-section. In many cases, the histogram developed from these data had multiple peaks. When the trucks were traveling at speeds such that the data collection points were evenly distributed longitudinally along the cross-section (i.e., no data clusters), the histogram looked very “flat.” Figure 11 shows a comparison of the different shapes of histograms generated as a part of this analysis.

Actual Data Used

Development of the "true" histogram for any location on the track was entirely unfeasible. This would require the reduction of all lateral position data for all four trucks for the entire life of the project. (See note on the time commitments of each task at the end of this report.) Therefore, a sampling of the lateral position data was used to generate a histogram of the actual traffic wander histogram at WesTrack. This sampling included data recorded at all 11 positions of the front antenna (i.e., –127 mm [–5 in.] to +127 mm [+5 in.], with 25.4-mm [1-in.] increments). For the purpose of this analysis, it was assumed that all four trucks behaved exactly the same at each antenna position (e.g., truck WT-1, at antenna position 127 mm left, behaves exactly the same as

truck WT-*n* at antenna position 127 mm left). The following is a list of the lateral offset data used for this analysis:

- 127 mm (5 in.) left – 7/31/97, 8/2/97
- 101.6 mm (4 in.) left – 11/28/97
- 76.2 mm (3 in.) left – 8/9/97
- 50.8 mm (2 in.) left – 7/31/97, 8/3/97, 1/7/98
- 25.4 mm (1 in.) left – 12/1/97, 12/4/97
- Centered – 8/8/97, 8/9/97, 8/10/97, 8/11/97, 8/12/97
- 25.4 mm (1 in.) right – 11/29/97
- 50.8 mm (2 in.) right – 8/2/97
- 76.2 mm (3 in.) right – 8/10/97
- 101.6 mm (4 in.) right – 4/30/97, 5/2/97
- 127 mm (5 in.) right – 7/31/97, 8/3/97

Operations Performed to Calculate Histogram

Six steps were required to develop a histogram from the lateral offset data files. These steps are outlined below:

1. Determination of coordinates needed – The data indicating the location on the track at which each data point was recorded was in the form of a position index ranging from 0 to 65535. This index was converted to meters with the formula: meters = index / 23.149064. With this conversion, the position index of any location on the track could be computed. Three WesTrack pavement sections were chosen for histogram calculations. The sections chosen were 4, 14, and 23, since these sections developed low, medium, and high rutting, respectively. Separate histograms were developed for the beginning of each section and the end of each section. The position indices for the above cross-sections are shown in Table 3.

   However, because the longitudinal location of the truck on the track was established by the front antenna box, the WesTrack position coordinates listed in Table 3 were only correct for the front of the truck. The length of the truck (32.5 m) was added to the WesTrack position coordinates in order to determine the proper rear antenna data. Table 4 shows the position indices for the rear antenna data.

2. Filter of data files – Utilizing the "Autofilter" function in Microsoft® Excel, all data not falling within the WesTrack position coordinate ranges listed in Tables 3 and 4 were deleted from the data files. This was performed to reduce the data files to a more manageable size for the computer performing the analysis.

   In addition to filtering the data for the proper location, data records were removed from analysis if the speed of the truck was slower than 62 km/h (38.5 mi/h). Trucks traveling at speeds slower than 62 km/h were either accelerating up to

loading speed or decelerating to a stop. These records represented a very small percentage of the traffic wander data.

3. Combination of filtered data files – Each raw data file contained approximately 43,000 lines of data. With the previously described parameters being recorded twice per second, it took four data files to record data for a 24-hour period. Therefore, after these files were filtered down to a manageable size, the four files that made up each 24-hour period were combined into a single file.

4. Generation of antenna histogram – A histogram of the antenna offset locations was generated using the "histogram" function in Excel with the bin size set at 5 mm (0.2 in.) increments. The antenna histograms for each day of data are included as appendices A and B. Appendix A contains the histograms for the front antenna and appendix B contains the histograms for the rear antenna. Note that the front antenna was adjusted up to 127 mm (5 in.) to the left or right of the center of the truck. The rear antenna remained fixed at the center of the truck.

5. Generation of extrapolated tire contact histogram for front and rear of truck – The next step involved using these front and rear antenna histograms and developing tire contact histograms for the front and rear of the trucks. The offset of the front antenna from the center of each truck was "subtracted out" of every front antenna histogram. These adjusted histograms represented histograms of the center of the truck. The data making up these histograms were then adjusted based upon the total number of truck passes over the entire life of the project for that particular front antenna offset. The formula used to adjust the histogram data is included as equation 1.

$$A = \frac{B \times C}{D} \tag{1}$$

Where: A = The bin value for the extrapolated histogram,
B = The bin value for the daily histogram,
C = The total number of truck passes at that antenna position over the project life, and
D = The total number of truck passes used to develop the histograms at that antenna position.

This resulted in histograms normalized to the total number of laps at each antenna position. These histograms were simply combined to develop the overall histogram for the center of the truck for the entire life of the project. Based upon this histogram, a new histogram was developed for the tire contact area. Each tire was assumed to be 229 mm (9 in.) wide. The dual tires were assumed to have a 114-mm (4.5-in.) gap between them. Figures 9 through 14 show the tire contact histograms for the front and rear of the trucks for the beginning and ending cross-

sections of WesTrack sections 4, 14, and 23. Tables 5 and 6 list the means and standard deviations for each of these histograms.

6. Generation of the overall extrapolated tire contact histogram – Noting that the means and standard deviations of the front and rear histograms were not the same, these histograms were combined to generate an overall histogram. First of all, it was assumed that the front histogram applied to axles 2 and 3, and the rear histogram applied to axle 8 (see Figure 2). Axle 1 was not included in this analysis. The axle spacing from axle 3 to axle 8 was 5.2 m (17 ft). Therefore, the locations of the means of the histograms for axles 4, 5, 6, and 7 were interpolated linearly. Using an Excel spreadsheet, the bin values for the histograms for axles 4, 5, 6, and 7 were calculated through linear interpolation using the mean as a reference. This process is illustrated graphically in Figure 18.

   The overall extrapolated tire contact histogram was generated as simply the sum of the histograms for each axle. Figures 19 through 24 show the overall extrapolated histograms for the beginning and ending cross-sections of WesTrack sections 4, 14, and 23. Table 7 contains the means and standard deviations of each of these histograms. Note how closely the standard deviations match. This indicates that for these six cross-sections, the overall traffic wander histogram appears to be almost identical. The fact that sections 4, 14, and 23 have substantially different rut depths does not appear to be significant. However, an analysis requiring less extrapolation may prove otherwise.

COMPARISON WITH TYPICAL HIGHWAY WANDER

Assuming typical traffic wander to be normally distributed with a standard deviation of 0.3 m (11.8 in.), the actual distribution determined by this analysis amounted to approximately 95 percent of a typical highway distribution. Table 8 shows the percentage of a typical highway distribution for each cross-section evaluated in this study.

COMPARISON WITH THEORETICAL HIGHWAY WANDER

The theoretical WesTrack wander analysis performed yielded theoretical histograms that included approximately 83 percent of the typical highway wander. The 95 percent that the actual wander includes indicates that the actual WesTrack wander more closely resembled typical highway wander than the theoretical WesTrack wander.

NOTE ON THE TIME AND MEMORY REQUIREMENTS

The overall histograms presented as a part of this analysis represent a substantial extrapolation of a relatively small snapshot of traffic wander data. Tables 9 and 10 provide details on the amount of front and rear antenna data analyzed as compared to the total amount of data available. This analysis looked at approximately 1.7 percent of the entire traffic wander data set. However, to properly appreciate the effort required to reduce this snapshot of data, the following details are provided detailing the analysis time and/or computer memory requirements for the major tasks.

(All analyses were performed using Microsoft® Excel 97 on an Intel® 300 MHz Pentium II with 64 megabytes of RAM.)

- Filter and combination of data files – The raw data files consisted of four 43,000-record data files for each day of data for each truck. Each file was provided in *.csv (ASCII) format and was approximately 2.5 megabytes in size. The time required to convert to Excel format, convert the lateral position from a voltage value to a lateral distance value, put the time into the correct format, filter out the data records outside of the desired cross-sections, and filter out the data records recorded at speeds slower than 62 km/h (38.5 mi/h) was approximately 15 minutes of uninterrupted operator time for an operator familiar with the steps required. After the data files were converted to Excel format but before they were filtered to reduce them to a more manageable size, each file was approximately 10 megabytes in size. After filtering and combination of the four daily data files into a single file, the file size was approximately 0.5 megabytes.

- Generation of antenna histogram – Utilizing the histogram function within Excel and creating histogram plots for each of the six cross-sections required approximately 10 minutes of operator time. The completed reduced data file was approximately 1 megabyte in size.

  Assuming an experienced operator spent 1.25 hours reducing each day of data, the analysis up to this point represents 52.5 hours of uninterrupted time. Realizing that this represents only 1.7 percent of the data of six cross-sections, reducing the entire data set in this manner for six cross-sections required some 3,000 operator-hours.

- Generation of extrapolated tire contact histograms – Approximately 16 hours were spent developing the spreadsheets to convert the antenna histograms into tire contact histograms and to extrapolate the overall histograms. Another 10 hours were spent copying the data into the spreadsheets and preparing graphic outputs.

SUMMARY

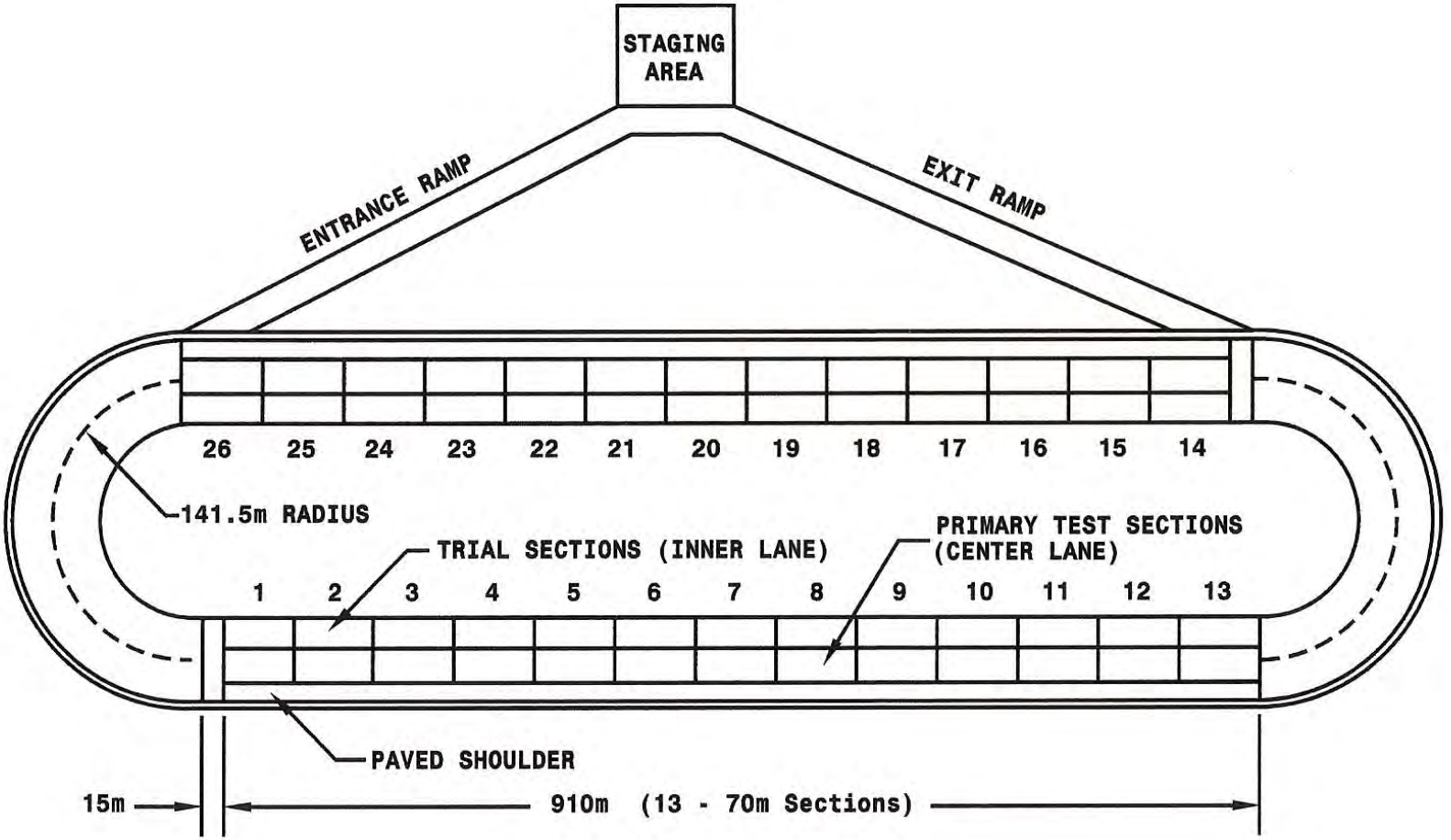
This WesTrack report has presented a discussion of the theoretical and actual traffic wheelpath distribution at WesTrack. The theoretical wheelpath distribution was calculated assuming 229-mm (9-in.) wide tires with 114-mm (4.5-in.) gaps between dual tires. Wander was simulated by adjusting the front antenna arrays on each truck. The final wheelpath distribution represents a normal distribution truncated at 412.8 mm (16.25 in). This covers approximately 83 percent of a typical highway distribution.

This report has also described an analysis of a snapshot of the actual traffic wander data from the WesTrack Project. The snapshot of data was extrapolated into histograms covering the life of the project. Based upon this analysis, the actual traffic wander appears to include approximately 95 percent of the typical highway wander. The snapshot of data represents approximately 1.7

percent of the total traffic wander data gathered at the track. Such a large extrapolation may not be appropriate and a full analysis is recommended.

REFERENCES

1. Buiter, R., Cortenraad, W.M.H., Van Eck, A.C., and Van Rij, H., "Effects of Transverse Distribution of Heavy Vehicles on Thickness Design of Full-Depth Asphalt Pavements," *Transportation Research Record 1227*, Transportation Research Board, National Research Council, Washington, D.C., 1993.



1 m = 3.28 ft

Figure 1. WesTrack section layout.

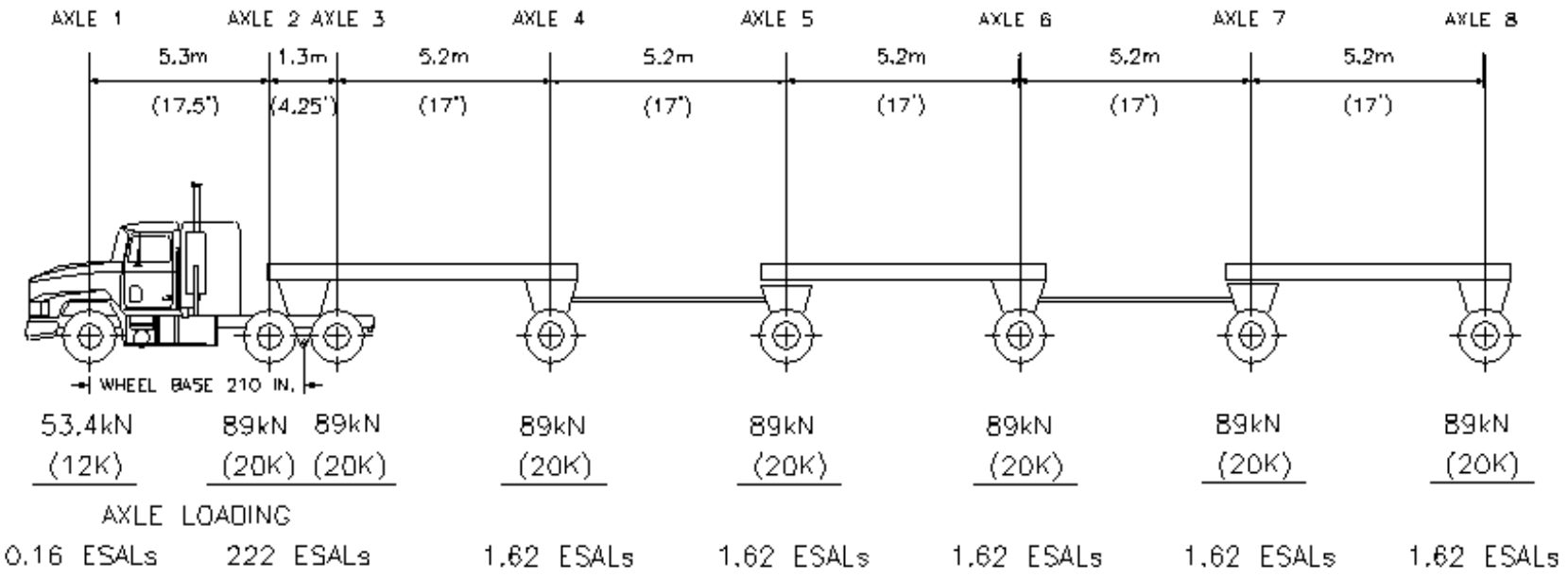
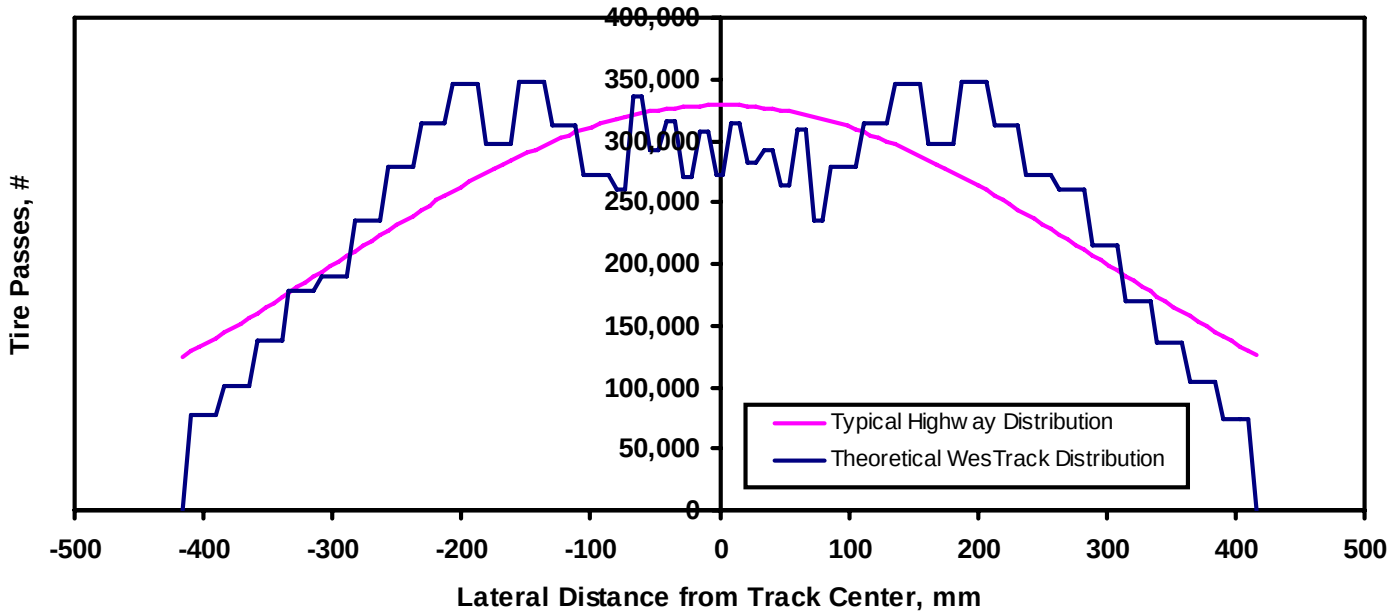
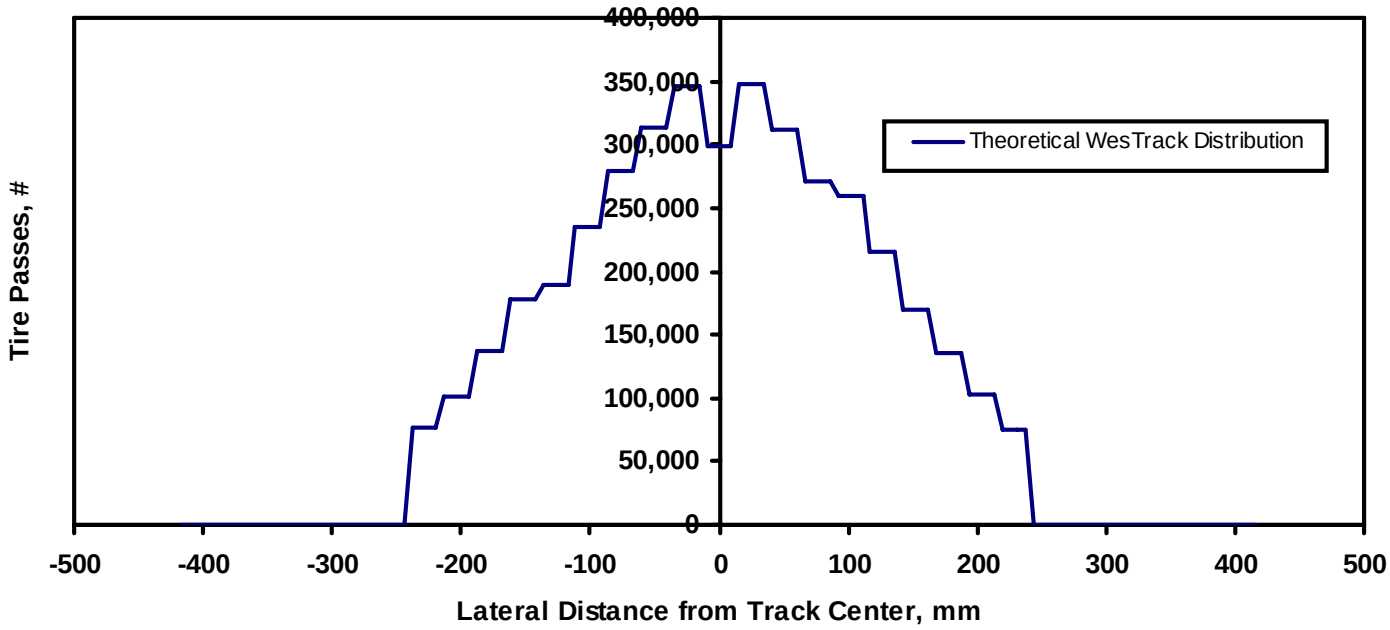


Figure 2. WesTrack truck configuration.



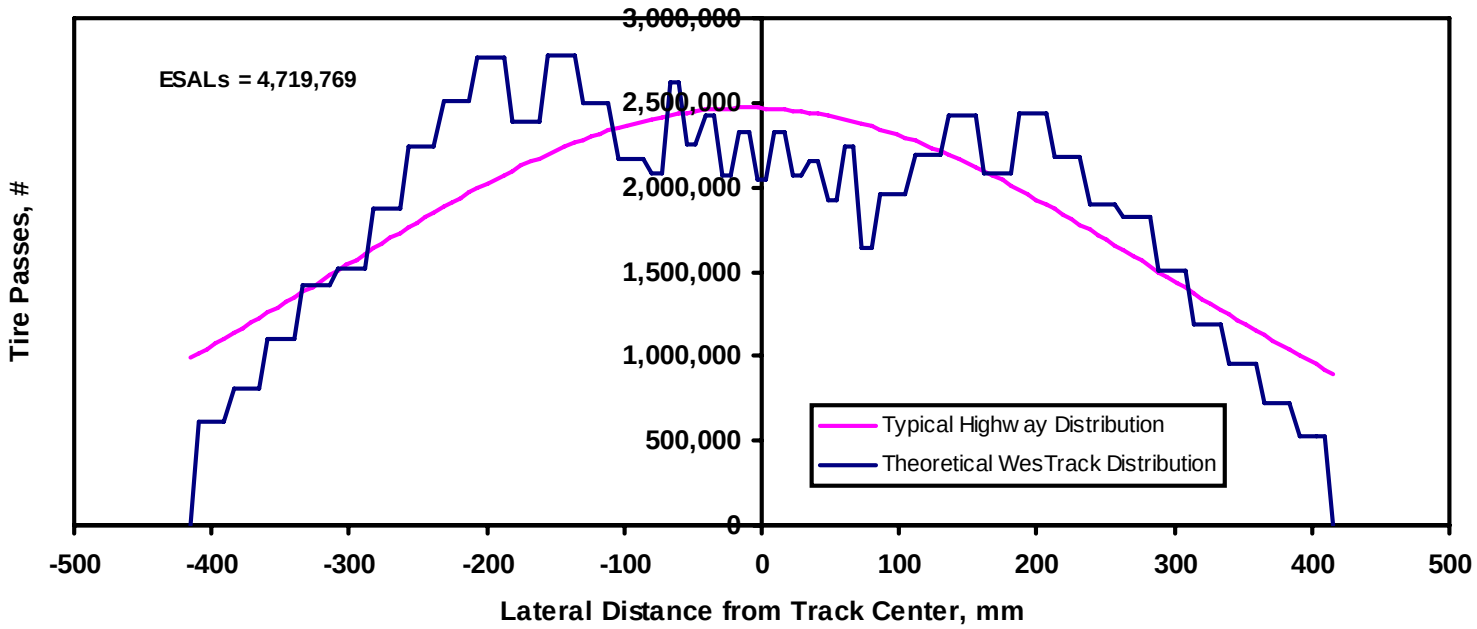
1 in. = 25.4 mm

Figure 3. Final theoretical tire pass histogram for dual tires.



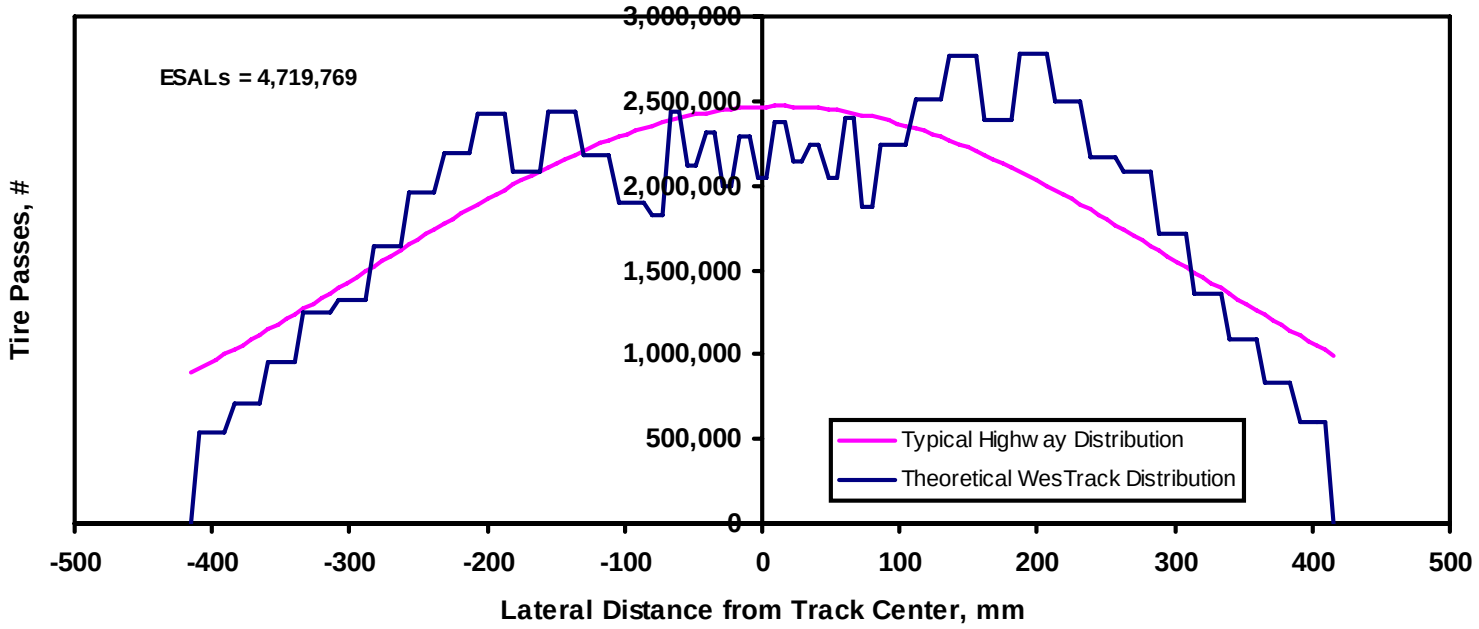
1 in. = 25.4 mm

Figure 4. Final theoretical tire pass histogram for single tires.



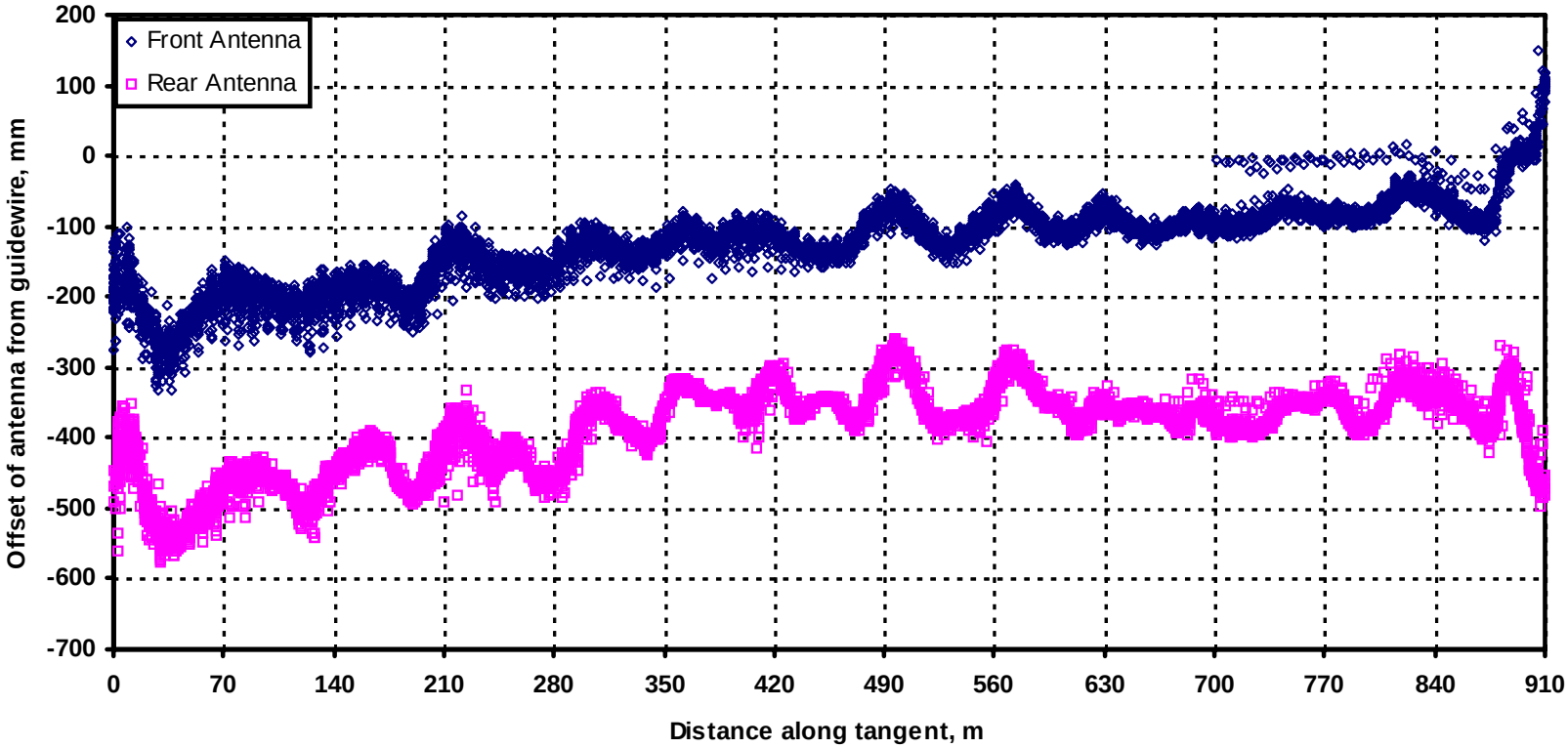
1 in. = 25.4 mm

Figure 5. Final theoretical tire pass histogram for left wheelpath.



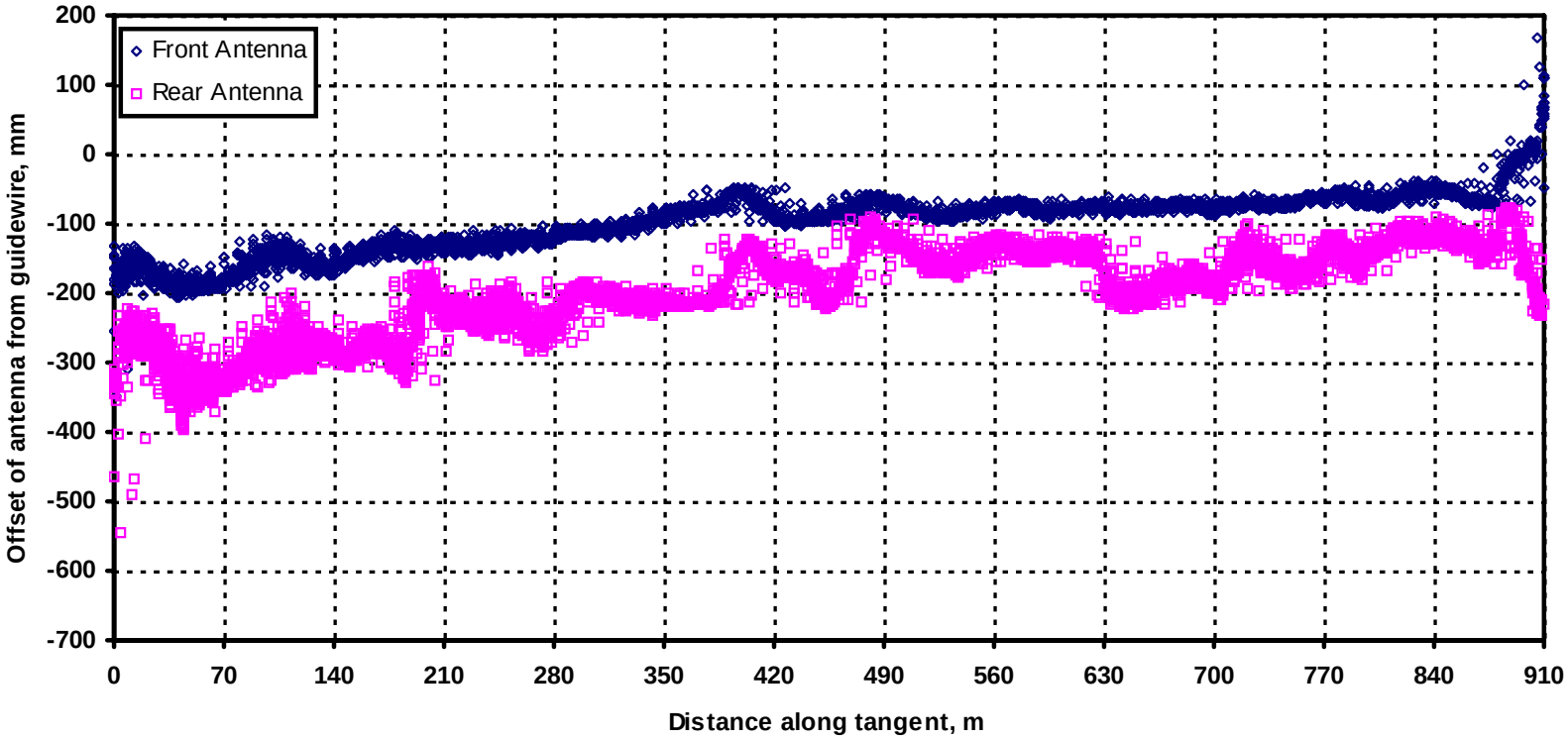
1 in. = 25.4 mm

Figure 6. Final theoretical tire pass histogram for right wheelpath.



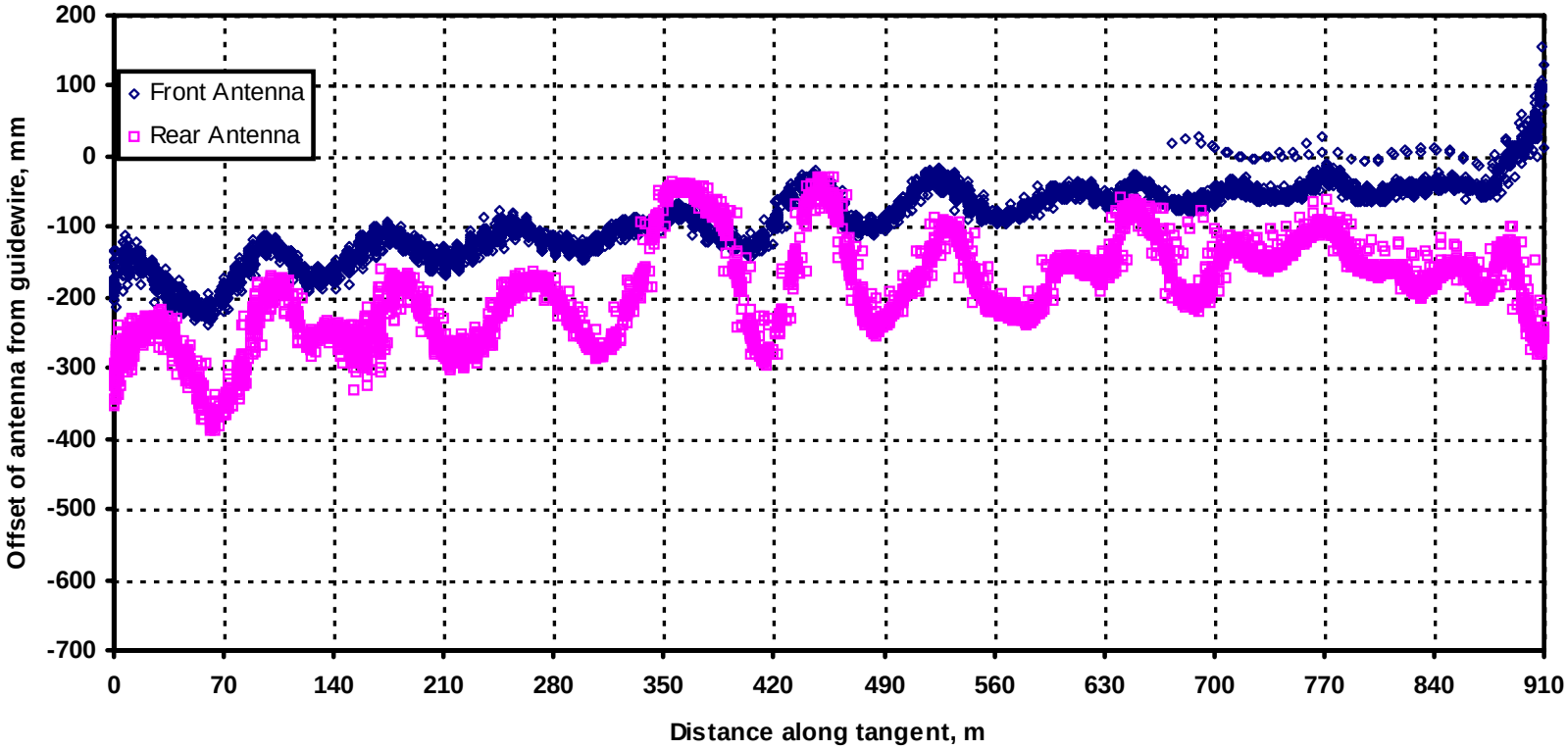
1 m = 3.28 ft

Figure 7. Truck path down south tangent (WT-1, antenna centered, date 8/9/97).



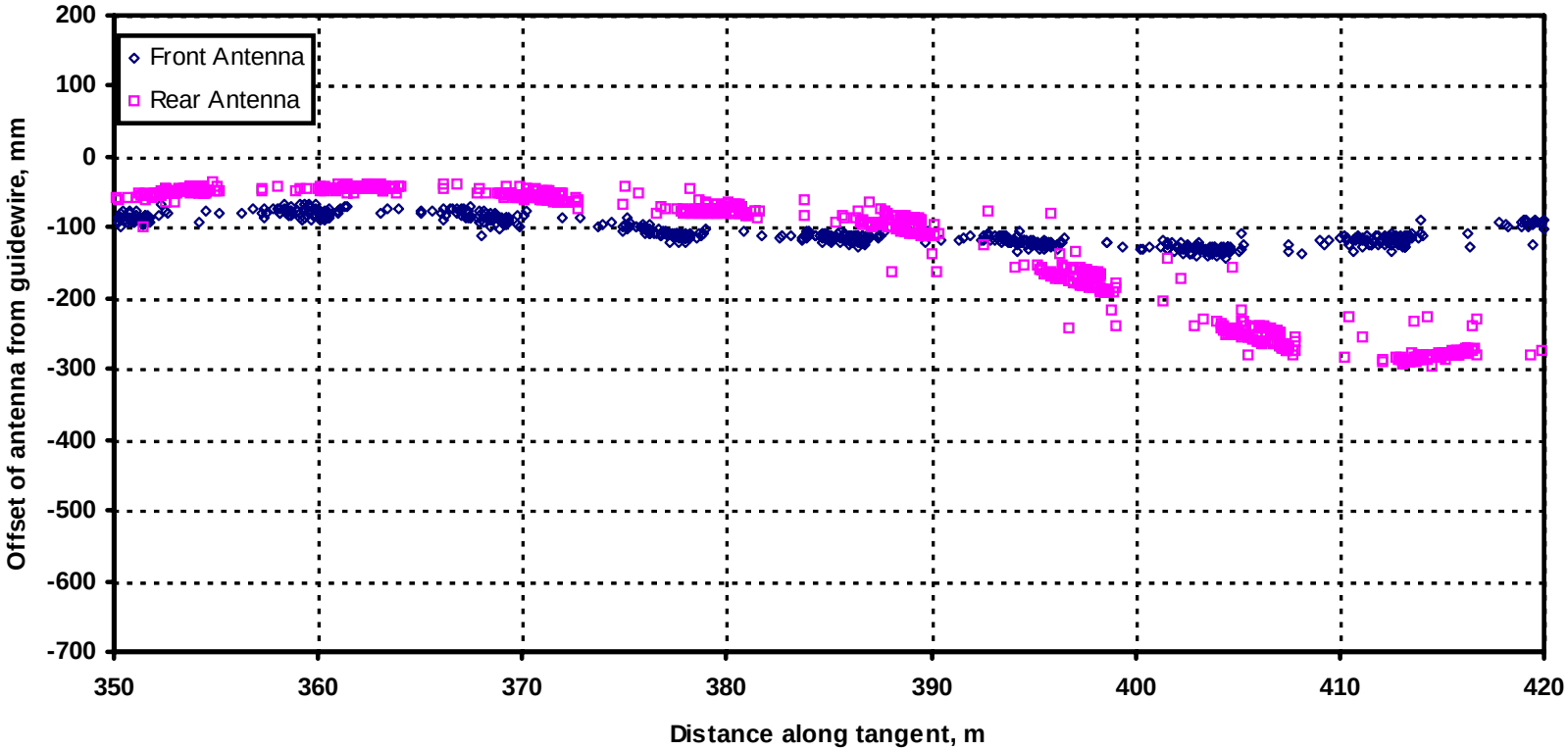
1 m = 3.28 ft

Figure 8. Truck path down south tangent (WT-3, antenna set 127 mm [5 in.] left, date 7/31/97).



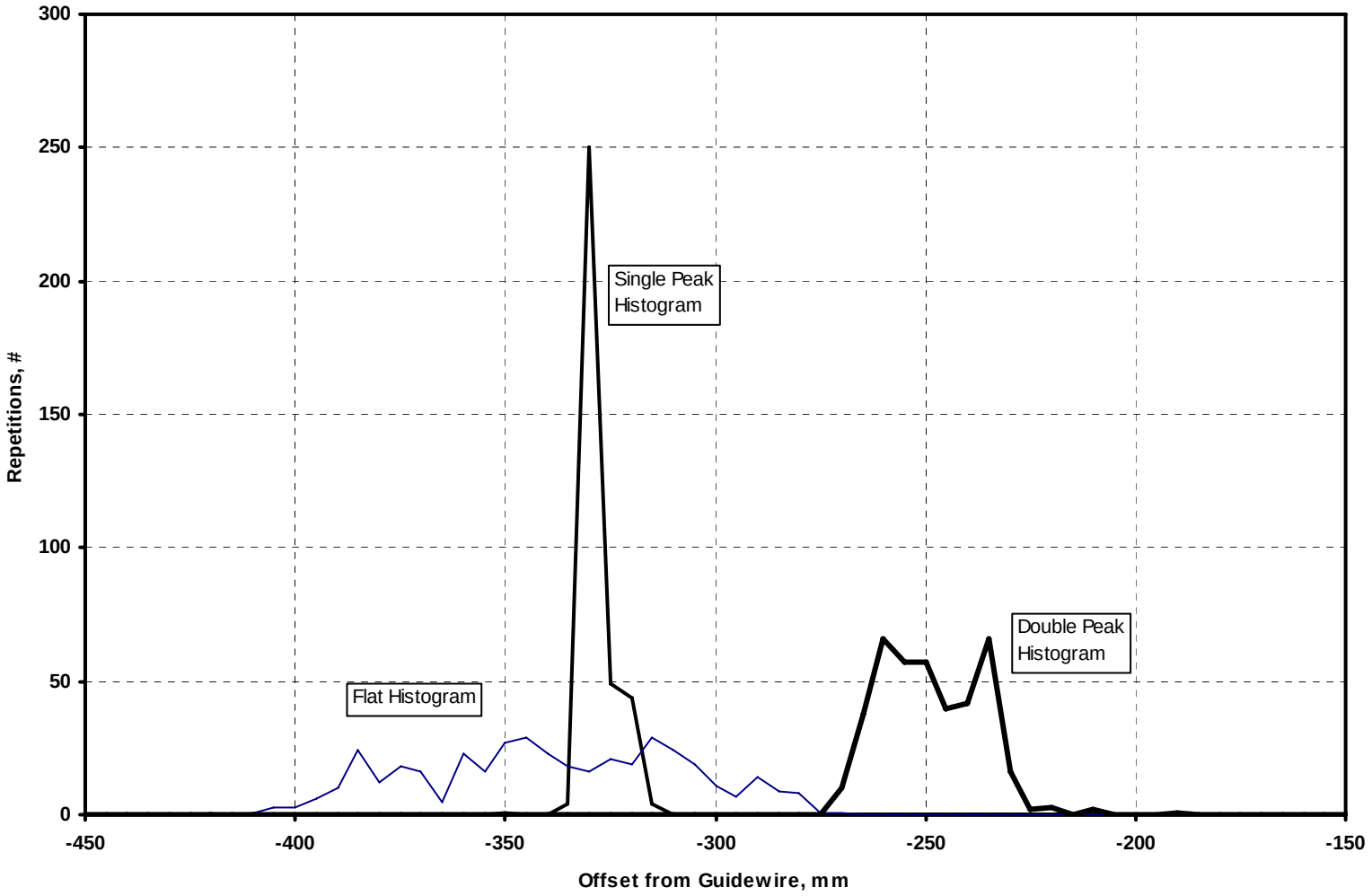
1 m = 3.28 ft

Figure 9. Truck path down south tangent (WT-2, antenna set 127 mm [5 in.] right, date 7/31/97).



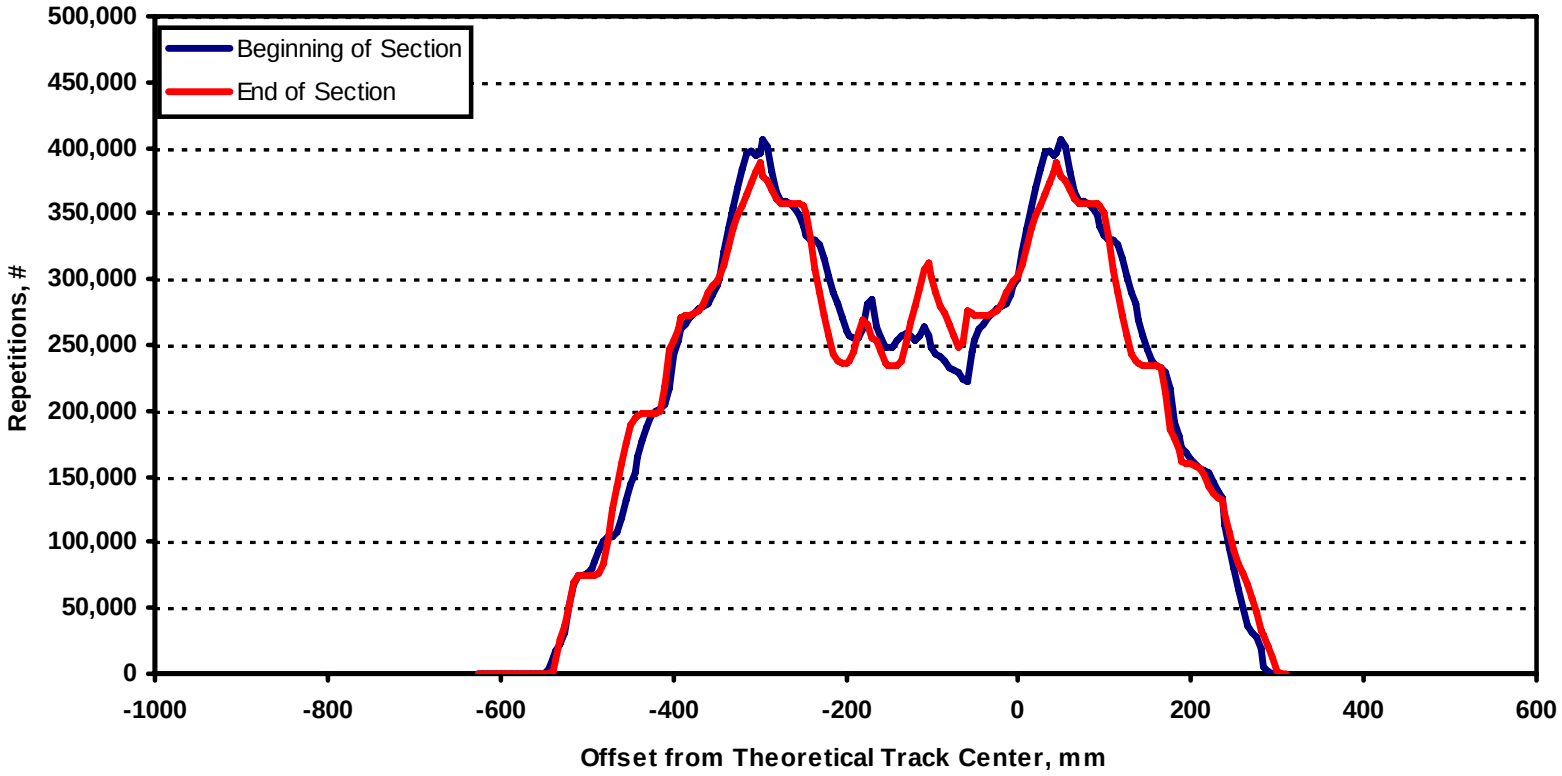
1 m = 3.28 ft

Figure 10. A snapshot of the data point collection locations (WT-2, antenna set at 127 mm [5 in.] right, date 7/31/97).



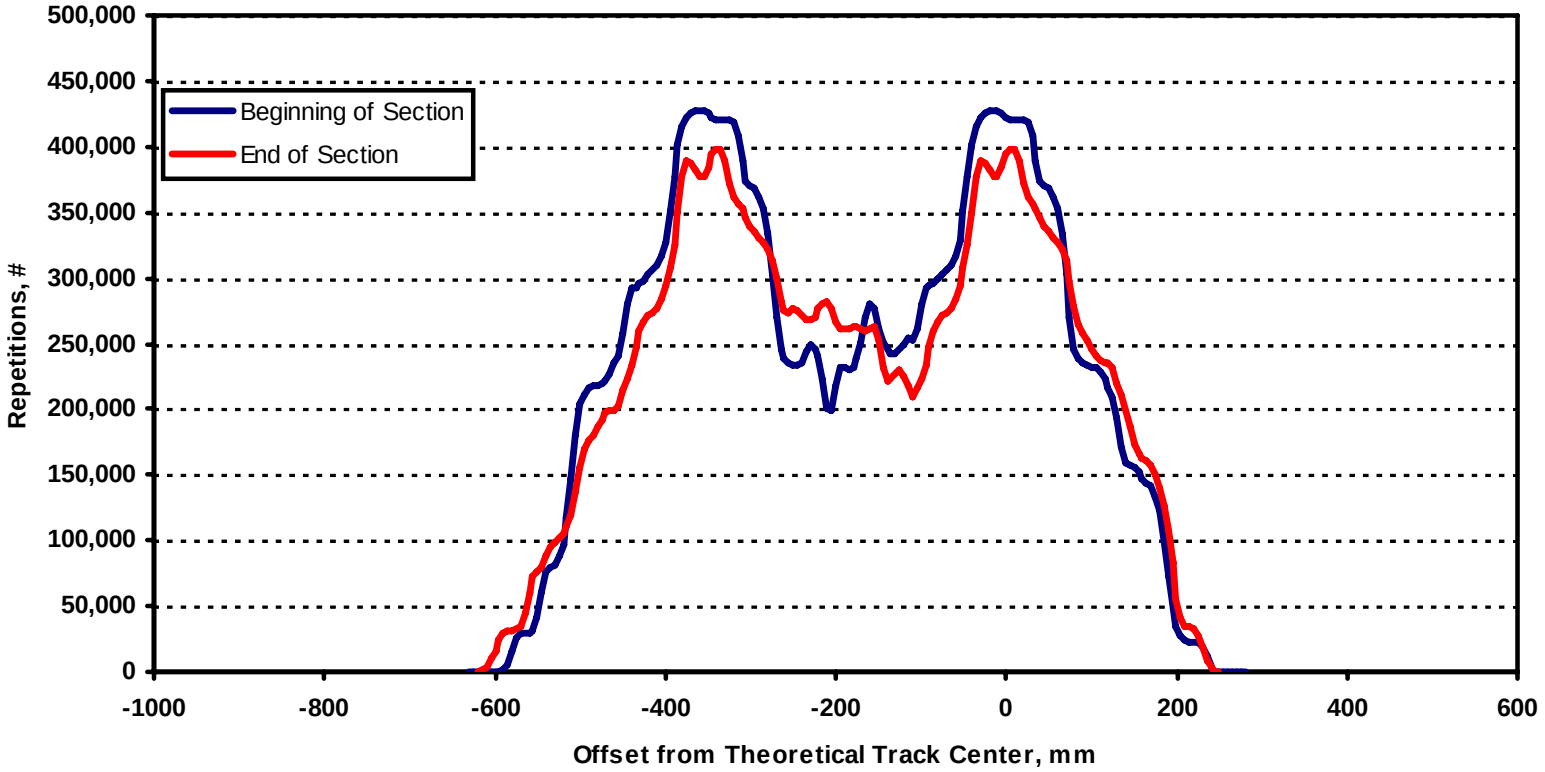
1 in. = 25.4 mm

Figure 11. Examples of the different types of histograms generated using WesTrack actual wander data.



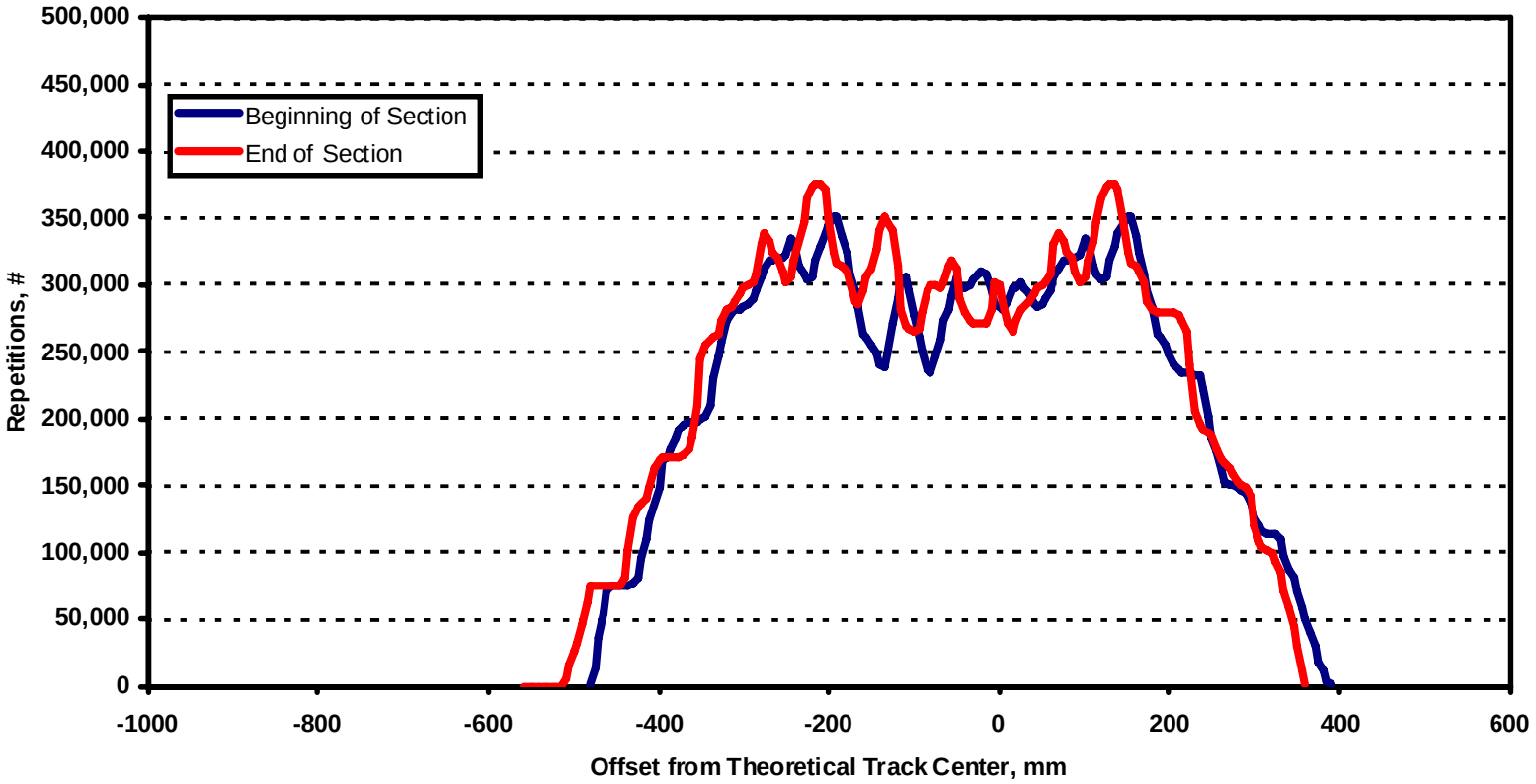
1 in. = 25.4 mm

Figure 12. Histogram of the front of the truck for the beginning and ending cross-sections of WesTrack section 4.



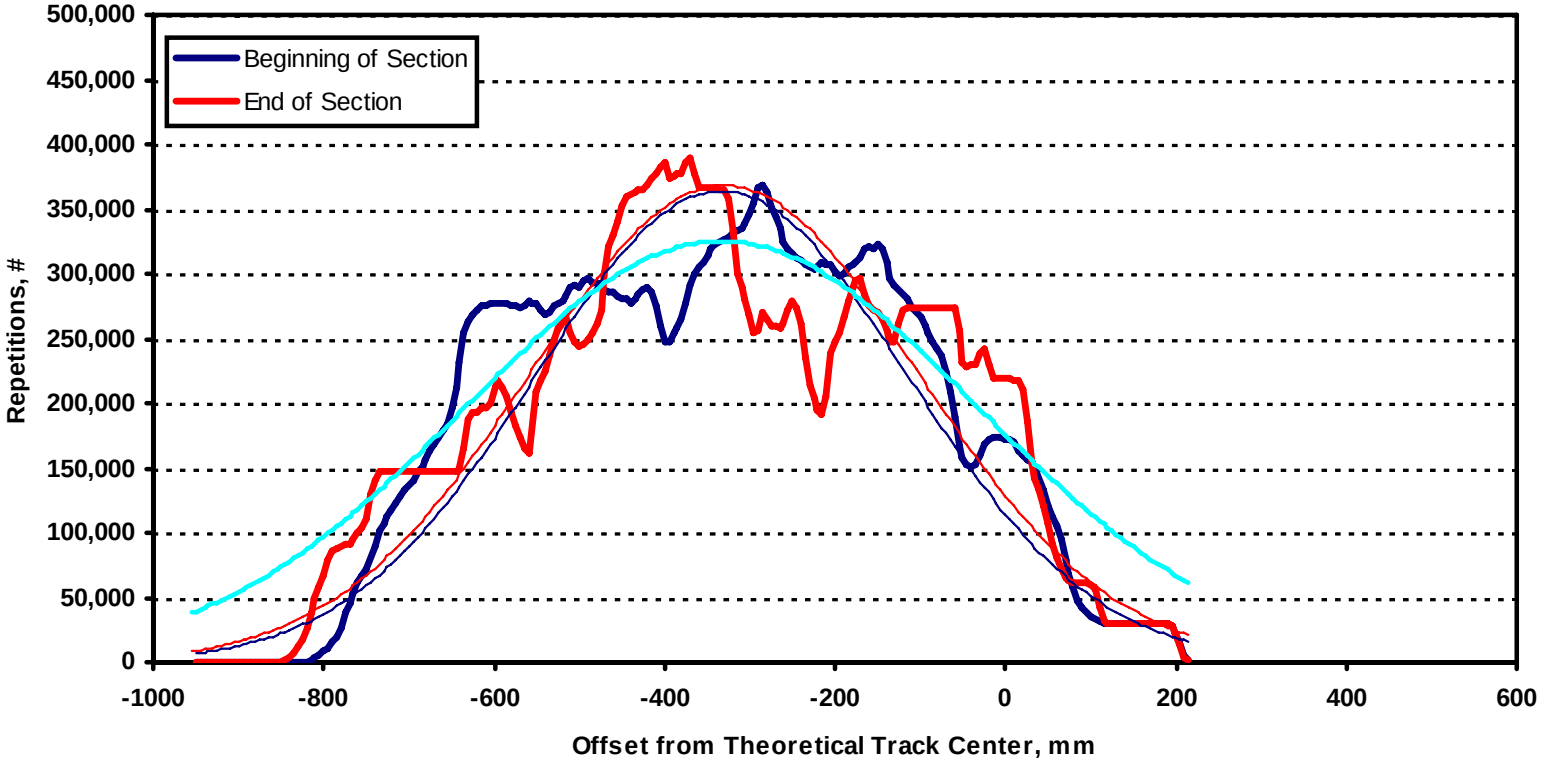
1 in. = 25.4 mm

Figure 13. Histogram of the front of the truck for the beginning and ending cross-sections of WesTrack section 14.



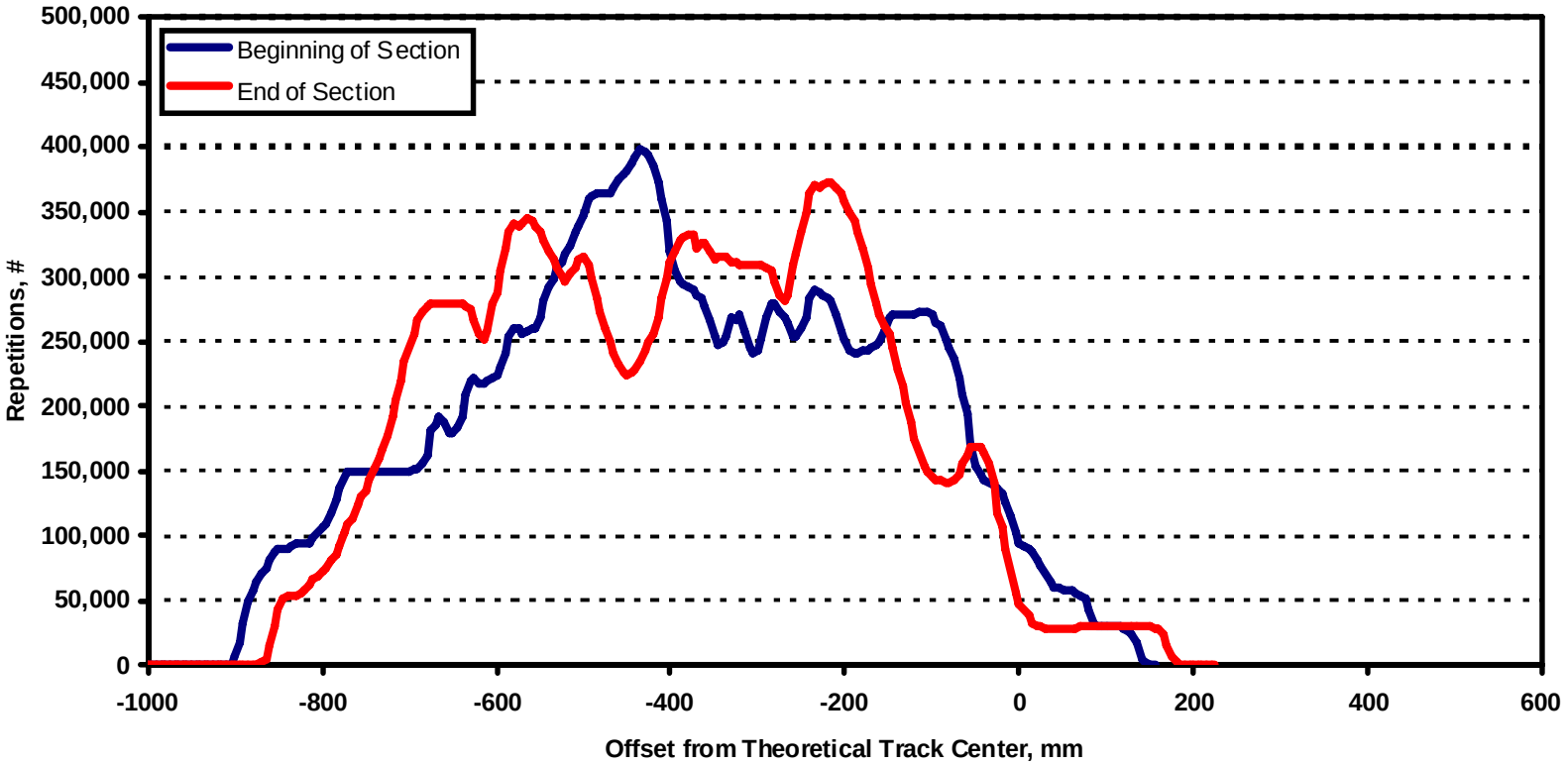
1 in. = 25.4 mm

Figure 14. Histogram of the front of the truck for the beginning and ending cross-sections of WesTrack section 23.



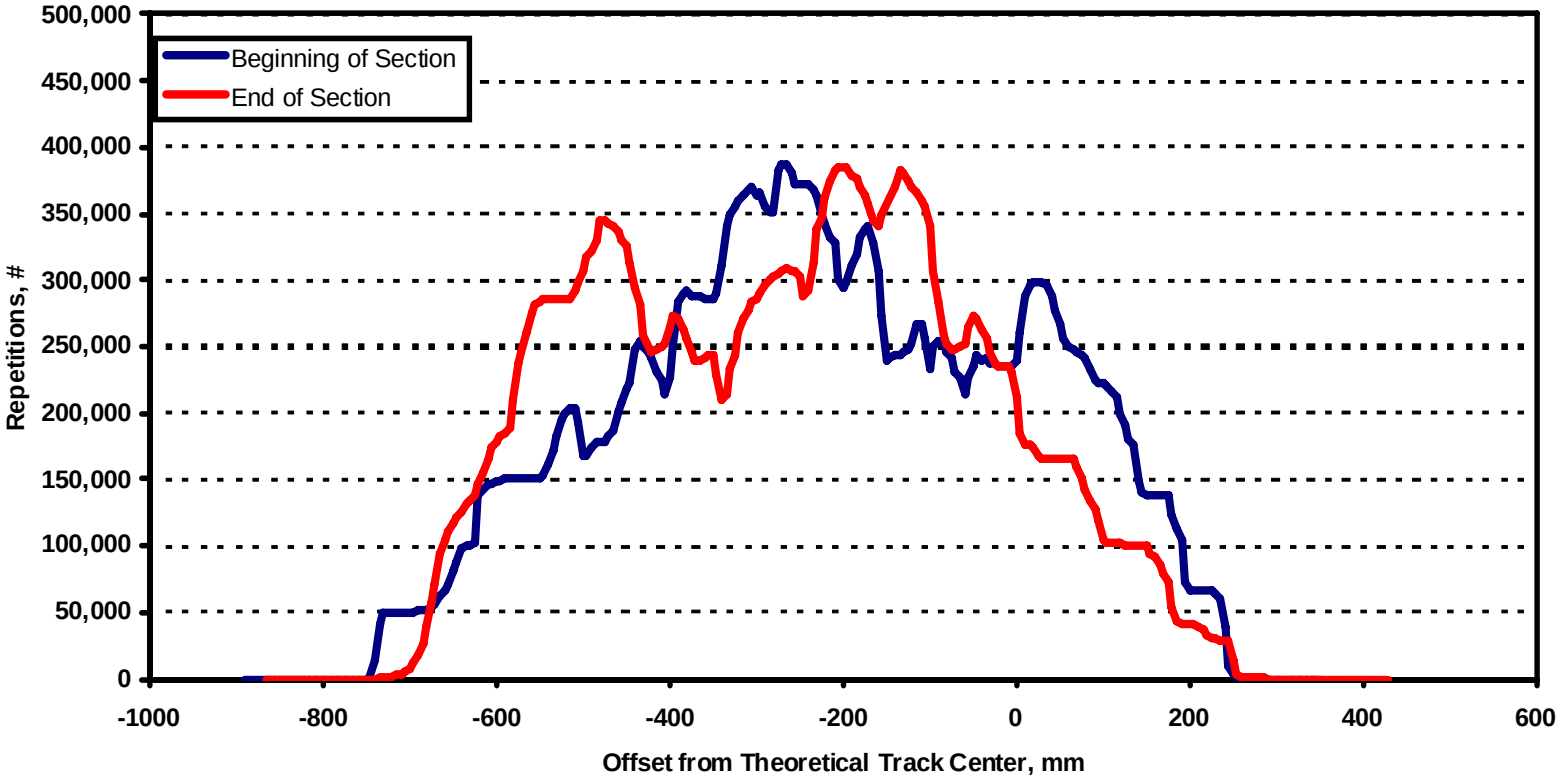
1 in. = 25.4 mm

Figure 15. Histogram of the rear of the truck for the beginning and ending cross-sections of WesTrack section 4.



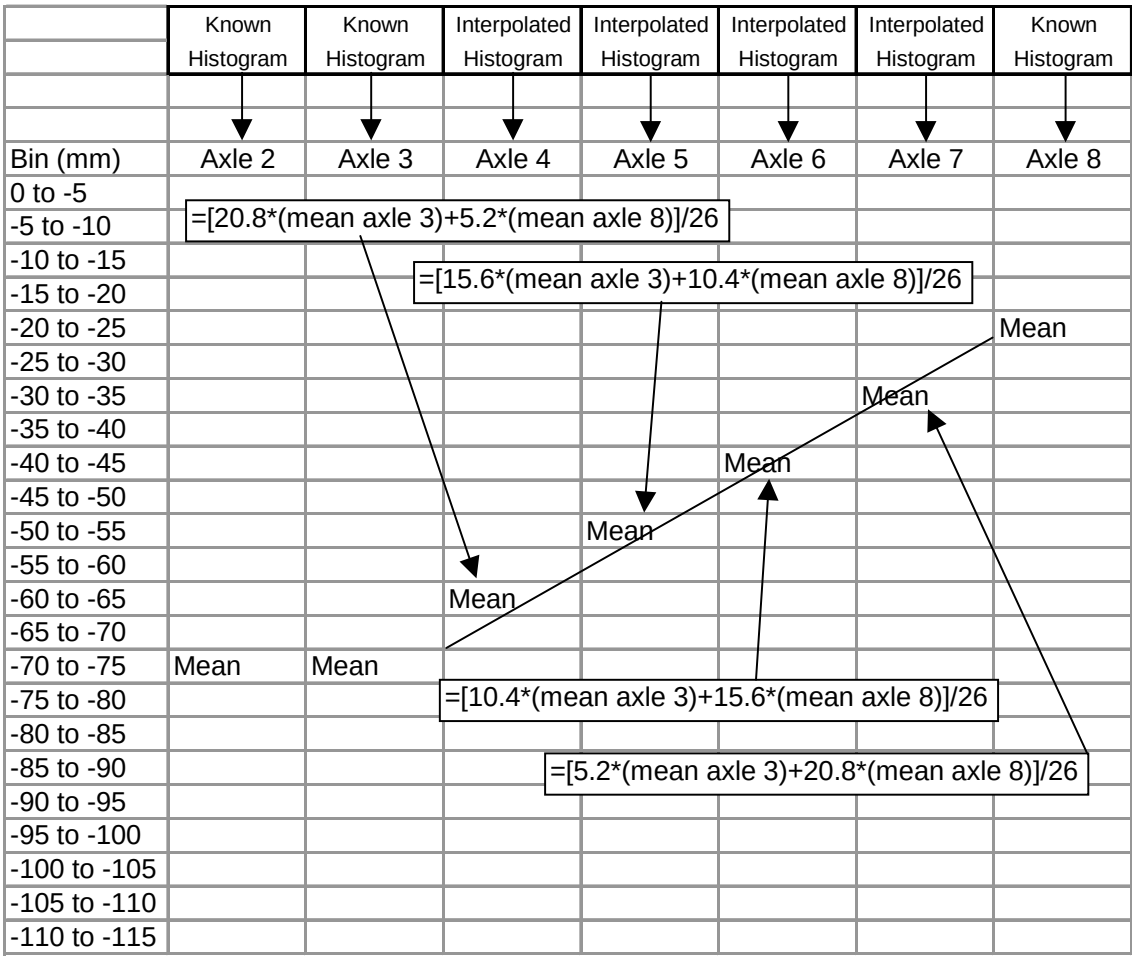
1 in. = 25.4 mm

Figure 16. Histogram of the rear of the truck for the beginning and ending cross-sections of WesTrack section 14.



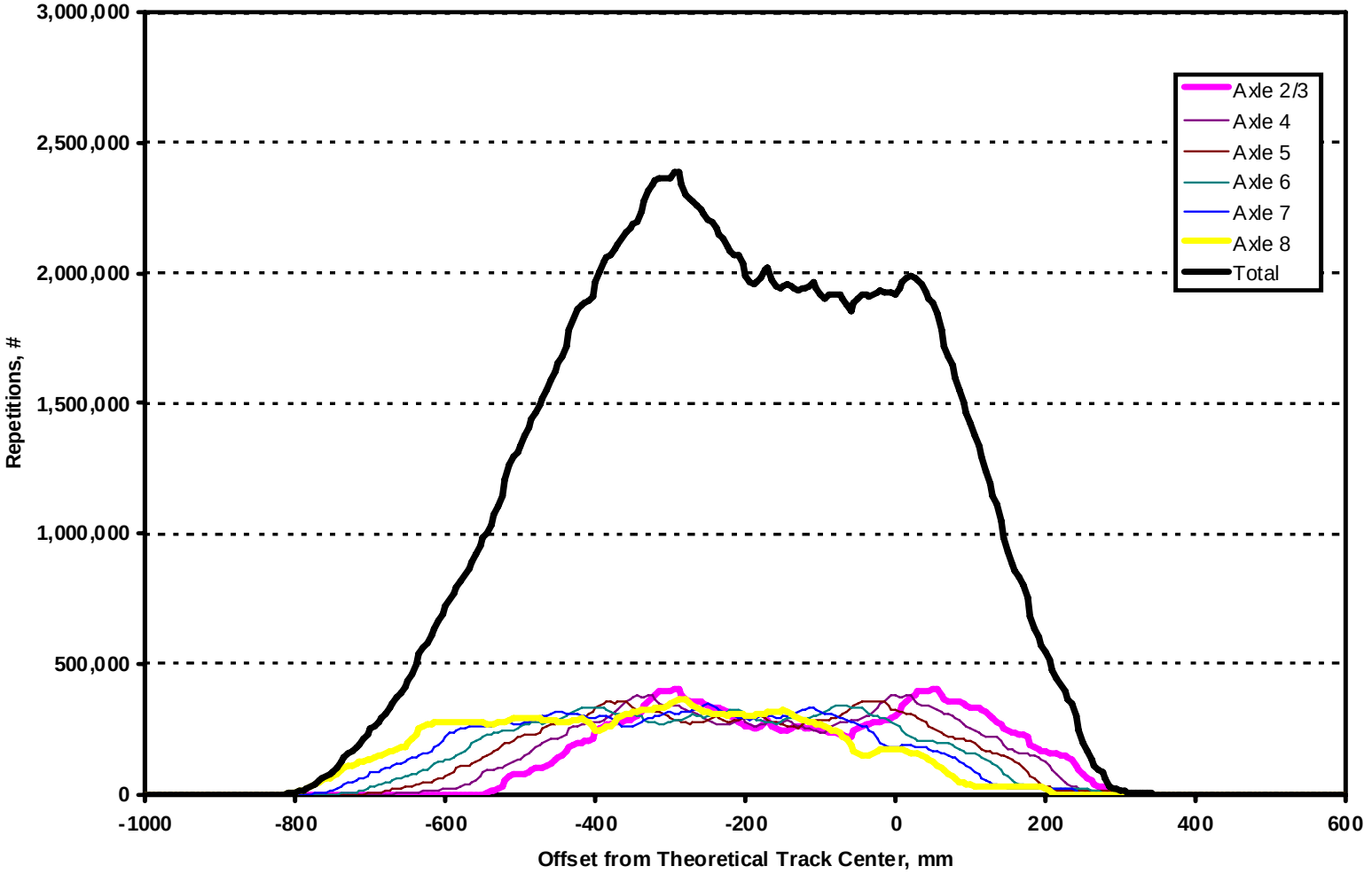
1 in. = 25.4 mm

Figure 17. Histogram of the rear of the truck for the beginning and ending cross-sections of WesTrack section 23.



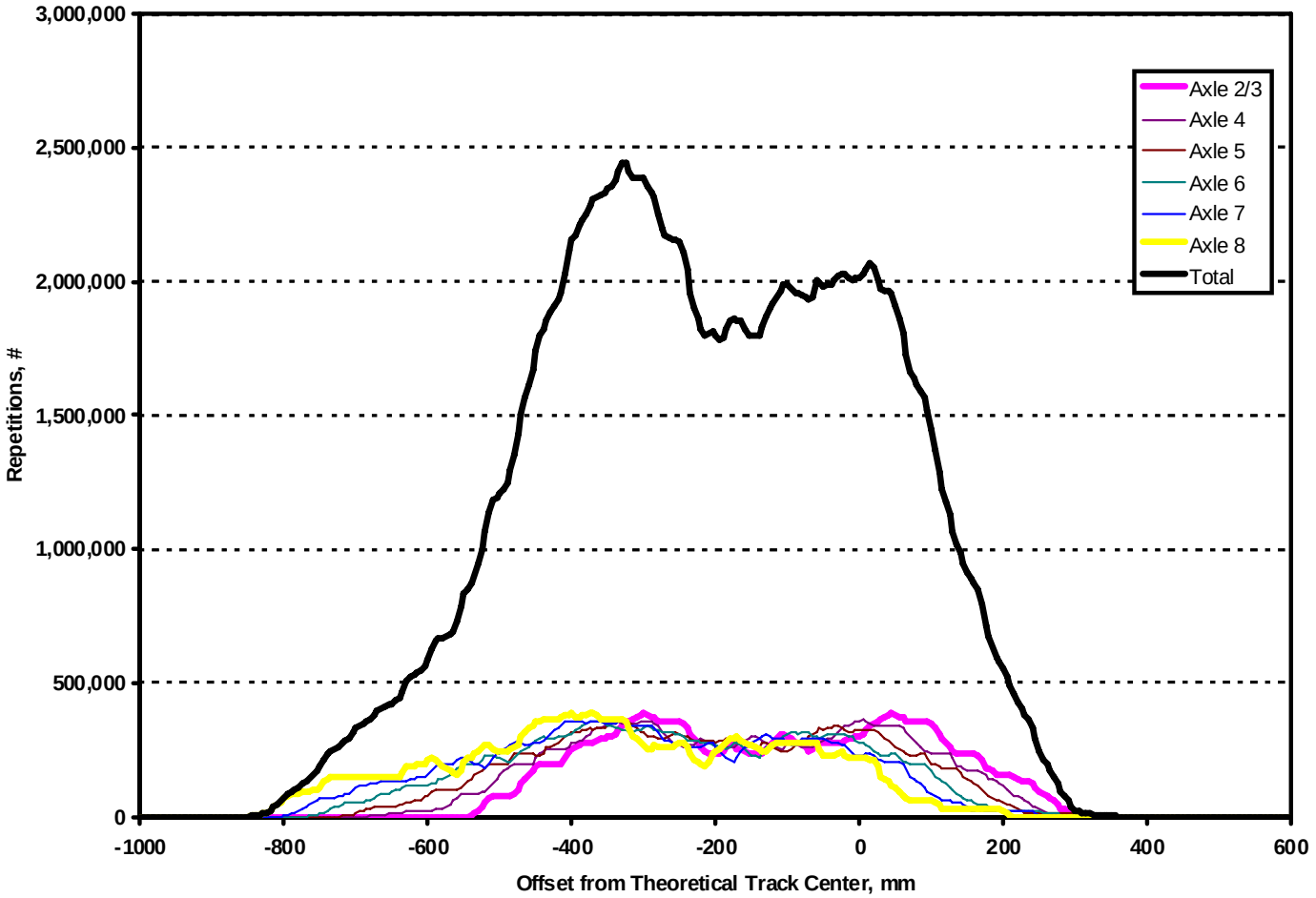
1 in. = 25.4 mm

Figure 18. Graphical illustration of the procedure to generate histograms for axles 4, 5, 6, and 7.



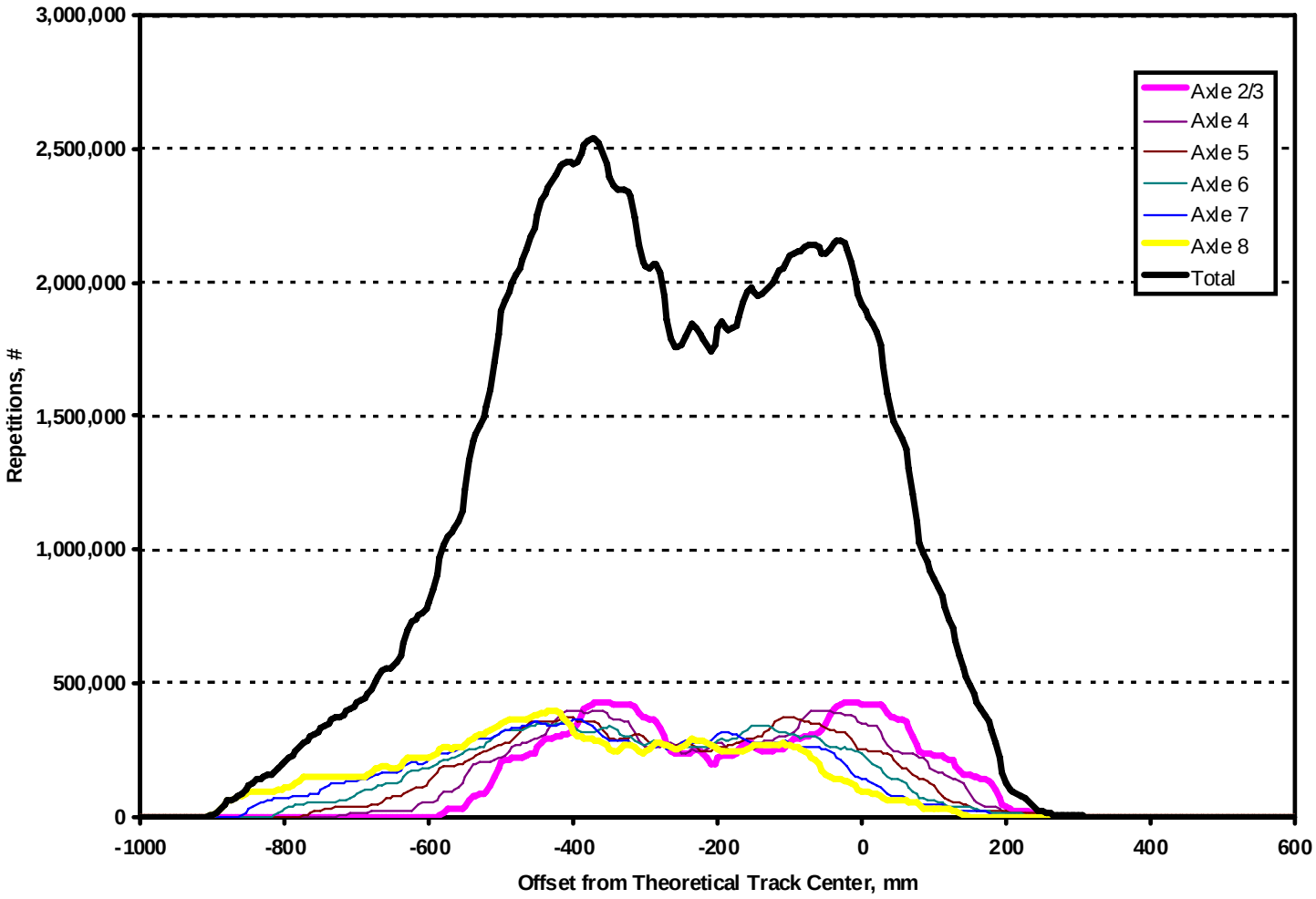
1 in. = 25.4 mm

Figure 19. Histogram for the beginning cross-section of WesTrack section 4.



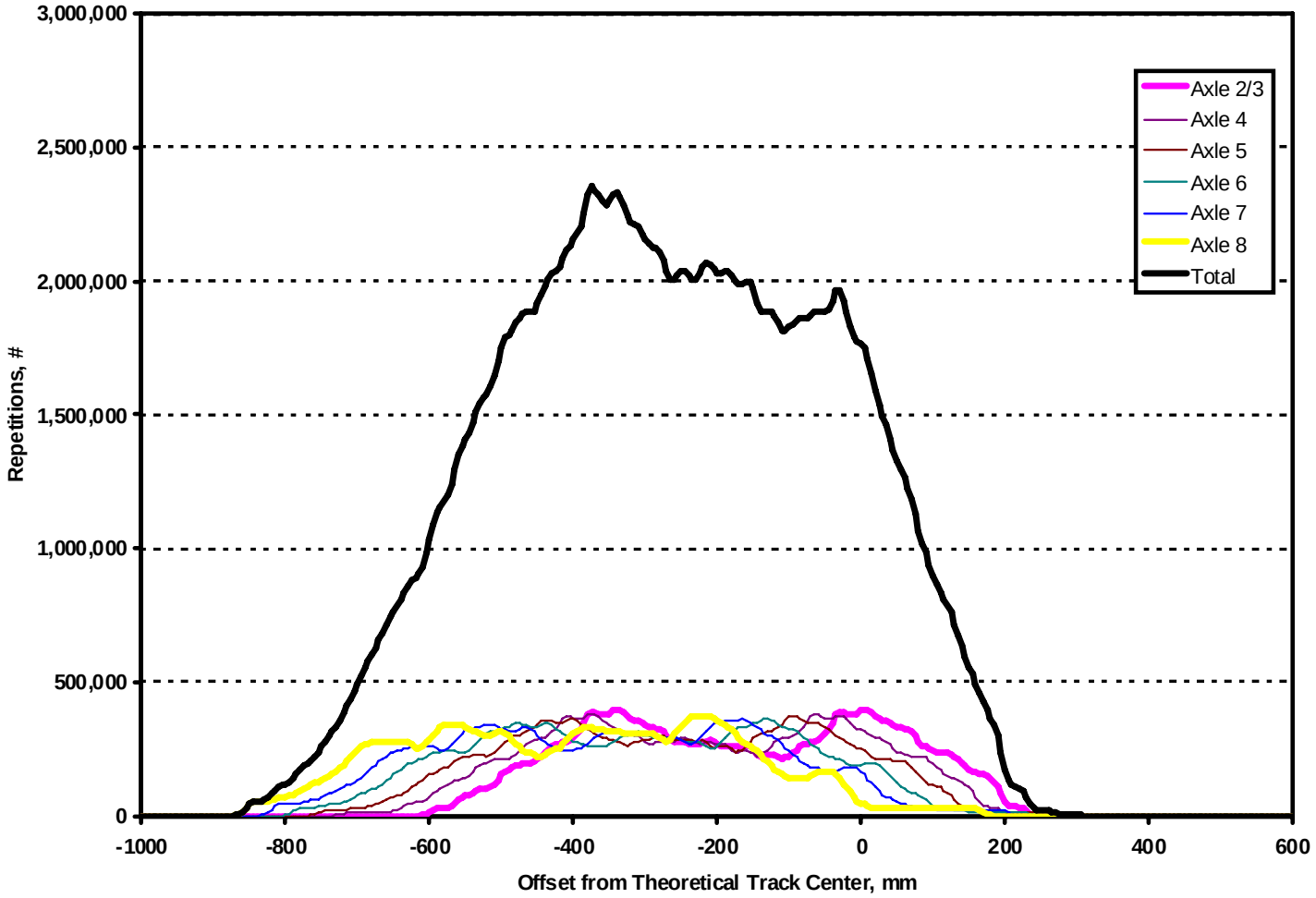
1 in. = 25.4 mm

Figure 20. Histogram for the ending cross-section of WesTrack section 4.



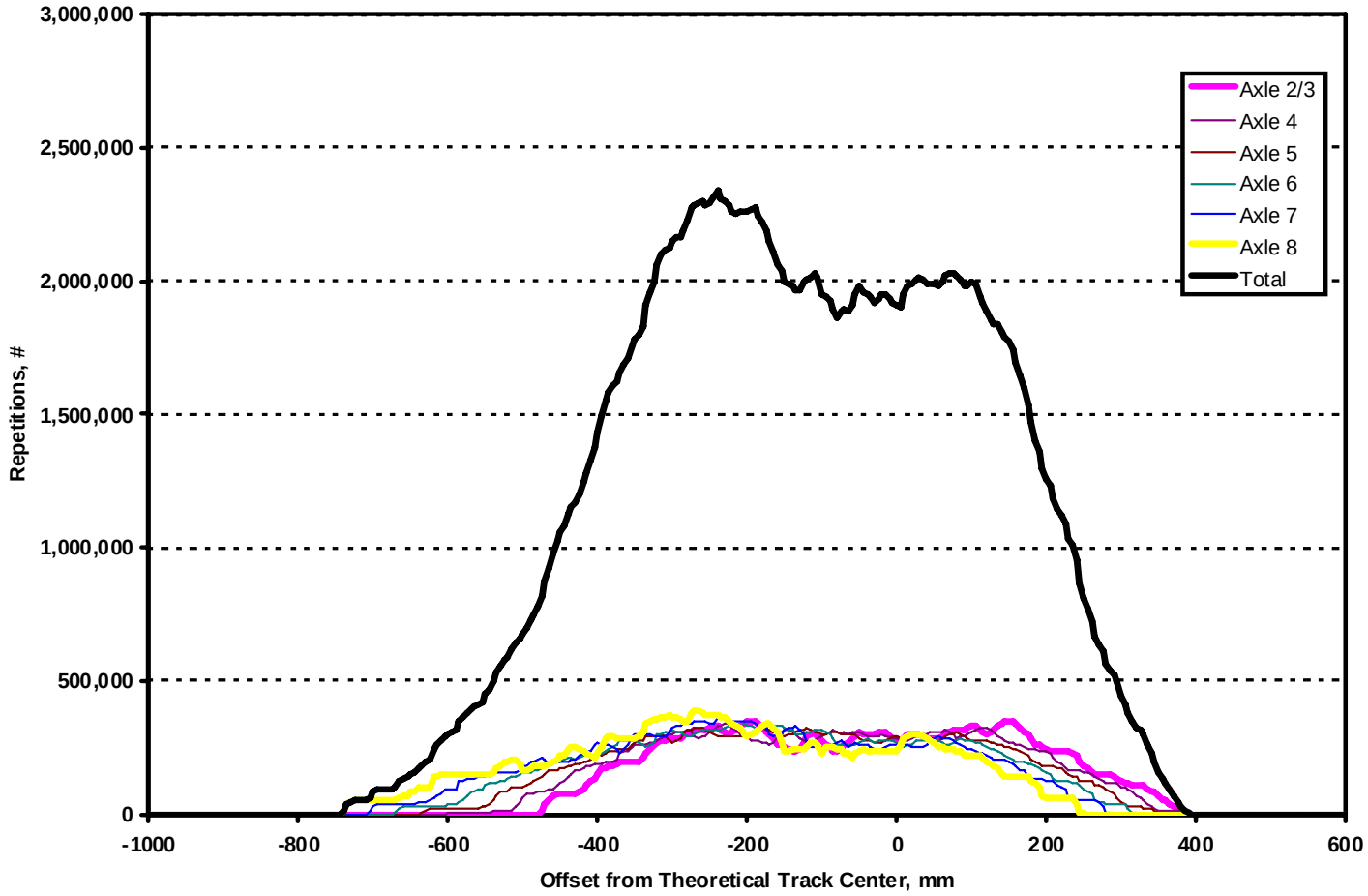
1 in. = 25.4 mm

Figure 21. Histogram for the beginning of cross-section of WesTrack section 14.



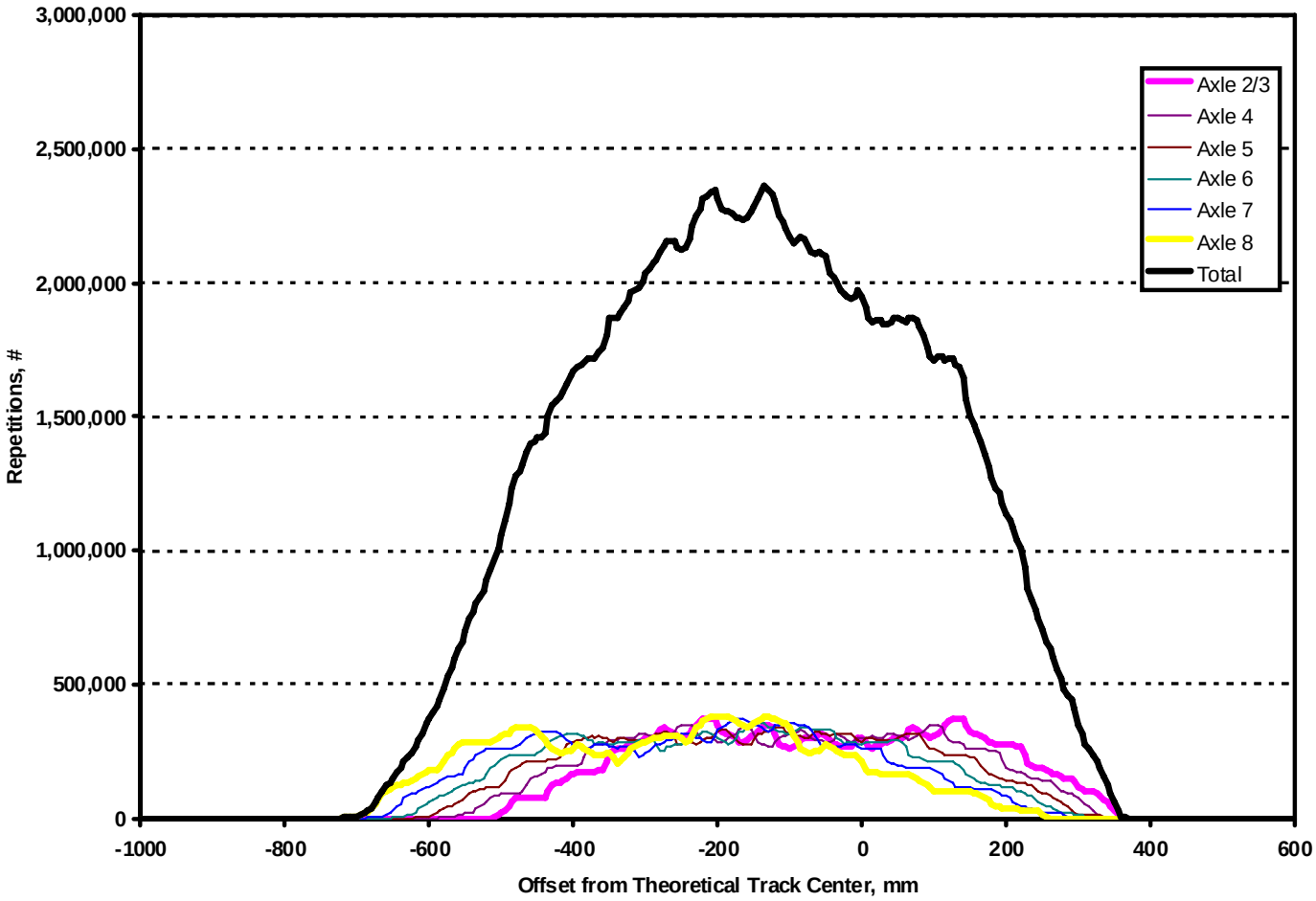
1 in. = 25.4 mm

Figure 22. Histogram for the ending cross-section of WesTrack section 14.



1 in. = 25.4 mm

Figure 23. Histogram for the beginning cross-section of WesTrack section 23.



1 in. = 25.4 mm

Figure 24. Histogram for the ending cross-section for WesTrack section 23.

Table 1. Netherlands study measurement locations and recorded results.[1]

Road Number	Date	Lane Width, m (ft)	Standard Deviation, m (in.)	Lanes
13	15/07/82	3.16 (10.4)	0.24 (9.2)	2x3
12	21/07/82	3.55 (11.6)	0.265 (10.43)	2x2
20	25/07/82	3.26 (10.7)	0.294 (11.6)	2x2
16	27/07/82	3.50 (11.5)	0.276 (10.9)	2x3
216	29/07/82	3.20 (10.5)	0.228 (9.0)	2x2
15	20/08/82	3.50 (11.5)	0.313 (12.3)	2x3
12	03/09/82	3.50 (11.5)	0.301 (11.9)	2x2
27	16/09/82	3.50 (11.5)	0.270 (10.6)	2x2
12	24/04/83	3.30 (10.8)	0.267 (10.5)	2x2
225	09/05/83	3.10 (10.2)	0.249 (9.8)	2x1
4	09/03/84	3.24 (10.6)	0.224 (8.8)	2x2
44	12/03/84	2.98 (9.8)	0.235 (9.3)	2x2
12	14/03/84	3.28 (10.8)	0.293 (11.5)	2x2
28	04/04/84	3.47 (11.4)	0.305 (12.0)	2x2
--	27/11/84	3.41 (11.2)	0.252 (9.9)	2x1
59	04/10/85	3.40 (11.2)	0.304 (12.0)	2x2
27	30/05/86	3.32 (10.9)	0.309 (12.2)	2x2
59	04/10/85	3.20 (10.5)	0.268 (10.6)	2x1
44	05/11/85	3.30 (10.8)	0.263 (10.4)	2x2
44	12/11/86	2.99 (9.8)	0.237 (9.3)	2x2
44	2/12/86	3.15 (10.3)	0.257 (10.1)	2x2

Table 2. Number of ESALs at each antenna location.

Antenna Location	WT-1 ESALs	WT-2 ESALs	WT-3 ESALs	WT-4 ESALs	Total ESALs
127 mm (5 in.) left	364,424	0	427,896	14,653	806,972
101.6 mm (4 in.) left	257,467	0	0	0	257,467
76.2 mm (3 in.) left	194,234	0	183,007	0	377,242
50.8 mm (2 in.) left	95,053	0	332,813	0	427,867
25.4 mm (1 in.) left	84,159	0	0	38,436	122,595
Center	247,941	13,059	195,480	16,512	472,992
25.4 mm (1 in.) right	0	330,485	19,795	119,200	469,480
50.8 mm (2 in.) right	8,907	68,423	223,898	59,951	361,181
76.2 mm (3 in.) right	0	27,926	17,114	292,929	337,969
101.6 mm (4 in.) right	0	0	0	303,166	303,166
127 mm (5 in.) right	0	345,902	71,397	365,540	782,838
Total	1,252,185	785,795	1,471,400	1,210,387	4,719,769

Table 3. Locations of the cross-sections used for the development of the actual traffic wander histograms (front antenna).

Section	*Station (m)*	*WesTrack Position Coordinate*
4	0+20 - 0+30	5324 - 5556
4	0+60 - 0+70	6250 - 6482
14	0+10 - 0+20	32999 - 33230
14	0+50 - 0+60	33925 - 34156
23	0+10 - 0+20	47583 - 47814
23	0+50 - 0+60	48509 - 48740

Table 4. Locations of the cross-sections used for the development of the actual traffic wander histograms (rear antenna).

Section	*Station (m)*	*WesTrack Position Coordinate*
4	0+52.5 - 0+62.5	6077 - 6308
5	0+22.5 - 0+32.5	7003 - 7234
14	0+42.5 - 0+52.5	33751 - 33983
15	0+10.5 - 0+20.5	34677 - 34909
23	0+42.5 - 0+52.5	48335 - 48567
24	0+10.5 - 0+20.5	49261 - 49493

Table 5. The means and standard deviations of the tire contact histograms for the front of the WesTrack trucks.

Location of Histogram	*Mean(mm)*	*Standard Deviation(mm)*
Beginning of section 4	-121	200
End of section 4	-123	202
Beginning of section 14	-177	197
End of section 14	-171	200
Beginning of section 23	-53	206
End of section 23	-65	206

1 in. = 25.4 mm

Table 6. The means and standard deviations of the tire contact histograms for the rear of the WesTrack trucks.

Location of Histogram	***Mean(mm)***	***Standard Deviation(mm)***
Beginning of section 4	-333	219
End of section 4	-331	228
Beginning of section 14	-391	228
End of section 14	-397	218
Beginning of section 23	-221	226
End of section 23	-262	216

1 in. = 25.4 mm

Table 7. The means and standard deviations of the overall extrapolated tire contact histograms of the WesTrack trucks.

Location of Histogram	***Mean(mm)***	***Standard Deviation(mm)***
Beginning of section 4	-213	222
End of section 4	-213	226
Beginning of section 14	-268	225
End of section 14	-269	225
Beginning of section 23	-126	224
End of section 23	-150	223

1 in. = 25.4 mm

Table 8. Percentage of typical highway wander for each cross-section.

Location of Histogram	***% of Typical Highway Traffic Wander***
Beginning of section 4	95.1%
End of section 4	96.2%
Beginning of section 14	96.2%
End of section 14	96.4%
Beginning of section 23	94.9%
End of section 23	94.6%

Table 9. Front antenna analyzed data as compared to entire data set.

Front Antenna Position	***Total No. of Truck Passes at Each Antenna Position***	***Approximate No. of Truck Passes Used to Develop Histograms***	***% of Total Data***
127 mm (5 in.) Left	77,002	714	0.9%
101.6 mm (4 in.) Left	24,568	497	2.0%
76.2 mm (3 in.) Left	35,997	347	1.0%
50.8 mm (2 in.) Left	40,827	1143	2.8%
25.4 mm (1 in.) Left	11,698	874	7.5%
Centered	45,133	1815	4.0%
25.4 mm (1 in.) Right	44,798	433	1.0%
50.8 mm (2 in.) Right	34,463	427	1.2%
76.2 mm (3 in.) Right	32,249	308	1.0%
101.6 mm (4 in.) Right	28,928	596	2.1%
127 mm (5 in.) Right	74,698	644	0.9%
Total	450,361	7,798	1.7%

Table 10. Rear antenna analyzed data as compared to entire data set.

Front Antenna Position	***Total No. of Truck Passes at Each Antenna Position***	***Approximate No. of Truck Passes Used to Develop Histograms***	***% of Total Data***
127 mm (5 in.) Left	77,002	719	0.9%
101.6 mm (4 in.) Left	24,568	497	2.0%
76.2 mm (3 in.) Left	35,997	347	1.0%
50.8 mm (2 in.) Left	40,827	1154	2.8%
25.4 mm (1 in.) Left	11,698	882	7.5%
Centered	45,133	1813	4.0%
25.4 mm (1 in.) Right	44,798	439	1.0%
50.8 mm (2 in.) Right	34,463	426	1.2%
76.2 mm (3 in.) Right	32,249	319	1.0%
101.6 mm (4 in.) Right	28,928	590	2.0%
127 mm (5 in.) Right	74,698	672	0.9%
Total	450,361	7,858	1.7%

APPENDIX A

DAILY HISTOGRAMS FROM FRONT ANTENNA LATERAL OFFSET DATA

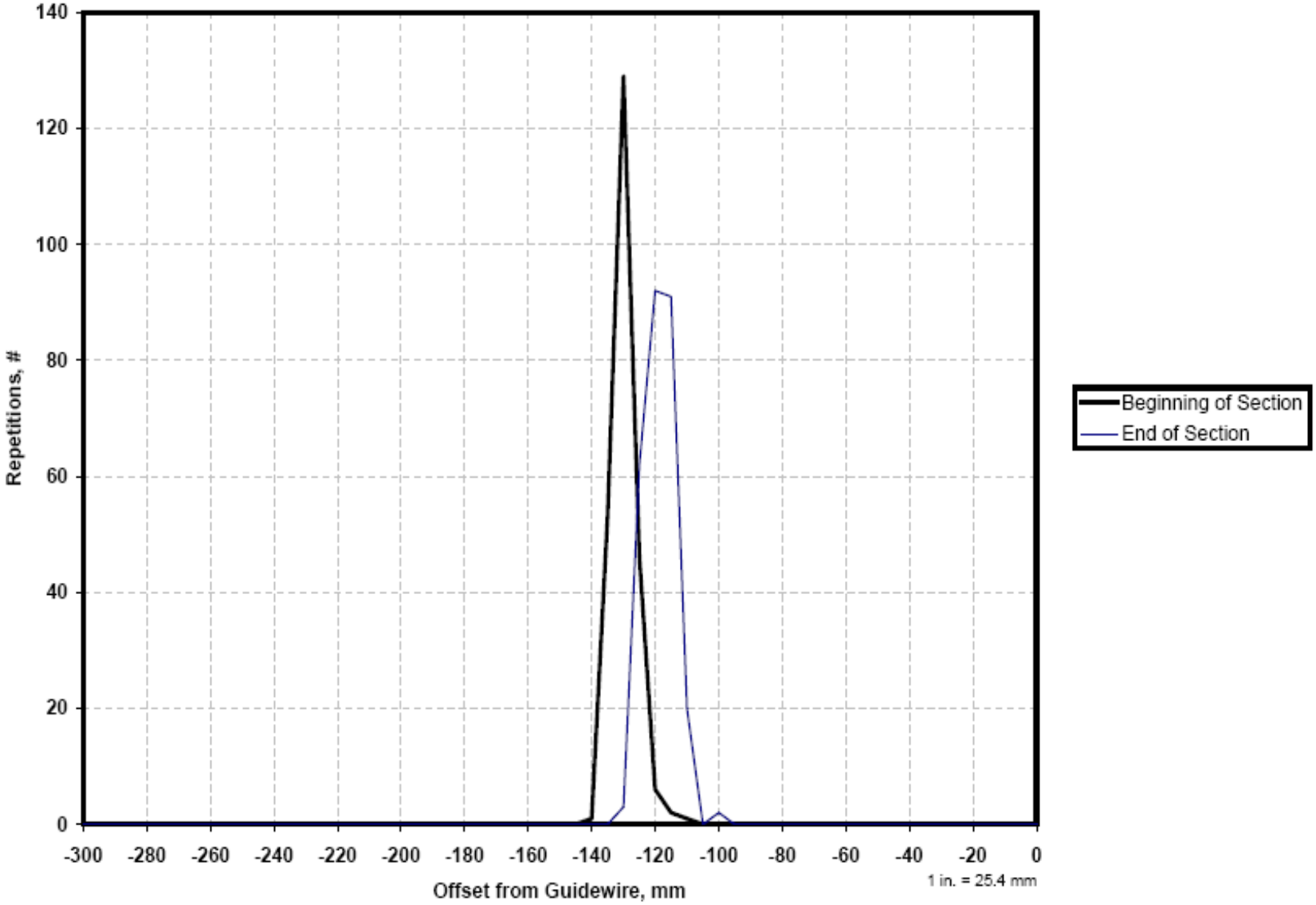


Figure A1. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 127 mm (5 in.) Left, 7/31/97.

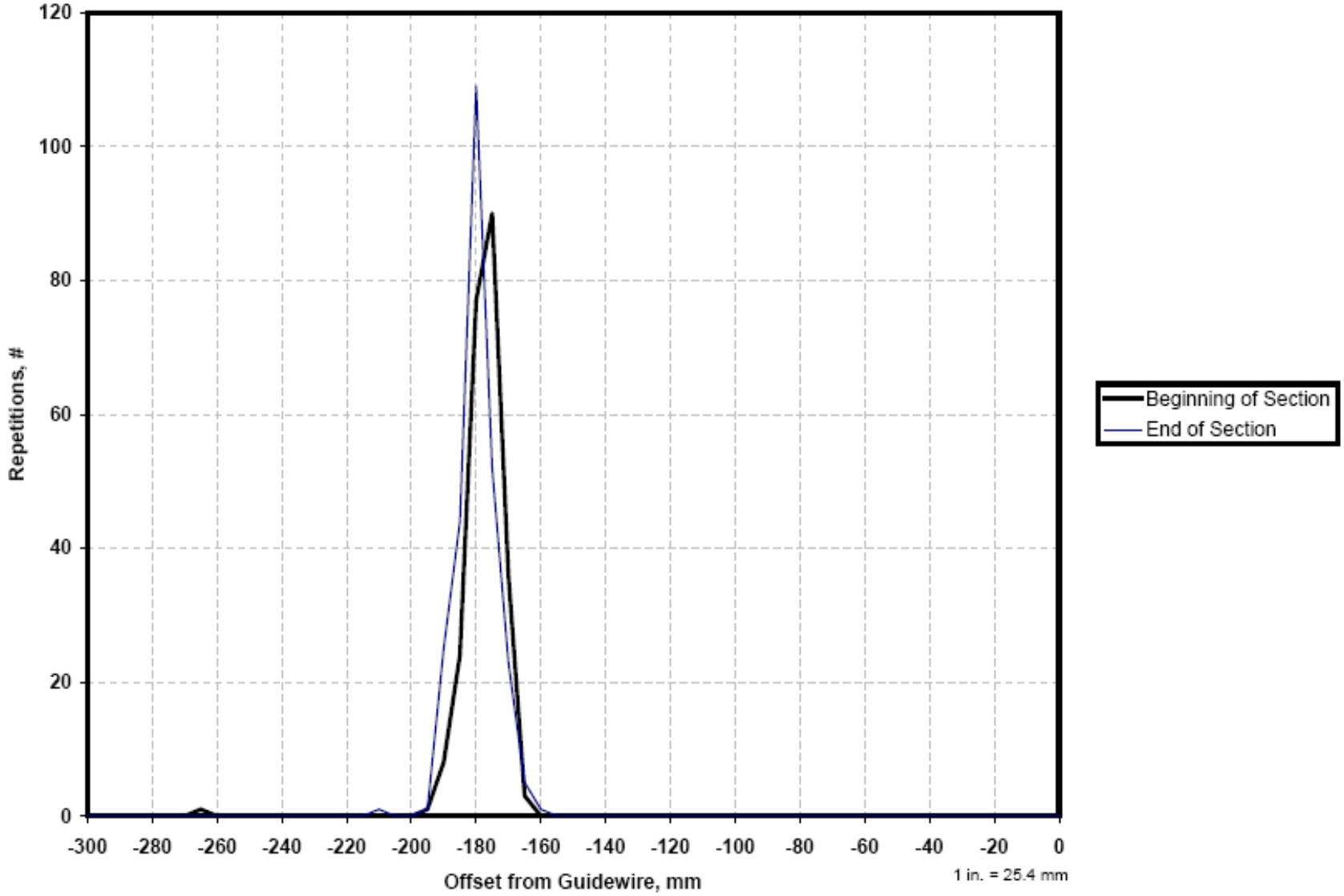


Figure A2. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 127 mm (5 in.) Left, 7/31/97.

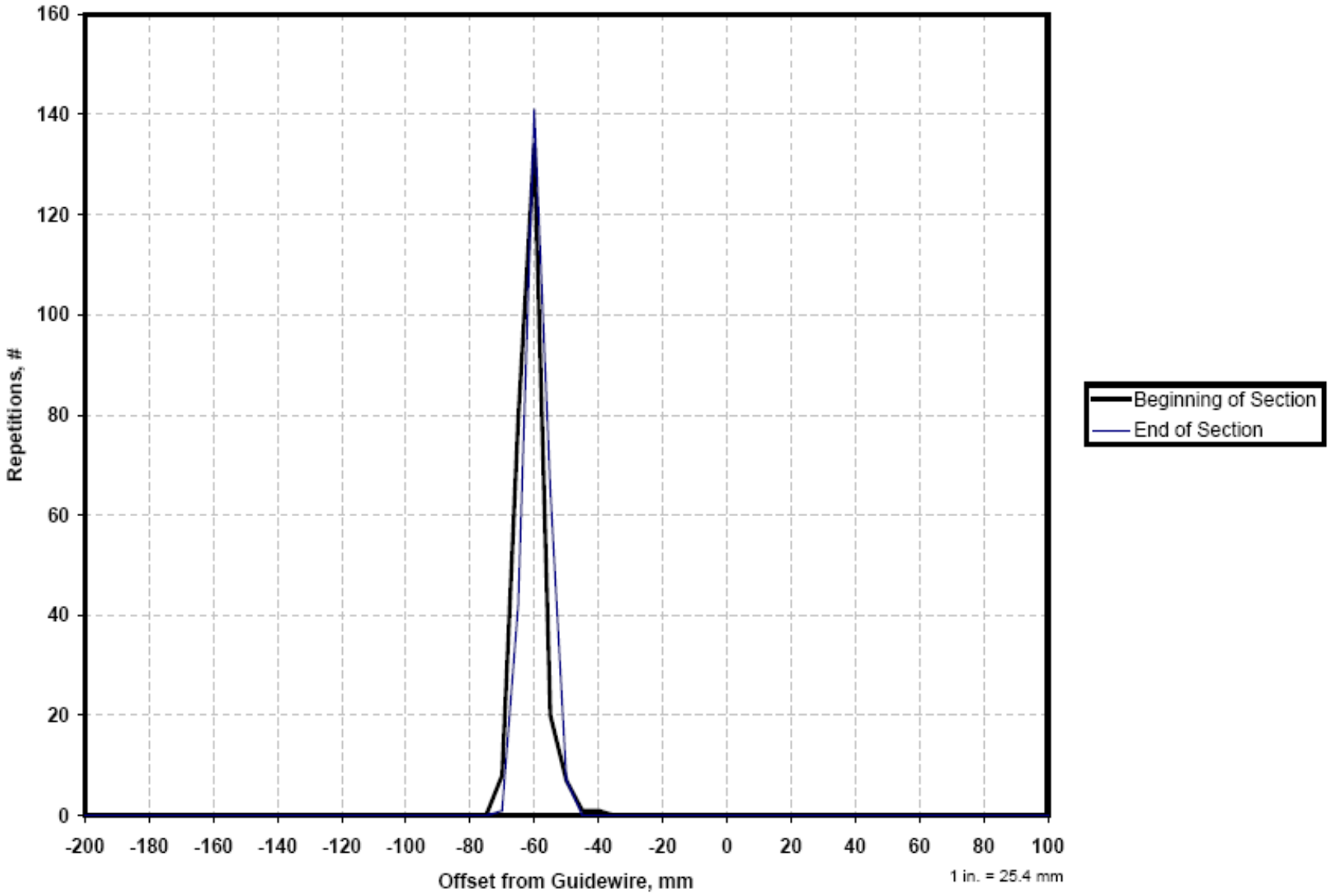


Figure A3. Front Antenna Offset Histogram for Section 23 with Front Antenna Set at 127 mm (5 in.) Left, 7/31/97.

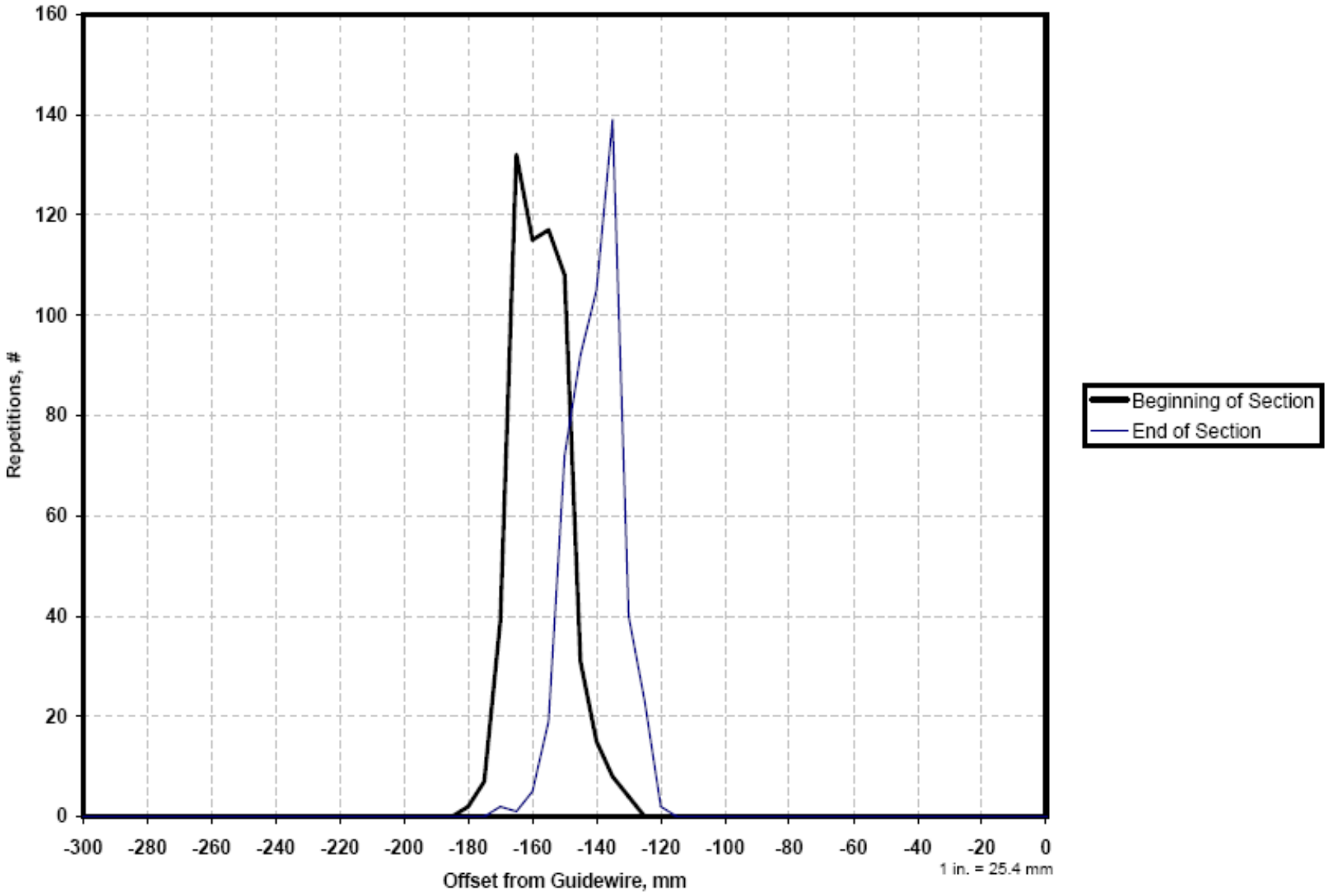


Figure A4. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 127 mm (5 in.) Left, 8/2/97.

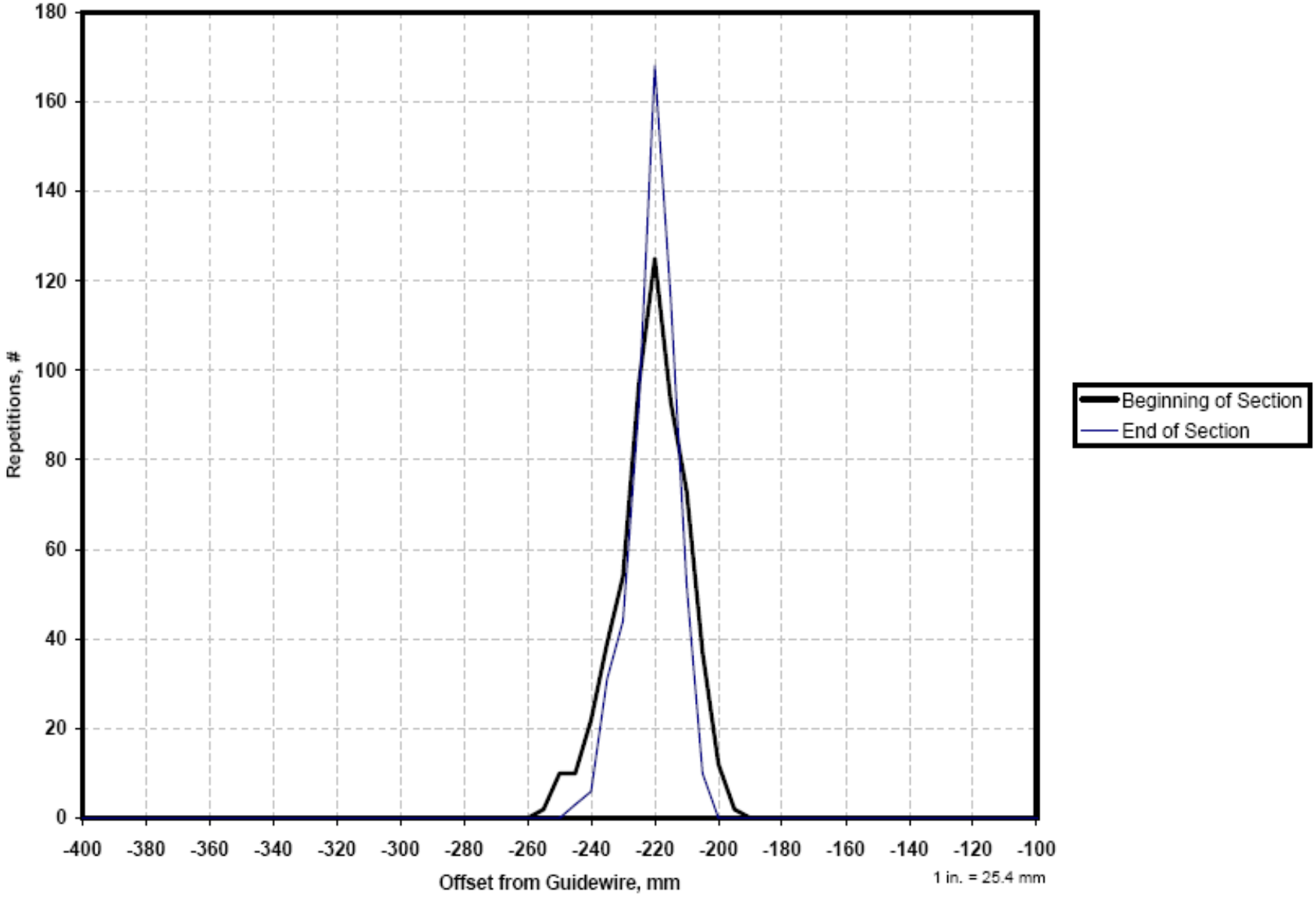


Figure A5. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 127 mm (5 in.) Left, 8/2/97.

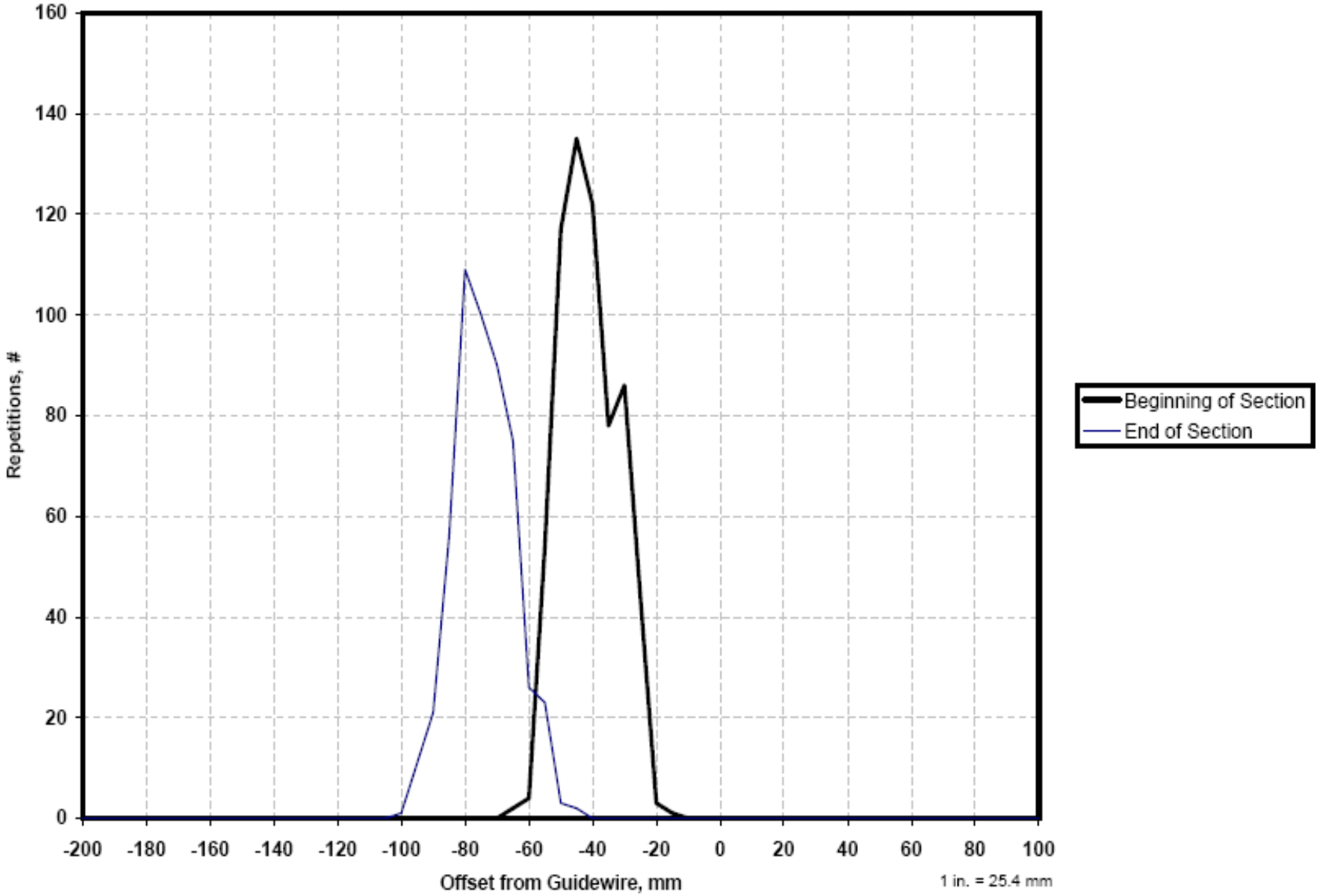


Figure A6. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 127 mm (5 in.) Left, 8/2/97.

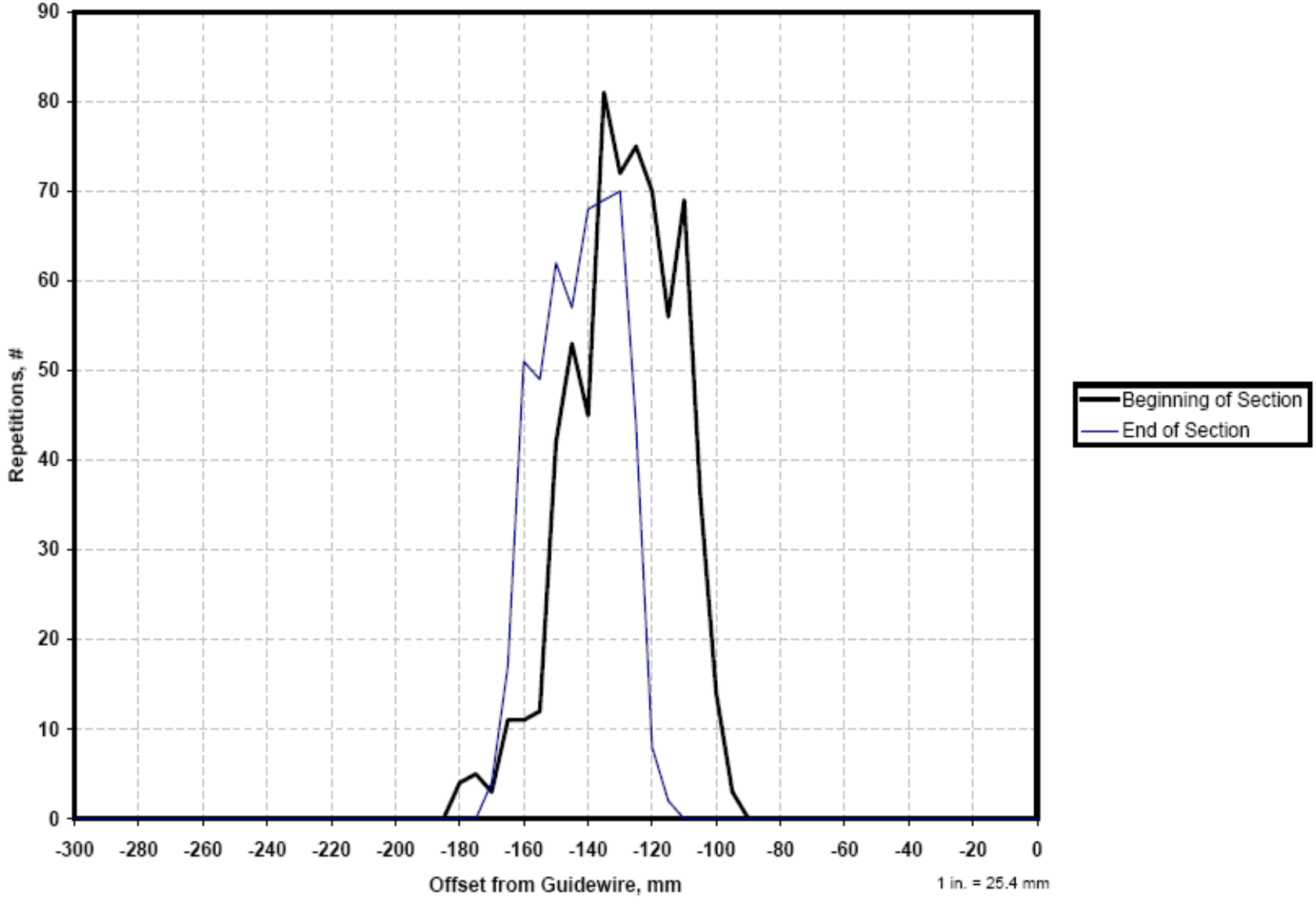


Figure A7. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 101.6 mm (4 in.) Left, 11/28/97.

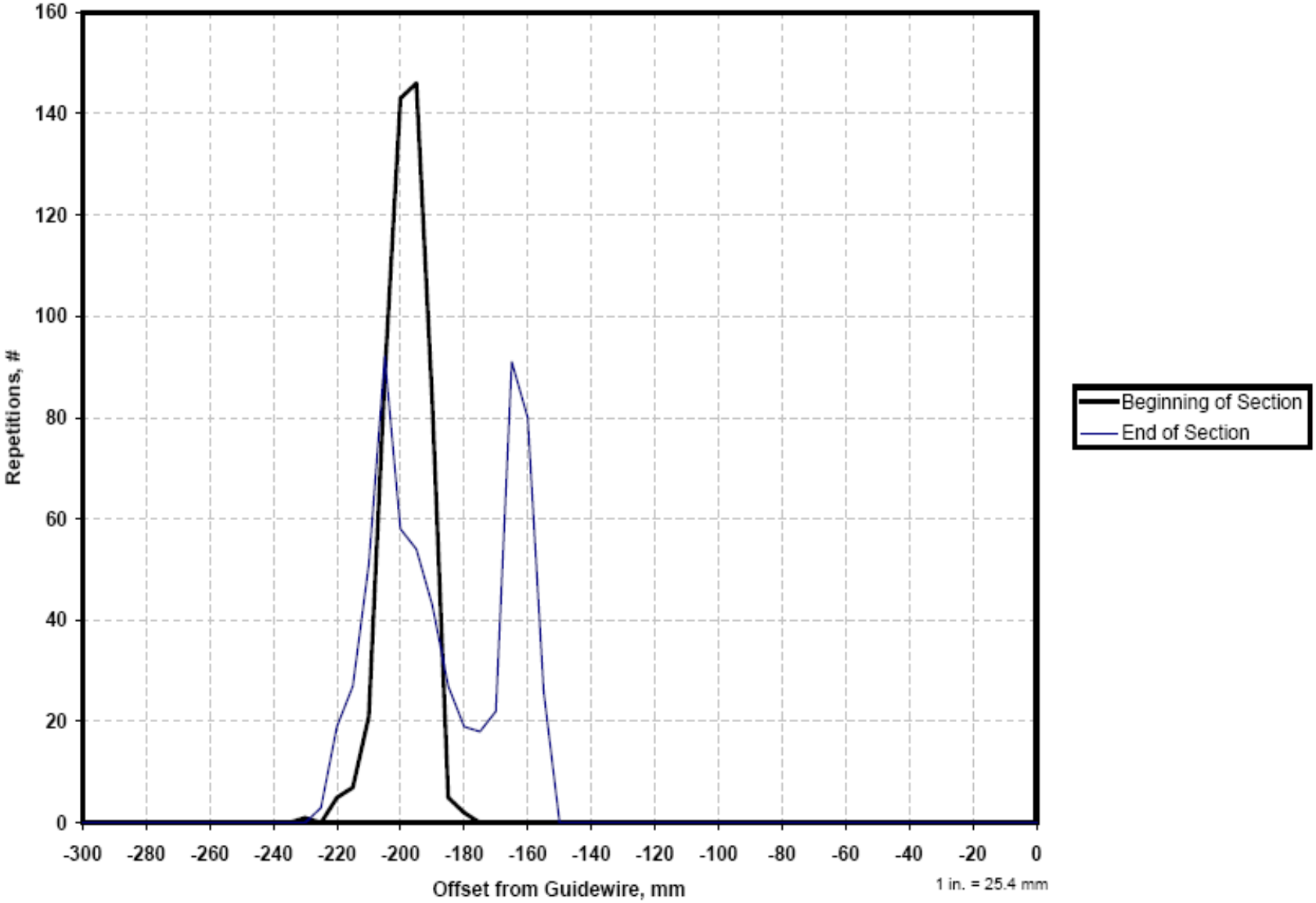


Figure A8. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 101.6 mm (4 in.) Left, 11/28/97.

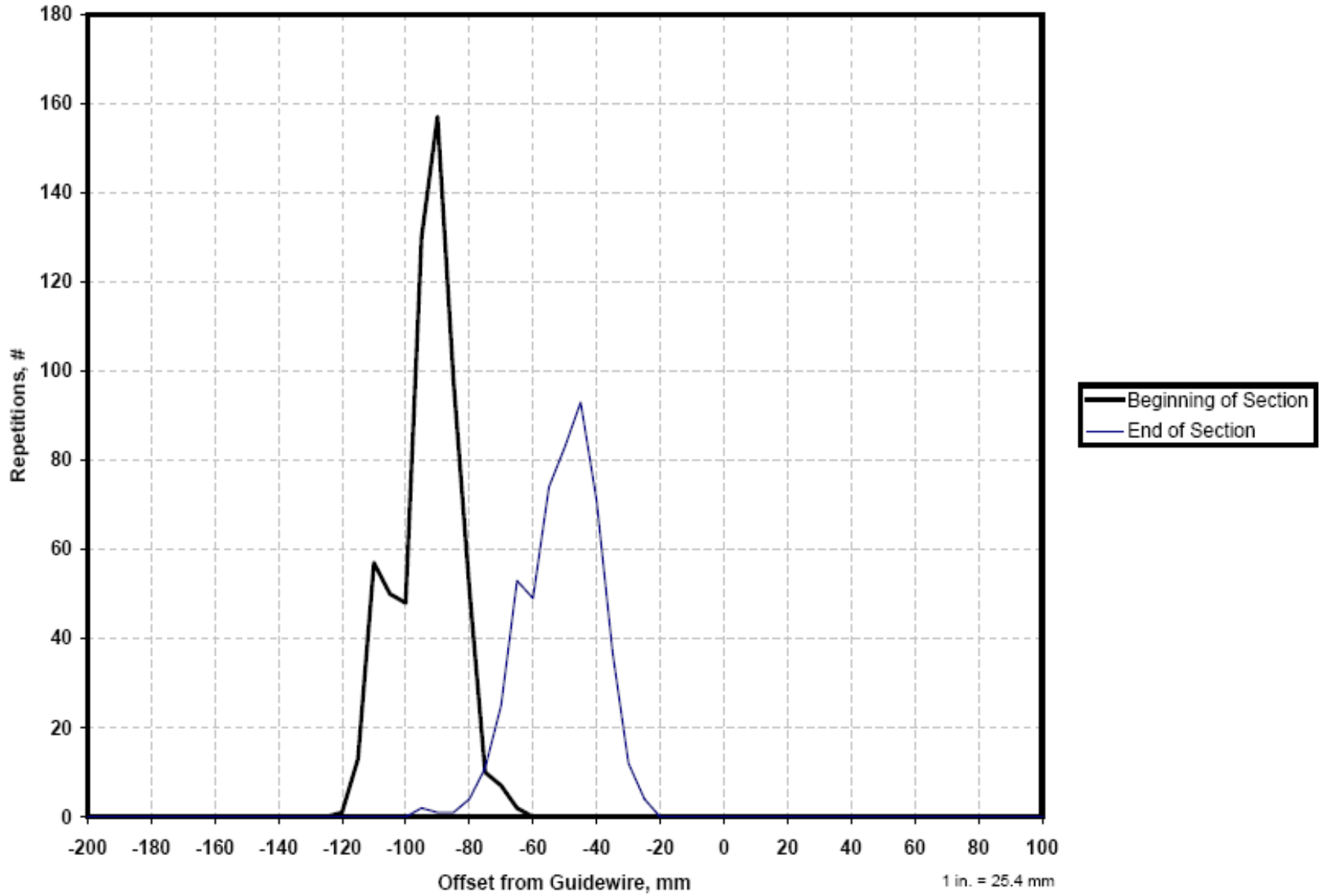


Figure A9. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 101.6 mm (4 in.) Left, 11/28/97.

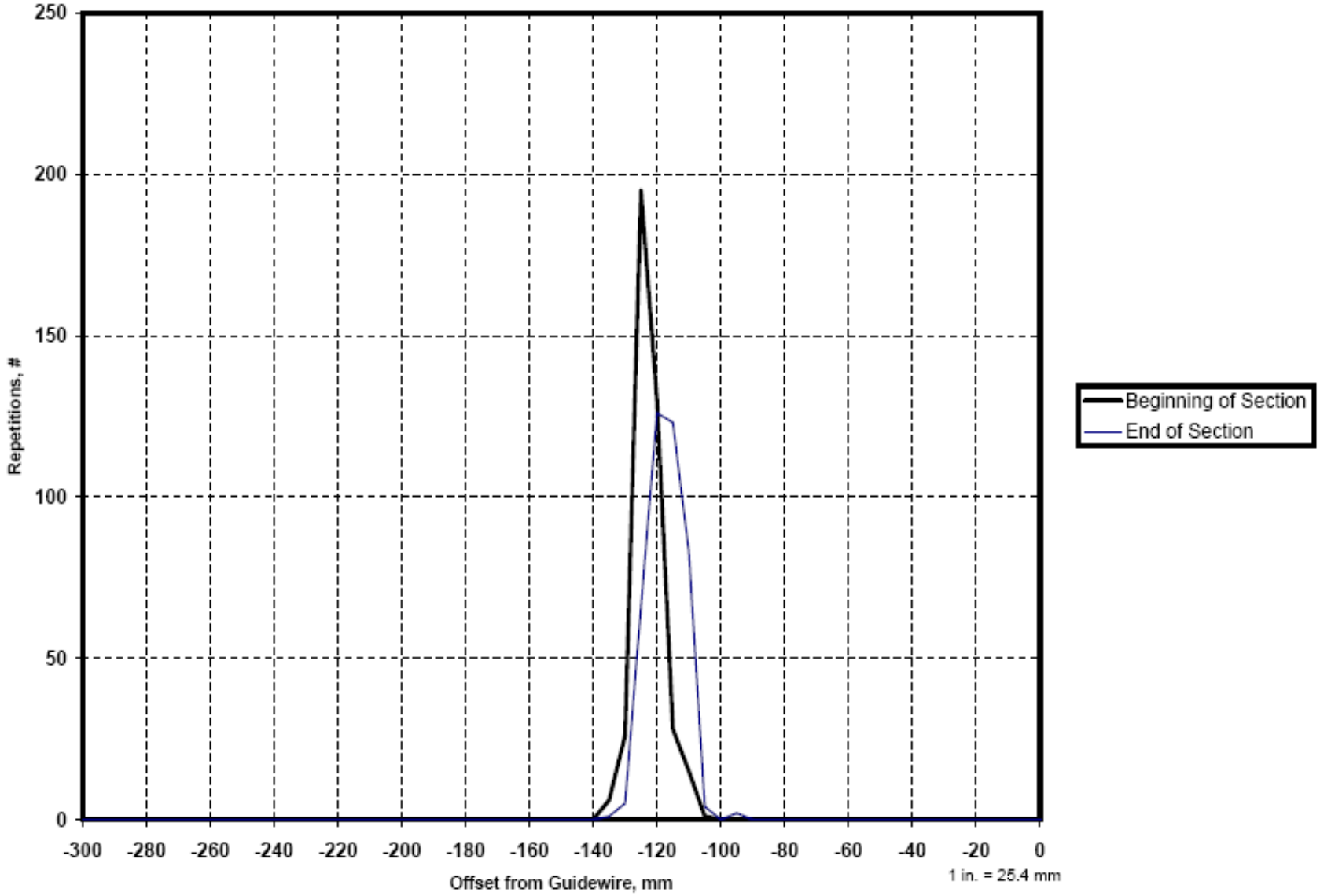


Figure A10. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 76.2 mm (3 in.) Left, 8/9/97.

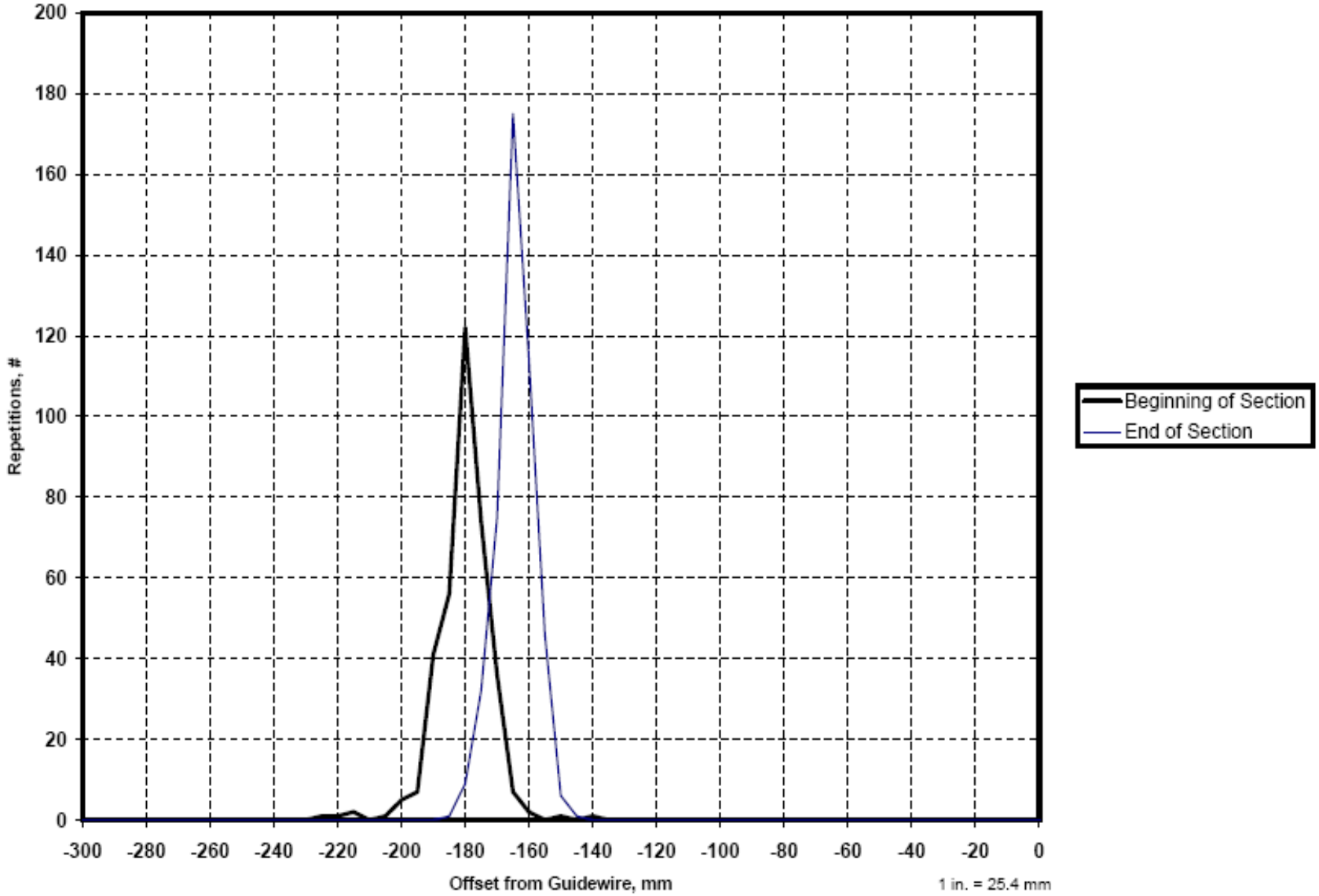


Figure A11. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 76.2 mm (3 in.) Left, 8/9/97.

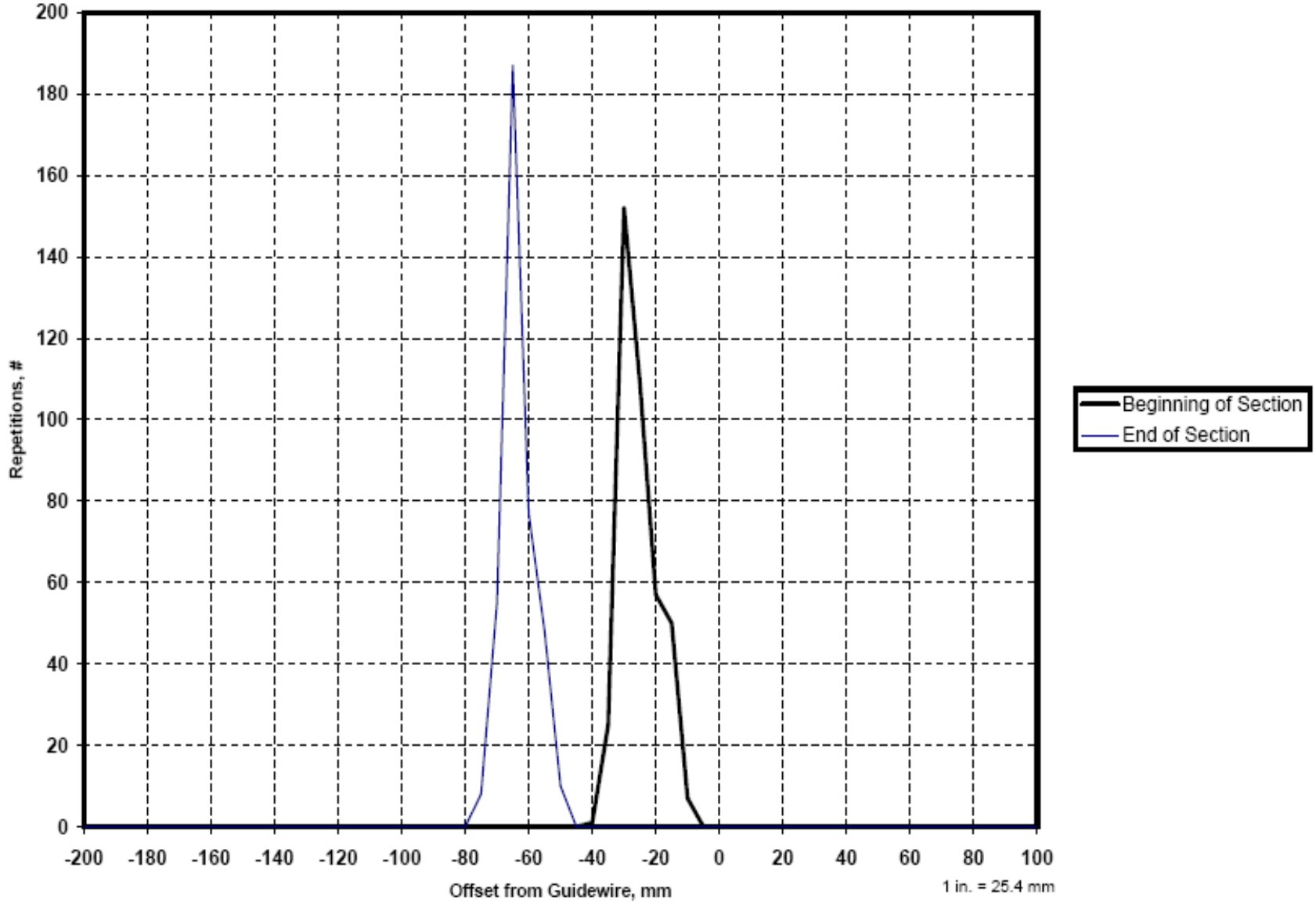


Figure A12. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 76.2 mm (3 in.) Left, 8/9/97.

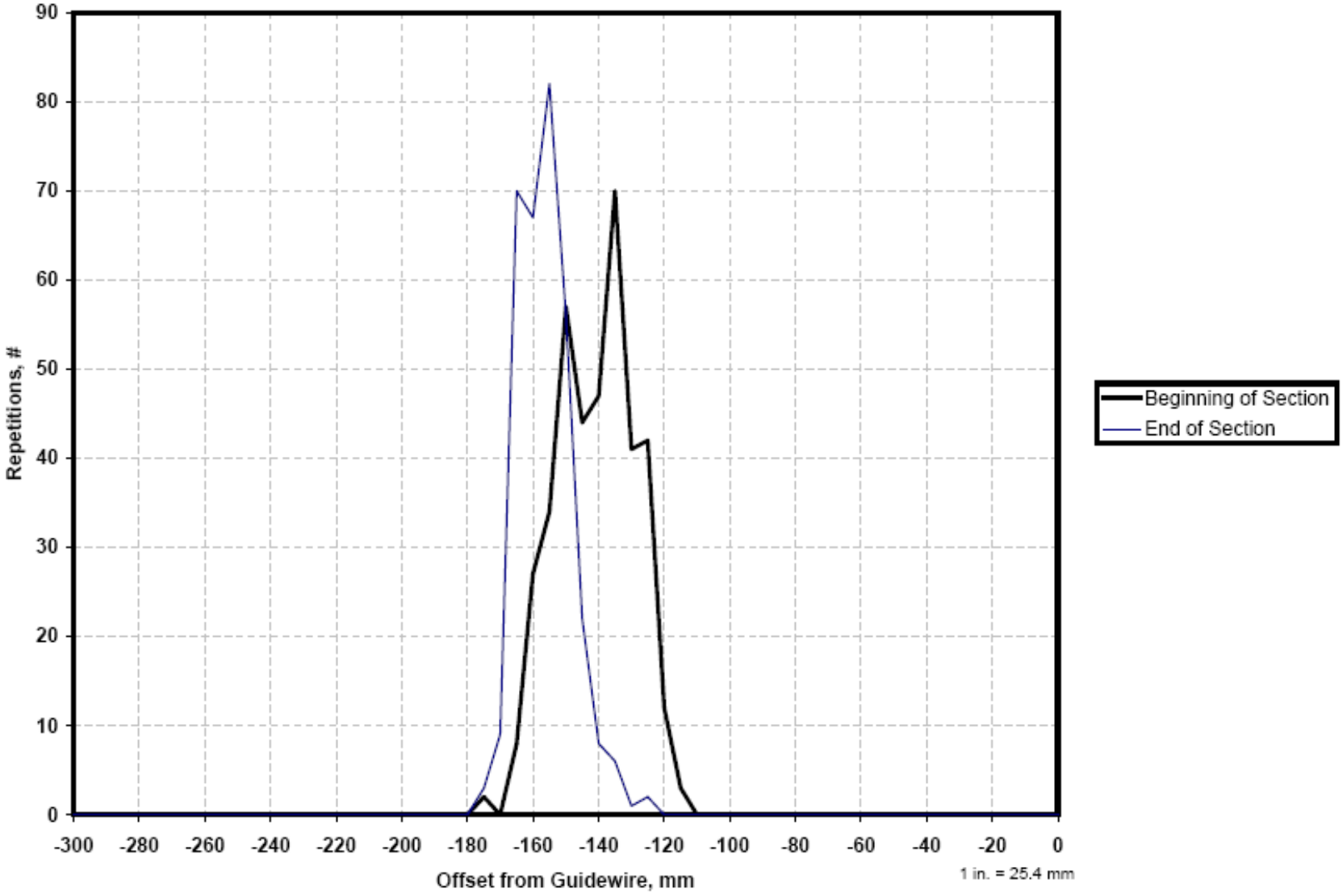


Figure A13. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 50.8 mm (2 in.) Left, 7/31/97.

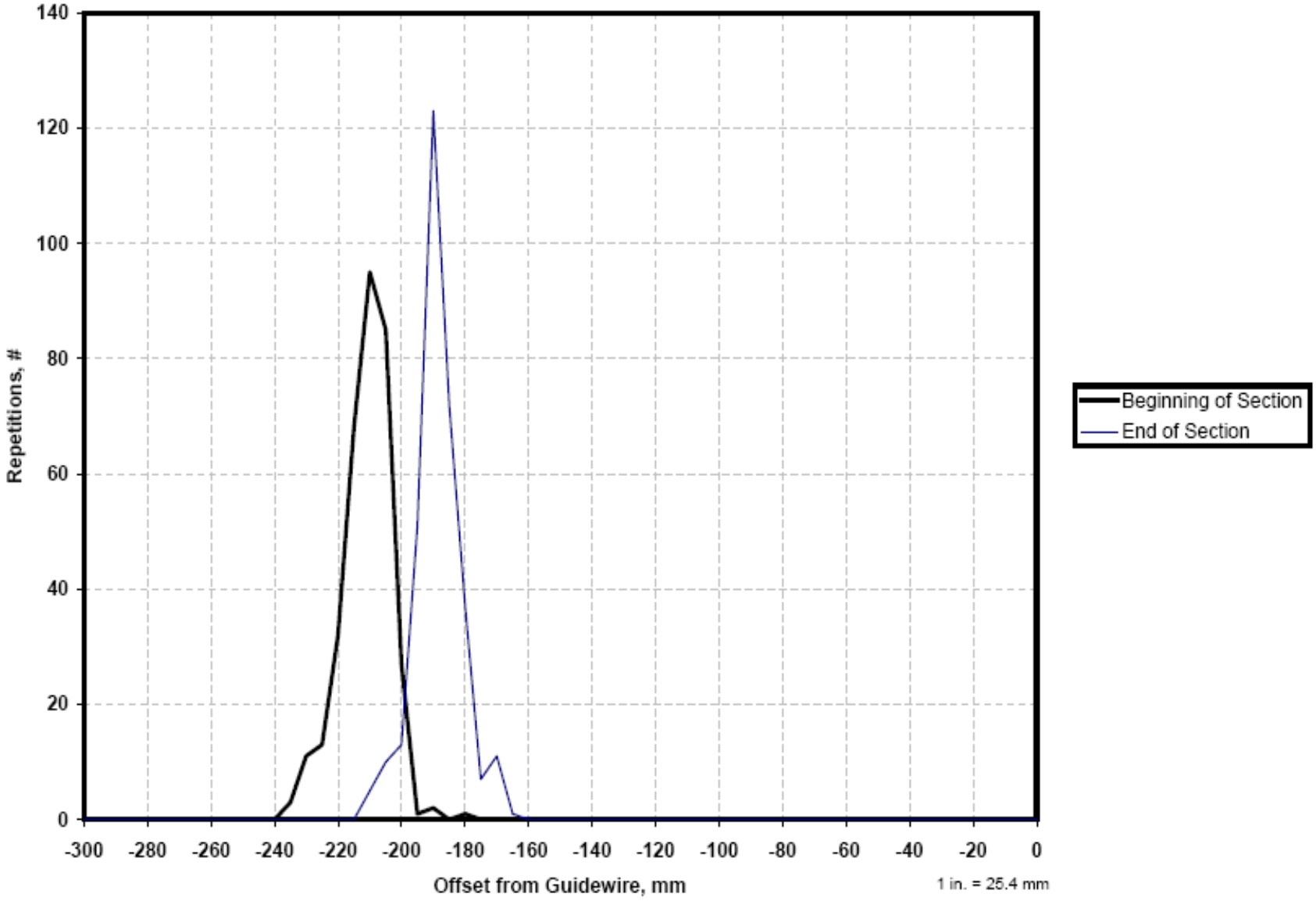


Figure A14. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 50.8 mm (2 in.) Left, 7/31/97.

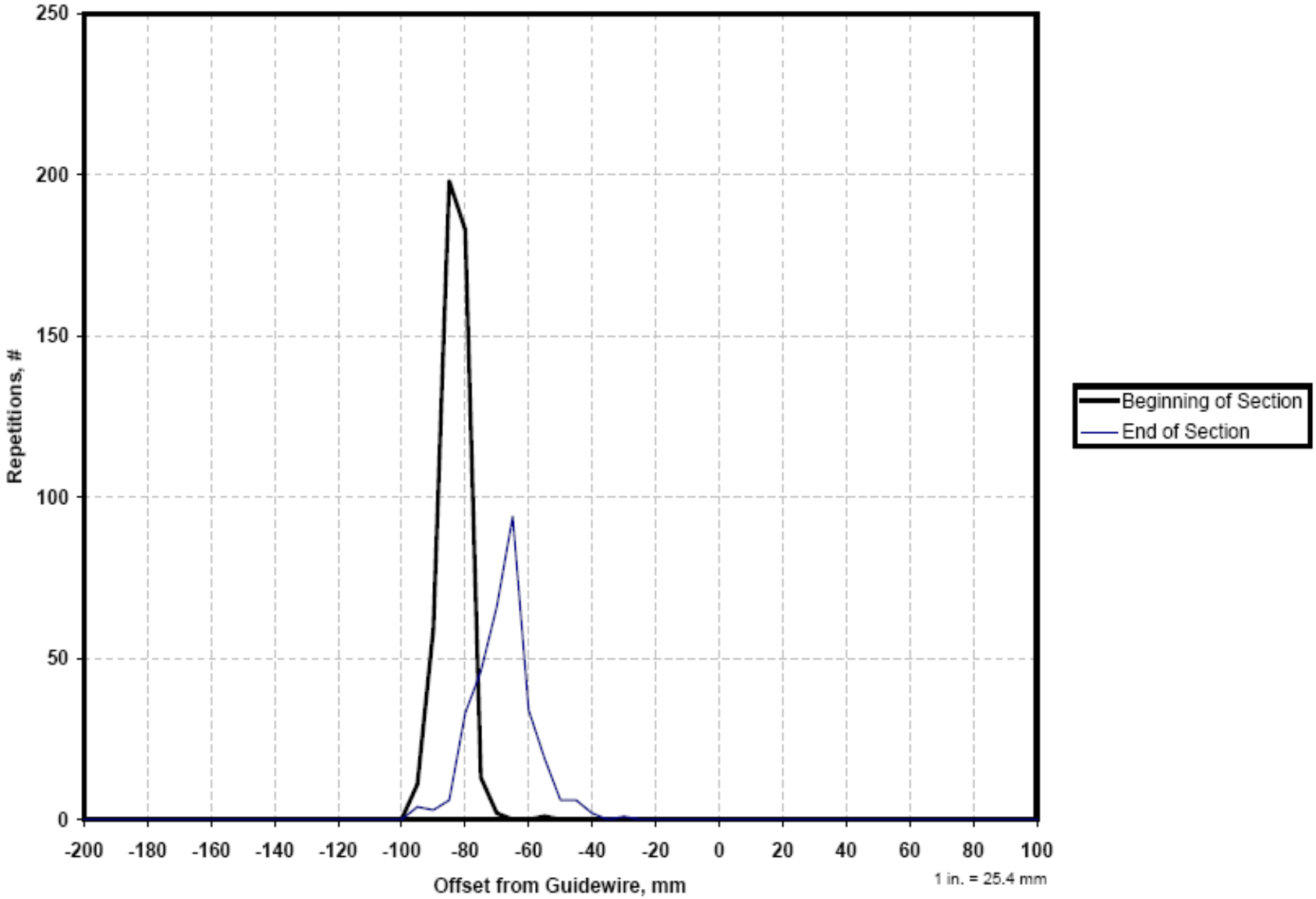


Figure A15. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 50.8 mm (2 in.) Left, 7/31/97.

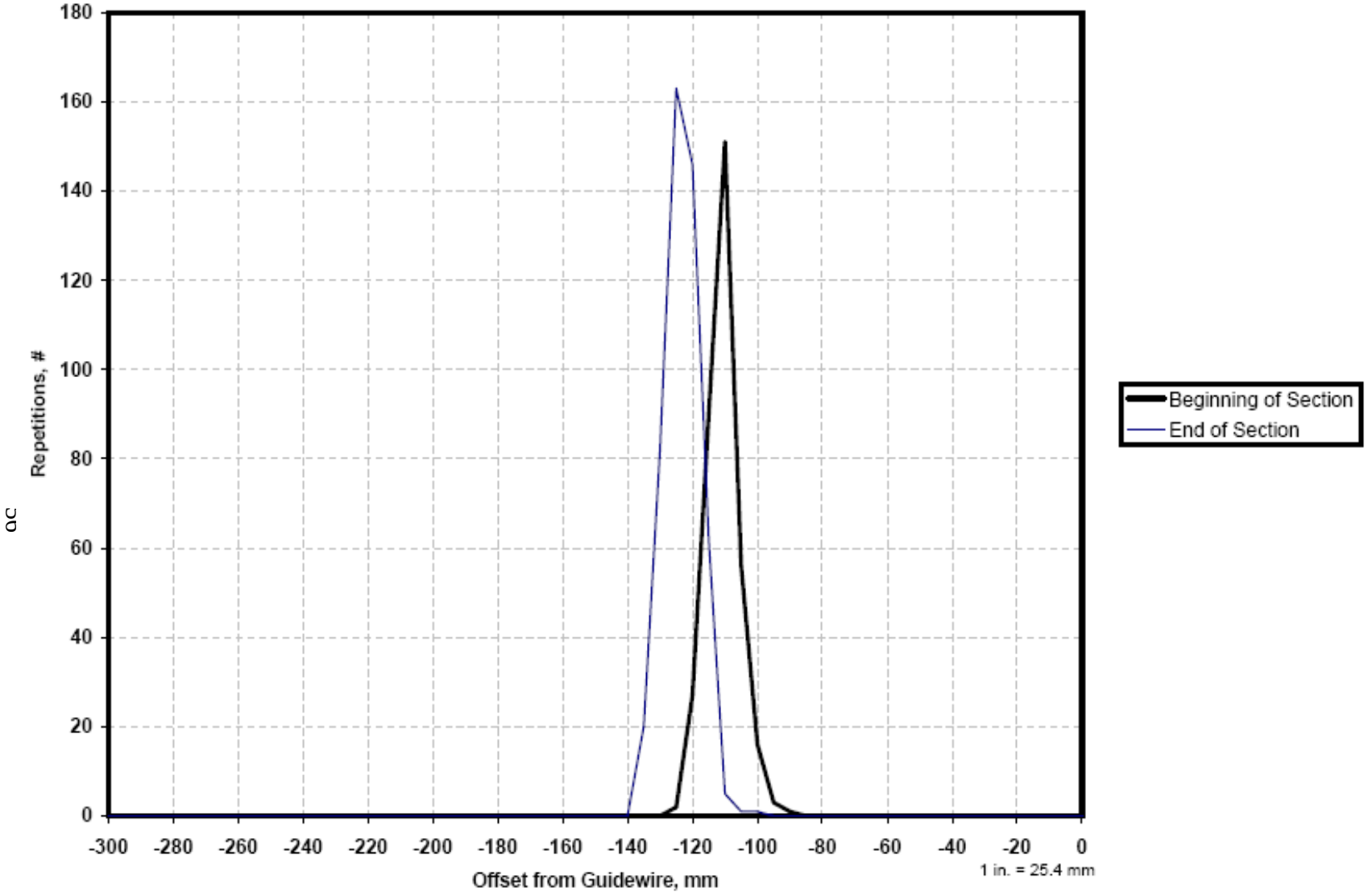


Figure A16. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 50.8 mm (2 in.) Left, 8/3/97.

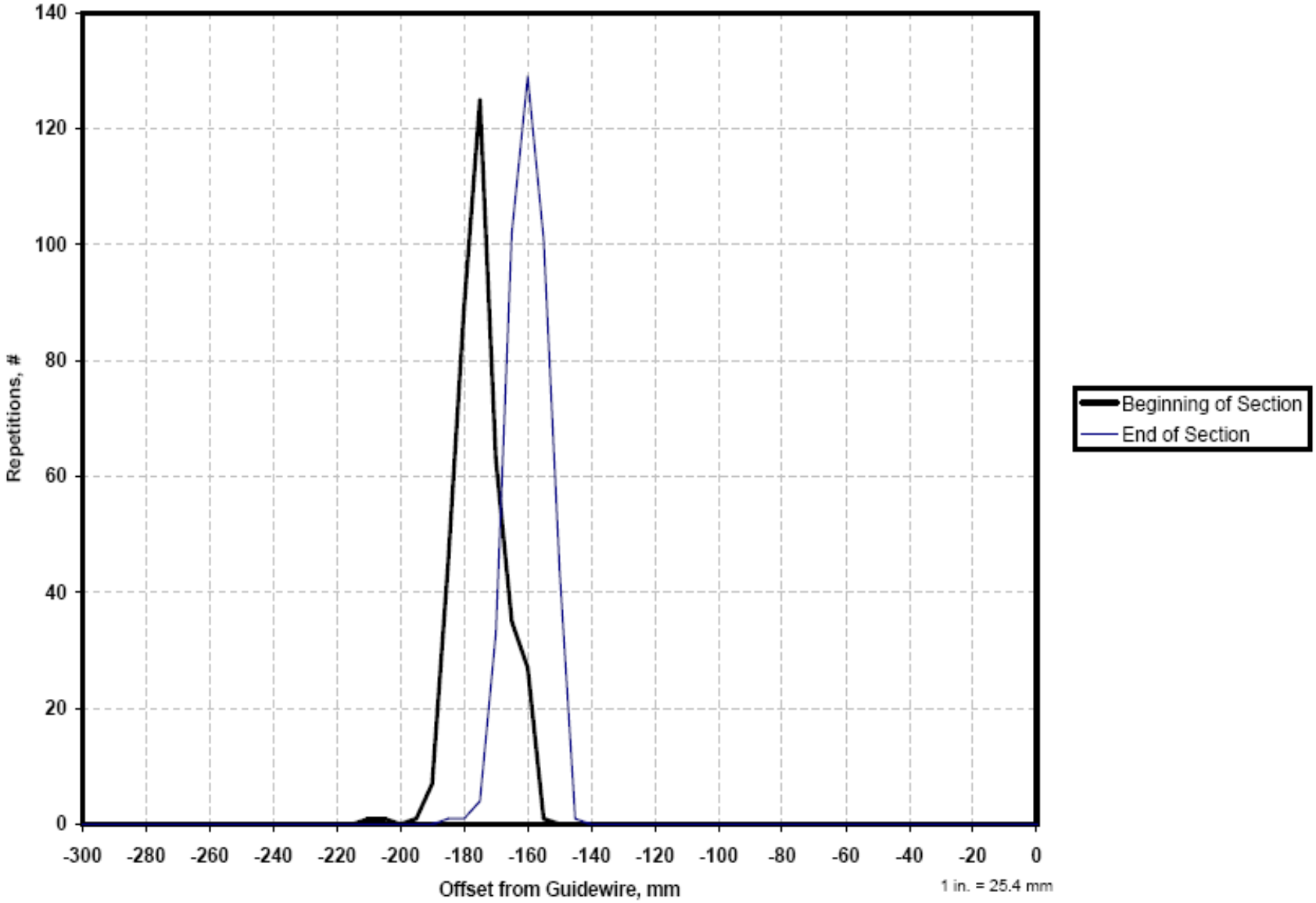


Figure A17. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 50.8 mm (2 in.) Left, 8/3/97.

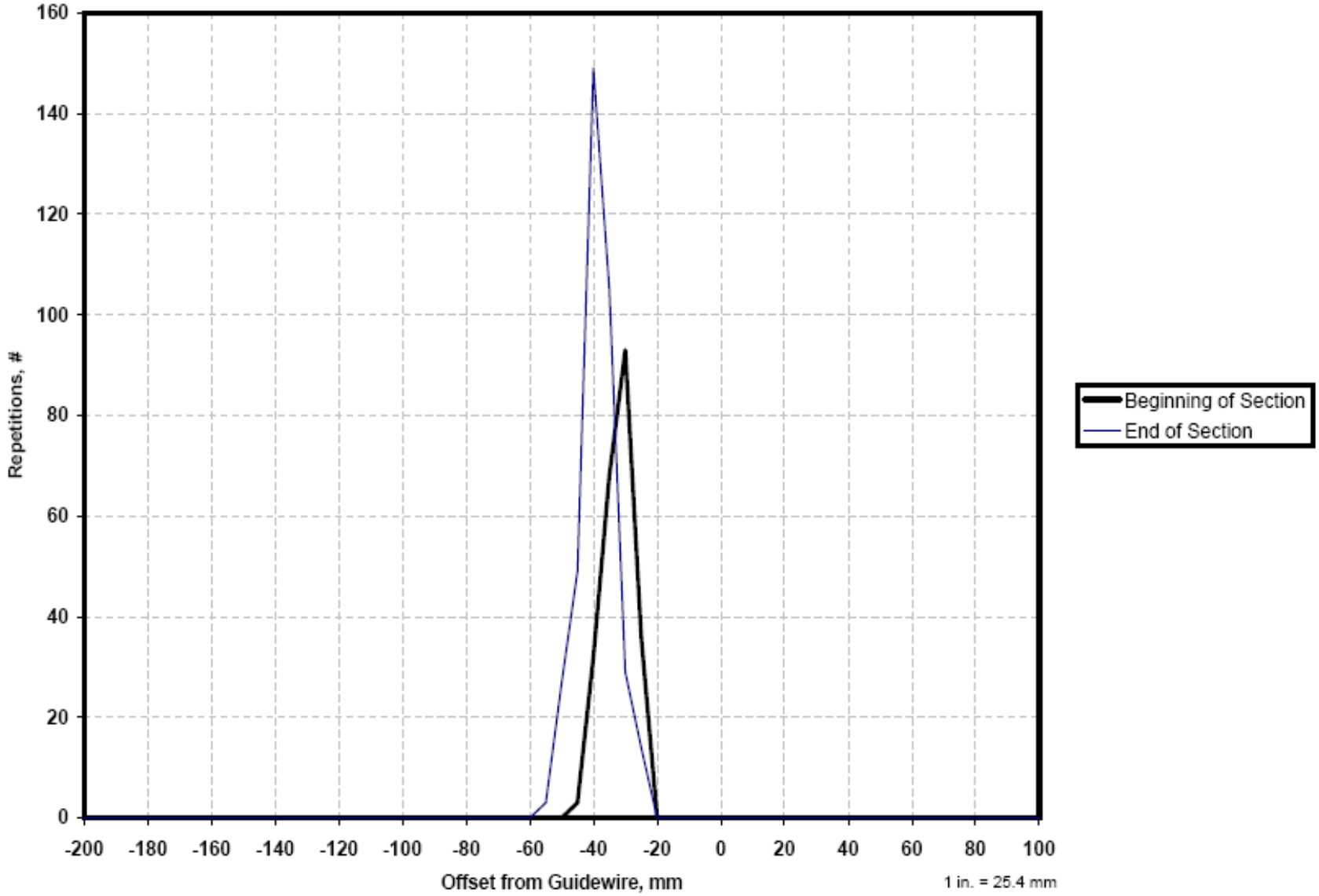


Figure A18. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 50.8 mm (2 in.) Left, 8/3/97.

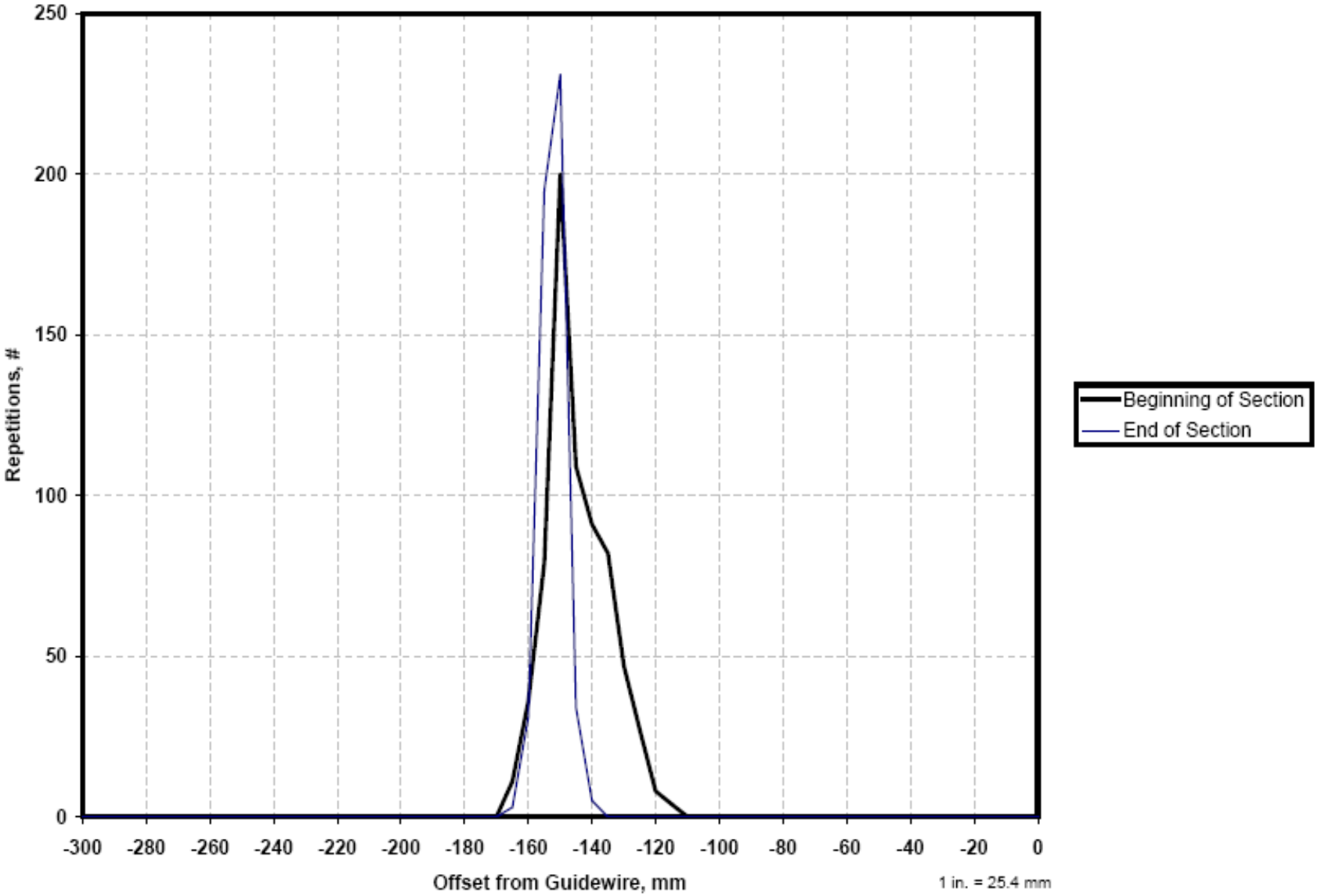


Figure A19. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 50.8 mm (2 in.) Left, 1/7/98.

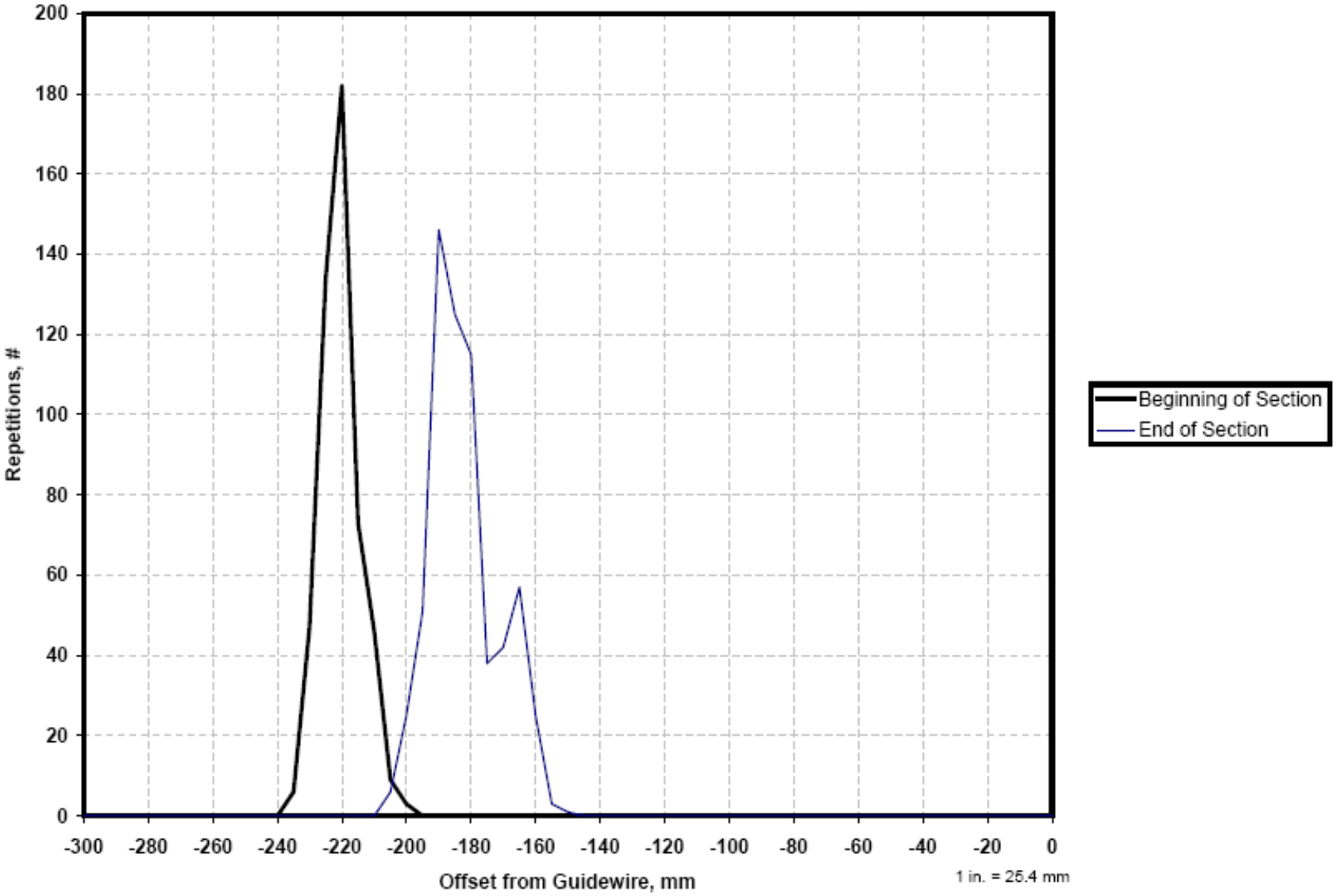


Figure A20. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 50.8 mm (2 in.) Left, 1/7/98.

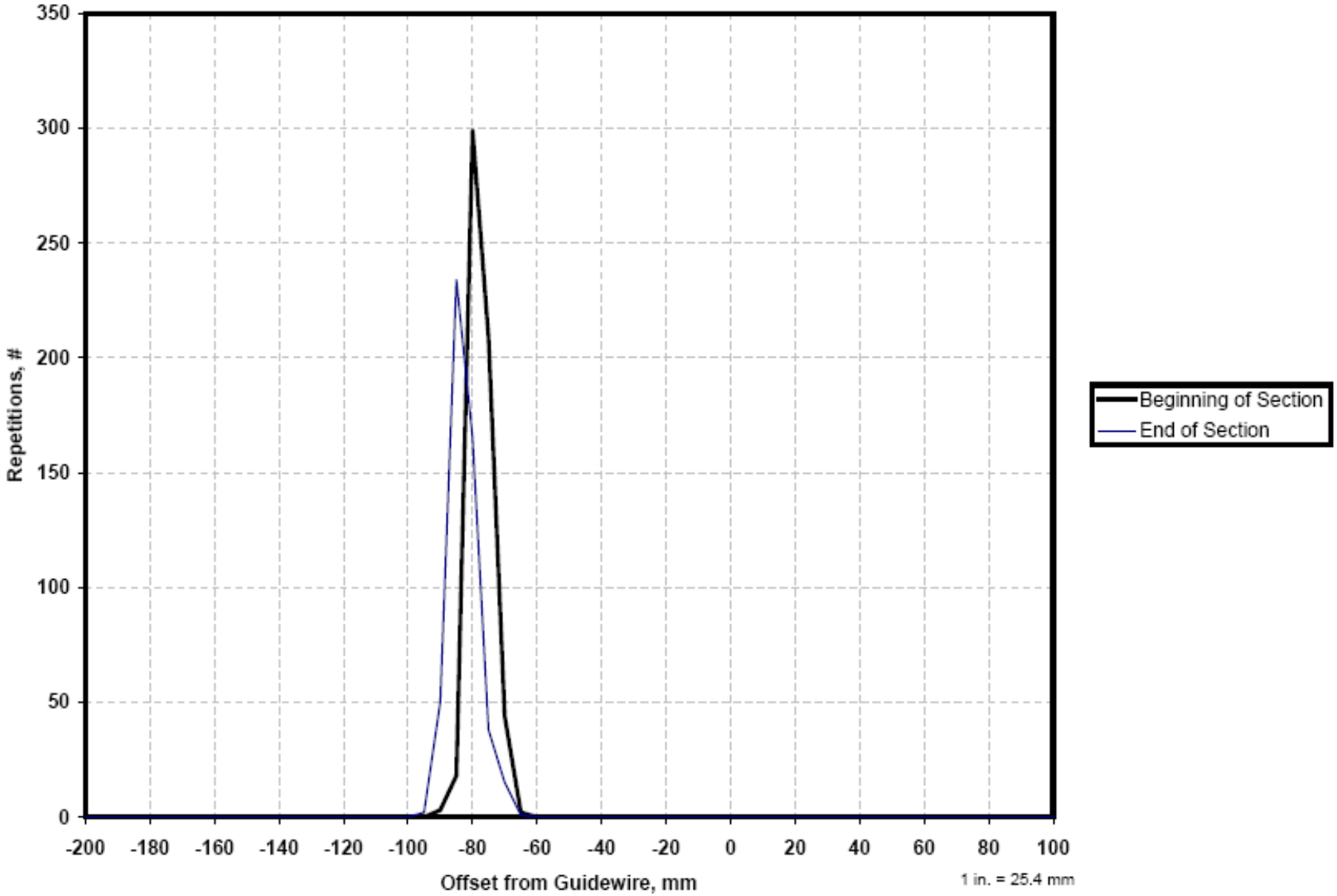


Figure A21. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 50.8 mm (2 in.) Left, 1/7/98.

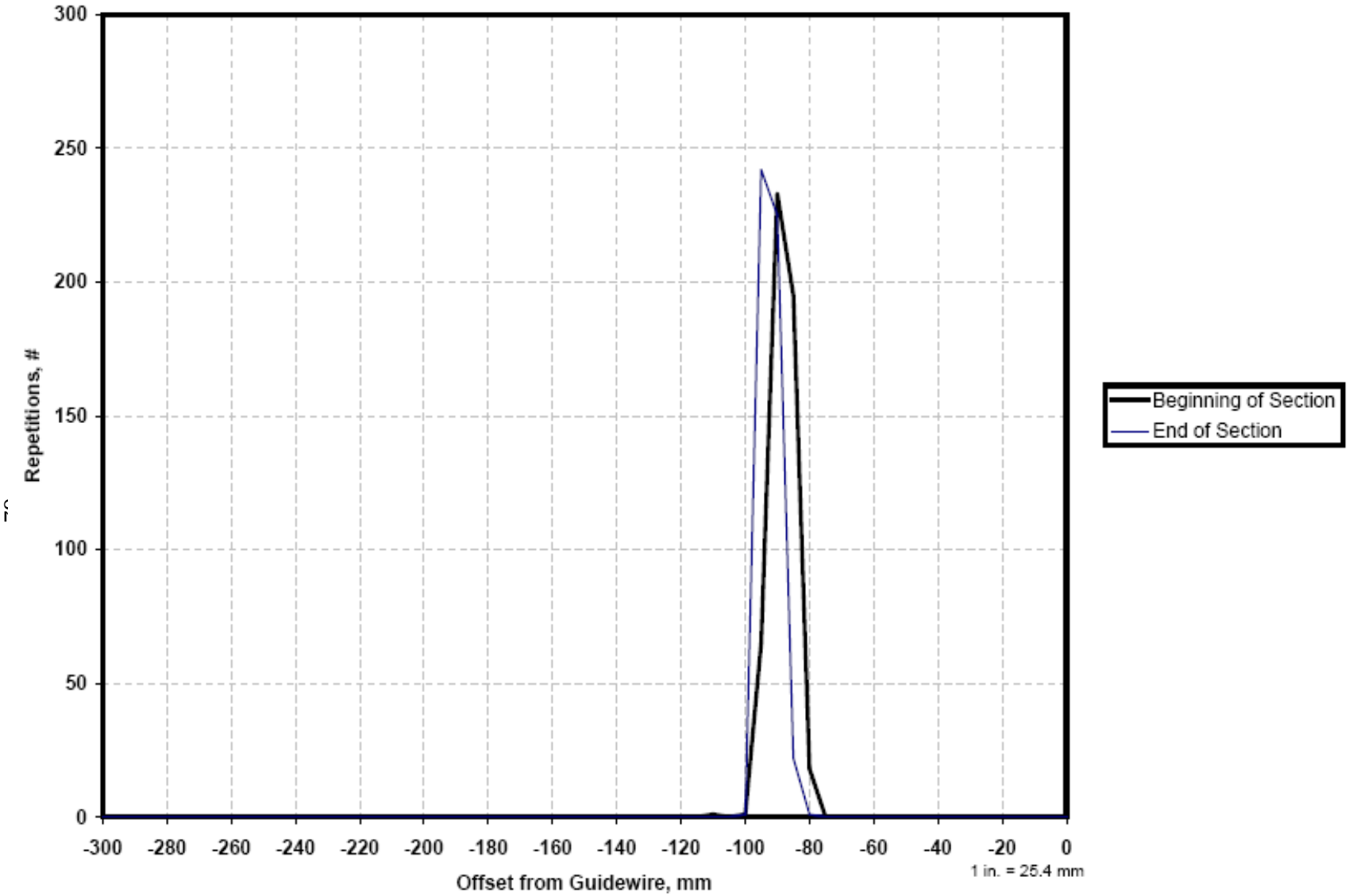


Figure A22. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/1/97.

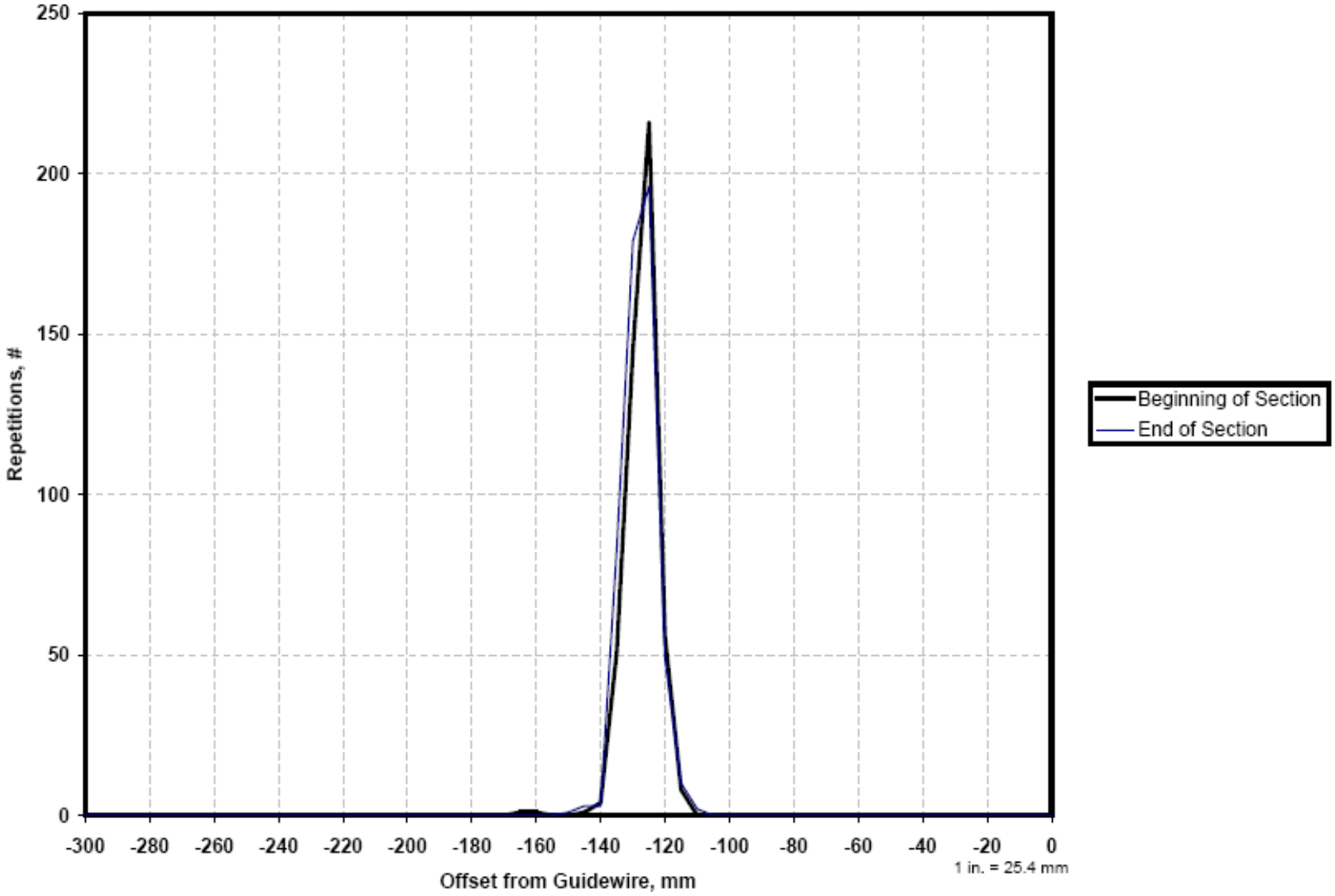


Figure A23. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/1/97.

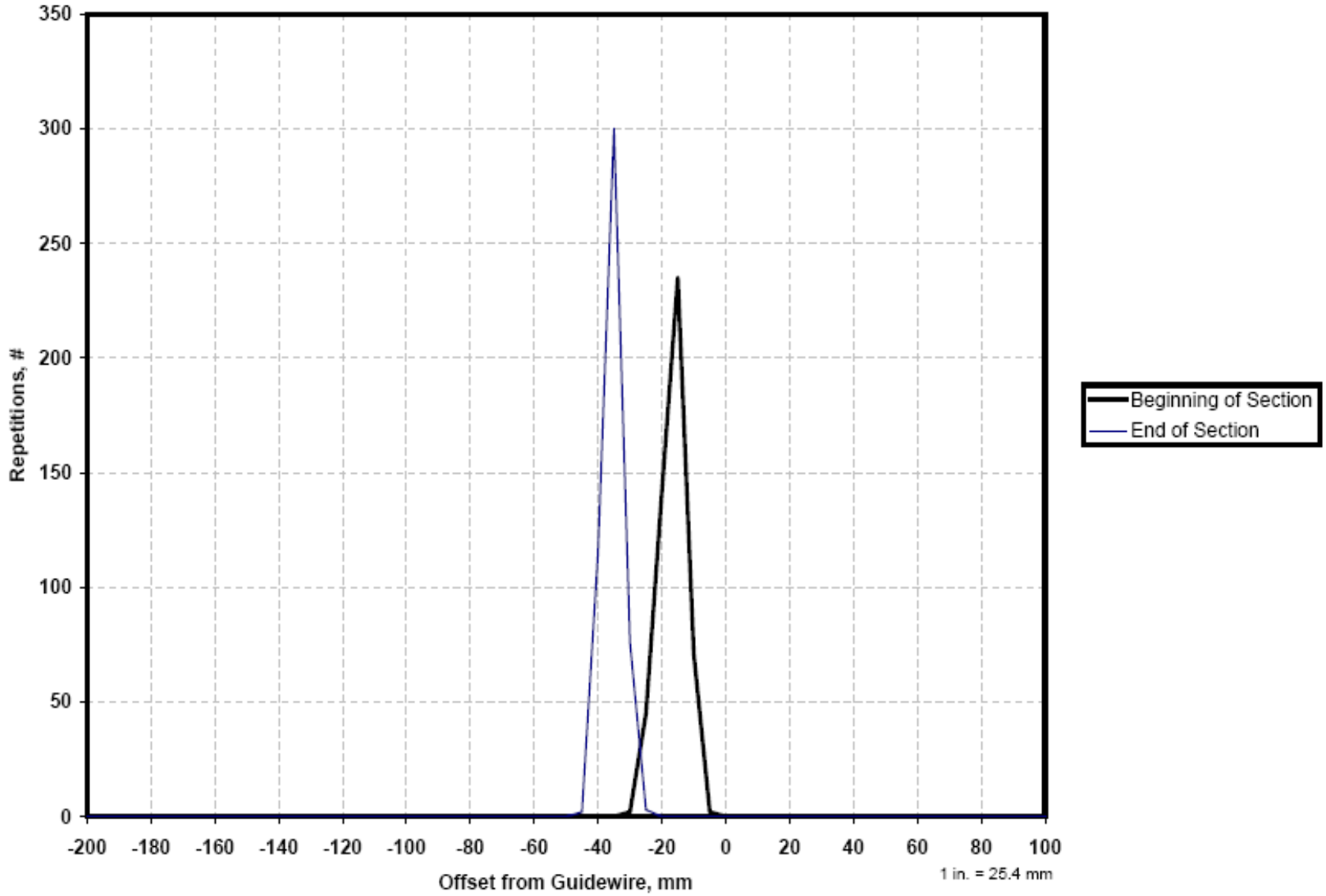


Figure A24. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/1/97.

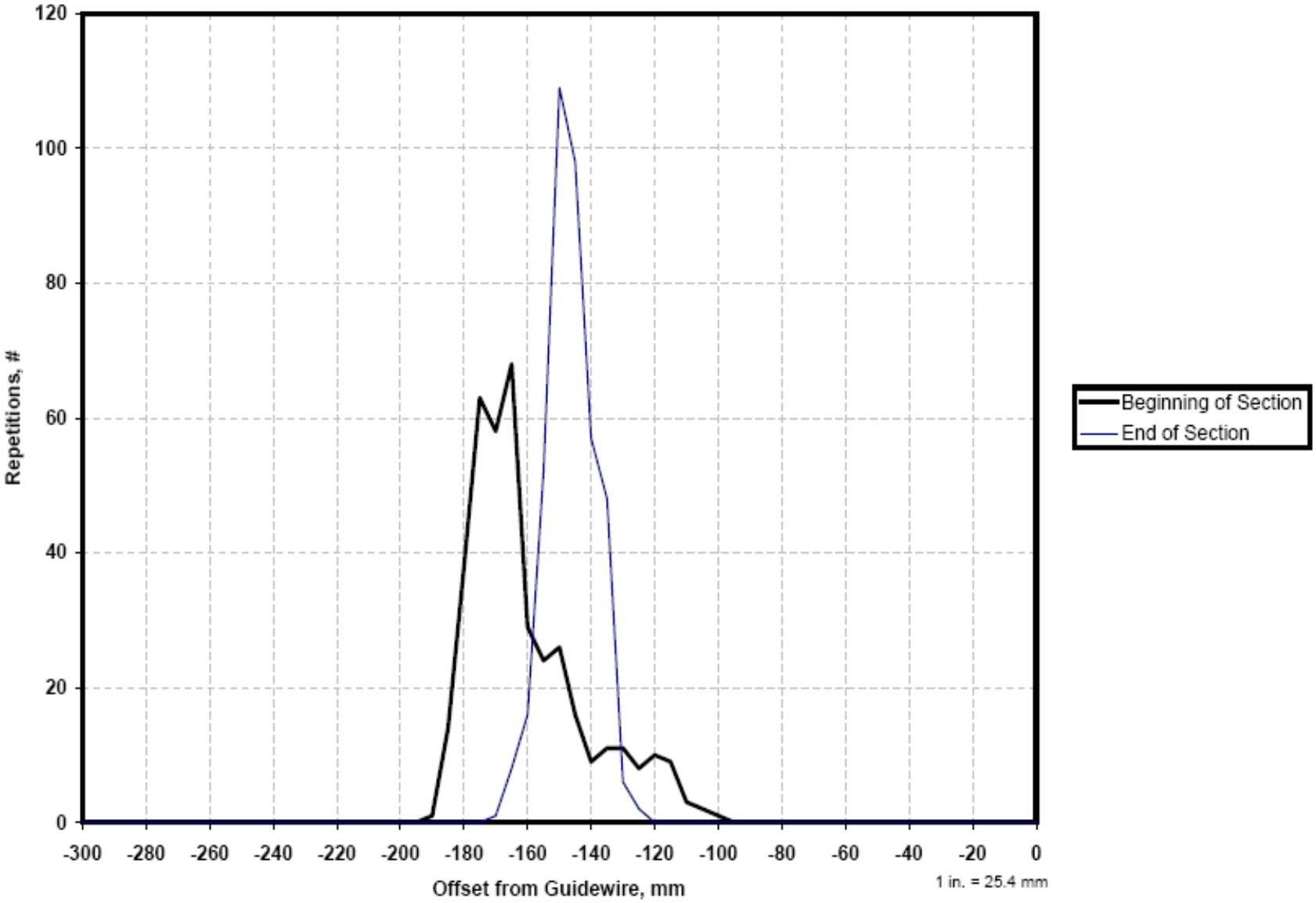


Figure A25. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/4/97.

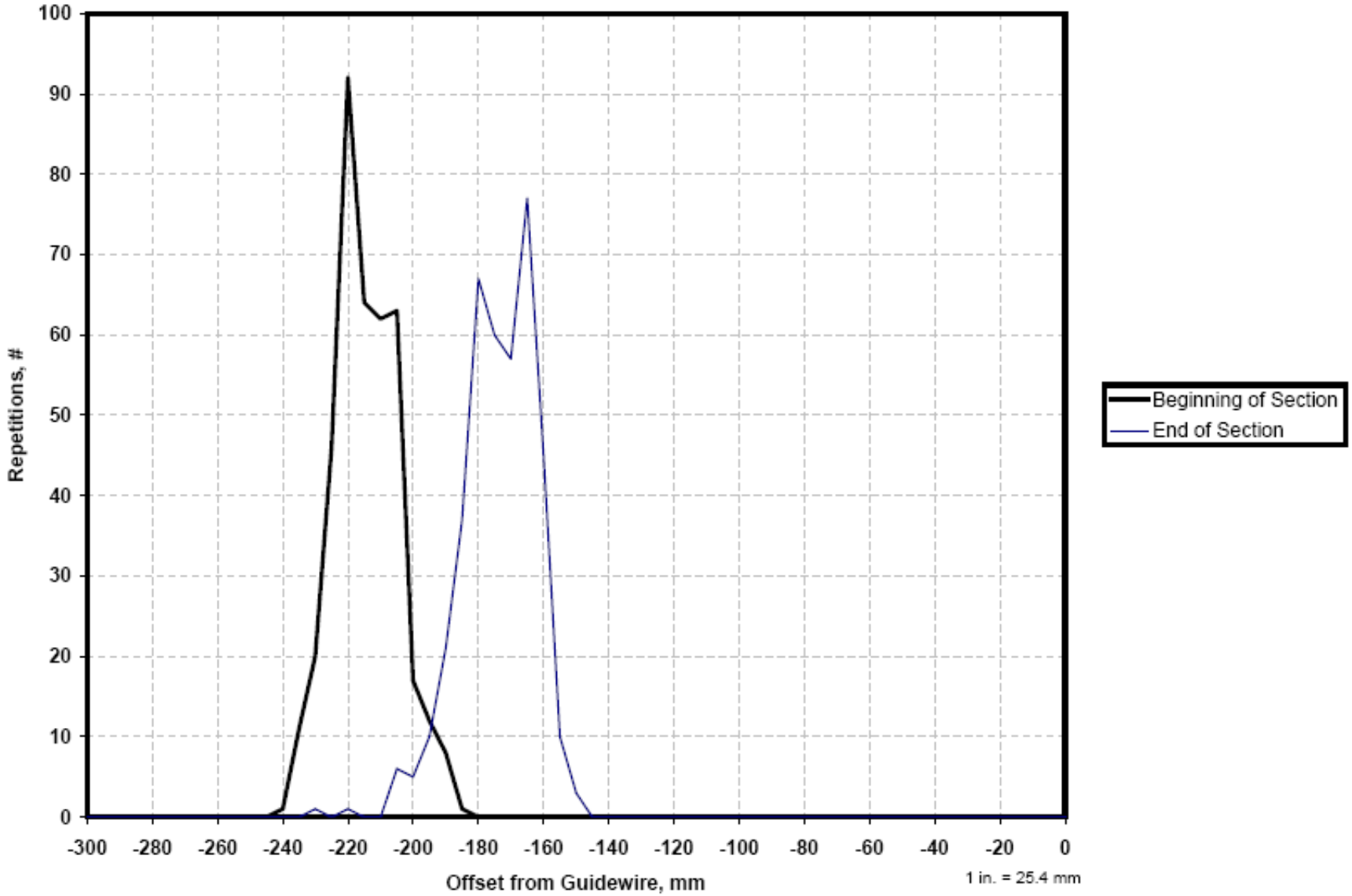


Figure A26. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/4/97.

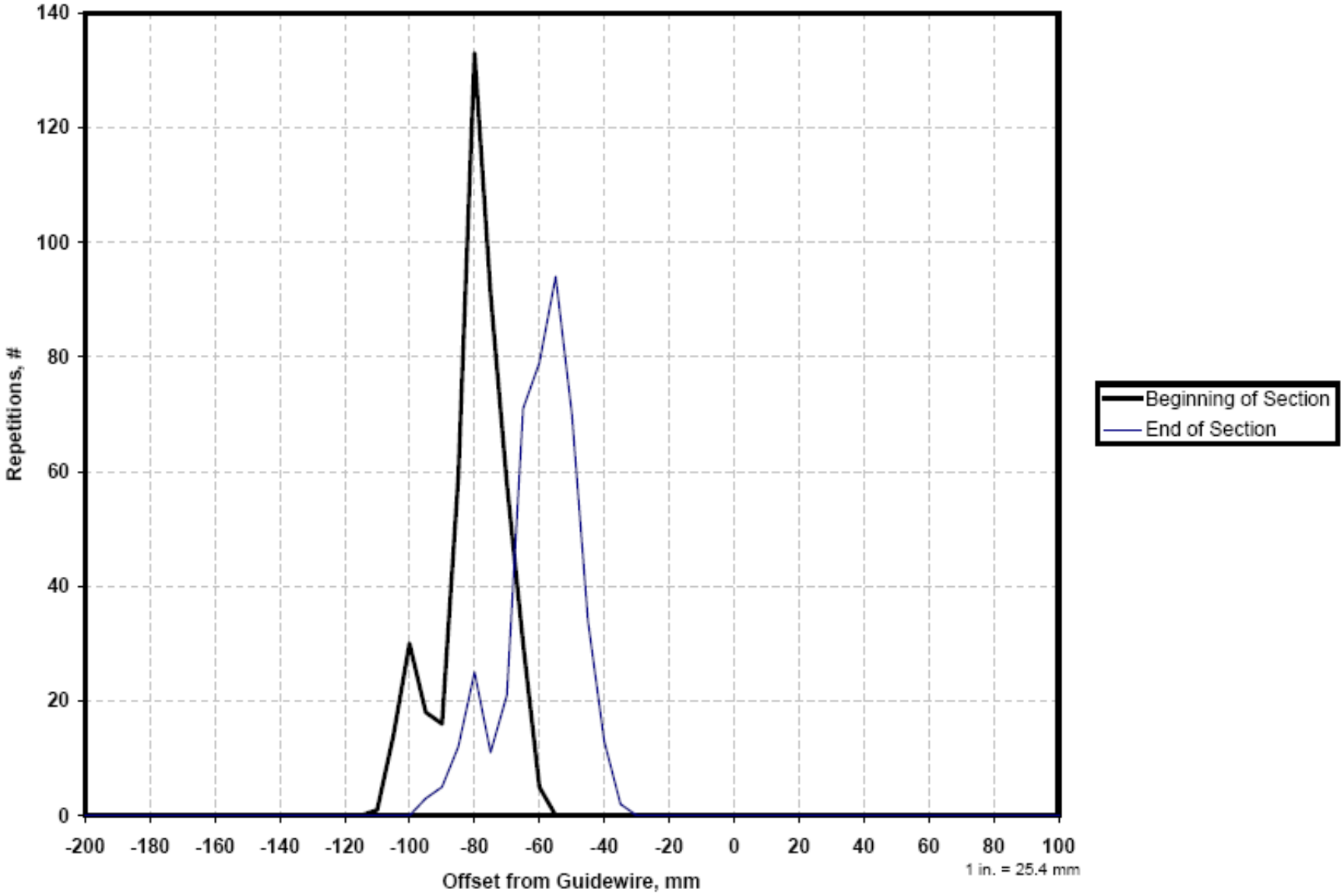


Figure A27. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/4/97.

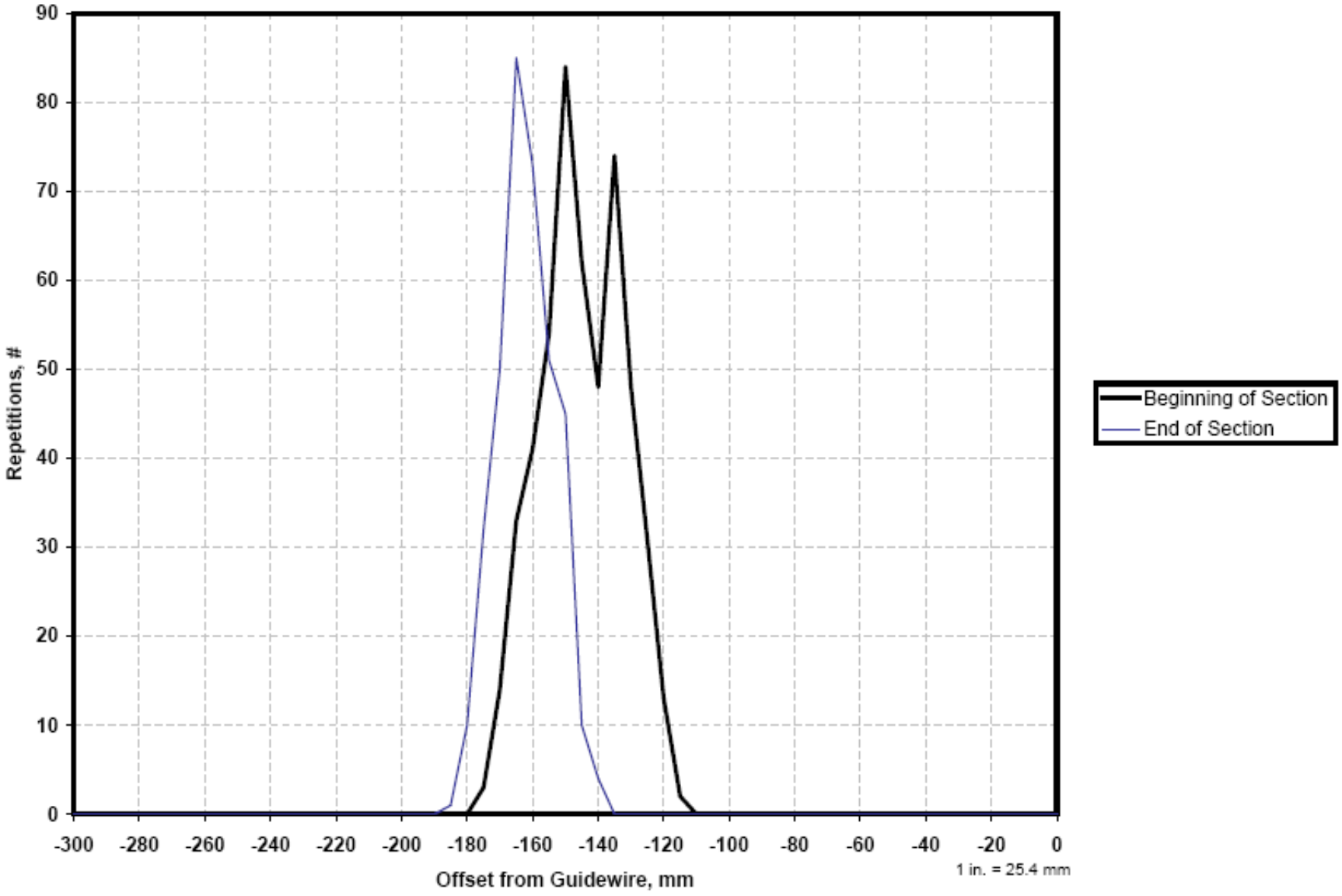


Figure A28. Front Antenna Offset Histogram for Section 4 With Front Antenna Centered, 8/8/97.

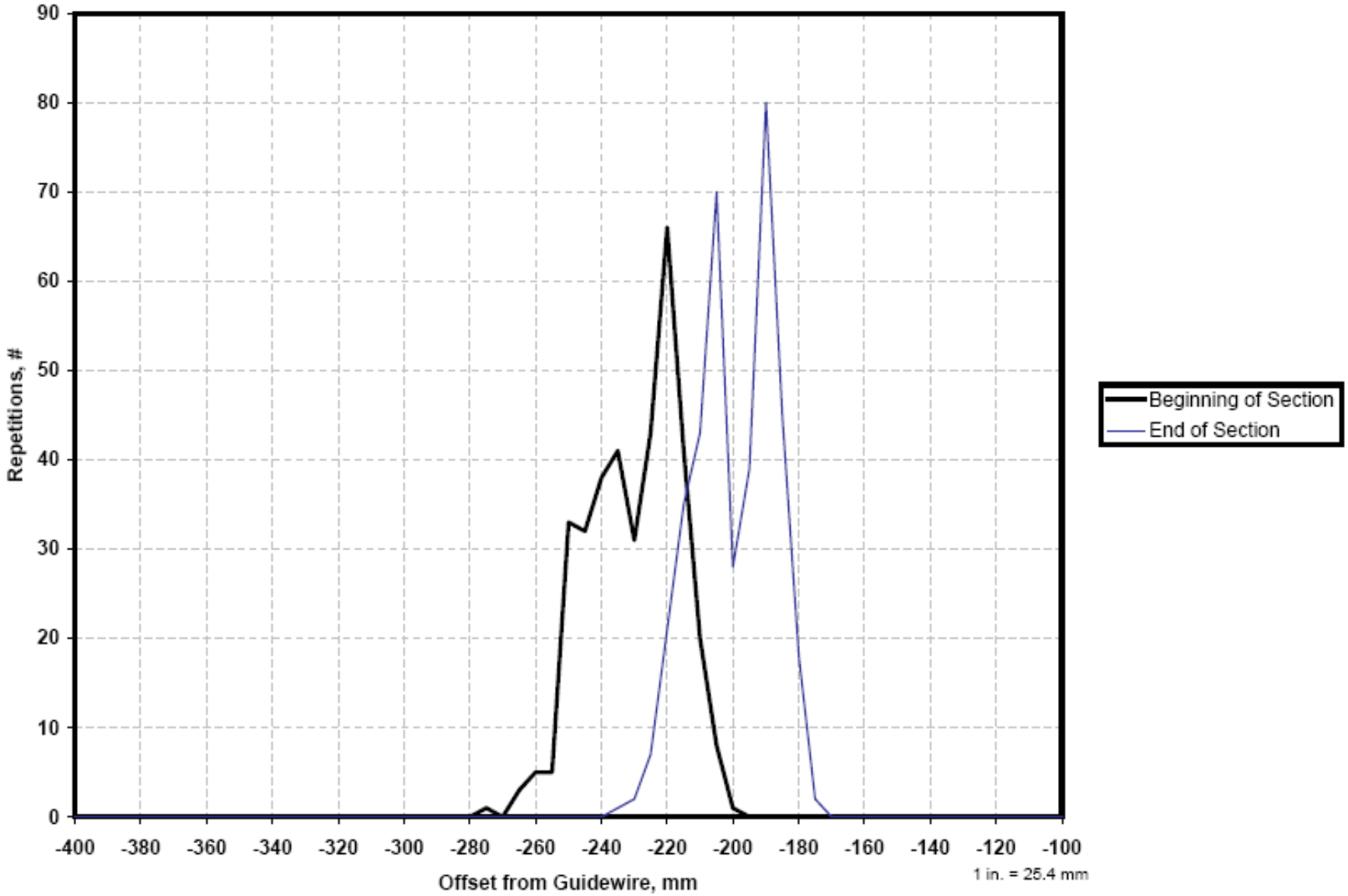


Figure A29. Front Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/8/97.

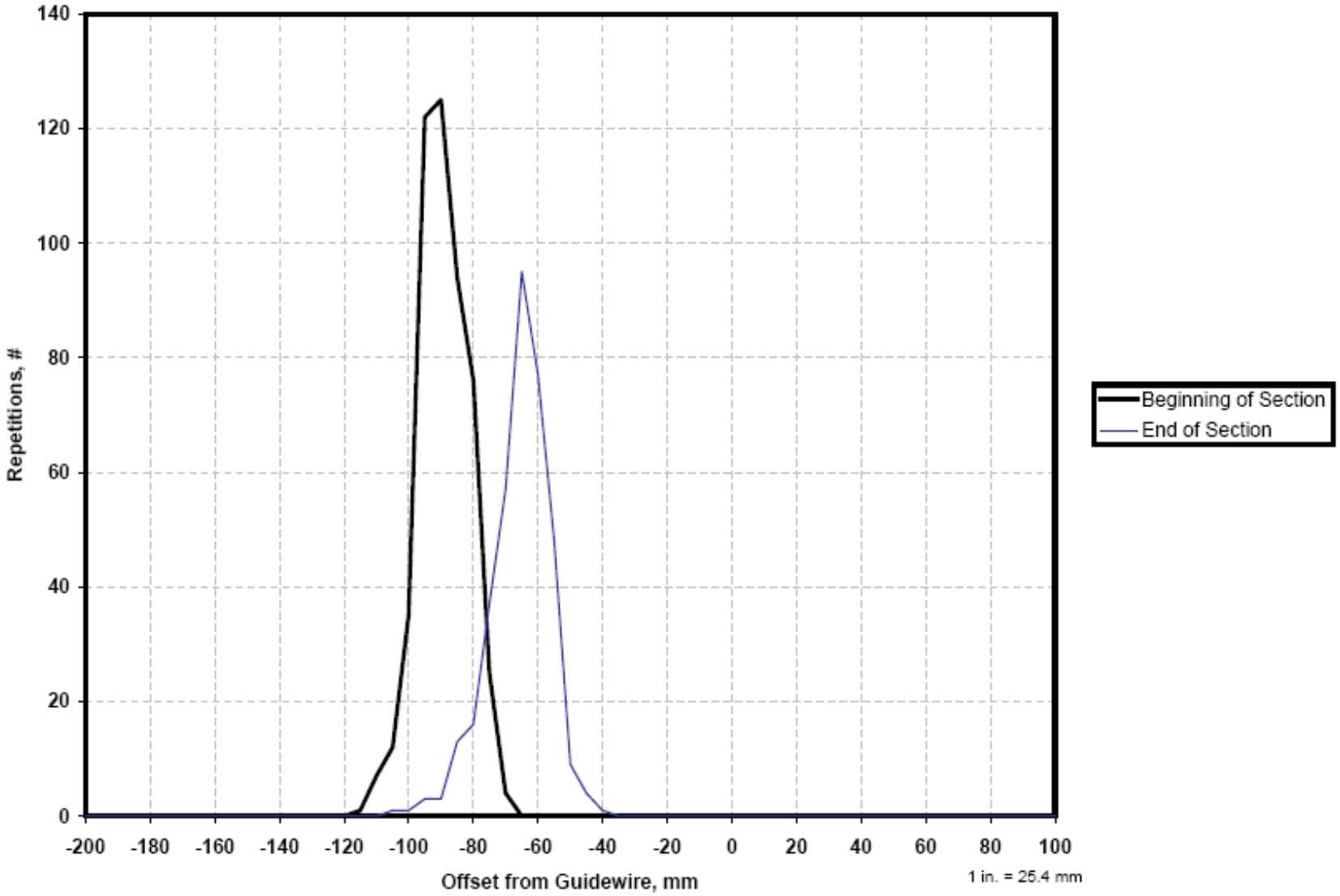


Figure A30. Front Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/8/97.

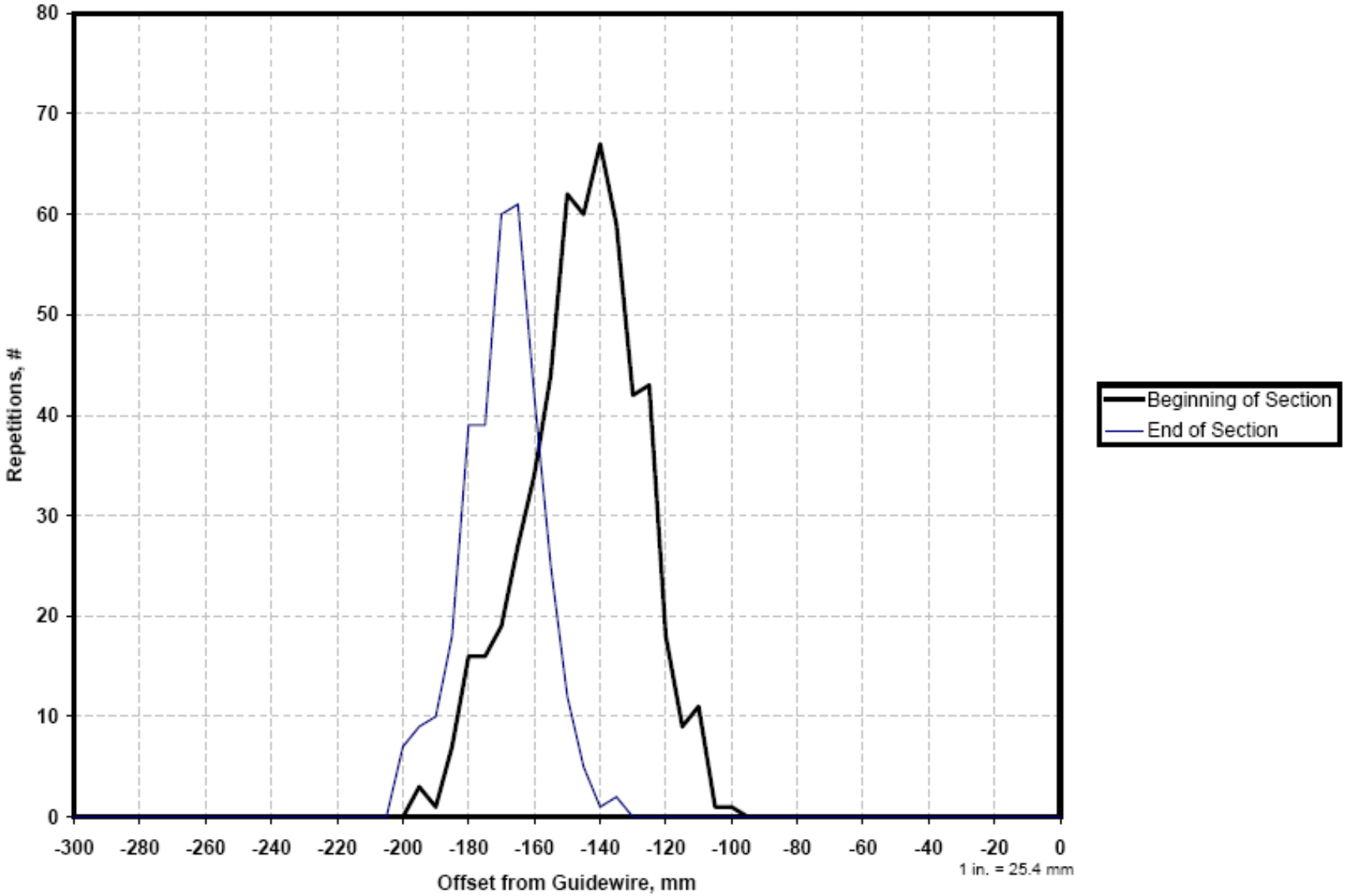


Figure A31. Front Antenna Offset Histogram for Section 4 With Front Antenna Centered, 8/9/97.

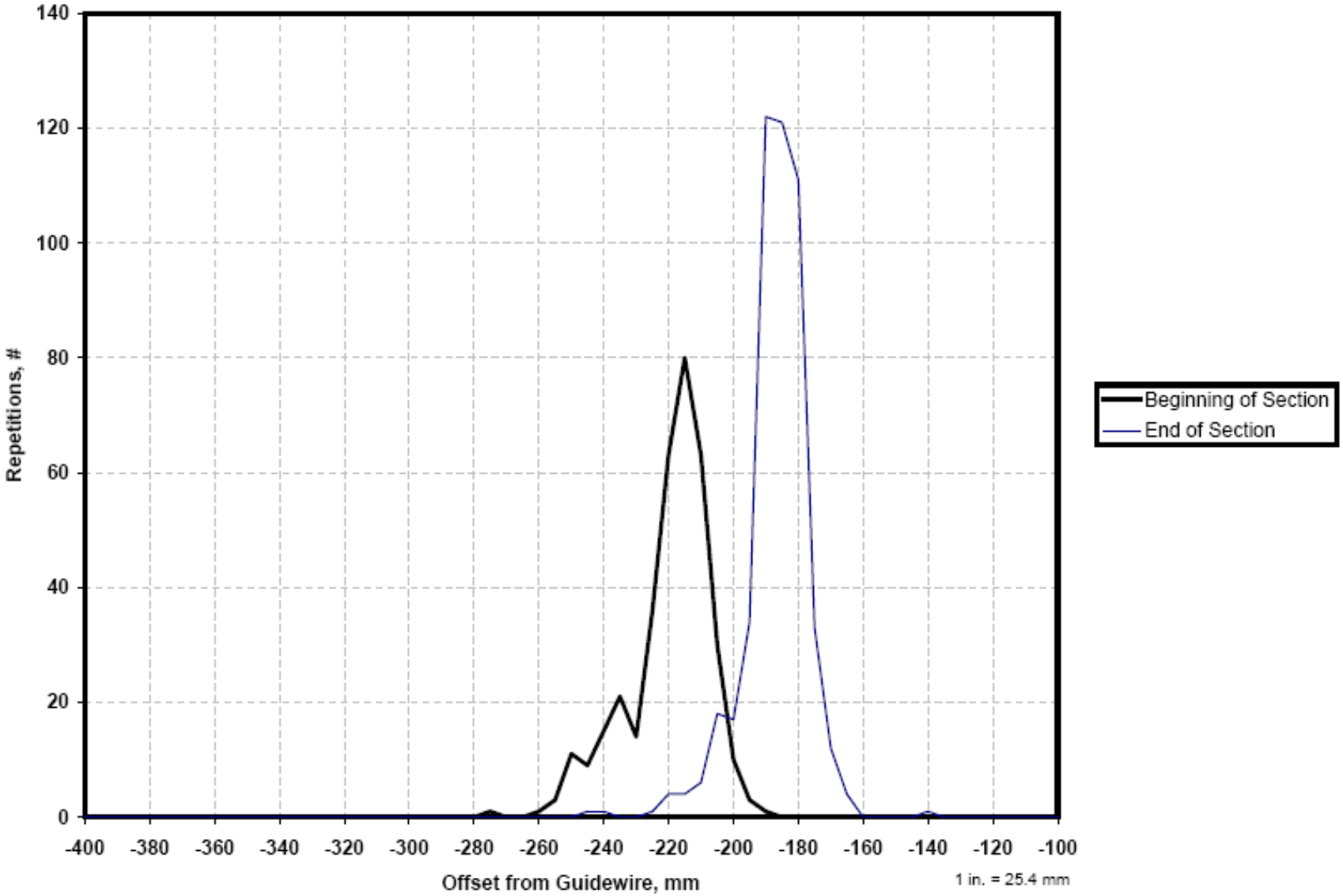


Figure A32. Front Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/9/97.

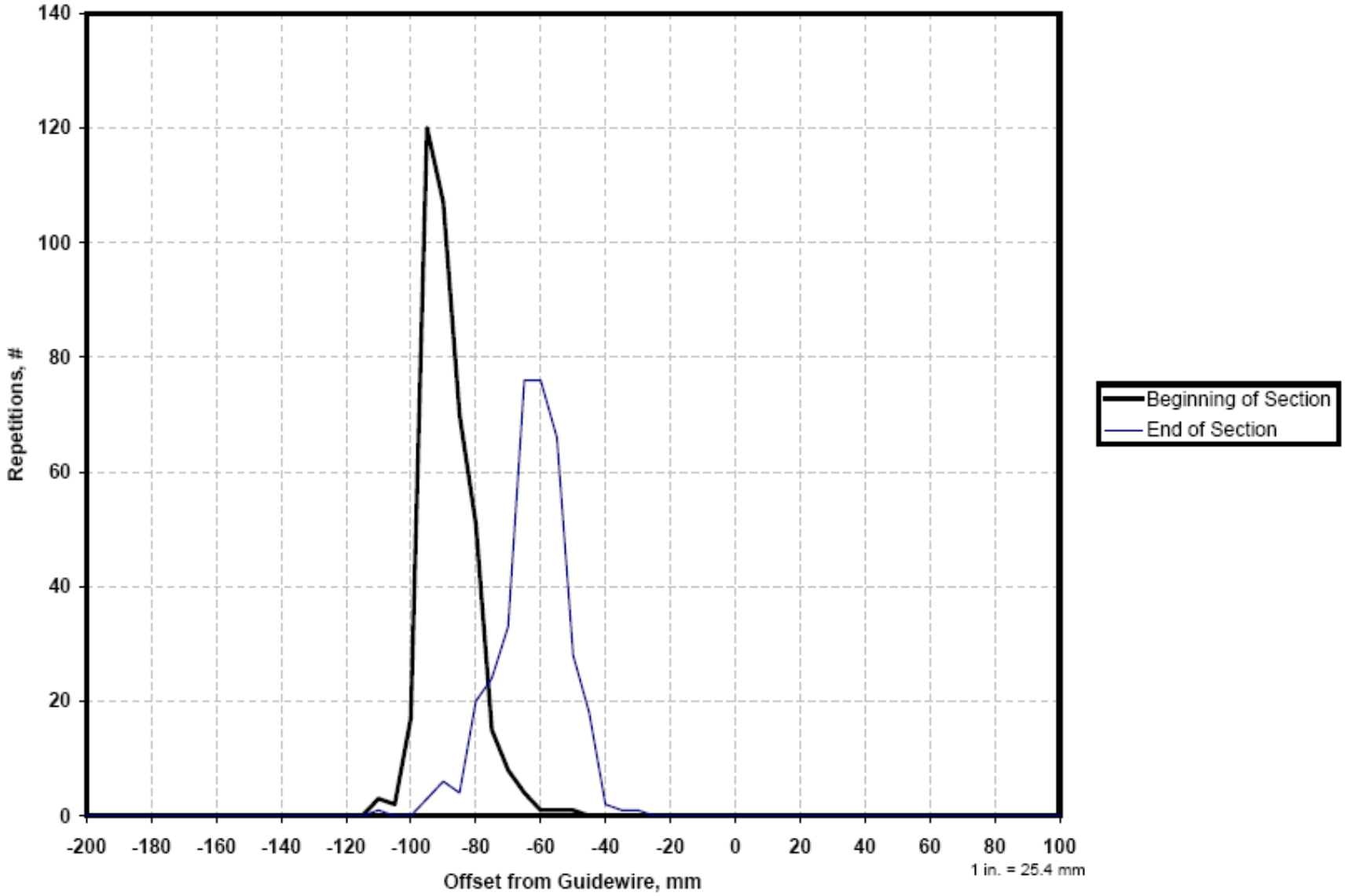


Figure A33. Front Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/9/97.

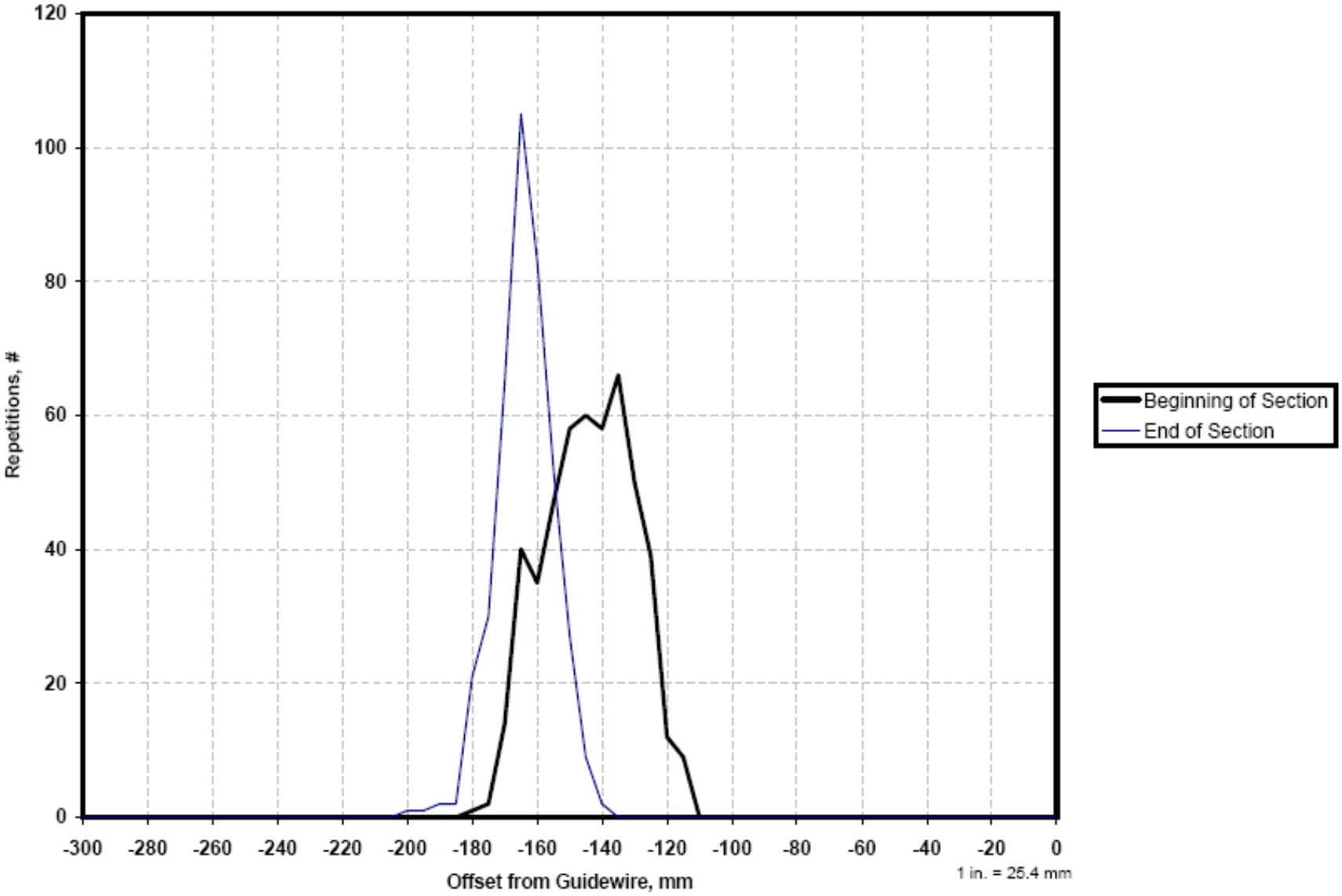


Figure A34. Front Antenna Offset Histogram for Section 4 With Front Antenna Centered, 8/10/97.

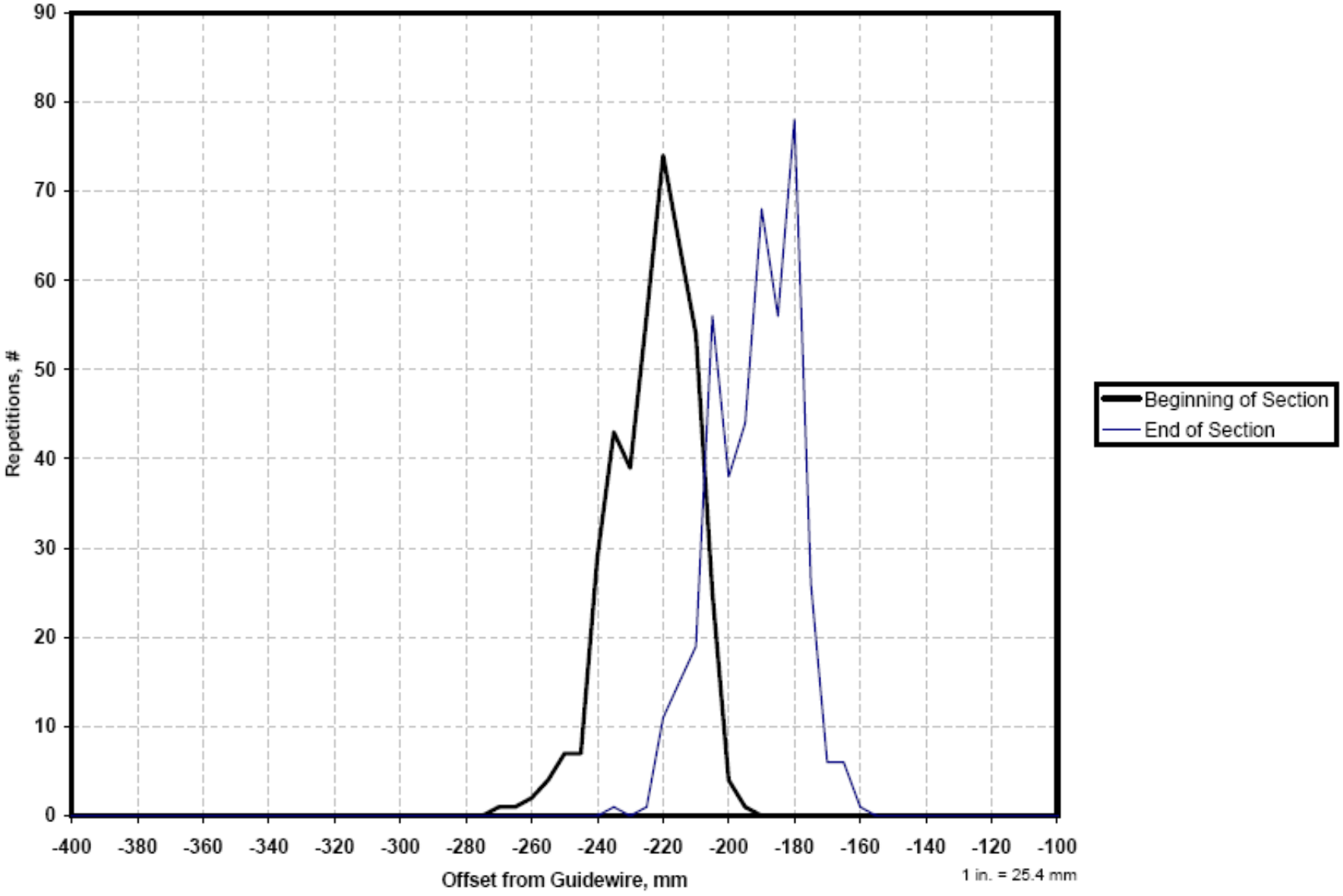


Figure A35. Front Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/10/97.

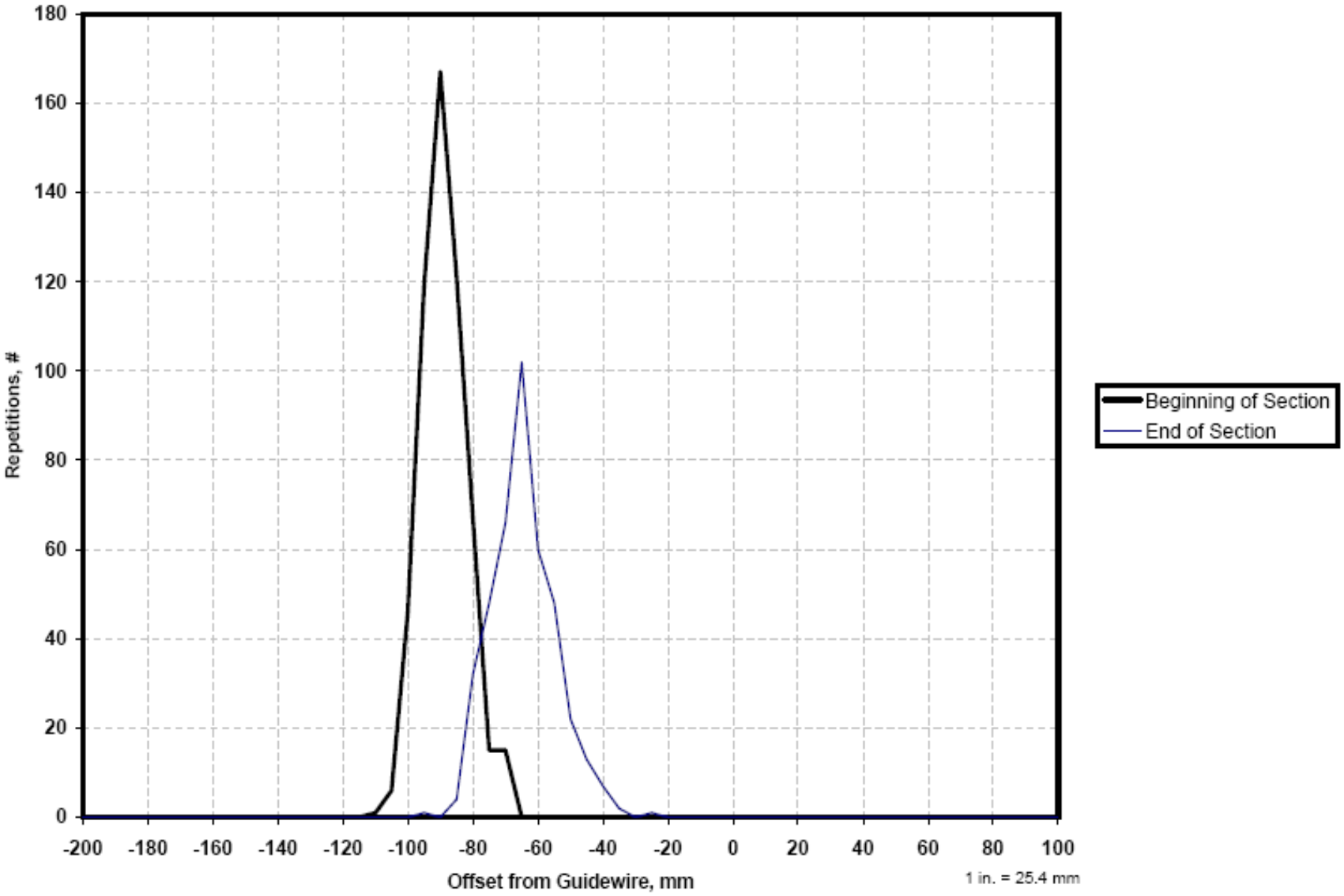


Figure A36. Front Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/10/97.

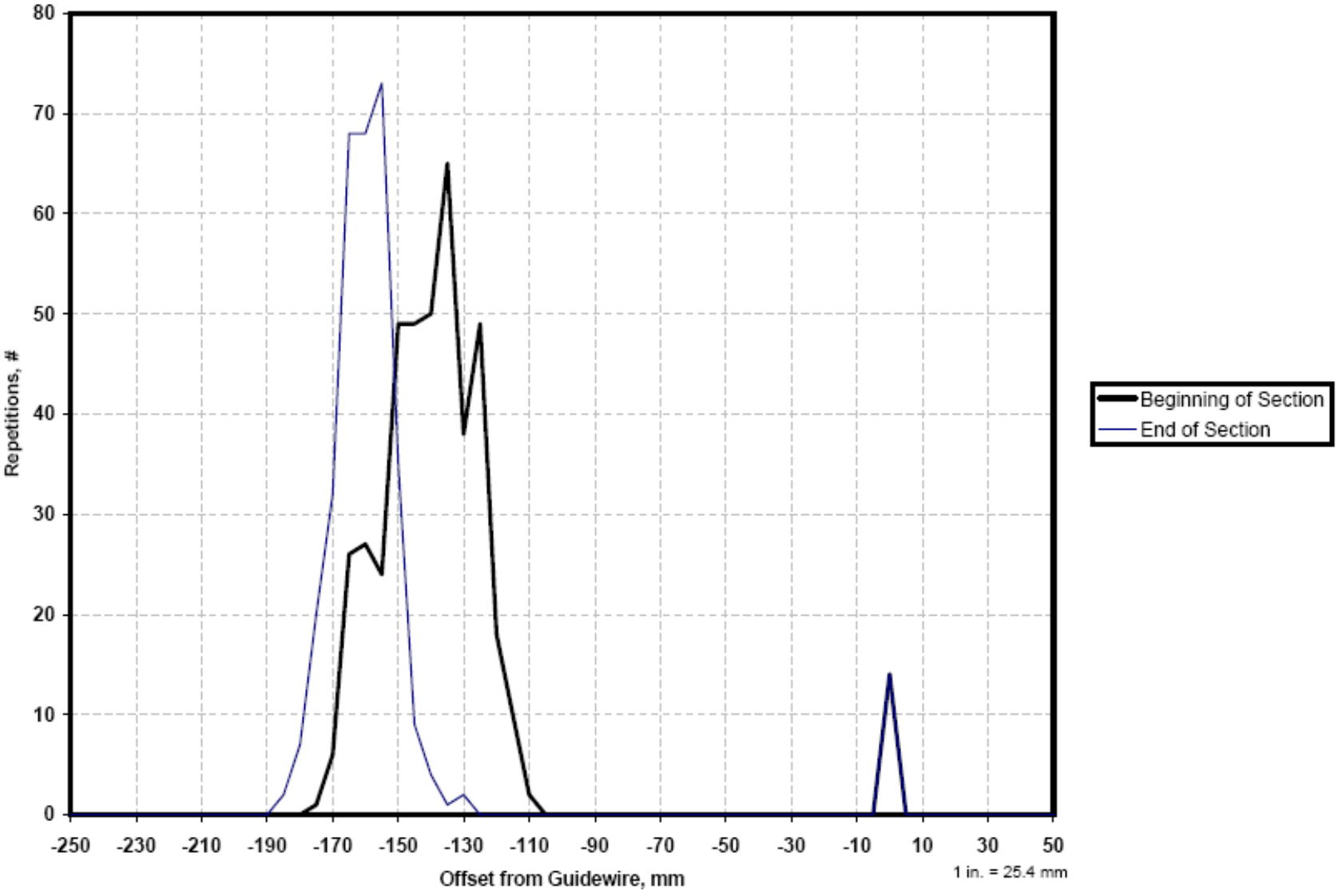


Figure A37. Front Antenna Offset Histogram for Section 4 With Front Antenna Centered, 8/11/97.

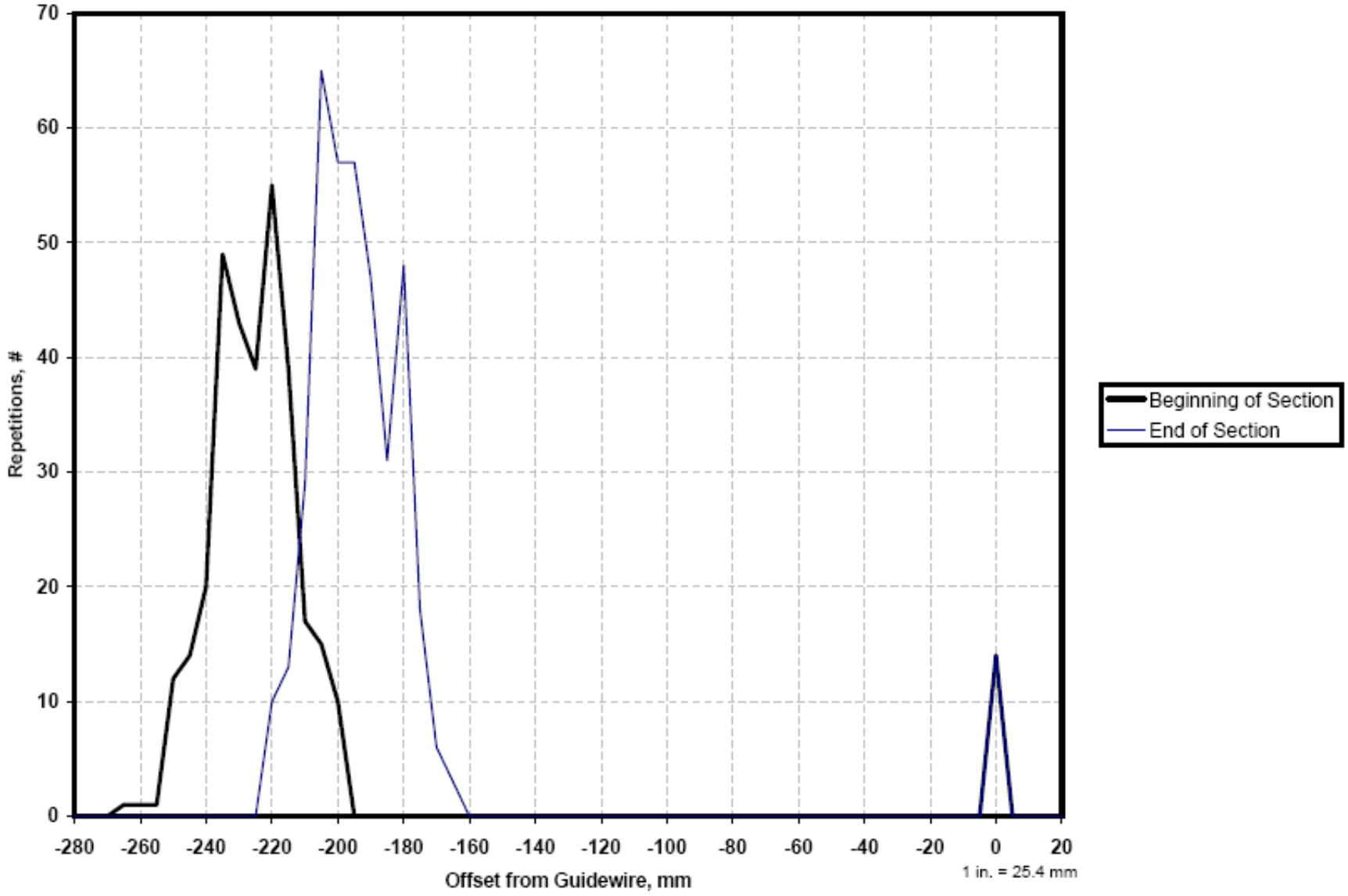


Figure A38. Front Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/11/97.

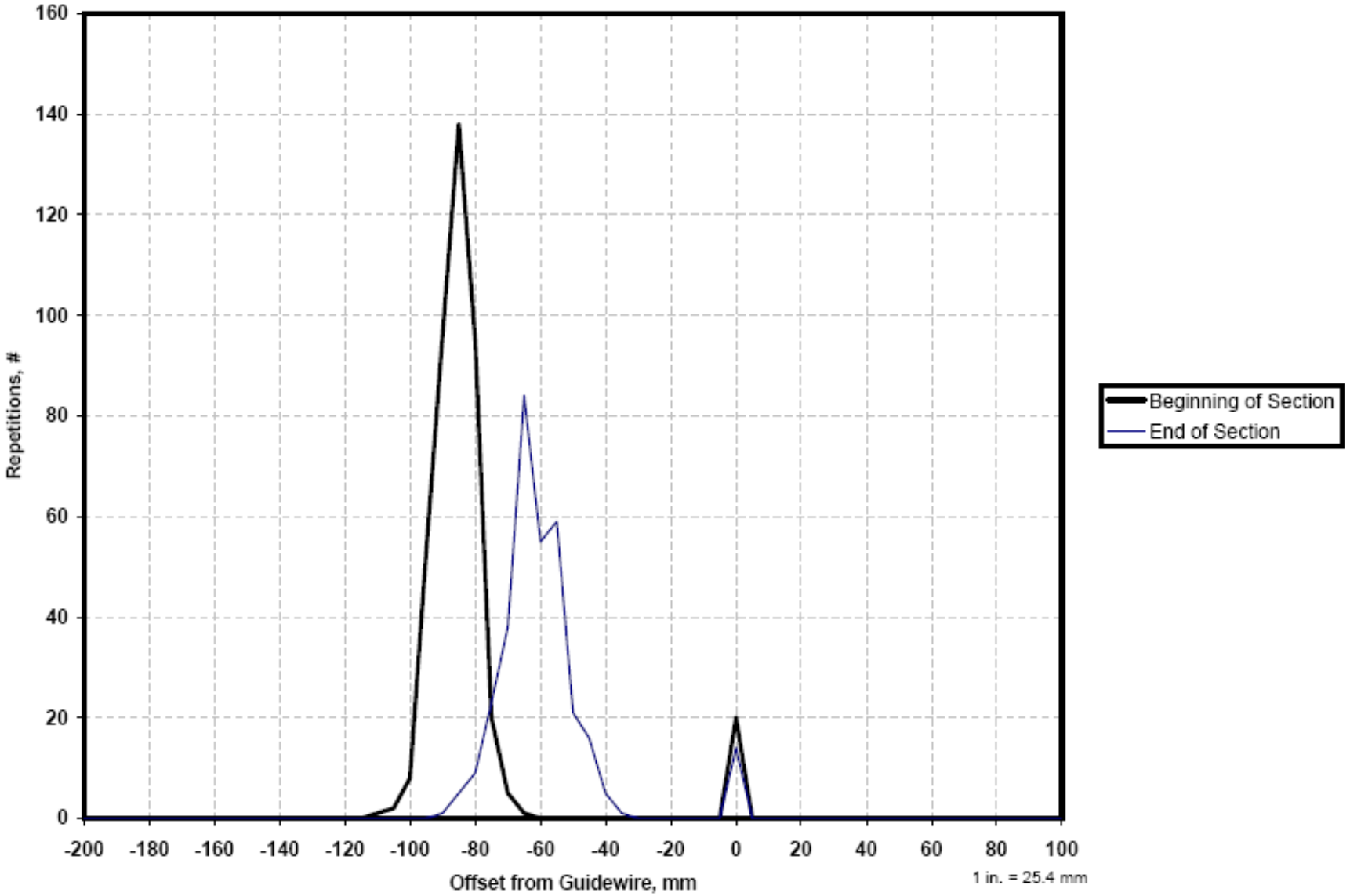


Figure A39. Front Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/11/97.

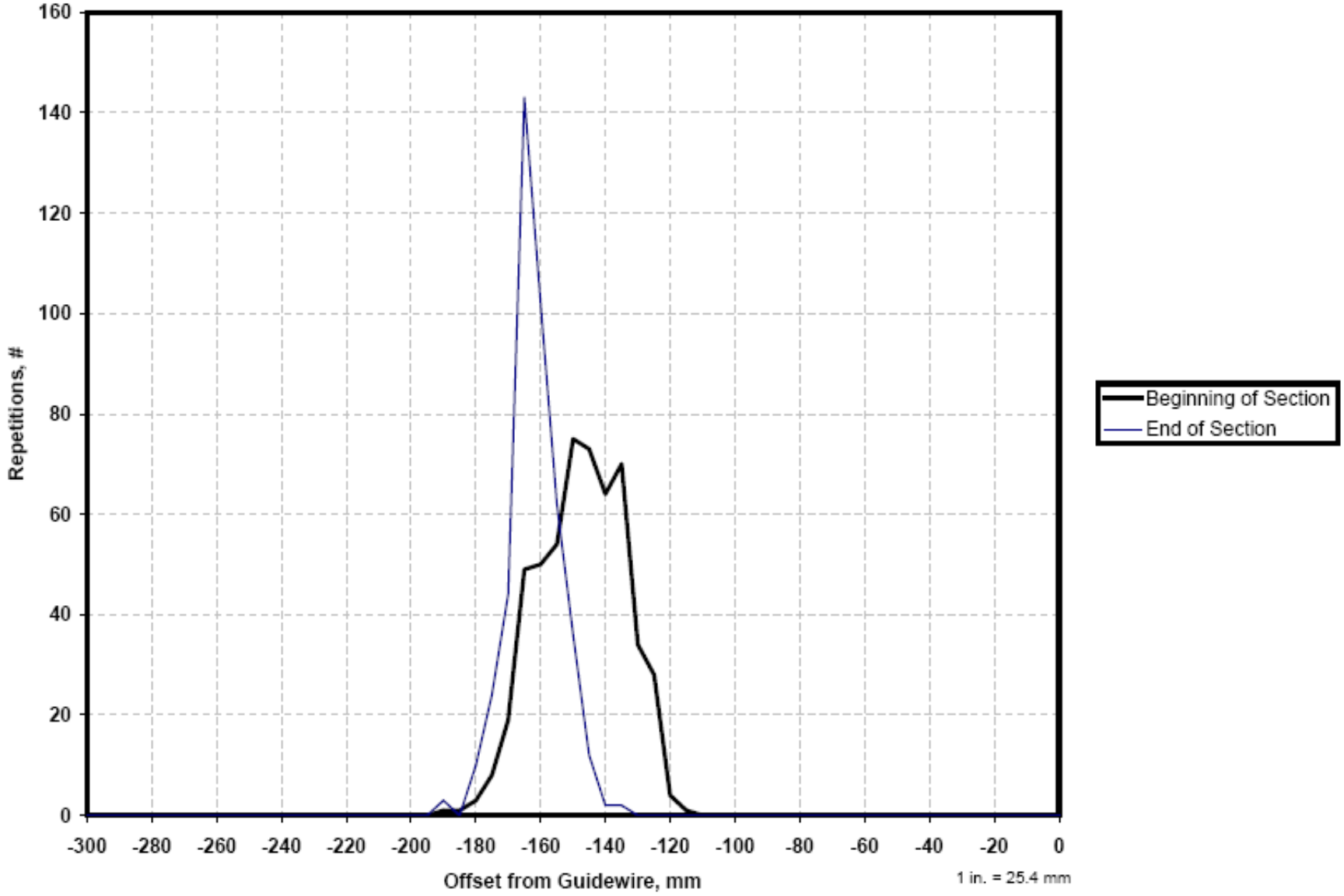


Figure A40. Front Antenna Offset Histogram for Section 4 With Front Antenna Centered, 8/12/97.

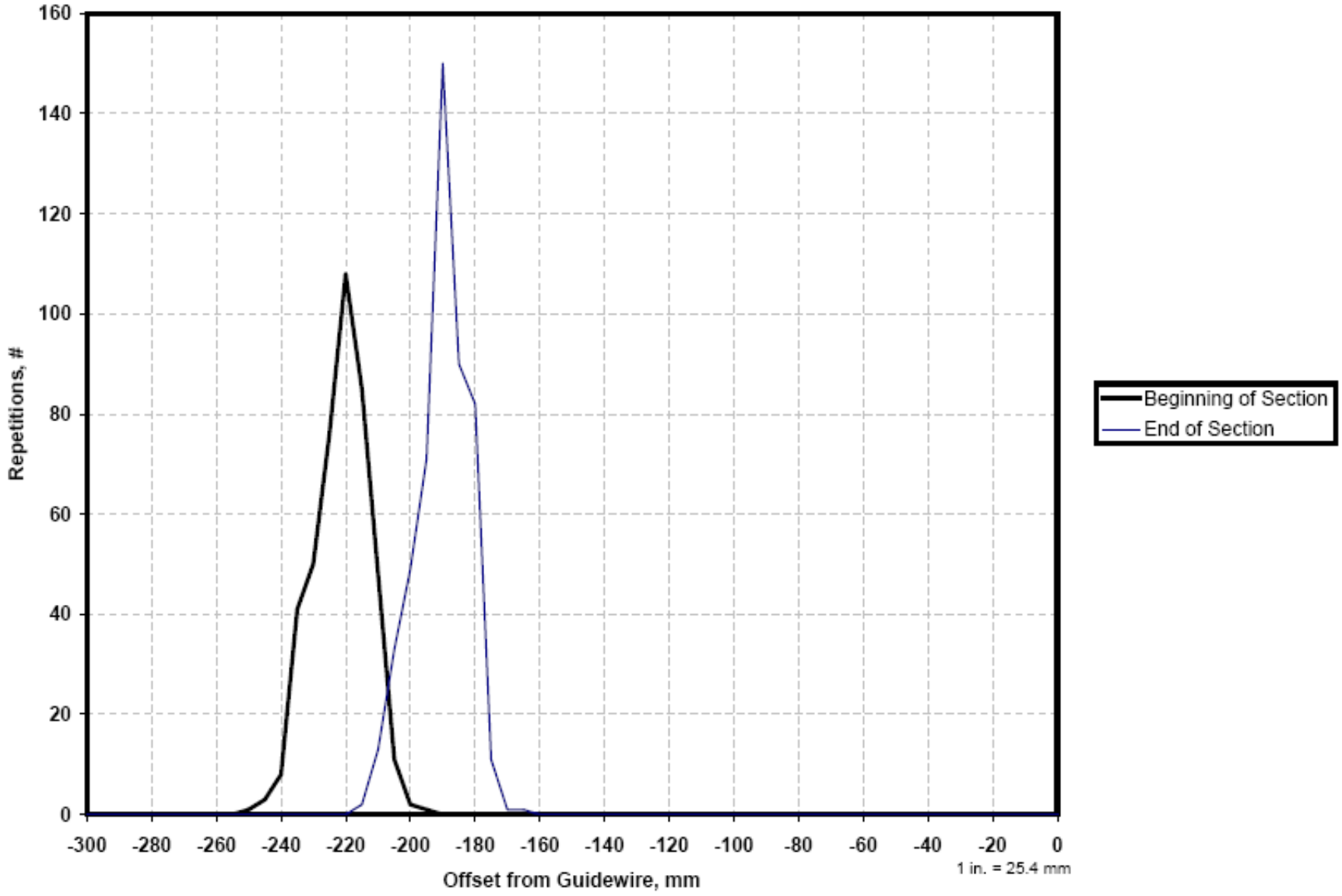


Figure A41. Front Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/12/97.

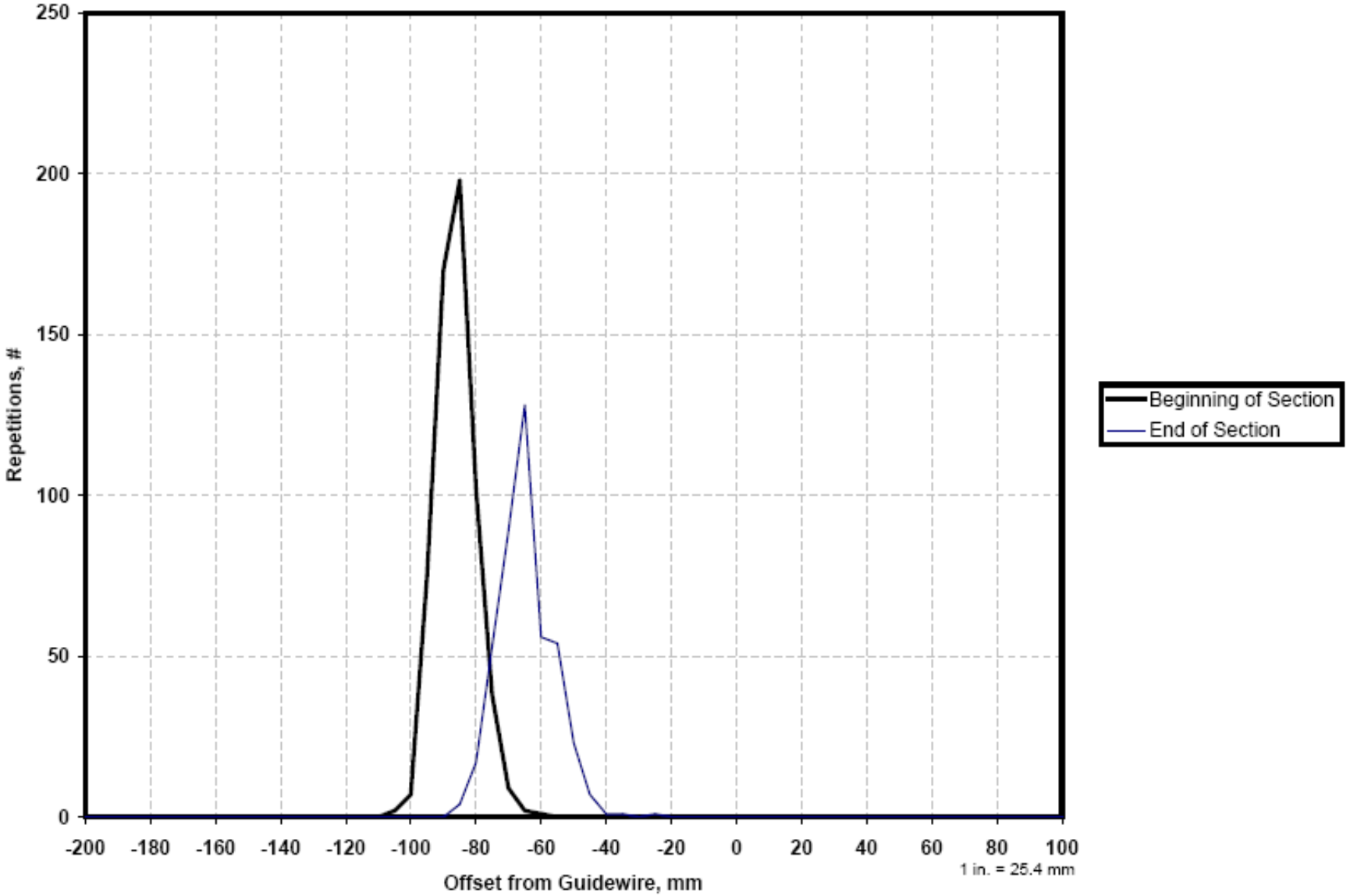


Figure A42. Front Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/12/97.

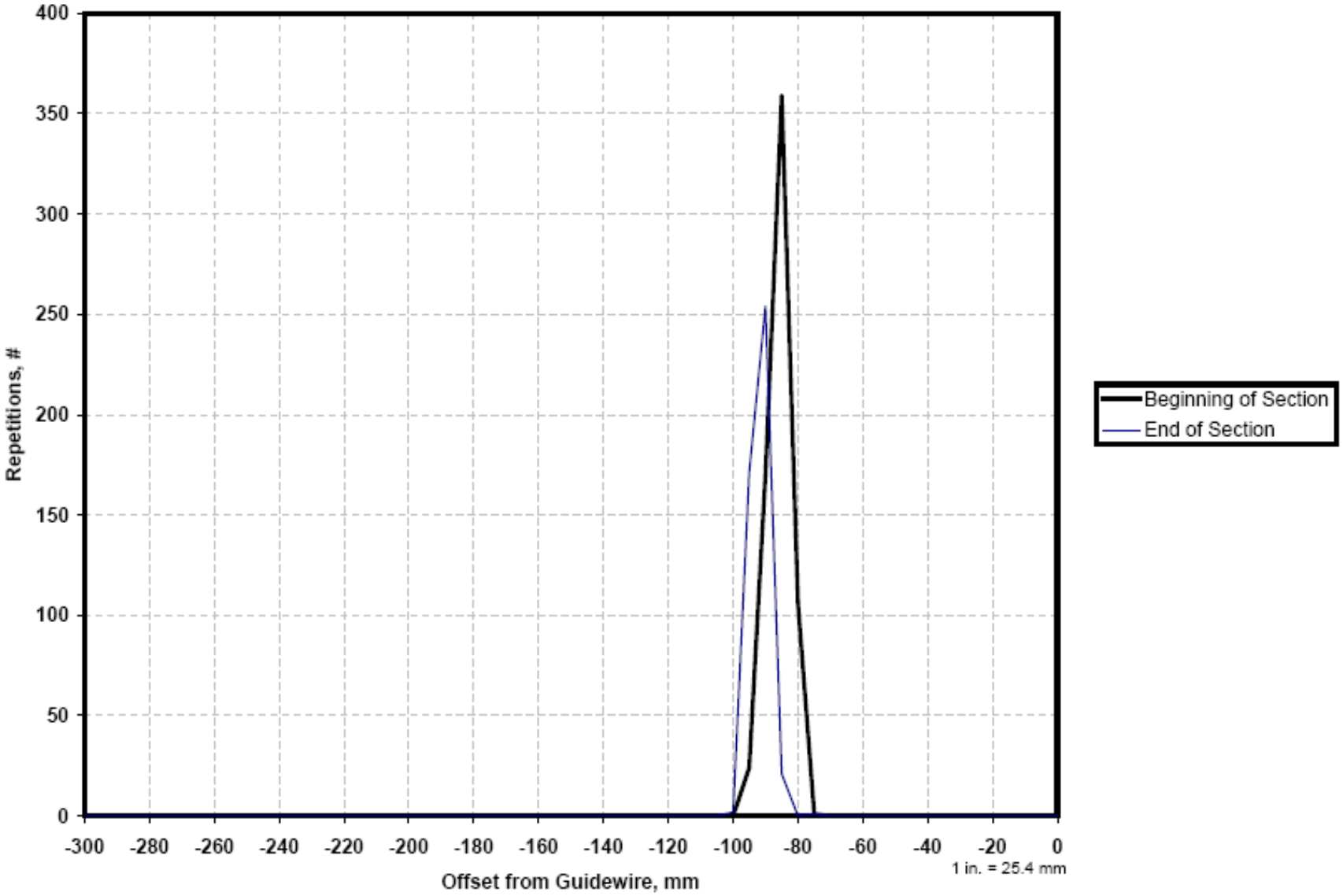


Figure A43. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 25.4 mm (1 in.) Right, 11/29/97.

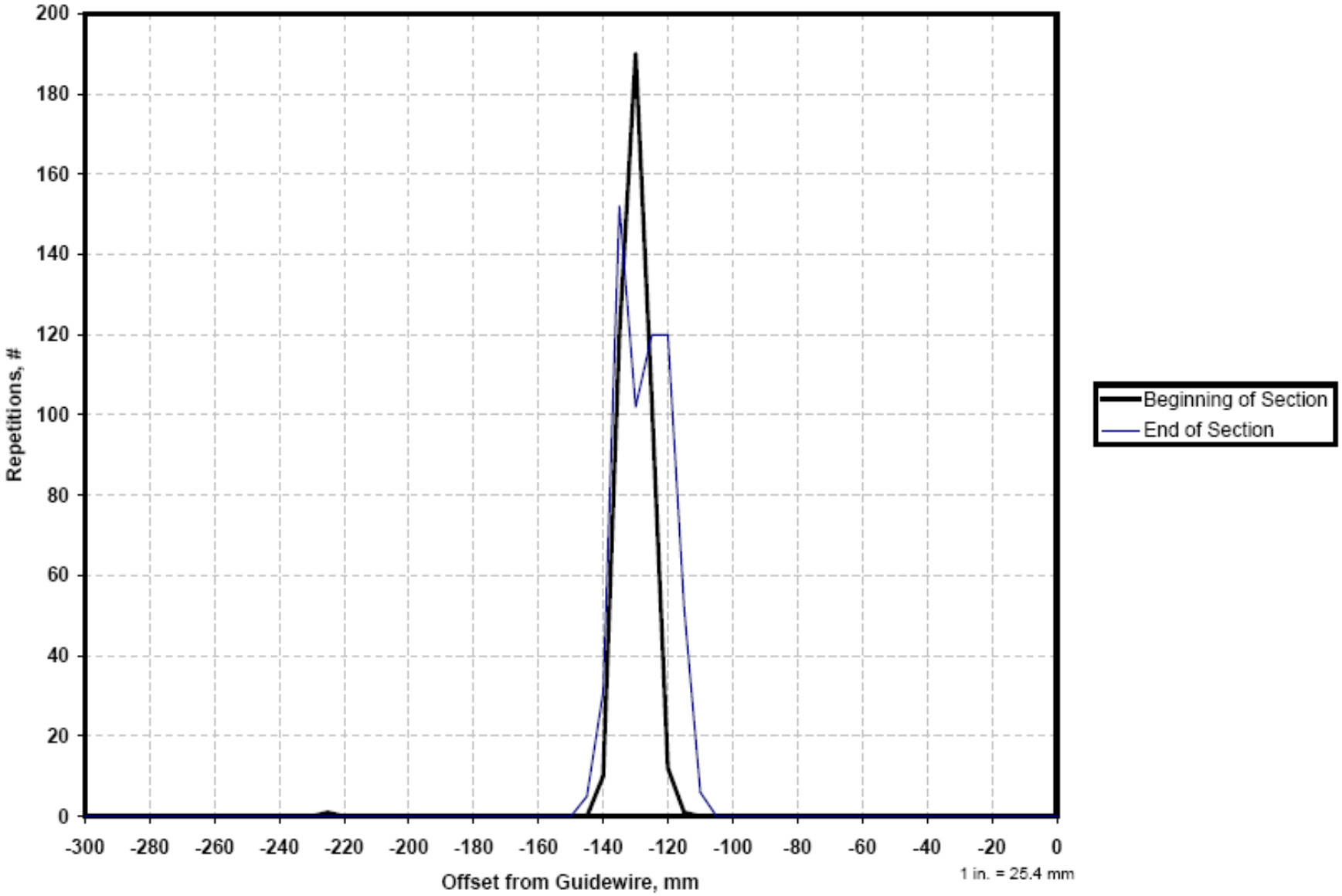


Figure A44. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 25.4 mm (1 in.) Right, 11/29/97.

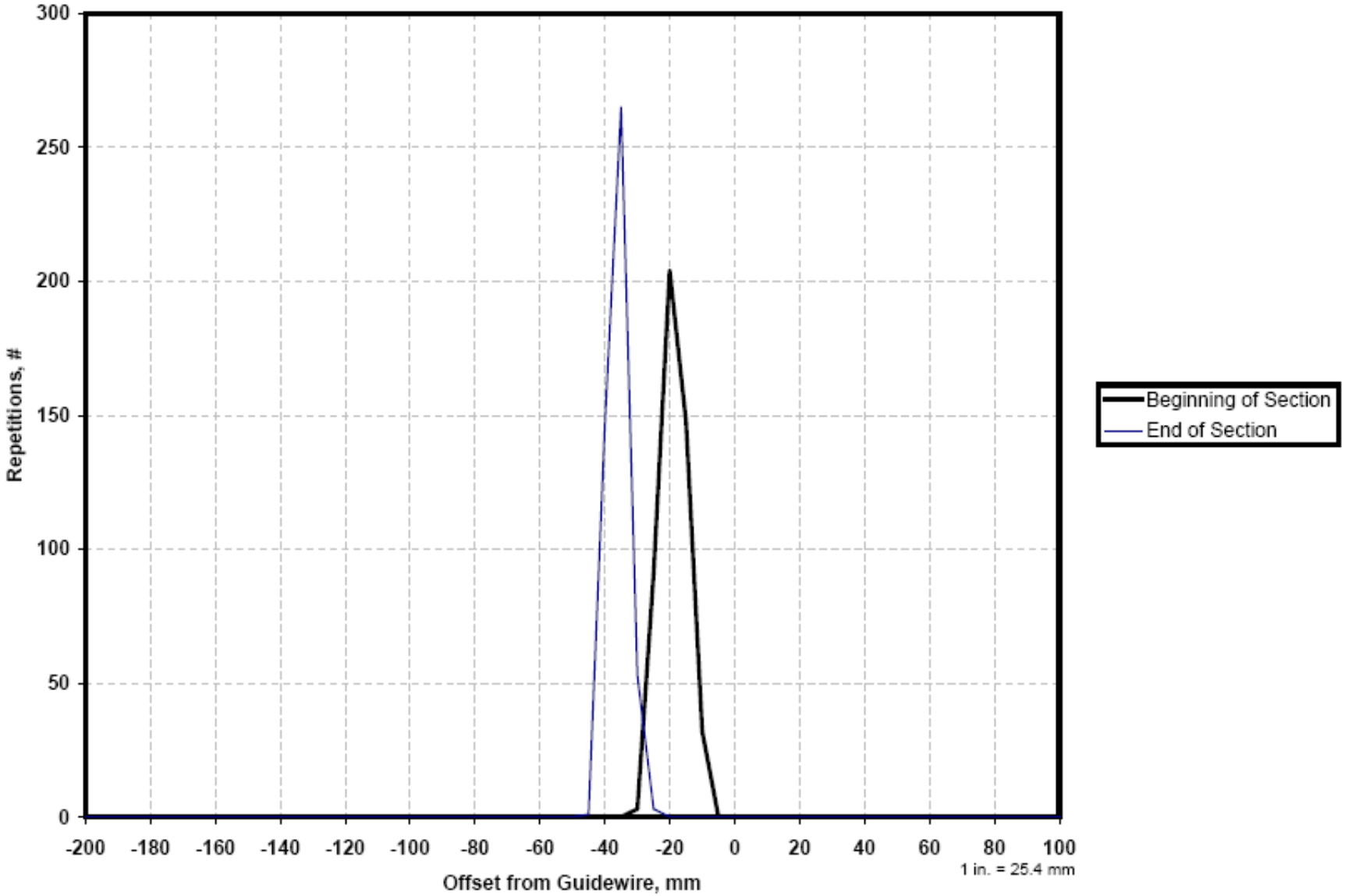


Figure A45. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 25.4 mm (1 in.) Right, 11/29/97.

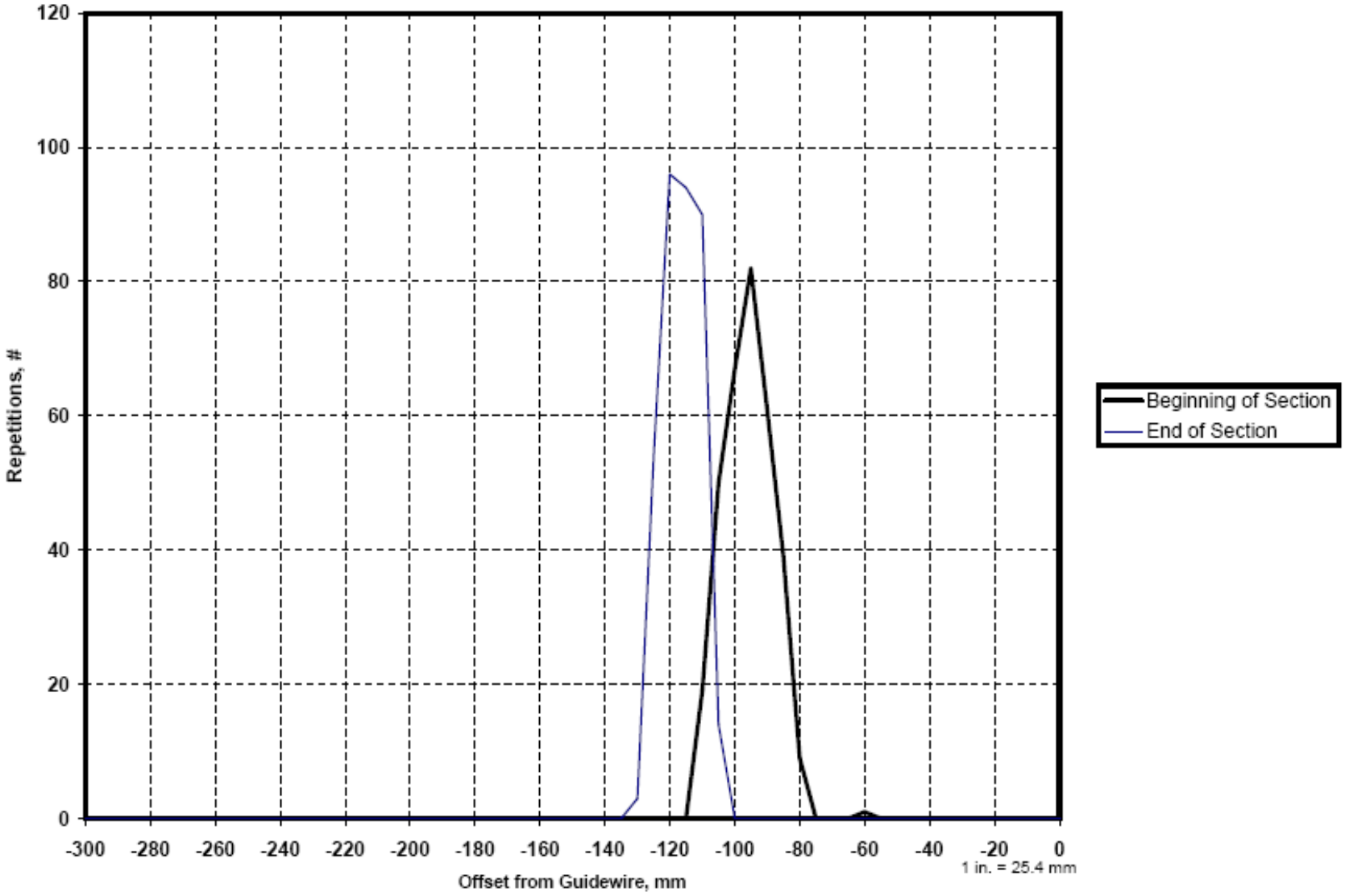


Figure A46. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 50.8 mm (2 in.) Right, 8/2/97.

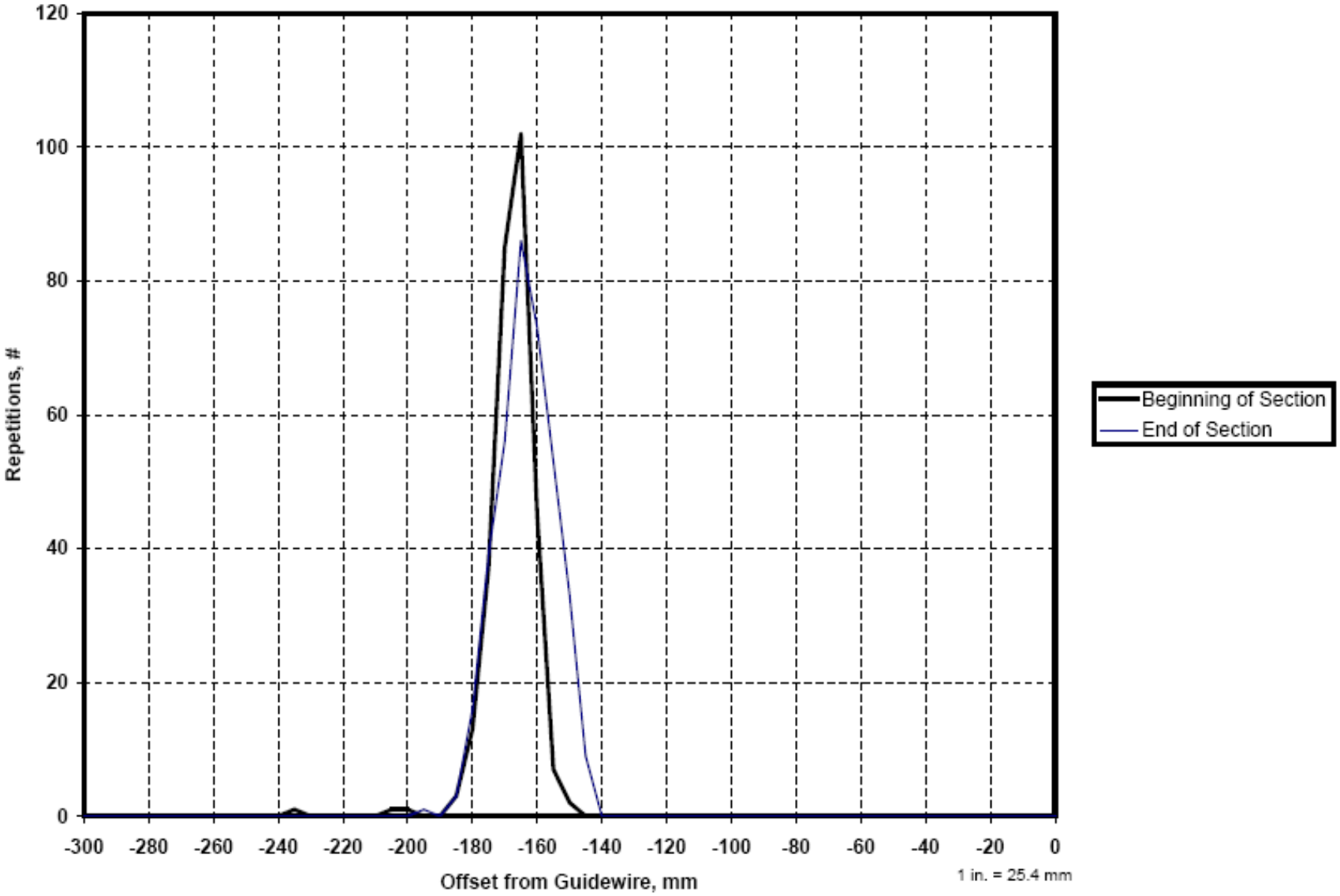


Figure A47. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 50.8 mm (2 in.) Right, 8/2/97.

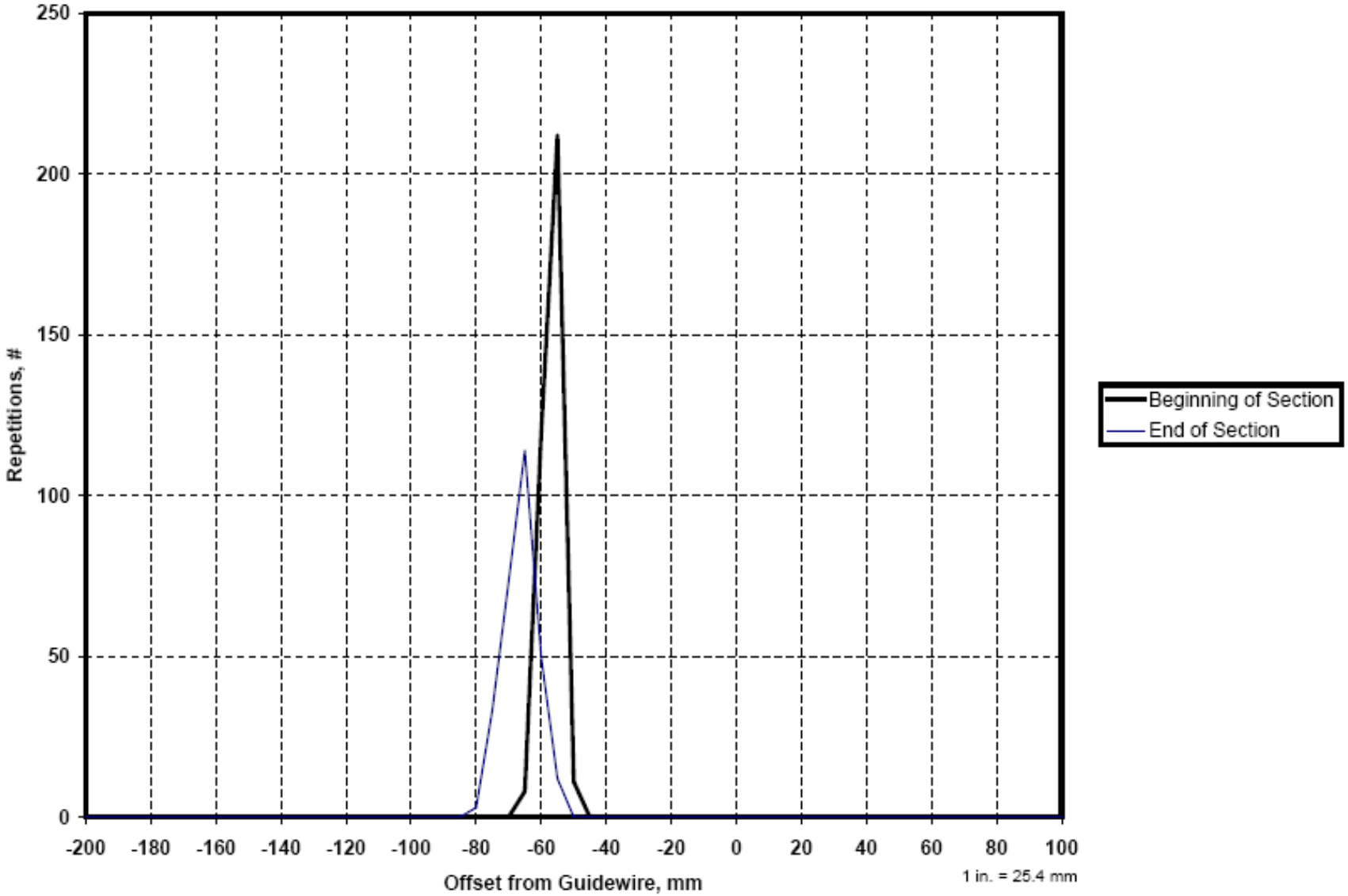


Figure A48. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 50.8 mm (2 in.) Right, 8/2/97.

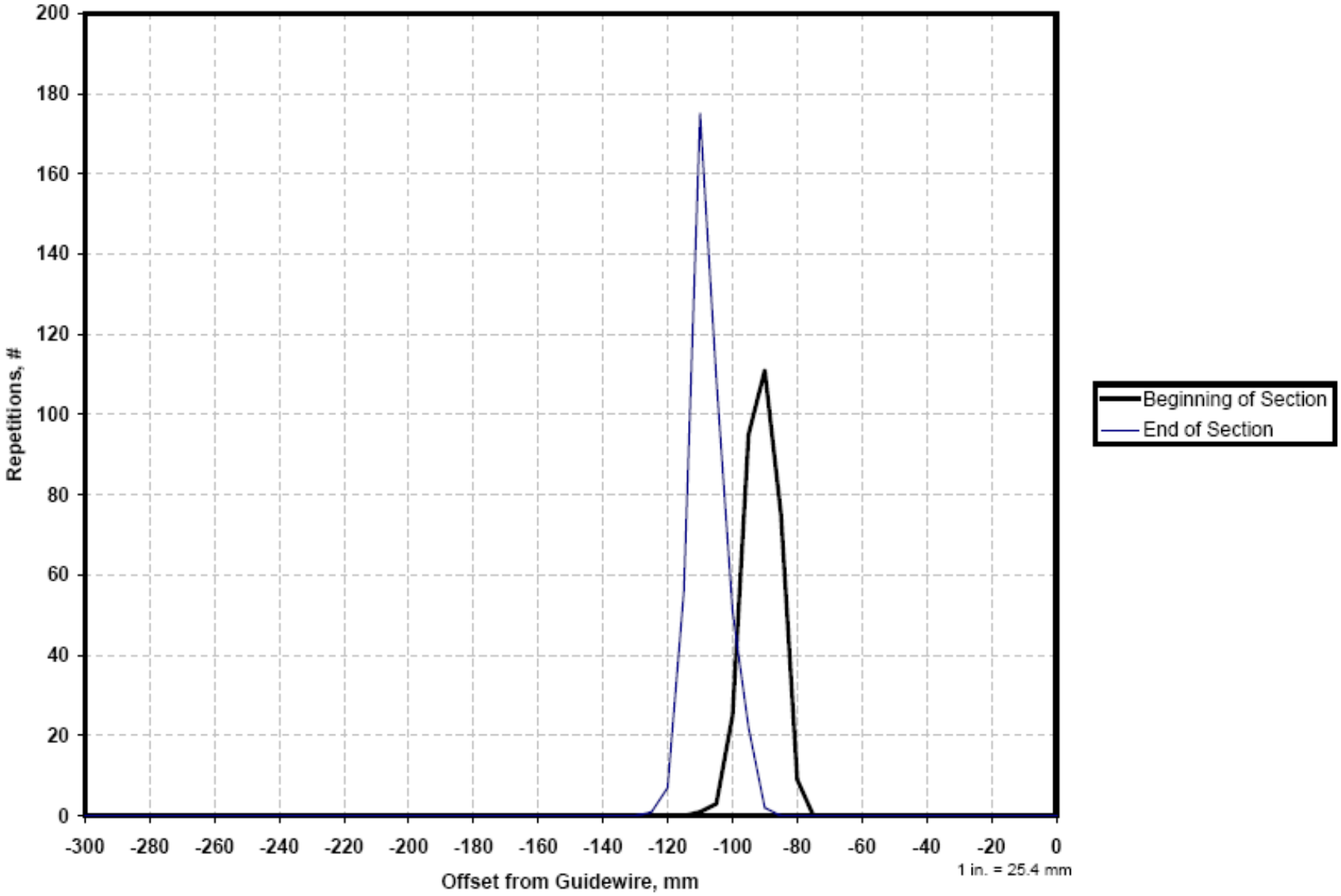


Figure A49. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 76.2 mm (3 in.) Right, 8/10/97.

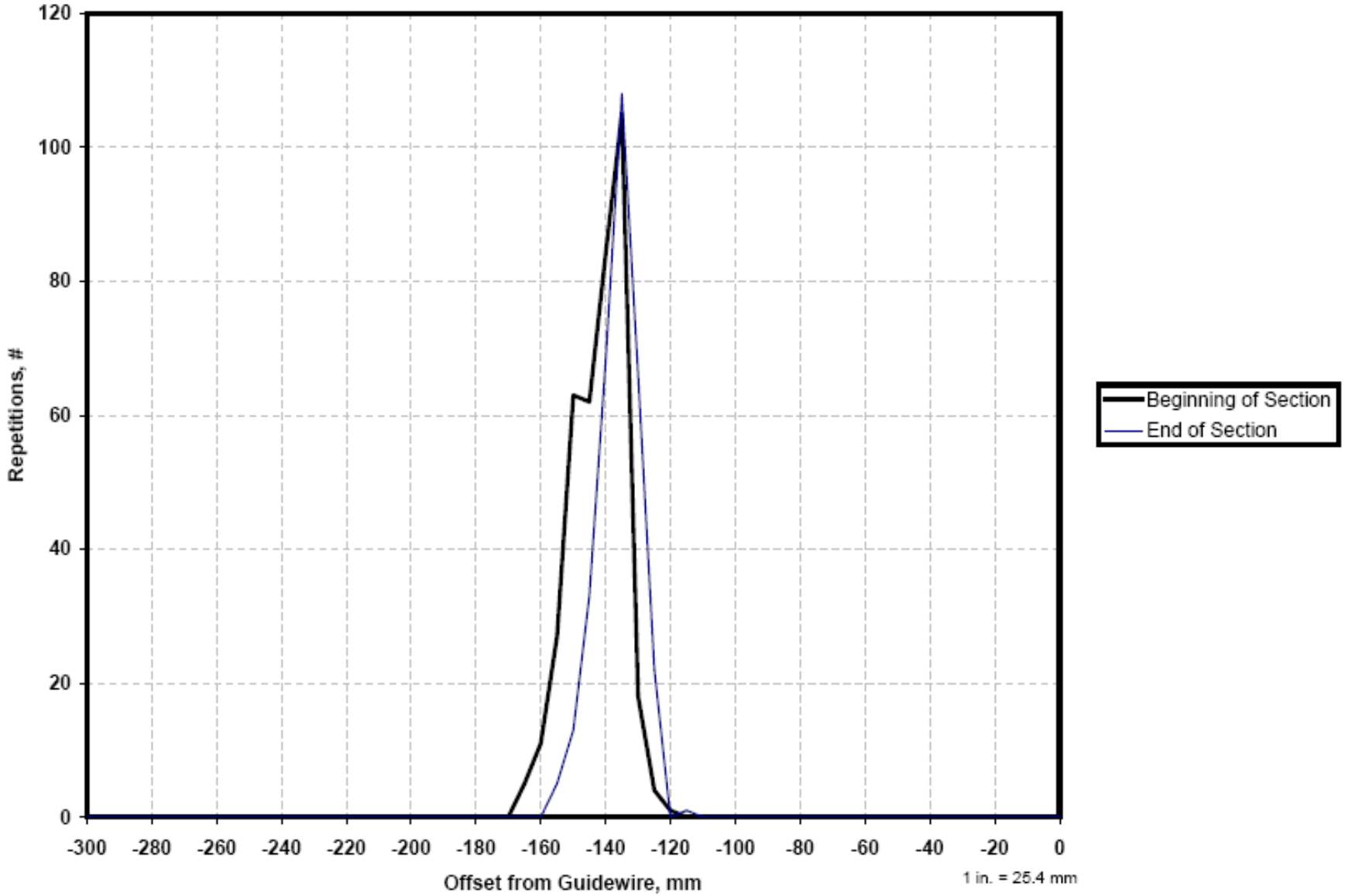


Figure A50. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 76.2 mm (3 in.) Right, 8/10/97.

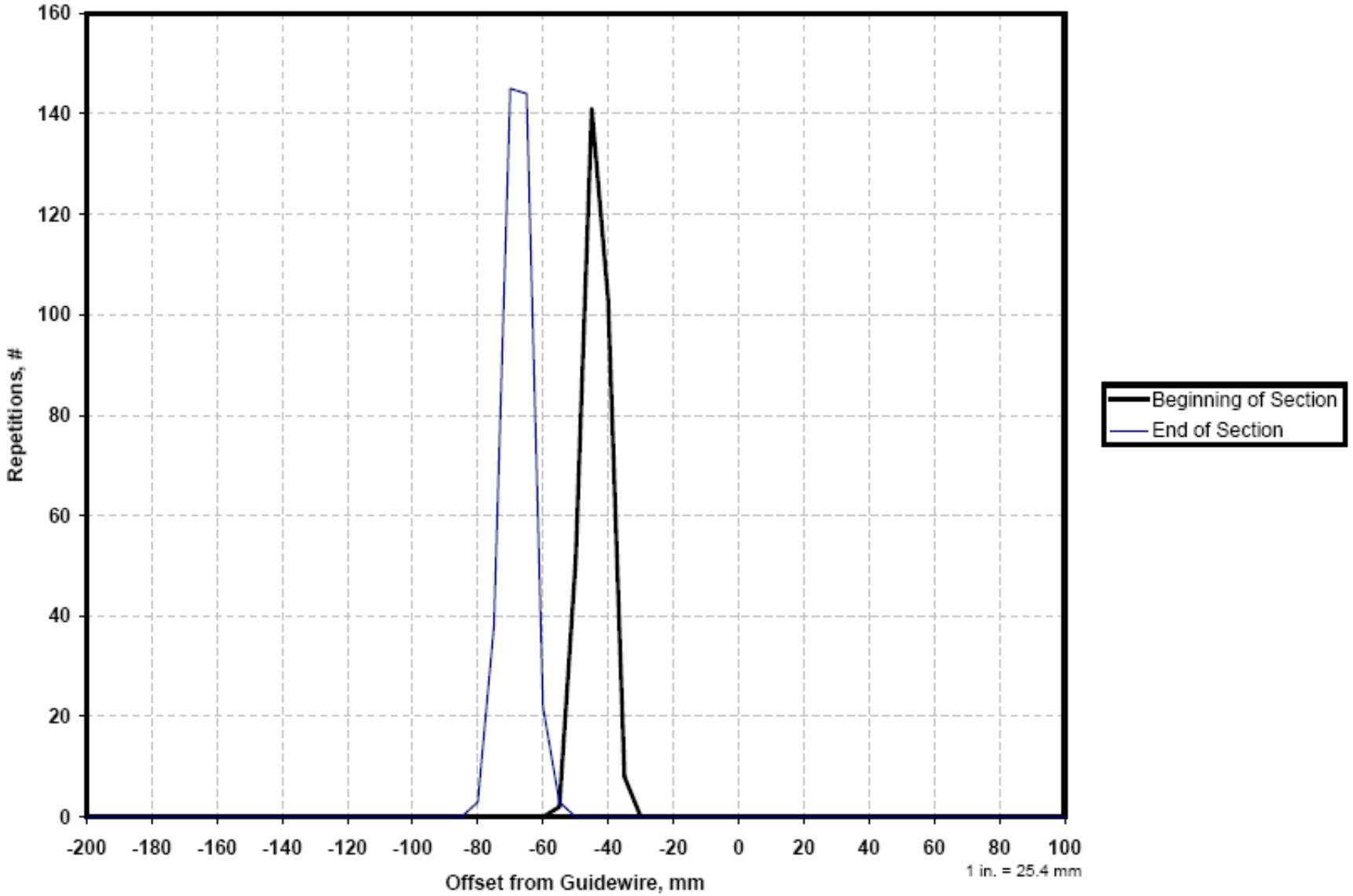


Figure A51. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 76.2 mm (3 in.) Right, 8/10/97.

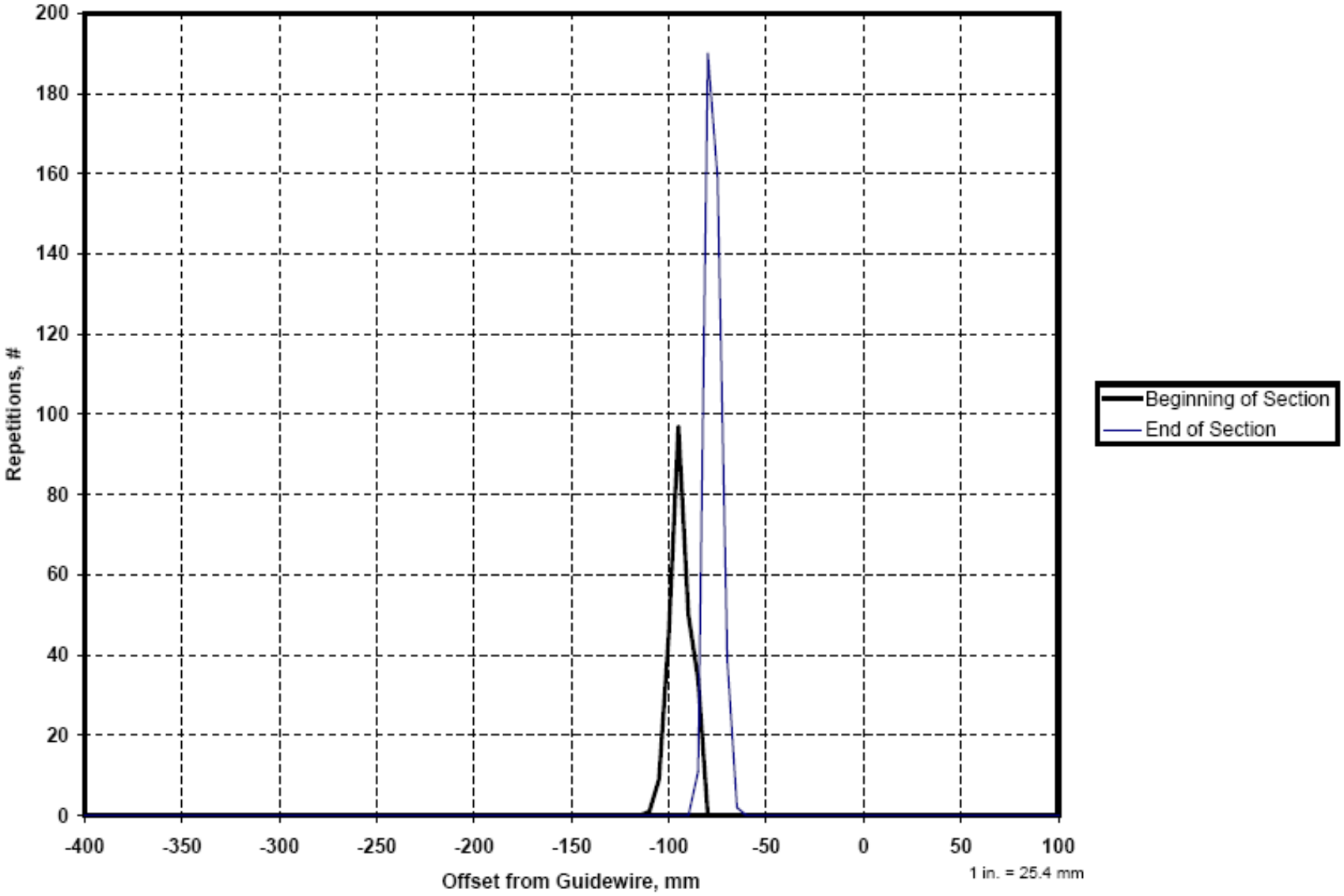


Figure A52. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 101.6 mm (4 in.) Right, 4/30/97.

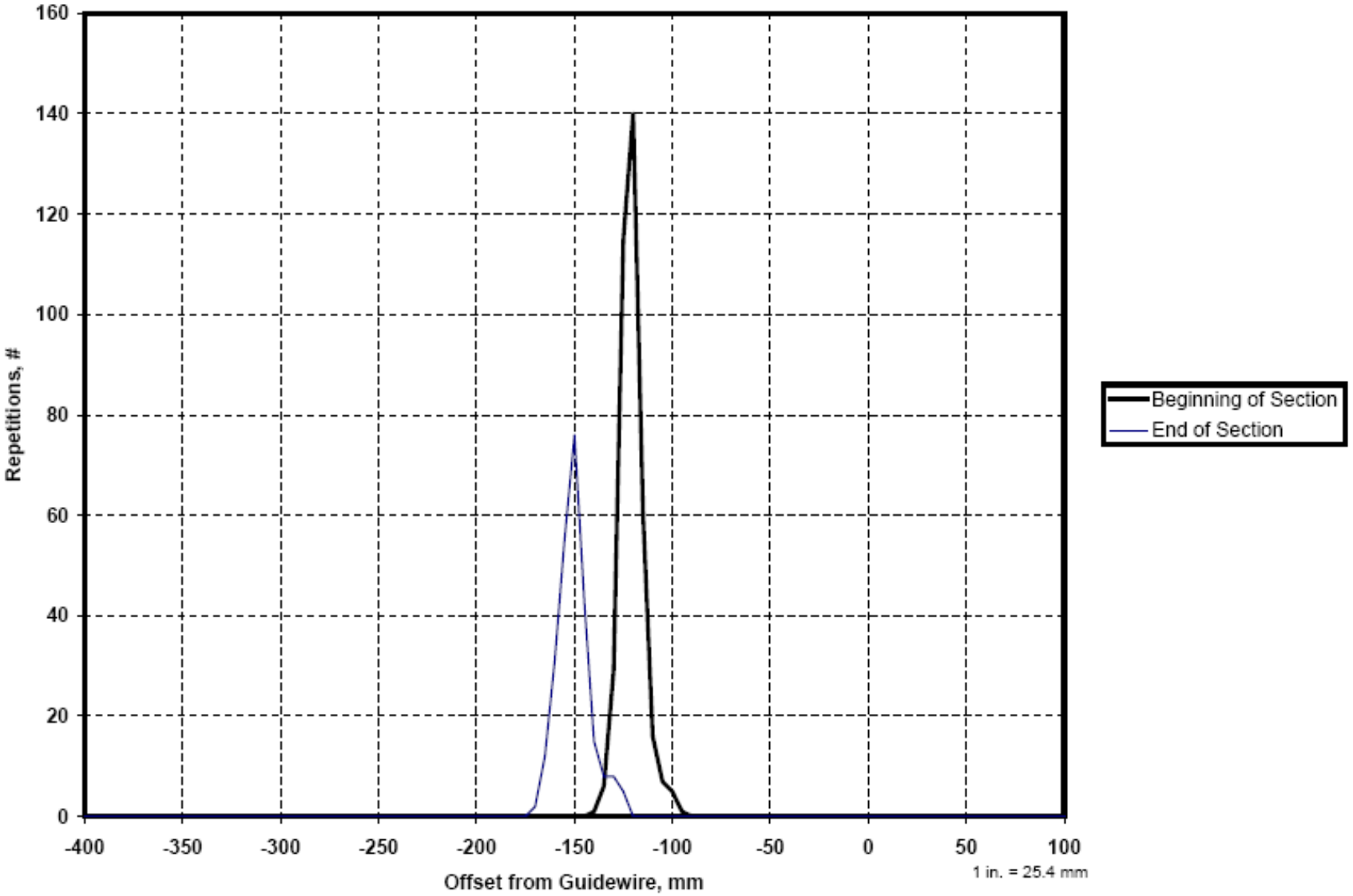


Figure A53. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 101.6 mm (4 in.) Right, 4/30/97.

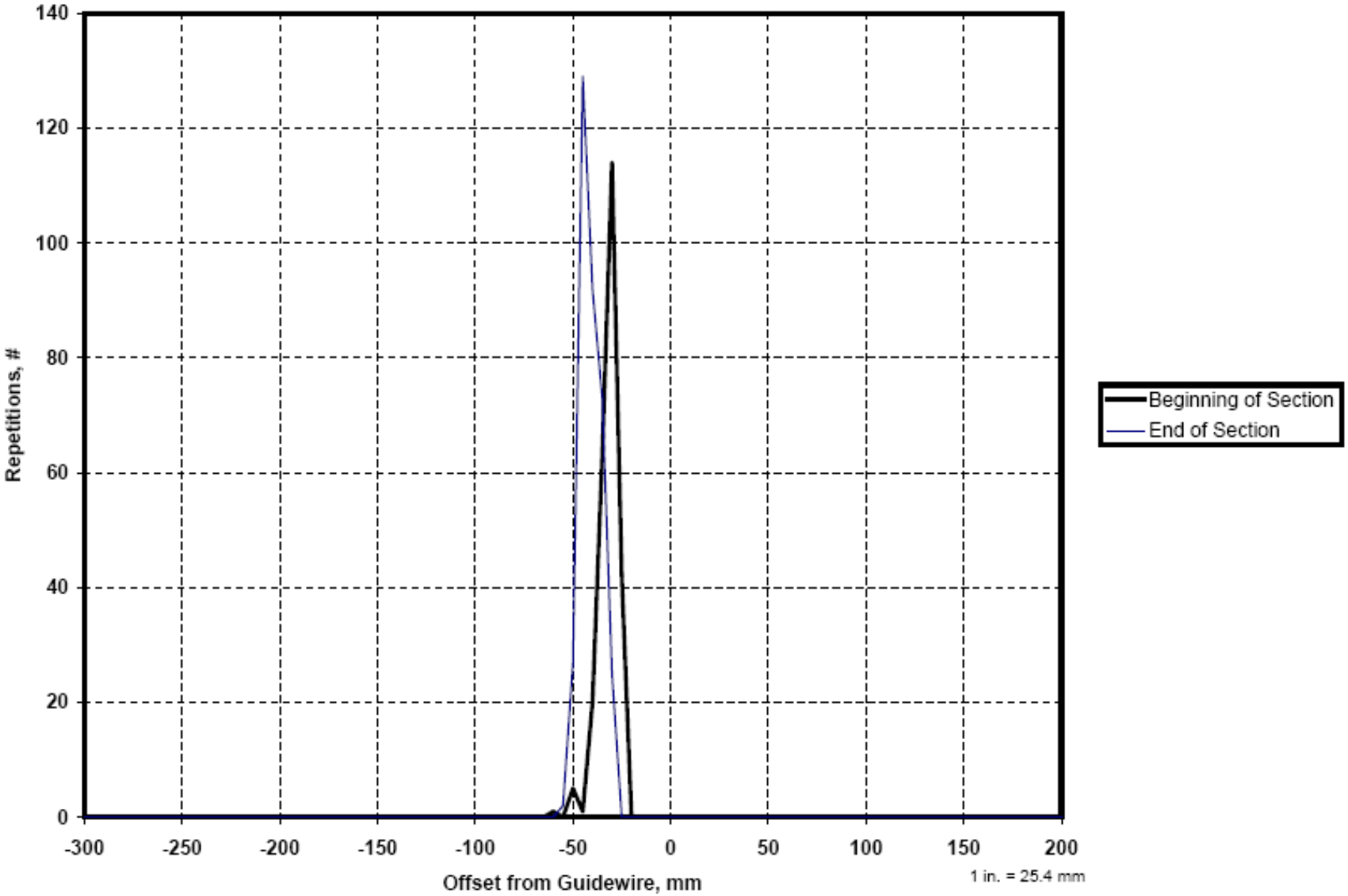


Figure A54. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 101.6 mm (4 in.) Right, 4/30/97.

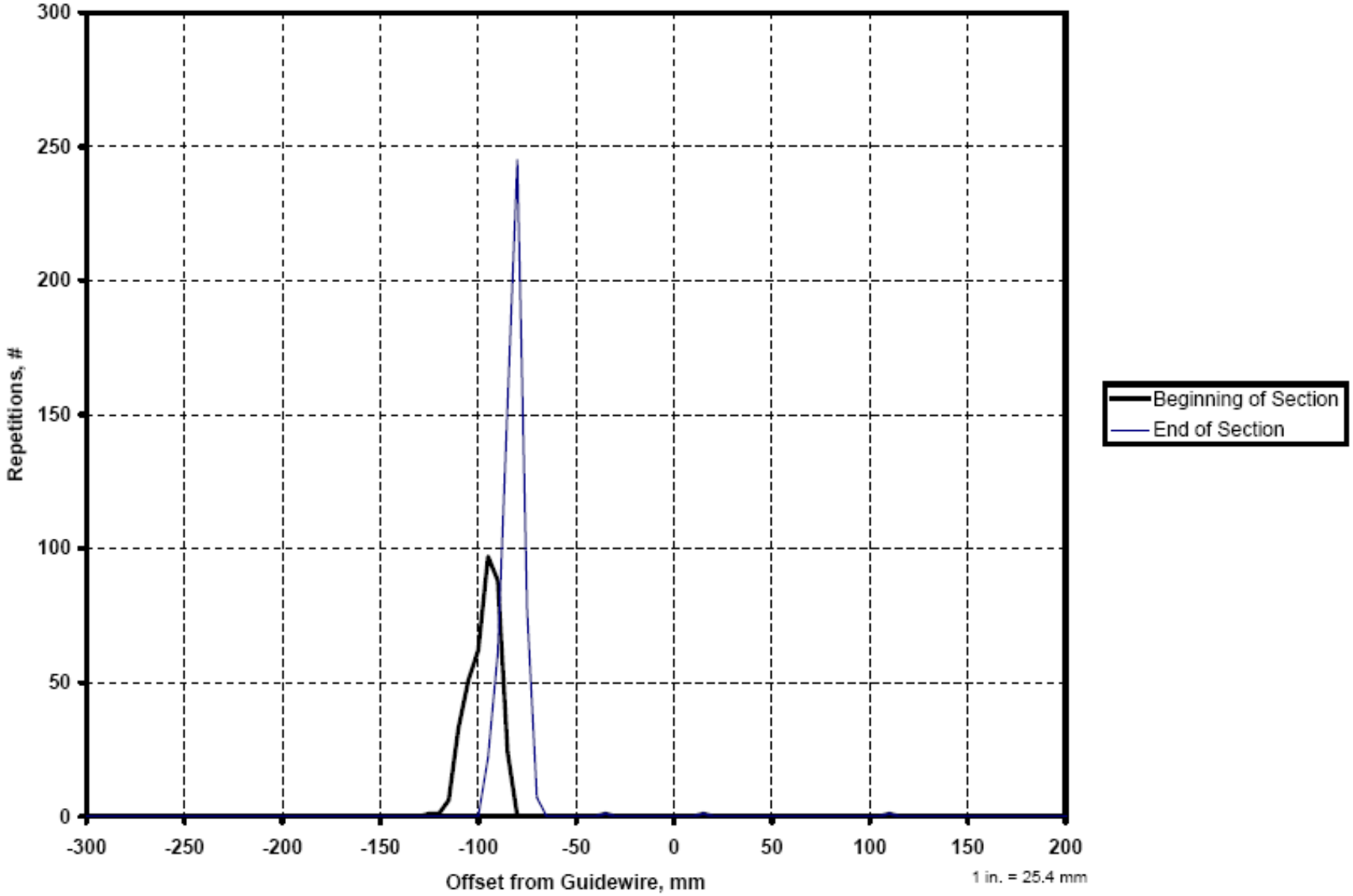


Figure A55. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 101.6 mm (4 in.) Right, 5/2/97.

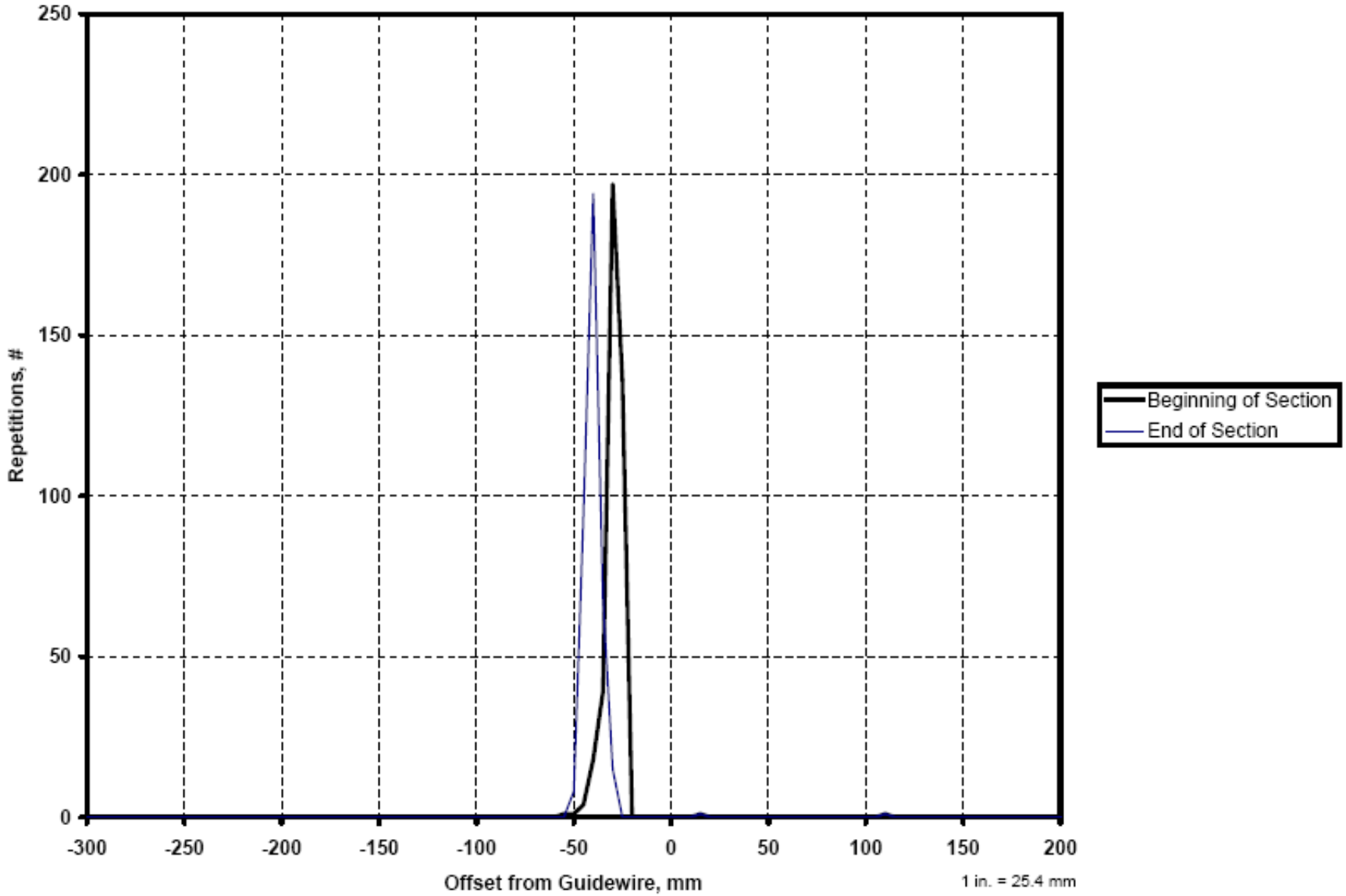


Figure A57. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 101.6 mm (4 in.) Right, 5/2/97.

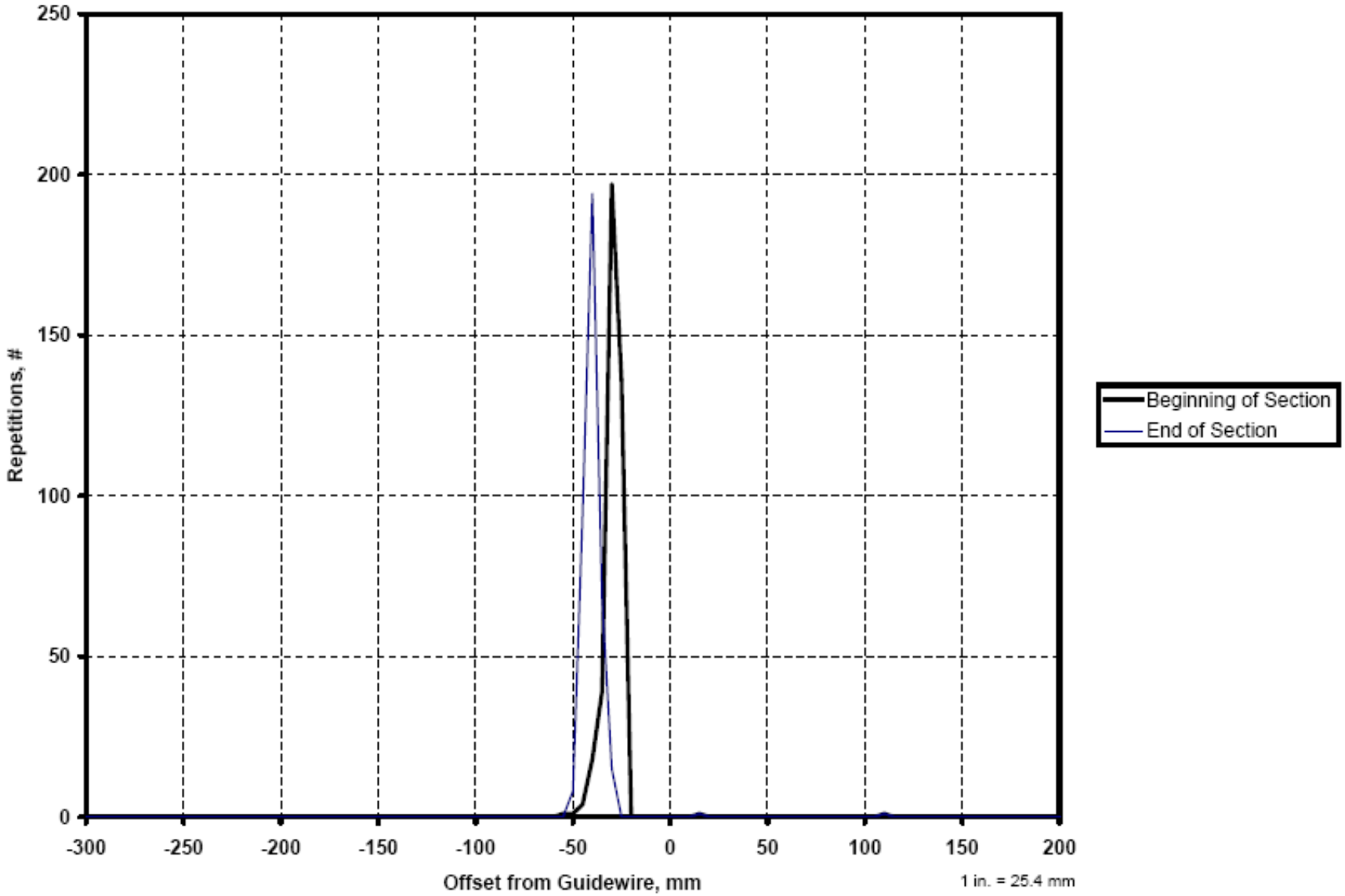


Figure A57. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 101.6 mm (4 in.) Right, 5/2/97.

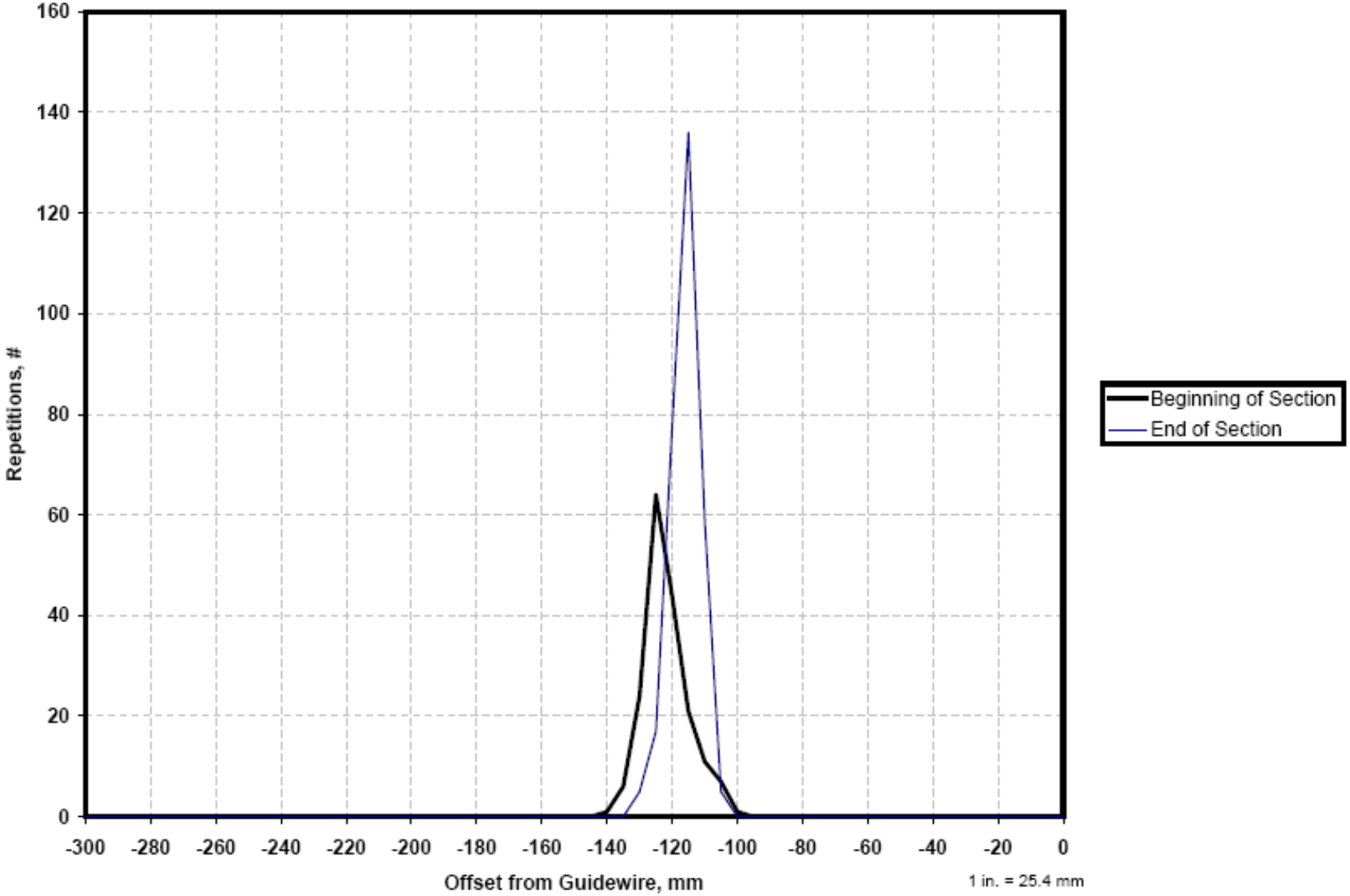


Figure A58. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 127 mm (5 in.) Right, 7/31/97.

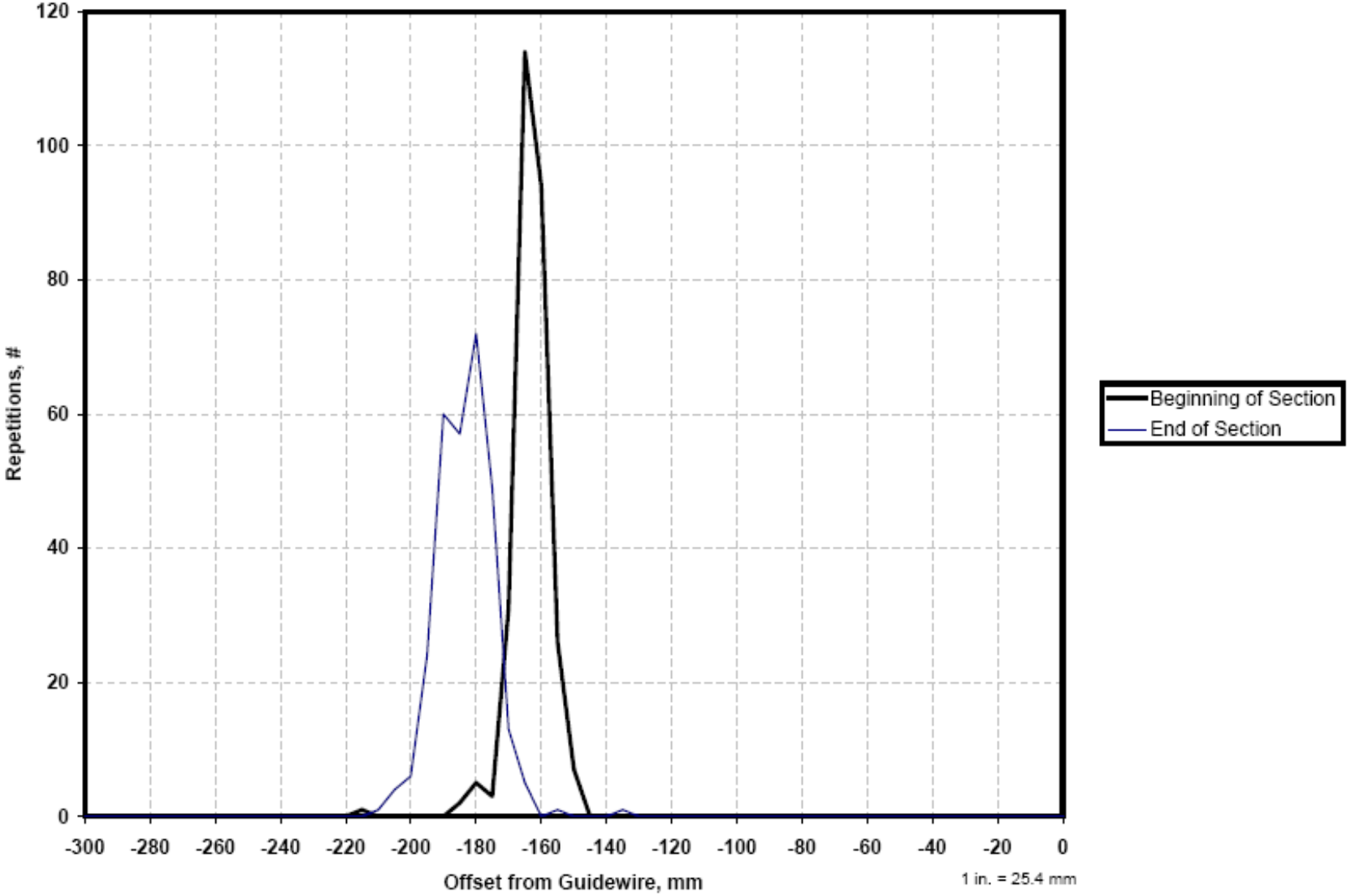


Figure A59. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 127 mm (5 in.) Right, 7/31/97.

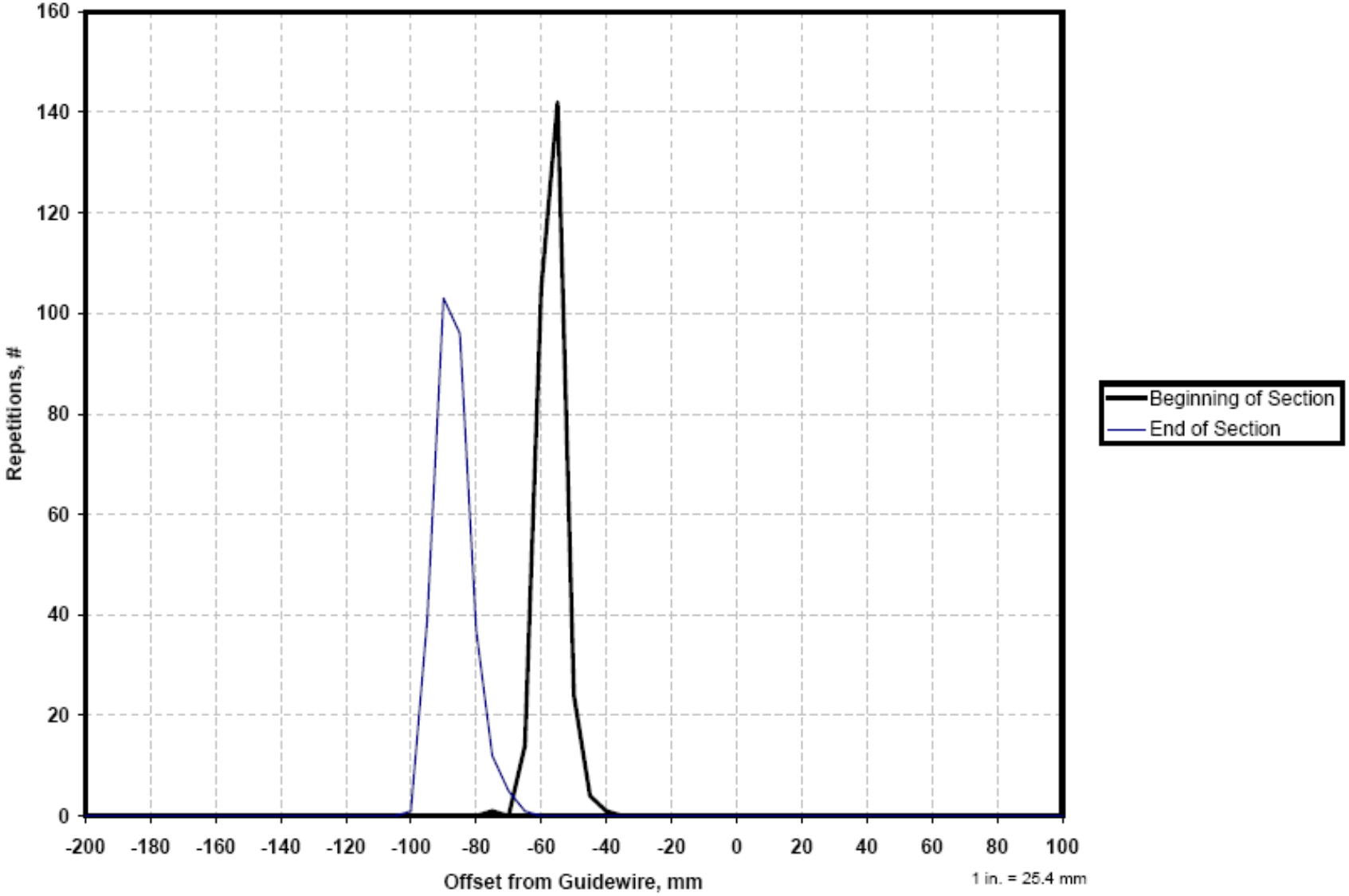


Figure A60. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 127 mm (5 in.) Right, 7/31/97.

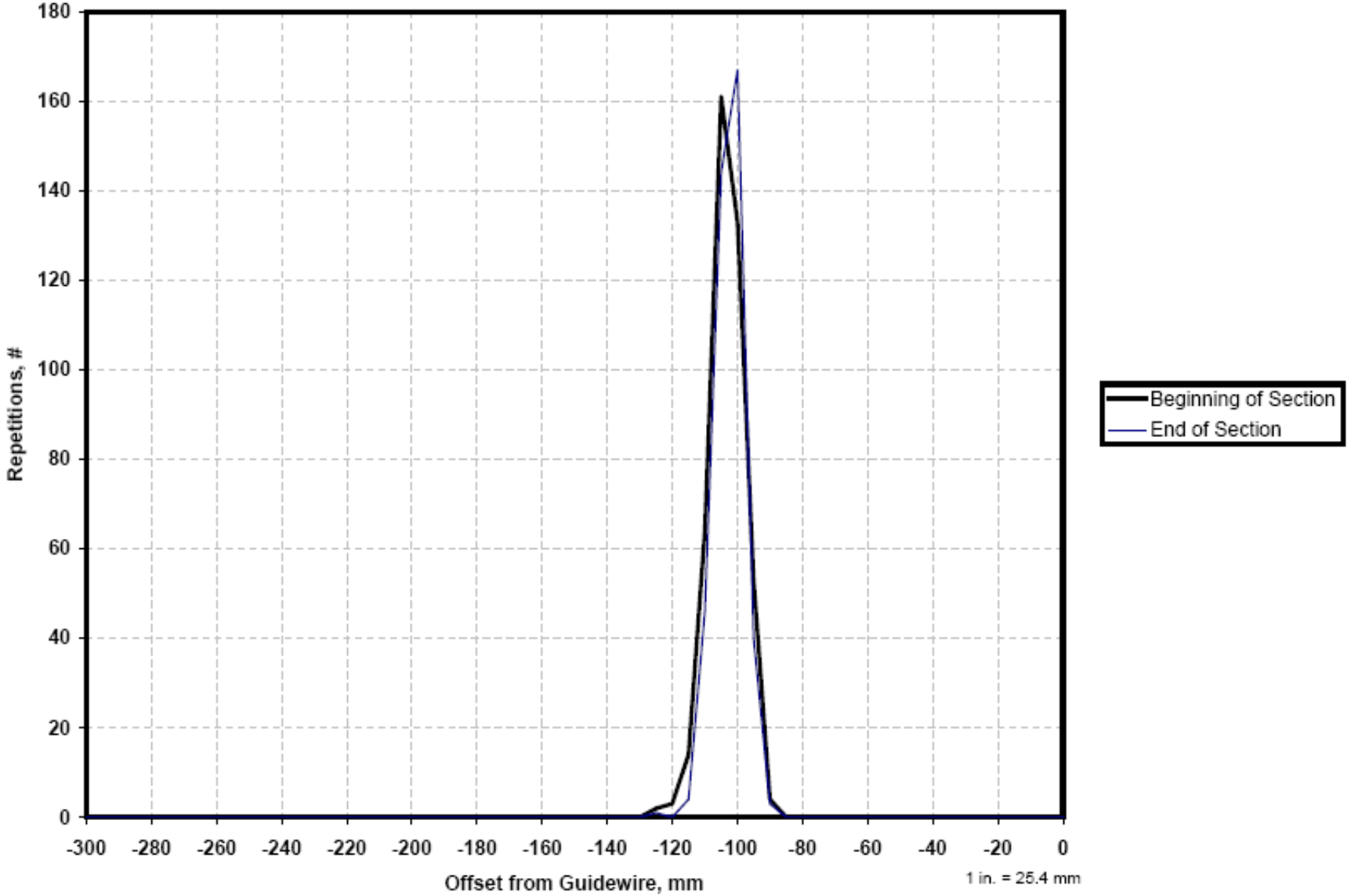


Figure A61. Front Antenna Offset Histogram for Section 4 With Front Antenna Set at 127 mm (5 in.) Right, 8/3/97.

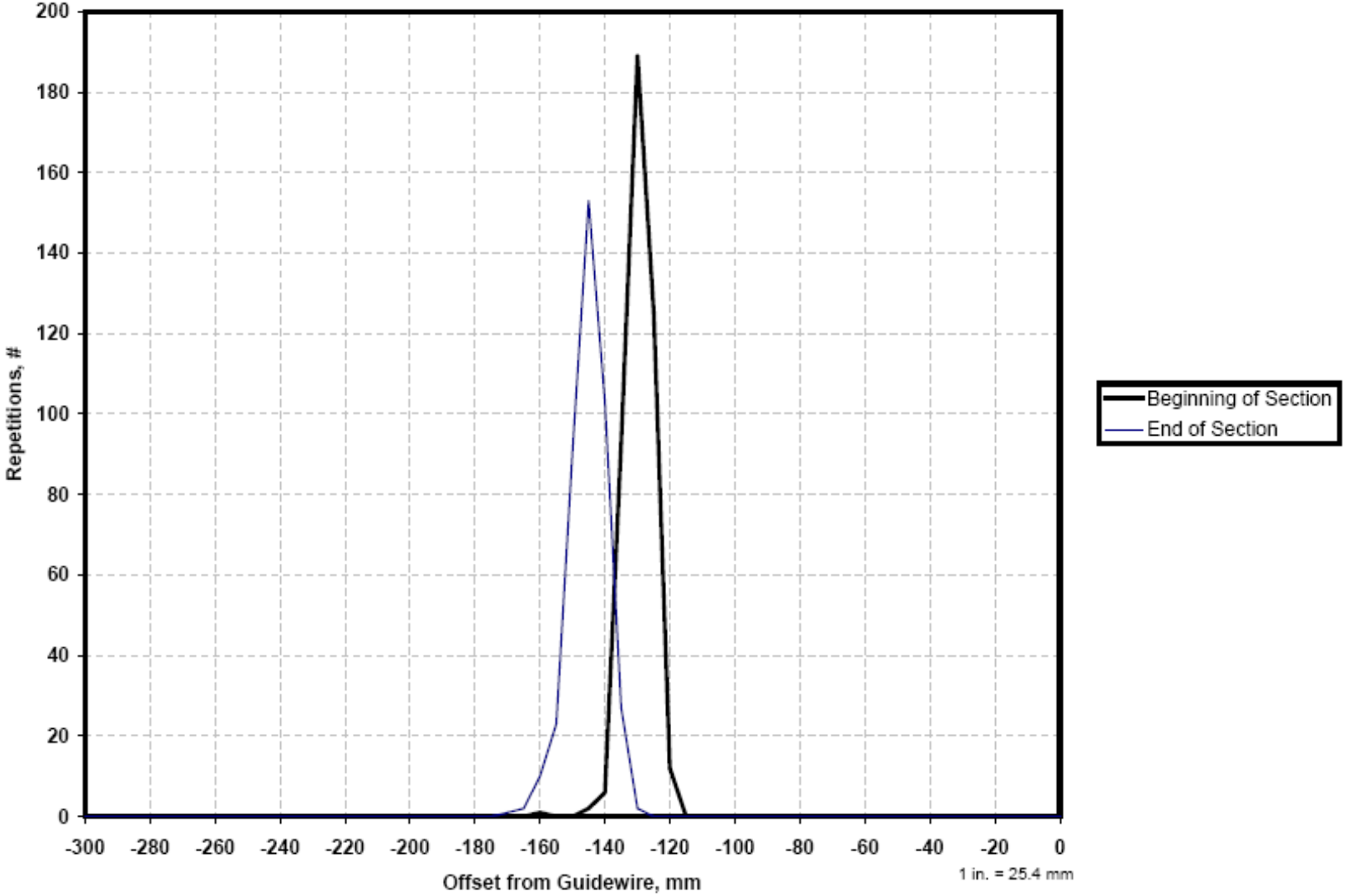


Figure A62. Front Antenna Offset Histogram for Section 14 With Front Antenna Set at 127 mm (5 in.) Right, 8/3/97.

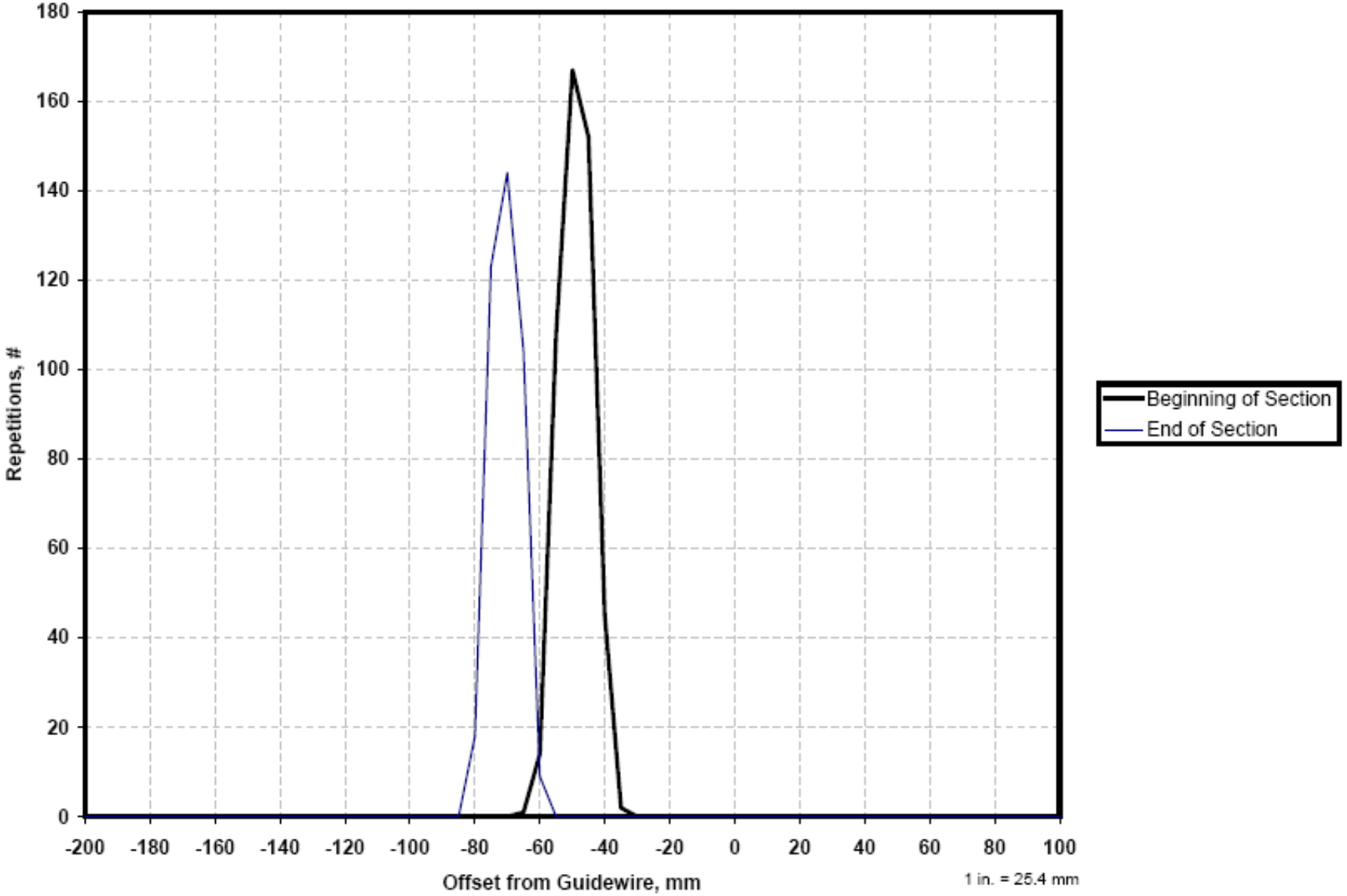


Figure A63. Front Antenna Offset Histogram for Section 23 With Front Antenna Set at 127 mm (5 in.) Right, 8/3/97.

APPENDIX B

DAILY HISTOGRAMS FROM REAR ANTENNA LATERAL OFFSET DATA

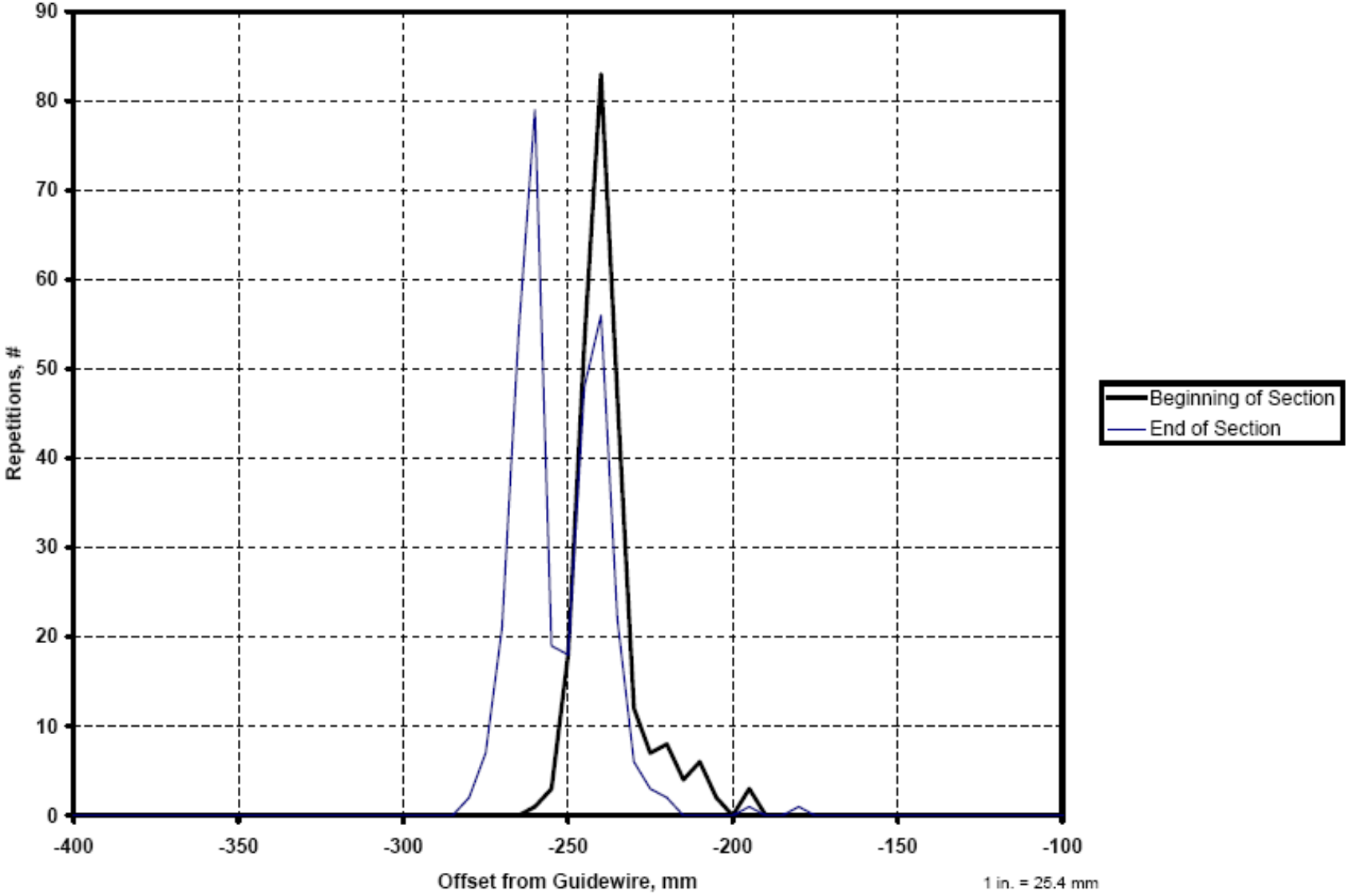


Figure B1. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 127 mm (5 in.) Left, 7/31/97.

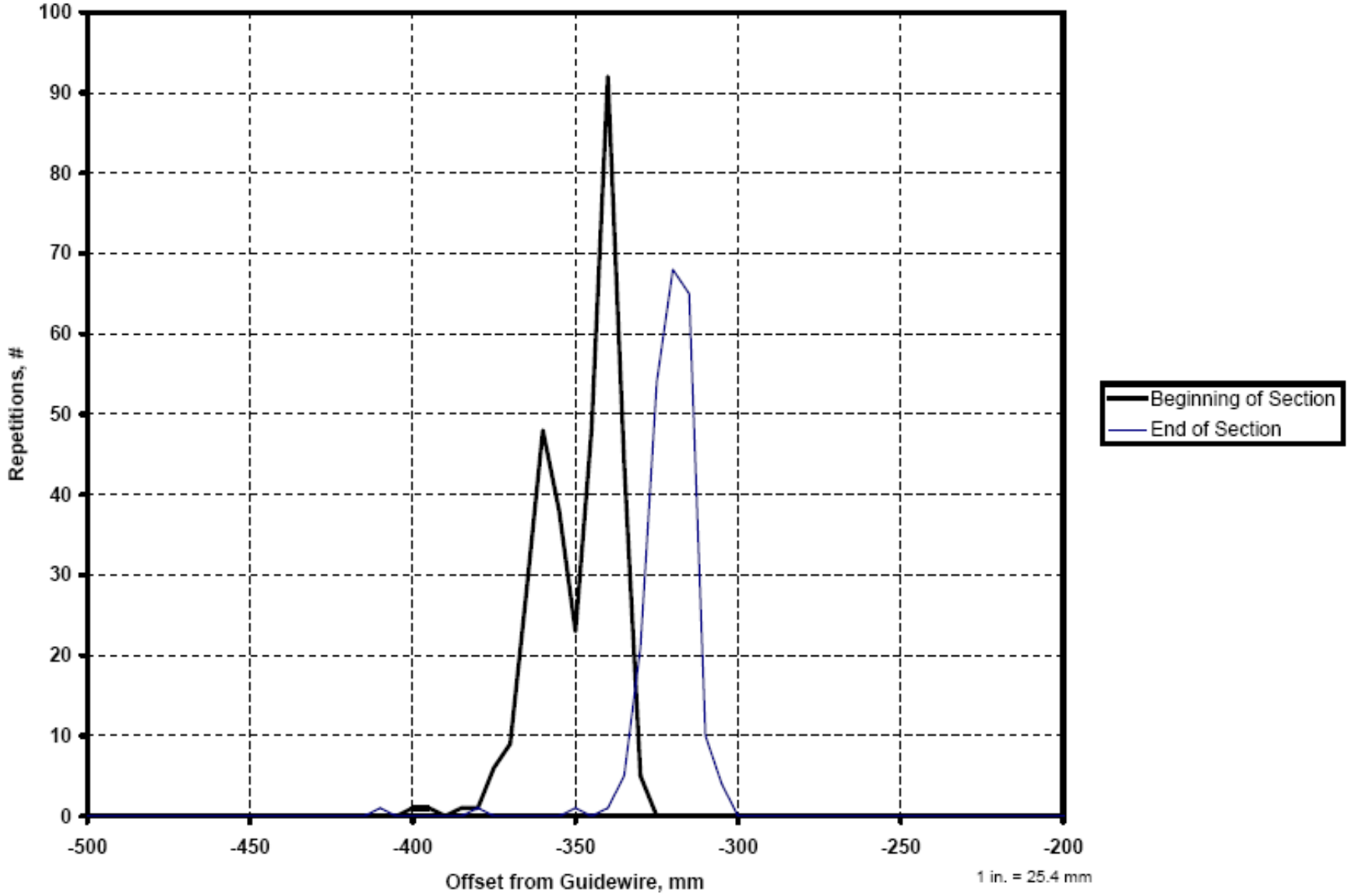


Figure B2. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 127 mm (5 in.) Left, 7/31/97.

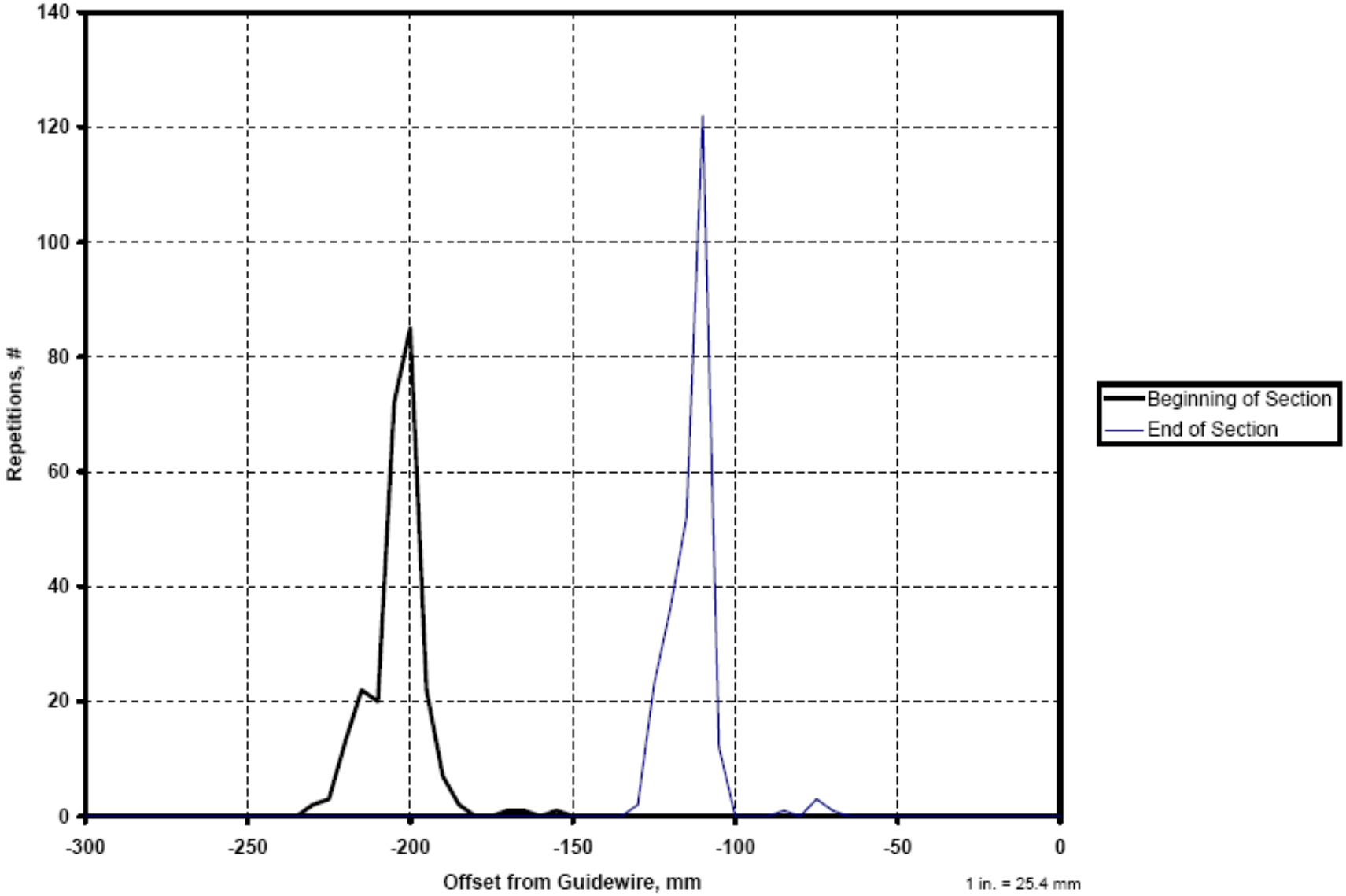


Figure B3. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 127 mm (5 in.) Left, 7/31/97.

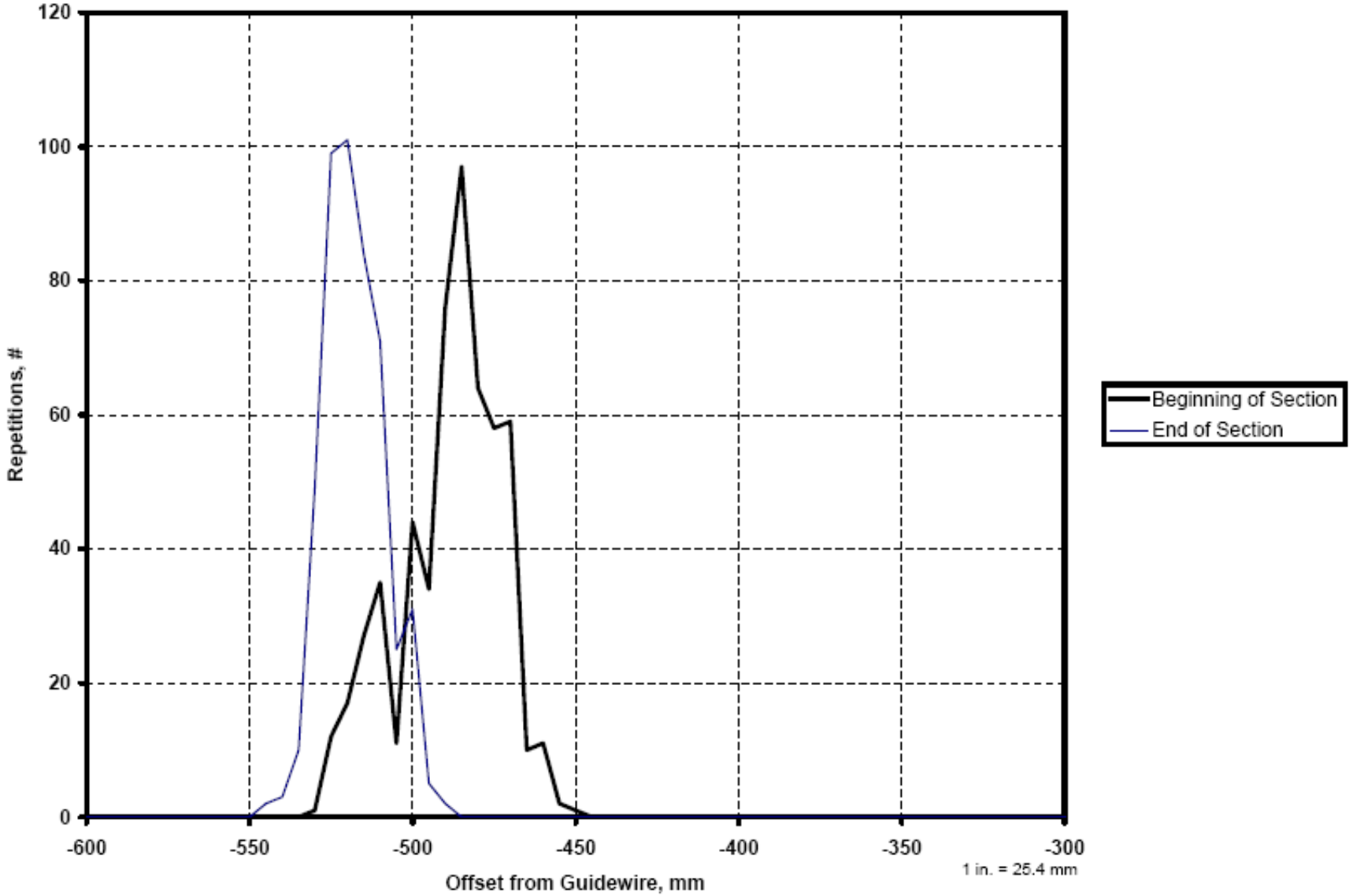


Figure B4. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 127 mm (5 in.) Left, 8/2/97.

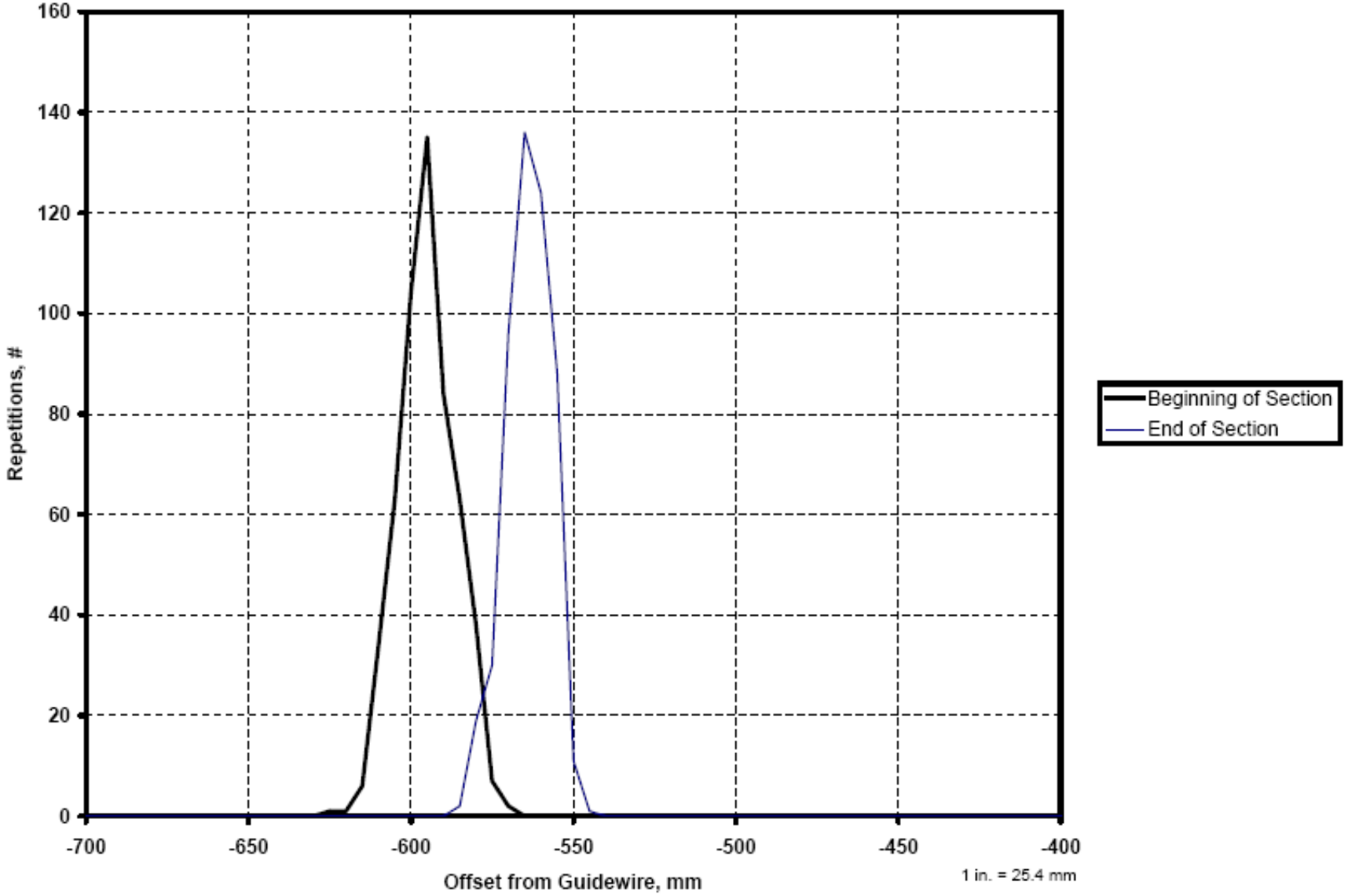


Figure B5. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 127 mm (5 in.) Left, 8/2/97.

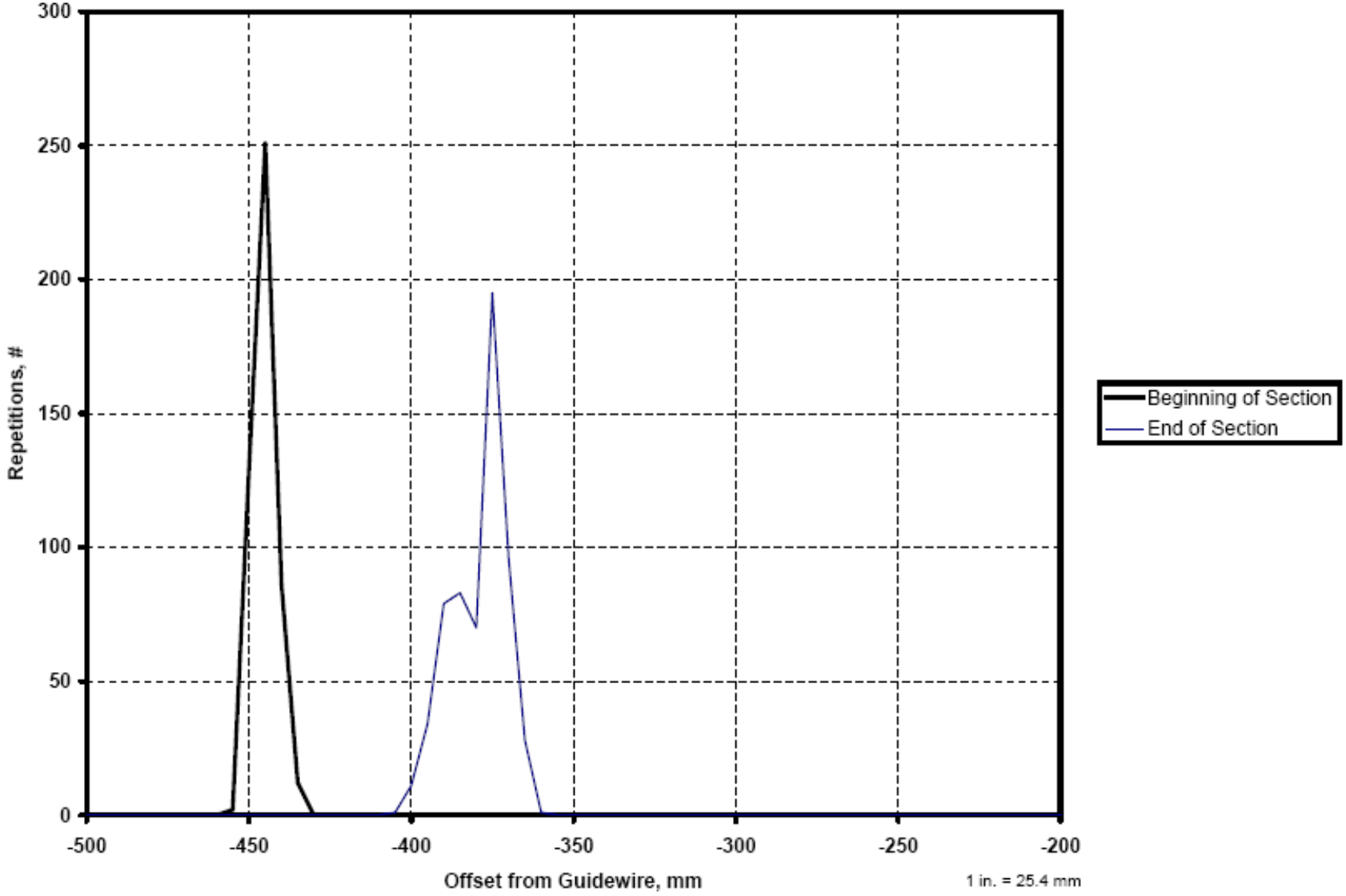


Figure B6. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 127 mm (5 in.) Left, 8/2/97.

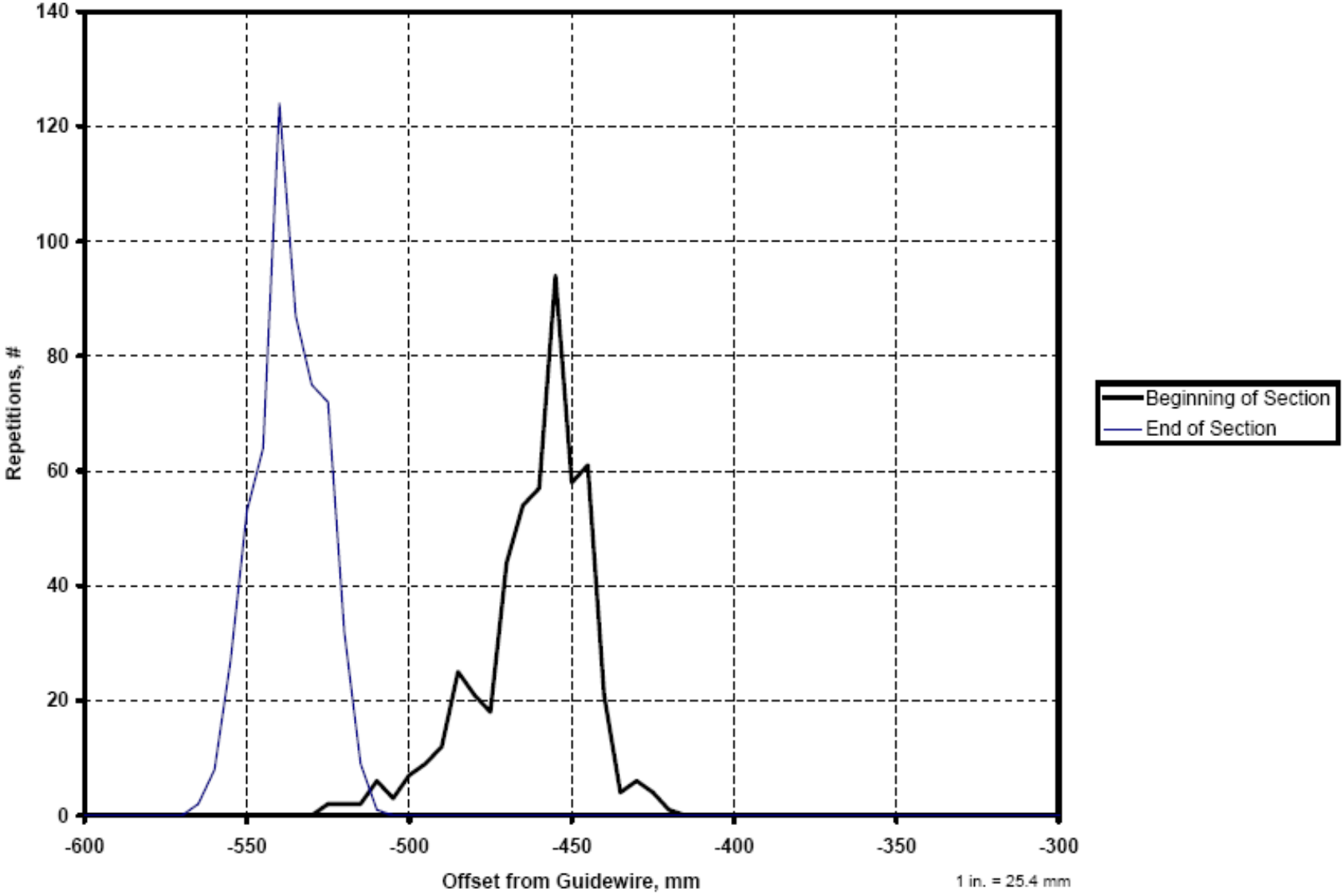


Figure B7. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 101.6 mm (4 in.) Left, 11/28/97.

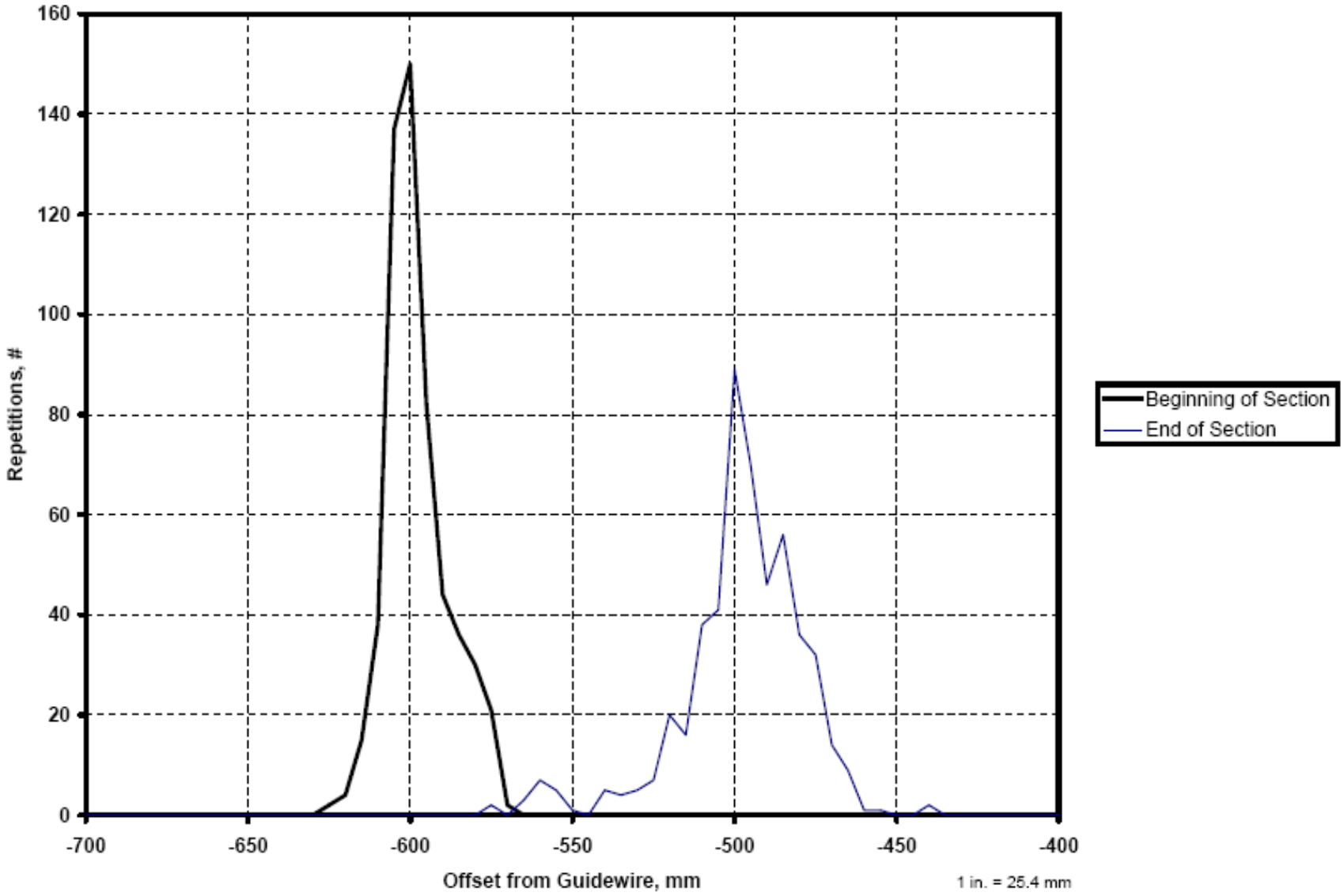


Figure B8. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 101.6 mm (4 in.) Left, 11/28/97.

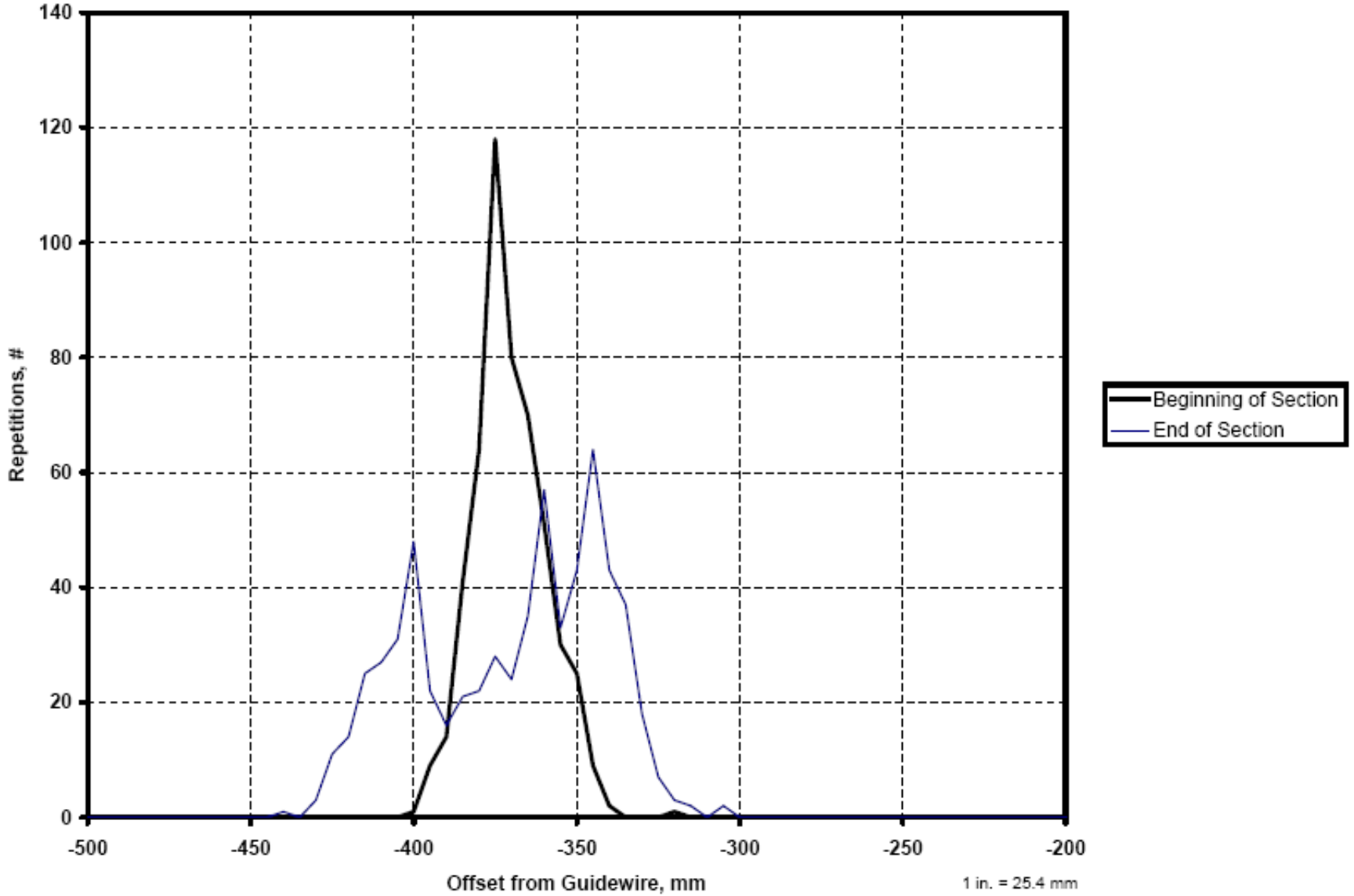


Figure B9. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 101.6 mm (4 in.) Left, 11/28/97.

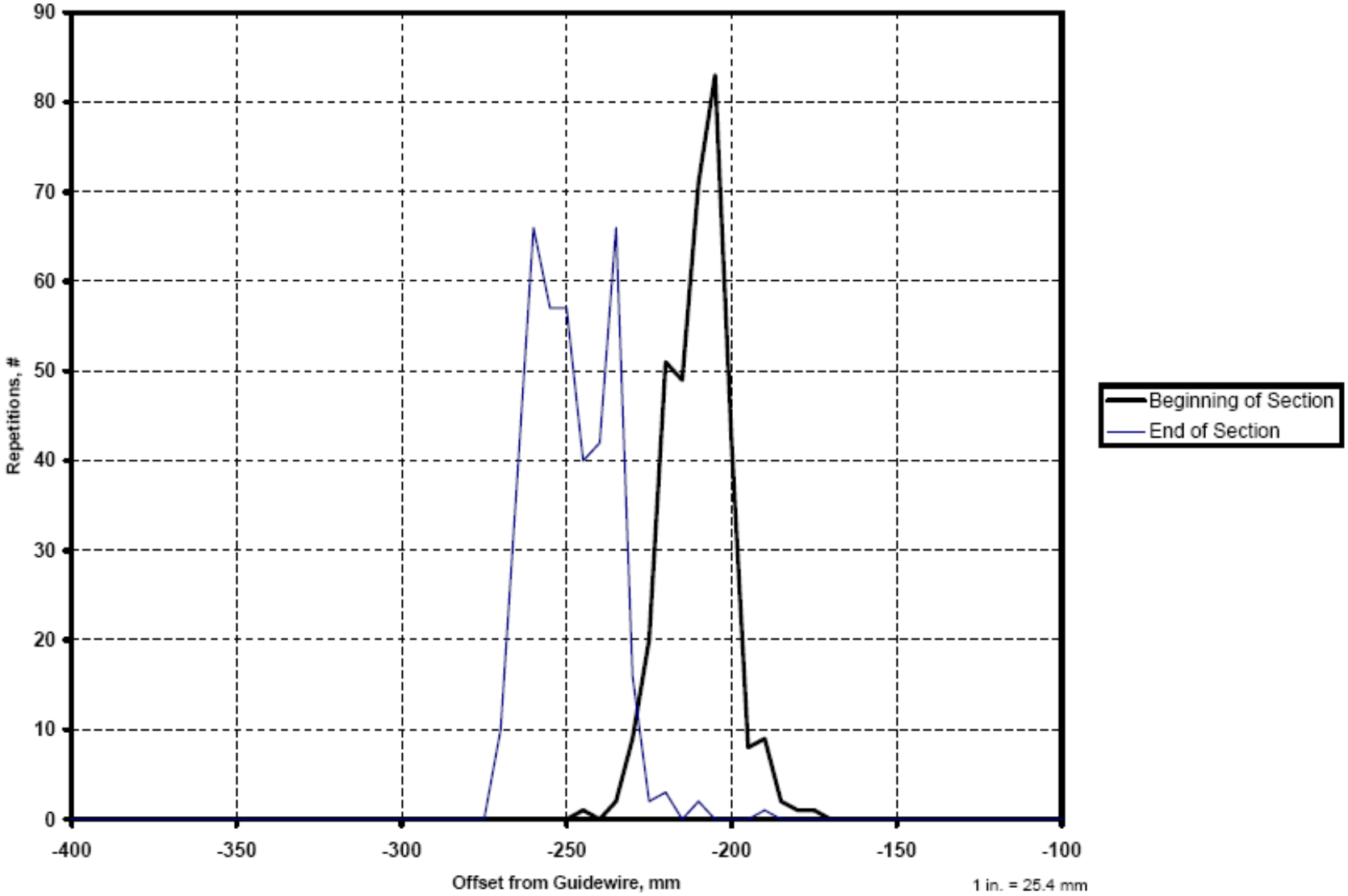


Figure B10. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 76.2 mm (3 in.) Left, 8/9/97.

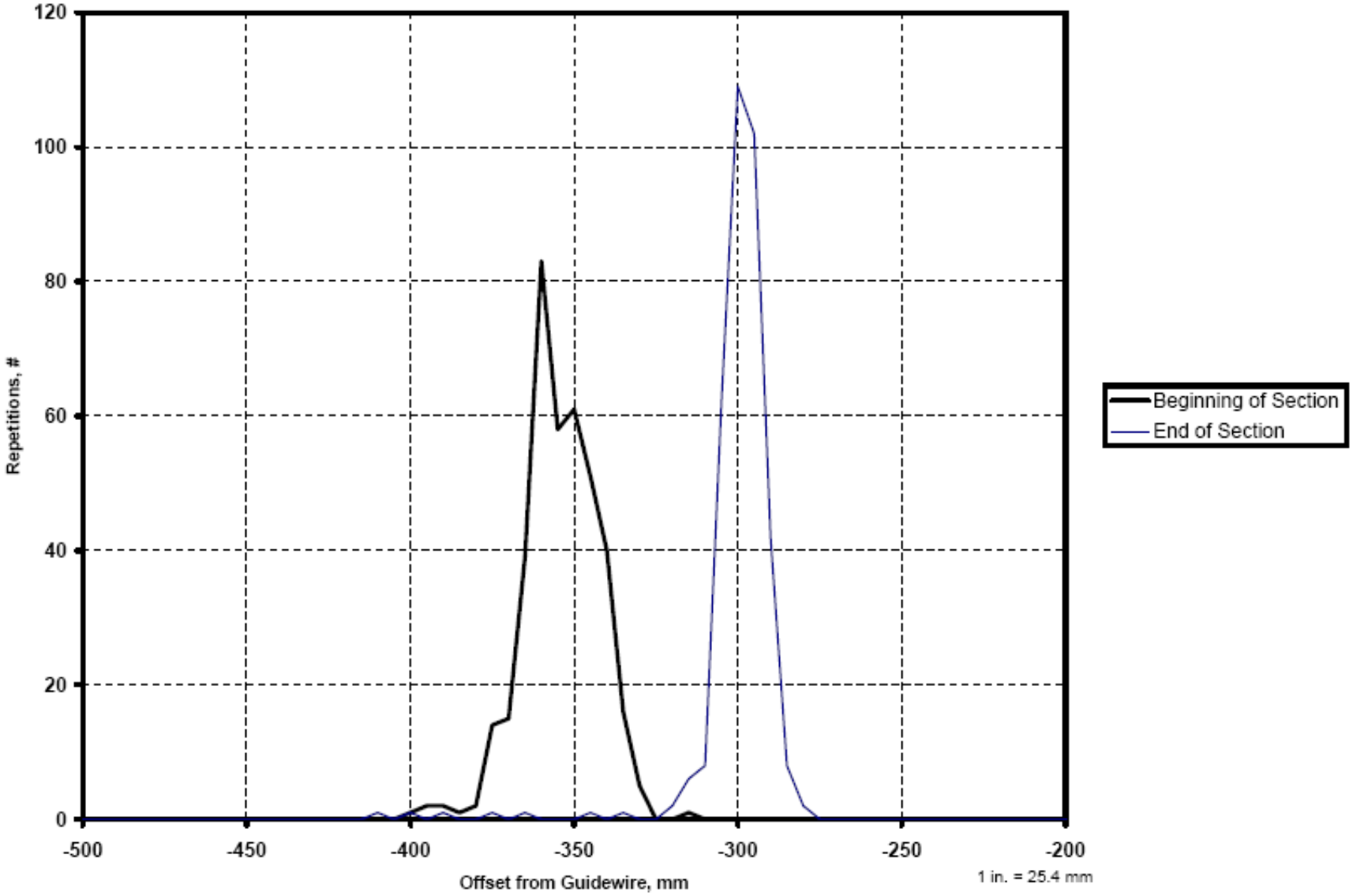


Figure B11. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 76.2 mm (3 in.) Left, 8/9/97.

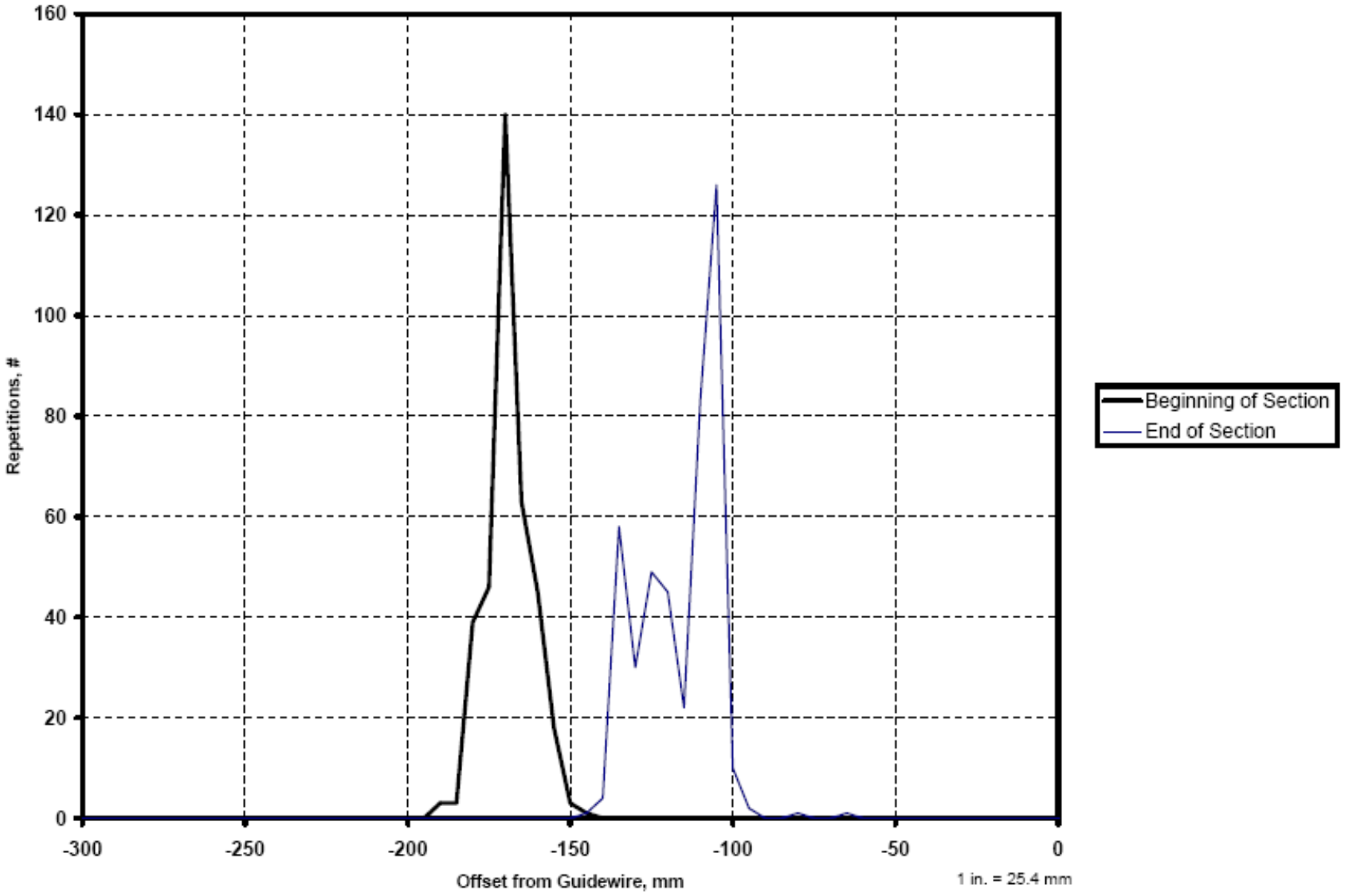


Figure B12. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 76.2 mm (3 in.) Left, 8/9/97.

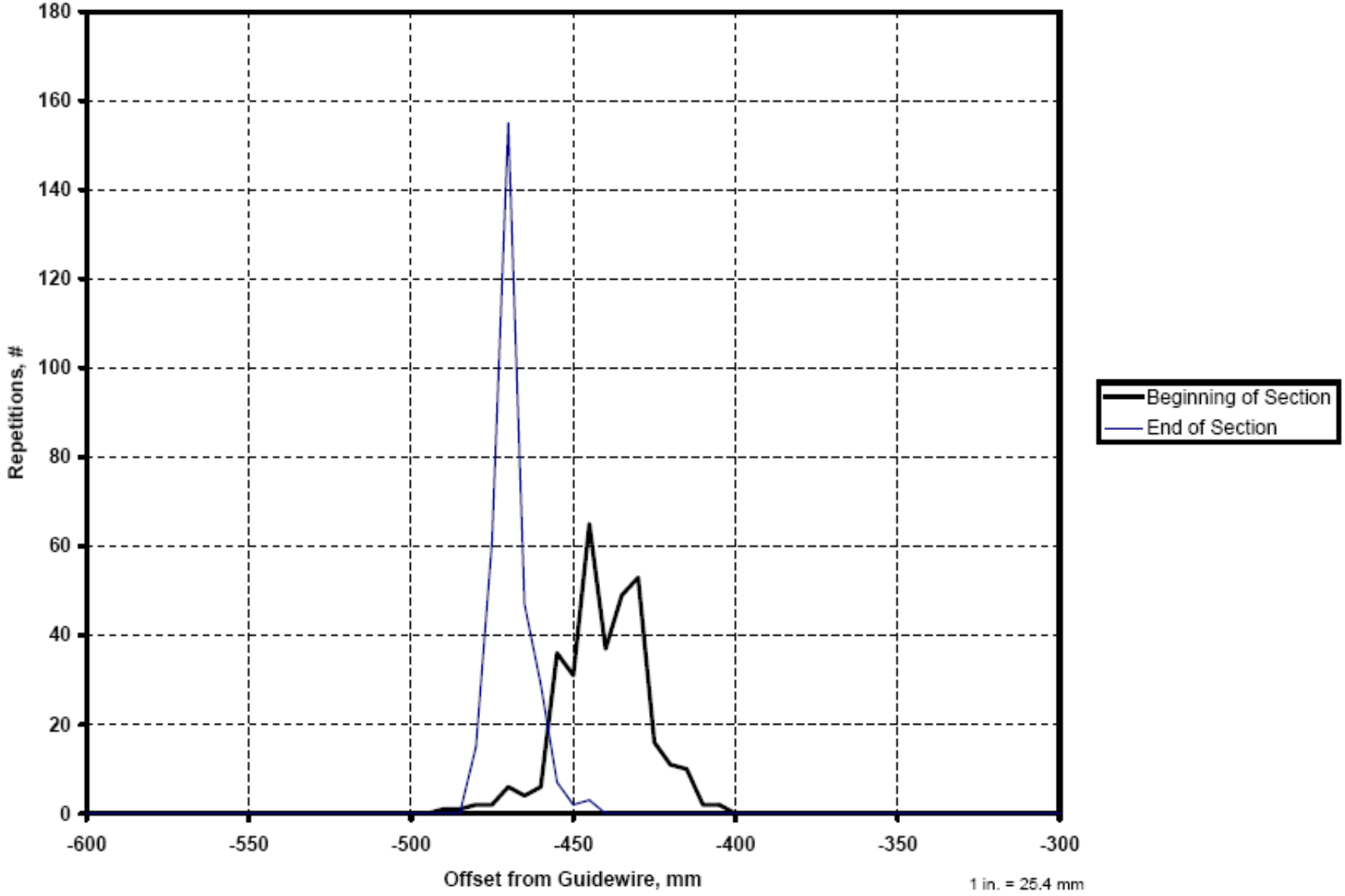


Figure B13. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 50.8 mm (2 in.) Left, 7/31/97.

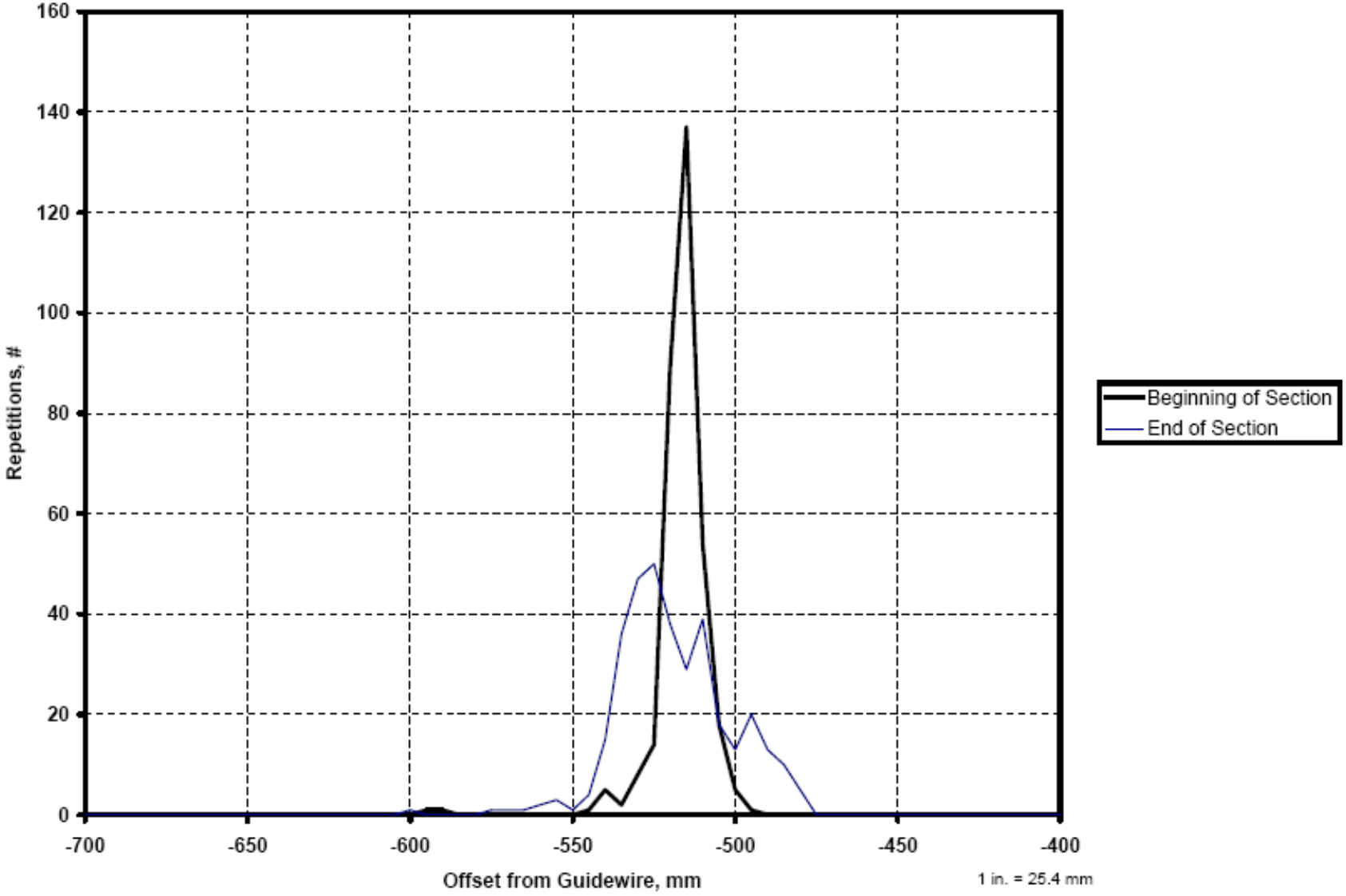


Figure B14. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 50.8 mm (2 in.) Left, 7/31/97.

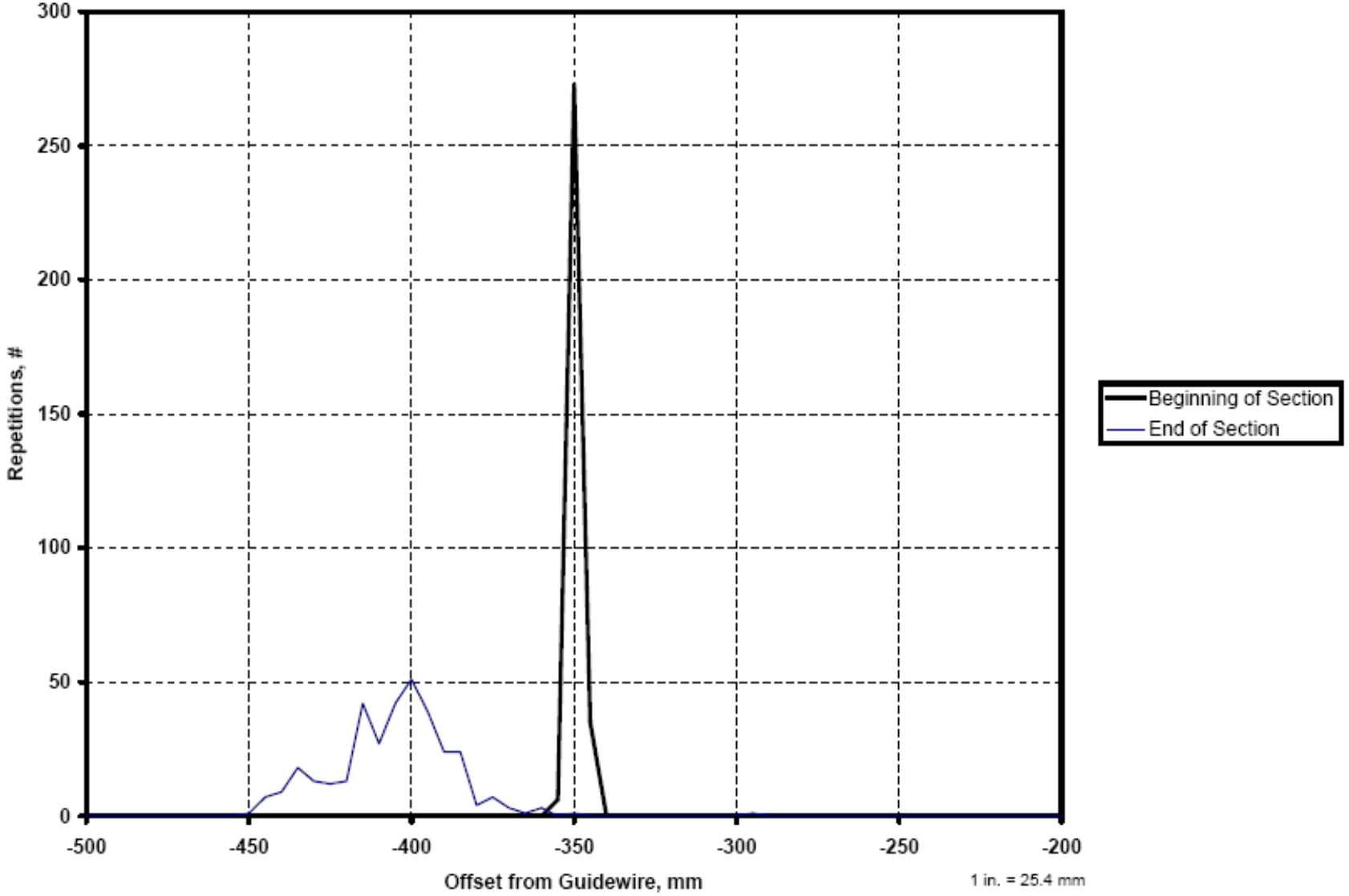


Figure B15. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 50.8 mm (2 in.) Left, 7/31/97.

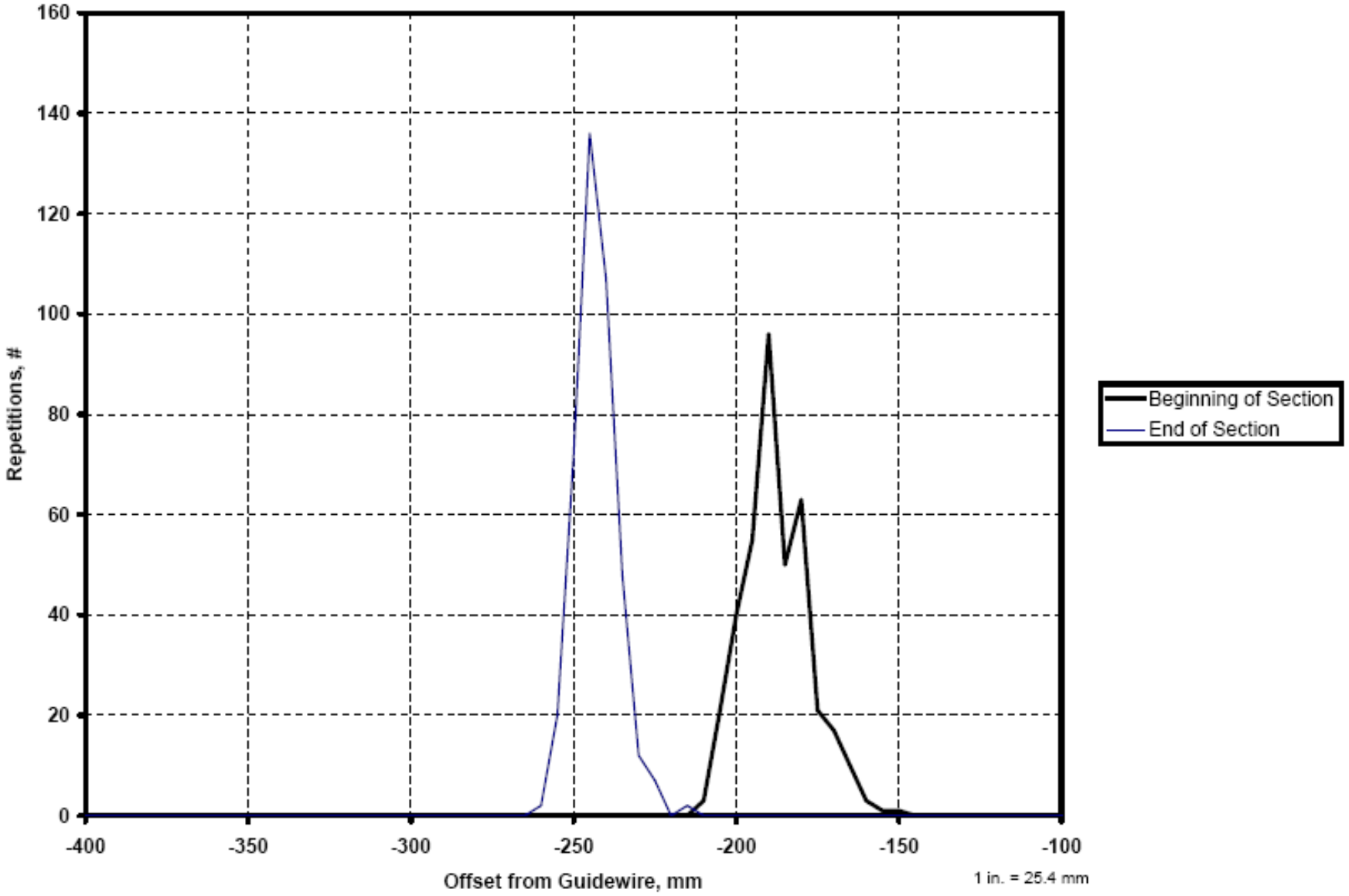


Figure B16. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 50.8 mm (2 in.) Left, 8/3/97.

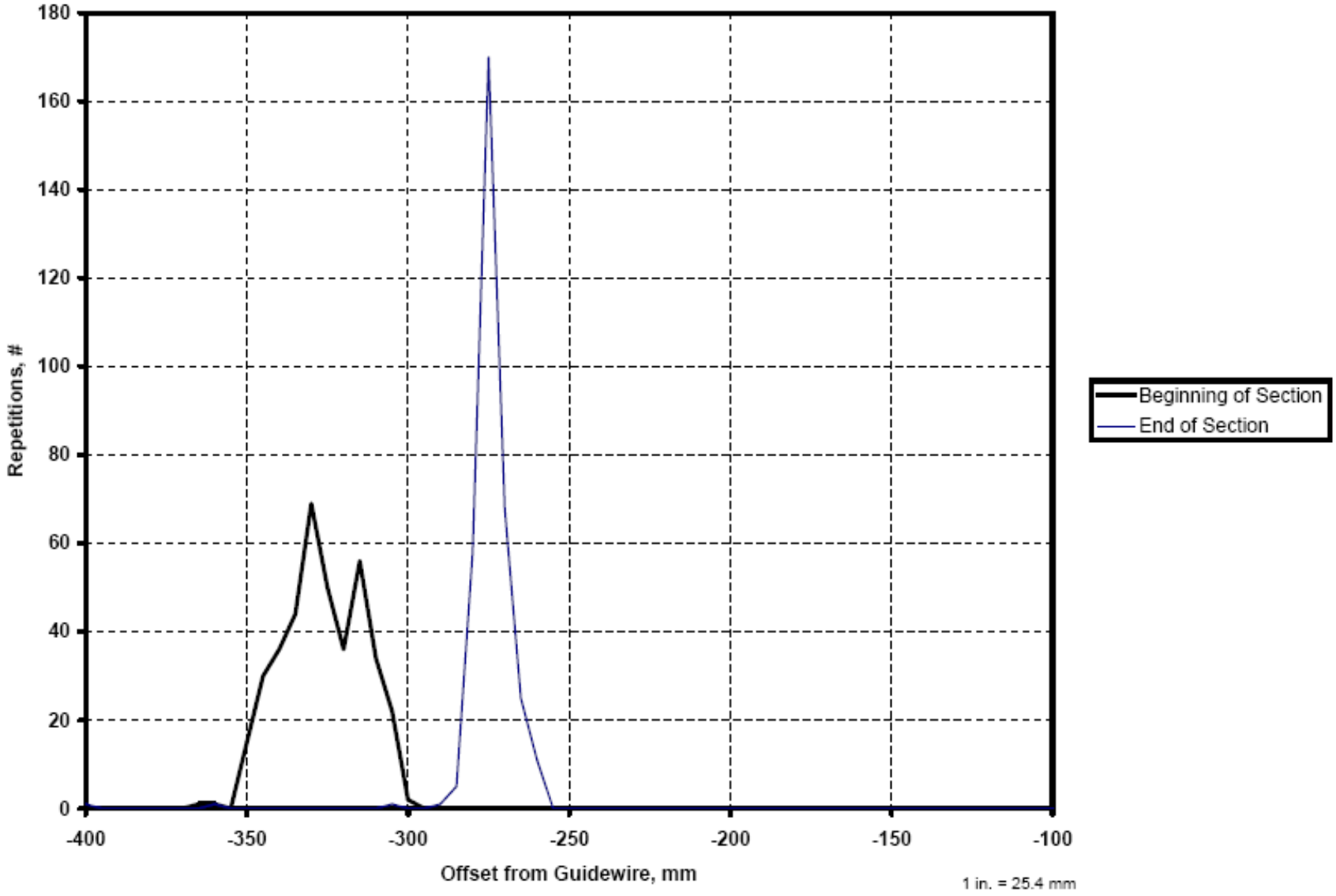


Figure B17. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 50.8 mm (2 in.) Left, 8/3/97.

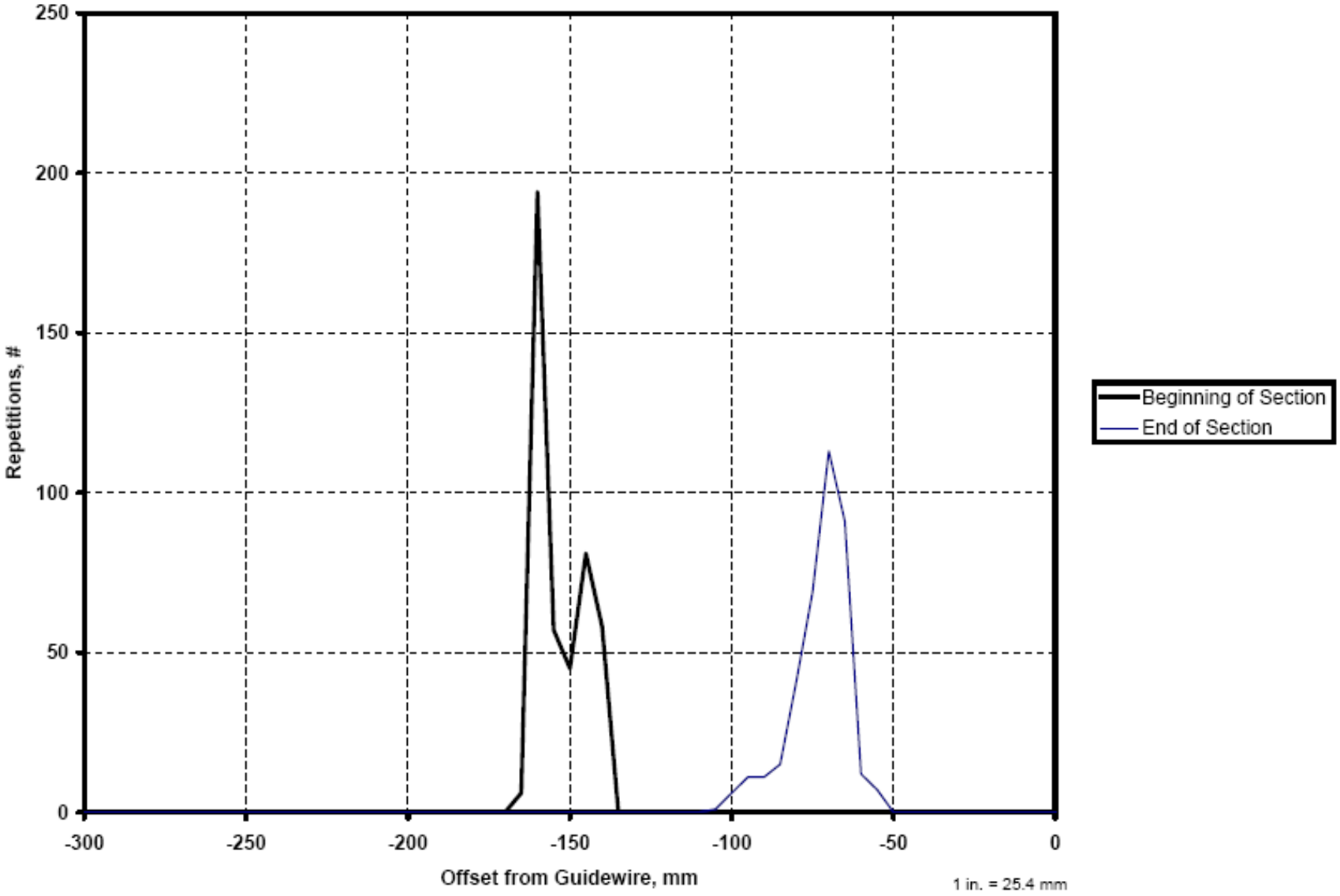


Figure B18. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 50.8 mm (2 in.) Left, 8/3/98.

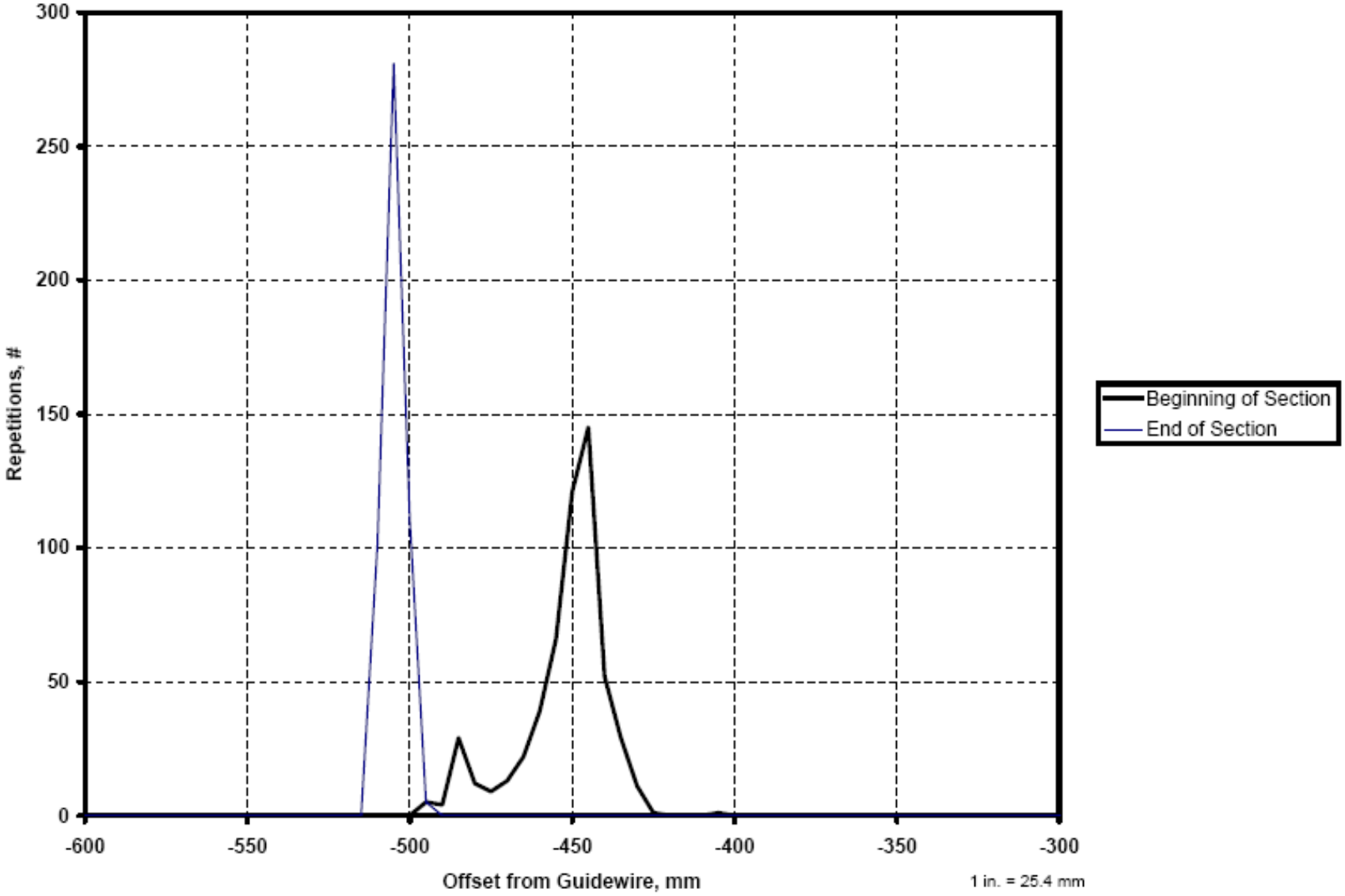


Figure B19. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 50.8 mm (2 in.) Left, 1/7/98.

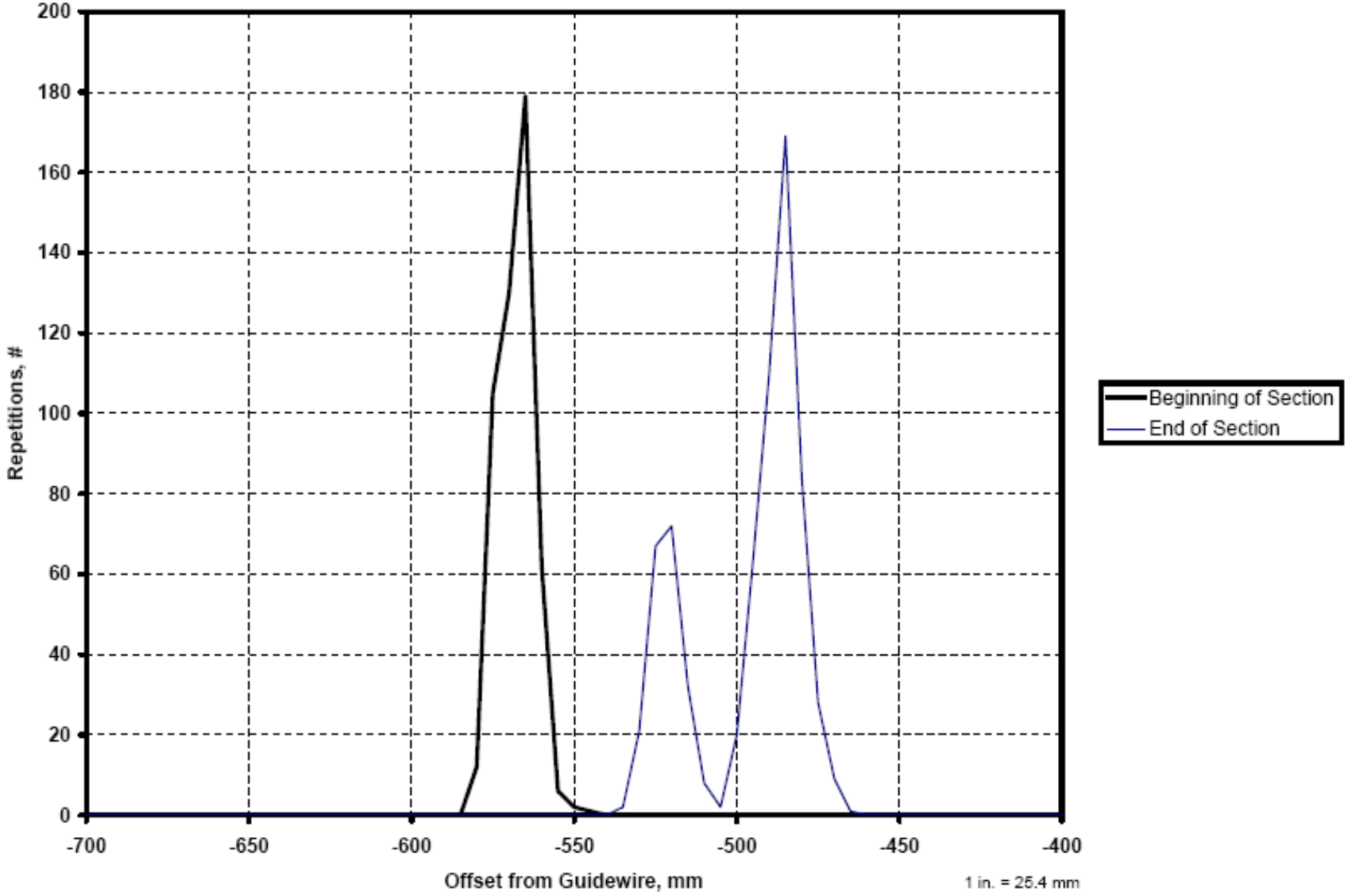


Figure B20. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 50.8 mm (2 in.) Left, 1/7/98.

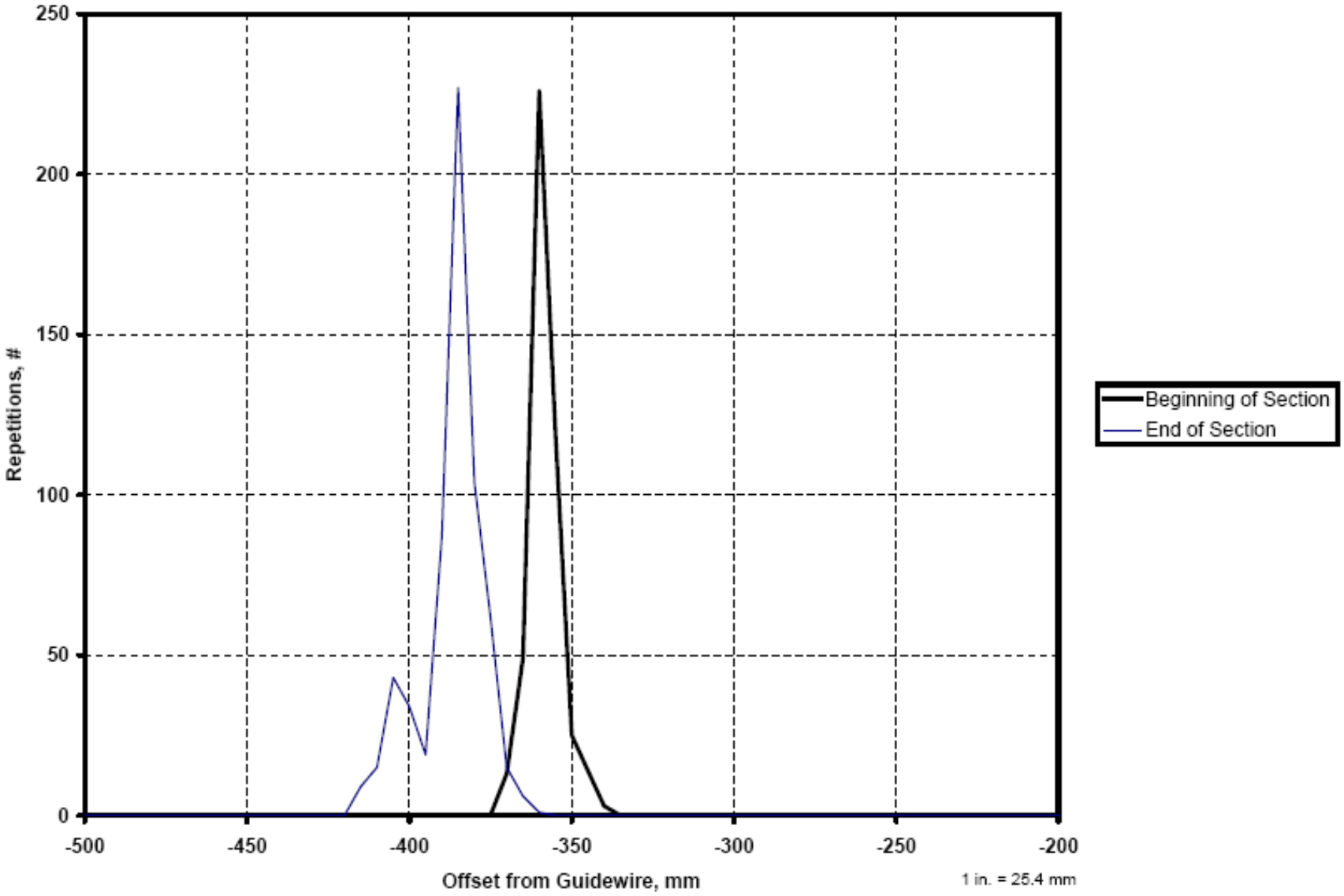


Figure B21. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 50.8 mm (2 in.) Left, 1/7/98.

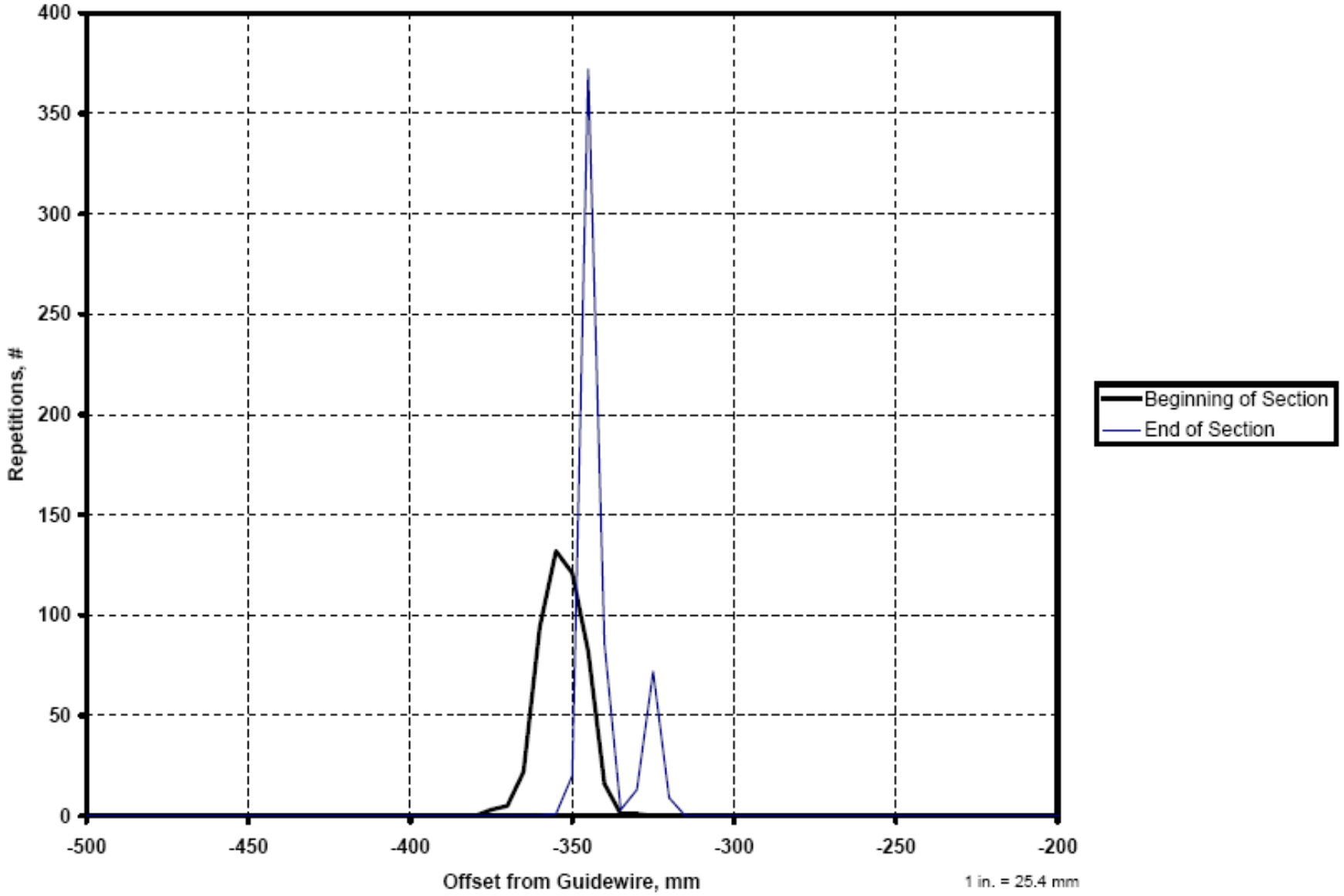


Figure B22. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/1/97.

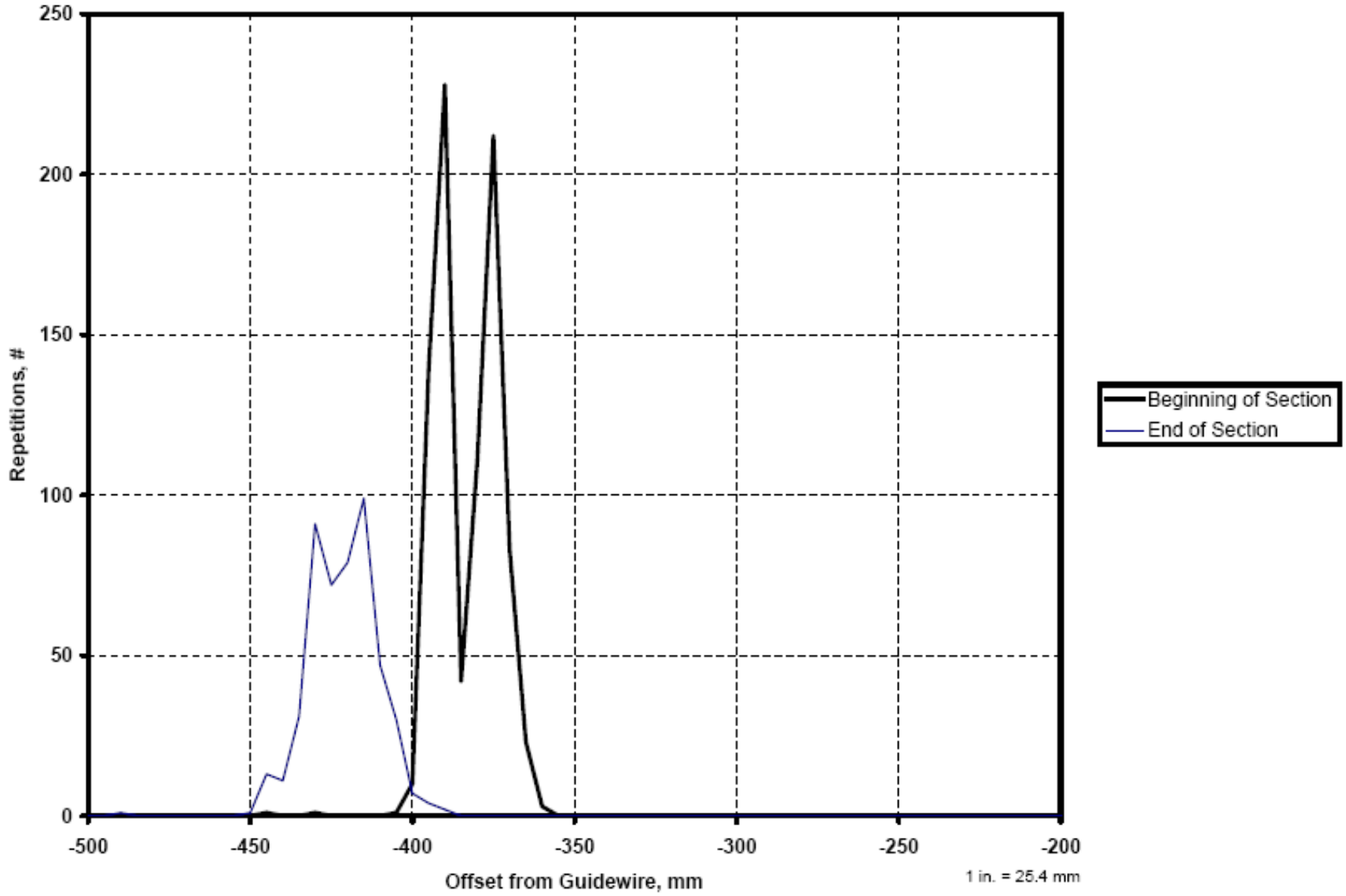


Figure B23. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/1/97.

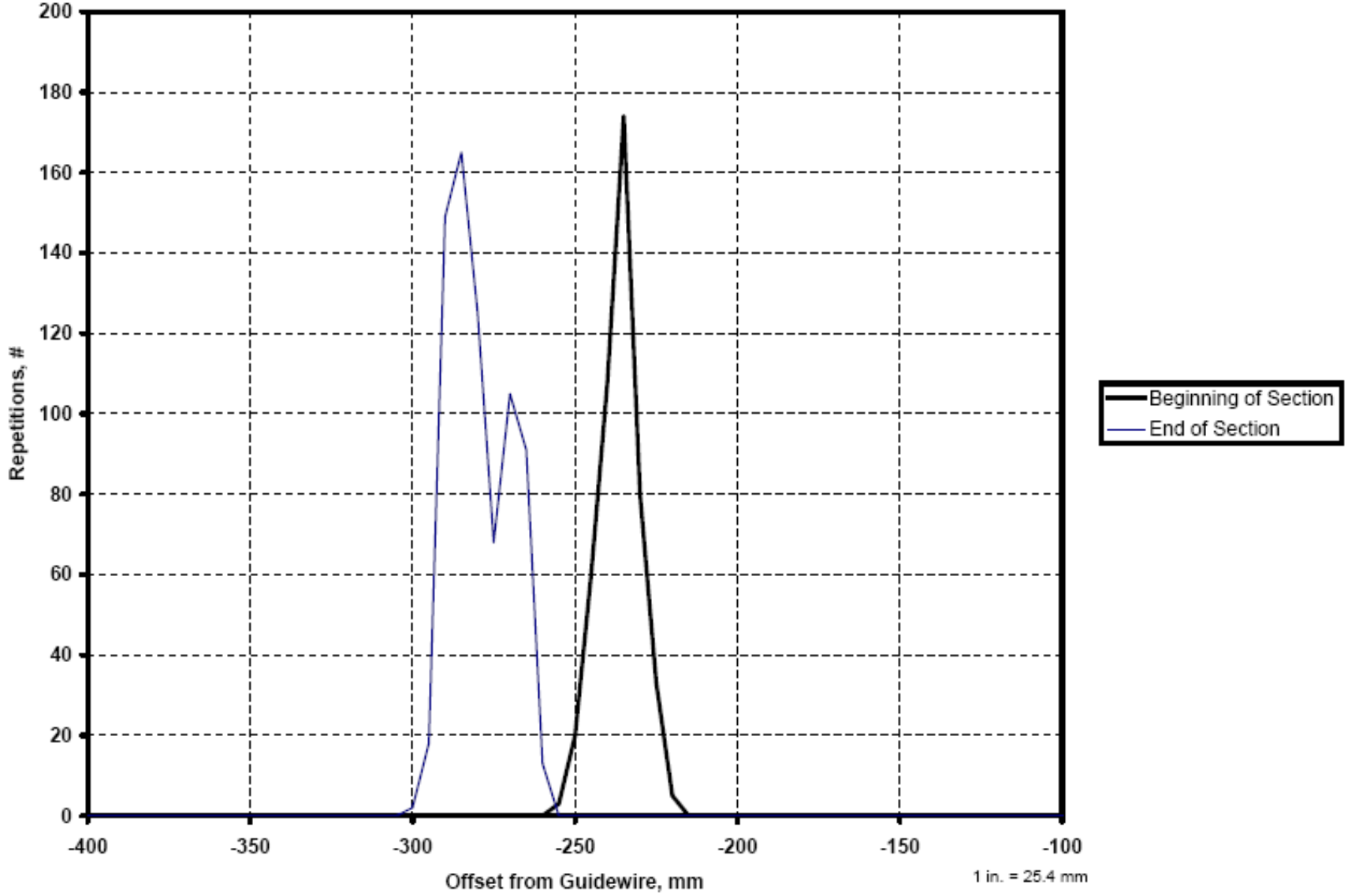


Figure B24. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/1/97.

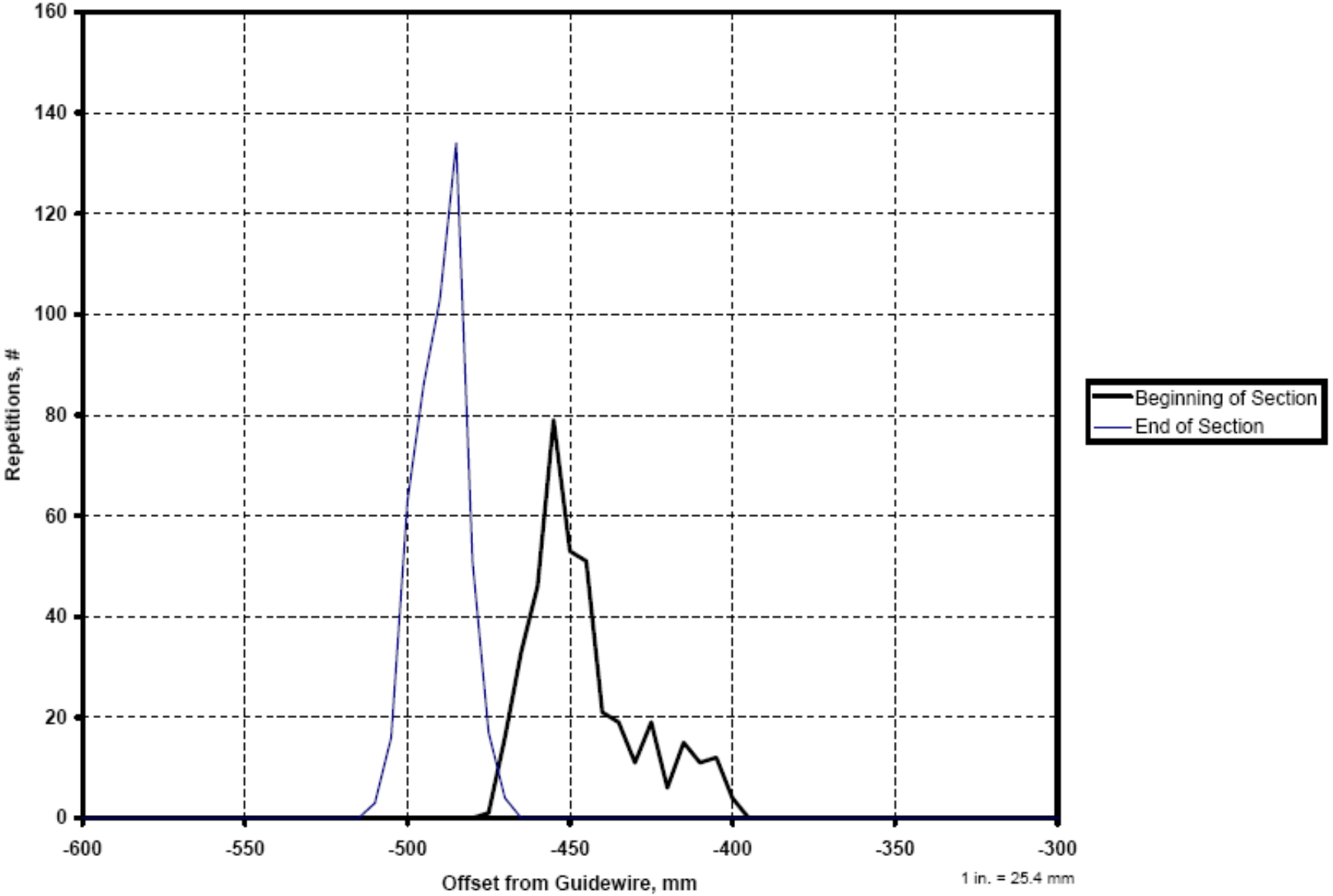


Figure B25. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/4/97.

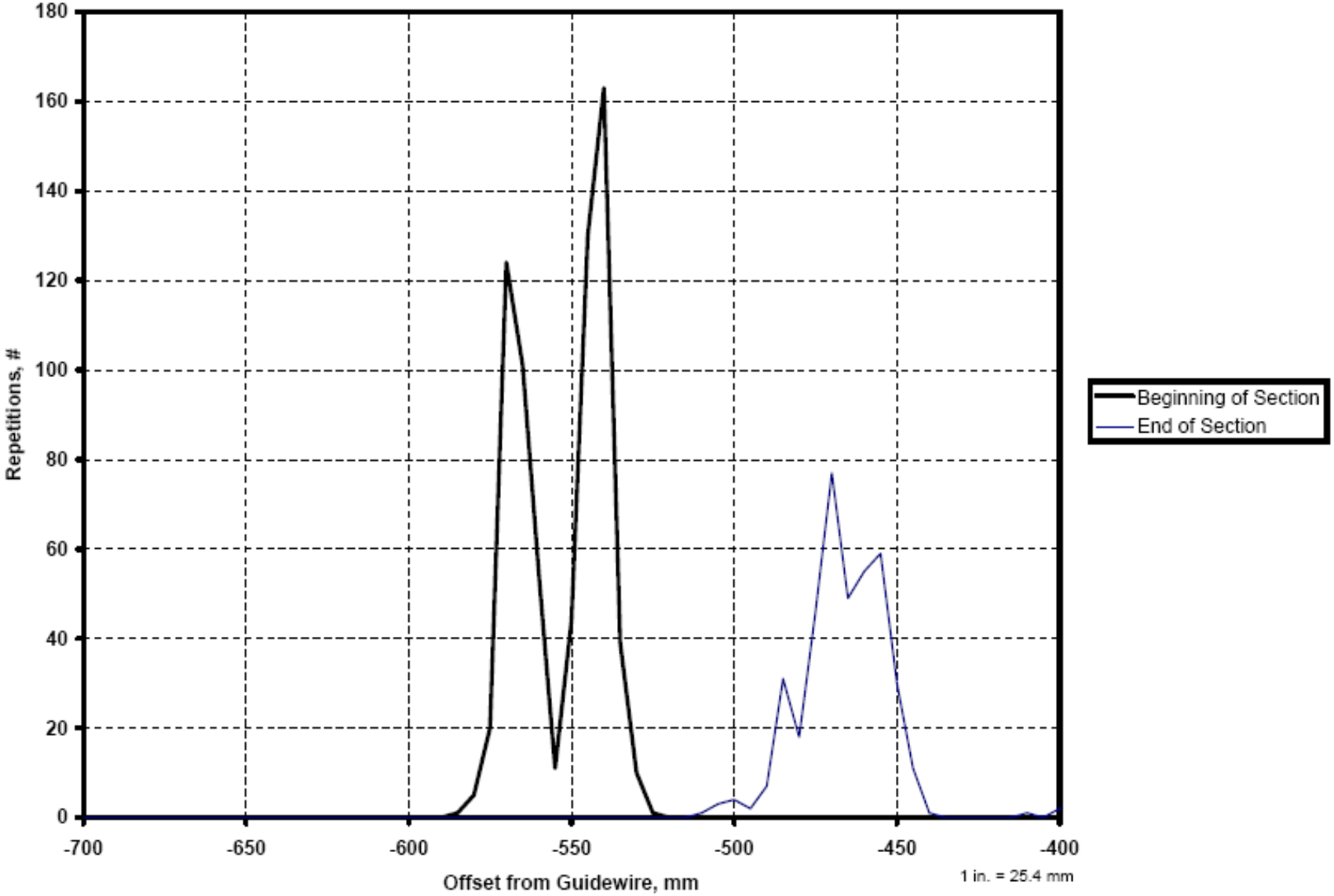


Figure B26. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/4/97.

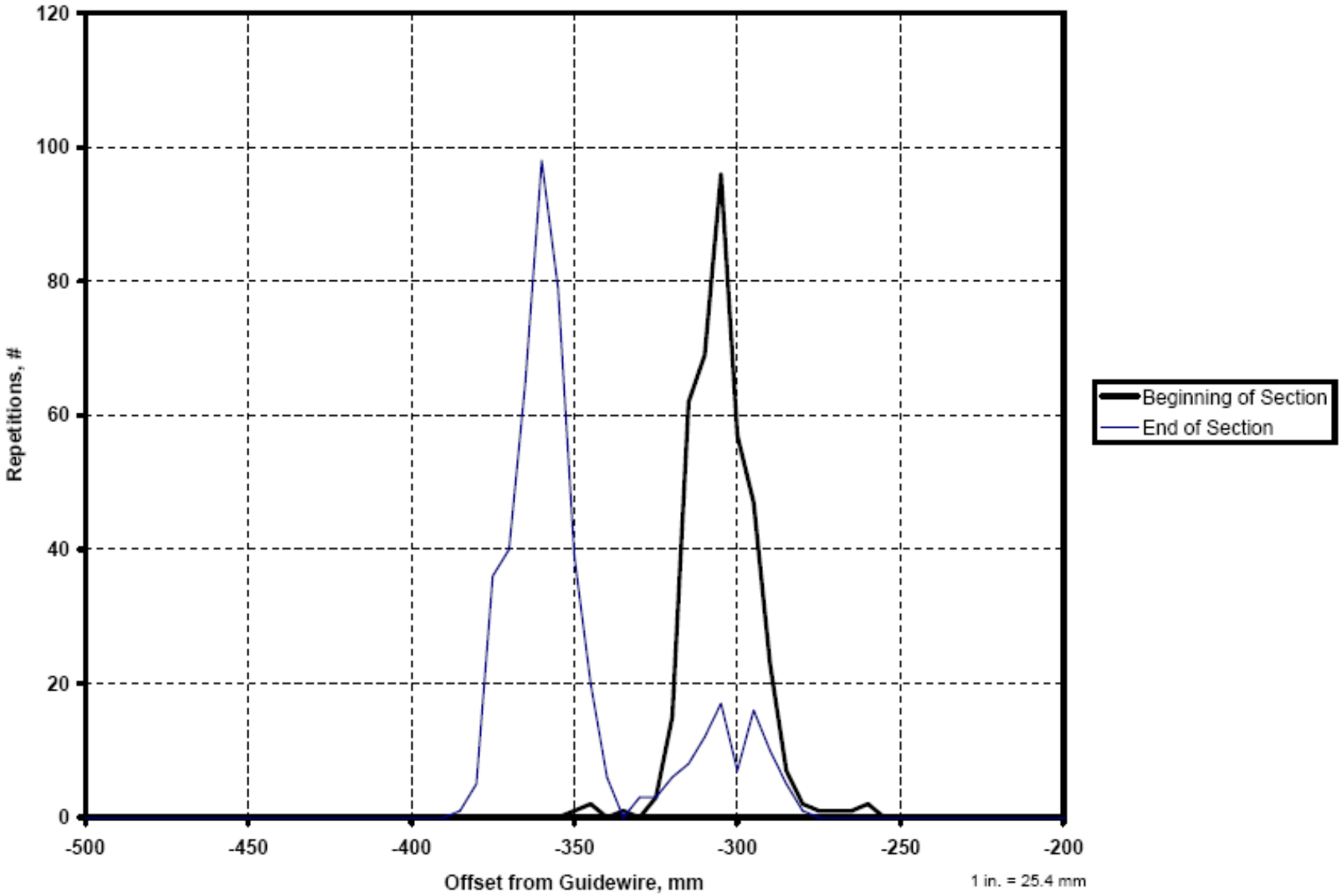


Figure B27. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 25.4 mm (1 in.) Left, 12/4/97.

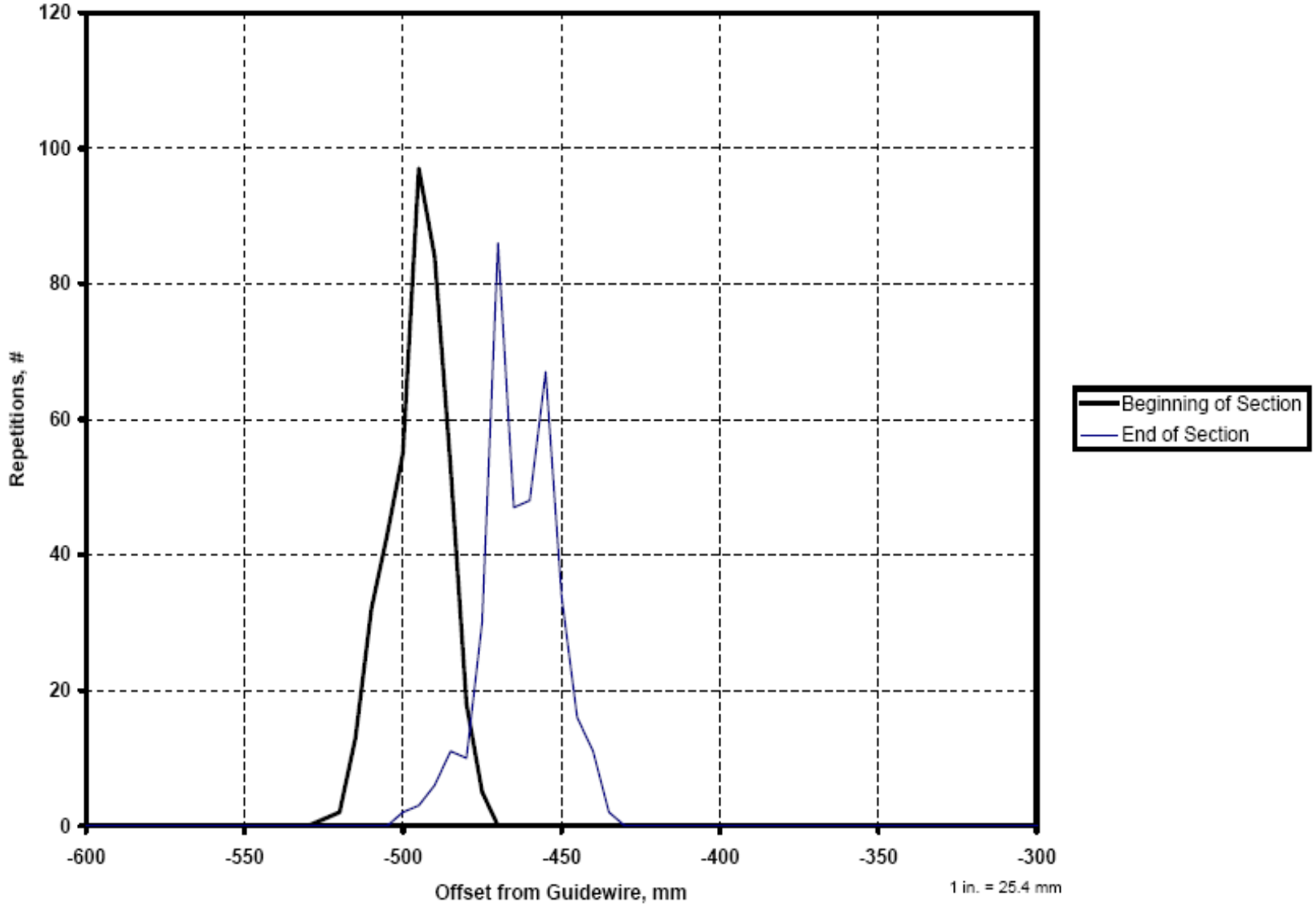


Figure B29. Rear Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/8/97.

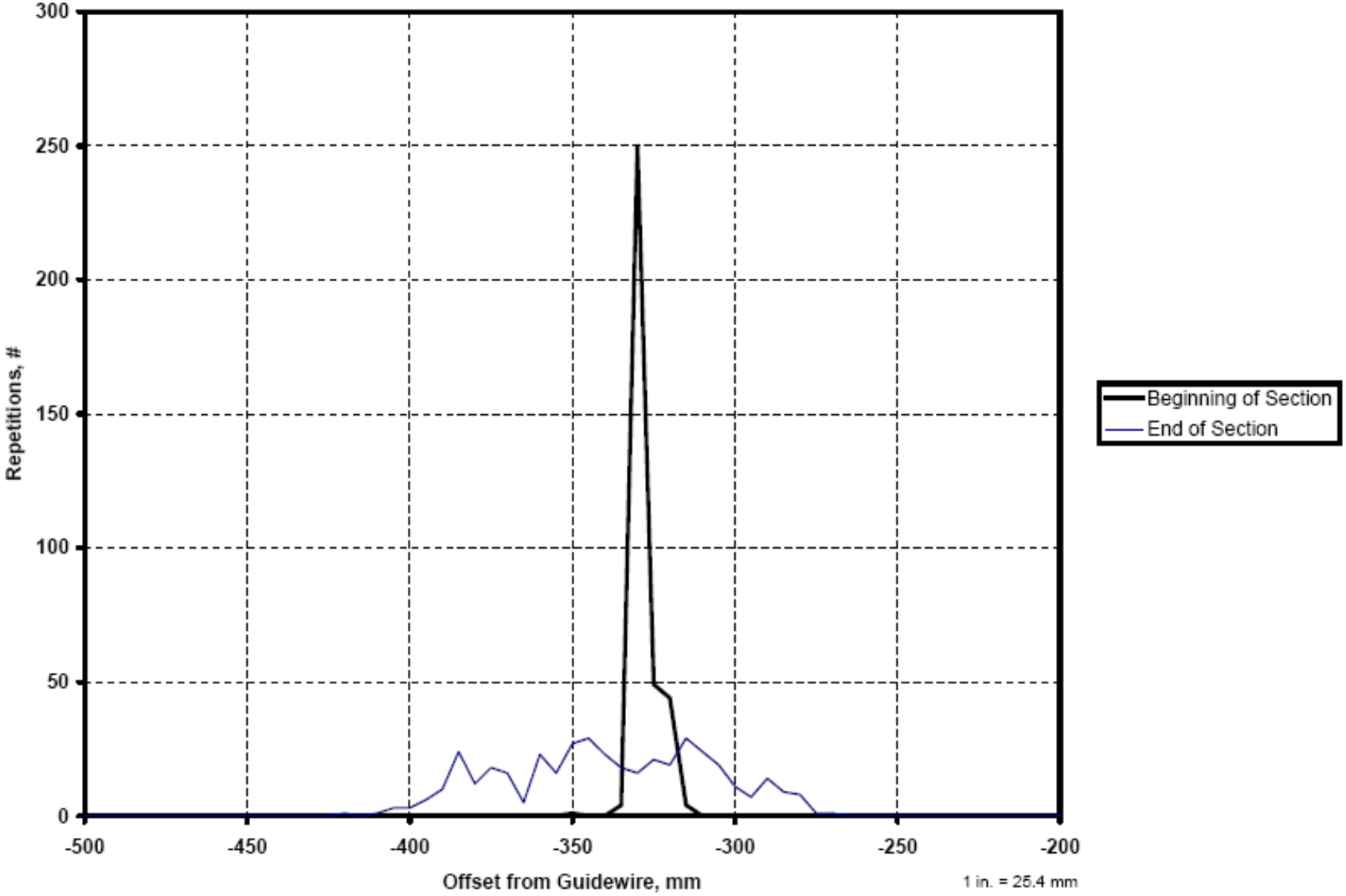


Figure B30. Rear Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/8/97.

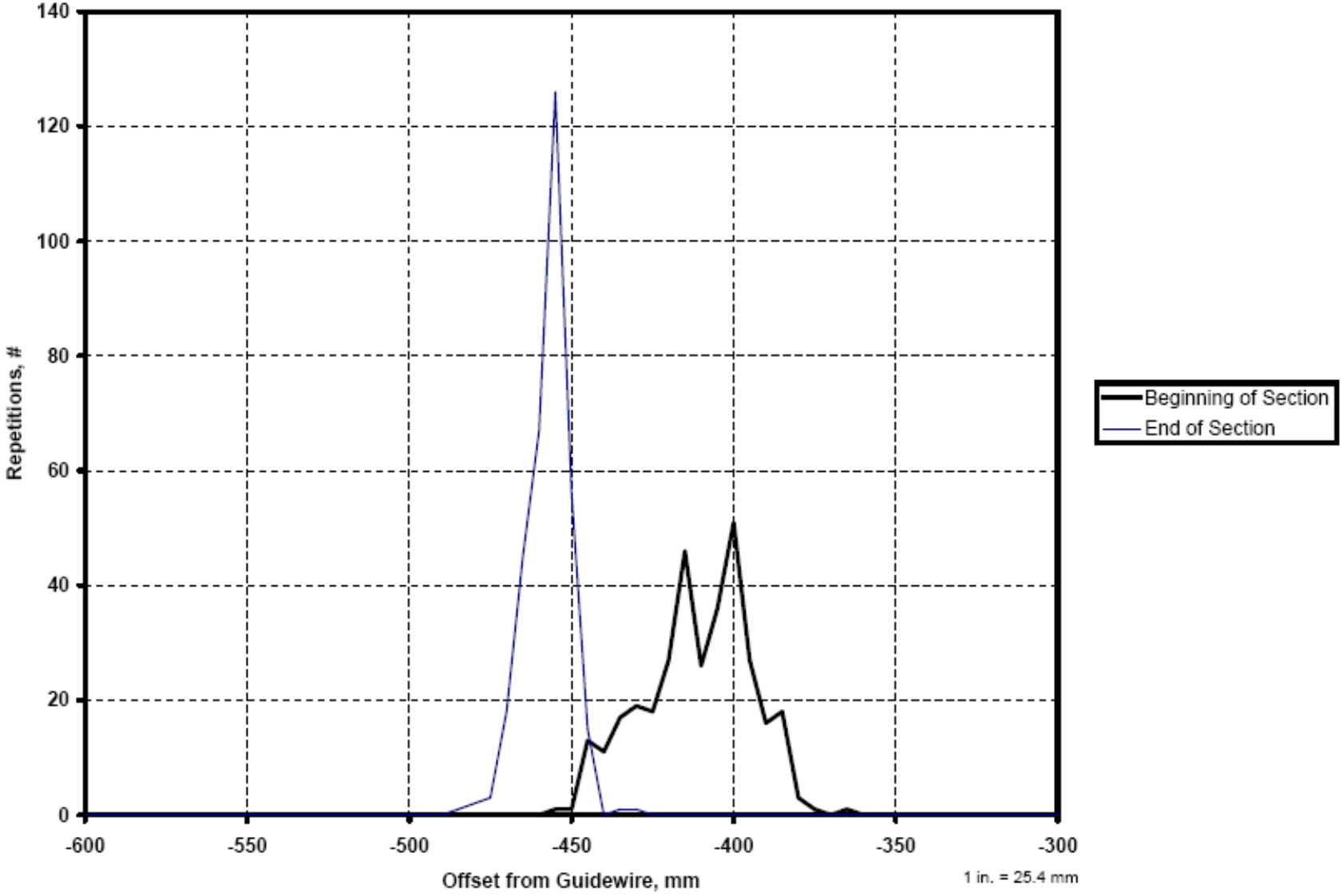


Figure B31. Rear Antenna Offset Histogram for Section 4 With Front Antenna Centered, 8/9/97.

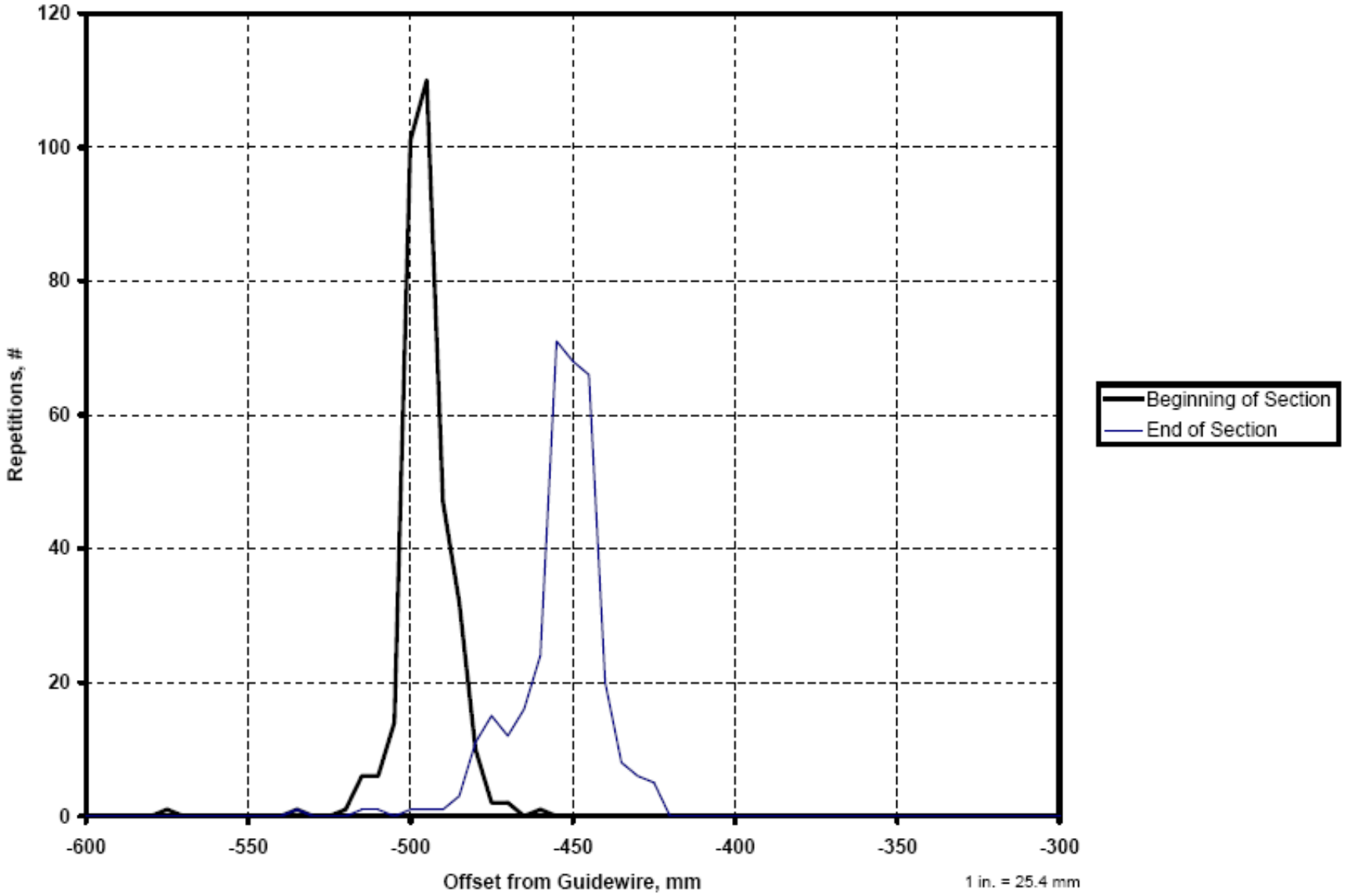


Figure B32. Rear Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/9/97.

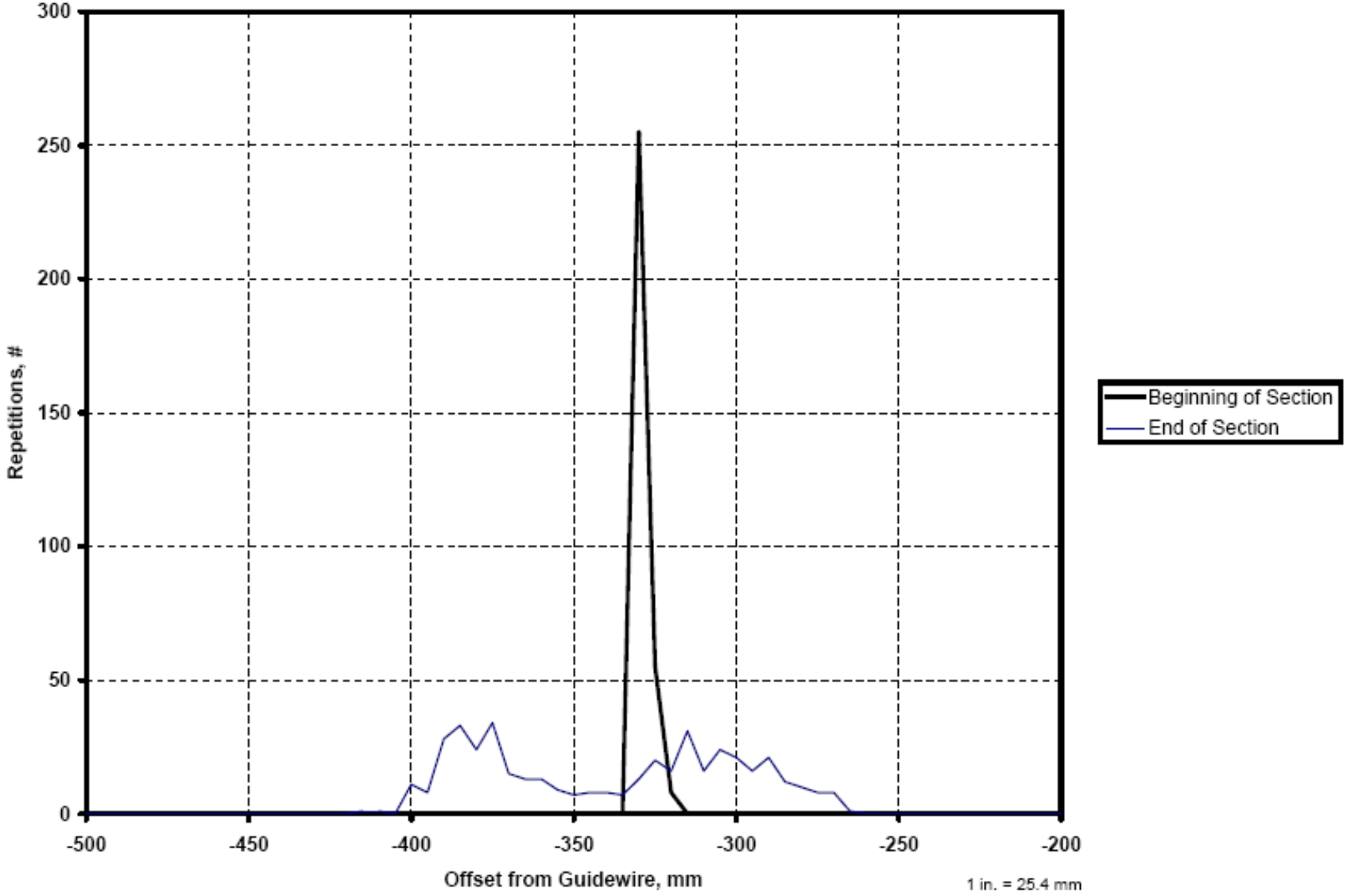


Figure B33. Rear Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/9/97.

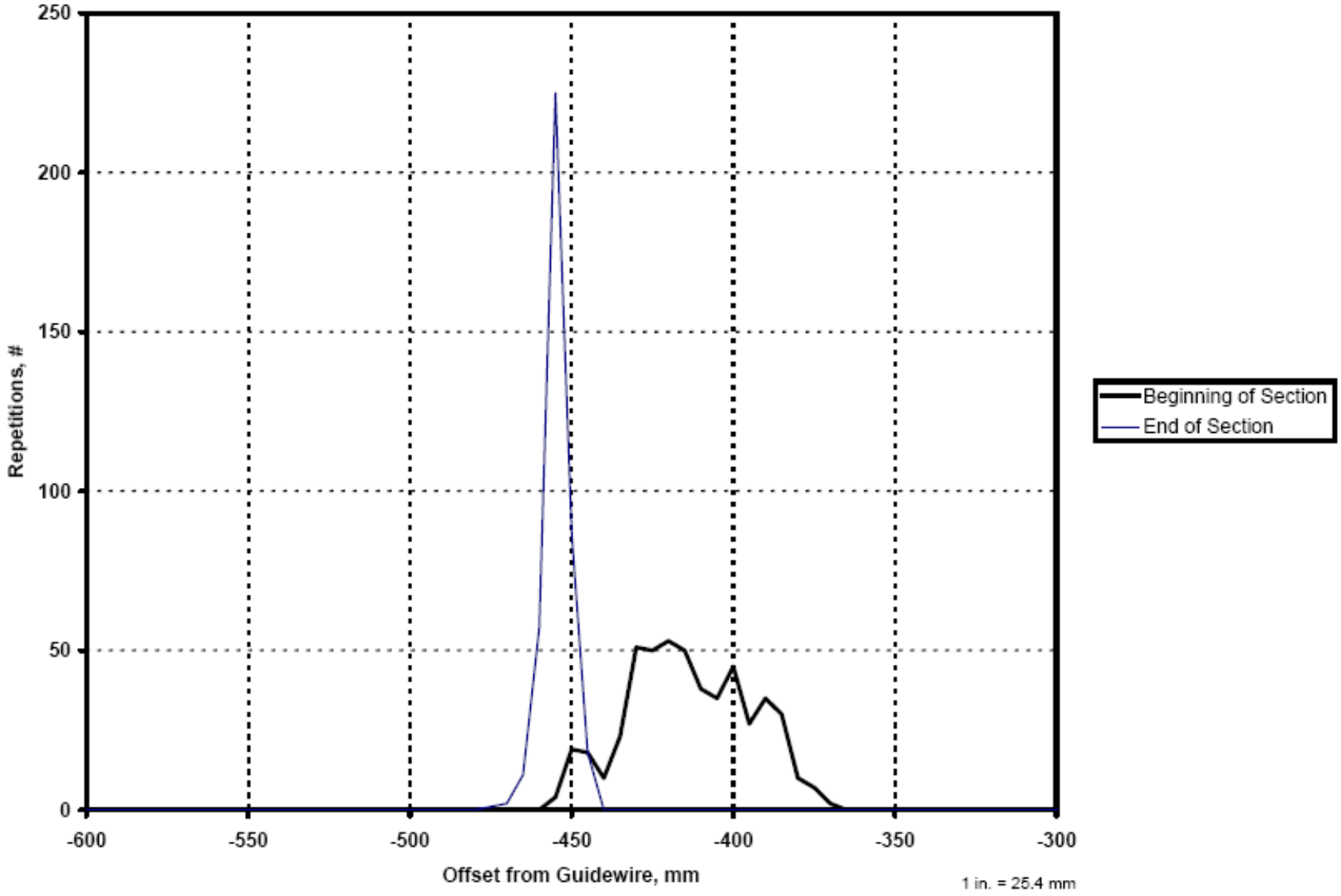


Figure B34. Rear Antenna Offset Histogram for Section 4 With Front Antenna Centered, 8/10/97.

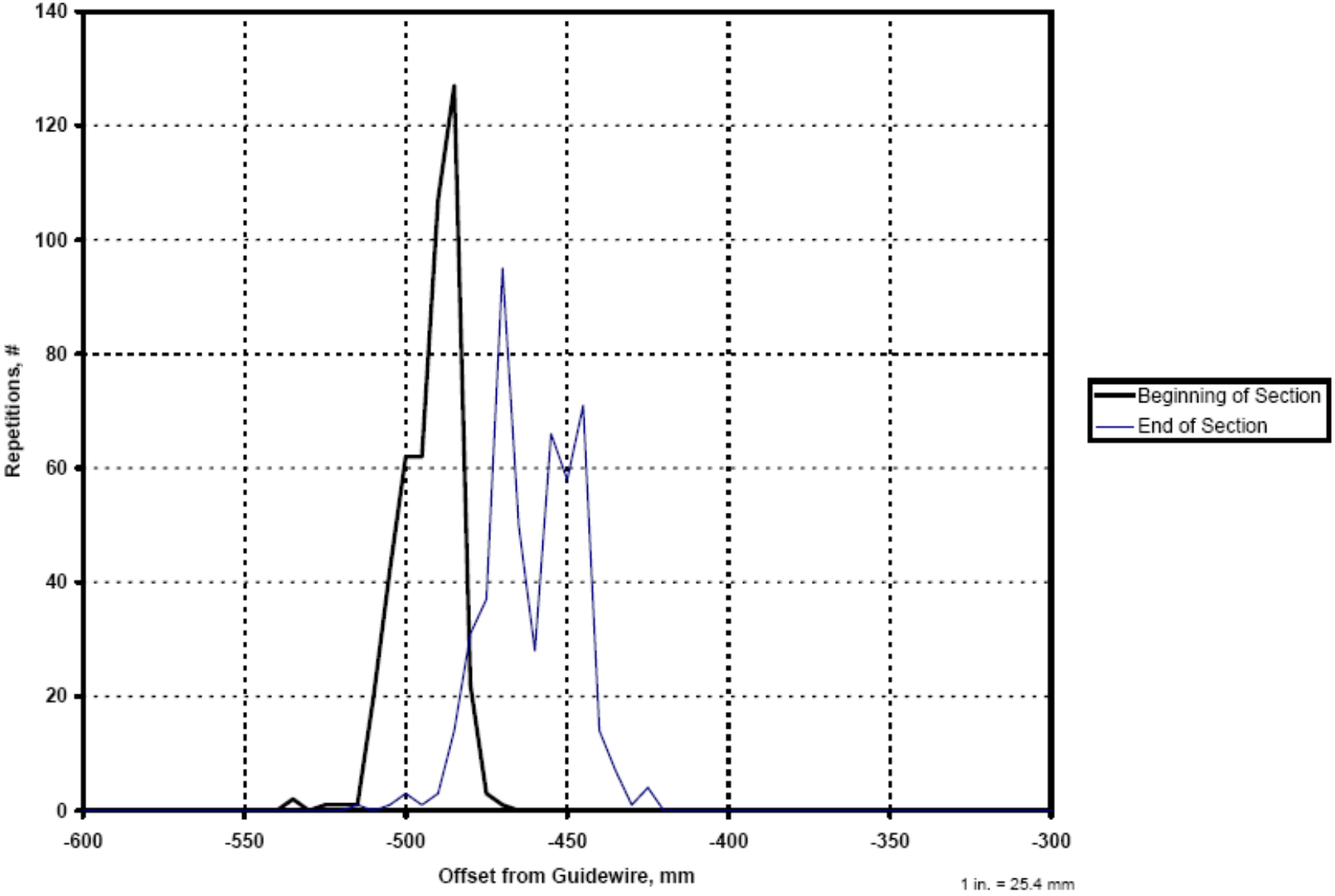


Figure B35. Rear Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/10/97.

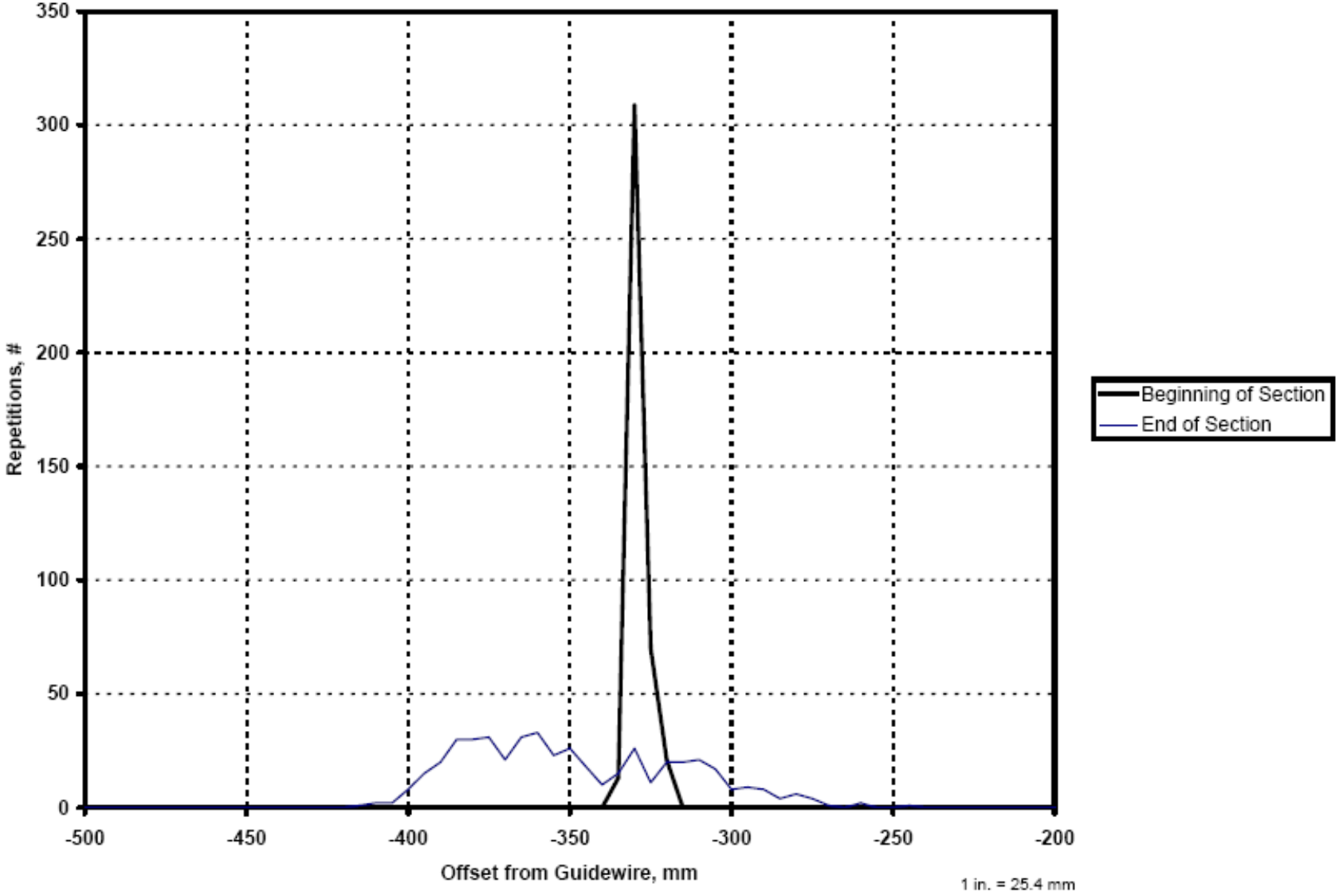


Figure B36. Rear Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/10/97.

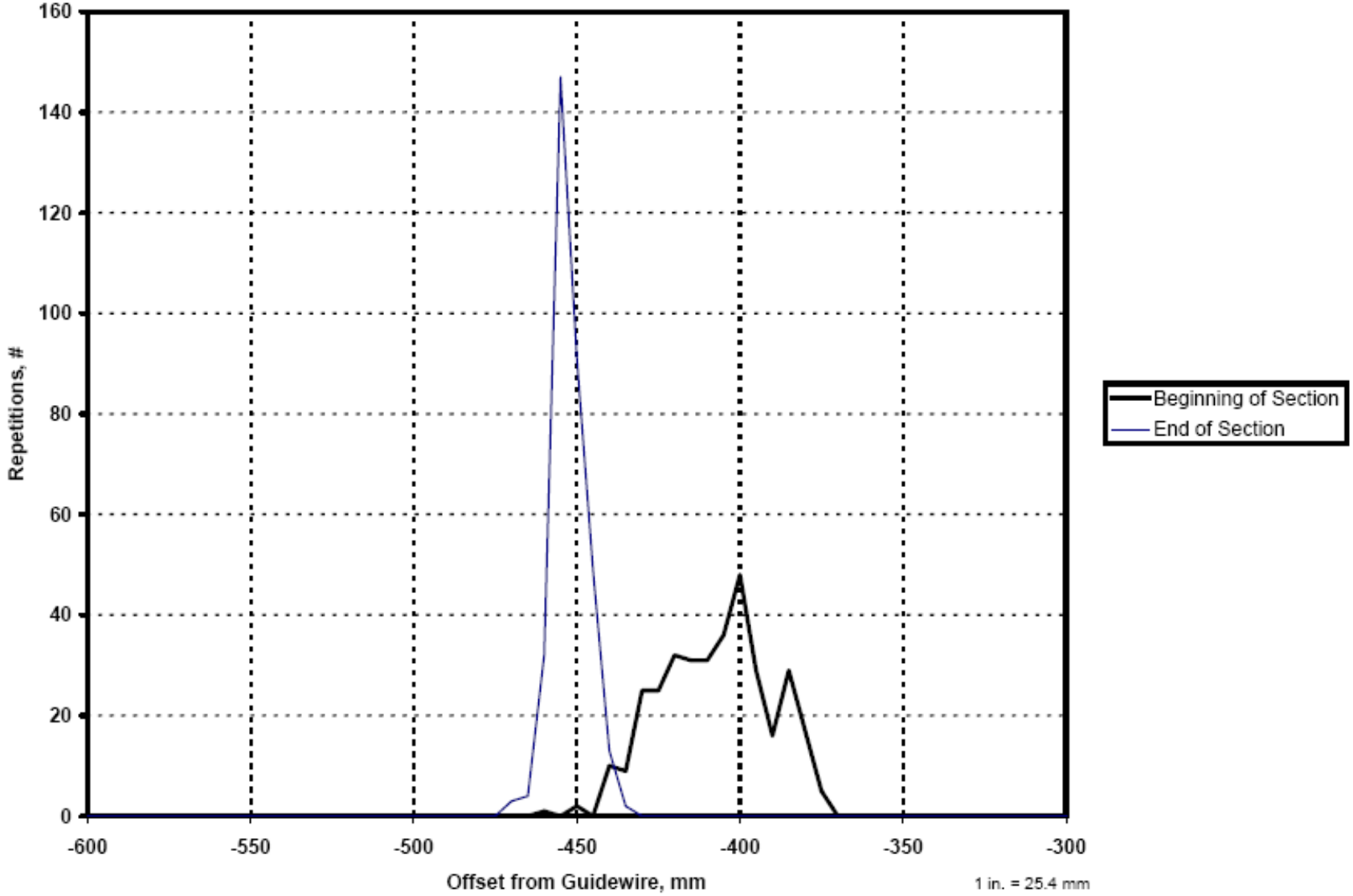


Figure B37. Rear Antenna Offset Histogram for Section 4 With Front Antenna Centered, 8/11/97.

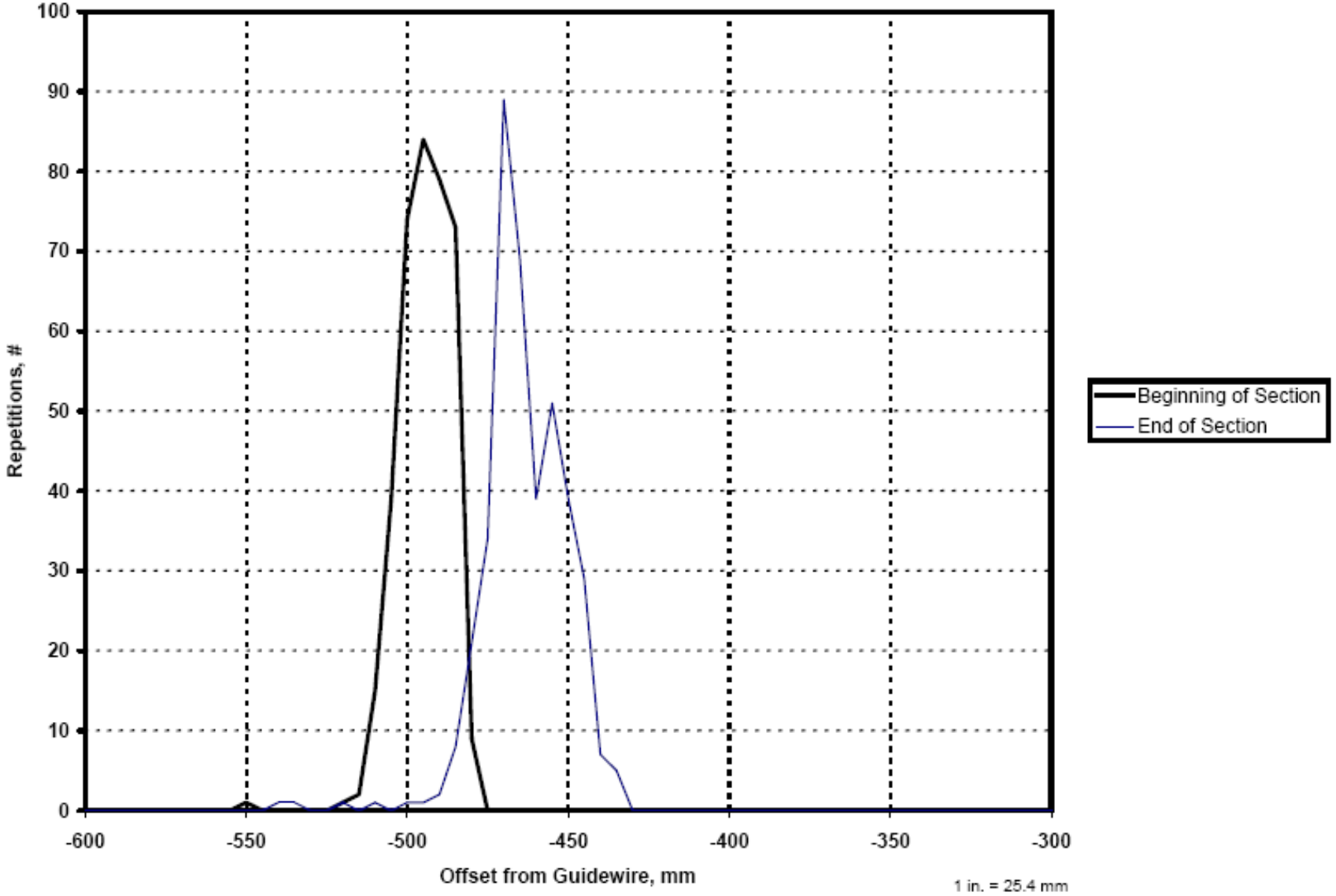


Figure B38. Rear Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/11/97.

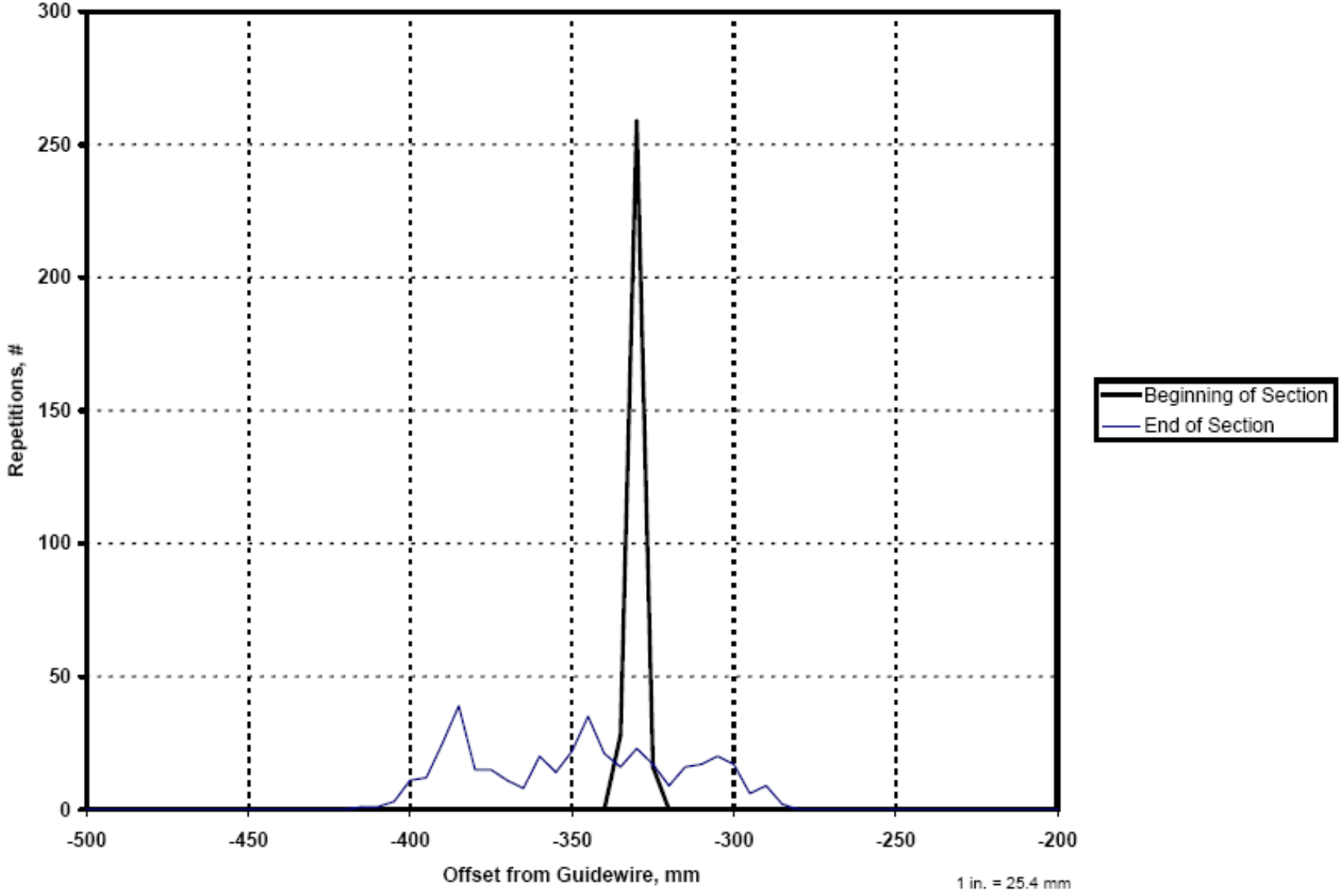


Figure B39. Rear Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/11/97.

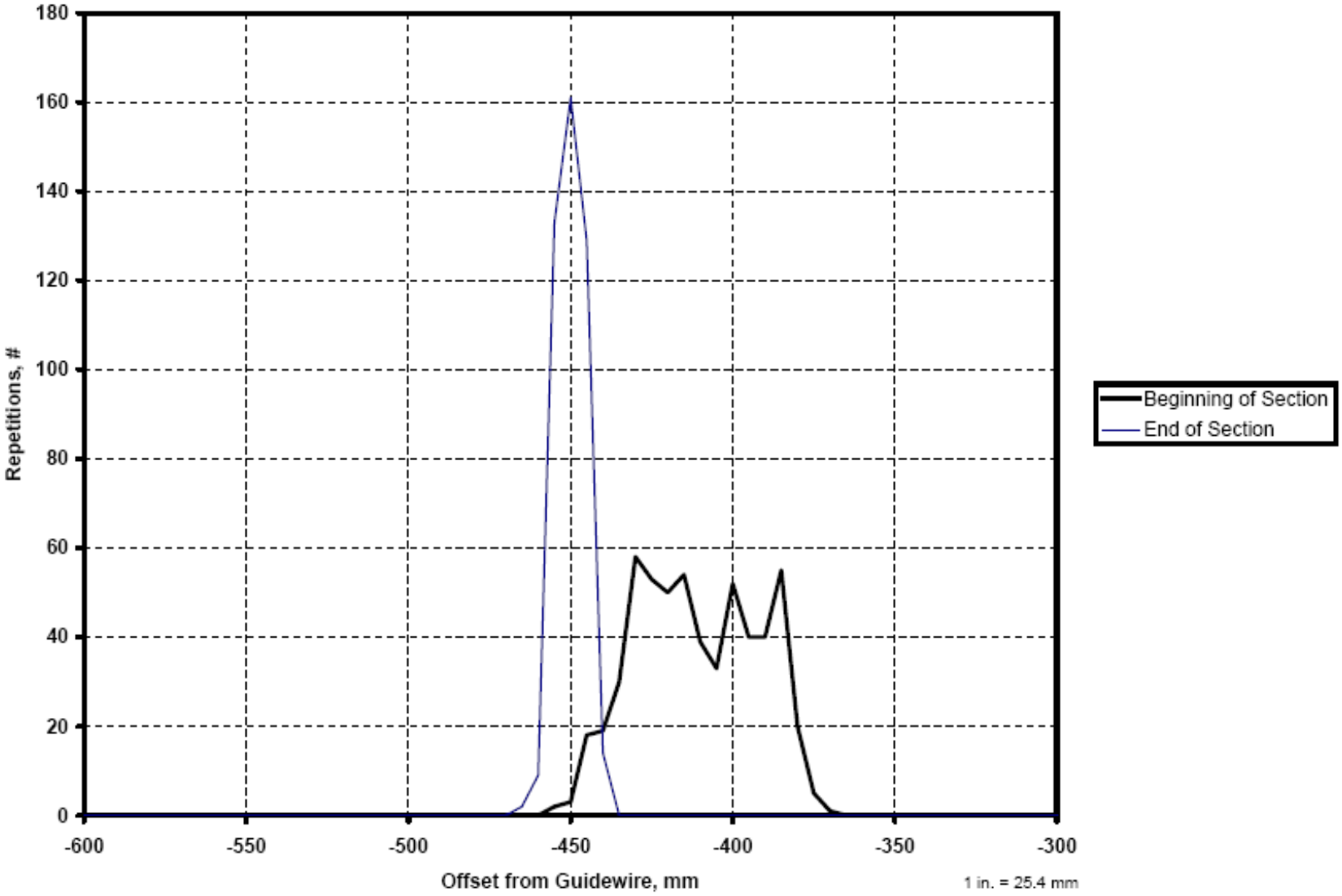


Figure B40. Rear Antenna Offset Histogram for Section 4 With Front Antenna Centered, 8/12/97.

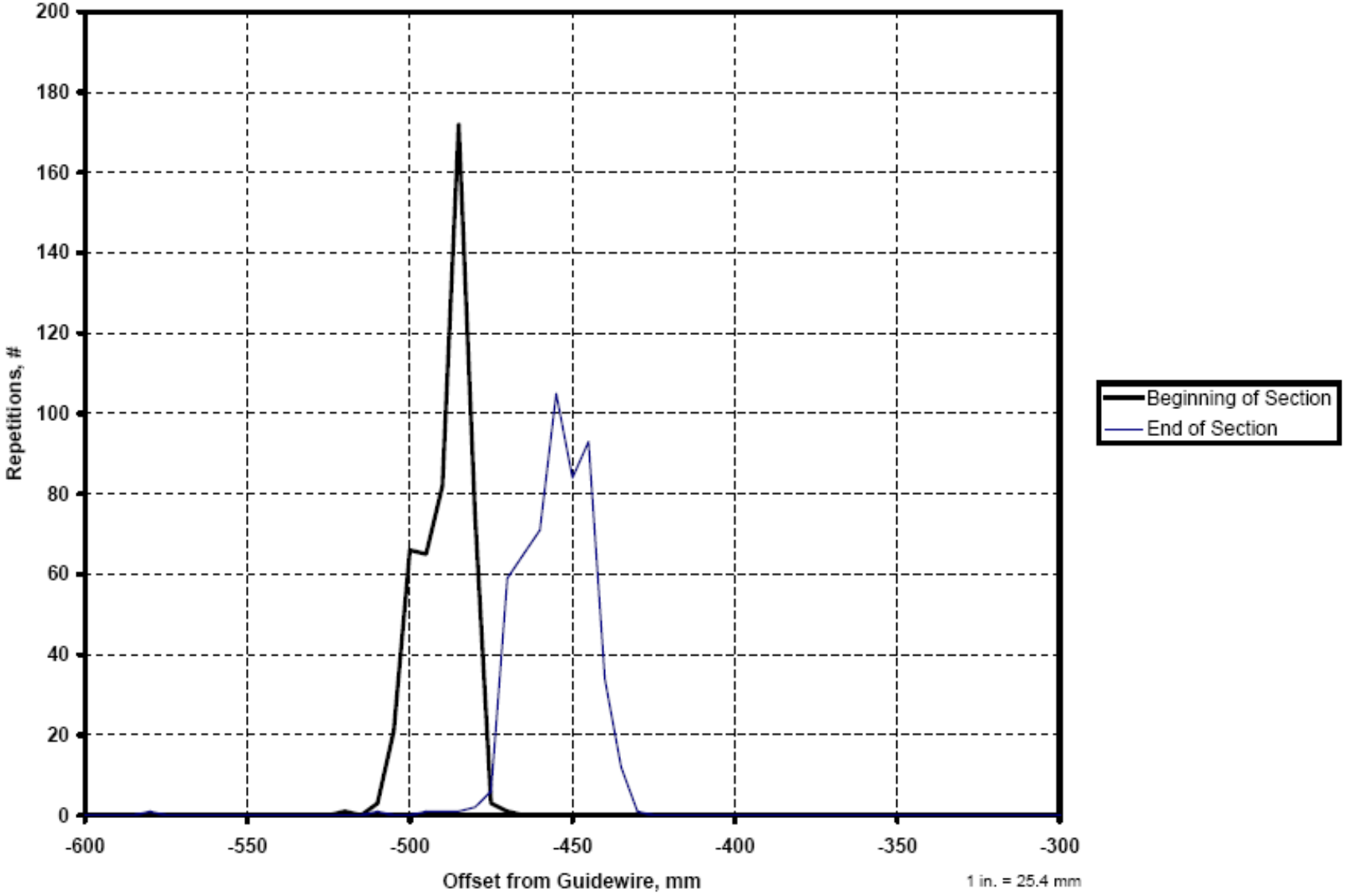


Figure B41. Rear Antenna Offset Histogram for Section 14 With Front Antenna Centered, 8/12/97.

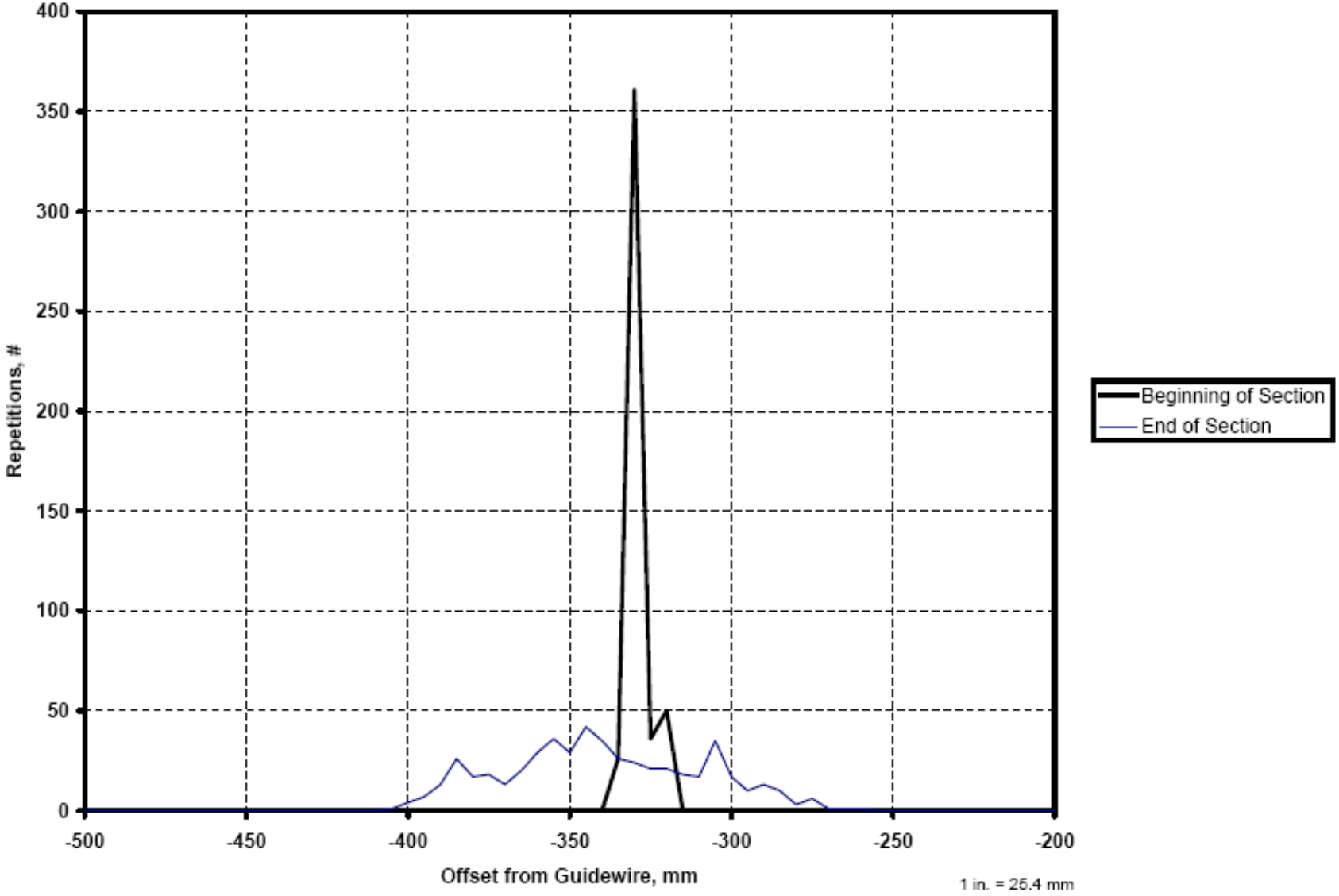


Figure B42. Rear Antenna Offset Histogram for Section 23 With Front Antenna Centered, 8/12/97.

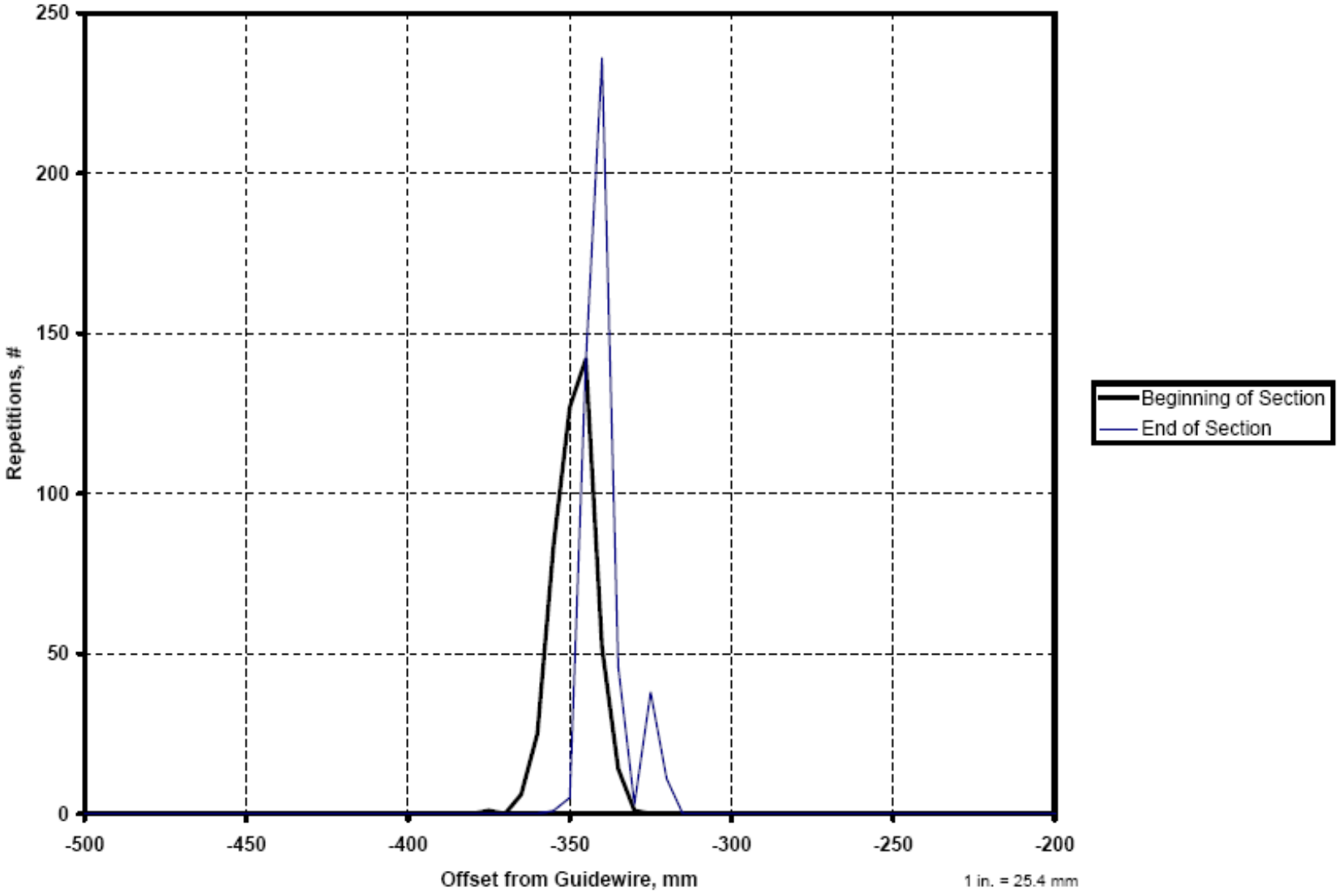


Figure B43. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 25.4 mm (1 in.) Right, 11/29/97.

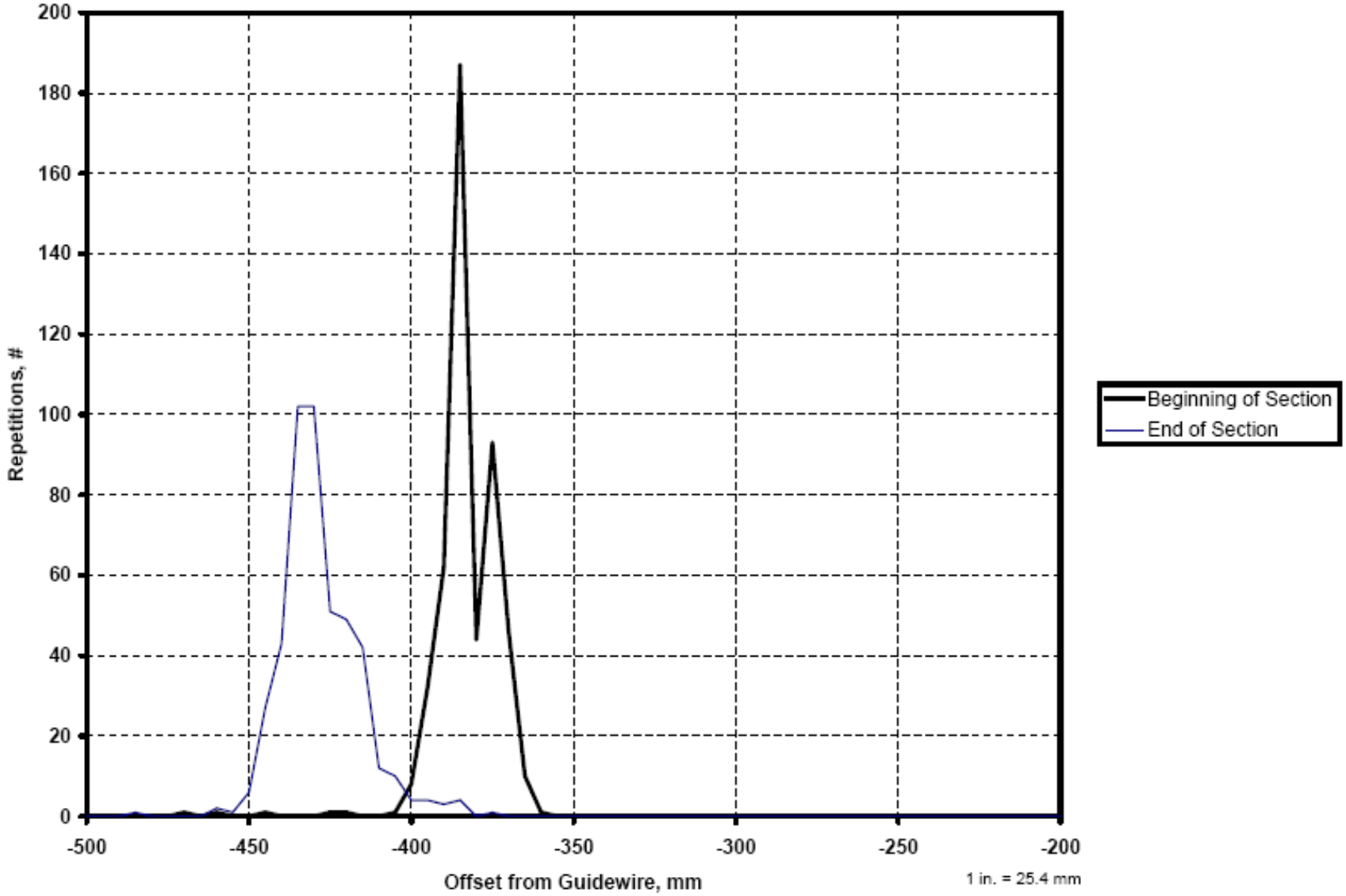


Figure B44. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 25.4 mm (1 in.) Right, 11/29/97.

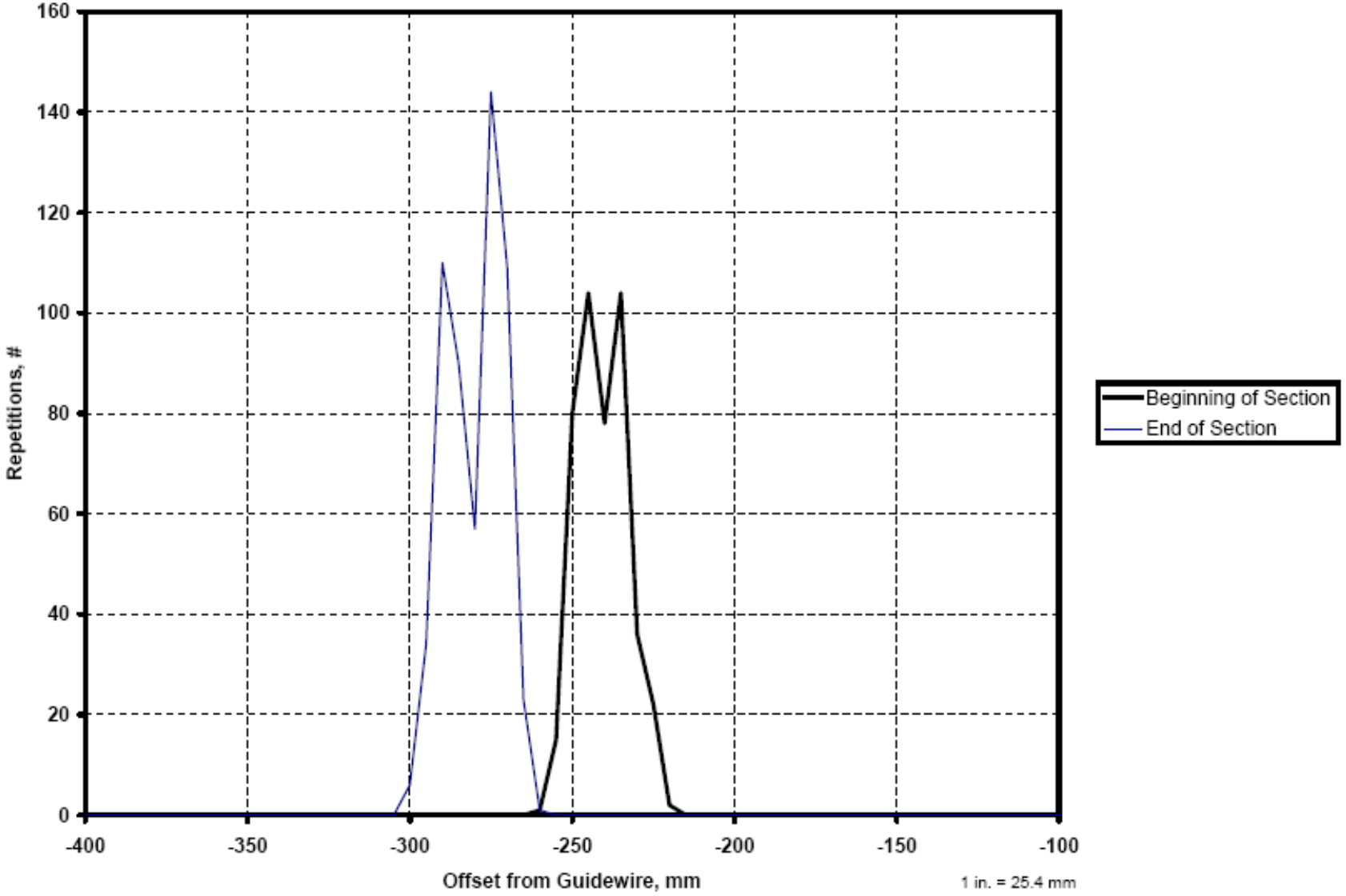


Figure B45. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 25.4 mm (1 in.) Right, 11/29/97.

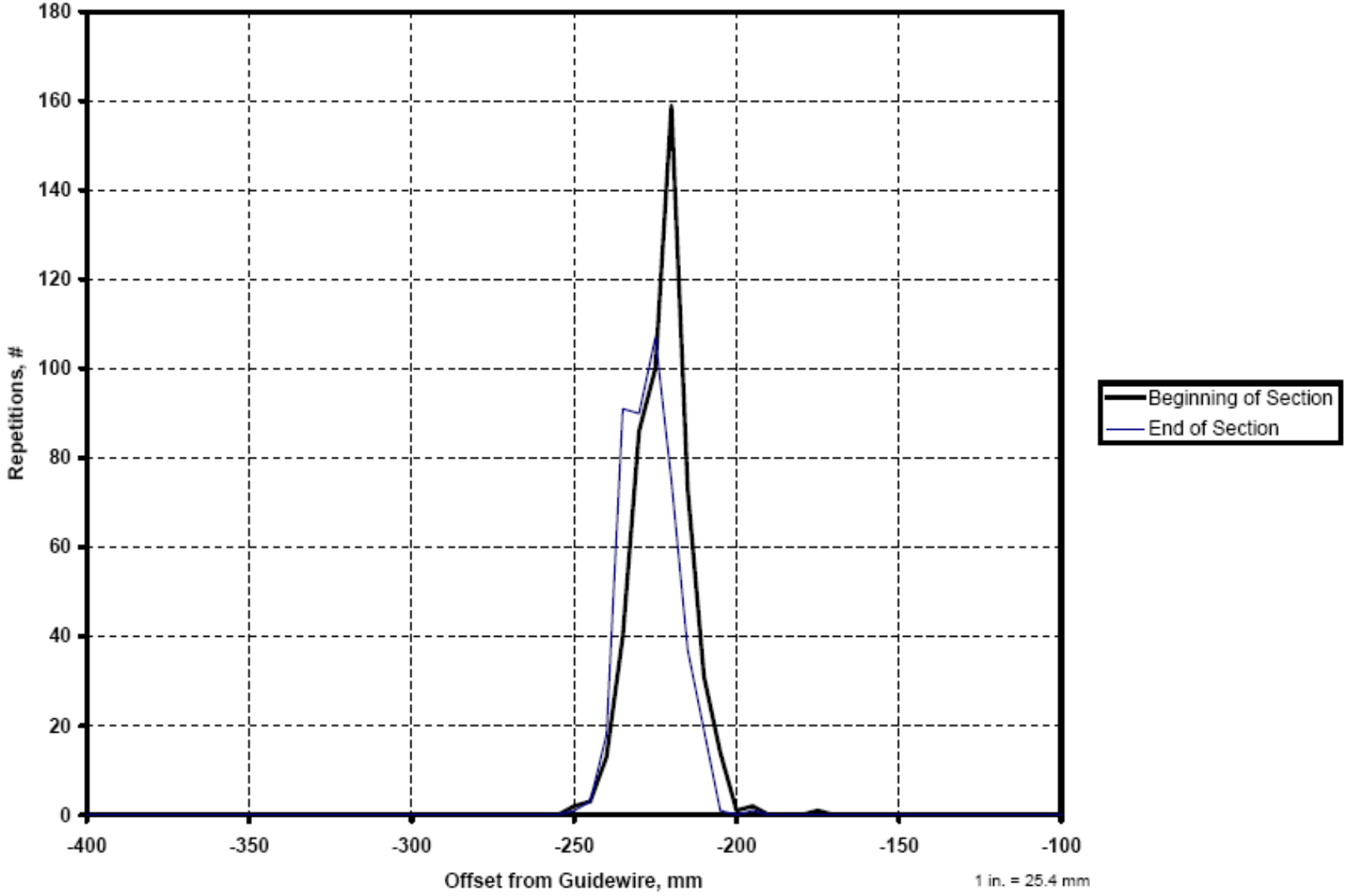


Figure B46. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 50.8 mm (2 in.) Right, 8/2/97.

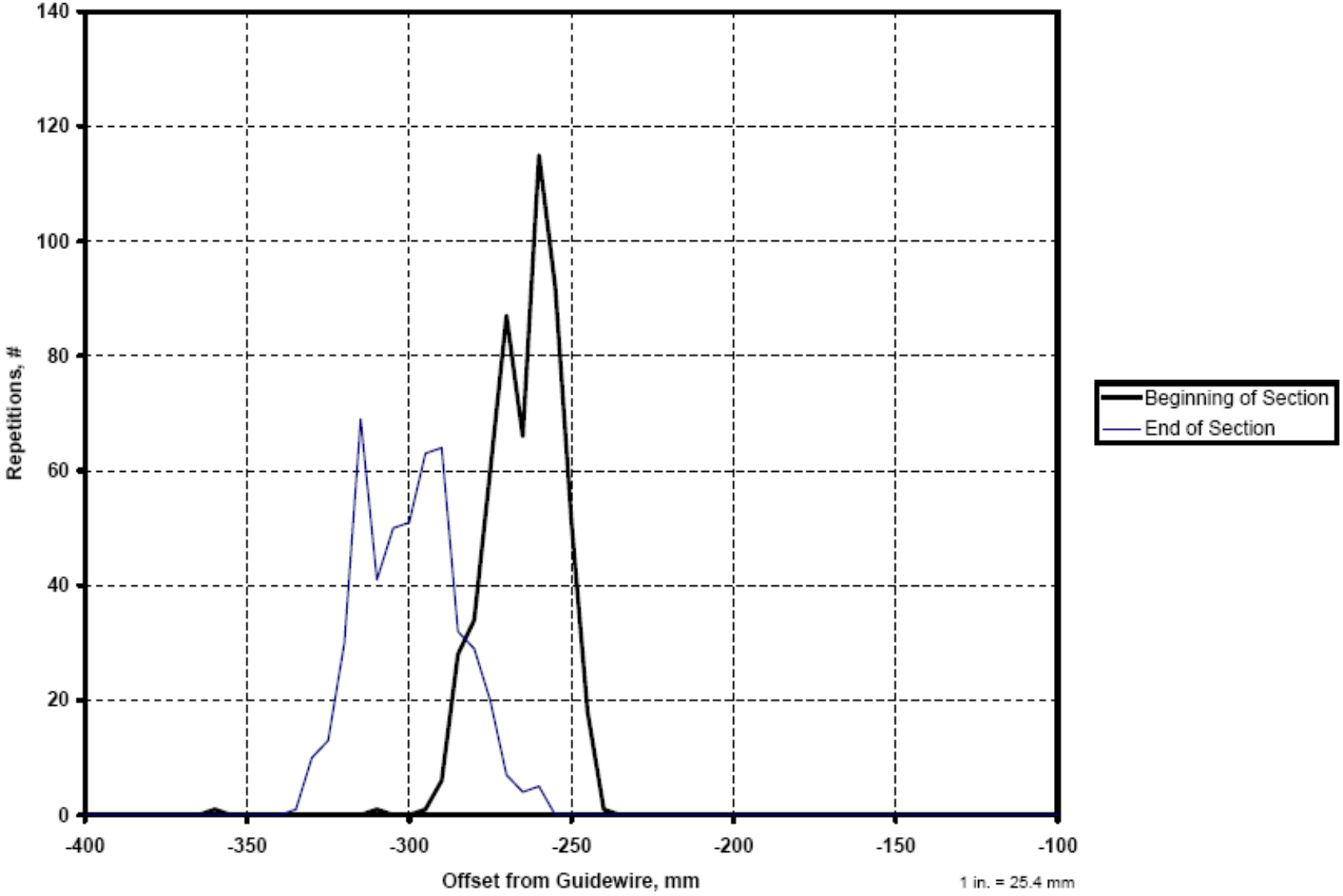


Figure B47. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 50.8 mm (2 in.) Right, 8/2/97.

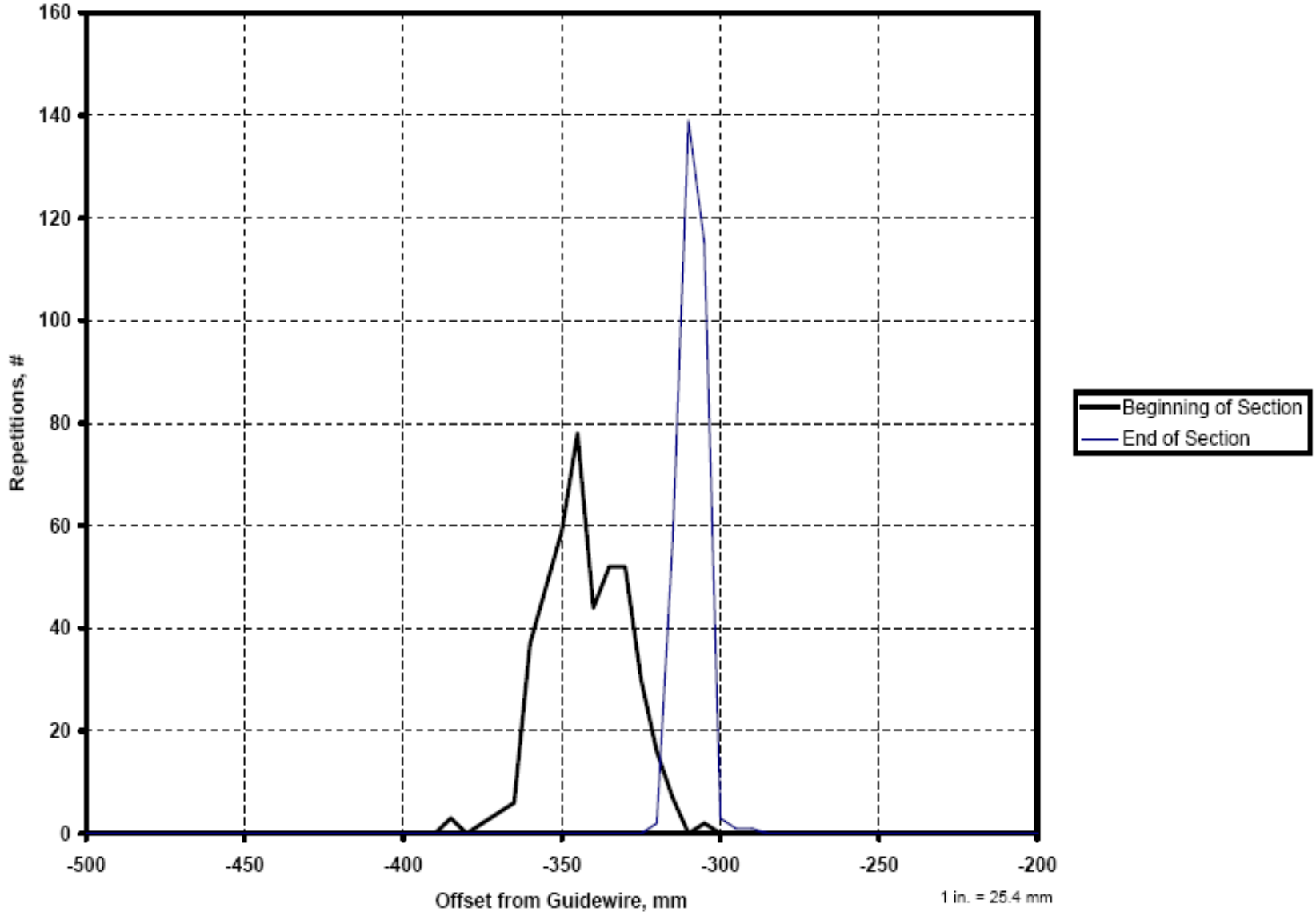


Figure B49. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 76.2 mm (3 in.) Right, 8/10/97.

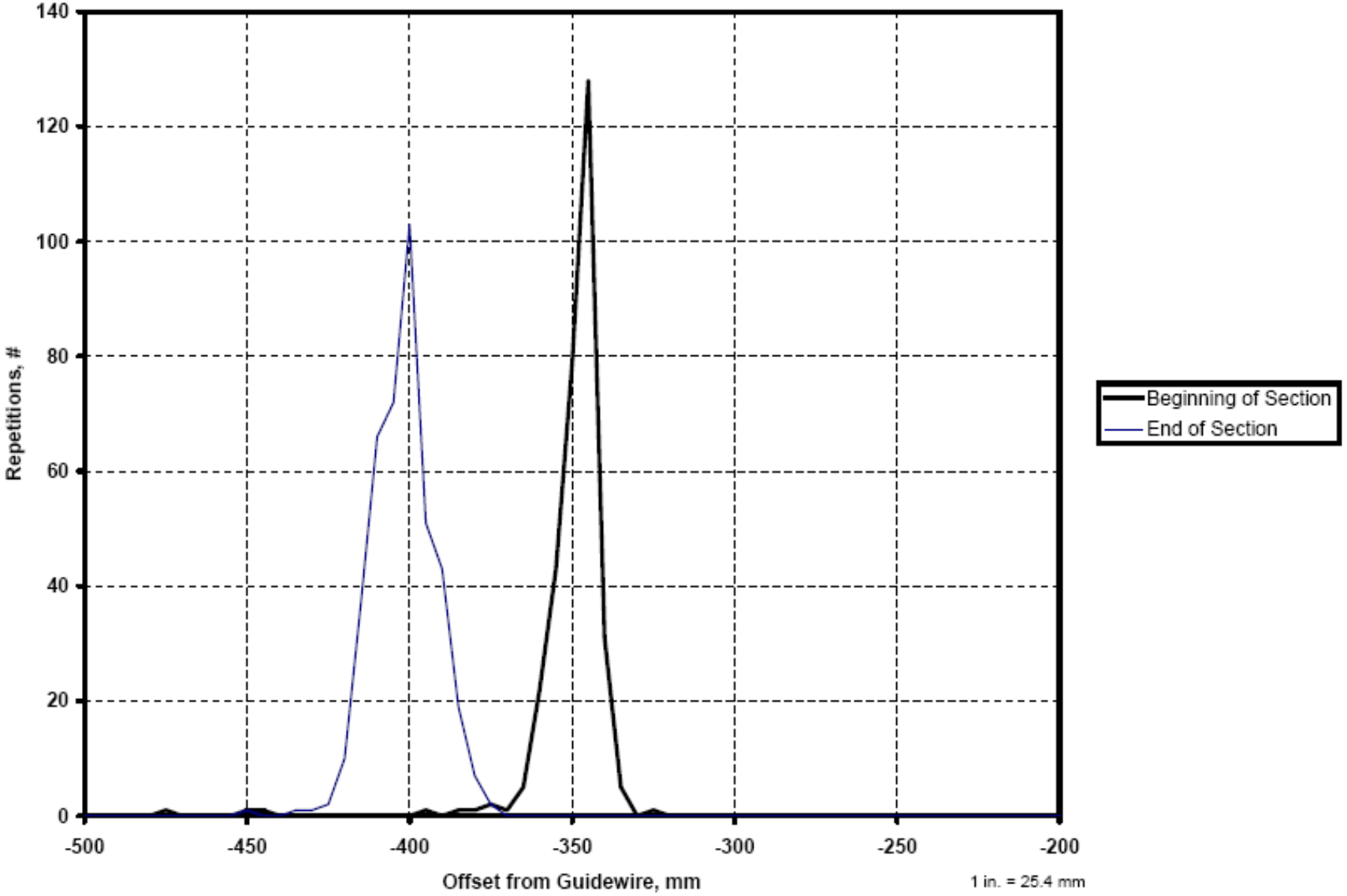


Figure B50. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 76.2 mm (3 in.) Right, 8/10/97.

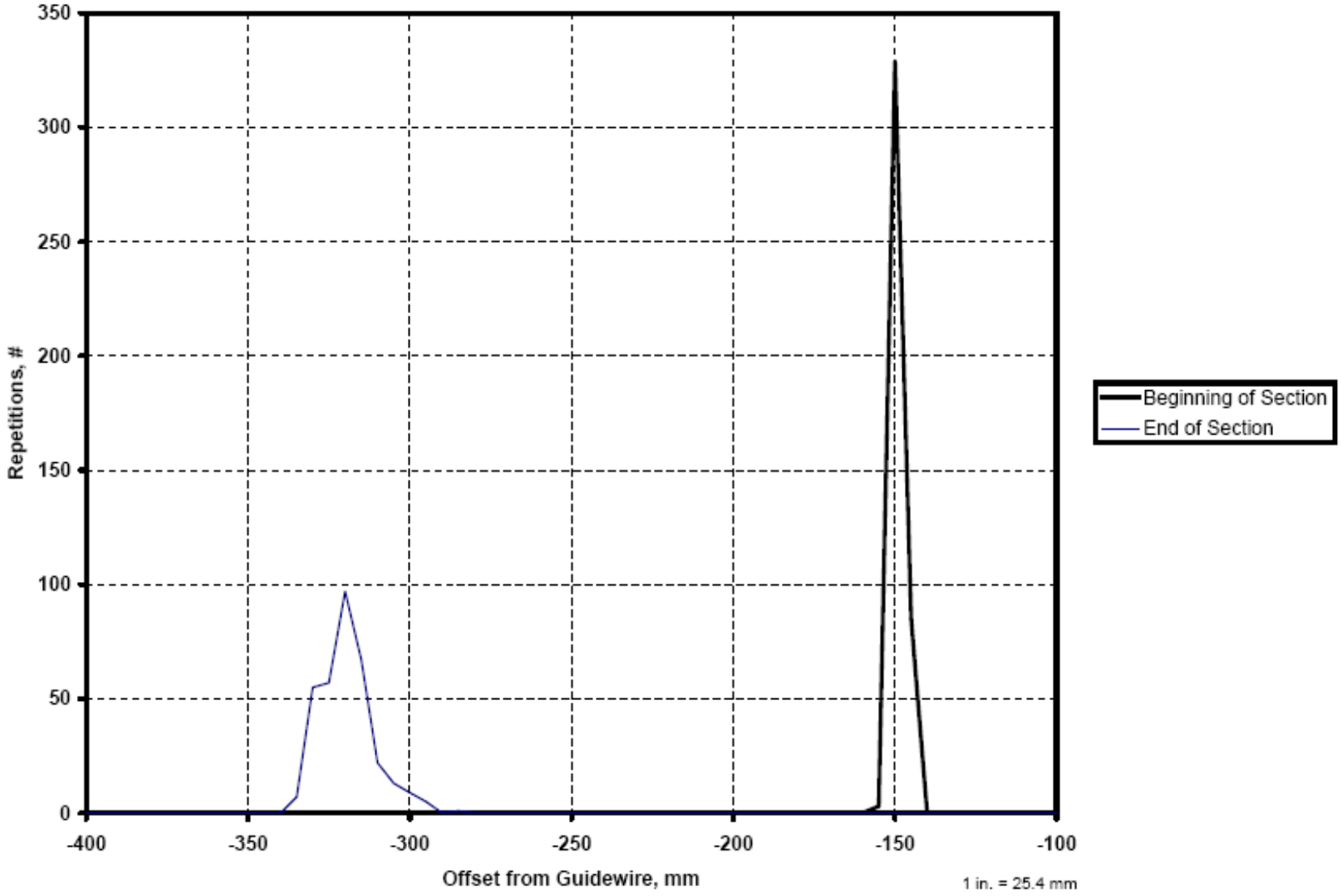


Figure B51. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 76.2 mm (3 in.) Right, 8/10/97.

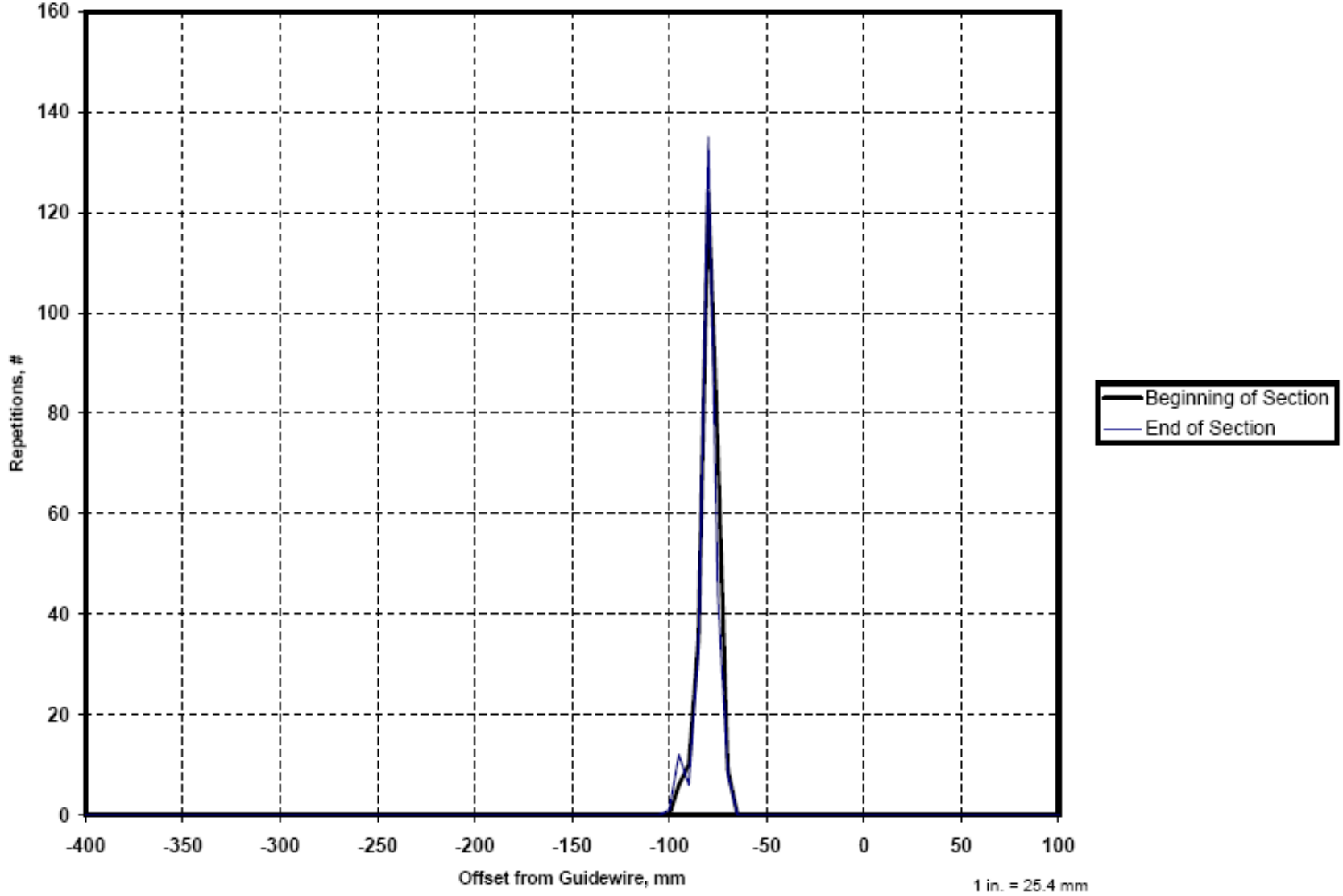


Figure B52. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 101.6 mm (4 in.) Right, 4/30/97.

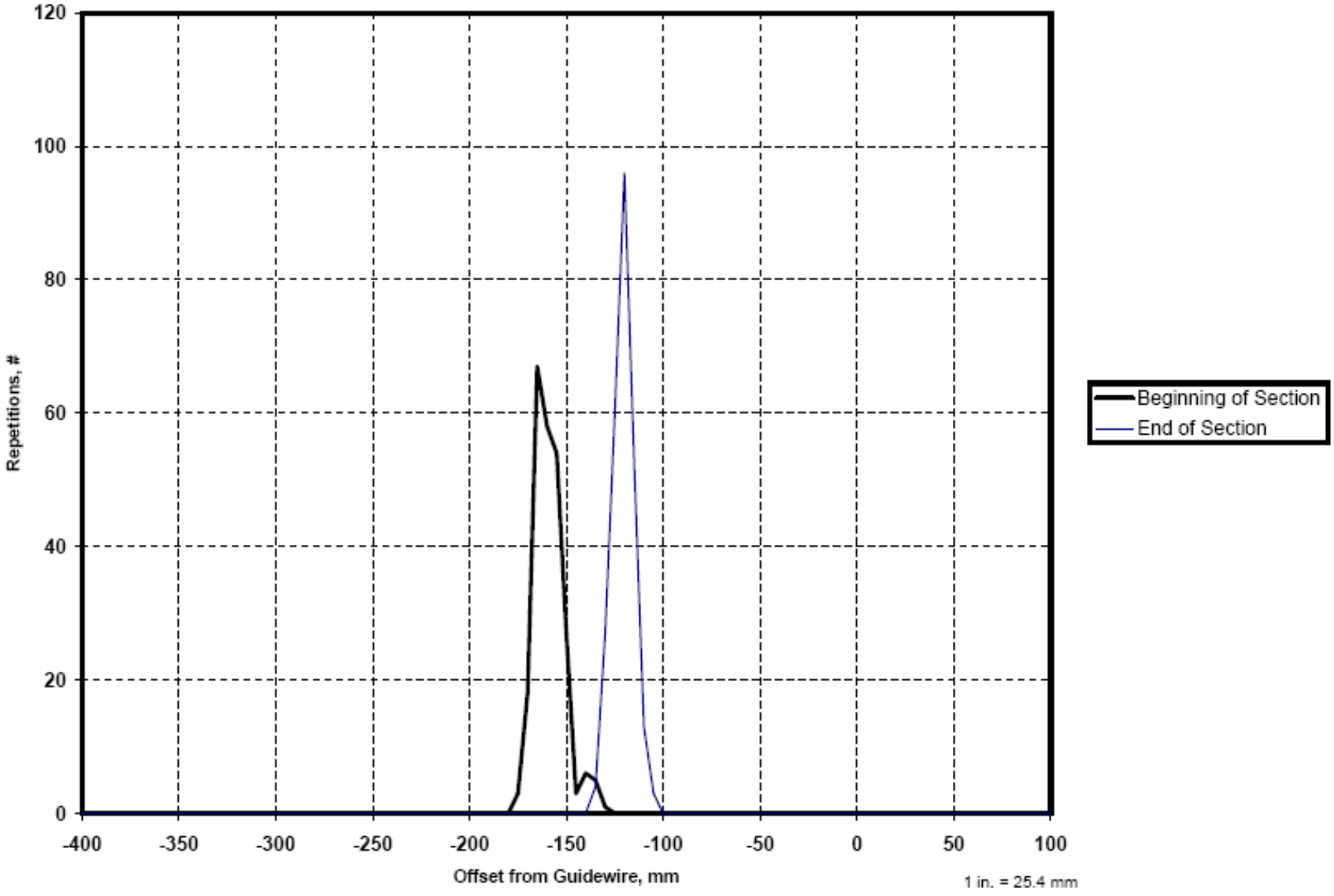


Figure B53. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 101.6 mm (4 in.) Right, 4/30/97.

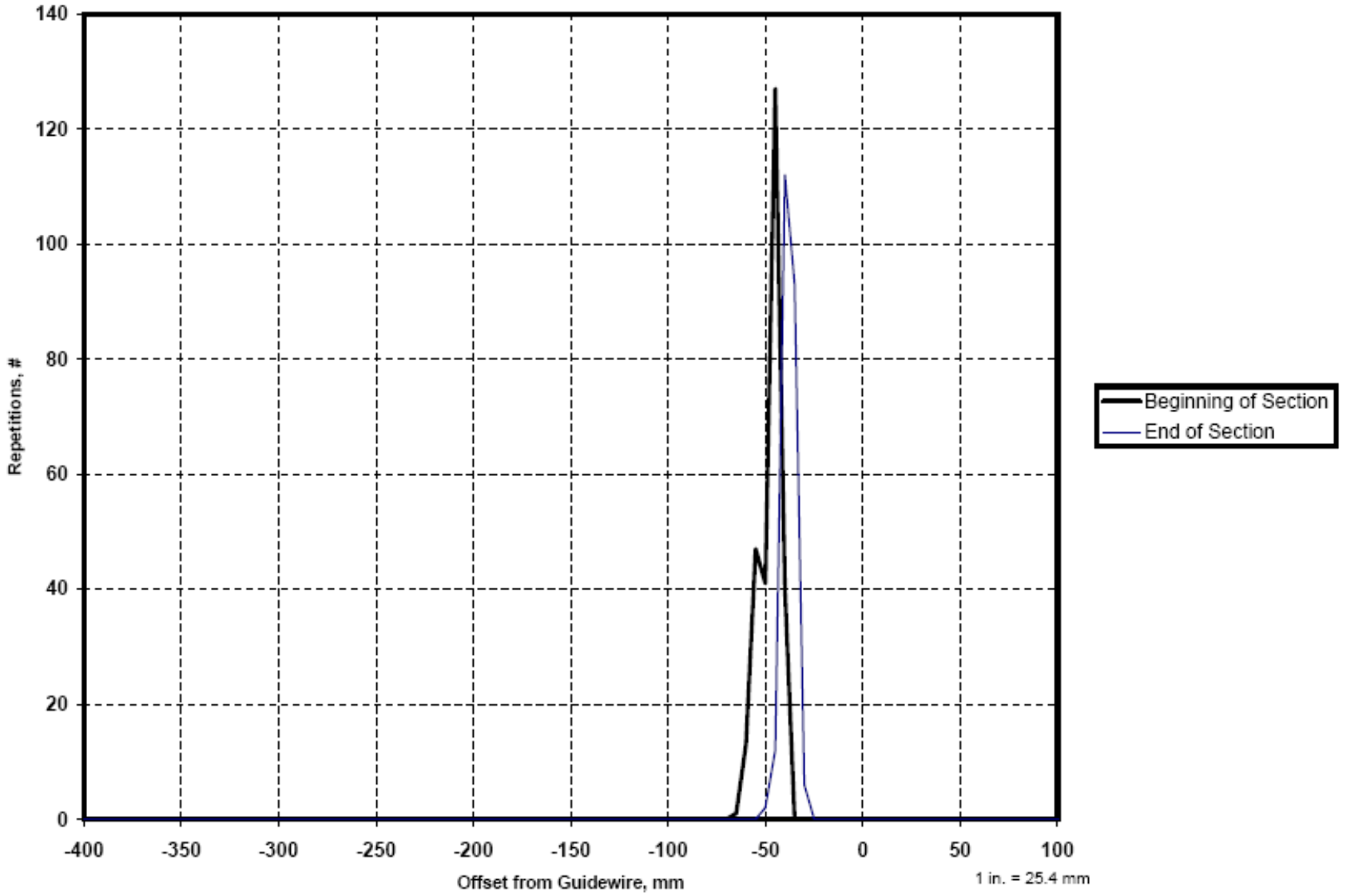


Figure B54. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 101.6 mm (4 in.) Right, 4/30/97.

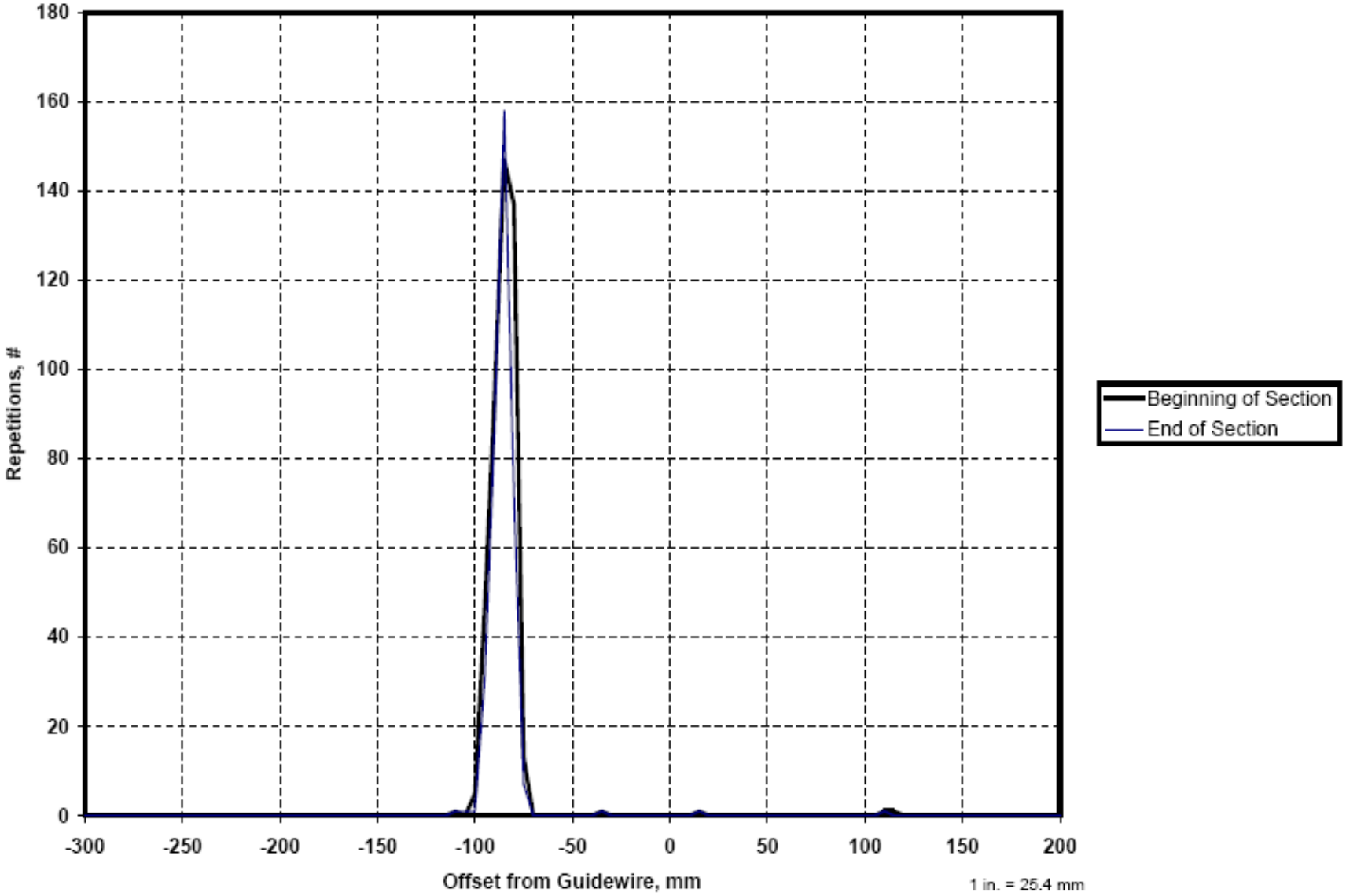


Figure B55. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 101.6 mm (4 in.) Right, 5/2/97.

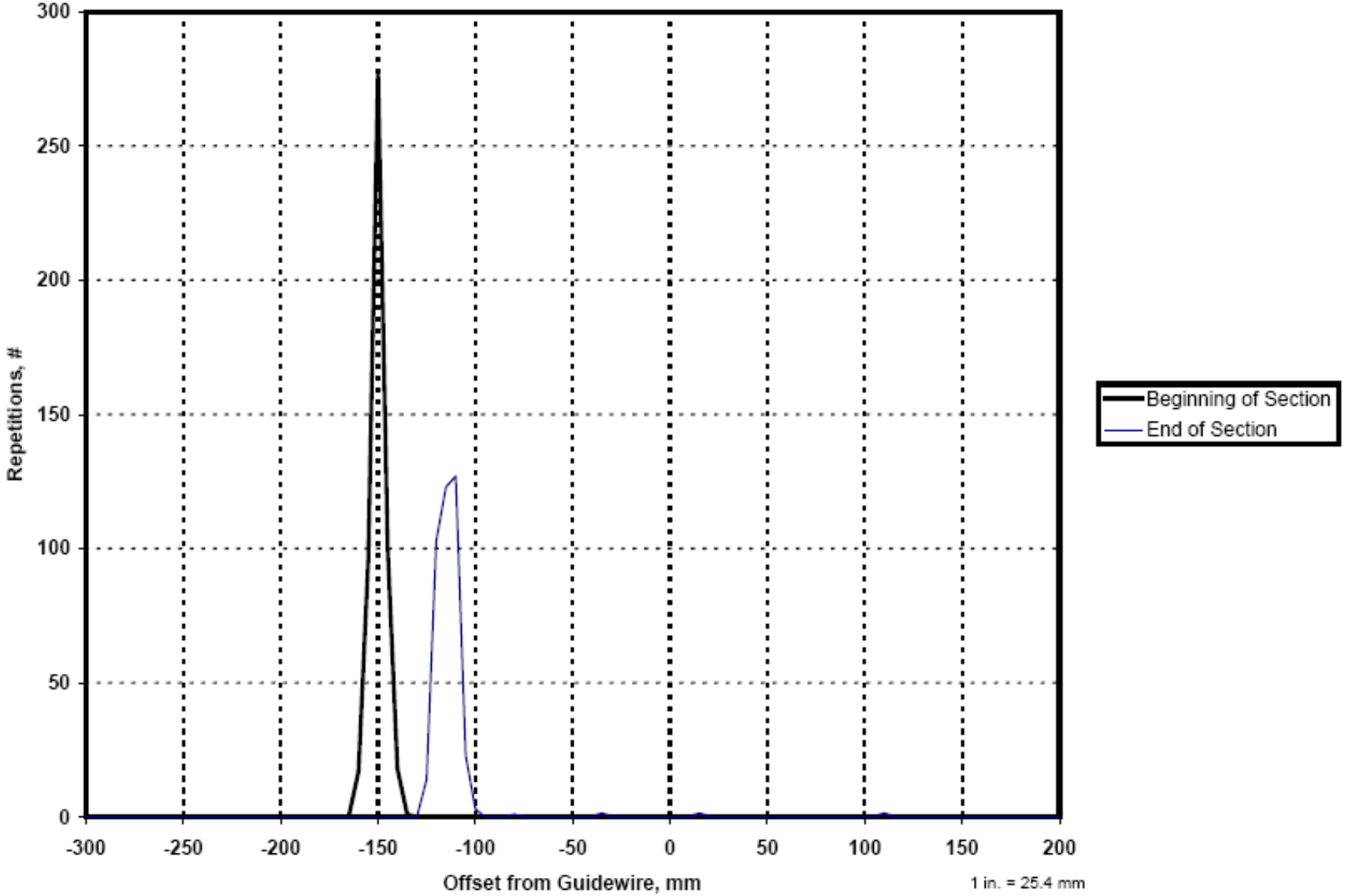


Figure B56. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 101.6 mm (4 in.) Right, 5/2/97.

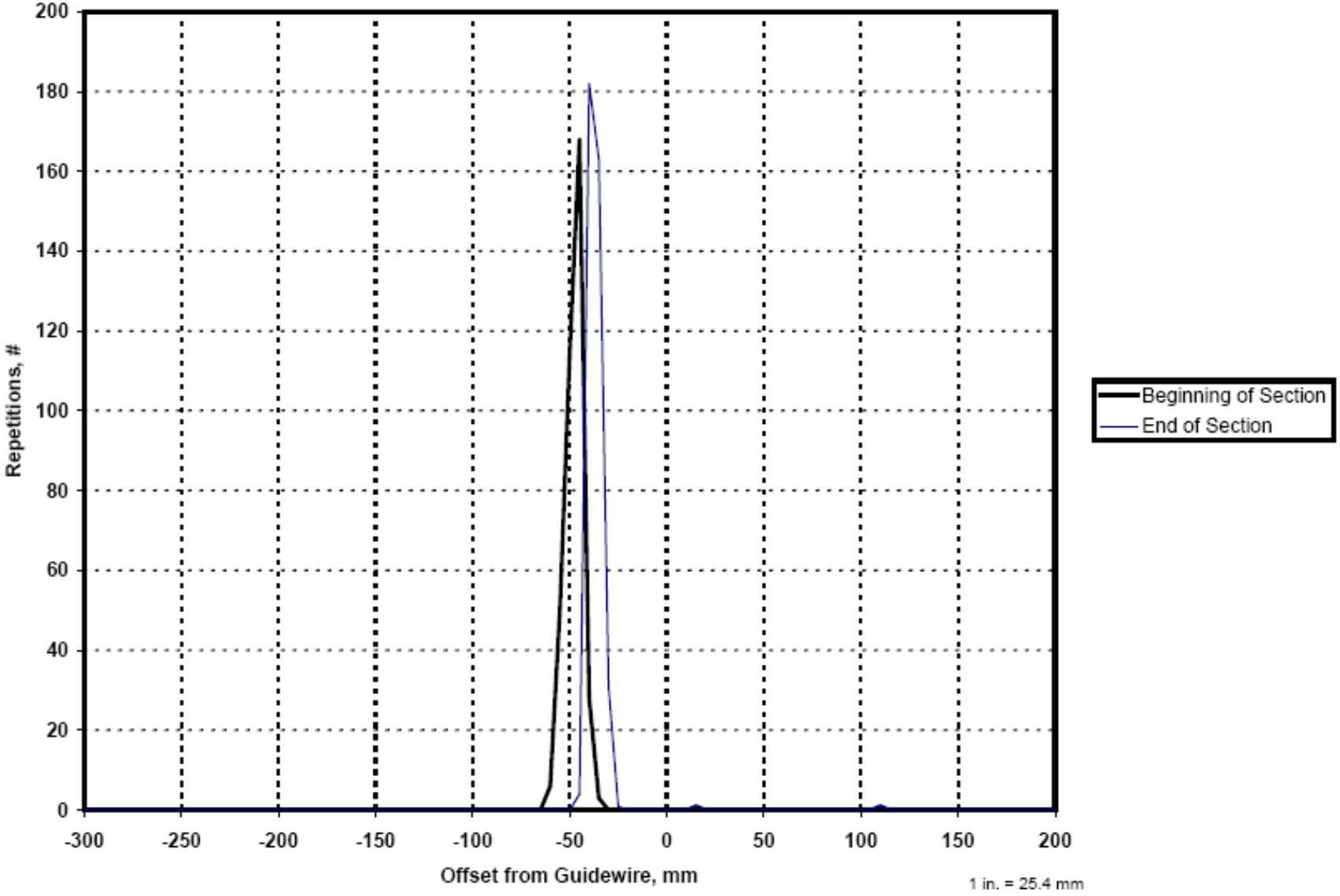


Figure B57. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 101.6 mm (4 in.) Right, 5/2/97.

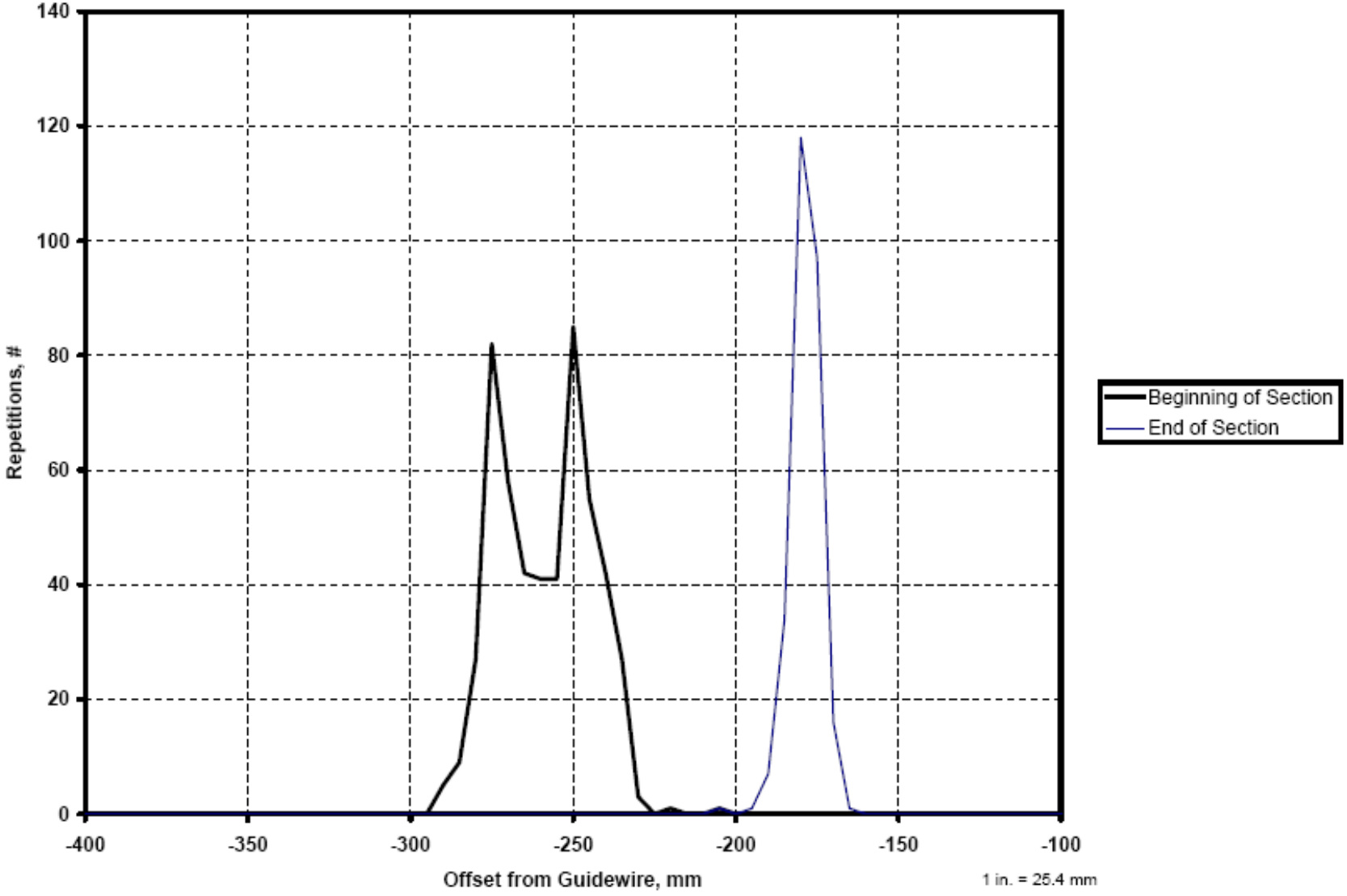


Figure B58. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 127 mm (5 in.) Right, 7/31/97.

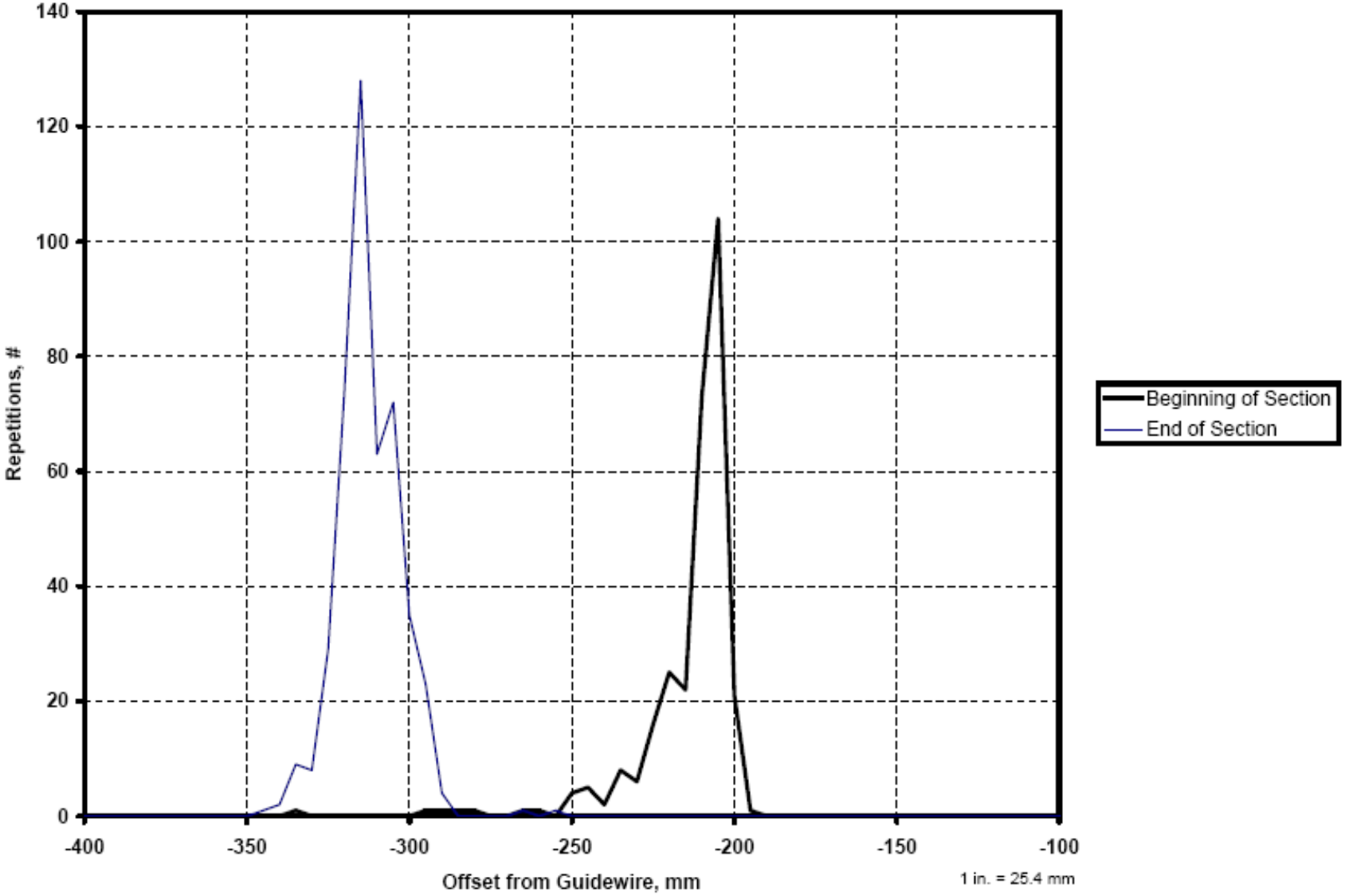


Figure B59. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 127 mm (5 in.) Right, 7/31/97.

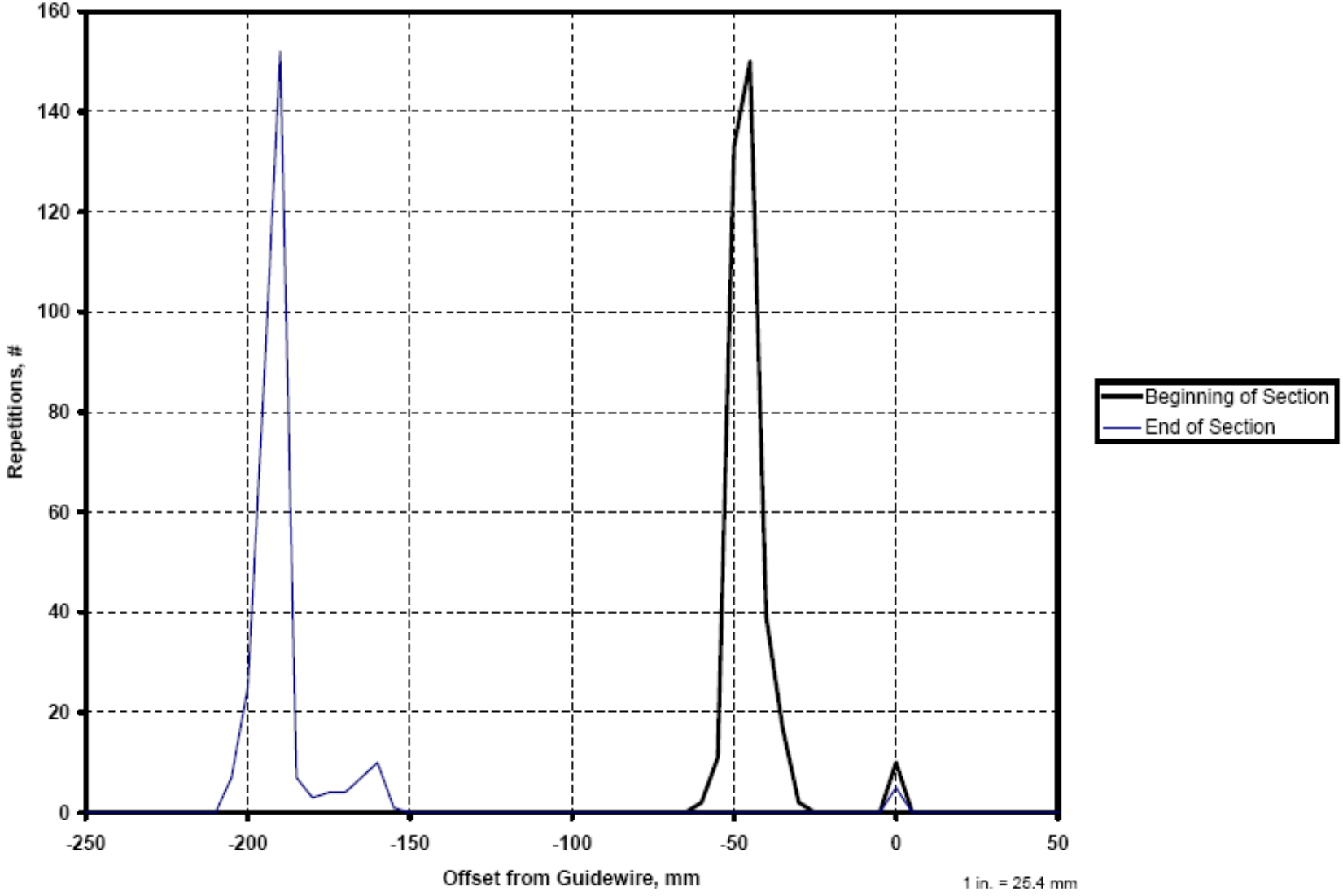


Figure B60. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 127 mm (5 in.) Right, 7/31/97.

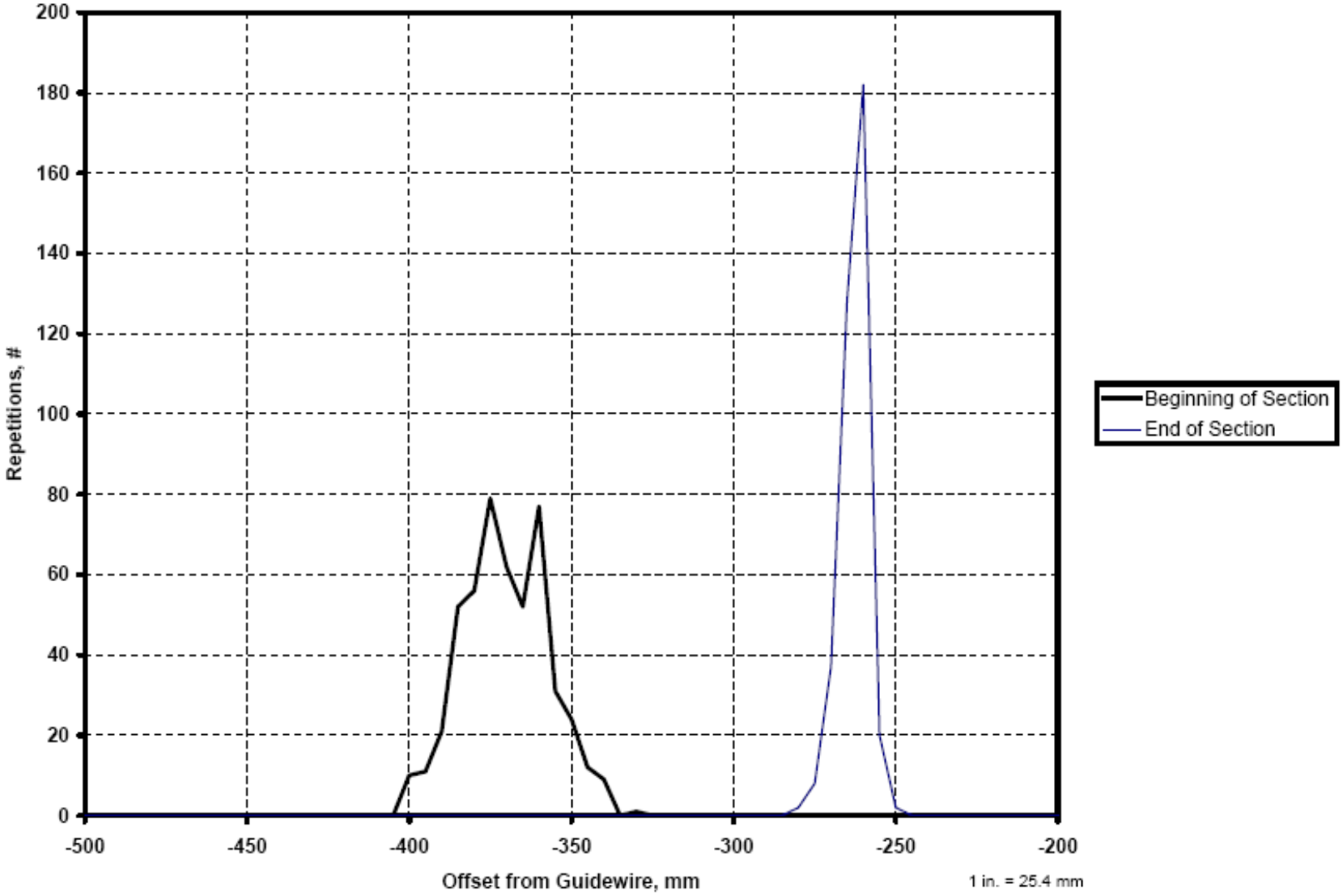


Figure B61. Rear Antenna Offset Histogram for Section 4 With Front Antenna Set at 127 mm (5 in.) Right, 8/3/97.

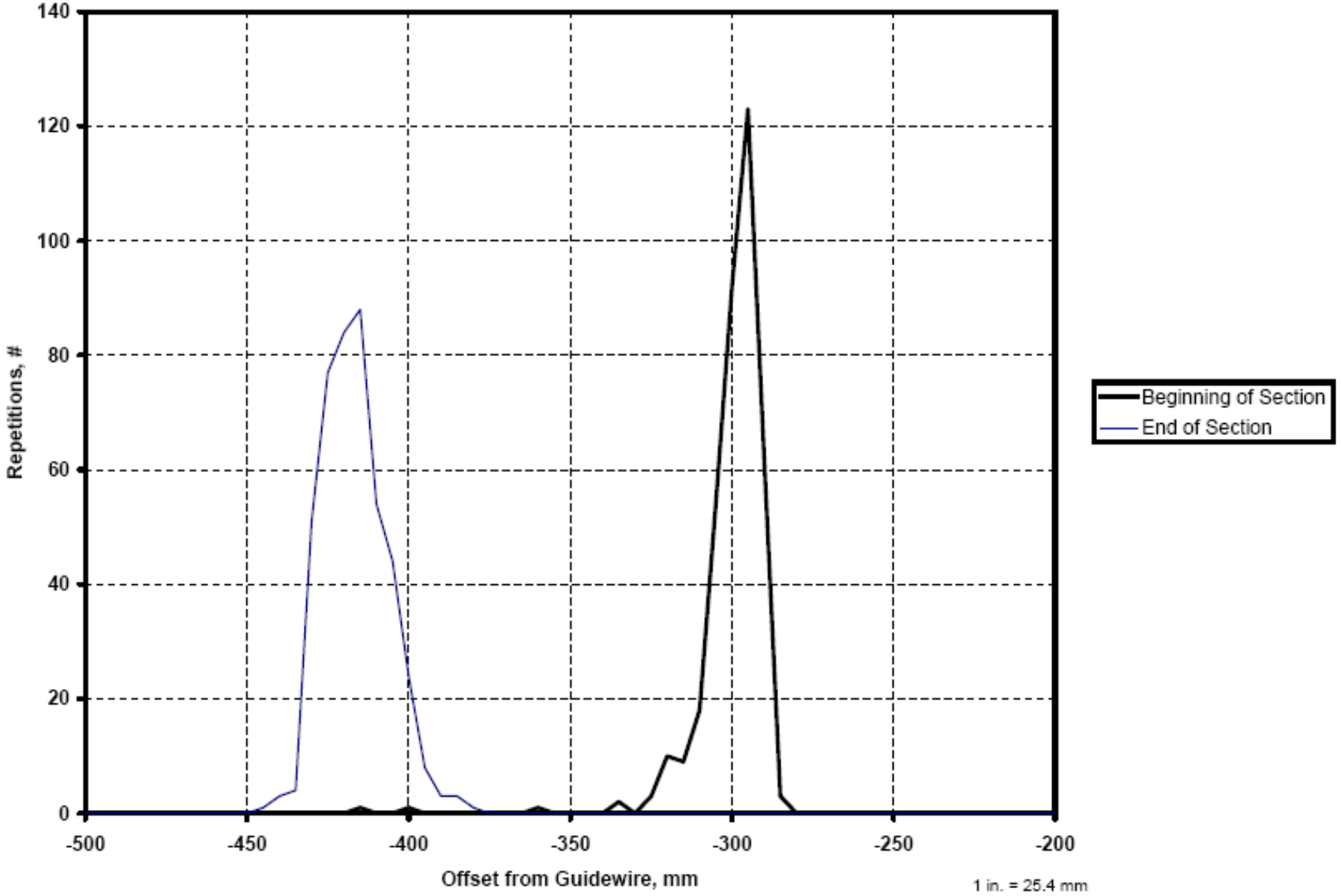


Figure B62. Rear Antenna Offset Histogram for Section 14 With Front Antenna Set at 127 mm (5 in.) Right, 8/3/97.

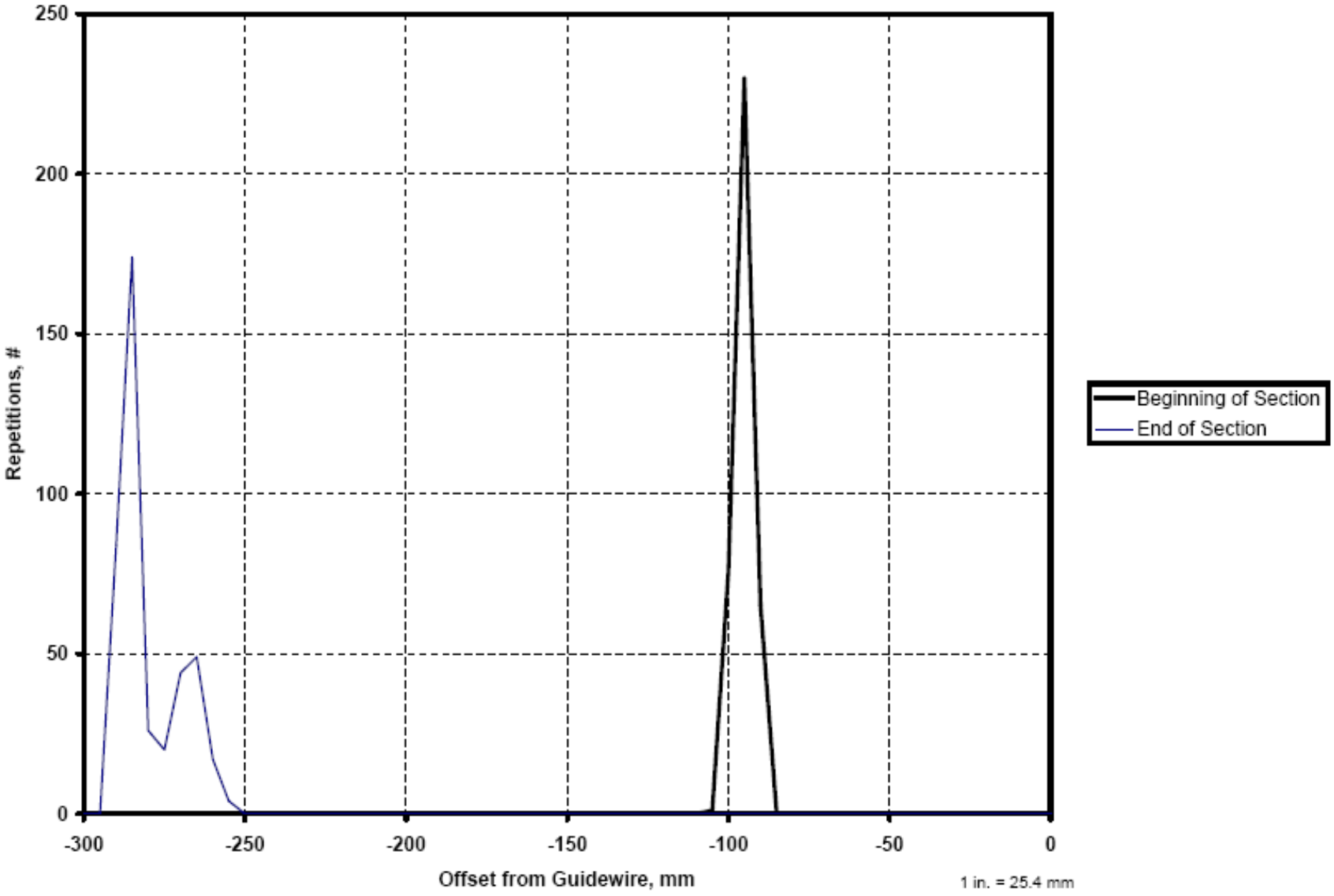


Figure B63. Rear Antenna Offset Histogram for Section 23 With Front Antenna Set at 127 mm (5 in.) Right, 8/3/97.

Rut Depth Data and Equipment for WesTrack Original and Replacement Sections

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report NCE-7
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

This document covers the equipment used, procedures for data reduction, and the final reported WesTrack rut depth data. The data are reported for both the original WesTrack test sections and the replacement sections built in the early summer of 1997. The rut depth values reported are for both maximum rut depth and downward rut depth for all sections.

EQUIPMENT

Before the project began, WesTrack team members reviewed the state-of-the-art equipment for measuring transverse profiles. Many different types of equipment were available at the time; however, some were not considered due to cost or the length of time required for data collection. The WesTrack Team decided to use the same equipment that was used by the Federal Highway Administration (FHWA) Long-Term Pavement Performance (LTPP) program. The equipment used is the commercially available Dipstick® and is made by FACE.

However, after using the Dipstick device on the WesTrack sections, the equipment operators observed that the maximum and minimum rut depths were not always captured by the transverse profile for sections with high ruts. This led the team to review other transverse profile equipment that possessed a shorter collection increment. Two devices were used: the first is referred to as the "Arizona device" (AZ device) and the second is referred to as the "laser device." The following is a brief description of each transverse profile device used at WesTrack.

Dipstick

The Dipstick, as shown in Figure 1, is a device capable of making very accurate measurements of transverse profile at 0.305-m (1-ft) intervals. The Dipstick device is used by the LTPP program to measure transverse profiles for more than 800 sites, with approximately 3,000 test sections. The Dipstick used by the WesTrack Team incorporated a computer to automatically record the profile data.

The procedure used at WesTrack consisted of installing reference points (PKnails) on each side of the test lane spaced at 10-m (33-ft) intervals. A temporary line was marked across the test section using the PKnail reference points and a chalk line. This allowed the engineering technician operating the Dipstick to follow a straight line in relation to permanent reference points.

The Dipstick was operated by starting at the reference PKnail nearest the fog line and moving in 0.305-m (1-ft) intervals toward the center of the lane. When the Dipstick met the centerline, the process was repeated toward the starting point. This allowed a comparison of two identical profiles of the pavement surface. These profiles were checked by the operator before starting the next profile location.

The Dipstick device collected high-quality profile data, and results were very repeatable. However, once wheelpath rutting became severe, the measured profile did not always contain the maximum rut depth for all test sections. Additionally, the extreme depth of rutting for some off-

target test sections went beyond the physical limits of the equipment. Due to these circumstances, another device was sought to record the transverse profile for extremely rutted sections.

Arizona Device

The WesTrack Team reviewed many transverse profile devices; however, some commercially available devices were beyond the price range available to the project. The team was fortunate to procure a device referred to as the "Arizona device" (AZ device), which is shown in Figure 2. The device was loaned to the team by the Arizona Department of Transportation.

The AZ device consists of an aluminum bar that is fixed to a stand on one end and to a jack on the other end. The portion of the device that transfers the transverse profile into a usable format consists of a wheel, slide, and armature. The profile is recorded by taping a 4.25-m (14-ft) piece of graph paper to the bar. Before the transverse profile is scribed onto the graph paper, the floor jack and a level are used to level the beam. Once the leveling is complete, the armature is pulled across the pavement surface and the profile is scribed onto the graph paper by means of a pen.

This device worked very well; however, some variability existed due to the mechanical nature of the device. Additionally, the graph paper profile had to be reduced in the office by an engineering technician, through a laborious process. This prompted the WesTrack Team to develop a new device.

Laser Profile Device

A new device for measuring transverse profiles was developed by the Nevada Automotive Testing Center (NATC), with input from NCE and the FHWA. Requirements for the device were established by NCE before NATC began building the device. The first prototype built was a single beam fitted with rolling wheels at each end, as shown in Figure 3. A stepper-motor and belt, fastened between the ends, pulled a laser emitter/receiver across the underside of the beam. The return signal, which indicated the distance from the laser to the pavement surface, and the position across the beam were stored in a laptop computer that was also attached to the beam. Additionally, in order to generate enough power to run the device, an external generator was used.

This laser profile device required three modifications. The first modification was the intensity of the laser emitter. The emitter used by NATC was very costly, but, it did not produce enough energy for a strong return from a black pavement surface. The second modification was to correct the deflection in the beam due to the dead weight of the equipment. A bowing in the beam was reflected in the recorded data. Lastly, the beam was parallel to the pavement surface, and did not allow the determination of the pavement cross slope. Therefore, a means to level the beam was required.

Several attempts were made to make these modifications using the existing equipment. However, different measures had to be employed. To solve the laser intensity problem, FHWA loaned the WesTrack Team a more powerful laser-emitting device, which was readily incorporated into the

laser profiler. This allowed the device to be used on different material surfaces. To remove the bow in the beam, a second beam was added. This allowed the original beam to be prestressed through the use of bolts and flanges. Finally, a trailer jack was welded to the end of the beam to allow leveling of the beam.

DATA REDUCTION

The data collected from each device were reduced in a similar manner, with the only differences being the process used to develop the transverse profile. A detailed description for each device's data reduction process follows.

Dipstick

The Dipstick data reduction consisted of downloading the data onto a floppy disk. Once this was complete, the FACE software was required to convert the data into a usable format. This produced two transverse profiles, reflecting the operation of the Dipstick in the field.

The two profiles were again compared to ensure the quality of the collected data. Once complete, the outward profile was plotted and the cross slope of the pavement surface was calculated. Subtracting the slope of the pavement from the collected profile, an altered profile was created. This allowed for the visual determination of the rut depth for each wheelpath.

Arizona Device

The data reduction of the AZ device was a very labor-intensive process that required both visual transfer of data and a reduction for rut depth determination that was similar to that performed with the Dipstick. An engineering technician took each profile and laid it out flat on a long table. An axis was laid out based upon the beginning location and the increments of the grid paper. At 50-mm (2-in.) intervals, the elevation from the reference point was recorded. These data were then transferred to a Microsoft® Excel spreadsheet. The cross slope was removed and the rut depth for each wheelpath was visually determined.

Laser Profile Device

In raw form, the laser profile data reflected the voltage output received by the laser sensor and the position across the beam from the stepper-motor. These data were then converted into elevation and lateral position, based upon a known relationship of voltage to elevation, and the increment of transverse movement, respectively. The cross slope of the pavement was removed and the rut depth for each wheelpath was then visually determined.

FINAL RUT DEPTH DATA

Table 1 contains the dates and accumulated 80-kN (18,000-lb) equivalent single-axle loads (ESALs) at each monitoring session and the corresponding maximum rut depth in the right wheelpath for the original 26 sections. Table 2 contains the accumulated ESALs and the maximum right wheelpath rut depth for the eight replacement sections. The maximum rut depth was calculated as the average rut depth in the first and last station of the section. Tables 3 and 4 contain the downward rut depths in the right wheelpath for the original 26 sections and the replacement sections and the corresponding ESALs accumulated before each monitoring session. The downward rut depth does not include any shear flow and was also calculated as the average rut depth in the first and last station of the section. Tables 5 and 6 contain the maximum rut depths in the left wheelpath for the 26 original sections and the eight replacement sections.

The rut depths for the first six monitoring sessions were calculated from the transverse profile measurements using the FACE Dipstick. For monitoring sessions 7 through 32, the rut depths were calculated from the AZ transverse profiles. For the remaining monitoring sessions, the laser device was used. Fluctuations in the accumulation of rut depth with ESALs were primarily due to the precision and bias of the measuring devices and changes in traffic wander. A large increase in rutting between monitoring sessions 47 and 48 was noticed in some sections. This increase was most likely due to the fact that traffic loading was only applied when the air temperature was above 32°C for this period (June 2, 1998 through September 17, 1998).

Figure 1. FACE Dipstick device.

Figure 2. Arizona transverse profile device.

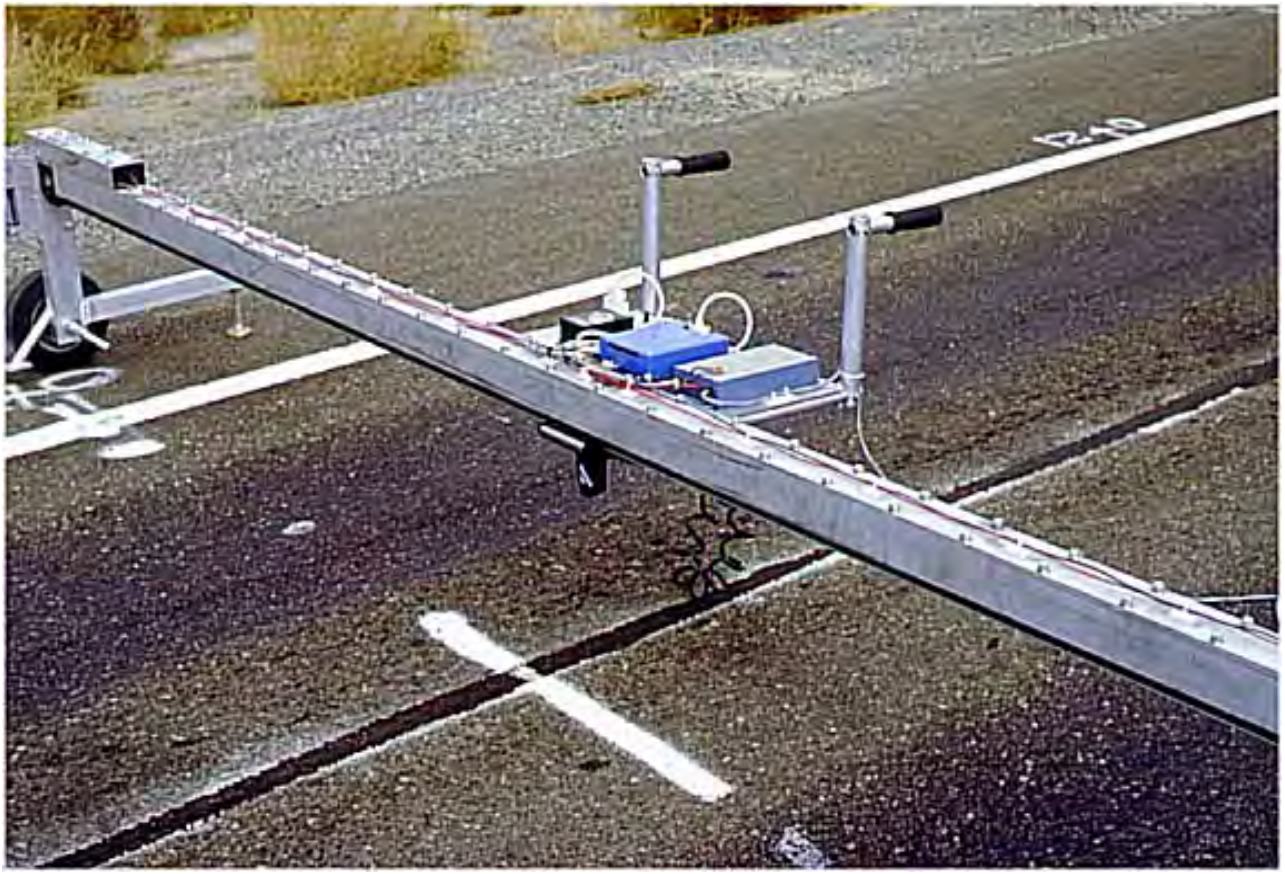

Figure 3. Laser transverse profile device.

Table 1. Maximum rut depth in the right wheelpath vs. ESALs.

Monitoring Session	Date	Total ESALs to Date	Average Rut Depth by Section (mm)																										Device used to obtain rut depth
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
1	3/18/1996	4,518	2	0	1	2	2	1	2	2	2	1	1	2	1	2	2	1	1	1	2	2	1	3	1	2	3	3	Dipstick
2	4/15/1996	80,063	3	2	3	4	4	5	4	4	3	3	2	3	3	3	3	4	4	3	4	5	4	4	2	5	4	2	Dipstick
3	4/29/1996	150,644	4	3	5	3	2	6	6	4	3	5	2	2	4	4	4	6	3	2	5	5	4	5	4	5	6	4	Dipstick
4	5/13/1996	233,736	6	5	7	4	7	11	9	5	6	7	4	3	6	8	6	8	5	2	5	7	6	5	6	7	8	9	Dipstick
5	5/28/1996	296,504	7	5	7	3	6	10	7	5	5	6	3	4	5	8	6	7	6	2	5	8	5	5	5	7	7	9	Dipstick
6	6/10/1996	336,073	7	5	7	3	7	12	7	7	4	6	2	3	4	9	6	8	9	3	5	10	5	5	5	8	7	11	Dipstick
7	6/24/1996	436,966	6	4	6	5	10	13	17	10	13	9	5	4	10	8	6	7	7	4	8	11	15	7	8	13	12	10	AZ Device
9	7/22/1996	516,563	8	5	8	6	13	17	25	13	20	10	7	8	14	9	6	9	9	5	10	12	24	6	10	18	22	15	AZ Device
10	8/5/1996	662,883	9	5	8	7	16	23	33	15	25	11	9	9	20	13	6	8	12	6	11	12	31	8	13	19	24	15	AZ Device
12	9/3/1996	835,823	10	6	10	7	19	22	35	15	31	10	9	9	23	10	7	8	10	7	12	15	37	10	15	23	26	15	AZ Device
13	9/19/1996	967,780	9	6	8	8	17	21	37	16	29	10	7	9	21	11	7	8	10	6	12	14	36	8	14	21	25	15	AZ Device
14	9/30/1996	1,070,221	9	7	9	8	19	22	37	16	29	13	9	9	22	12	6	9	10	6	12	13	37	9	14	23	25	14	AZ Device
15	10/14/1996	1,205,574	10	6	10	7	18	21	33	15	26	12	9	10	21	13	8	9	11	6	12	13	37	8	14	23	26	15	AZ Device
16	10/28/1996	1,365,970	10	7	9	8	17	21	33	16	30	12	8	9	20	11	8	11	11	7	13	15	36	10	12	24	26	16	AZ Device
17	11/11/1996	1,463,101	9	6	10	7	17	21	36	17	30	13	8	9	20	13	8	9	12	9	13	17	35	9	13	22	27	15	AZ Device
19	12/9/1996	1,626,437	9	6	10	7	18	21		17		10	8	8		13	8	8	11	6	13	15		11	14	22		14	AZ Device
20	12/19/1996	1,711,938	9	6	8	8	21	23		15		11	8	9		13	8	11	11	7	13	14		9	15	20		18	AZ Device
21	1/9/1997	1,790,400	11	6	10	7	20	21		15		13	10	9		15	8	9	12	8	13	16		10	14	24		17	AZ Device
23	2/18/1997	1,794,199	9	5	10	8	20	23		16		13	8	9		13	8	10	11	9	12	14		9	10	21		19	AZ Device
24	3/3/1997	1,880,144	8	6	11	8	23	24		15		13	9	10		14	10	9	12	9	13	14		11	15	22		21	AZ Device
25	3/17/1997	2,047,631	11	9	10	8	20	26		19		12	9	9		13	9	9	13	7	15	16		10	15	20		19	AZ Device

1 in. = 25.4 mm

Sections out of test, no measurements taken.

Table 1. Maximum rut depth in the right wheelpath vs. ESALs (continued).

Monitoring Session	Date	Total ESALs to Date	Average Rut Depth by Section (mm)																									Device used to obtain rut depth
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
26	3/31/1997	2,229,566	11	9	9	11	22	27		20		11	8	9		13	9	8	11	7	16	14		9	13	22		19	AZ Device
27	4/14/1997	2,369,909	11	7	12	9	23	29		19		12	10	11		13	9	10	11	8	13	16		10	13	22		20	AZ Device
28	4/29/1997	2,546,035	10	8	12	11	20	28		23		13	10	10		13	8	9	11	7	12	12		9	12	24		20	AZ Device
29	5/16/1997	2,774,052	10	7	11	11	22	30		23		13	10	10		13	9	10	13	8	13	15		10	13	26		21	AZ Device
30	7/14/1997	2,825,970	9	6	10	11						12	11	10		10	10	9	12	7	11	14		7	15				AZ Device
31	8/5/1997	3,027,764	11	9	11	11						14	9	10		11	8	9	11	8	12	14		8	16				AZ Device
32	8/19/1997	3,194,168	12	10	10	14						13	9	12		13	9	9	11	9	13	15		8	19				AZ Device
33	9/2/1997	3,338,264	11	8	10	13						13	8	10		12	9	10	10	9	13	15		8	19				Laser
34	9/16/1997	3,407,976	11	8	11	13						12	8	10		13	9	10	11	9	14	15		8	18				Laser
35	10/27/1997	3,530,248	10	7	11	12						12	8	10		12	8	9	11	8	13	15		8					Laser
36	11/18/1997	3,727,207	10	7	11	12						12	8	10		13	8	9	10	8	13	15		8					Laser
37	12/2/1997	3,886,594	10	7	10	12						11	8	10		13	8	10	11	9	13	15		8					Laser
38	12/16/1997	4,000,077	10	7	11	12						12	8	10		13	9	10	11	8	13	15		8					Laser
39	12/30/1997	4,100,720	10	7	11	12						12	8	10		13	8	10	11	8	13	15		8					Laser
40	1/13/1998	4,203,408	11	7	12	12						12	8	10		13	8	10	10	8	13	15		8					Laser
41	1/27/1998	4,247,038	11	7	11	13						13	8	10		13	8	11	11	8	13	15		9					Laser
42	2/10/1998	4,339,085	11	9	12	13						13	9	10		13	9	12	11	9	13	16		8					Laser
43	3/4/1998	4,369,711	11	9	12	13						14	8	10		13	9	13	12	9	13	16		8					Laser
44	3/26/1998	4,473,690	11	8	12	13						15	8	8		13	9	11	12	9	14	16		9					Laser
45	4/15/1998	4,635,856	11	8	13	13						13	8	9		13	9	11	12	9	13	15		9					Laser
46	5/7/1998	4,719,839	11	8	13	13						15	8	10		13	9	12	11	9	13	16		10					Laser
47	6/2/1998	4,817,861	11	8	13	13						15	9	10		13	9	12	11	9	13	17		10					Laser
48	9/17/1998	4,871,710	12	9	15	15						16	9	15		16	10	14	11	11	15	18		11					Laser
49	3/9/1999	5,003,303	12	9	14	15						17	9	14		17	9	15	12	11	14	18		11					Laser

1 in. = 25.4 mm

Sections out of test, no measurements taken.

Table 2. Maximum rut depth in the right wheelpath vs. ESALs for new sections.

Monitoring	Date	Average Rut Depth by Section (mm)								
Session		ESALS	35	36	37	38	39	54	55	56
Additional Data	7/22/1997	35,135		27	14					17
Additional Data	7/23/1997	40,593	14					11	10	
Additional Data	7/24/1997	48,298		28		8	8			
Additional Data	7/25/1997	61,001	15	29	16	8	8	12	10	18
Additional Data	7/28/1997	93,000	15	31	16	9	8	13	11	19
Additional Data	7/29/1997	102,235	14	30	17	9	8	13	11	20
Additional Data	7/30/1997	118,043	15	31	17	9	8	14	12	19
Additional Data	7/31/1997	128,415	15	30	17	9	9	14	11	20
Additional Data	8/1/1997	141,463	16	30	17	9	9	14	12	20
Additional Data	8/4/1997	188,454	17	33	19	10	10	15	14	22
31	8/5/1997	201,794	16	36	18	8	8	15	15	23
32	8/19/1997	368,198	20	36	26	13	11	17	21	27
33	9/2/1997	512,294	19	35	26	12	12	17	20	26
34	9/16/1997	582,006	20	36	26	13	11	17	21	27
35	10/27/1997	704,278	18	Milled		11	11	Milled		
36	11/18/1997	901,237	18			11	10			
37	12/2/1997	1,060,624	18			11	10			
38	12/16/1997	1,174,107	18			11	10			
39	12/30/1997	1,274,750	18			11	10			
40	1/13/1998	1,377,438	18			11	10			
41	1/27/1998	1,421,068	18			11	11			
42	2/10/1998	1,513,115	18			11	10			
43	3/4/1998	1,543,741	18			12	11			
44	3/26/1998	1,647,720	18			11	10			
45	4/15/1998	1,809,886	18			11	10			
46	5/7/1998	1,893,869	18			11	10			
47	6/2/1998	1,991,891	18			11	11			
48	9/17/1998	2,045,740	19			12	12			
49	3/9/1999	2,177,333	19			12	12			

1 in. = 25.4 mm

No measurements were taken.

Sections out of test, no measurements taken.

Table 3. Downward rut depth in the right wheelpath vs. ESALs.

Monitoring Session	Date	Total ESALs to Date	Average Rut Depth by Section (mm)																									Device used to obtain rut depth
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
1	3/18/1996	4,518	2	0	1	2	2	1	2	2	2	1	1	2	1	2	2	1	1	1	2	2	1	3	1	2	3	3	Dipstick
2	4/15/1996	80,063	3	2	3	3	3	5	4	4	3	3	2	3	3	3	3	4	3	3	4	5	4	4	2	5	4	2	Dipstick
3	4/29/1996	150,644	3	3	5	2	2	6	5	4	3	5	2	2	4	4	4	6	3	2	5	5	4	5	4	5	6	4	Dipstick
4	5/13/1996	233,736	6	5	7	4	7	11	7	5	5	7	3	3	5	8	6	8	5	2	5	7	7	5	6	7	8	9	Dipstick
5	5/28/1996	296,504	7	5	7	3	6	10	7	5	5	6	3	3	5	6	6	7	6	2	5	8	5	5	5	7	7	9	Dipstick
6	6/10/1996	336,073	7	5	7	3	7	12	7	7	4	6	2	3	4	8	6	8	6	3	5	8	5	5	5	8	7	11	Dipstick
7	6/24/1996	436,966	6	4	6	5	10	13	15	10	10	8	4	4	9	8	6	7	6	4	7	9	13	7	6	13	9	9	AZ Device
9	7/22/1996	516,563	7	5	7	5	13	19	19	13	13	11	7	7	13	10	5	9	9	4	9	12	18	8	9	18	19	14	AZ Device
10	8/5/1996	662,883	7	5	8	7	15	22	21	15	15	11	8	7	16	10	5	8	11	6	11	11	22	8	9	18	21	14	AZ Device
12	9/3/1996	835,823	9	5	9	7	16	21	26	14	18	11	7	8	17	9	7	8	10	6	11	13	24	9	12	16	21	13	AZ Device
13	9/19/1996	967,780	8	5	8	6	17	21	24	15	19	10	6	8	15	9	6	8	10	6	11	14	25	8	12	20	20	14	AZ Device
14	9/30/1996	1,070,221	8	5	8	8	18	21	25	15	17	12	8	7	16	11	6	9	9	6	12	13	25	9	12	20	21	14	AZ Device
15	10/14/1996	1,205,574	7	5	8	7	16	21	25	15	18	12	7	8	18	12	8	8	11	6	12	12	23	8	13	22	23	15	AZ Device
16	10/28/1996	1,365,970	8	6	9	7	17	21	26	16	18	12	8	8	15	11	8	10	11	7	12	15	24	9	12	23	22	13	AZ Device
17	11/11/1996	1,463,101	8	6	9	7	16	21	25	16	18	13	8	7	17	10	8	9	11	7	12	15	25	8	11	22	20	15	AZ Device
19	12/9/1996	1,626,437	7	5	9	6	16	21		15		10	8	7		10	8	8	10	6	11	14		9	13	22		14	AZ Device
20	12/19/1996	1,711,938	9	5	8	6	19	21		14		11	8	7		13	8	10	9	7	12	14		8	12	20		17	AZ Device
21	1/9/1997	1,790,400	8	6	9	7	19	21		15		13	9	8		13	8	9	11	8	13	15		9	13	21		16	AZ Device
23	2/18/1997	1,794,199	8	5	8	7	18	23		16		13	8	8		13	8	9	11	8	11	14		9	10	21		17	AZ Device
24	3/3/1997	1,880,144	7	5	11	7	21	24		15		12	8	9		13	10	8	12	9	11	13		10	13	22		19	AZ Device
25	3/17/1997	2,047,631	9	8	10	8	20	25		19		11	8	8		12	9	9	12	7	13	12		9	13	20		18	AZ Device

1 in. = 25.4 mm

Sections out of test, no measurements taken.

Table 3. Downward rut depth in the right wheelpath vs. ESALs (continued).

Monitoring Session	Date	Total ESALs to Date	Average Rut Depth by Section (mm)																									Device used to obtain rut depth
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
26	3/31/1997	2,229,566	10	8	9	8	22	26		20		10	8	8		13	8	8	11	7	13	13		8	12	22		18	AZ Device
27	4/14/1997	2,369,909	9	6	11	9	22	28		19		12	9	10		12	8	10	11	8	12	14		10	13	22		18	AZ Device
28	4/29/1997	2,546,035	9	7	12	11	20	28		22		13	9	9		11	8	9	10	7	12	12		9	12	23		20	AZ Device
29	5/16/1997	2,774,052	10	7	11	10	21	29		22		13	9	9		12	9	10	12	8	13	14		8	13	23		22	AZ Device
30	7/14/1997	2,825,970	9	6	10	11						12	10	8		10	9	9	12	7	11	12		7	15				AZ Device
31	8/5/1997	3,027,764	10	8	11	11						13	9	8		11	8	9	11	8	11	14		8	16				AZ Device
32	8/19/1997	3,194,168	10	8	10	14						12	9	10		13	9	9	11	9	13	14		8	16				AZ Device
33	9/2/1997	3,338,264	10	8	10	13						13	8	9		12	9	9	10	9	13	14		8	13				Laser
34	9/16/1997	3,407,976	10	8	11	13						12	8	9		12	9	9	10	8	14	15		8	14				Laser
35	10/27/1997	3,530,248	10	7	10	12						12	8	9		12	8	9	11	8	13	15		7					Laser
36	11/18/1997	3,727,207	10	7	10	12						12	8	8		12	8	9	10	8	12	15		8					Laser
37	12/2/1997	3,886,594	9	7	10	12						11	8	9		13	8	10	10	8	13	15		8					Laser
38	12/16/1997	4,000,077	10	7	11	12						12	8	9		12	9	10	11	8	13	15		8					Laser
39	12/30/1997	4,100,720	10	7	11	12						12	8	9		13	8	10	11	8	13	15		8					Laser
40	1/13/1998	4,203,408	10	7	12	12						12	8	9		13	8	10	10	8	13	15		8					Laser
41	1/27/1998	4,247,038	10	7	11	12						13	8	9		12	8	11	11	8	13	15		8					Laser
42	2/10/1998	4,339,085	10	8	12	13						13	9	9		13	9	12	11	8	13	16		8					Laser
43	3/4/1998	4,369,711	10	9	12	13						14	8	10		13	9	13	12	9	13	16		8					Laser
44	3/26/1998	4,473,690	11	8	12	13						15	8	8		13	9	11	12	9	14	16		9					Laser
45	4/15/1998	4,635,856	11	9	13	13						13	8	8		13	9	11	12	8	13	15		9					Laser
46	5/7/1998	4,719,839	11	8	13	13						15	8	9		13	9	12	11	9	13	16		10					Laser
47	6/2/1998	4,817,861	11	8	13	13						15	9	9		13	9	12	11	9	13	17		10					Laser
48	9/17/1998	4,871,710	12	9	15	15						16	9	14		16	10	14	11	11	15	18		11					Laser
49	3/9/1999	5,003,303	11	9	14	15						17	9	13		17	9	15	12	11	14	18		11					Laser

1 in. = 25.4 mm

Sections out of test, no measurements taken.

Table 4. Downward rut depth in the right wheelpath vs. ESALs for the replacement sections.

Monitoring	Date	Average Rut Depth by Section (mm)								
Session		ESALS	35	36	37	38	39	54	55	56
Additional Data	7/22/1997	35,171		19	9					14
Additional Data	7/23/1997	40,590	11					10	7	
Additional Data	7/24/1997	48,334		20		5	5			
Additional Data	7/25/1997	61,037	11	20	9	5	4	10	7	16
Additional Data	7/28/1997	93,036	10	22	10	6	5	11	7	16
Additional Data	7/29/1997	102,272	9	21	10	6	5	11	7	16
Additional Data	7/30/1997	118,079	10	21	10	6	5	11	8	16
Additional Data	7/31/1997	128,451	11	21	10	6	6	11	7	15
Additional Data	8/1/1997	141,499	10	22	10	5	5	11	8	17
Additional Data	8/4/1997	188,491	12	24	12	7	7	12	9	17
31	8/5/1997	203,756	12	28	13	8	7	13	9	18
32	8/19/1997	368,234	13	28	16	9	10	13	14	22
33	9/2/1997	518,895	15	26	16	8	9	13	13	21
34	9/16/1997	582,042	14	27	15	8	9	14	13	21
35	10/27/1997	704,315	14	Milled		7	8	Milled		
36	11/18/1997	913,092	14			8	8			
37	12/2/1997	1,063,520	14			8	8			
38	12/16/1997	1,174,138	14			8	8			
39	12/30/1997	1,263,852	14			8	8			
40	1/13/1998	1,377,469	14			8	8			
41	1/27/1998	1,421,098	14			8	8			
42	2/10/1998	1,513,145	14			8	8			
43	3/4/1998	1,543,771	14			8	9			
44	3/26/1998	1,647,695	15			9	8			
45	4/15/1998	1,809,769	14			8	8			
46	5/7/1998	1,893,843	14			9	9			
47	6/2/1998	1,991,891	14			9	9			
48	9/17/1998	2,045,740	16			10	10			
49	3/9/1999	2177333	15			8.8	10			

1 in. = 25.4 mm

No measurements were taken.

Sections out of test, no measurements taken.

Table 5. Maximum rut depth in the left wheelpath vs. ESALs.

Monitoring Session	Date	Total ESALs to Date	Average Rut Depth by Section (mm)																										Device used to obtain rut depth
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
1	3/18/1996	4,518	0	0	0	2	1	0	3	1	1	0	1	1	0	0	0	0	0	3	0	2	1	2	3	2	1	0	Dipstick
2	4/15/1996	80,063	0	2	1	3	3	3	2	2	1	2	2	1	1	0	0	0	2	3	2	5	2	1	3	3	1	7	Dipstick
3	4/29/1996	150,644	4	6	8	3	5	7	4	4	3	5	4	1	3	5	5	6	3	2	2	7	4	3	3	3	4	9	Dipstick
4	5/13/1996	233,736	5	8	11	4	7	13	10	6	5	7	6	4	6	7	7	8	5	2	4	9	5	4	5	4	9	11	Dipstick
5	5/28/1996	296,504	5	7	10	4	6	11	8	6	5	6	5	2	6	6	6	7	4	2	4	9	4	3	4	5	7	10	Dipstick
6	6/10/1996	336,073	5	6	9	4	9	12	7	6	5	4	3	3	5	7	6	7	6	3	3	9	4	3	5	6	6	14	Dipstick
7	6/24/1996	436,966																											AZ Device
9	7/22/1996	516,563																											AZ Device
10	8/5/1996	662,883																											AZ Device
12	9/3/1996	835,823																											AZ Device
13	9/19/1996	967,780																											AZ Device
14	9/30/1996	1,070,221																											AZ Device
15	10/14/1996	1,205,574	6	7	8	7	24	23	42	15	32	10	10	10	25	6	7	9	10	10	10	16	32	7	17	21	36	24	AZ Device
16	10/28/1996	1,365,970	7	9	11	6	23	21	42	16	31	11	11	10	29	7		7	10	11	10	15	33	8	17	18	34	19	AZ Device
17	11/11/1996	1,463,101	6	7	8	9	24	22	40	16	33	9	11	10	28	7		6	10	10	11	18	34	7	19	22	43	22	AZ Device
19	12/9/1996	1,626,437	5	7	8	9	23	23		17		10	11	10		9	4	8	8	10	9	17		6	16	21		22	AZ Device
20	12/19/1996	1,711,938	4	7	7	6	22	24		15		11	10	11		6		9	10	10	9	15			18	18		24	AZ Device
21	1/9/1997	1,790,400	7	8	12	8	20	19		16		11	10	11		6	6	9	9	11	11	18		7	19	19			AZ Device
23	2/18/1997	1,794,199	7	7	13	7	24	22		18		10	10	11		8	8	12	10	11	10	16		8	15	20			AZ Device
24	3/3/1997	1,880,144	6	7	11	8	27	24		17		11	10	11		7	5	10	12	10		16		10	19	22			AZ Device
25	3/17/1997	2,047,631	8	9	14	7	25	26		17		13	8	8		7	4	9	11	11	8	18		9	19	20			AZ Device

1 in. = 25.4 mm

Sections out of test, no measurements taken.

No measurements were taken.

Table 5. Maximum rut depth in the left wheelpath vs. ESALs (continued).

Monitoring Session	Date	Total ESALs to Date	Average Rut Depth by Section (mm)																										Device used to obtain rut depth
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
26	3/31/1997	2,229,566	6	7	8	7	25	27		23		11	11	10		6	4	6	9	10	10	16		8	14	19			AZ Device
27	4/14/1997	2,369,909	6	7	8	9	25			21		14	12	11		8	6	8	8	11	11	15		11	19	18			AZ Device
28	4/29/1997	2,546,035	6	7	7	7	30	30		24		12	11	12		7	4	8	11	11	10	16		8	21	23			AZ Device
29	5/16/1997	2,774,052	7	12	9	9	33	26		24		14	10	11		8	5	11	9	10	12	18		9	19	23			AZ Device
30	7/14/1997	2,825,970	8	10	14	13						10	9	10		8		8	12	12	11	15		7	14				AZ Device
31	8/5/1997	3,027,764	6	8	8	15						12	8	9		7	5	7	8	11	10	15		8	15				AZ Device
32	8/19/1997	3,194,168	6	8	10	10						14	12	12		9	5	9	9	13	11	18		7	18				AZ Device
33	9/2/1997	3,338,264	11	13	14	14						14	13	12		15	8	11	10	15	11	18		8	22				Laser
34	9/16/1997	3,407,976	11	13	16	14						14	12	11		16	9	12	10	14	11	17		9	16				Laser
35	10/27/1997	3,530,248	10	13	17	15						13	12	13		12	8	11	9	13	10	16		8					Laser
36	11/18/1997	3,727,207	10	13	16	15						11	12	13		12	7	10	10	15	11	17		8					Laser
37	12/2/1997	3,886,594	10	14	15	15						13	11	11		12	7	11	9	15	11	17		7					Laser
38	12/16/1997	4,000,077	11	14	15	15						14	12	11		11	7	11	10	14	11	17		8					Laser
39	12/30/1997	4,100,720	10	15	14	15						15	13	12		11	7	11	10	14	11	17		8					Laser
40	1/13/1998	4,203,408	10	17	14	15						15	13	14		11	7	12	11	15	10	18		7					Laser
41	1/27/1998	4,247,038	10	17	13	16						12	12	13		12	7	12	9	16	11	18		8					Laser
42	2/10/1998	4,339,085	11	16	12	13						12	11	11		11	8	14	9	14	11	17		9					Laser
43	3/4/1998	4,369,711	11	19	11	12						12	11	11		10	8	15	9	13	10	17		8					Laser
44	3/26/1998	4,473,690	13	13	12	12						15	10	9		10	9	10	10	13	11	16		8					Laser
45	4/15/1998	4,635,856	13	12	13	14						14	10	10		11	8	9	10	13	11	16		7					Laser
46	5/7/1998	4,719,839	14	14	16	15						16	10	10		10	9	11	10	13	11	16		7					Laser
47	6/2/1998	4,817,861	13	13	17	15						16	10	10		10	8	11	10	13	11	16		7					Laser
48	9/17/1998	4,871,710	14	16	16	16						19	10	13		14	9	16	11	17	12	19		10					Laser
49	3/9/1999	5,003,303	13	15	16	15						22	10	13		15	8	16	10	16	11	18		11					Laser

1 in. = 25.4 mm

Sections out of test, no measurements taken.

No measurements were taken.

Table 6. Maximum rut depth in the left wheelpath vs. ESALs for the replacement sections.

Monitoring	Date	Average Rut Depth by Section (mm)								
Session		ESALS	35	36	37	38	39	54	55	56
Additional Data	7/22/1997	35,135		28	12					20
Additional Data	7/23/1997	40,593	13					10	12	
Additional Data	7/24/1997	48,298		28		8	8			
Additional Data	7/25/1997	61,001	12	29	14	8	8	10	12	21
Additional Data	7/28/1997	93,000	13	30	15	8	9	11	12	23
Additional Data	7/29/1997	102,235	13	29	15	8	8	12	12	23
Additional Data	7/30/1997	118,043	12	28	14	8	9	11	12	23
Additional Data	7/31/1997	128,415	13	29	15	8	8	11	12	23
Additional Data	8/1/1997	141,463	13	30	16	9	9	11	13	23
Additional Data	8/4/1997	188,454	14	32	18	11	10	13	15	25
31	8/5/1997	201,794	13	29	21	11	12	12	15	25
32	8/19/1997	368,198	12	35	23	13	11	14	23	28
33	9/2/1997	512,294	17	34	26	12	12	15	24	29
34	9/16/1997	582,006	16	34	25	12	12	14	22	29
35	10/27/1997	704,278	16	Milled		10	11	Milled		
36	11/18/1997	901,237	15			10	11			
37	12/2/1997	1,060,624	16			10	12			
38	12/16/1997	1,174,107	16			10	12			
39	12/30/1997	1,274,750	16			10	12			
40	1/13/1998	1,377,438	15			11	13			
41	1/27/1998	1,421,068	16			10	11			
42	2/10/1998	1,513,115	18			13	12			
43	3/4/1998	1,543,741	17			12	11			
44	3/26/1998	1,647,720	17			13	12			
45	4/15/1998	1,809,886	16			13	11			
46	5/7/1998	1,893,869	17			13	12			
47	6/2/1998	1,991,891	17			14	12			
48	9/17/1998	2,045,740	21			15	14			
49	3/9/1999	2,177,333	20			14	13			

1 in. = 25.4 mm

No measurements were taken.

Sections out of test, no measurements taken.

Site Investigation and Track Layout

U.S. Department of Transportation
Federal Highway Administration

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INTRODUCTION

This work activity report details the effort that went into the site selection for the WesTrack project.

SITE INVESTIGATION

The location of the test track was in a flat area of land adjacent to the Carson River, about 30 km (20 mi) east of Carson City, Nevada. Portions of this area were used for agriculture, while other portions were in their native (desert) state. The track location was roughly 1.8 km (6,000 ft) long and 0.3 km (1,000 ft) wide. The site investigation conducted for this location included an analysis of the climate, environmental impact, flood potential, and geotechnical investigation of the area.

CLIMATE/SEASONAL

The selected test track site offered an almost ideal location to conduct the year-round, multiyear test from the standpoint of a favorable and controlled climate. On average, continuous testing could be conducted 361 days per year in an area that received less than 100 mm (4 in.) of average annual precipitation and no annual subgrade soil freeze-thaw (frost penetration) conditions. The annual average daytime temperature is 21°C (69°F) and humidity is low (20-30 percent).

The high desert climate and river valley location on the eastern side of the Sierra Nevada mountains meant that the probability of rain or snow and high or low temperature extremes influencing the test schedule or test results was extremely low. The Sierra Nevada mountains rise to elevations of 2,700 to 3,400 m (9,000 to 11,000 ft) above sea level, which limited the amount of moisture the site received from Pacific weather patterns.

The dryness ensured a stable moisture environment for more controlled subgrade soil support conditions. In addition, the lack of precipitation and moderate cold season during the winter months meant almost no frost penetration or freeze-thaw problems. The lack of extreme temperatures also meant that there would be favorable construction and operation conditions and fewer problems with environmental cracking. Overall, the climate and environmental conditions were well suited for the required load-associated deterioration of the pavement sections over a 2-year period.

ENVIRONMENTAL IMPACT

The Nevada Automotive Test Center (NATC), the site of the test track, was established in 1957 in Carson City, Nevada. In 1969, after 12 years of planning, a proving ground site was established 45 km (28 mi) east of Carson City. NATC is one of the largest independent proving grounds in the world. It has a 1,400-hectare (3,500-acre) deeded proving ground along 12 km (7.5 mi) of the Carson River. The Carson River and Nevada State Route 2B (Fort Churchill

Road) cross the main proving ground area. In addition, NATC has 392,000 leased hectares (967,000 acres).

Following are key points relating to the impact of test track construction and operation on the environment:

- The site was ready to grade and had little vegetation other than varied sagebrush. The proposed test track location qualified as a "categorical exclusion" as defined in the Code of Federal Regulations (40 CFR 1508.4) and using Department of Transportation guidelines as outlined in 23 CFR 771.117 for that determination. Specifically, locating the test track on this site would not induce an impact to planned growth or land use for the area; require the relocation of people; have an impact on any natural, cultural, recreational, historic, or other resource; involve significant air, noise, or water quality impacts; have an impact on travel patterns or otherwise have any significant environmental impact. No "unusual environmental circumstances," such as a significant environmental impact, a substantial controversy on environmental grounds, significant impact on historical properties, or any inconsistency with Federal, State, or local law, requirement, or administrative determination relating to the environmental aspects of the proposed test track existed.

- A chain link fence was installed around the test track to keep out wildlife and trespassers. Also, the available large land mass was an added safety factor to ensure the overall safety of the program. NATC's location guaranteed that security and safety would not be compromised and that vehicles could be run 24 hours per day, 365 days per year. Because of the Department of Defense work NATC performs, a security procedure was already in place that further limited access to the site 24 hours per day.

FLOOD POTENTIAL/RISK

A portion of the test track was within zone A of the Carson River flood plain as shown on the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) Panel 320029 0155C, dated September 30, 1992. This zone on the FIRM panel shows an approximate 100-year flood plain for this portion of the Carson River; however, the water surface elevations had not been established and a regulatory floodway had not been defined. The regulatory floodway would define the maximum amount of encroachment that can take place in the flood plain and define the portion of the flood plain that must be left open for the conveyance of the 100-year flow.

The test track location was under the jurisdiction of Lyon County, Nevada. The County Public Works Department did not require an engineering analysis to examine the impacts of the project on the flood plain and surrounding properties.

The test track was sited as far west of the river as possible. The nearest the track centerline was to the river was 85 m (280 ft). The track elevation was approximately 0.6 m (2 ft) above the

original ground line. Review of the peak annual discharges for the Carson River near Fort Churchill, Nevada (which is a short distance downstream from the project site), indicated that a flow of 15,300 ft^3/s (433 m^3/s) was recorded in 1963 and a flow of 16,600 ft^3/s (470 m^3/s) in 1986. Those two discharges were the largest of record dating back to 1911. The regulatory peak 100-year discharge for the Carson River at Dayton (approximately 26 km (16 mi) upstream from the project site) is 36,000 ft^3/s (1,019 m^3/s). The 50-year and 10-year regulatory peak discharges were 23,500 ft^3/s (665 m^3/s) and 7,600 ft^3/s (215 m^3/s), respectively. Table 1 summarizes the peak discharges at the Fort Churchill gauge.

Based on current information, some potential existed for flooding of the track. Discussions with Mr. Henry C. Hodges, Sr., resident of the immediate area since 1969, indicated that the high flow of 1986 would have inundated a portion of the track's original ground, but would not have been in its "regulatory floodway" (i.e., fast-moving water).

Based on a review of the flow records for the Carson River near Fort Churchill, a summary was prepared to compare the highest recorded peak discharges to the discharge-frequency curve published by FEMA. The historic flow records were obtained from United States Geological Survey (USGS) records for the USGS gauge near Fort Churchill, just downstream of the project site. The discharge-frequency curve was developed by FEMA for the Lyon County Flood Insurance Study. The FEMA discharges are the regulatory discharges that must be used by Lyon County for flood plain management purposes until revised by FEMA based upon better technical information.

Although the circumstances surrounding each flood are different, the data indicated that there was a 3 in 100 chance that the peak discharge rates recorded for the 1986 flood would recur. Given this probability of recurrence, there was a chance that water would encroach the south side of the test track and vehicle running would have to be halted until the subgrade dried out.

FALLING WEIGHT DEFLECTOMETER (FWD) TESTING

Historically, nondestructive test data obtained with an FWD have been used more for evaluating roads with a paved surface prior to preparing a pavement rehabilitation design. However, because of the observed repeatability of Dynatest FWD measurements collected from unpaved or earth-surfaced roads, these measurements were obtained on natural ground surface at the site of the WesTrack Project. The primary motivation for collecting these measurements was for use in characterizing the in-place stiffness and support characteristics of the natural soil. A secondary reason was to evaluate the uniformity (or nonuniformity) of the soil and try to correct excessively weak or strong areas during construction.

The approach involved collecting FWD measurements at close intervals along the planned alignment of the track. The measurements were obtained after only a surface blading operation was applied to remove vegetation and loose material. Basic back-calculation procedures and the results of test pits and boring logs were then used to evaluate nonuniformity, estimate the resilient modulus of the soil at selected locations, and identify potential areas of overexcavation and recompaction prior to embankment construction. The resilient modulus values obtained provided a basis for designing the thicknesses of all pavement surface and subsurface layers.

Summaries of the FWD deflection data collected and results of the backcalculated resilient modulus values are provided here. The summaries include both numerical and graphical representation of the FWD deflection data and resilient modulus values. The analysis section details the back-calculation process and describes the procedure used to identify the areas that are excessively strong or weak and potentially in need of overexcavation and recompaction.

Nondestructive Testing Data Collection Program

FWD data were collected at three different times prior to the initiation of track construction:

- October 24, 1994.
- February 15, 1995.
- April 24, 1995.

The reasons for the second and third rounds of FWD data collection were to account for a slight realignment of the track, to respond to concerns raised by the Federal Highway Administration (FHWA) Technical Panel (in a February 2-3, 1995 meeting), and to examine the effects of any seasonal changes in soil moisture.

In all three instances, FWD deflection testing was conducted on the natural ground surface along two parallel lines (i.e., the north and south tangents of the track). Measurements were obtained every 10 m (33 ft) along the 925-m (3,034-ft) length of both tangents. The load levels used were in the range of 5 to 13 kN (1 to 4 kips) and three drop heights were used along with one seating drop. The seven sensors were spaced at 0, 305, 457, 610, 914, 1,219, and 1,524 mm (0, 12, 18, 24, 36, 48, and 60 in.) from the 450-mm (17.7-in.) diameter load plate.

FWD Data Analysis

The bulk of the analysis of the FWD data is focused on back-calculation of resilient modulus values. However, some observations can be made based solely upon examination of the deflection plots in Figures 1 through 4.

- In essentially all instances, there is a large difference between the deflection at sensor 1 (beneath the plate) and sensor 2 (just outside the plate). This phenomenon is attributed to shearing of the soil along the edge of the plate. Although the measurements were repeatable, the loading conditions were not accurately simulated by elastic layer theory. Consequently, sensors 1 and 2 deflection values were disregarded in the back-calculation analysis process.

- There was a significant difference in the deflections measured during all three periods. Mostly, these differences were attributed to unusually large differences in seasonal moisture content of the soil. Fall is almost always an extremely dry period at the site. Winter is usually relatively dry and spring relatively wet (because of snow melt and increased water levels in the Carson River). Snowfall in the mountains during 1994 and 1995 was unusually high (roughly 200 percent

of normal) and snow melt runoff began earlier than normal. This resulted in a higher and prolonged groundwater level during 1995. Actually, this was not that unfortunate because it did indicate a possible worst-case scenario for subgrade soil support after pavement construction.

The following sections summarize the backcalculation and nonuniformity analysis results of the FWD data. These provide the basis for structural design and subgrade soil overexcavation recommendations.

Back-Calculation of Resilient Modulus

Various methods for back-calculating the resilient modulus (M_R) of the subgrade soil were used for the three sets of FWD data. This was necessary because of the effect that the level of the groundwater table had on the deflections.

Analysis of October 1994 Data

As previously discussed, the October 1994 data were obtained during a dry period of the year. The groundwater table level was apparently very low and beyond the range of influence on measured surface deflections. Consequently, back-calculation analysis was performed using the relatively simple equation provided in the 1993 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures*:[1]

$$M_R = 0.24 \frac{P}{d_r r} \quad (1)$$

where:

M_R	=	back-calculated resilient modulus (psi)
P	=	applied FWD load (lb)
d_r	=	deflection at a distance, r, from the center of the load (in.)
r	=	distance from the center of load (in.)

The modulus value for a given location was calculated as the mean associated with the three deflection load levels (P) and the three farthest radial distances (r) from the center of the load. Figures 5 and 6 provide the results in the form of profile plots for the north and south tangents, respectively. These figures also provide an indication of the variability (i.e., standard deviation) associated with each deflection location.

Examination of these original results indicates that there was a significant difference in deflection and soil support in going from the east end of the track to the west. This difference may be explained by the fact that the area in the west end had been previously deep-disked and irrigated for agricultural purposes. Thus, this was used as criteria for placing the track at the easternmost location. The mean and standard deviation of the back-calculated resilient moduli for the north, south, and combined tangents is contained in Table 2.

Analysis of February 1995 Data

Originally, data collected during February 1995 were taken to account for a slight shift in the location of the track. Geometrically, the track was reoriented by a few degrees and the south tangent was moved in by 3 m (10 ft) to account for a reduced radius of the turnaround.

After the data were collected, it was clear that some significant change had taken place. When combined with the results of the borehole logs, the change was attributed to an increase in the level of the water table and an associated increase in soil moisture content.

The presence of the water table at roughly 2.5 m (8 ft) below the surface negated the use of the single layer AASHTO back-calculation equation (equation 1). The shear effect along the edge of the load plate also compromised the use of any of the automated back-calculation programs that rely heavily on sensor 1 deflections. Consequently, an interactive back-calculation program, MATCH (which is based on the original ELSYMS elastic layer program), was applied where only the deflections at the three farthest locations from the FWD were considered. MATCH is a time-consuming, labor-intensive, interactive back-calculation program. Thus, analysis of the FWD data was carried out only on deflections obtained every 50 m (165 ft).

Profile plots of the back-calculation results are presented in Figures 7 and 8 for the north and south tangents, respectively. From these data, the mean and standard deviation of resilient modulus values are shown in Table 3.

It should be noted that these values are representative of the back-calculated moduli for the 2.5 m (8 ft) soil layer above the water table.

Analysis of April 1995 Data

April 1995 data were targeted at gathering one more round of preconstruction information and determining if the prolonged moisture state had any additional effect on deflection since the February testing. Like the analysis of the February deflection data, the interactive MATCH program was used to backcalculate the resilient modulus values. Profile plots of these results are presented in Figures 9 and 10 for the north and south tangents, respectively.

From these data, the mean and standard deviation of resilient modulus values are shown in Table 4.

Again, these values are representative of the back-calculated moduli for the 2.5 m (8 ft) soil layer above the water table.

Evaluation of Nonuniformity in the Subgrade Soil

After its use in back-calculation, the FWD deflection data were then used to evaluate the nonuniformity of the subgrade soil. Deflections at sensors 3 and 6 were selected for this analysis. Sensor 3 was chosen because it was the closest to the load plate not influenced by shear at the edge of the plate. Sensor 6 was selected because of its direct indication of subgrade soil support at depth. The average deflections and one standard deviation were calculated for

these sensors. Figures 11 through 14 provide plots of the average deflection, the 66 percent confidence level (i.e., one standard deviation), and the 90 percent confidence level (i.e., 1.645 standard deviations) for the north and south tangents using data collected in February 1995. Areas targeted for overexcavation were those points that fell outside the 90 percent confidence level at sensor 6. These points were supported using results from sensor 3 (e.g., if the deflection fell out of the 90 percent confidence level at sensor 6, and close to or out of the 90 percent confidence level at sensor 3, it was identified as a potential problem area).

Deflection data showed a significant increase in magnitude on the north tangent from approximately station 700 to the end of testing at station 950. There also was an indication of high deflection from station 0 to station 50. On the south tangent, high deflections exist from station 10 to approximately station 200, at station 270, at station 330, from station 360 to station 380, at station 800, and the area from station 870 to the end of testing at station 950.

TEST PITS

In late October 1994, ten test pits were dug in locations uniformly spaced along both sides of the test track. (The locations were along the original alignment of the track and did not precisely match up with the tangent sections identified in the latest plan.) The test pits were excavated to a depth of 1.5 m (5 ft) using a backhoe. The soil profile to this depth was thoroughly logged and bulk samples were collected for gradation analysis, Atterberg Limits, soil classification, in situ moisture determination, and compaction/density. No in-place density tests (i.e., sand cones or nuclear density) were performed and no determination of the depth to the groundwater table was made. The results of the lab testing and soil classification are summarized in Figure 15.

Consistent with the depositional processes of the Carson River, the soils at the site consisted of varying proportions and blends of fine-grained clays, sands, and silts. In fact, eight different unified soil classes were identified. In situ moisture contents ranged from less than 4 percent up to 22 percent, with the higher moisture contents found in the soils nearest the areas previously irrigated. The optimum moisture content and maximum dry density (based on AASHTO T-99) were found to be in the range of 16 to 20 percent and 1,600 to 1,746 kg/m^3 (100 to 109 lb/ft^3), respectively.

BORINGS

Because of concern over the relatively shallow depth to the water table and the presence of multiple underlying soil layers (and their potential influence on the nondestructive test program), an additional level of subsurface investigation was carried out on February 23, 1995. This time, the investigation of the site was carried out using a drill rig, where the target borehole depth was 6 m (20 ft), as opposed to the 1.5-m (5-ft) depth for the test pits. Information, as summarized in Figure 16, is not as refined as information on the test pits, but is consistent with those findings and does identify the depth to water table (at that time) at approximately 2.5 m (8 ft).

It should be noted that there is a significant seasonal difference between the time the test pits were dug in October 1994 and the time the boring logs were obtained. Although the winter of 1994 through 1995 was relatively mild in terms of temperature, the Sierra Nevada Mountains did receive roughly 200 percent of the average precipitation (snowfall). Combined with the mild temperatures, flow along the Carson River was well above normal and tended to raise the groundwater level and increase the moisture content of the soil at the site. This caused higher deflections and lower soil resilient modulus values.

OVEREXCAVATION RECOMMENDATIONS

Based on deflection data results, back-calculated resilient modulus values, and historical information of the subgrade soil at the test site, the areas recommended for overexcavation and recompaction are summarized in Table 5.

TRACK GEOMETRICS

HORIZONTAL ALIGNMENT

A plan view showing the horizontal alignment of the test track is given in Figure 17. The track consists of two tangent sections connected by two spiral curves. All test sections are located on the straight tangents between the turnarounds. The tangent sections are 11 m (36 ft) wide and consist of two 3.7-m (12-ft) lanes and a 1.2-m (4-ft) asphalt concrete shoulder outside the test lane followed by a 1.8-m (6-ft) gravel shoulder. The inside of the track has a 0.6-m (1.2-ft) gravel shoulder. The center lane serves as the test lane while the inside lane serves as both a shoulder and asphalt concrete trial lane.

VERTICAL ALIGNMENT

The planned location of the test track was in an area that had less than 0.1 percent elevation change longitudinally and less than 1 percent cross fall. Therefore, the track construction in the longitudinal direction was nearly flat. The pavement surface had a 2 percent cross slope to the inside of the track for drainage. The aggregate shoulders on either side had a 6 percent cross slope away from the pavement. Beyond the shoulders, the cross slope of the embankment was 6-to-1. A drainage plan was developed and is reflected in the construction plans.

TEST SECTION LENGTHS

Several factors were considered in identifying an optimum length for each experimental test section in the WesTrack Project:

- Vehicle dynamics.
- Construction uniformity.
- Performance monitoring.

- Destructive sampling.
- Cost.

In response to the first four items, the desirable length for each section should have been about 100 m (328 ft). However, the high cost associated with construction and operation of a test track consisting of 26 100-m sections made this length prohibitive. Consequently, it was necessary to examine other means of construction, maintenance, and operation that would permit a shorter section, but still maintain the potential to collect high-quality, useful data.

After considering the impact of all the factors that influenced the design of the section length, 70 m (230 ft) was chosen for the WesTrack Project. This length is greater than the 61-m (200-ft) length originally recommended in the "Performance-Related Specifications for Asphalt Concrete—Phase II" study and included in the original project solicitation.[2] The main reasons for the increase in length were to:

- Avoid the problems associated with roughness from one section being transferred through vehicle dynamics to an adjacent section.
- Provide for more uniformity of mix in the actual zone to be monitored.

Figure 18 provides a diagram illustrating the layout of an experimental section based upon the 70-m length. Note that 25 m (82 ft) are set aside for transition, 40 m (131.2 ft) for performance monitoring, and 5 m (16.4 ft) for destructive sampling.

Recognizing that cost was an overriding factor in keeping section length short, a discussion of how the actual test section lengths were derived follows.

Vehicle Dynamics

As truck loading progressed and the pavement sections began to deteriorate, there was a strong possibility that some test sections would deteriorate faster than others. There also was the potential for discrete bumps to develop at the cold joints. As the test sections started to develop different levels of roughness and as the cold joint bump amplitudes increased, it was likely that this roughness would excite dynamics within the vehicle. If the effects of the vehicle dynamics were not considered in the track design, then roughness from one section could be carried to an adjacent section, thus resulting in "sympathetic failures." This phenomenon is addressed by allowing a transition zone of significant length between the test sections so that the vehicle dynamics have time to dampen or stabilize before loading the actual monitoring section.

To address the length of transition required to dampen vehicle energetics excited by a cold joint bump or section of high amplitude roughness, a representative "triple" vehicle combination was leased and instrumented with accelerometers. The time (or distance based on 64 km/h (40 mi/h)) required to dampen unsprung and sprung mass oscillations was measured.

In summary, with the axles loaded to 89 kN (20,000 lb), the suspension effects are significantly attenuated and dampen quickly. Figure 19 shows the worst-case measured event, which was a 45-mm high (1.8-in.) bump impacted at 64 km/h (40 mi/h). The time histories from the top are

vehicle speed (mi/h), bumper or sprung mass vertical acceleration (g's) and front axle vertical acceleration (leaf spring – g's), and intermediate axle vertical acceleration (air ride – g's). At 64 km/h (40 mi/h), it required approximately 0.45 seconds for the suspension energy to dampen to 95 percent of the maximum acceleration variation. This translates to 8 meters (26 ft) of vehicle travel. Based on these results, a 25-m (82-ft) transition zone between test sections was determined to be sufficient for the vehicle dynamics (arising from either a bump at the cold joint or localized roughness in the "upstream" section) to dampen.

In addition to localized roughness and cold joint bumps, longer wavelength amplitudes (i.e., greater than 15-m (49-ft) wavelengths) would potentially be present in the track at the time of construction or as pavement loading progressed. These longer wavelengths could also affect vehicle sprung mass oscillations. Because these long-wavelength, low-frequency vehicle oscillations might also result in sympathetic failures in the test sections, these vehicle frequencies would be monitored. The vehicle instrumentation installed on one tractor allowed correlation of the pavement performance measurements with vehicle performance data. The instrumentation is shown in Table 6.

These data were recorded by NATC initially and at 4-week intervals to correspond to the pavement performance and pavement strain gauge measurements. Approximately ten vehicle passes at 64 km/h (40 mi/h) per test section were recorded and processed (i.e., 30 minutes of data). If these longer wavelengths began to set up vehicle dynamics that led to sympathetic failure, vehicle loading was suspended until the transition sections were maintained.

Construction Uniformity

A transition length was not only required to address the technical issue associated with vehicle dynamics, but also was required so that the construction contractor had adequate distance after a cold start to establish mix uniformity. The "PRS for AC – Phase II" study recommended 12 m (40 ft), which was probably based on the 12-m transition length used at the AASHO Road Test. Unlike the AASHO Road Test (which had only one AC mix design), the WesTrack Project is targeted at studying the performance of three gradations at a combination of three different asphalt contents and three different air voids, each of which required special attention to laydown and compaction procedures. Although a transition length greater than 30 m (98.4 ft) would be desirable to help achieve mix uniformity, the selection of the 25 m (82 ft) to account for vehicle dynamics should also be satisfactory for developing a uniform mix. (This was confirmed by an asphalt paving contractor during the Technical Panel Meeting in February 1995.) Three independent construction operations were to be employed to achieve better mix uniformity and to avoid roughness that might be induced at a cold joint:

- A mat reference was to be used with the paver to provide the smoothest joint possible between adjacent sections.
- The mix was to be laid and compacted approximately 3 m (10 ft) beyond the end of a given test section. Most of this length would then be broken and removed prior to placement of the next test section. Removal would be carried out in a manner that least disturbed the underlying base material.

- After construction, a profilograph was to be used to measure the smoothness, and, if necessary, diamond grinding used to remove any waves, bumps, or excessive thickness.

Performance Monitoring

The "PRS for AC – Phase II" study recommended a length of 46 m (150 ft) for monitoring the performance of the asphalt concrete mix in each individual section. This length was based on the general opinion that the 30.5-m (100-ft) length used for AASHO Road Test sections was not adequate. The 152.5-m (500-ft) length use for general pavement studies (GPS) sections in the Long-Term Pavement Performance (LTPP) program was based primarily on the ride quality requirement to measure roughness for wavelengths up to 76 m (250 ft). If ride quality were not a requirement, the sections might have been shorter to control longitudinal variability of soil, structure, and performance within a section. Forty meters (131.2 ft) was selected for performance monitoring in the WesTrack Project because of cost and the WesTrack Team's concern over the treatment of longitudinal variability. The 40-m length is longer than the 30.5-m length used at the AASHO Road Test and, unlike the LTPP study, it was not considered essential to account for long wavelength roughness in this study.

Destructive Sampling

According to the plan for field sampling and laboratory testing, numerous core and slab specimens were collected during the loading period. These specimens were obtained from both wheelpaths, but were relatively close together. Thus, 5 m (16.4 ft) of pavement length was considered satisfactory for destructive sampling. In order to keep subsequent distress downstream of the sampling area from affecting future sampling locations, all sampling commenced near the end of the section and progressed upstream. Quality repairs in the sampled area were performed to reduce the potential for sympathetic failure in a downstream section. However, additional sampling requirements throughout the project necessitated that sampling occur in the transition and monitoring area of the track.

Cross Section

The test track construction plan involved the use of the existing subgrade material, a base course, and a variety of asphalt concrete mixtures. Maximum uniformity of the subgrade soil and base course, in terms of structural load-carrying capacity and thickness, were critical to the success of the project. Consequently, a cross section that provided a high-level, uniform foundation was a key consideration in the structural and geometric design.

The hot-mix asphalt (HMA) was constructed with different aggregate gradations, asphalt contents, and in-place air voids as part of the experimental design; however, the thickness of the HMA remained constant for all sections.

Three separate horizontal cross sections were considered for the test track (see Figure 20). The first (cross section A) was the one initially proposed and served as the basis for the original cost estimate. It consisted of two separate travel lanes, one that served as the actual experimental test

lane and the other as both a trial construction lane and a traffic bypass lane. These two lanes were separated by a median barrier. One advantage of this horizontal configuration is that it permits a "practice" placement of the mix before it is constructed on the actual test lane. A second advantage is that its lane separation permits the track to continue to be trafficked while one side is closed for repair or testing. The disadvantage of this section was its cost.

The second section (cross section B) considered was the simplest. It involved the elimination of the trial construction lane/bypass lane. The advantage was the major reduction in cost. The disadvantage was the fact that the contractor could no longer have a "practice run" at achieving the desired mix characteristics before placing the final experimental section. Given that 21 different asphalt mixes were being evaluated, this was considered a major disadvantage.

The third section (cross section C) also represented a step down from the original section in that the median and median barrier between the trial and test lanes were eliminated. The main impact of this was that the trial lane could no longer be used as a bypass lane while one side of the track was being sampled, surveyed, or rehabilitated. Thus, track loading would have to be discontinued during any of these activities. Since projected track down times related to these activities were minimal (roughly 10 percent of the time), and since unbalanced loading (loading one side of the track while not the other) was generally undesirable from a performance evaluation standpoint, sacrificing the bypass lane was not considered critical. The reduction in construction cost, however, was significant.

After review during the February 2-3, 1995, meeting, the consensus of both the WesTrack Team and FHWA Technical Panel was to pursue cross section C and realize the cost savings associated with the overall reduced width while still retaining the trial construction benefit of the trial lane. As previously indicated, the pavement had a 2 percent cross slope to the inside of the track, while the aggregate portion of the shoulders had a 6 percent cross slope away from the pavement. For improved subsurface drainage, the base material was "daylighted." Also, the side slope on the embankments had a 6-to-1 slope.

Turnarounds

The final geometrics were based upon analysis of the pavement loading, comments from the FHWA Technical Panel, driverless vehicle requirements, and suspension and tire wear considerations. It was determined that a superelevation rate (e) of 0.18 and side-friction factor (f) of 0.05 were optimal for developing the final curve design. These values are based on suspension dynamics, trailer off-tracking, and irregular tire tread wear issues. Secondly, the lateral control system for the driverless trucks was less complicated at the reduced lateral acceleration.

Based on these considerations and previous limitations, the curve design was revised in accordance with the following design parameters (see Figure 17):

- The spiral curve design placed 50 percent of the superelevation run-out in the curve. (This compares to 33 percent for a conventional superelevation design.)

- The superelevation rate was increased from e = 0.15 to e = 0.18 because the track was not in a location where snow and ice conditions prevail. (Also, asphalt pavers have been used in the past at this superelevation rate without any need for ballast or equipment modifications.)
- The design included a vehicle transition length of 15 m (50 ft) exiting each curve to allow vehicle speed and dynamics to stabilize after exiting the curve.

Although the spiral curve design was slightly more aggressive than AASHTO highway design guidelines, the track was designed as a dedicated facility, with a dedicated speed, and the spiral design provided a smooth change from the tangent section to the circular curve, and vice versa.

SUMMARY

This WesTrack technical report contains an in-depth description of the site investigation that went into selecting the location of WesTrack. This investigation included analysis of the climate, environmental impact, flood potential, and a geotechnical investigation consisting of FWD testing, test pits, and borings. The report also describes an investigation of the proper length of the track including discussions on test section length, transition areas, and vehicle dynamics.

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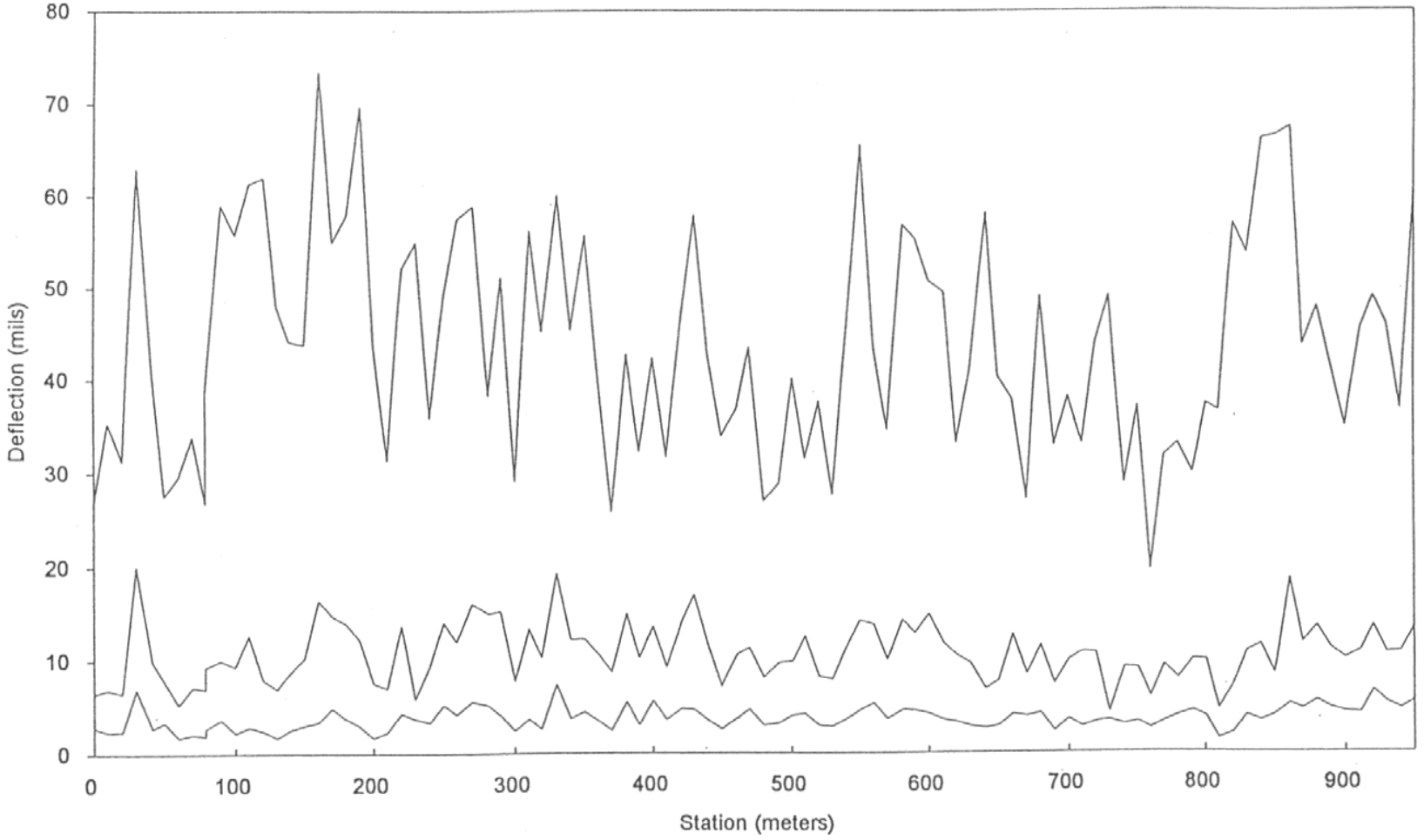
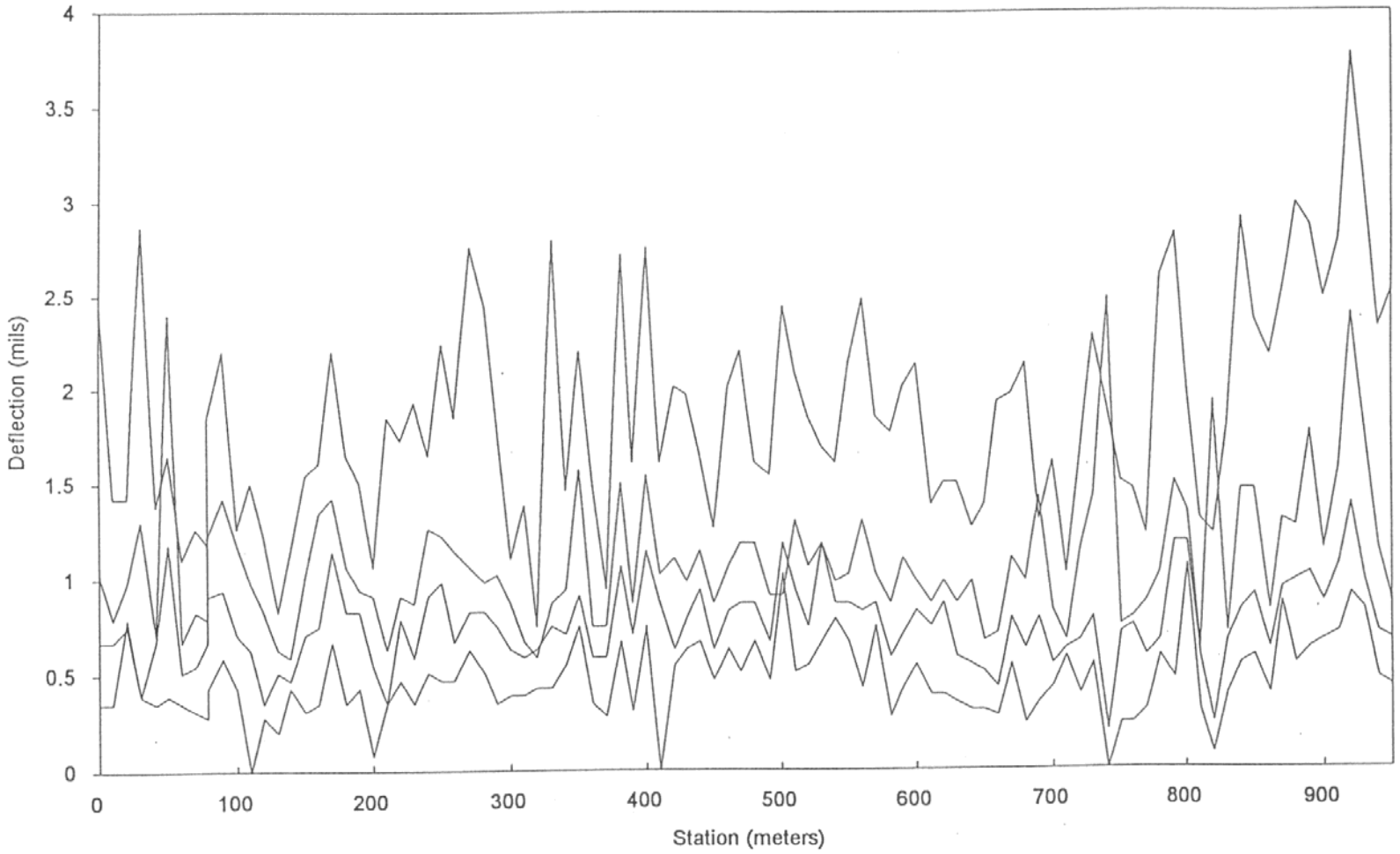
1. *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

2. Shook, J.F., and Diaz, M.A., "Performance-Related Specifications for Asphalt Concrete – Phase II, Proposed Plans for Accelerated Pavement Test Track Study," Report FHWA-RD-91-071 (unpublished), Federal Highway Administration, January 1992.



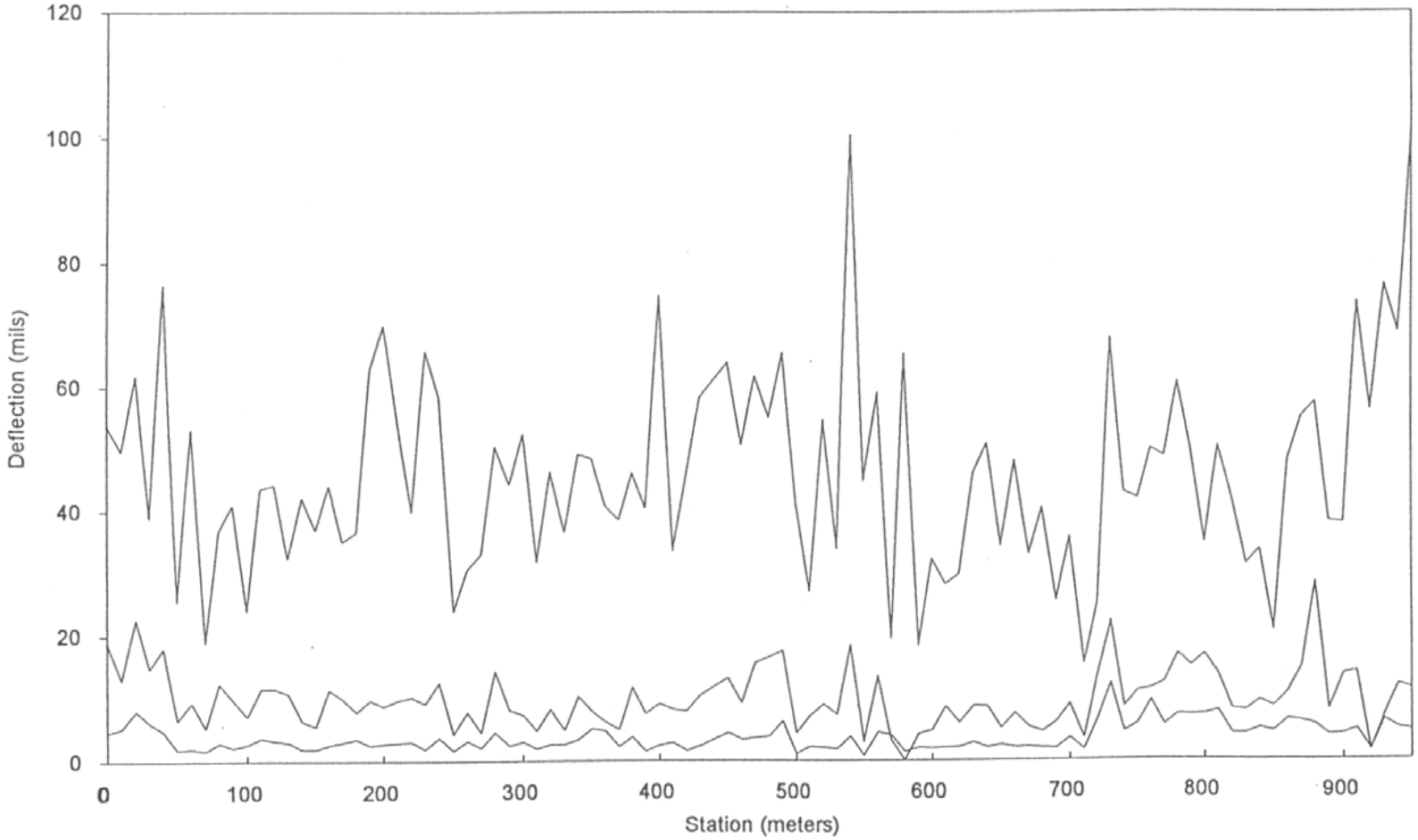
1 ft = 0.3048 m
1 mil = 0.0254 mm

Figure 1. Deflection plots, south tangent – sensors 1, 2, and 3, February 1995.



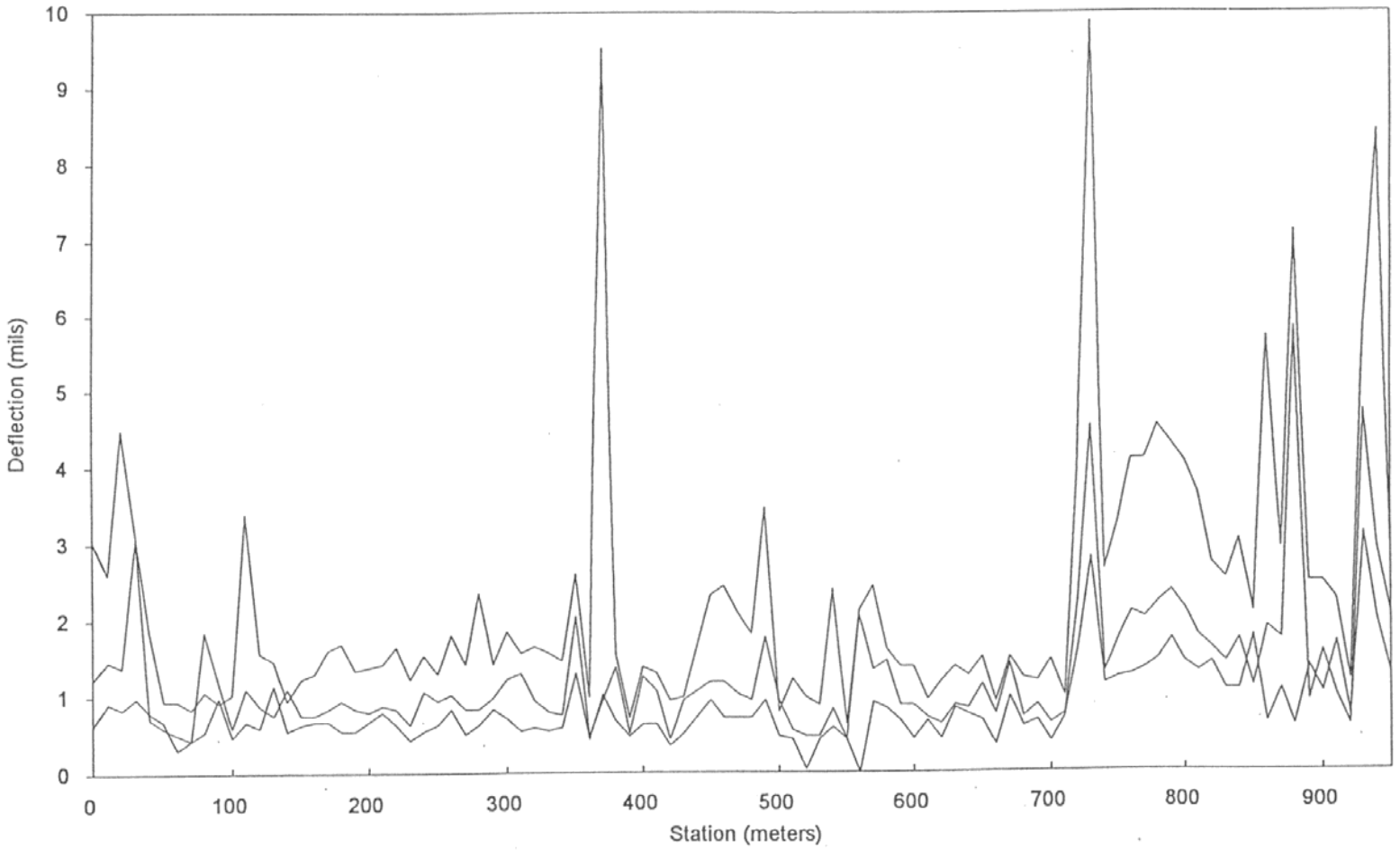
1 ft = 0.3048 m
1 mil = 0.0254 mm

Figure 2. Deflection plots, south tangent – sensors 4, 5, 6, and 7, February 1995.



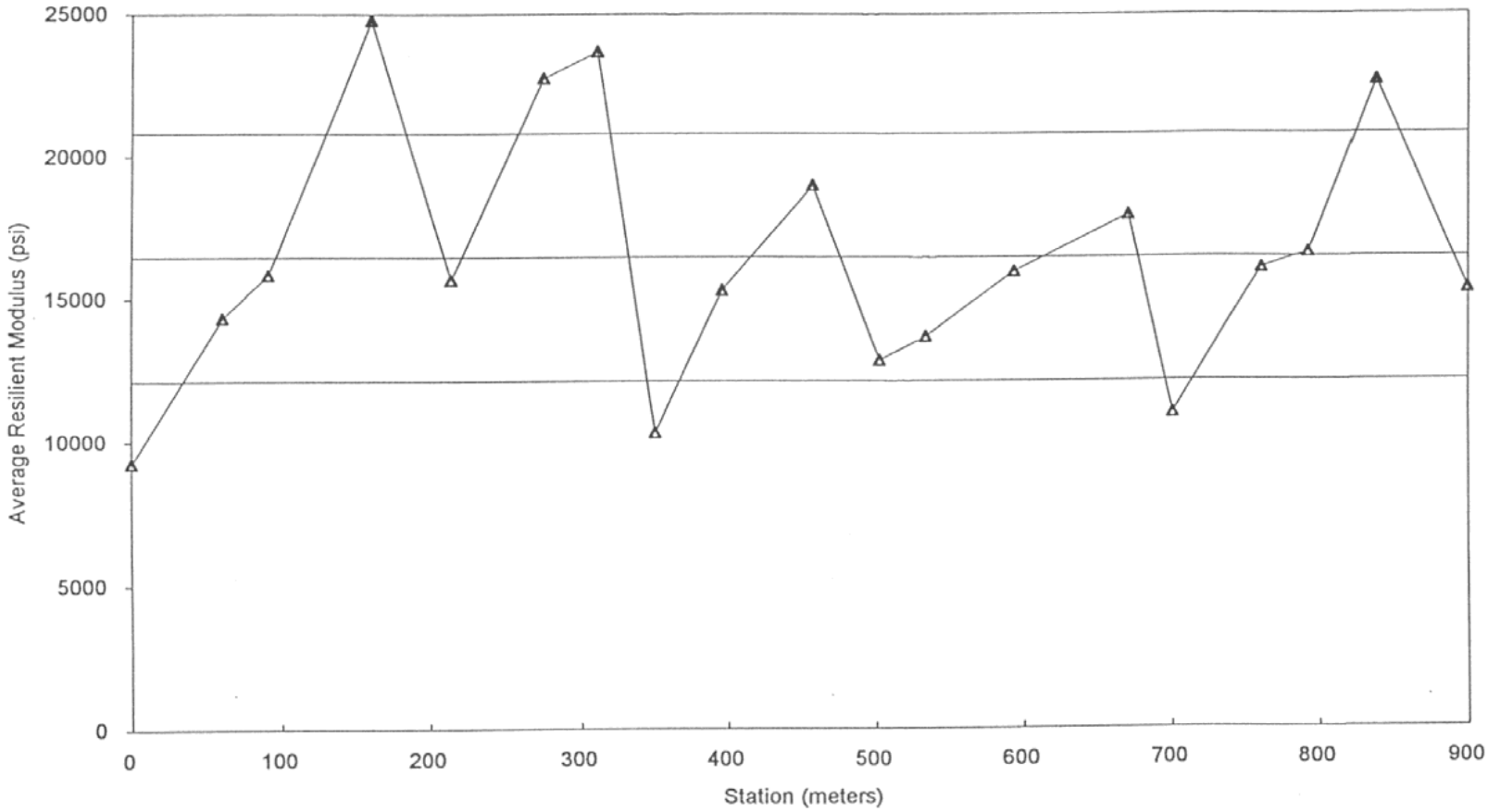
1 ft = 0.3048 m
1 mil = 0.0254 mm

Figure 3. Deflection plots, north tangent – sensors 1, 2, and 3, February 1995.



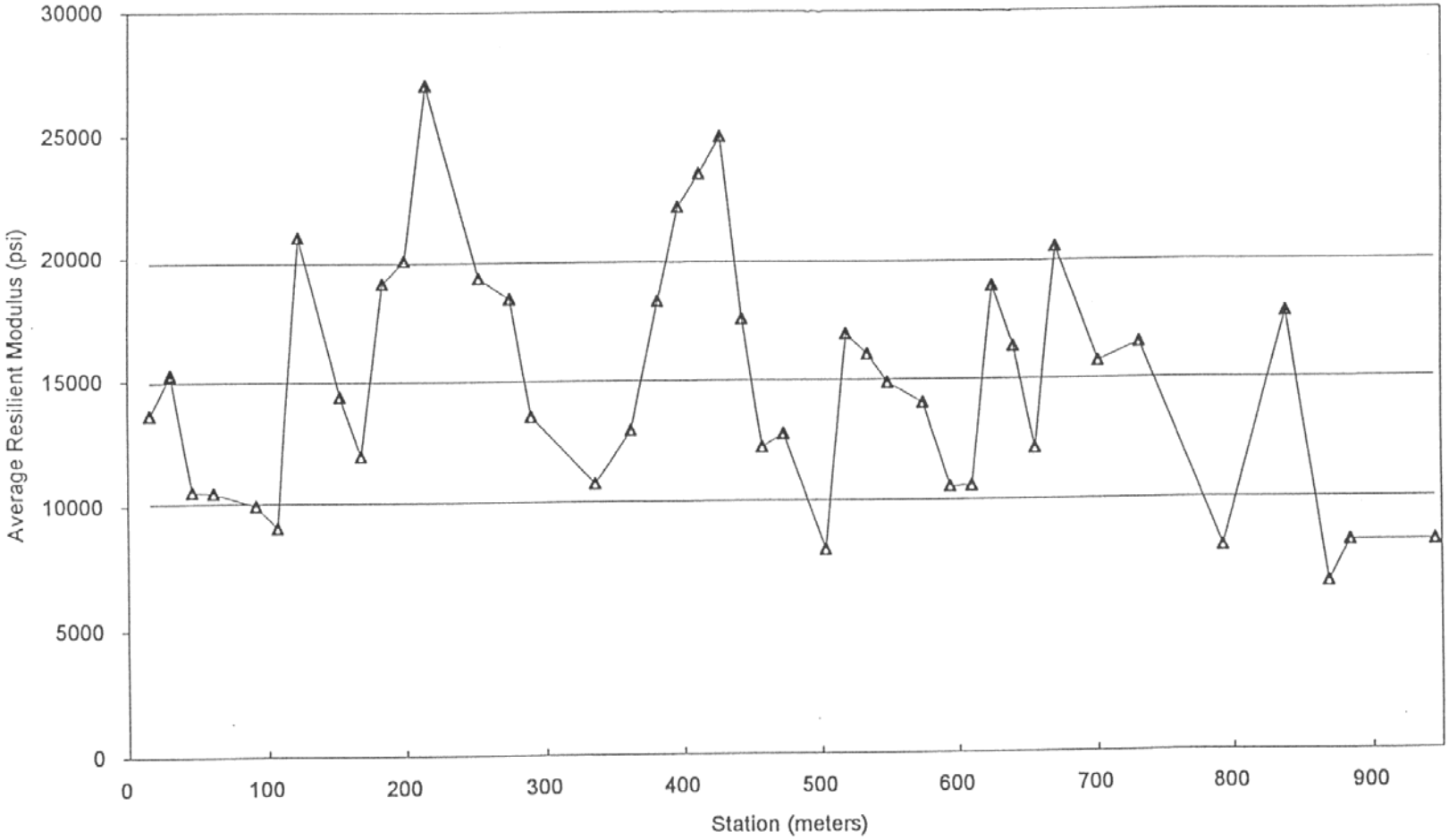
1 ft = 0.3048 m
1 mil = 0.0254 mm

Figure 4. Deflection plots, north tangent – sensors 4, 5, 6, and 7, February 1995.



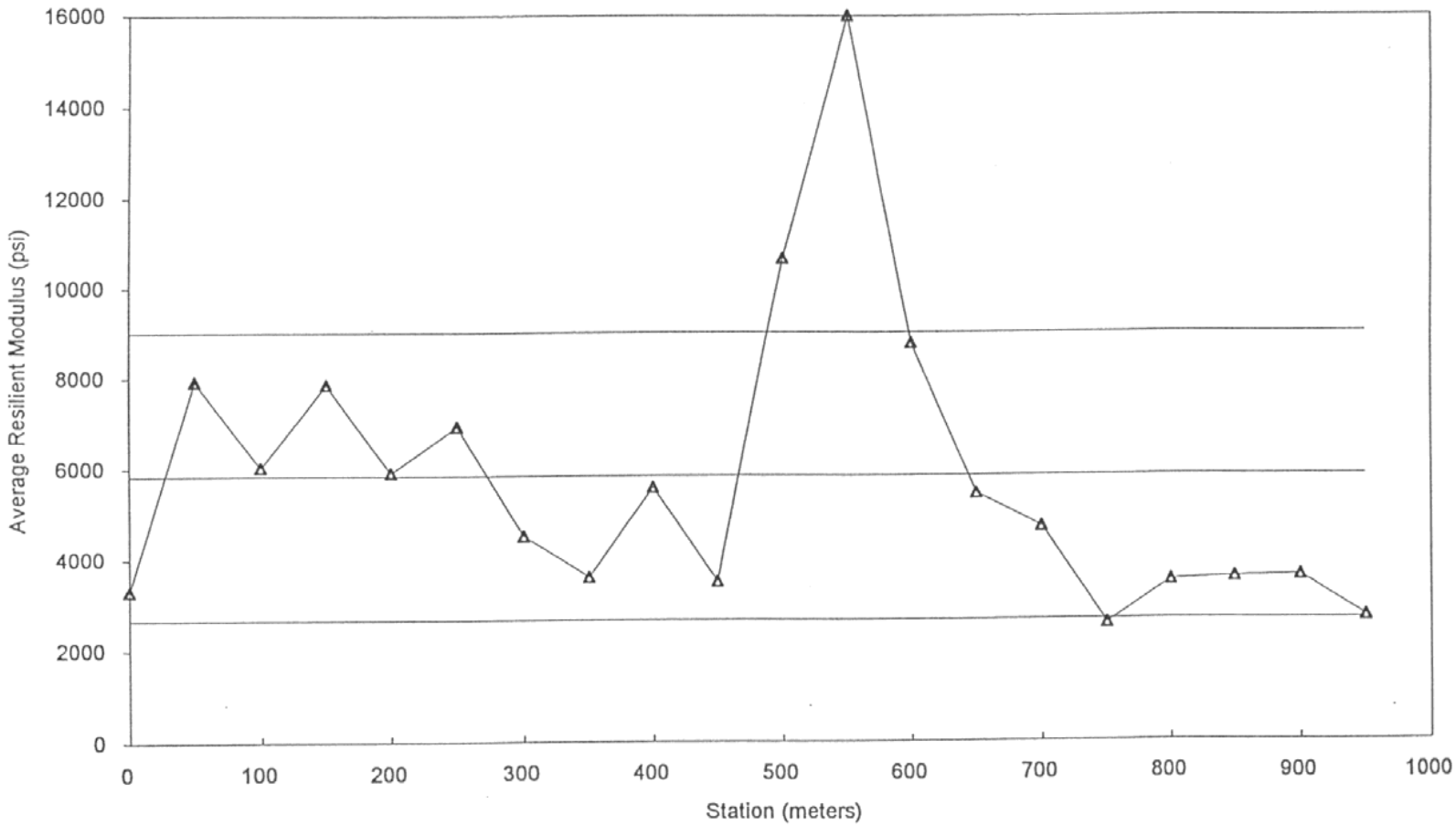
1 ft = 0.3048
1 psi = 6.895 kPa

Figure 5. Subgrade soil resilient modulus, north tangent, October 1994.



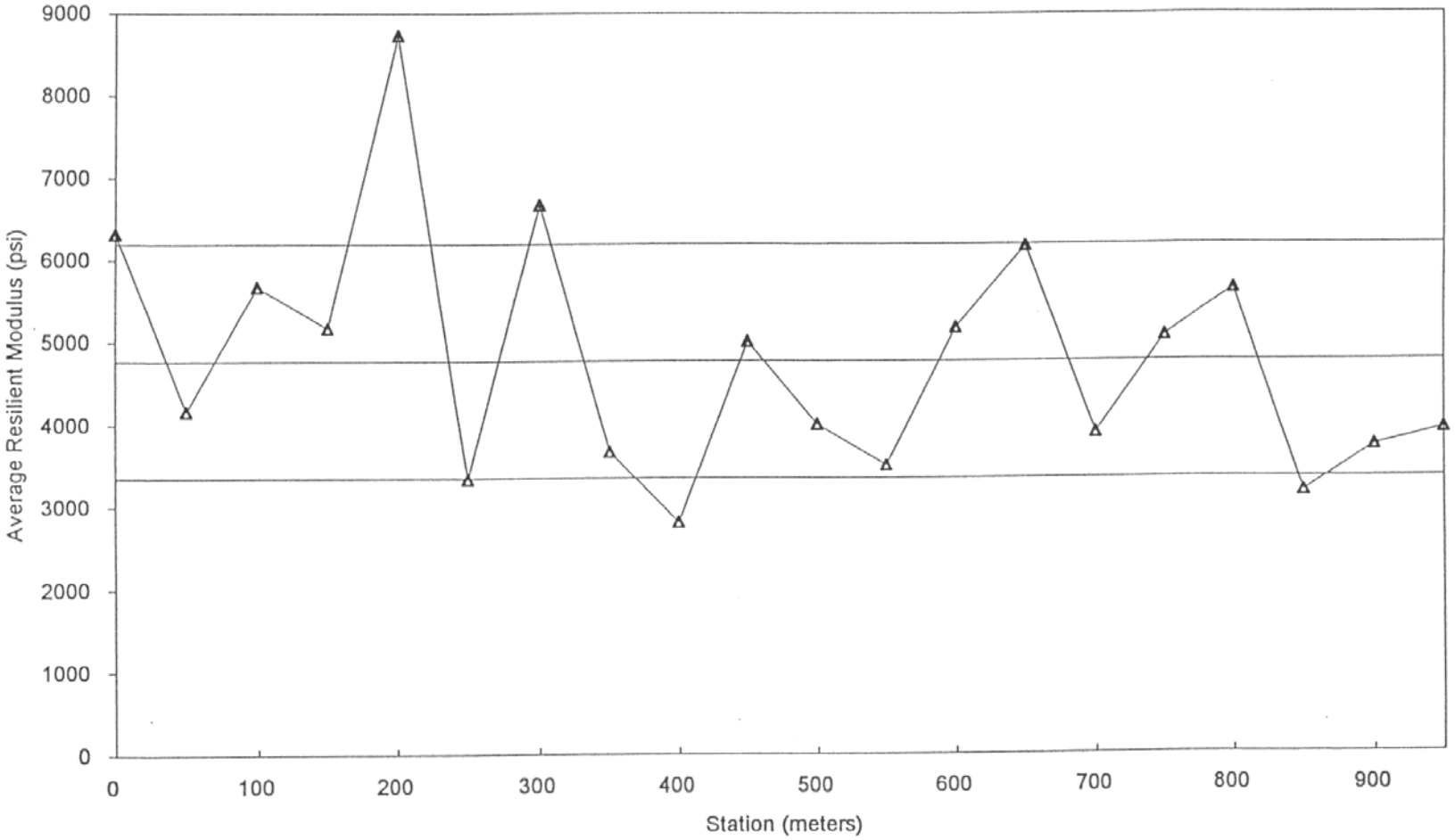
1 ft = 0.3048 m
1 psi = 6.895 kPa

Figure 6. Subgrade soil resilient modulus, south tangent, October 1994.



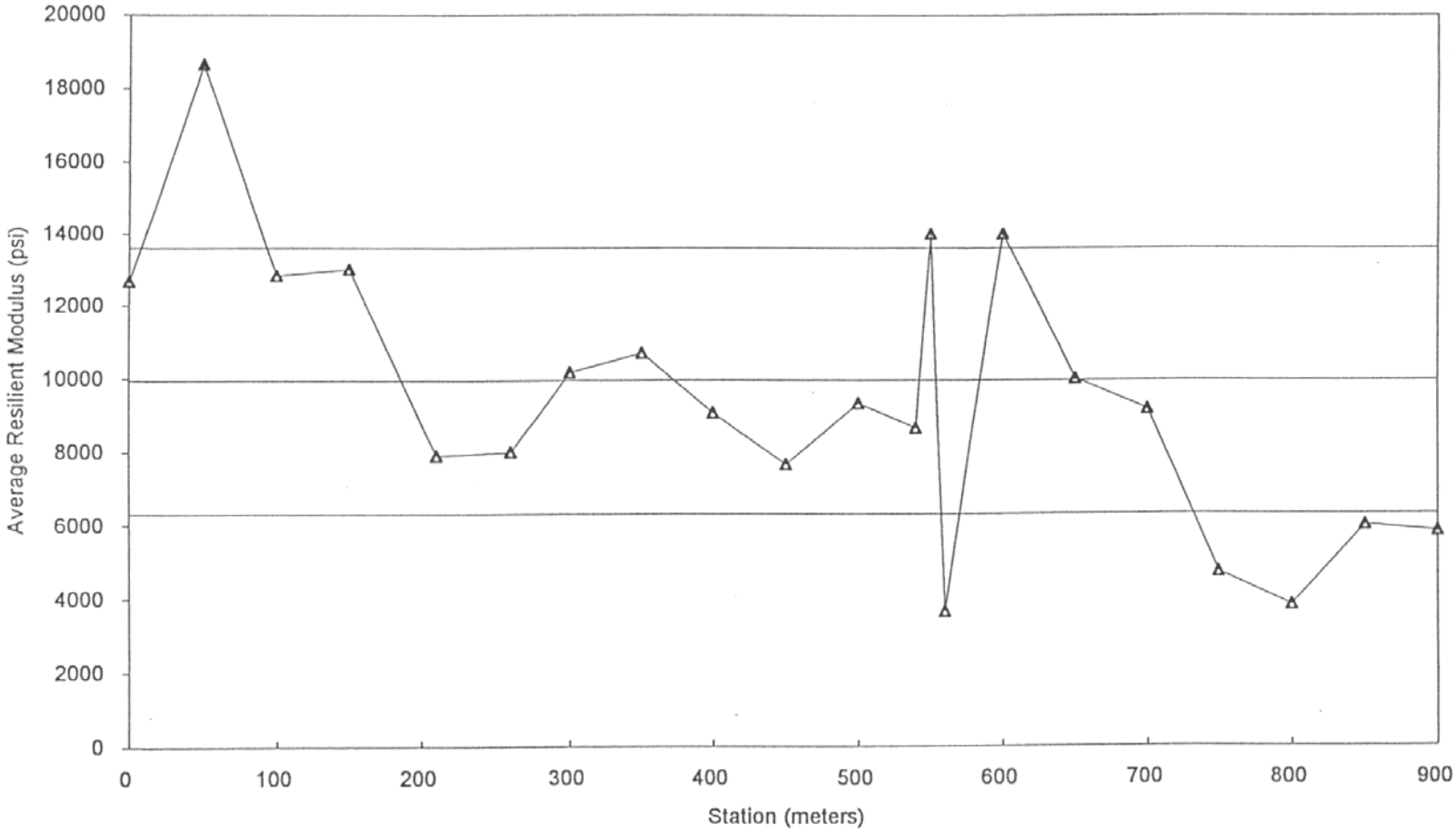
1 ft = 0.3048 m
1 psi = 6.895 kPa

Figure 7. Subgrade soil resilient modulus, north tangent, February 1995.



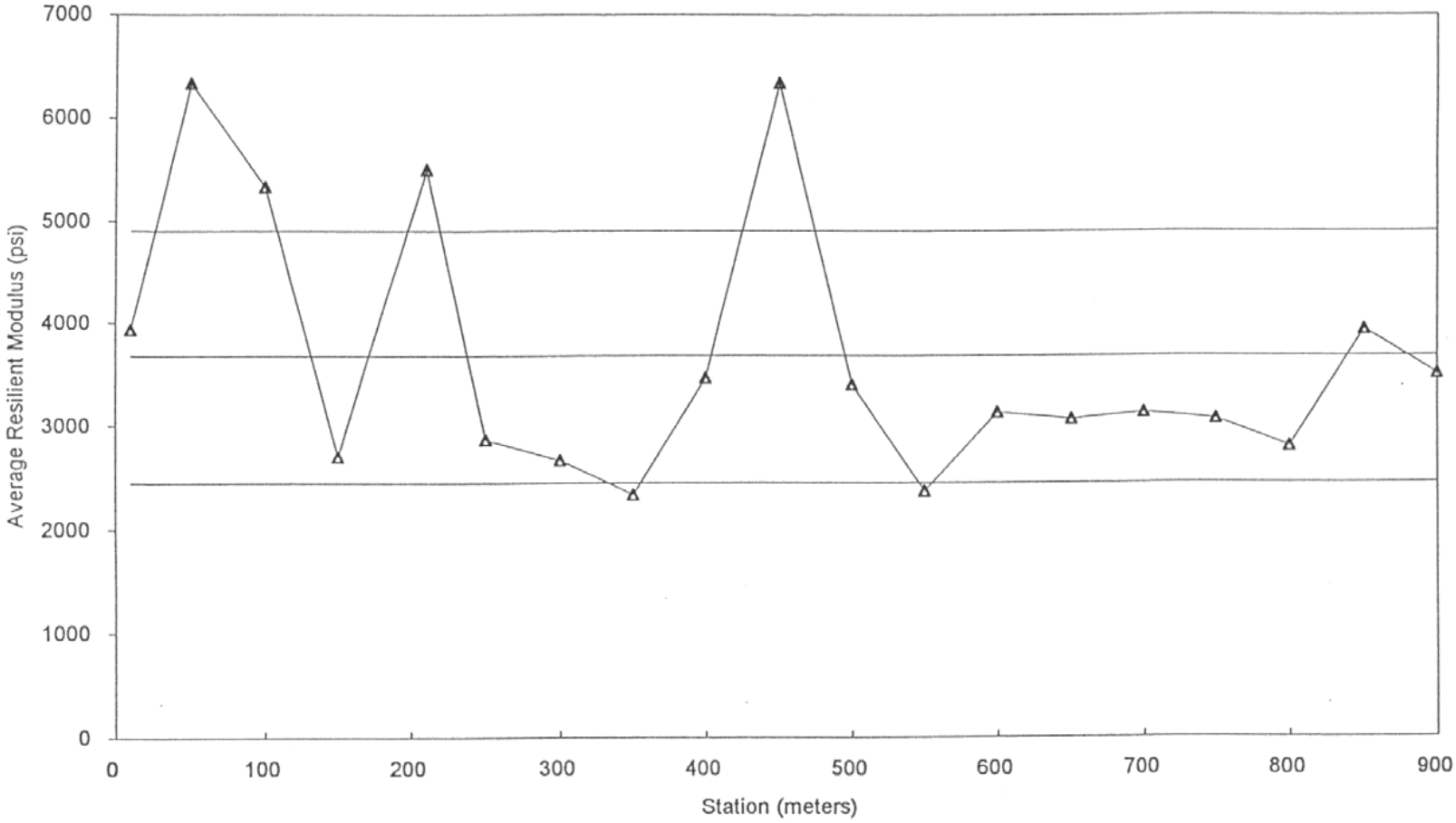
1 ft = 0.3048 m
1 psi = 6.895 kPa

Figure 8. Subgrade soil resilient modulus, south tangent, February 1995.



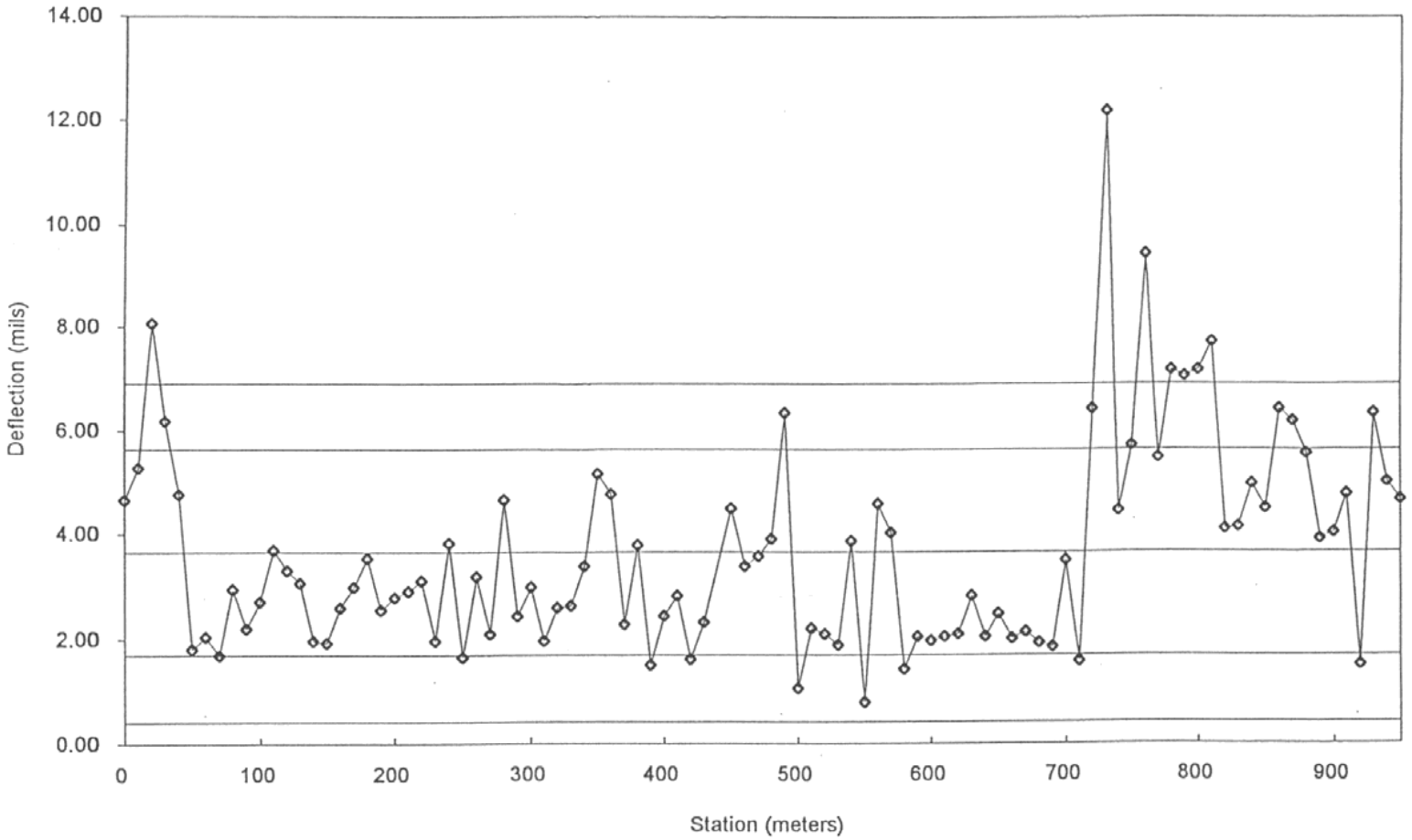
1 ft = 0.3048 m
1 psi = 6.895 kPa

Figure 9. Subgrade soil resilient modulus, north tangent, April 1995.



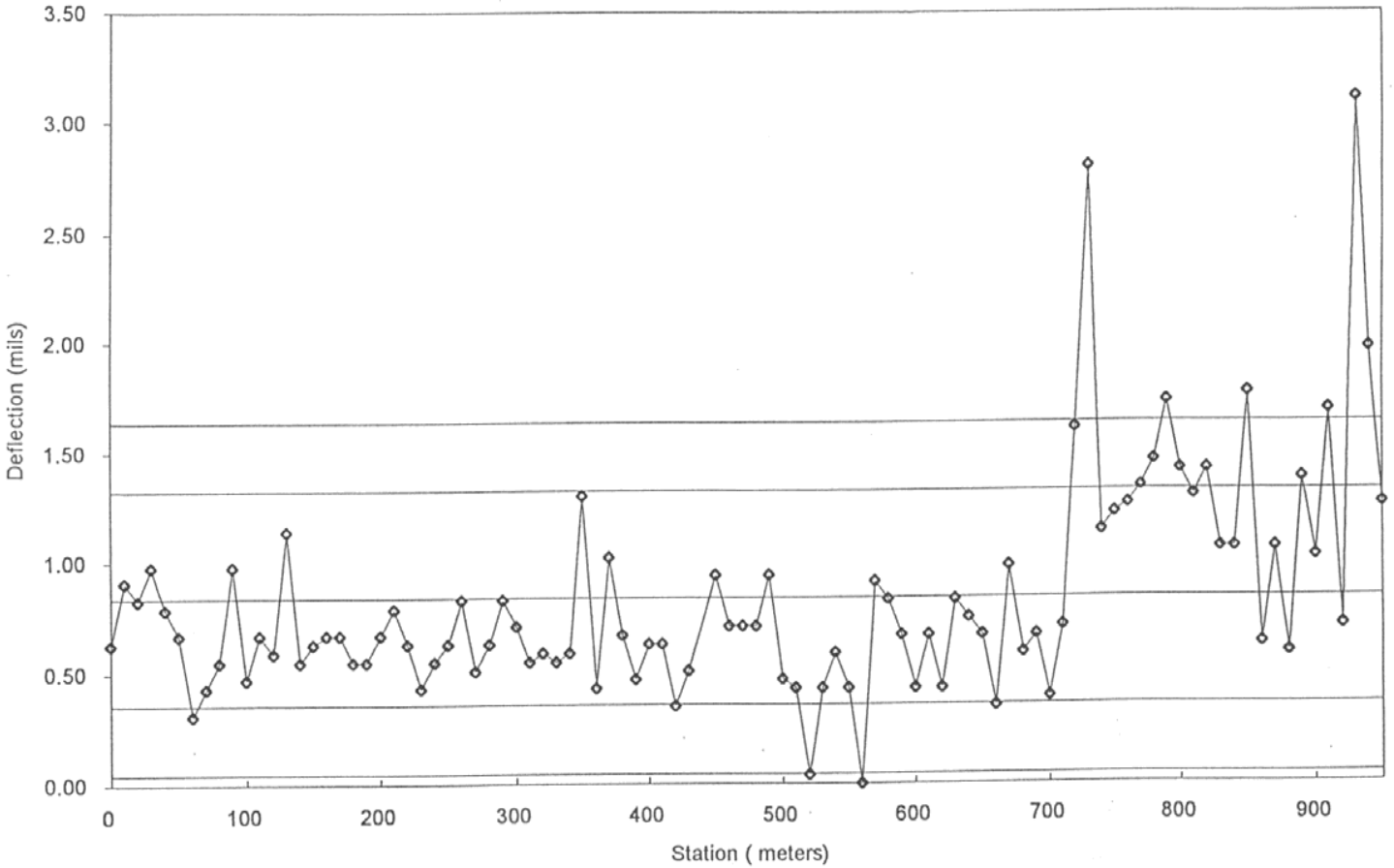
1 ft = 0.3048 m
1 psi = 6.895 kPa

Figure 10. Subgrade soil resilient modulus, south tangent, April 1995.



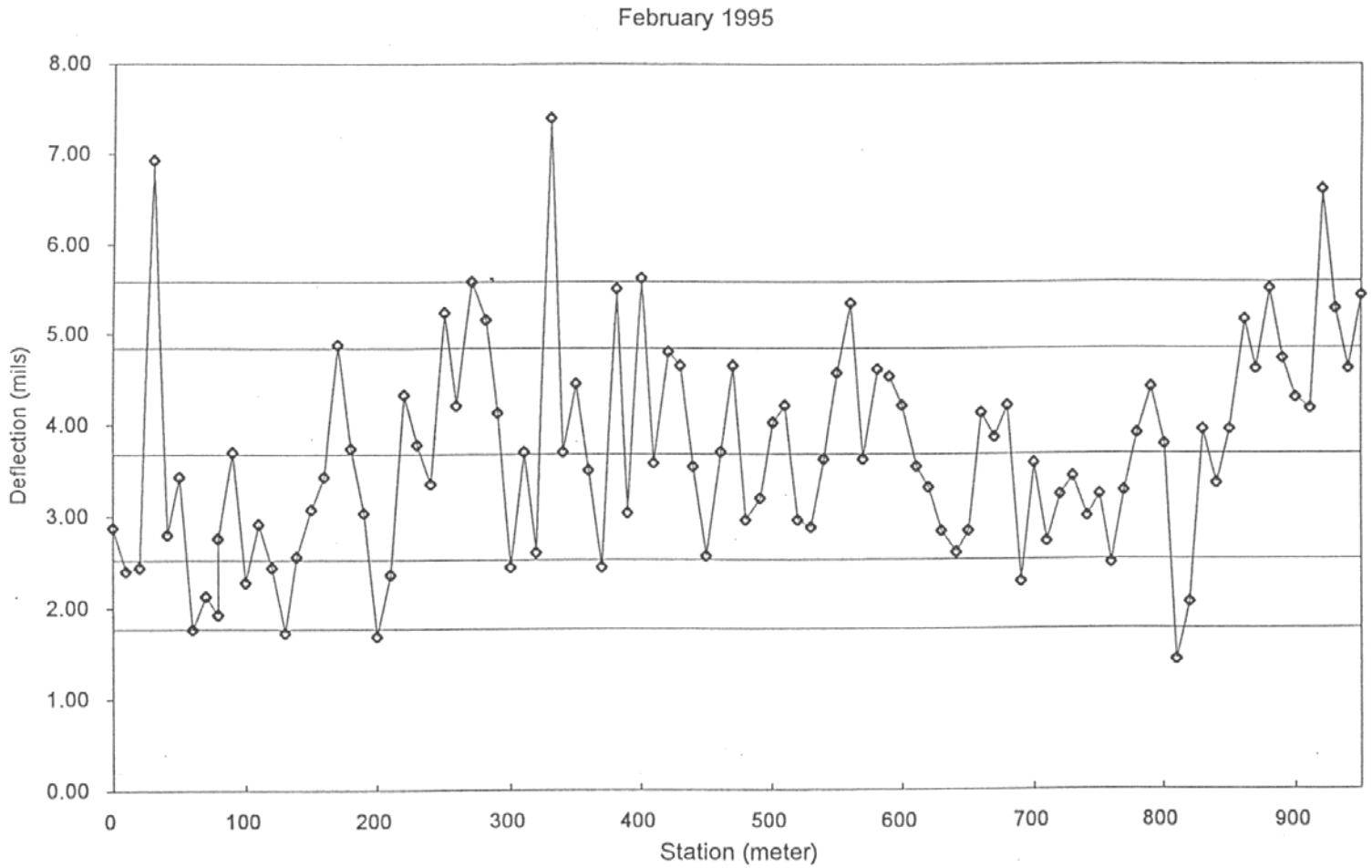
1 ft = 0.3048 m
1 mil = 0.0254 mm

Figure 11. FWD sensor 3 deflection profile (north tangent, February 1995) indicating 66 and 90 percent confidence limits.



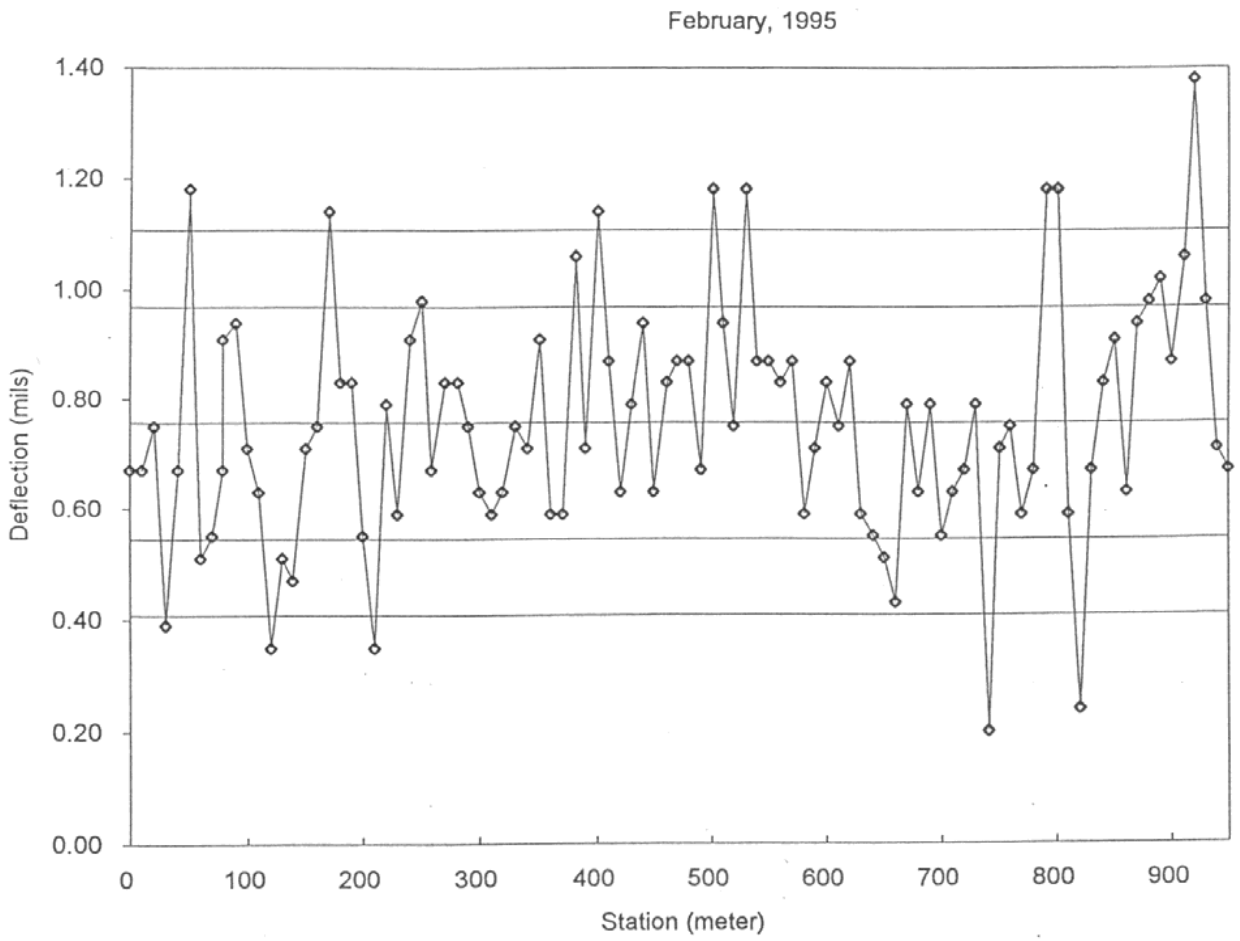
1 ft = 0.3048 m
1 mil = 0.0254 mm

Figure 12. FWD sensor 6 deflection profile (north tangent, February 1995) indicating 66 and 90 percent confidence limits.



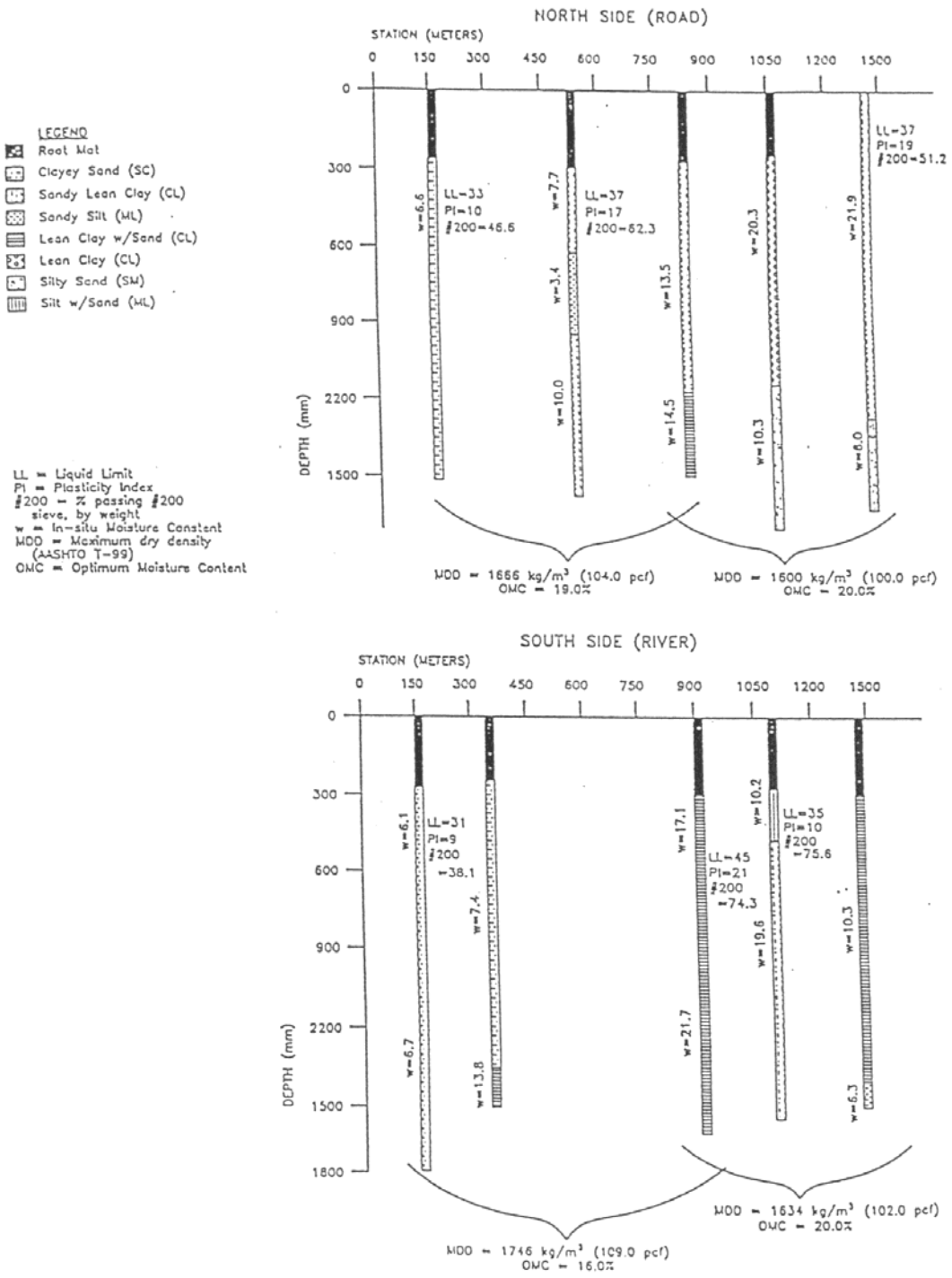
1 ft = 0.3048 m
1 mil = 0.0254 mm

Figure 13. FWD sensor 3 deflection profile (south tangent, February 1995) indicating 66 and 90 percent confidence limits.



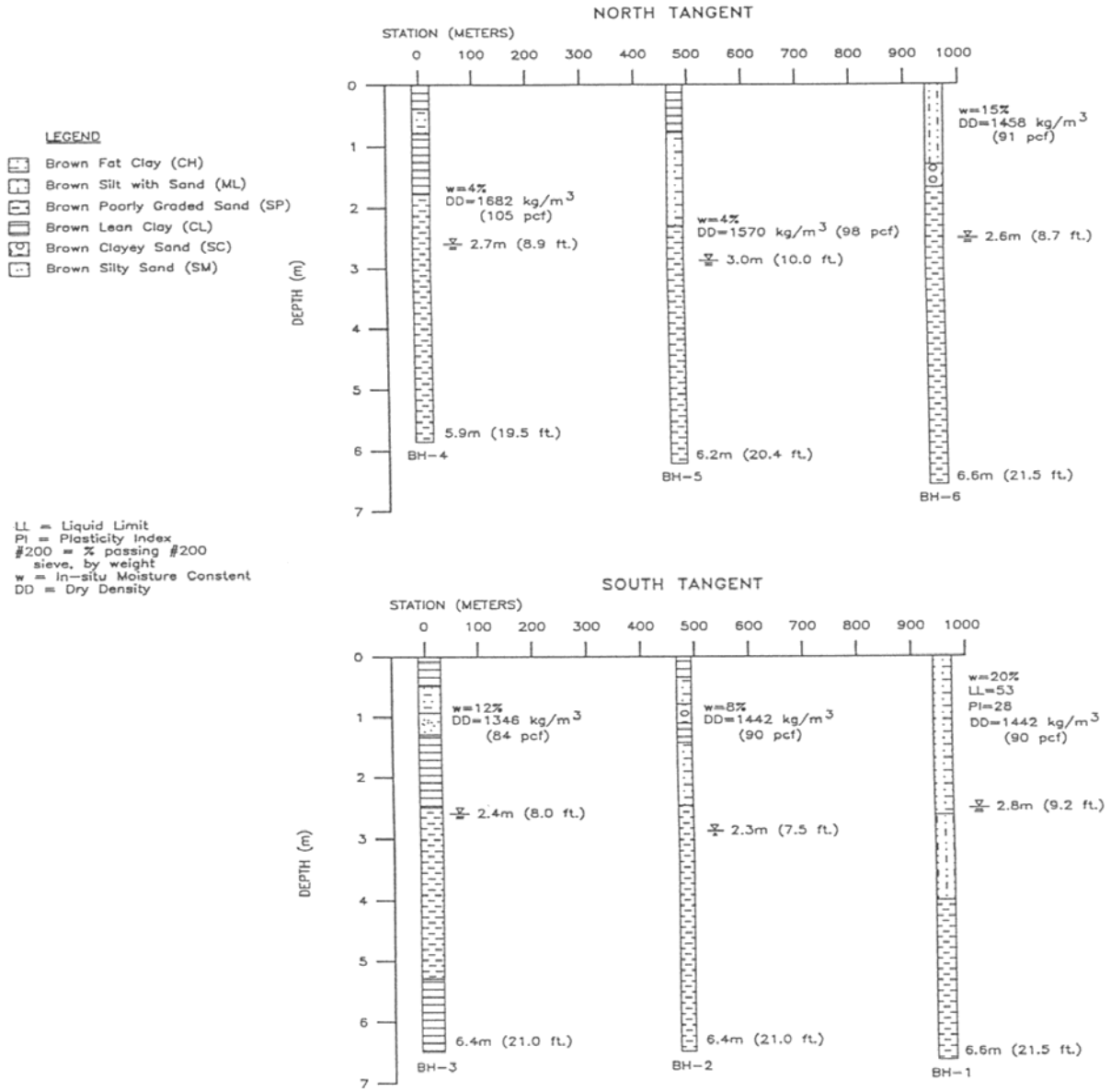
1 ft = 0.3048 m
1 mil = 0.0254 mm

Figure 14. FWD sensor 6 deflection profile (south tangent, February 1995) indicating 66 and 90 percent confidence limits.



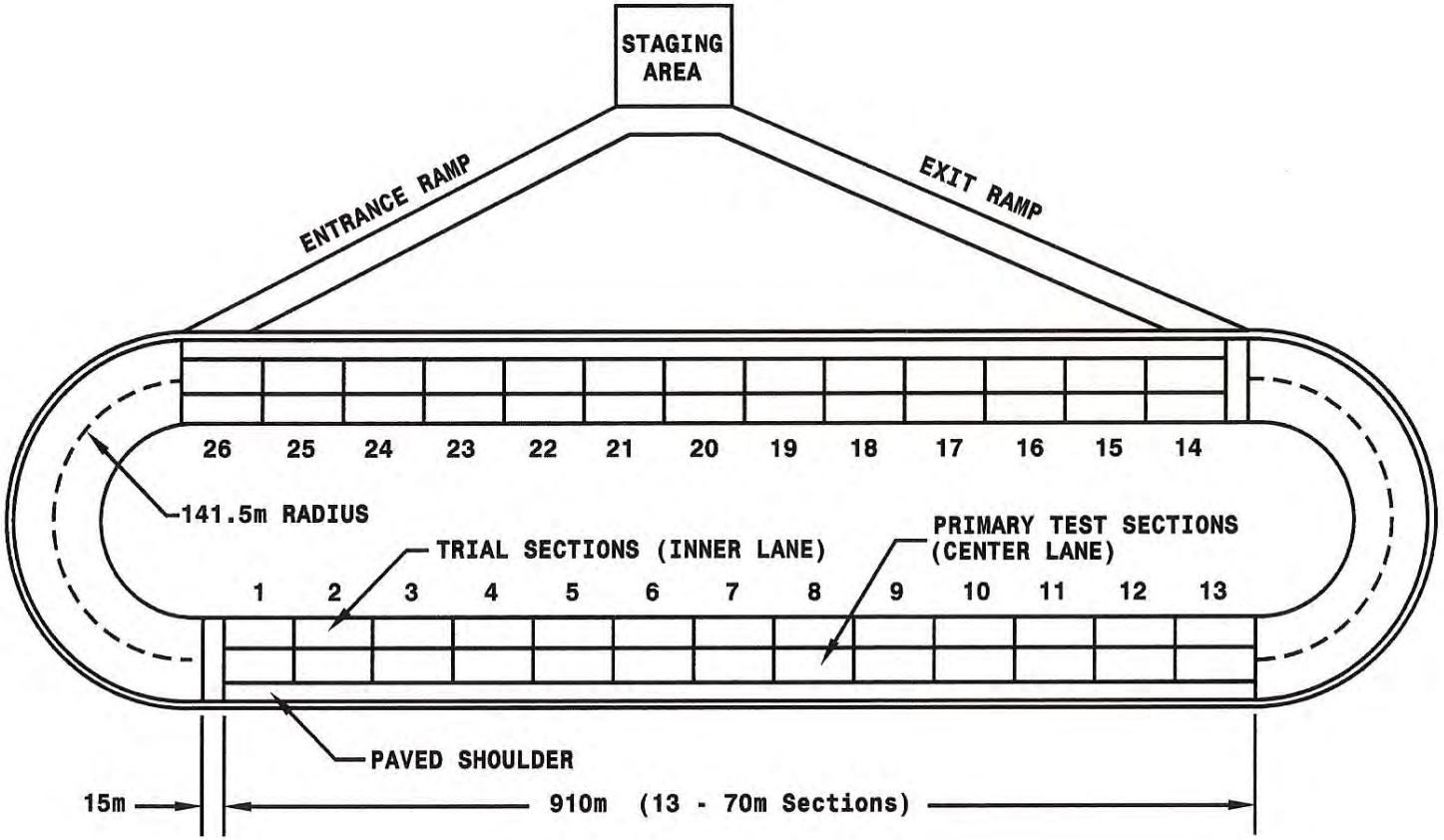
1 ft = 0.3048 m

Figure 15. Test pit logs on existing subgrade material.



1 ft = 0.3048 m

Figure 16. Results of subgrade soil boring logs.



1 ft = 0.3048 m

Figure 17. Layout of test track (not to scale).

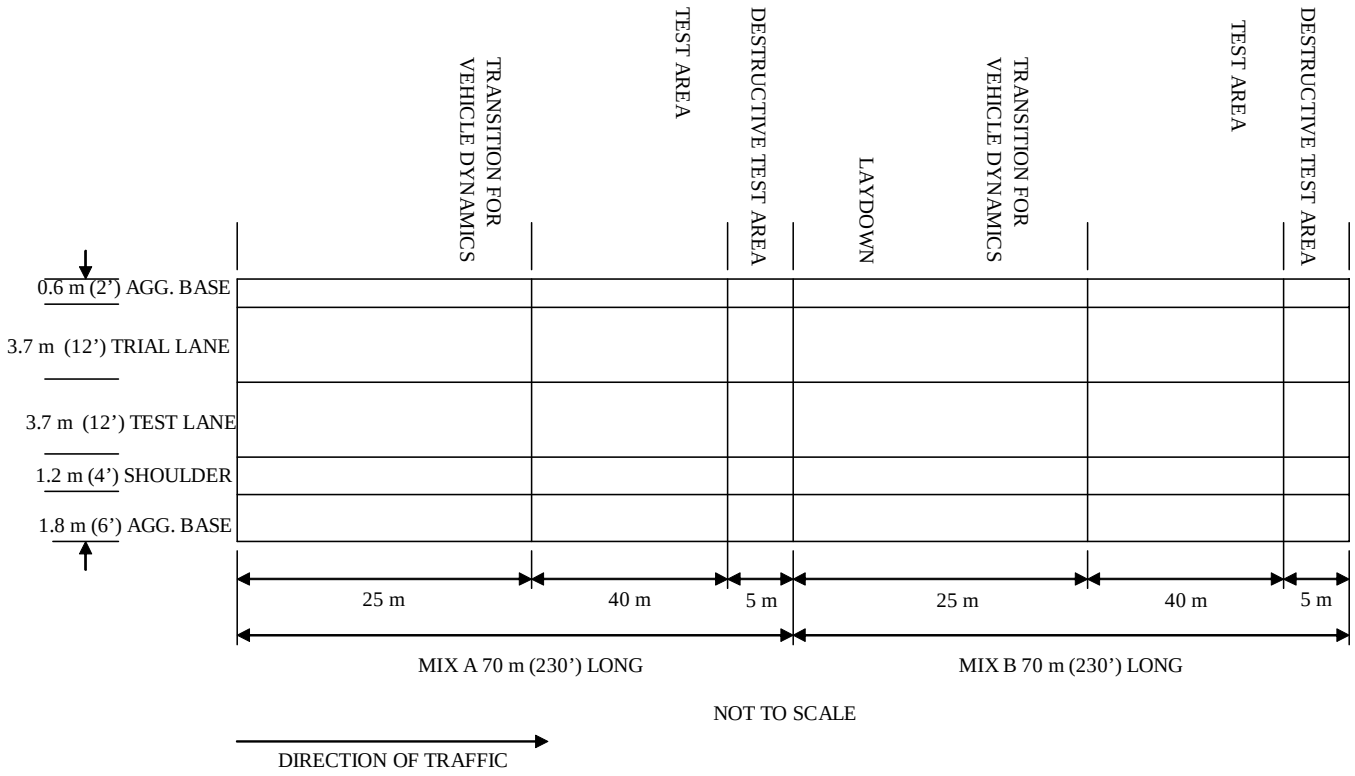


Figure 18. Test section dimensions.

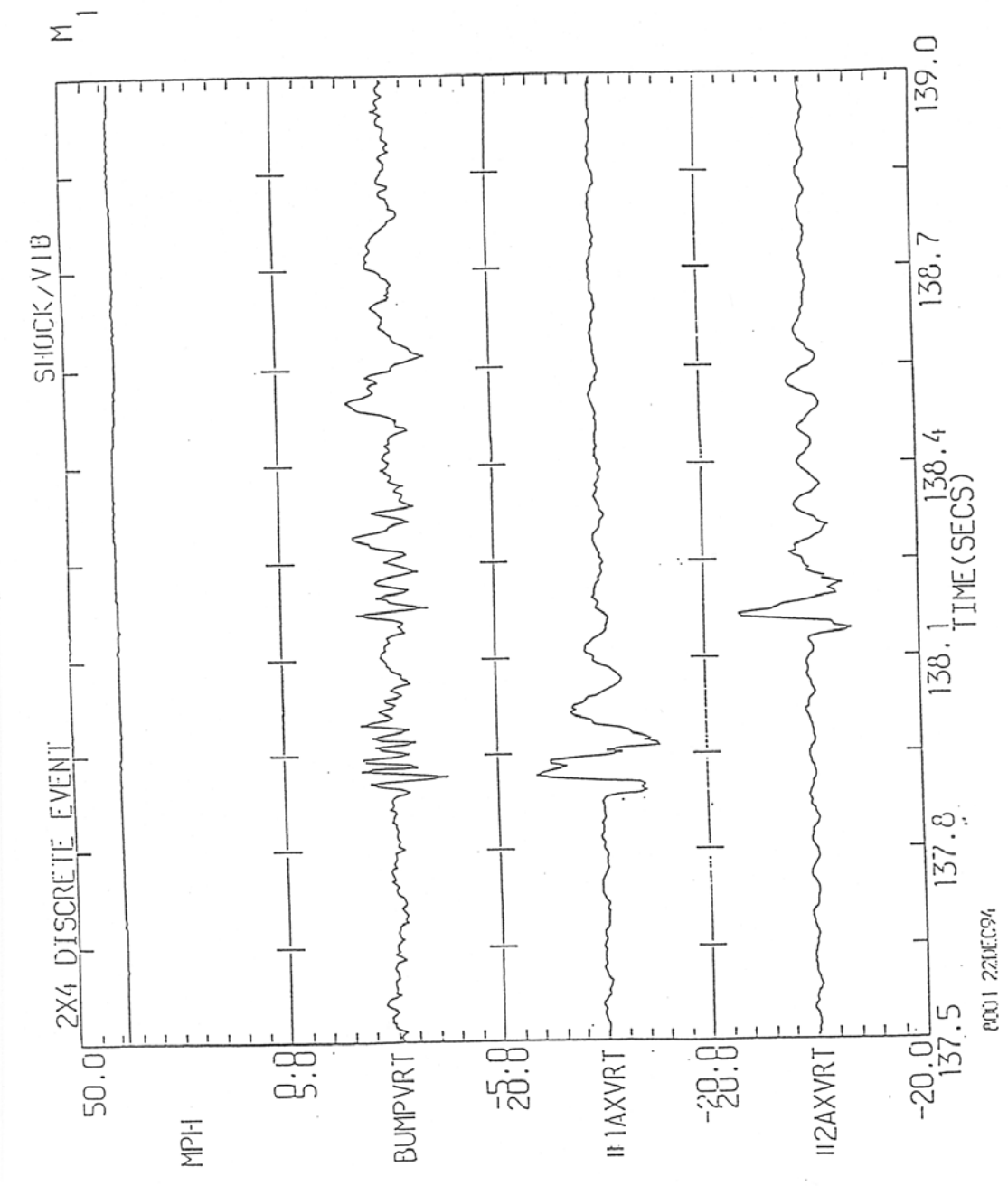
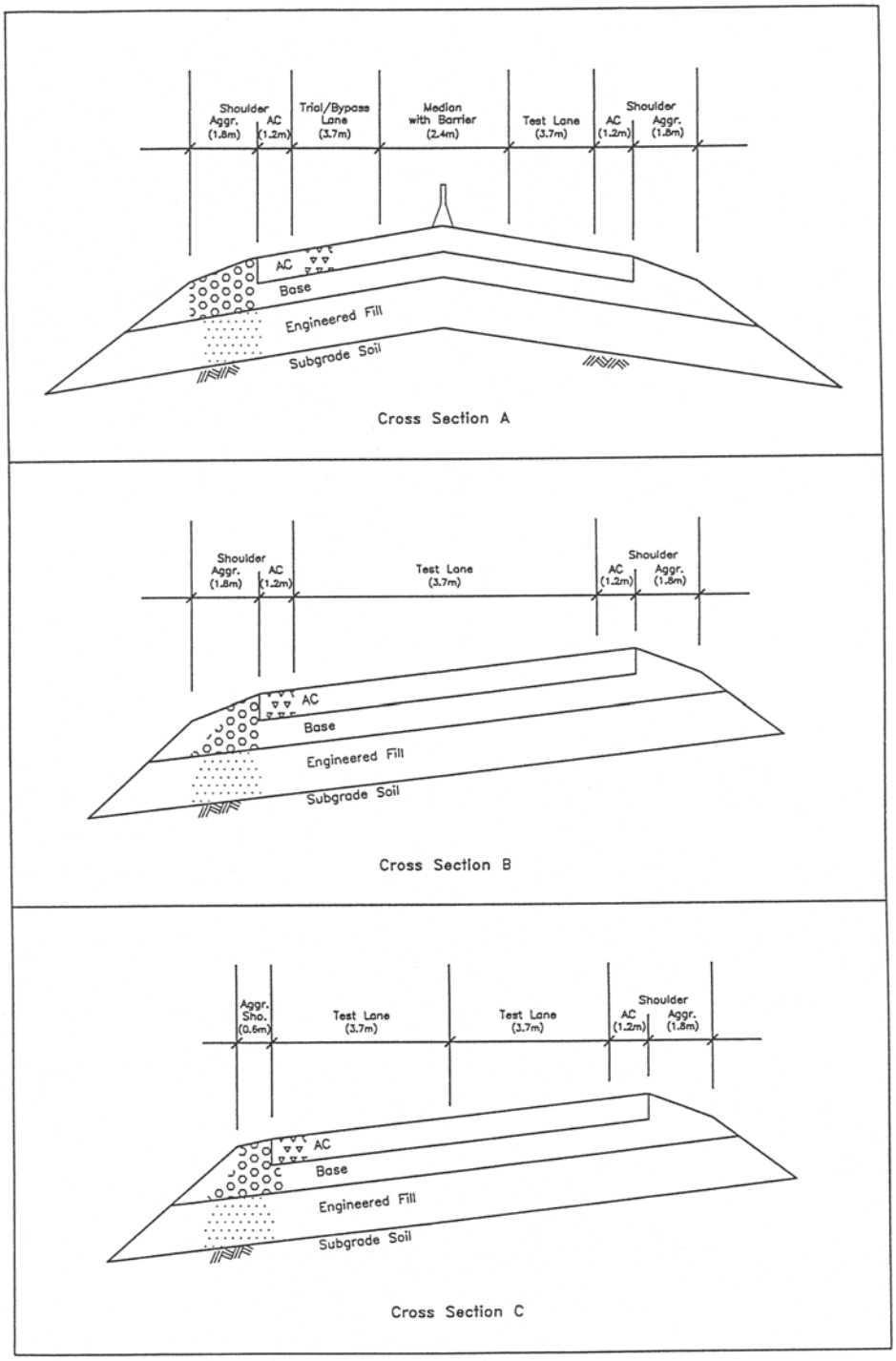


Figure 19. Vehicle dampening associated with 45-mm (1.8-in.) bump in road.



1 ft = 0.3048 m

Figure 20. Three alternative pavement cross sections considered.

Table 1. Summary of historic peak discharges, Carson River near Fort Churchill, USGS Gauge 10312000.

Date	Recorded Peak Discharge (ft^3/s)	Approximate Recurrence Interval
1986	16600	30
1963	15300	28
1956	9680	15
1951	7850	11
1965	7220	9
1983	6350	8
1943	6300	8
1980	6170	8
1914	6150	8
1982	5530	7
1938	5500	7

Source: USGS 1 ft^3/s = 0.0283 m^3/s
Location: Approximately 3 km downstream of project site.

Table 2. Back-calculated resilient modulus for north and south tangents (October 1994 subgrade FWD testing).

Tangent	Resilient Modulus, kPa (psi)	
	Mean	Standard Deviation
North	113,492 (16,472)	29,902 (4,340)
South	102,985 (14,947)	33,313 (4,835)
Combined	108,239 (15,710)	36,500 (5,300)

Table 3. Mean and standard deviation modulus for each WesTrack tangent (February 1995 subgrade FWD testing).

Tangent	Resilient Modulus, kPa (psi)	
	Mean	Standard Deviation
North	40,182 (5,832)	21,862 (3,173)
South	32,858 (4,769)	9,804 (1,423)
Combined	36,520 (5,301)	15,833 (2,298)

Table 4. Mean and standard deviation for April 1995 subgrade FWD testing.

Tangent	Resilient Modulus, kPa (psi)	
	Mean	Standard Deviation
North	68,618 (9,959)	25,114 (3,645)
South	25,335 (3,677)	8,468 (1,229)
Combined	46,977 (6,818)	16,791 (2,437)

Table 5. Subgrade soil overexcavation.

Station (meter)	South Tangent Sensor 6	South Tangent Sensor 3	Overexcavation Recommended
30	X	X	Y
50	X		N
60		X	N
70		X	N
80		X	N
130	X		Y
140		X	Y
180	X		Y
210		X	Y
220	X		Y
280		X	N
340		X	N
390	X	X	Y
400	X		N
410	X	X	Y
510	X		N
540	X		N
740	X		N
790	X		N
800	X		N
810		X	N
820	X	X	Y
880	X	X	Y
890	X		N
910	X		Y
920	X	X	Y
930		X	N
950		X	N

Station (meter	North Tangent Sensor 6	North Tangent Sensor 3	Overexcavation Recommended
10	X		N
20		X	N
510	X		N
550	X	X	N
710	X	X	Y
720	X	X	Y
750		X	N
770	X	X	Y
780	X	X	Y
790	X	X	Y
800	X	X	Y
840	X		N
900	X		N
910	X	X	Y
920	X	X	Y
930	X	X	Y

1 ft = 0.3048 m

Table 6. WesTrack test vehicle instrumentation.

Channel(s)	Description of Location
1-8	Tractor and trailer axle vertical accelerations (to measure axle accelerations as the truck passes over the pavement strain gauges).
9	Tractor frame vertical acceleration (over the tandem axles to measure accelerations at the fifth wheel).
10	Vehicle speed or vehicle displacement from identification marker.

HMA Spec USER'S GUIDE

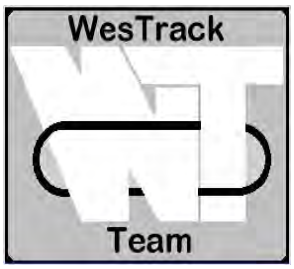
WesTrack Technical Report
NCE-9

Prepared by:
WesTrack Team

Primary Author:

Todd Scholz

July, 2000



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1.0 INTRODUCTION

HMA Spec is a Windows™-based program designed to generate performance-related specifications (PRS) for hot-mix asphalt (HMA) pavements. More specifically, the software program has been developed to assist State Highway Agencies (SHAs) in determining appropriate pay adjustments to a contractor's bid price based on the predicted performance of as-constructed HMA pavements.

HMA Spec was developed as part of the WesTrack Project's Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction, which was originally sponsored by the Federal Highway Administration (FHWA) under Contract No. DTFH61-94-C-00004. When the Transportation Equity Act for the 21st Century transferred most of the Highway Trust Fund support for research from the Federal Government to the States, the National Cooperative Highway Research Program (NCHRP) took over sponsorship of the project in its final year.

1.1 PURPOSE

This document describes how to install and use the beta version (July 2000) release of the *HMA Spec* software program. Users should understand that the program is a beta version, meaning that its developers have tested it but other users have not. Thus, it may contain "bugs." In addition, it may not contain all of the features intended for its Version 1.0 release.

1.2 SCOPE

This document covers all aspects of installing and using the *HMA Spec* software. The first-time reader should read this entire document, which covers software installation in Chapter 2, an overview of the software in Chapter 3, and details of the software in Chapter 4. Also, the reader is strongly encouraged to read PART II of the WesTrack final report,[(1)] in order to have an understanding of the project.

2.0 SOFTWARE INSTALLATION

This chapter provides recommendations for the computer system on which *HMA Spec* will be installed followed by instructions for installing the software.

2.1 RECOMMENDED SYSTEM ATTRIBUTES

This version of *HMA Spec* was developed for computers with reasonably up-to-date hardware components. The following system attributes are required or recommended:

- Operating system: Windows 95, Windows 98, or Windows NT 4.0 is required; Windows 98 or Windows NT 4.0 is recommended.
- Central processing unit (CPU): Pentium is required; Pentium II or better is recommended.
- Free hard disc space: at least 20 megabytes is required; more is recommended.
- Random access memory (RAM): 16 megabytes is required; 64 megabytes or more is recommended.
- Monitor type and resolution: VGA set to 800×600 pixels is required; SVGA or better set to 800×600 pixels or greater is recommended.
- Drives: Compact disc (CD) drive is required.

2.2 INSTALLATION

The *HMA Spec* software package is bundled in an installation program (Setup.exe) contained on the HMA Spec CD. To install the *HMA Spec* software package, follow the six steps below. (Note: underlined characters indicate commands that can be made by using the keyboard as well as the mouse.)

1. Insert the HMA Spec CD into the CD drive.
2. Click on the Windows Start menu button and select Run…
3. Select Browse… When the Browse dialog box opens, navigate to the CD.
4. Double-click on the Setup.exe file (or highlight the file and click on Open).
5. Click on the OK button on the Run form.
6. Follow the instructions given in the Setup Wizard.

PLEASE READ THIS IMPORTANT NOTE!

The Setup Wizard will halt the installation process whenever it attempts to copy an older version of a file that already exists on your hard disk or whenever it attempts to copy a file that is in use at the time of installation.

1. If the Setup Wizard attempts to copy older versions of certain files, it will ask if you want to keep the newer version. Figure 1 shows an example of the dialog box displayed when this occurs. ***Click on the Yes button to keep the newer version.***
2. If the Setup Wizard detects a conflict while attempting to copy a file that is in use, it will display the dialog box shown in figure 2. ***Click on the Ignore button whenever this occurs.*** You will then see the dialog box shown in figure 3. ***Confirm that you want to ignore this error by clicking on the Yes button.***

3.0 *HMA Spec* OVERVIEW

This chapter provides a brief overview of the *HMA Spec* software program. The following paragraphs provide a brief description of the purpose, components, and limitations of the software program.

3.1 PURPOSE

HMA Spec determines an appropriate pay factor for an as-constructed pavement lot based on the predicted performance of the pavement lot. In particular, *HMA Spec* utilizes a Monte Carlo simulation process to predict the life-cycle costs (LCC) of the target (as-designed) and delivered (as-constructed) pavement lots for which a specification is developed. The difference between the predicted LCCs forms the basis for a pay adjustment (if warranted) based on superior or inferior predicted performance of the as-constructed HMA pavement lot. The Monte Carlo simulation process relies on the prediction of pavement performance (in the form of distresses) in association with a maintenance and rehabilitation decision tree to determine if a rehabilitation treatment is warranted based on the magnitude of predicted distress. In the beta version of *HMA Spec*, only three treatments are included: Do Nothing, Hot-Mix Asphalt (HMA) Overlay, and Cold Mill followed by an HMA Overlay. However, *HMA Spec* allows the user to define additional treatments. If a treatment other than "Do Nothing" is warranted, *HMA Spec* determines the thickness of an HMA overlay to last the remainder of the analysis period utilized during the Monte Carlo simulation process. The cost and timing of the treatments are used in the calculation of the LCC of the pavement.

The beta version of *HMA Spec* includes default models for predicting the magnitude of rut depth and the percentage of fatigue cracking based on traffic loading and mixture volumetrics (air void content, asphalt content, and – depending on mixture type – the percentage of aggregate passing the No. 200 sieve). The pavement performance prediction models are based on the findings from the WesTrack Project. This version of *HMA Spec* also includes default decision trees that determine the type of treatment that should be applied to a given HMA pavement based on the magnitude of distress predicted from the pavement performance prediction models. It should be emphasized that the *HMA Spec* program was designed to allow incorporation of user-defined pavement performance prediction models and maintenance and rehabilitation decision trees.

However, the information contained in this document is limited to the default models and decision trees only.

3.2 COMPONENTS

The *HMA Spec* software package was developed in a modular fashion. As such, it contains a number of components (or modules). In a very general sense, the *HMA Spec* program is comprised of two main components (figure 4): one to generate a performance-related specification (preconstruction output); and one to determine an appropriate pay factor for the as-constructed pavement (postconstruction assessment). However, within each of these general components are additional, more detailed components:

- **Generation of a specification (preconstruction output):**
  - Specifying fixed inputs:
    - Definition of pavement design parameters.
    - Definition of a maintenance and rehabilitation decision tree.
    - Definition of treatment unit costs.
    - Definition of traffic parameters.
  - Using the Specification Wizard:
    - Specifying a specification description.
    - Specifying a pavement lot configuration.
    - Selection of fixed inputs.
    - Selection of models to predict pavement performance.
    - Selection of included acceptance quality characteristics (AQCs).
    - Defining AQC means and standard deviations.
    - Defining Monte Carlo simulation parameters.
    - Running a Monte Carlo simulation.
    - Generating a specification document.
  - Viewing and printing the specification document.
- **Determination of an appropriate pay factor for the as-constructed pavement (postconstruction assessment):**
  - Entering actual AQC values.
  - Calculating the pay factor for the as-constructed pavement lot.

It must be emphasized that each component listed above (except the component involving the specification description) plays a significant role in determining an appropriate pay factor for the as-constructed pavement lot. Thus, *HMA Spec* users should be aware of the impact that each

component has on the ultimate output of the program. Chapter 4 of this document provides detailed information about all of the principal components of the *HMA Spec* software package.

3.3 LIMITATIONS

The beta version (July 2000) of the *HMA Spec* software program is very comprehensive in that it embodies the vast majority of the essential features for determining a fair and defensible assessment of the pay factor for an as-constructed pavement lot. However, the beta version does have limitations, which include, but are not limited to, the following:

- Pavement lots: The *HMA Spec* software allows the user to define the size of the pavement lot and the number of sublots in the pavement lot. However, the Guide Specification[(1)] defines a pavement lot as 2,000 tons (1,820 Mg) and each lot as being comprised of five sublots. Thus, although provision has been made to define a lot size and the number of sublots per lot, *HMA Spec* presently does not alter the software-generated specification to reflect user-defined lot size and number of sublots. However, pay factors generated by *HMA Spec* do apply to the user-defined lot size.
- Rehabilitation treatments: Although *HMA Spec* was designed to allow user-defined rehabilitation treatments, only three treatments have been implemented in the beta version: Do Nothing, HMA Overlay, and Cold Mill followed by an HMA Overlay. Furthermore, calculation of the LCC of the pavement lot requires an HMA Overlay treatment. That is, for *HMA Spec* to calculate LCC for a pavement lot, the decision tree must contain at least one HMA Overlay as a treatment. Nevertheless, the software was designed to accommodate additional ancillary treatments (such as a mill operation or crack sealing) that can be defined in association with an HMA Overlay.
- Present worth value determination: *HMA Spec* was designed to calculate the present worth of future rehabilitation treatments in three different ways: using real dollars and a real discount rate, using nominal dollars and a nominal discount rate, or using a method that inflates costs at a specified inflation rate then discounts them at a specified interest rate. The beta version release of *HMA Spec* only allows present worth determination based on real dollars and a real discount rate.

4.0 *HMA Spec* DETAILS

This chapter provides detailed information about the principal components of the *HMA Spec* software package:

- Running *HMA Spec* from within the Windows operating system.
- Using the main module (i.e., the control form).
- Establishing fixed inputs (i.e., the inputs not under the contractor's control but required by the software for generating a specification and pay factor for a pavement lot).
- Developing a specification (i.e., generating preconstruction output).
- Viewing and printing the developed specification document.
- Determining the pavement lot pay factor (i.e., postconstruction assessment).

4.1 RUNNING *HMA Spec*

To run *HMA Spec* from the Windows Start menu (see figure 5):

1. Click on the Windows Start button.
2. Position the mouse pointer on the Programs menu choice.
3. Scroll across to the first submenu and position the pointer over the *HMA Spec* menu choice.
4. Scroll across to the second submenu and position the pointer over the *HMA Spec* menu choice.
5. Click on *HMA Spec* to start the program.

You also can start *HMA Spec* in a variety of other ways (e.g., through Windows Explorer, through the Windows Start menu/Run… feature, by creating a shortcut icon). The Windows operating system documentation and Help system provide guidance on how to execute programs through various means.

4.2 MAIN MODULE OVERVIEW

When *HMA Spec* is executed, the user will first see the "Splash Screen" (figure 6), which is displayed while the software is being loaded into memory. When *HMA Spec* has finished loading into memory, the user will see the main module as shown in figure 7. The principal components of this module are described in further detail in the following paragraphs.

4.2.1 Background Form

The main module of *HMA Spec* is comprised of a background form containing a menu bar, a status bar, and a control form (figure 7). The background form and all other forms within *HMA Spec* contain the menu/control features shown in figure 8. That is, the menu in the upper left corner of figure 8 is displayed (and can be used) when the user clicks on the icon in the upper left corner of the form. Similarly, the form can be minimized, restored (if minimized or resized), or closed by clicking on one of the three buttons in the upper right corner of the form

Note: The menu/control features on several forms of the beta version of HMA Spec have been disabled. However, control buttons have been provided for closing forms and should be used in lieu of the form's menu/control features.

The background form also contains a menu bar and a status bar. The menu bar provides a means for:

- Exiting the program by clicking on the word File, then clicking on the word Exit.
- Selecting the units to be used in the development of a specification by clicking on Units.
- Accessing the help system by clicking on Help. Within the Help menu the user is provided with three options: 1) Contents, 2) Search for Help On…, and 3) About. Selecting the Contents menu choice displays a form showing the table of contents for the Help system, as illustrated in figure 9. The topics within each listed subject can be displayed within this form by double-clicking on the book icon next to the subject, as shown in figure 10. The contents of a particular topic can then be displayed by double-clicking on a subject listed below a given topic. Selecting the Search for Help On… menu choice displays the same form as in figures 9 and 10 except that the index to the Help system is displayed, as shown in figure 11. The Help system includes a "find" feature—click on the Find tab to search for keywords in the *HMA Spec* Help system.

The status bar (figure 7) of the main module displays several items. These include the units in use during the development of a specification, the present date and time, and the status of various keyboard settings (namely, the status of the Num Lock, Scroll Lock, Caps Lock, and Insert

toggle keys). The status of these keyboard settings has no bearing on the specification generated from the *HMA Spec* software.

4.2.2 Control Form

The control form of the main module (figure 7) provides access to the various other modules within *HMA Spec* through a number of features on the form. These include two tabs labeled Projects/Specifications and Input Parameters, as well as a number of command buttons. Further details on these features are provided in the following paragraphs.

Projects/Specifications Tab

Whenever *HMA Spec* is executed, the Projects/Specifications tab is displayed and set active (indicated by the bold lettering on the tab). Initially the Projects/Specifications tab will be blank (i.e., displaying only the word PROJECTS), as shown in figure 7. However, as new projects and specifications for these projects are generated using *HMA Spec*, the tab will display these (see figure 12).

Figure 12 lists several projects on the Projects/Specifications tab with some of the projects showing associated specifications. For example, the figure indicates that three specifications have been generated for the Arlington Avenue project – California to La Rue, La Rue to Mt. Rose, and Mt. Rose to Plumb. Similarly, the specifications for US 395 include MP 45.5 to MP 50.0 and MP 50.0 to MP 50.7.

HMA Spec creates a Microsoft Access 97 (32-bit) database for each project, and specifications comprise records within the tables in the project database; this is why the ".mdb" extension is appended to user-defined project names.

Specification names for a given project can be "hidden" by clicking on the boxed minus (⊟) symbol, and any hidden specifications can be displayed by clicking on the boxed plus (⊞) symbol. For example, in figure 12, the specifications for the Interstate 80, Park Avenue, and Lakeside Drive projects are hidden. To display the specifications for these projects, click on the

boxed plus (⊞) symbol. Similarly, to "hide" the specifications displayed for the Arlington Avenue, Virginia Street, and US 395 projects, click on the boxed minus (⊟) symbol.

Figure 12 also shows that the control form contains a number of buttons, some of which have black lettering and some of which have gray lettering. Black lettering on buttons indicates that the button is active and, therefore, will perform certain tasks if clicked on. Gray lettering indicates the button is inactive and will not perform any tasks if clicked on. When the Projects/Specifications tab is active, the active buttons on the control form perform the following tasks:

- Open displays the first of several forms relating to the highlighted specification on the Projects/Specifications tab. To highlight a particular specification, click on the name of the specification on the Projects/Specifications tab. Refer to section 4.4 for details regarding the Specification Wizard.
- Copy makes a copy of a highlighted specification. This button is not functional in the beta version of *HMA Spec*.
- Delete deletes highlighted projects or specifications.
- New Spec displays the first of several forms for creating a new specification for a highlighted project. To highlight a particular project, click on the name of the project on the Projects/Specifications tab. Refer to section 4.4 for details regarding the Specification Wizard.
- New Project displays the dialog box shown in figure 13. To create a new project, type in the name of the project in this dialog box and click on the OK button. If no project with that name already exists, a new Microsoft Access 97 database will be created. Note that the beta version of *HMA Spec* does not allow duplicate project names. That is, all project names must be unique. Once created, any practical number of specifications can be added to the project.
- View Spec displays the specification document of a highlighted specification if it has been generated. To highlight a particular specification, click on the name of the specification on the Projects/Specifications tab. Refer to section 4.5 for further details regarding viewing and printing a specification document.

- Enter postconstruction data accesses the features of *HMA Spec* that allow the user to enter postconstruction test results from samples taken from the as-constructed pavement lot as well as calculate the pay factor for the as-constructed pavement lot. Refer to section 4.6 for details regarding this feature of the software.

Input Parameters Tab

The Input Parameters tab (see figure 14) of the control form provides access to the features for entering fixed inputs into the program. (Recall that fixed inputs are required to generate a specification but are not under the contractor's control.) The input parameters are categorized as follows:

- Pavement design parameters.
- Maintenance and rehabilitation decision trees.
- Costs.
- Traffic parameters.

Multiple input parameter sets can be created within each of these categories. For example, multiple pavement design parameter sets can be created or multiple maintenance and rehabilitation decision trees can be created, as shown in figure 15.

Parameter sets for a given category can be hidden by clicking on the boxed minus (⊟) symbol, and hidden parameter sets can be displayed by clicking on the boxed plus (⊞) symbol. For example, in figure 15 the parameter sets for the Costs and Traffic Parameters categories are hidden. To display the parameter sets for these categories, click on the boxed plus (⊞) symbol. Similarly, to hide the parameter sets displayed for the Pavement Design Parameters and Maintenance and Rehabilitation Decision Trees categories, click on the boxed minus (⊟) symbol.

As indicated in figure 15, the control form contains several buttons associated with the Input Parameters tab:

- Open displays the input form associated with the highlighted parameter set. For example, figure 15 indicates that the Pavement Design Parameter set named "Default – US Units" is highlighted. Clicking on the Open button with this parameter set highlighted would open the input form to allow viewing and editing of the pavement design parameters for

the "Default – US Units" parameter set. The input forms for all input parameters are described in detail in section 4.3.

- Copy makes a copy of a highlighted parameter set. This button is not functional in the beta version of *HMA Spec*.
- Delete deletes highlighted parameter sets.
- New… button opens an input form for a highlighted input parameter category. For example, figure 16 indicates that the Pavement Design Parameters category is highlighted. Clicking on the New… button with this category highlighted would open the input form to allow viewing and editing of the pavement design parameters for a new parameter set. Viewing/editing parameter sets is described next.

4.3 ESTABLISHING FIXED INPUTS

HMA Spec requires a number of inputs that are not under the contractor's control. For example, traffic plays a significant role in the performance of an HMA pavement, but the contractor has no control over the amount of traffic applied to the pavement. Therefore, although traffic is needed to predict pavement performance, it does not influence the magnitude of pay adjustment the contractor receives because traffic is applied equally to the as-designed and as-constructed pavement lots in determining the pay factor.

All required inputs that are not under the contractor's control are referred to as "fixed inputs" even though, as is the case with traffic, these can vary over time. The following paragraphs provide details for establishing fixed inputs in the beta version of *HMA Spec*.

4.3.1 Pavement Design Parameters

Figure 17 shows the input form for viewing and editing pavement design parameter sets. This form can be opened using the Input Parameters tab of the control form as described in section 4.2.2. The value for each item displayed on the Design Inputs tab of this form can be edited by clicking on the text box associated with the item. For example, the design life of the pavement can be changed from 20 (figure 17) to a different value by clicking on the text box associated with the words "Design life (years)…" and typing in a new value.

The items that can be edited using the Pavement Design Parameters input form are described in the following discussion. Only two of these items affect the magnitude of pay adjustments: HMA layer thickness and the reliability to use for overlay design. The rest are fixed inputs.

- Design life: This is the duration in years that the as-designed and as-constructed pavements are expected to last. The value entered for the design life should be the same as that used to design the pavement structure.
- Target smoothness: This is the target initial smoothness (International Roughness Index [IRI]) value in meters per kilometer (or inches per mile) of the as-designed and as-constructed pavements. This value is used in the design of an HMA overlay thickness if the maintenance and rehabilitation decision tree triggers an overlay.
- Terminal smoothness: This is the highest tolerable smoothness (IRI) value in meters per kilometer (or inches per mile) of the as-designed and as-constructed pavements. This value is used in the design of an HMA overlay thickness if the maintenance and rehabilitation decision tree triggers an overlay.
- Layer coefficient for HMA overlays: This is the layer coefficient for HMA materials as defined in the 1993 *AASHTO Guide for Design of Pavement Structures*.[(2)] This value is used in the design of an HMA overlay thickness if the maintenance and rehabilitation decision tree triggers an overlay.
- Pavement layer properties:
  - HMA layer thickness: This is the design thickness in millimeters (or inches) of the as-designed pavement structure and the expected thickness of the as-constructed pavement structure. The value entered in the Pavement Design Parameters form serves as the default value for the HMA layer thickness, *but it is not necessarily the mean thickness used in the Monte Carlo simulation process to determine LCC and pay factors*. The actual mean thickness value for the HMA layer that *is* used in the Monte Carlo simulation process is entered in one of the forms of the Specification Wizard (see section 4.4).
  - HMA layer modulus: This is the estimated elastic modulus value in megapascals (or pounds per square inch) of the HMA pavement layer. This value is used in predicting rut depth and fatigue cracking, but it is a fixed input

- Base course layer thickness and modulus: These are the thickness in millimeters (or inches) and the estimated resilient modulus in megapascals (or pounds per square inch) of the base course layer.
- Subbase layer thickness and modulus: These are the thickness in millimeters (or inches) and the estimated resilient modulus in megapascals (or pounds per square inch) of the subbase layer..
- Roadbed soil layer thickness and modulus: These are the thickness in millimeters (or inches) and the estimated resilient modulus in megapascals (or pounds per square inch) of the roadbed soil.

- Reliability to use for overlay design: This is the design reliability value, expressed as a percentage and delineated by the functional classification utilized in the overlay design procedure in the beta version of *HMA Spec*. The software requires that the user specify the functional classification of the pavement facility for which a specification is being generated (see section 4.4).

A description for the parameter set can be entered in the text box on the Description tab of this form. In addition, the buttons on this form perform the following tasks:

- Save saves the values and description for the parameter set. If the name of the parameter set has not been changed, the user is warned that a parameter set already exists and is requested to confirm over-writing the parameter set. To save a parameter set under a different name, edit the text in the "Name" box at the top of the form.
- Cancel closes the input form without saving changes (unless, of course, values were saved previously by clicking on the Save button).
- OK closes the form without saving changes (unless, of course, values were saved previously by clicking on the Save button). If this form is accessed from within the Specification Wizard (see section 4.4), the values that are established on the form become the values used within the specification being developed, even if the values are not saved.

4.3.2 Maintenance and Rehabilitation Decision Trees

Figure 18 shows the form for creating, editing, and viewing decision tree parameter sets. This form can be opened using the Input Parameters tab of the control form, as described in Section 4.2.2.

HMA Spec uses decision trees to determine the type of treatment to apply to a pavement based on the magnitude of predicted distress in each year of the analysis period and the criteria established at each node of the decision tree. In figure 18, nodes are shown to the right of the dog ( ) symbol and treatments are shown to the right of the cross ( ) symbol.

Nodes represent the part of the decision at which a decision is made. For example, the first (uppermost) node in the decision tree in figure 18 determines if the functional classification of the pavement facility is a rural interstate. If the expression "FUNCTIONAL_CLASSIFCATION = Interstate_Rural" is true, then the tree follows the path along the dotted line beneath the dog () symbol until it reaches the next node (or treatment). If the expression is false, then the tree follows the path along the dotted line beneath the boxed minus (⊟) symbol. For example, if the pavement facility *is* a rural interstate, the tree shown in figure 18 will follow the path that leads to the node "Fatigue_Cracking_Coarse_1 >= 5 OR Rut_Depth_Coarse_US_1 >= 0.25." If the pavement facility *is not* a rural interstate, the tree in figure 18 will follow the path that leads to the node "FUNCTIONAL_ CLASSIFICATION = Other_Principal_Arterial_Rural."

The decision tree always follows the path associated with true expressions and, if more than one true expression exists along a given path, it will follow the path of the first true expression it encounters. However, *the decision tree requires that each path must contain at least one true expression*; otherwise, an error will occur when an attempt is made to use the decision tree during the Monte Carlo simulation process. In addition, *the decision tree requires that each path lead to a treatment or set of treatments*. Multiple treatments can be triggered, and "Do Nothing" counts as a treatment. For example, the decision tree in figure 18 indicates that two treatments ("Mill 3 inches" and "HMA_Overlay") are triggered when the rut depth is greater than some threshold value (e.g., 0.25 inches for rural interstates). The treatment trigger criteria can be fully customized (see below).

The buttons on this form (figure 18) perform the following tasks:

- Save saves the decision tree under the name provided in the "Name" text box at the top of the form. *HMA Spec* contains default decision trees that cannot be saved under the name given to the default decision tree. To save a default decision, click on the Save As button and specify a different name for the decision tree.
- Save As allows decision trees to be saved under a different name, thus duplicating the decision tree.
- Open Tree displays a dialog box listing all saved decision trees. To open a particular decision tree, highlight (click on) the name of the decision tree you wish to open and click on the OK button on the dialog box (see figure 19).
- Cancel closes the form without saving changes (unless, of course, changes were saved first by clicking on the Save button).
- Add Expression adds a new expression beneath a highlighted node.
- Add Treatment adds a new treatment beneath a highlighted node or treatment.
- Edit Expression displays the ExpressionBuilder form, which allows the user to create and edit expressions. For example, if the expression FUNCTIONAL_CLASSIFICATION = Interstate_Rural is highlighted, clicking on the Edit Expression button displays the ExpressionBuilder form as shown in figure 20.
- Edit Treatment displays a dialog box listing all saved treatments (see figure 21). This form allows the user to edit the details of existing treatments, delete existing treatments, and define the details of new treatments. Highlighting an existing treatment and clicking on the Edit Treatment button displays the form shown in figure 22. Clicking on the Define New Treatment button displays the same form, except the default name is "New," as shown in figure 23.
- Check Tree Logic displays the form shown in figure 24. Values for expressions included in the decision tree can be entered in the text boxes of this form to test the logic of the tree.
- Delete Node will remove the expression from the tree. Note that all expressions and treatments underlying the highlighted node (i.e., everything along the path represented by the dotted line beneath the dog ( ) symbol) will also be deleted if these exist. For

example, clicking on the Delete Node button when the "FUNCTIONAL_CLASSIFICATION = Interstate_Rural" node in figure 18 is highlighted deletes everything associated with the "FUNCTIONAL_CLASSIFICATION = Interstate_Rural" node. However, deleting the "FUNCTIONAL_CLASSIFICATION = Interstate_Rural" node in figure 18 will not delete the other nodes beginning with "FUNCTIONAL_CLASSIFICATION."

- Clear Tree clears the window displaying the decision tree.
- Delete Tree removes the displayed tree from the database.
- Print Tree prints the displayed decision tree to the default printer attached to the computer.
- Close closes the form.

The decision tree form includes a feature to facilitate rapid editing. This feature is in the form of a pop-up menu that can be displayed by highlighting a node or treatment and clicking on the rightmost mouse button (see figure 25). The choices in this pop-up menu perform the same functions as the buttons described above with the same names.

4.3.3 Costs

The procedure for editing existing cost parameter sets is different that that for creating new cost parameter sets. The following paragraphs describe how these are accomplished.

Editing Existing Cost Information

Figure 26 shows the input form for viewing and editing existing cost parameter sets. This form can be opened using the Input Parameters tab of the control form, as described in section 4.2.2.

The features of this form are as follows:

- Treatment tab (figure 26) contains a grid displaying saved treatments, as well as the units and unit costs for the treatments. To edit the unit cost for a treatment, click on the box containing the unit cost and type in a new unit cost. Note that only the unit costs can be edited using this form. To create new treatments and unit costs, see the following section, Creating New Cost Sets.

- Time Value of Money tab (figure 27) is used for entering a real discount rate for use with real (or constant) dollars.
- Description tab contains a text box allowing the user to enter a description of the parameter set.
- Name text box at the top of the form displays the name of the parameter set; this box cannot be edited.
- The buttons on this form perform the following tasks:
  - Save saves the parameter set under the name provide in the Name text box.
  - Cancel closes the form without saving the parameter set (unless, of course, the parameter set was saved by clicking on the Save button).
  - OK closes the form.

Creating New Cost Sets

Figure 28 shows the form for creating new cost sets. This form can be opened using the Input Parameters tab of the control form, as described in section 4.2.2.

The features of this form are described in more detail as follows:

- Name text box is used to define a name for the cost set.
- Previously Defined Treatments grid, the upper grid, contains the details of previously defined treatments. These can be dragged down to the lower grid for inclusion in the new cost set. Position the mouse pointer over the desired treatment, then click and hold the left mouse button. Drag the pointer downward until it is over the lower grid, then release the mouse button.
- Add/Edit Treatment… button opens the Edit Treatment form (figures 22 and 23). This form can be used to edit existing treatments or create new ones.
- New Cost Variable Set grid contains the treatments to be included in the new cost set. Populate this grid by dragging treatments from the upper grid.
- Real discount rate text box is used to enter the real discount rate for the new cost set.
- Save button saves the new cost set to the database.
- Close button closes the form.

4.3.4 Traffic Parameters

Figure 29 shows the input form for viewing and editing traffic parameter sets. This form can be opened using the Input Parameters tab of the control form, as described in section 4.2.2. This form allows the user to define the initial level of traffic and how it grows over time. Any number of traffic parameter sets can be created and used in the development of a specification.

The features of this form are as follows:

- Traffic Inputs tab allows the user to specify the initial traffic level in 80-kN (18,000-lb) equivalent single axle loads (ESALs) or in terms of average daily traffic (ADT) expected on the pavement facility, as well as the growth in percent and the growth type (simple or compound). Use the drop-down list box at the top of the tab to select how to define traffic. If defining traffic by ESALs (figure 29), use the text boxes on this tab as follows:
  - Year of analysis period to specify traffic: Use this text box to specify the year in the analysis period to which the specified traffic level (i.e., cumulative ESALs) applies.
  - Cumulative ESALs for specified year: Use this text box to enter the total number of ESALs expected in the year specified previously. Figure 29 indicates that the expected number of ESALs in the first year of the analysis period is 50,000.
  - Growth Rate (Percent): Use this text box to specify the expected rate of growth (in percent) of traffic during the analysis period.
  - Growth Type: Use this drop-down list box to select the type of traffic growth (either simple or compound).

If defining traffic based on average daily traffic (figure 30), use the text boxes on this tab as follows:

- Year of analysis period to specify traffic is used to specify the year in the analysis period to which the specified traffic level (i.e., ADT) applies.
- Average daily traffic (ADT) for specified year is used to enter the average daily traffic expected in the year previously specified. Figure 30 indicates that the expected ADT in the first year of the analysis period is 50,000.
- Growth rate and growth type are as described above.
- Directional Factor (%) is used to indicate the percentage of ADT expected on the pavement facility. For example, if the specified ADT is based on a bi-directional

traffic count (i.e., total traffic passing a point on the facility) and half of the traffic is expected in each direction, then enter 50 in this text box. Figure 30 indicates the specified ADT is the ADT in one direction.

- Percent Trucks is used to enter the percentage of ADT that is comprised of trucks.
- Percent Trucks in Outer Lane is used to enter the percentage of ADT in the outer lane that is comprised of trucks.
- Average Truck Load Equivalency Factor is used to enter the average load equivalency factor of the expected mix of truck traffic.
- Final Annual ESAL to ADT Ratio displays the calculated ESAL to ADT ratio. It cannot be edited. This value is used to calculate the ESALs in the first year of the analysis period based on the specified ADT.

- Description tab contains a text box allowing the user to enter a description of the parameter set.
- Name text box at the top of the form allows the user to give a name to the parameter set.
- The buttons on this form perform the following tasks:
  - Save button saves the parameter set under the name provided in the Name text box.
  - Cancel button closes the form without saving the parameter set (unless, of course, the parameter set was saved previously by clicking on the Save button).
  - OK button closes the form. If this form is accessed from within the Specification Wizard (see section 4.4), the values that are established on the form become the values used within the specification being developed, even if the values are not saved.

4.4 DEVELOPING A SPECIFICATION (PRECONSTRUCTION OUTPUT)

This section provides details for developing a specification for a pavement lot. The beta version of *HMA Spec* was designed with the assumption that a specification is developed for a pavement lot and that a project could contain numerous pavement lots (and, therefore, specifications).

A specification is generated using the Specification Wizard, which contains a series of forms to guide the user through the process). Each form of the Specification Wizard provides a

description of the purpose of the form. The following paragraphs describe how to use the Specification Wizard.

4.4.1 Creating a Project

A project must be created before a specification can be developed for a pavement lot. Go to the Projects/Specifications tab of the control form of the main module (see section 4.2.2). To create a new project, highlight the word "PROJECTS" and click on the New Project button (see figure 7). This displays the dialog form shown in figure 31. Type in the name of the project and click on the OK button on this dialog form. Figure 32 shows that a project having the name "Park Avenue" has been created. The ".mdb" extension is used because *HMA Spec* creates a Microsoft Access 97 database for each project.

4.4.2 Creating a Specification

Once a project database has been created, any practical number of specifications can be created within the project database. First, select the desired units of measure (either US Customary or SI) from the Units menu choice on the menu bar of the background form. Then highlight the project name on the Projects/Specifications tab of the control form and click on the New Spec button (figure 12). This opens the first form of the Specification Wizard. The details of this form and all subsequent forms of the Specification Wizard are described in the following paragraphs.

Basic Specification Information Form

The first form of the Specification Wizard is the Basic Specification Information form, shown in figure 33. This form allows the user to provide basic information about the specification being developed. The only required information is the name of the specification and the specification level. Level 1 specifications utilize Level 1 pavement performance prediction models, whereas Level 2 specifications utilize Level 2 models. All other entries are for informational purposes only and have no bearing on the calculation of a pay factor for the pavement lot. However, the user is encouraged to include as much information as possible.

Most of the forms comprising the Specification Wizard have the same three buttons as on the Basic Specification Information form. These buttons perform the following tasks:

- Next button closes the current form of the Specification Wizard and opens the next form. Of course, the last form of the Specification Wizard does not have a Next button.
- Cancel button aborts development of the specification and returns the user to the control form.
- Back button closes the current form of the Specification Wizard and opens the previous form.

Lane Configuration and Dimensions Form

The next form of the Specification Wizard is the Lane Configuration and Dimensions form shown in figure 34. This form allows the user to define the pavement lot dimensions and functional classification. The dimensions of the pavement lot entered on this form are used in calculating the cost of future rehabilitation treatments and, therefore, have a direct impact on the pay factor calculated for the pavement lot.

The pavement lot dimensions are defined using the boxes in the frames labeled "Lanes" and "Project Length." It should be noted here that "Project Length" is potentially misleading in that the values entered in the text boxes on this frame define the pavement lot length. Define the dimensions of the pavement lot as follows:

- Using the drop-down list box on the frame labeled "Lanes," select the number of lanes from the list provided, as shown in figure 35.
- Using the check boxes on the frame labeled "Lanes," select which lanes are to be included in the specification for the pavement lot and enter the lane width in the text box adjacent to any checked boxes. Figure 35 indicates that only one of the two lanes is to be included in the specification.
- Using the text boxes on the frame labeled "Project Length," enter the beginning and ending stations for the pavement lot.

The functional classification of the pavement lot is used to determine the design reliability to be used in calculating an HMA overlay thickness if triggered by the decision tree used during the

development of the specification. Design reliability values for each functional classification can be defined using the Pavement Design Parameters input form described in section 4.3.1. A functional classification for the pavement lot is selected by clicking on the drop-down list box adjacent to the words "Functional Classification" at the bottom of the form and selecting a classification from the list, as shown in figure 36.

Design-Related Input Parameters and Life-Cycle Costs Model Parameters Form

The next form of the Specification Wizard is the Design-Related Input Parameters and Life-Cycle Costs Model Parameters form shown in figure 37. This form allows the user to select the fixed input parameters to be used in development of the specification. In particular, this form allows the user to select pavement design parameters (see section 4.3.1), traffic parameters (see section 4.3.4), the maintenance and rehabilitation decision tree (see section 4.3.2), and cost parameters (see section 4.3.3).

Select a particular parameter set by clicking on the drop-down list box within each frame on this form. For example, figure 38 illustrates how to select a traffic parameter set from the list of available parameter sets. Note that new parameter sets can be created by clicking on the New… button and existing parameters sets can be edited by clicking on the Edit… button corresponding to each set. In either case, these buttons open the forms described in section 4.3.

Definition of Pavement Performance Form

The next form of the Specification Wizard is the Definition of Pavement Performance form, shown in figure 39. This form allows the user to select the models to be used for predicting pavement performance. As shown in figure 39, the list boxes on the left of the form display available Level 1 and Level 2 prediction models for fatigue cracking and rut depth. Those containing the word "Coarse" (e.g., Rut_Depth_Coarse_US_1) apply to coarse mixtures, and those containing the word "Fine" (e.g., Fatigue_Cracking_Fine_2) apply to fine mixtures. (A coarse mixture is defined as having a gradation that goes below the restricted zone.) If a Level 1 specification is being developed, only the list box containing the Level 1 models is enabled. Similarly, if a Level 2 specification is being developed, only the list box containing the Level 2 models is enabled.

Select models to include in the specification by double-clicking on the names of the desired models. (Models can also be selected by highlighting the model name and clicking on the ">" button.) Figure 40 indicates that the Rut_Depth_Coarse_US_1 and Fatigue_Cracking_Coarse_1 models have been selected. The user can view a model by highlighting the model and clicking on the View… button.

The models selected using this form must be compatible with the decision tree selected on the previous form of the Specification Wizard. Otherwise, an error will occur when an attempt is made to use the decision tree during the Monte Carlo process (note, however, that this error is trapped by *HMA Spec*). For models to be compatible with a particular decision tree, the decision tree must contain expressions utilizing the models.

Acceptance Quality Characteristics (AQCs) Form

The next form of the Specification Wizard is the Acceptance Quality Characteristics (AQCs) form, shown in figure 41. This form allows the user to select the AQCs to be included in the specification. AQCs are materials and construction variables under the direct control of the contractor *and* utilized within the models identified on the previous form to predict performance. AQC levels (i.e., values) are varied in the Monte Carlo simulation process to simulate real-world variability during the construction process of the pavement lot. Varying the AQC levels in this way allows *HMA Spec* to predict the variation in life-cycle costs as a result of AQC variability. Hence, the selected AQCs for the specification are the variables used to determine the pay factor for the pavement lot and, therefore, a contractor's pay adjustment.

HMA Spec automatically selects all AQCs required by the models selected in the previous form. The beta version of *HMA Spec* allows additional AQCs to be selected if desired. However, any AQCs selected using this form that are not required by the performance prediction models have no bearing on the calculation of the pay factor for the pavement lot.

AQCs are selected in the same way that models are selected on the previous form. That is, the user should double-click on the AQC name or highlight the AQC name and click the ">" button.

Note that clicking the ">>" button selects all available AQCs, while "<" and "<<" remove one or all the AQCs from the selected list, respectively.

Target Values for Included AQCs Form

The next form of the Specification Wizard is the Target Values for Included AQCs form, as shown in figure 42. This form allows the user to define the target values (means and standard deviations) of each included AQC for the as-designed pavement lot. These values are used in association with the tolerable number of standard deviations from the mean to define how significantly AQCs are varied during the Monte Carlo simulation process. For example, figure 42 indicates a mean value for air voids equal to 8 percent with a standard deviation of 1.5 percent and a tolerable number of standard deviations of three. Thus, during the Monte Carlo simulation process, air voids will be allowed to vary three standard deviations about the mean (or from 3.5 to 12.5 percent).

To change the means and standard deviations for any of the AQCs, simply click on the appropriate text box and change the value. To change the tolerable number of standard deviations, click on the drop-down list box to the right of the Standard Deviation box and select a number from the list provided.

Simulation Control Form

The next form of the Specification Wizard is the Simulation Control form, as shown in figure 43. This form allows the user to define the number of iterations to be used during the Monte Carlo simulation process, and to provide an estimate of the contractor's bid price for the pavement lot and the duration of the analysis period.

The total number of iterations defines how many times *HMA Spec* conducts a life-cycle cost analysis during the simulation process for the pavement lot. The number of iterations to be used in the Monte Carlo simulation is the product of the two uppermost text boxes (i.e., those defining the number of lots to simulate and the number of sublots per lot). For example, figure 43 indicates that the number of lots to simulate is 500 and that each lot contains five sublots. Thus,

the total number of simulations to be performed is 500 × 5 = 2500. If the number of sublots were changed to 1, the total number of simulations to be performed would be 500 × 1 = 500.

The estimate of the contractor's bid price is used in the calculation of the pay factor relationship and, therefore, should be as accurate as possible. *HMA Spec* was designed to accommodate various units for the bid price; however, due to time constraints, the beta version is restricted to a bid price on a per-square-meter or per-square-yard basis.

The analysis period is the duration in years over which *HMA Spec* conducts the life cycle cost analysis during each iteration in the Monte Carlo simulation process. The default value displayed when this form is opened is twice the design life specified in the Pavement Design Parameters set. However, the user can change this value clicking on the text box.

Monte Carlo Simulation and Preconstruction Output Form

The final form of the Specification Wizard is the Monte Carlo Simulation and Preconstruction Output form, shown in figure 44. This form allows the user to save the values selected/entered in previous forms of the Specification Wizard (by clicking on the Save button) and to run the Monte Carlo simulation.

Monte Carlo Simulation Results Form

Following a Monte Carlo simulation, the results are displayed on the form shown in figure 45. This form displays the predicted life cycle cost for the as-designed pavement lot, as well as the pay factor relationship.

4.5 VIEWING AND PRINTING THE SPECIFICATION DOCUMENT

Once a specification has been generated, it can be viewed and printed. Highlight the specification to be viewed in the control form (figure 46) and click on the View Spec button to open the document viewer form (figure 47). As indicated, the document is divided into three sections: inputs, simulation results, and specification document. Click on the boxed plus (⊞) symbol adjacent to any or all of these sections to expand the tree to display the contents within

the section(s), as shown in figure 48. Note that expanded sections can be hidden (or collapsed) by clicking on the boxed minus (⊟) symbol.

To display the contents of a particular subsection, highlight the subsection title. For example, in figure 49, the subsection titled "9.5 HOT-MIX ASPHALT PLACEMENT" has been highlighted, and the contents of this subsection are displayed in the right portion of this form.

To print the contents of the specification document, select the Print menu choice from the File menu on this form. This displays the dialog box shown in figure 50. Choosing "Selection" on this dialog box prints the currently selected section (e.g., titled "9.5 HOT-MIX ASPHALT PLACEMENT" as shown in figure 50) whereas selecting "Entire Document" prints the entire document.

To close this form, select the Exit menu choice from the File menu, or click on the close (✕) button at the top right of the form.

4.6 DETERMINING THE LOT PAY FACTOR

Once a specification has been generated and the pavement lot has been constructed and sampled and tested, *HMA Spec* can be used to determine the actual pay factor for the as-constructed pavement lot. Highlight the specification name on the Projects/Specifications tab of the control form of the main module and click on the Enter postconstruction data button (see figure 46). This opens the form shown in figure 51 that allows the user to enter AQC test results, as well as the actual contractor's bid price, and to calculate the pay factor for the as-constructed pavement lot. Note that summary data can be entered on this form or individual test results can be entered for each AQC by clicking on the Enter Sample Values… button.

Once the contractor's actual bid price and test results and are entered, click on the Calculate Pay Factor button. This conducts a Monte Carlo simulation (see figure 52) that is identical to the one used during preconstruction specification development except that the contractor's actual bid price and actual AQC levels (means and standard deviations) are used. The results of the simulation process and the pay factor are displayed in the form shown in figure 53.

5.0 REFERENCES

1. Epps, J., Hand, A., Seeds, S., Scholz, T., Alavi, S., Ashmore, C., Monismith, C., Deacon, J., Harvey, J., and Leahy, R., *NCHRP Report 455*, "Recommended Performance-Related Specification for Hot-Mix Asphalt Construction: Results of the WesTrack Project," Transportation Research Board, National Research Council, Washington, D.C., 2002.
2. *AASHTO Guide for Design of Pavement Structures*, American Association of Sate Highway and Transportation Officials, Washington, D.C., 1993.

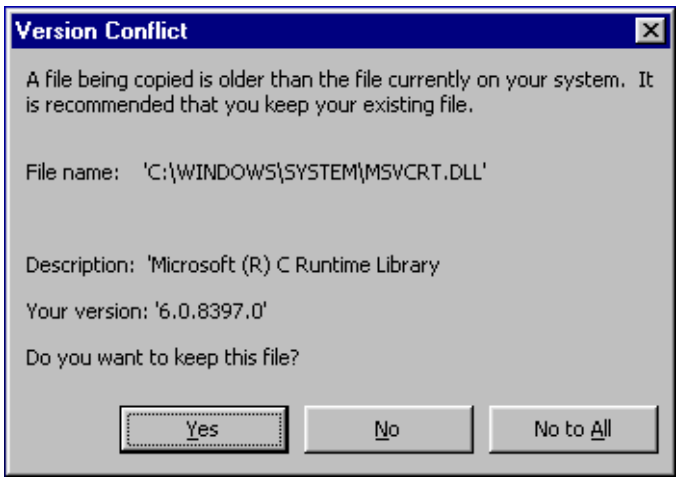


Figure 1. Version conflict error during software installation.

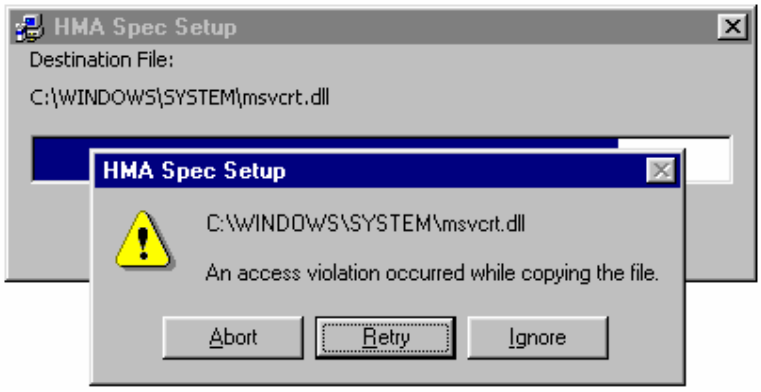


Figure 2. File-in-use error.

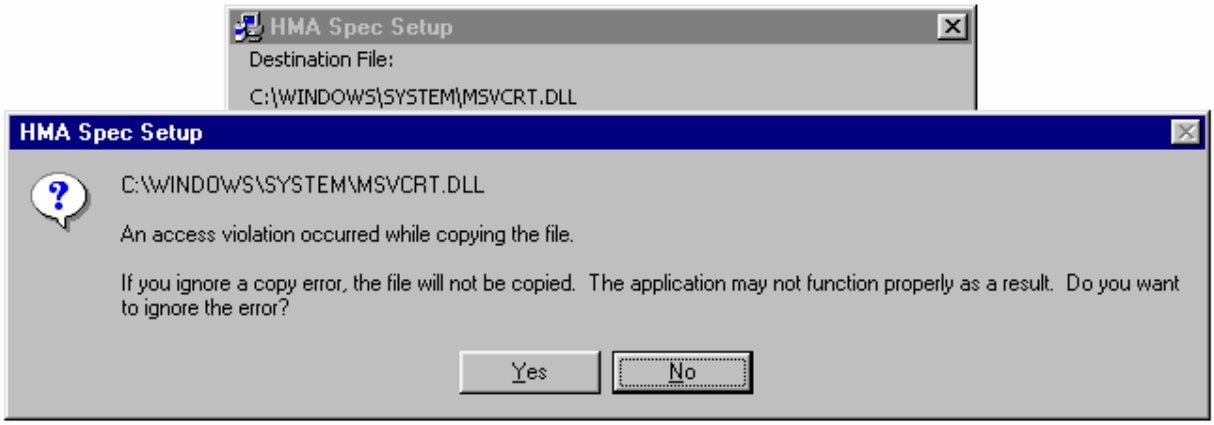


Figure 3. Confirmation of ignoring the file-in-use error.

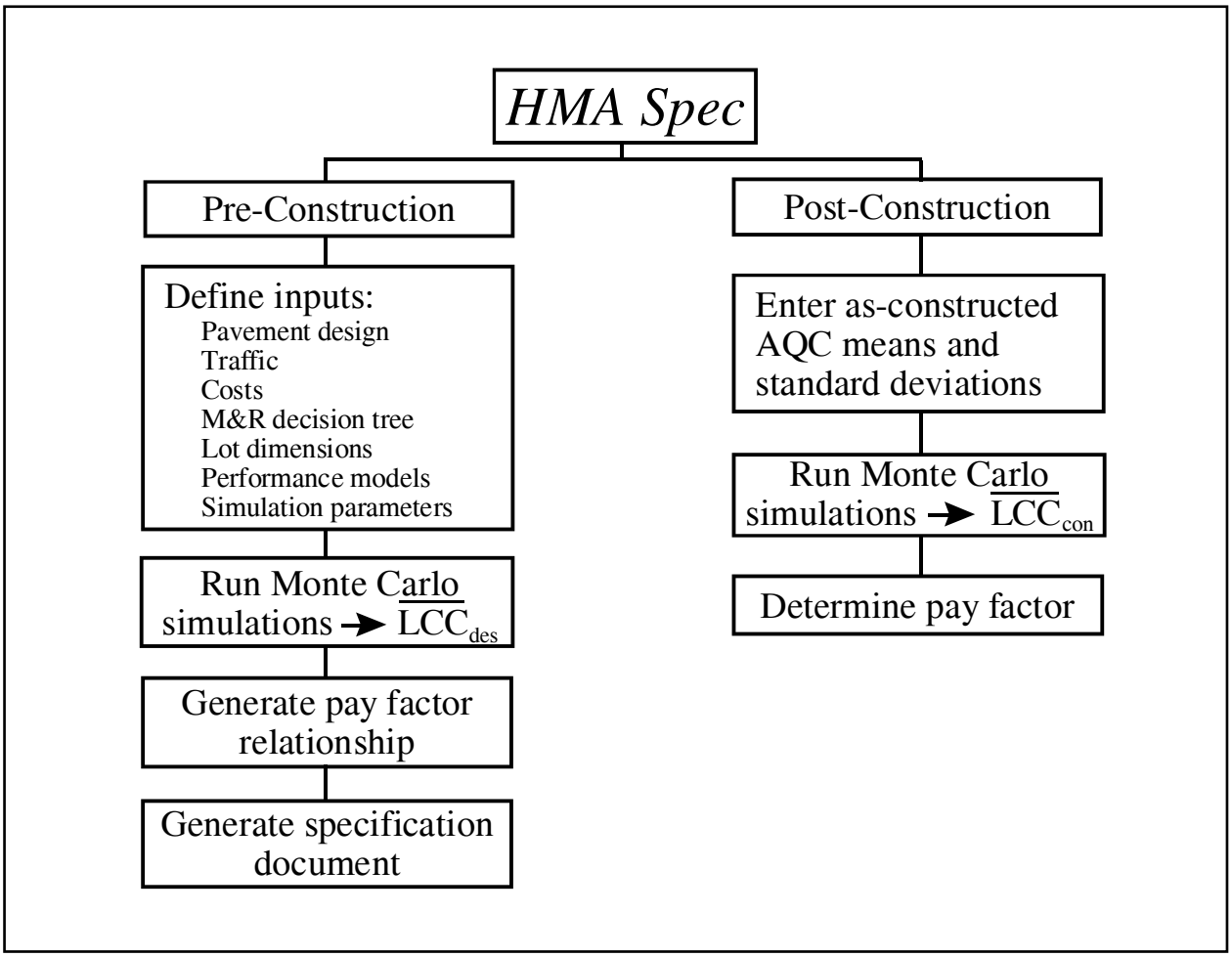


Figure 4. *HMA Spec* system framework.

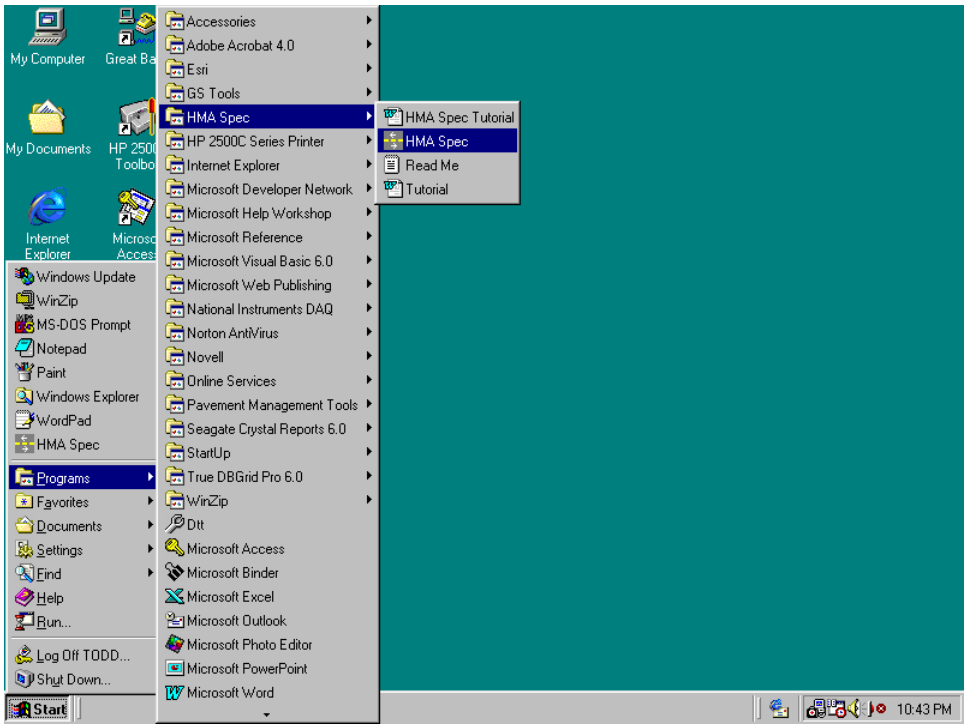


Figure 5. Using the Windows Start menu to execute *HMA Spec*.

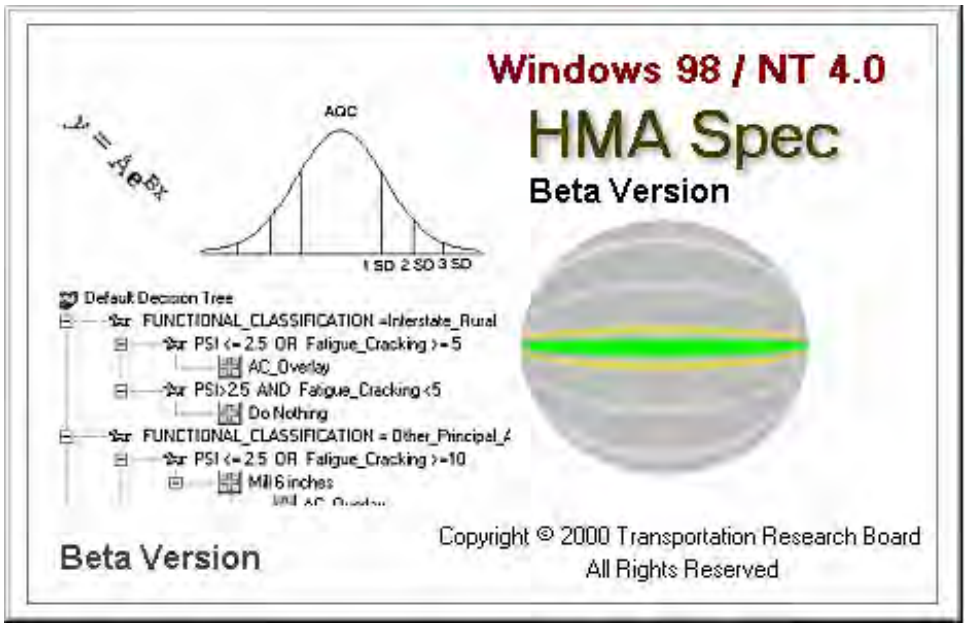


Figure 6. Splash screen displayed while *HMA Spec* is loading into memory.

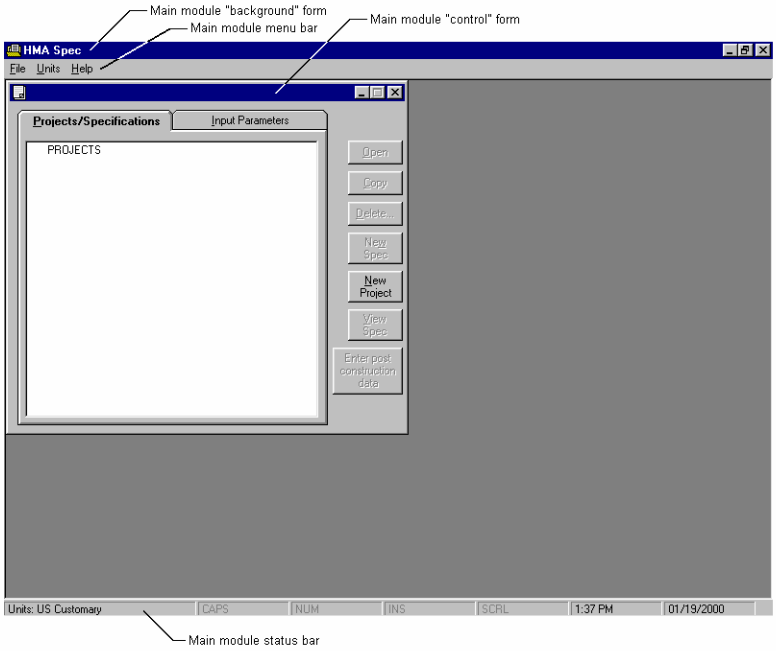


Figure 7. The *HMA Spec* main module.

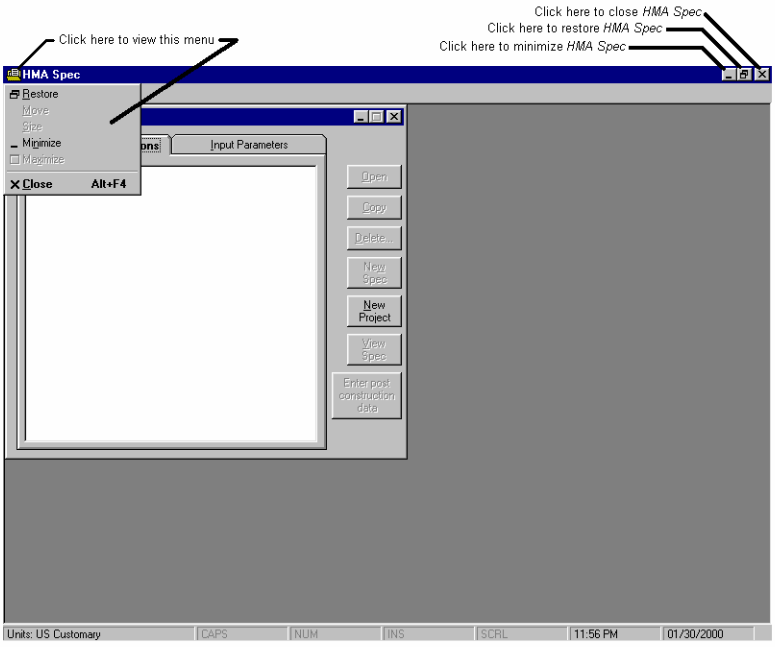


Figure 8. Control features of the main module (and other forms).

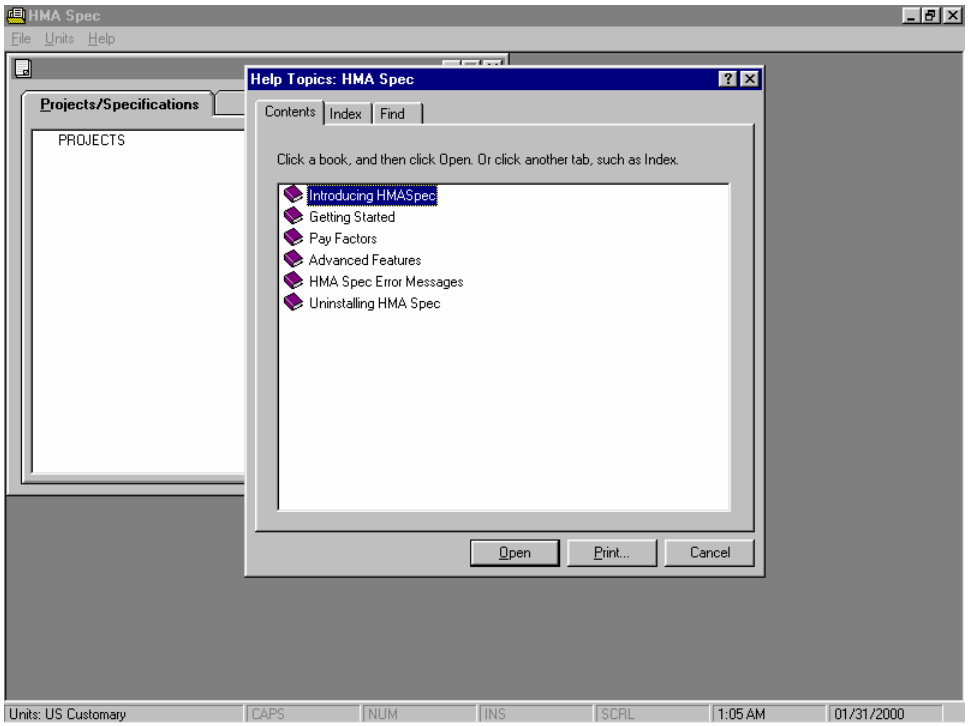


Figure 9. Help system contents.

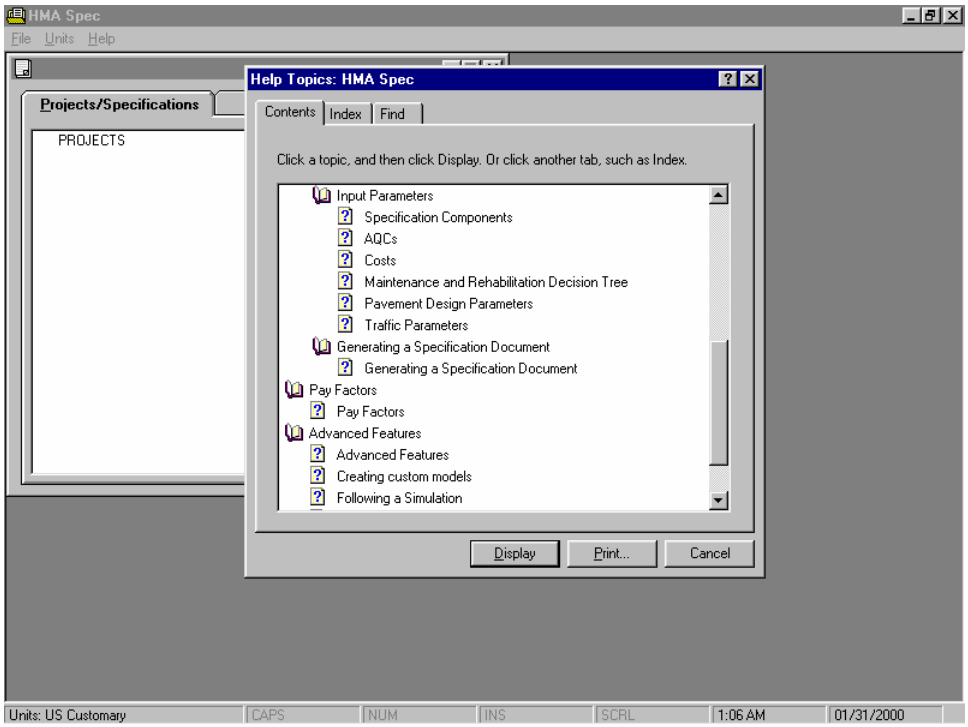


Figure 10. Help system topics.

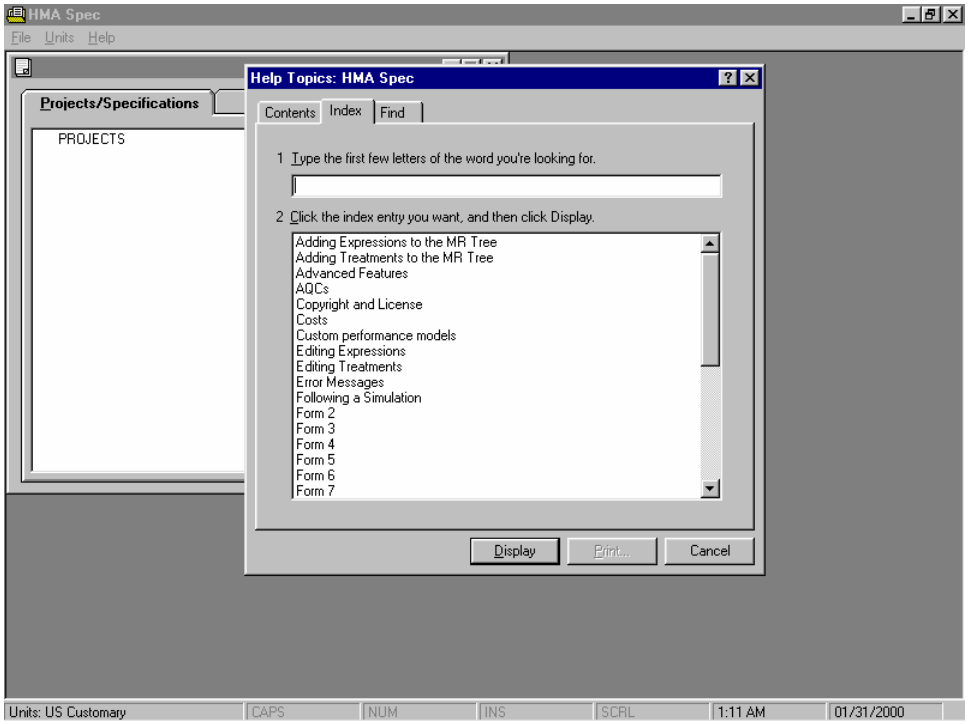


Figure 11. Help system index.

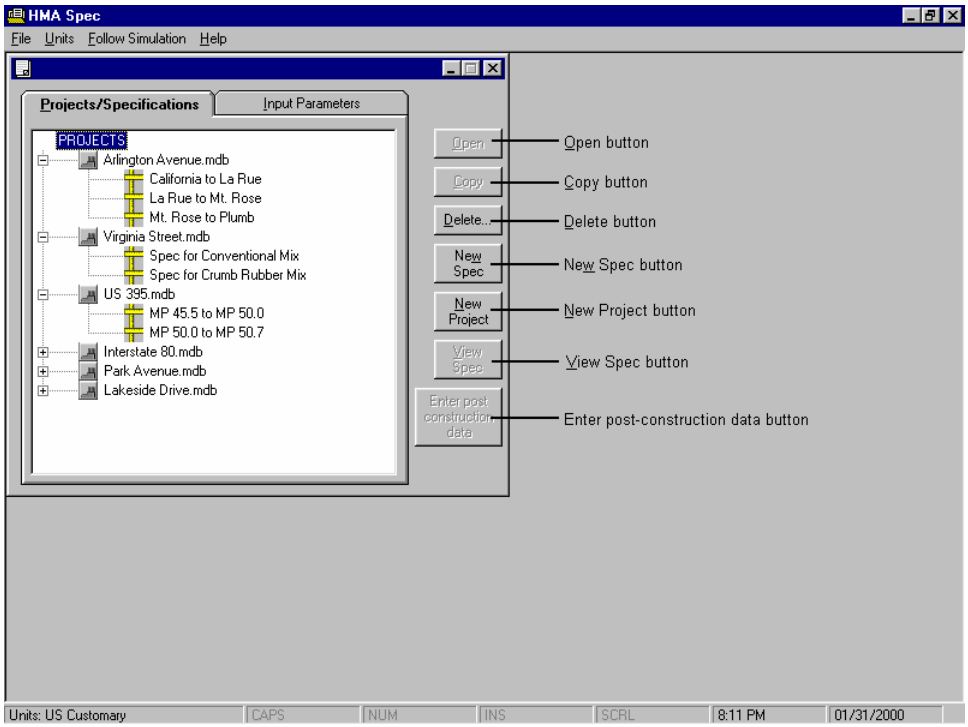


Figure 12. Tab showing projects and specifications.

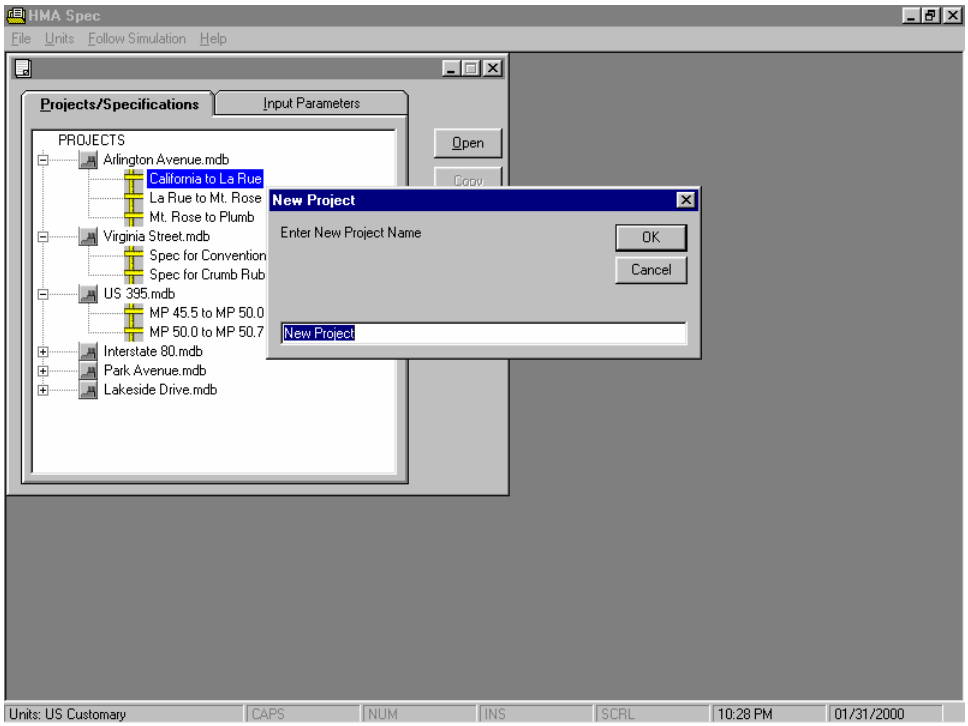


Figure 13. Dialog box requesting the name of a new project.

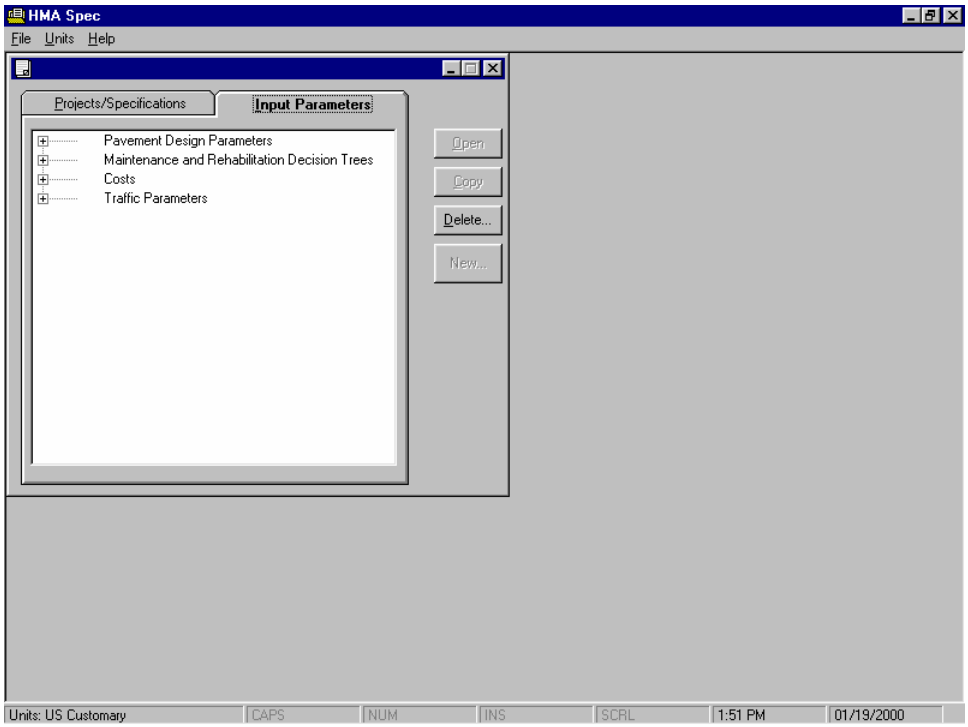


Figure 14. The Input Parameters Tab.

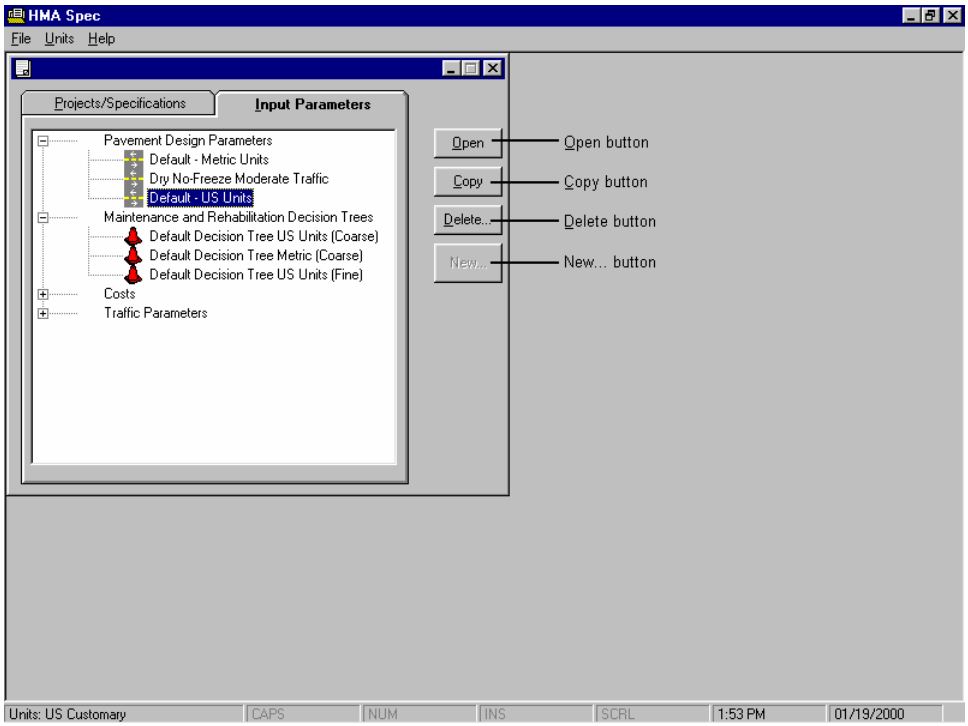


Figure 15. The Input Parameters tab showing various parameter sets.

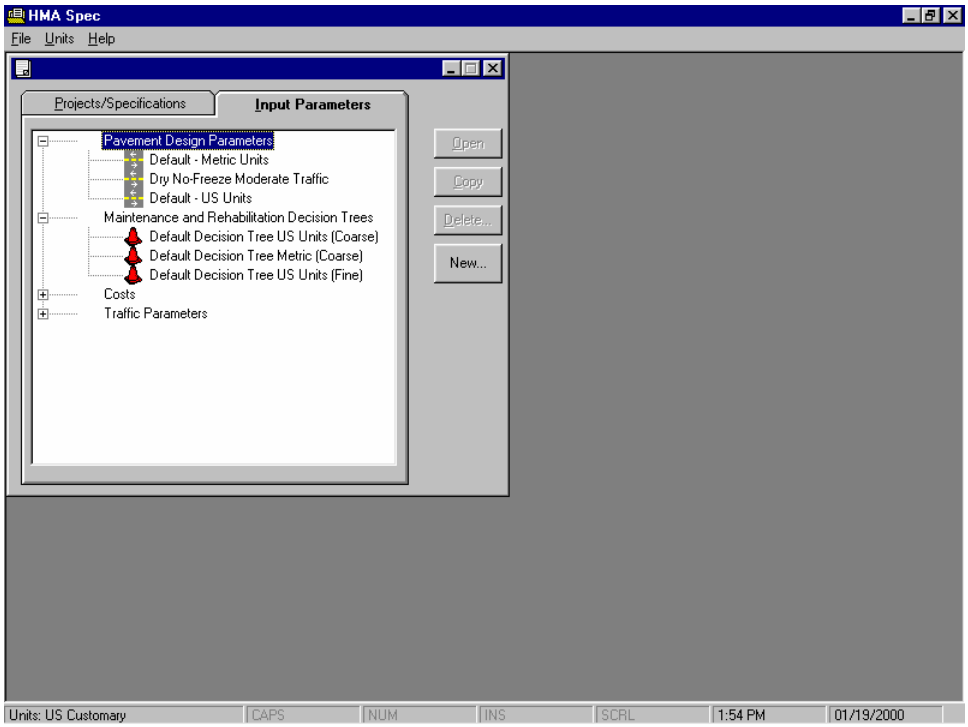


Figure 16. Clicking on the New… button would open the input form for viewing/editing a new pavement design parameters set.

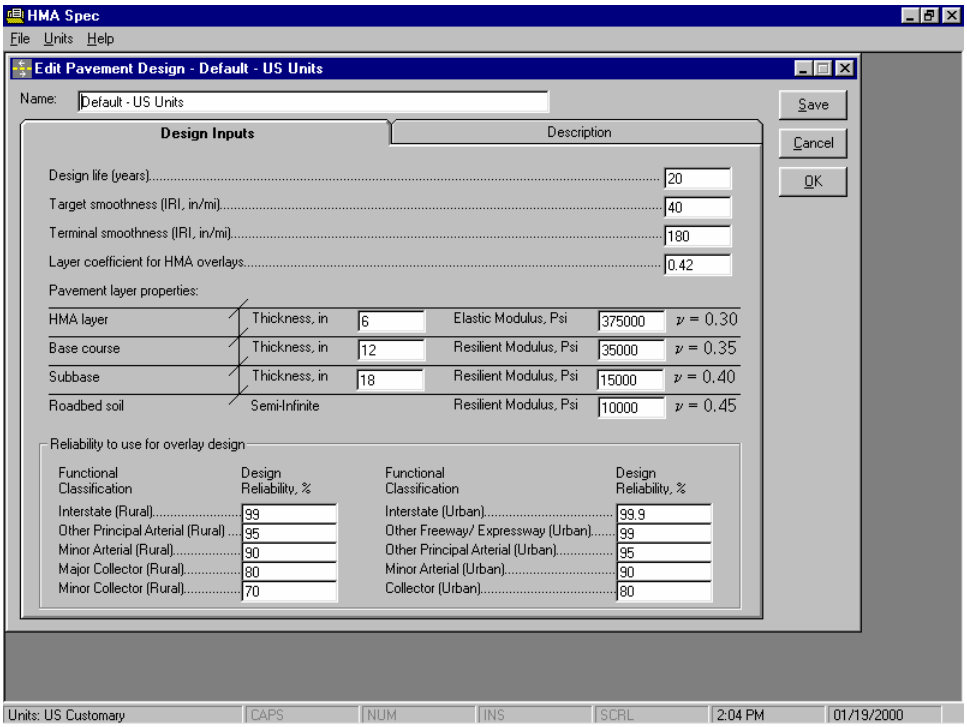


Figure 17. Pavement Design Parameters input form.

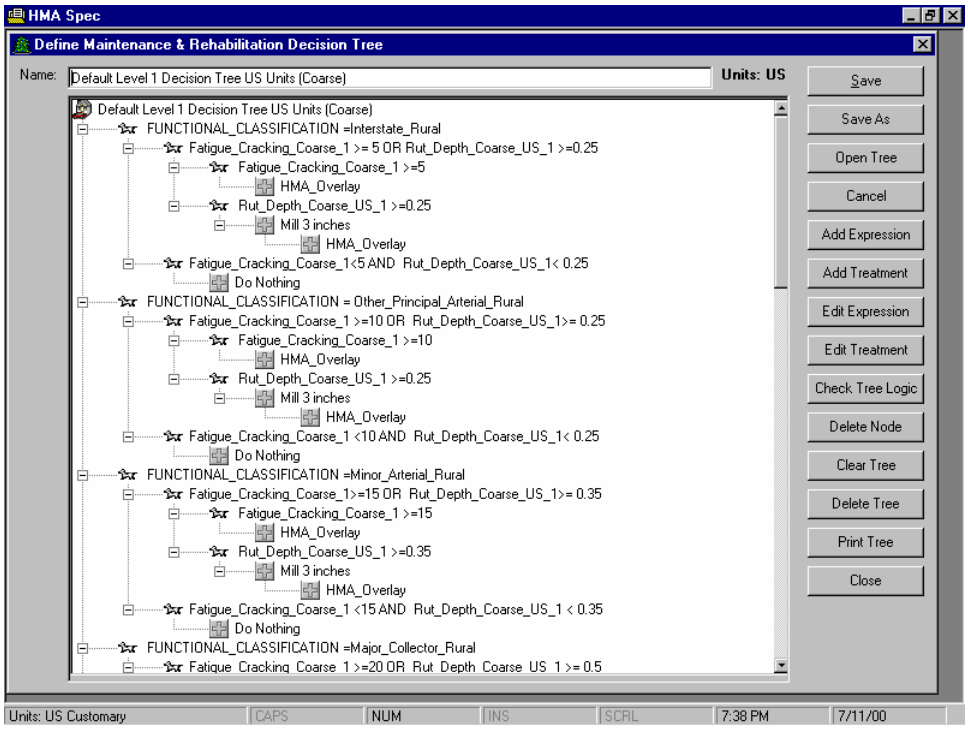


Figure 18. Form for creating, editing, and viewing decision trees.

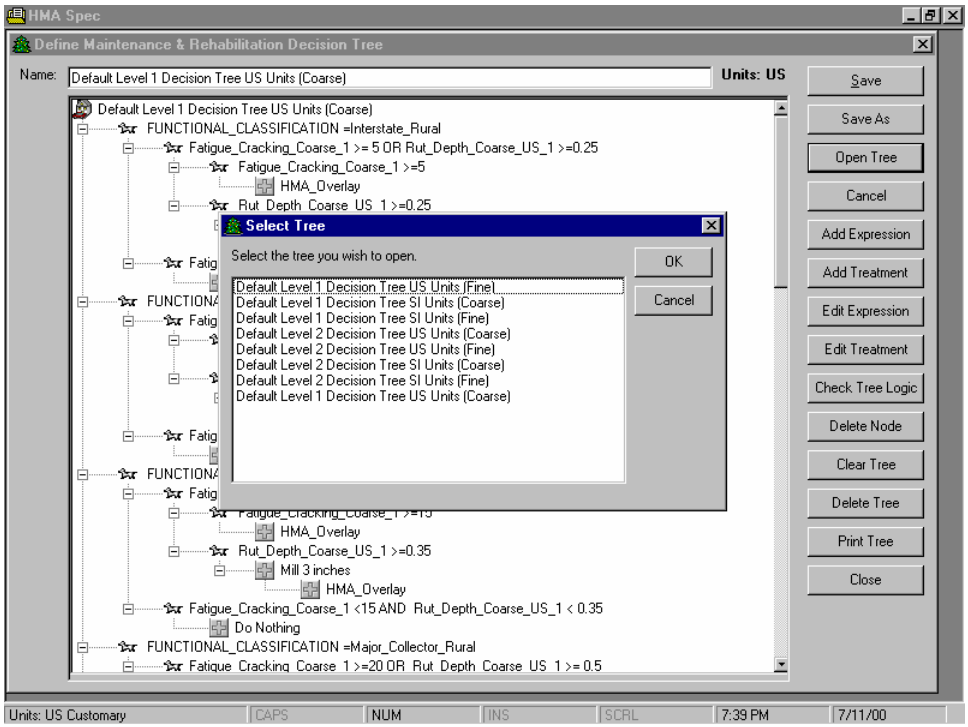


Figure 19. Open Tree dialog box.

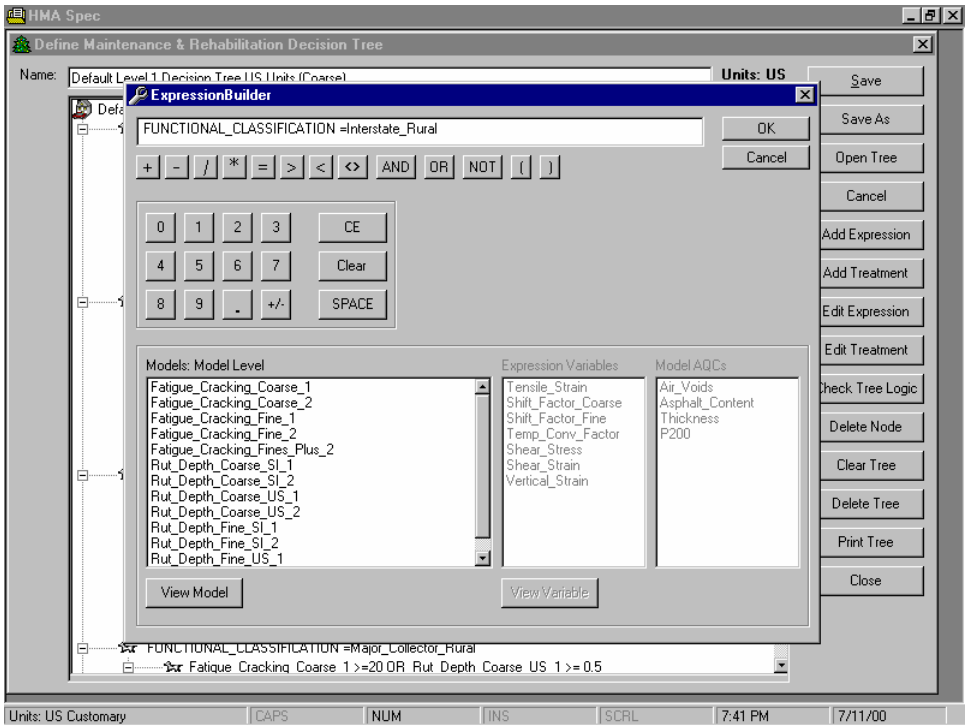


Figure 20. ExpressionBuilder form.

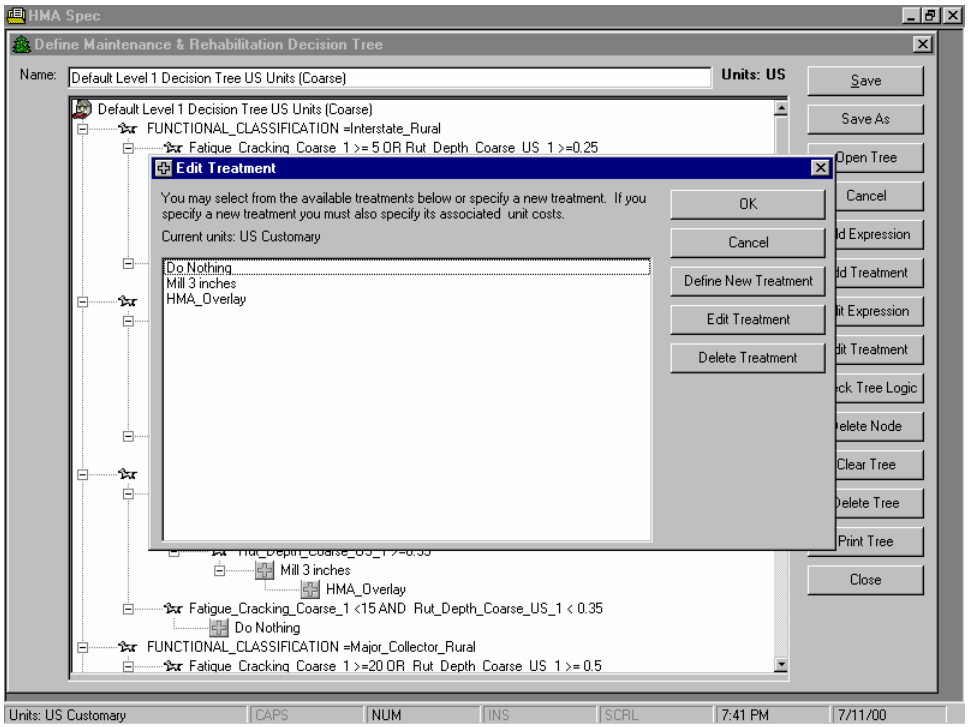


Figure 21. Edit Treatment dialog box.

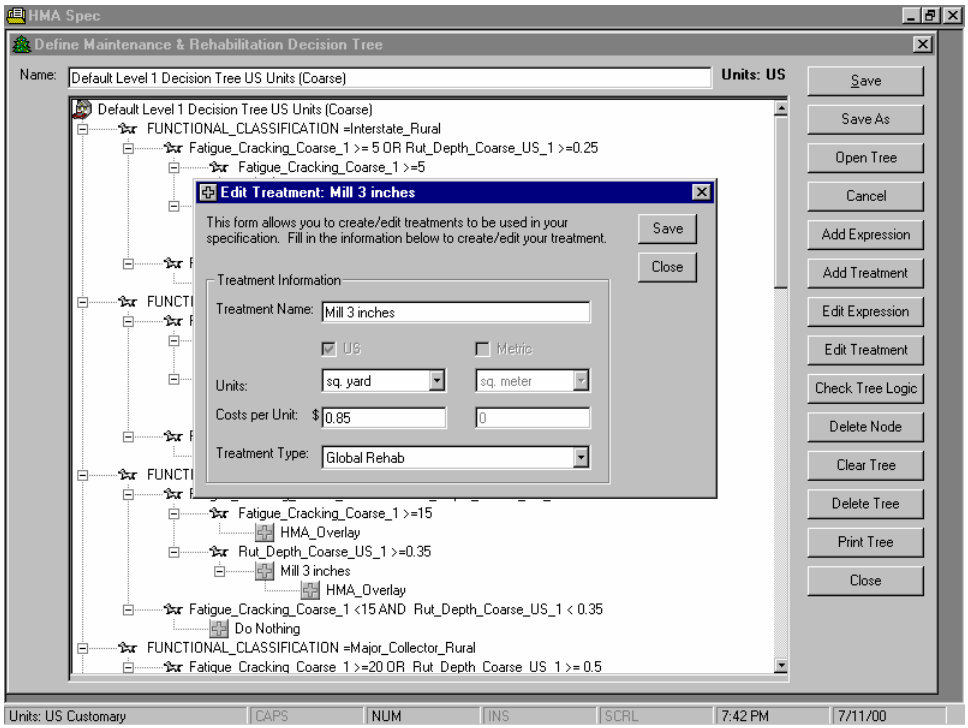


Figure 22. Form for editing the details of an existing treatment.

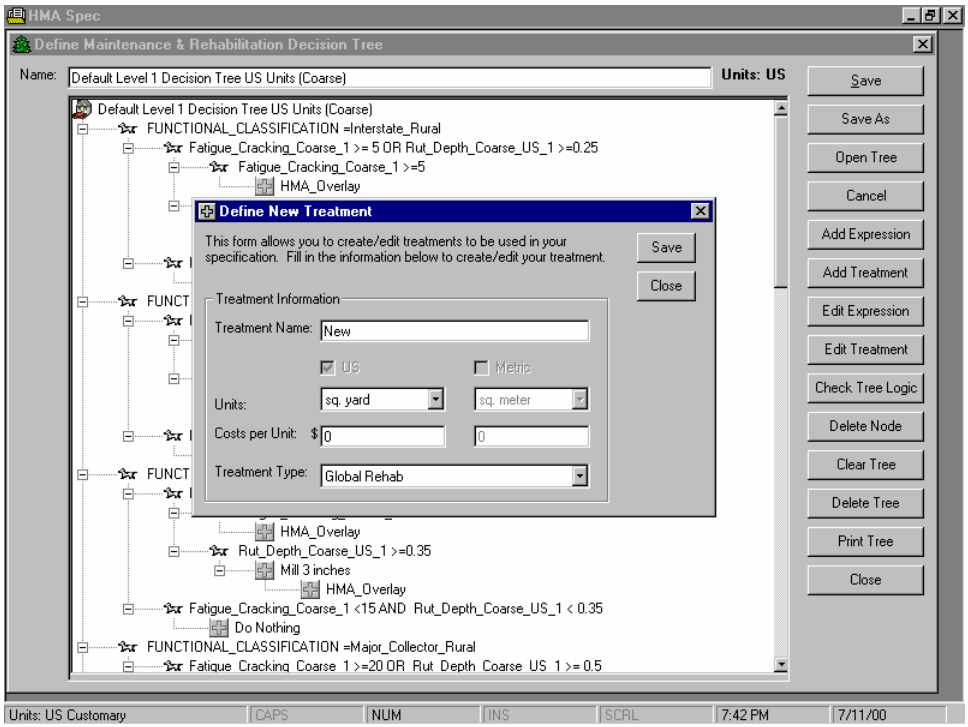


Figure 23. Form for defining the details of a new treatment.

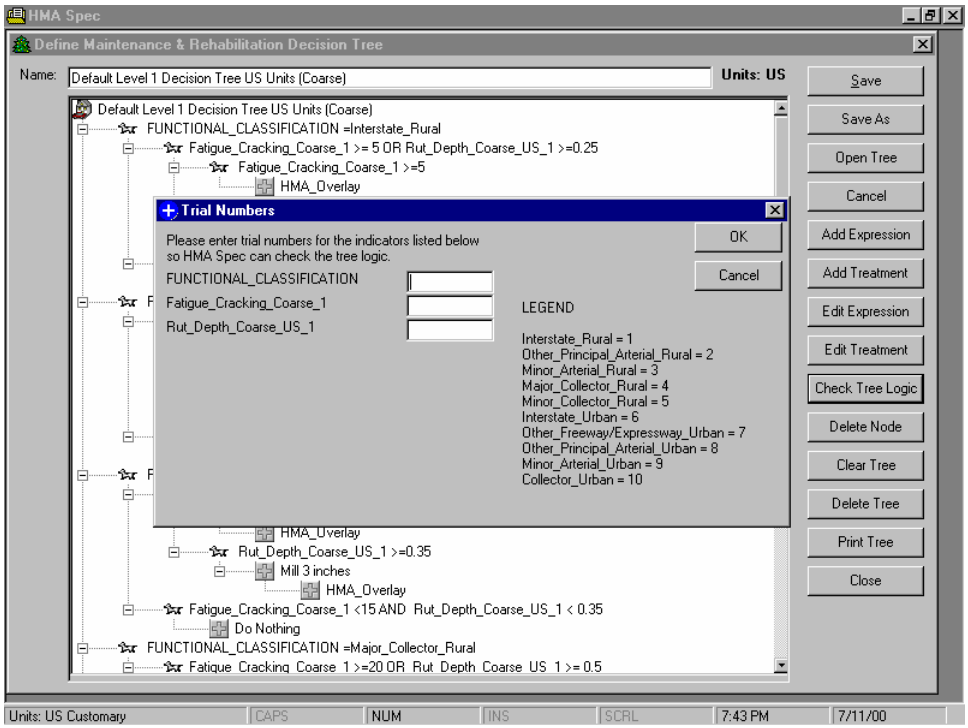
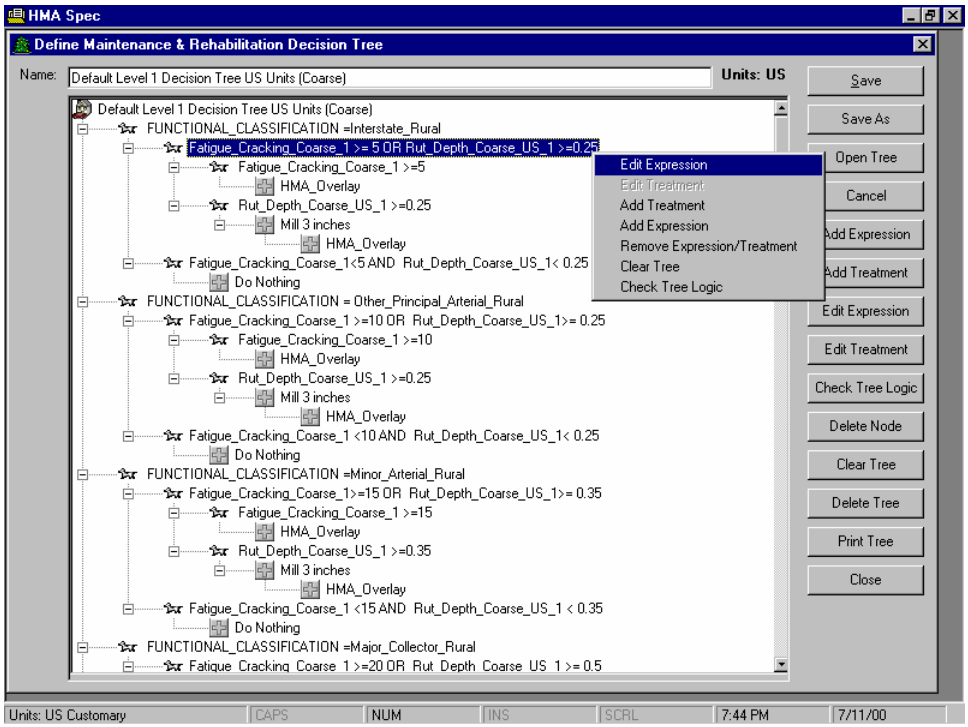


Figure 24. Form for checking decision tree logic.



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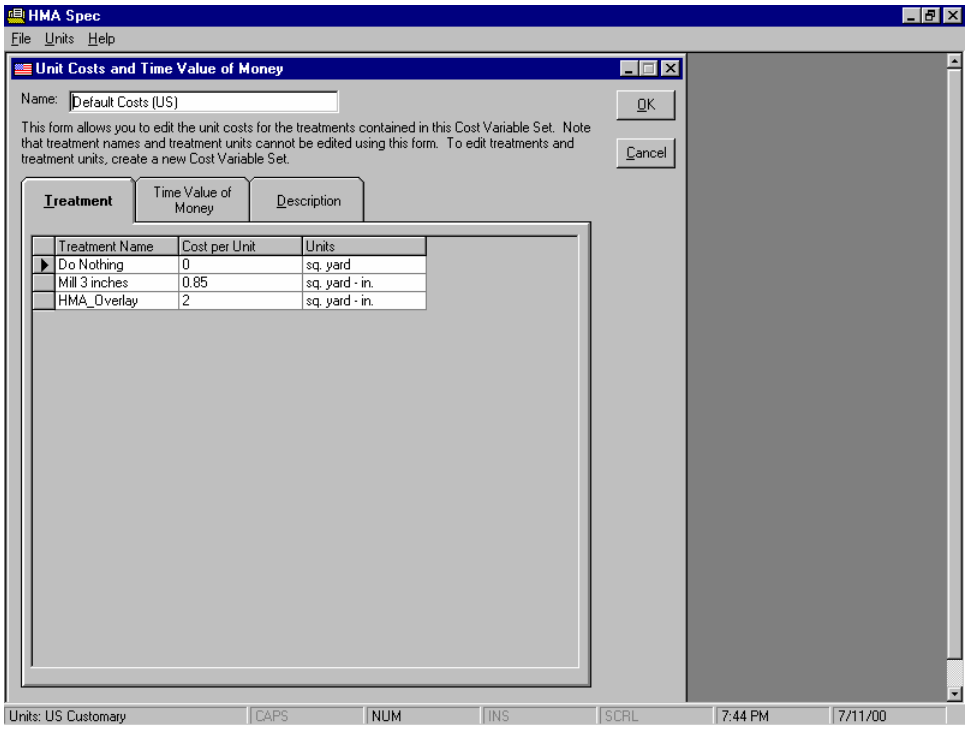

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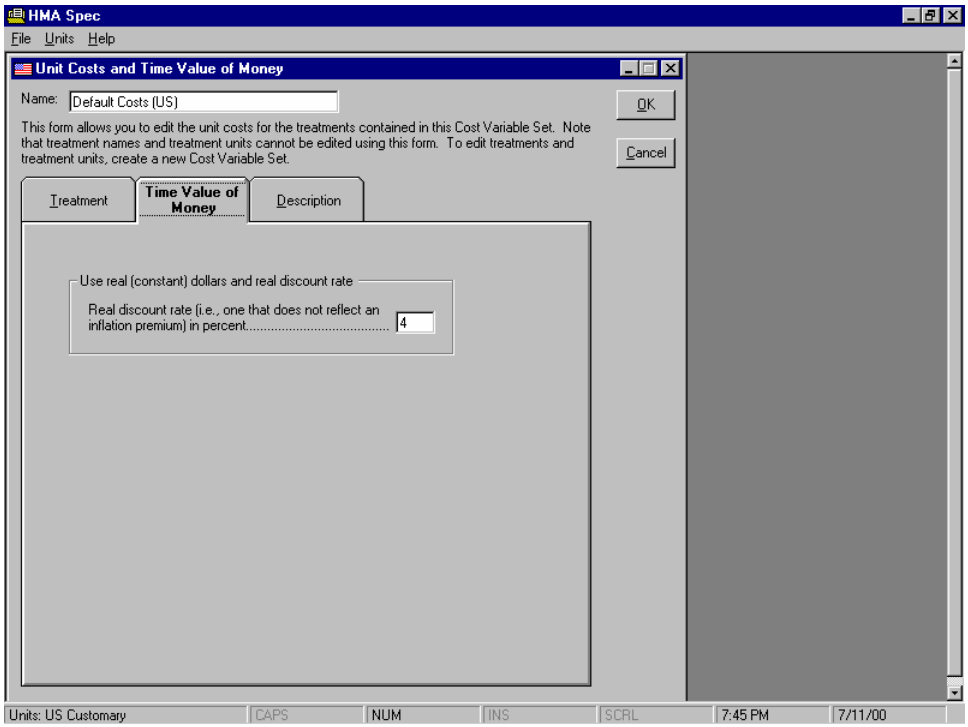

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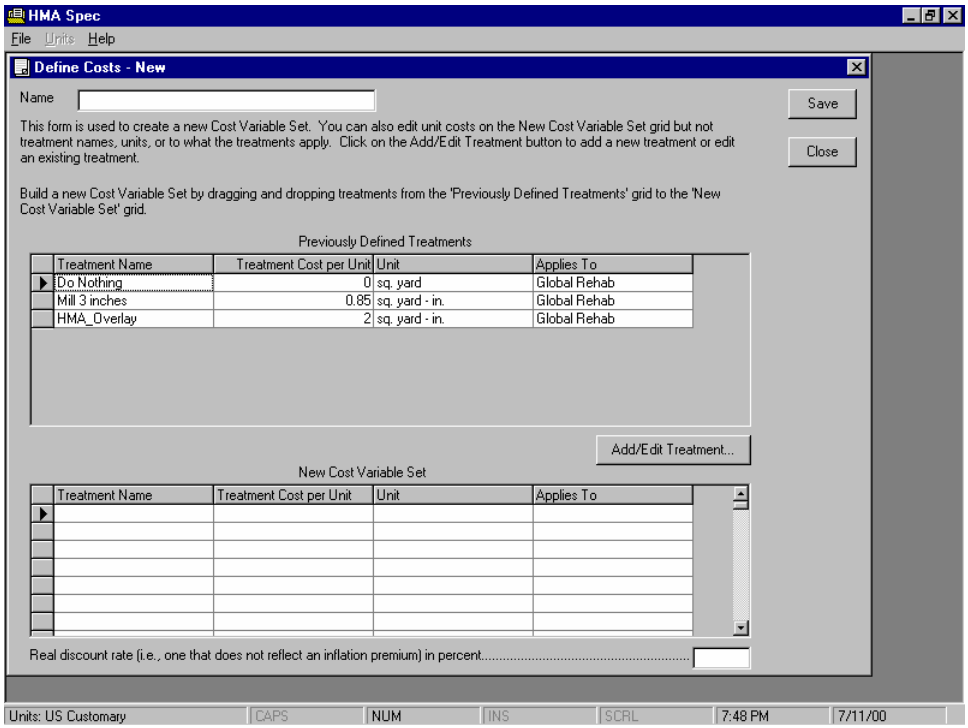

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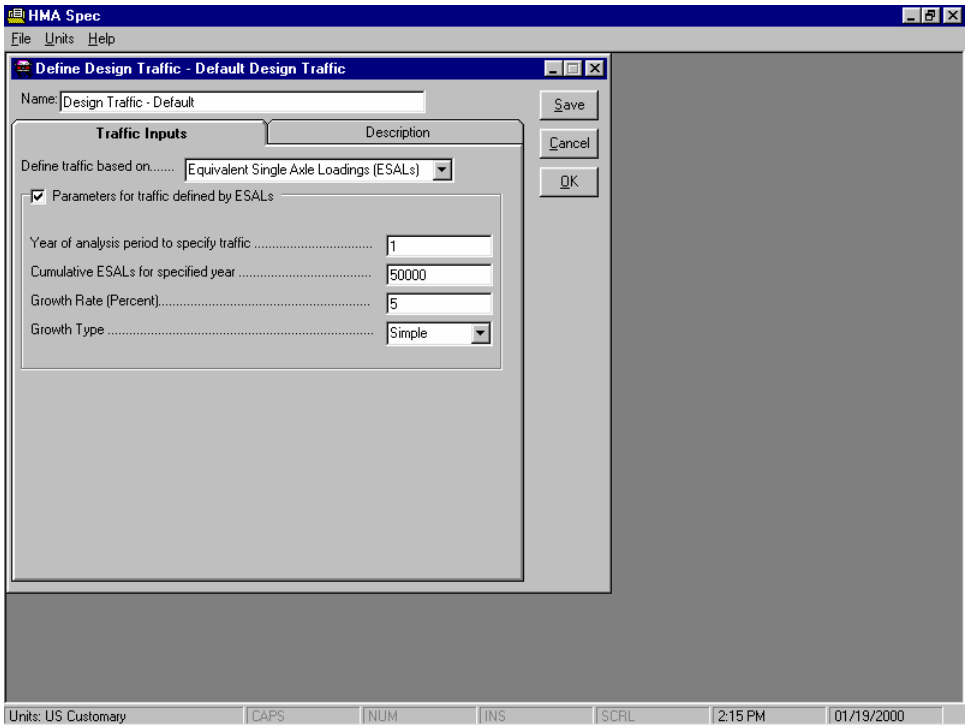
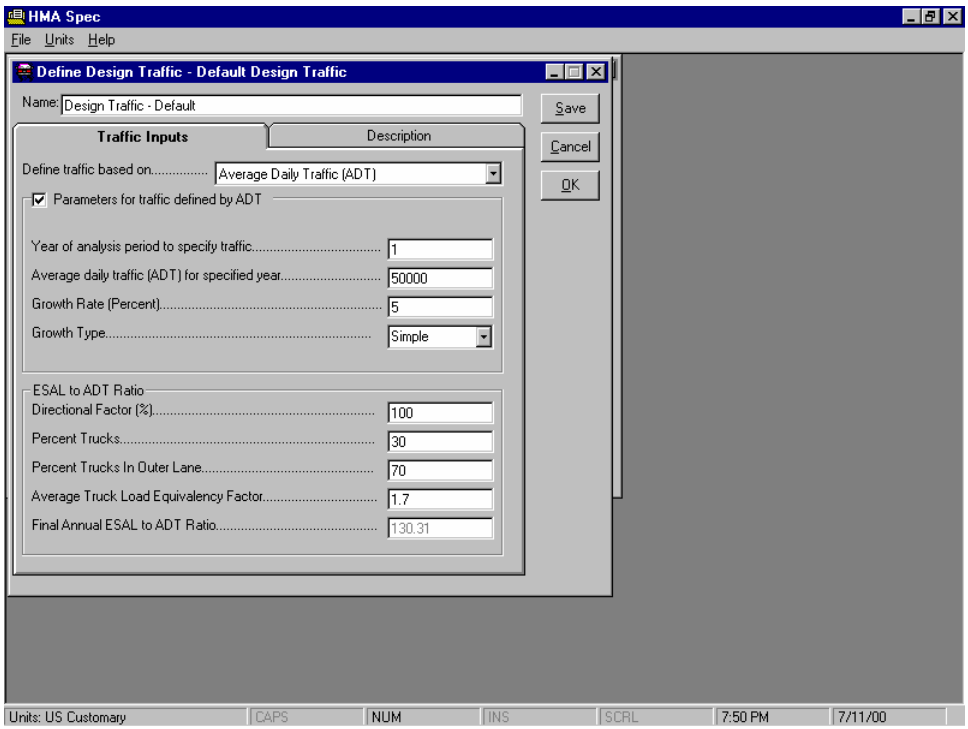


Figure 29. The Traffic Parameters input form.



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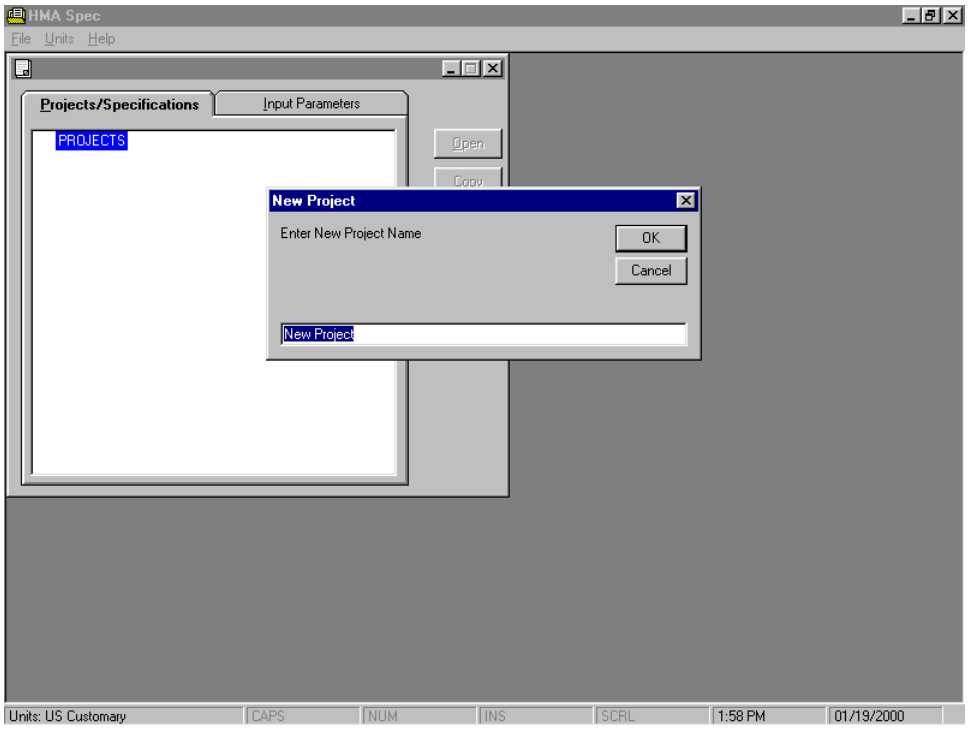

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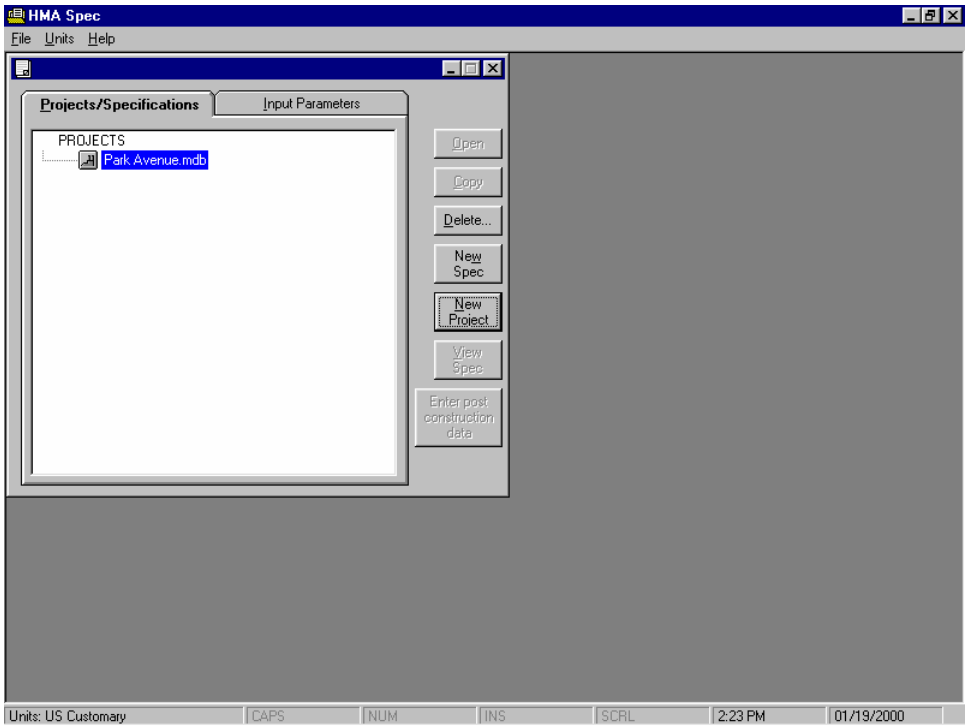
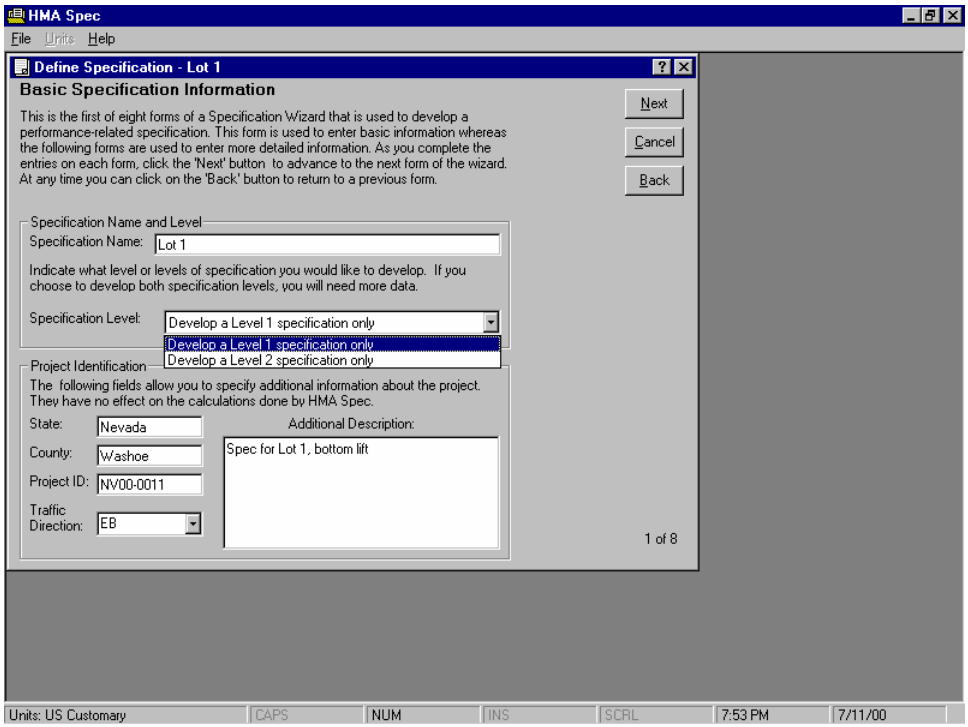


Figure 32. Control form indicating that a project named “Park Avenue” was created.



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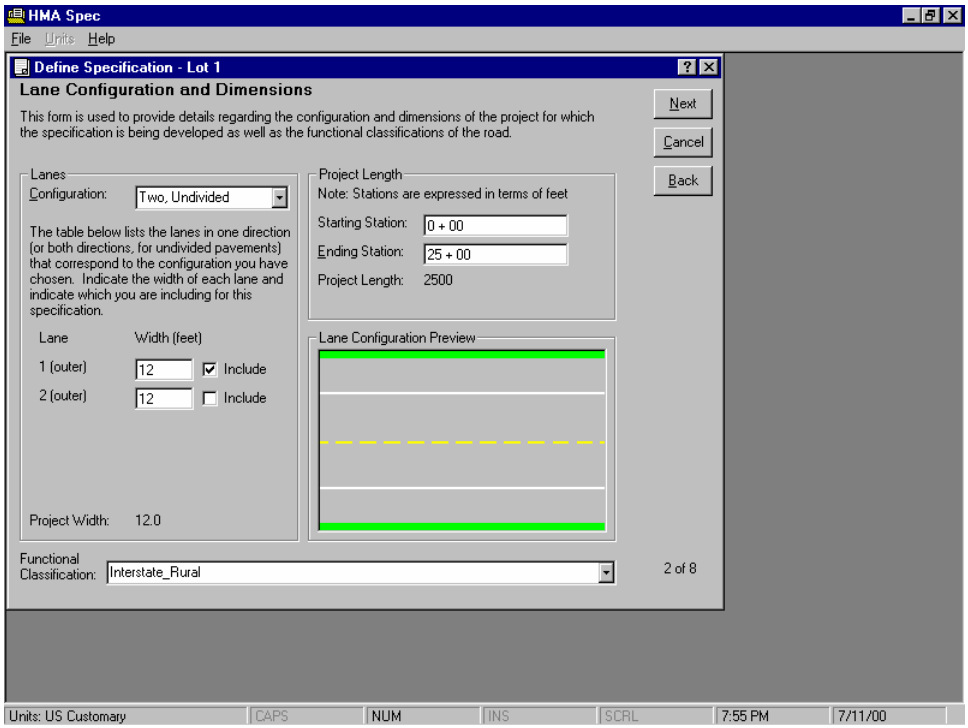

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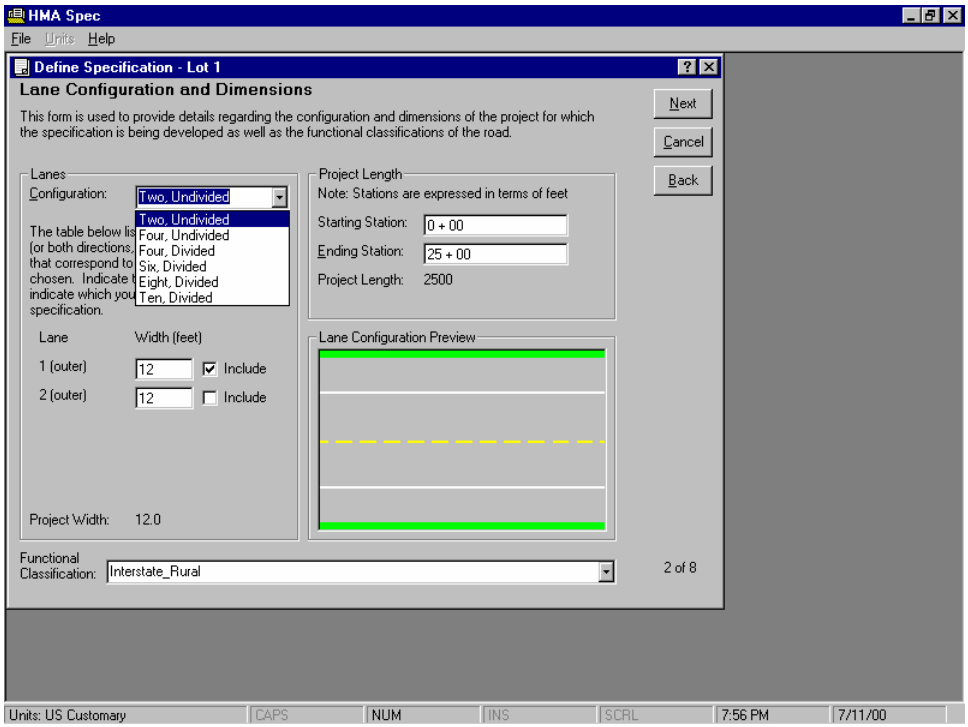

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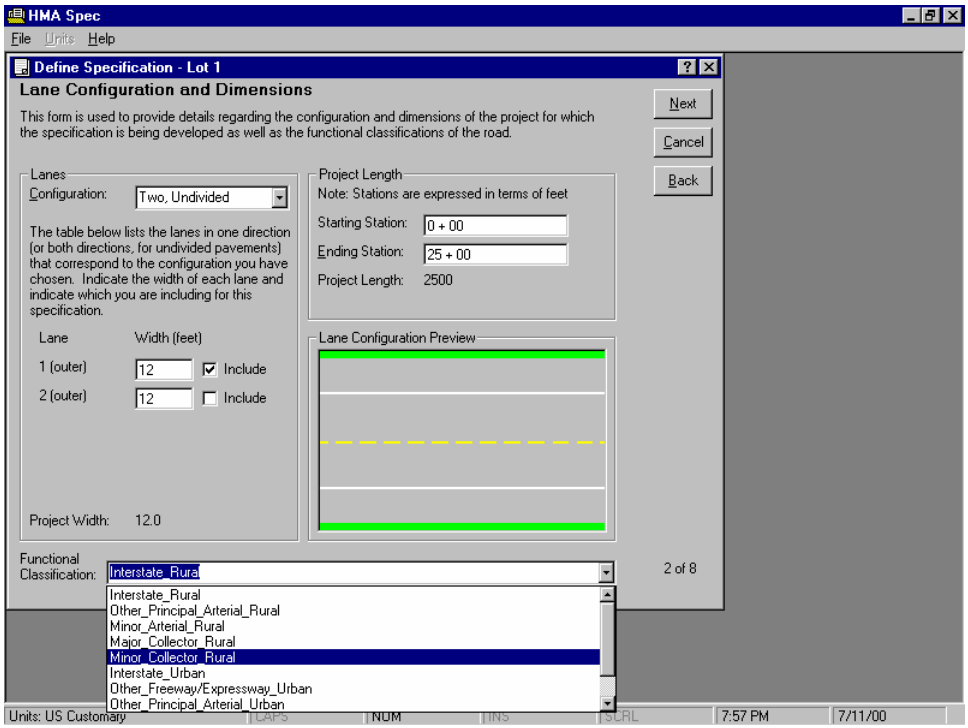

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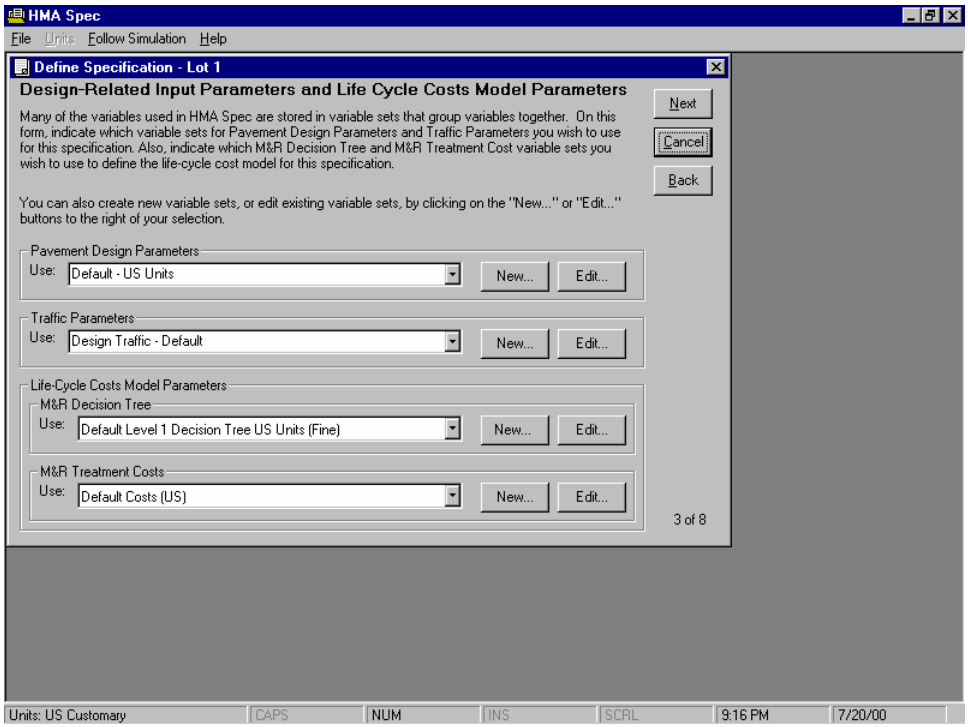

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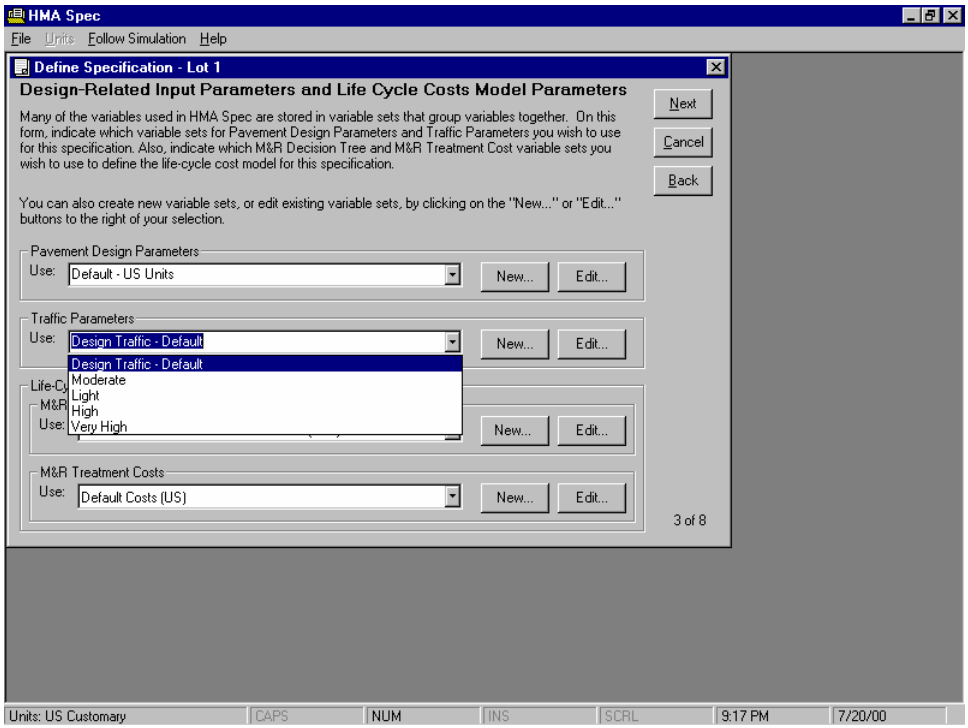

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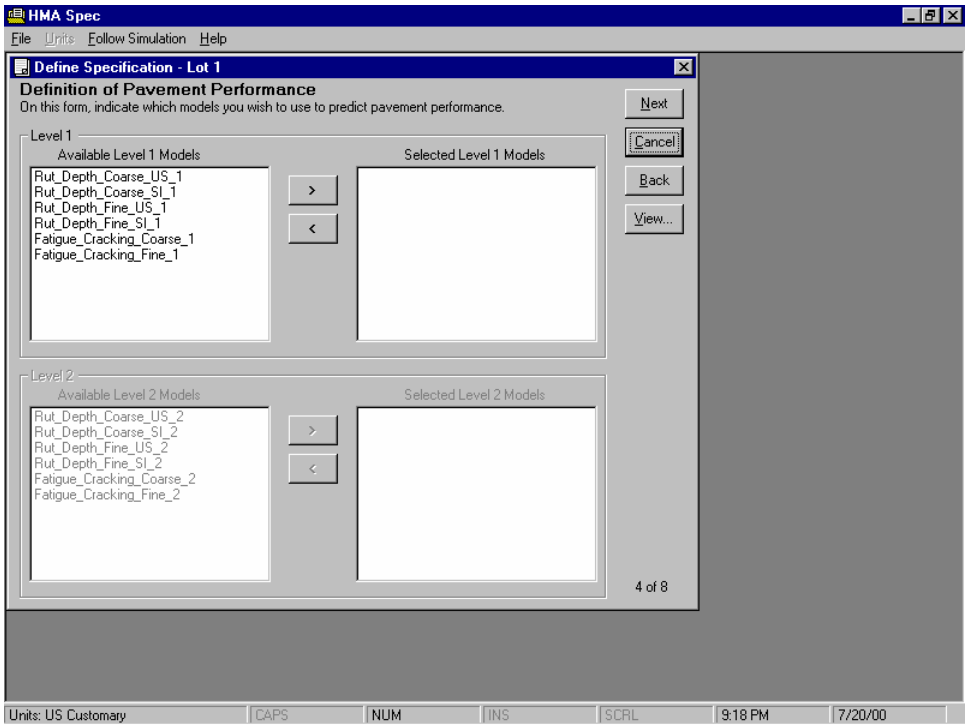

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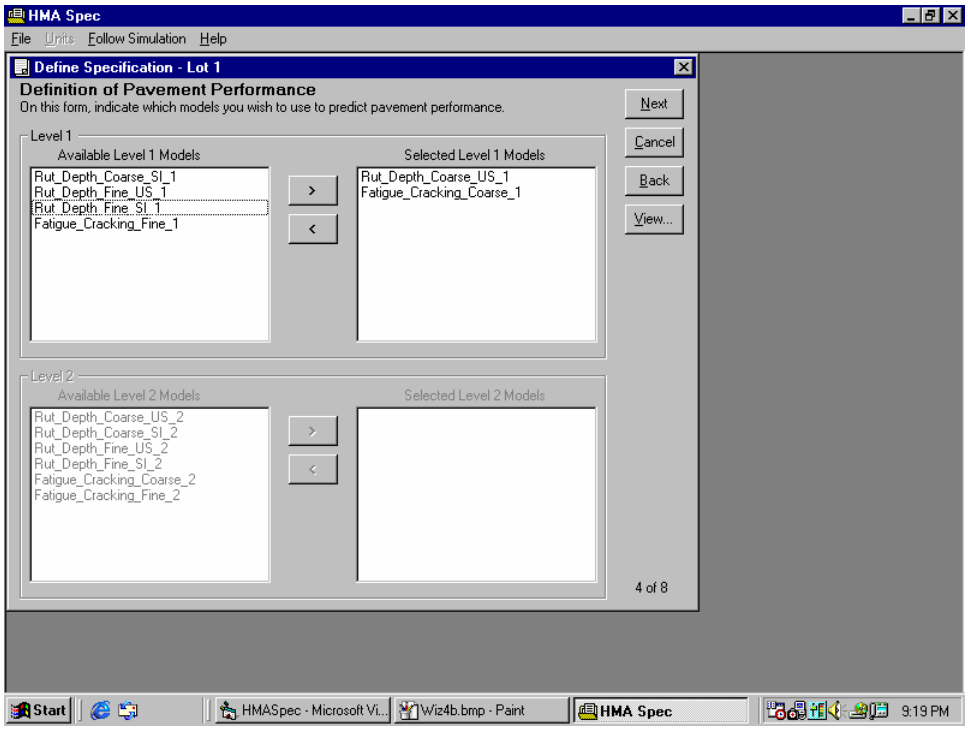

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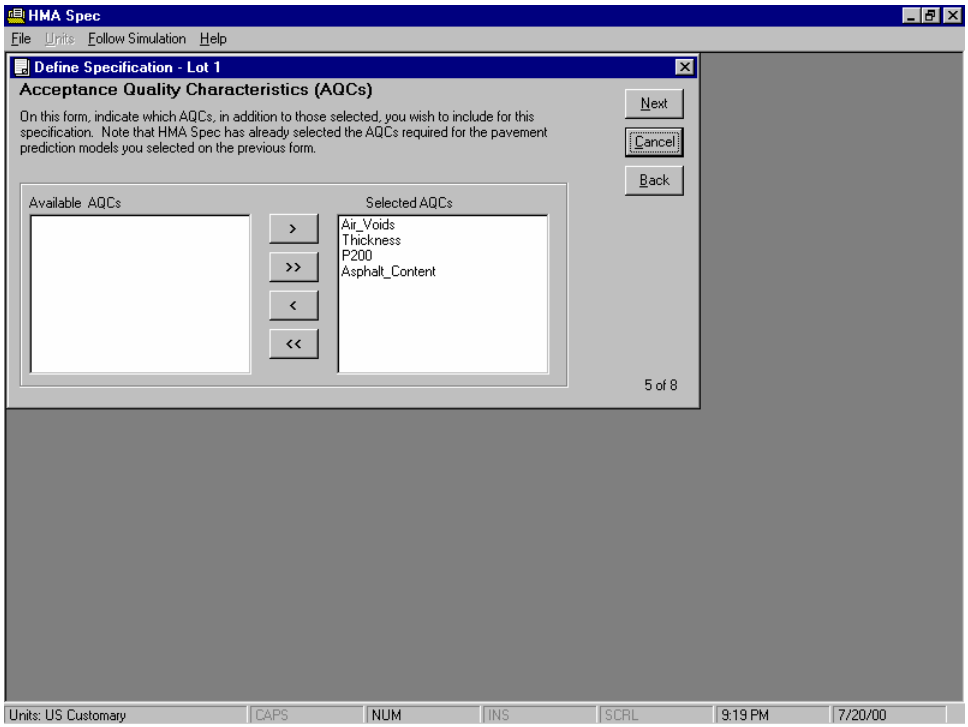

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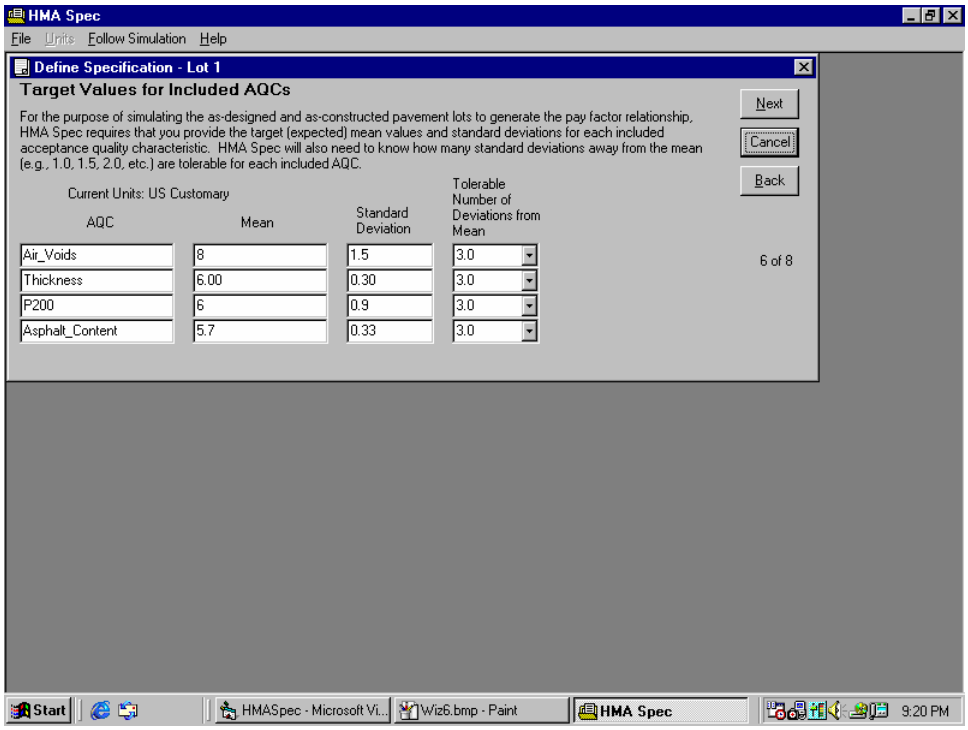

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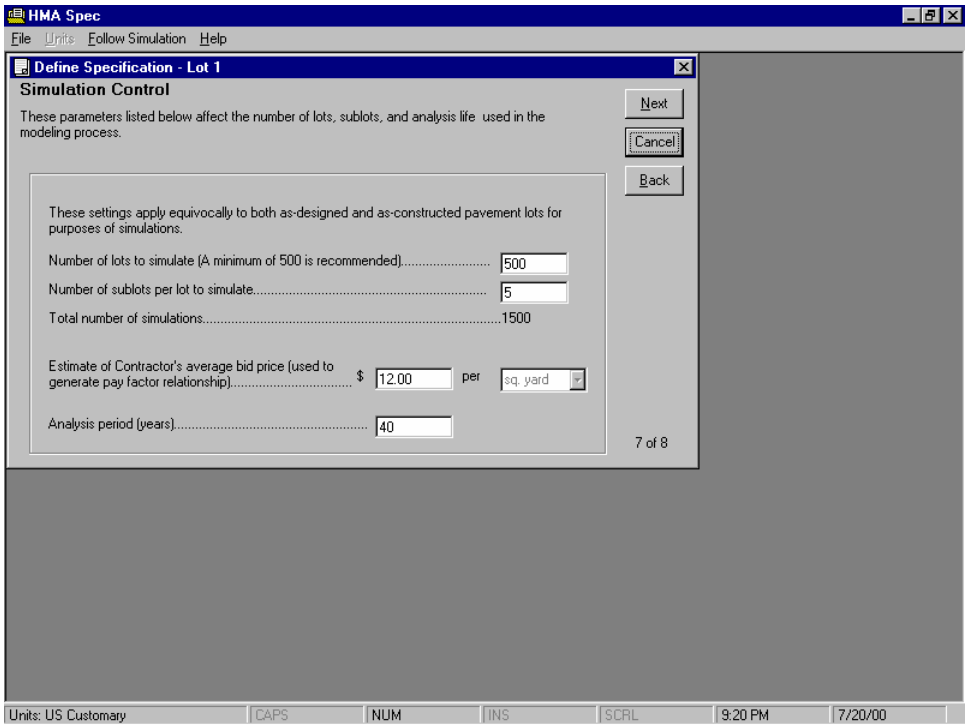

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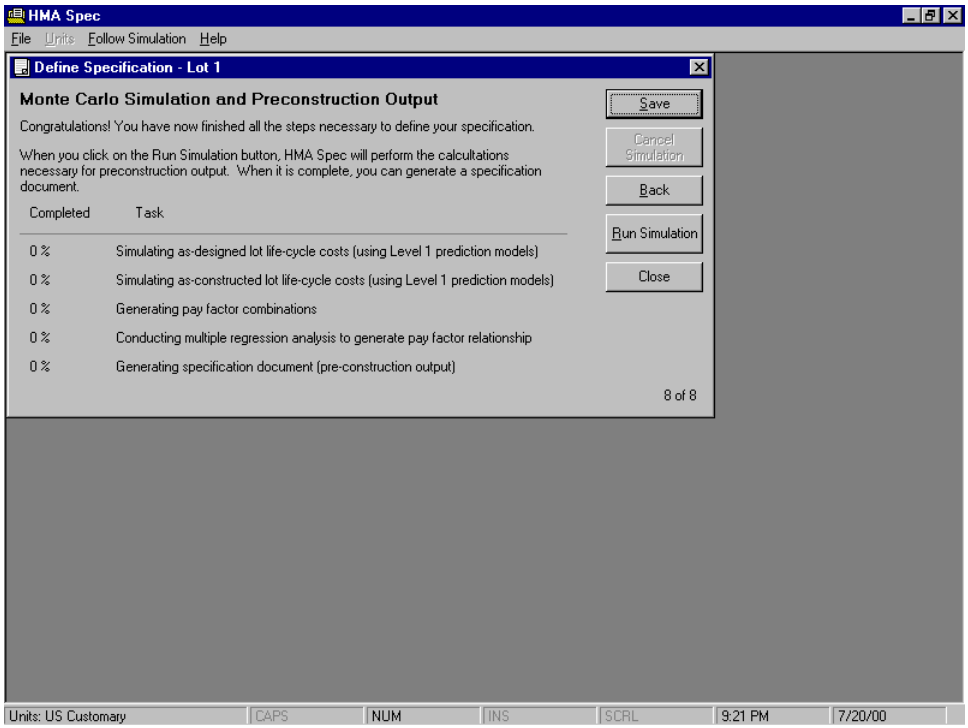

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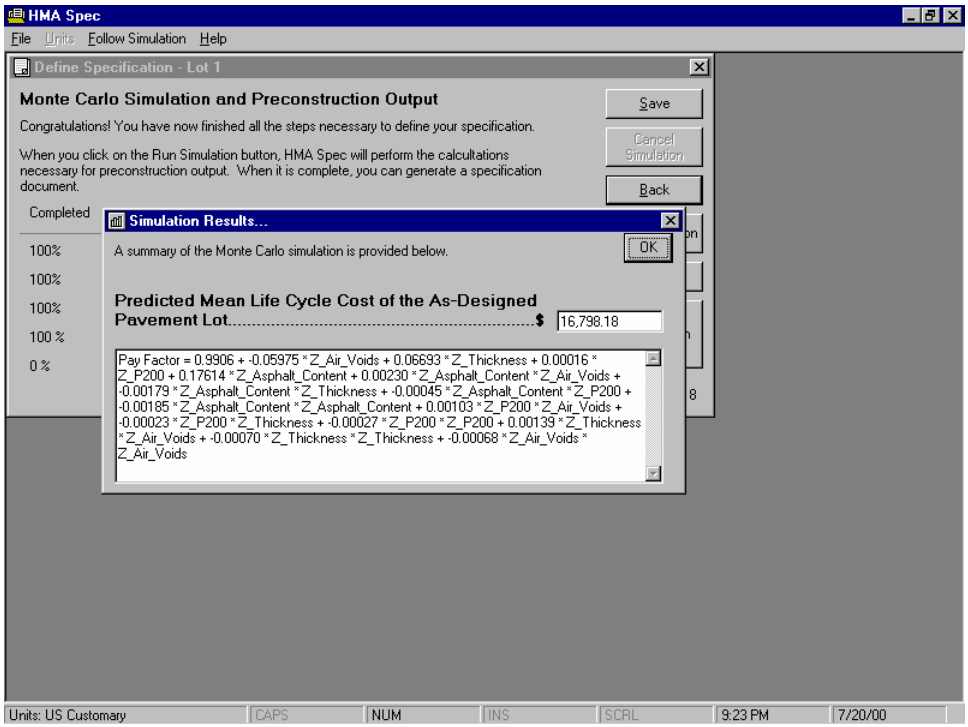

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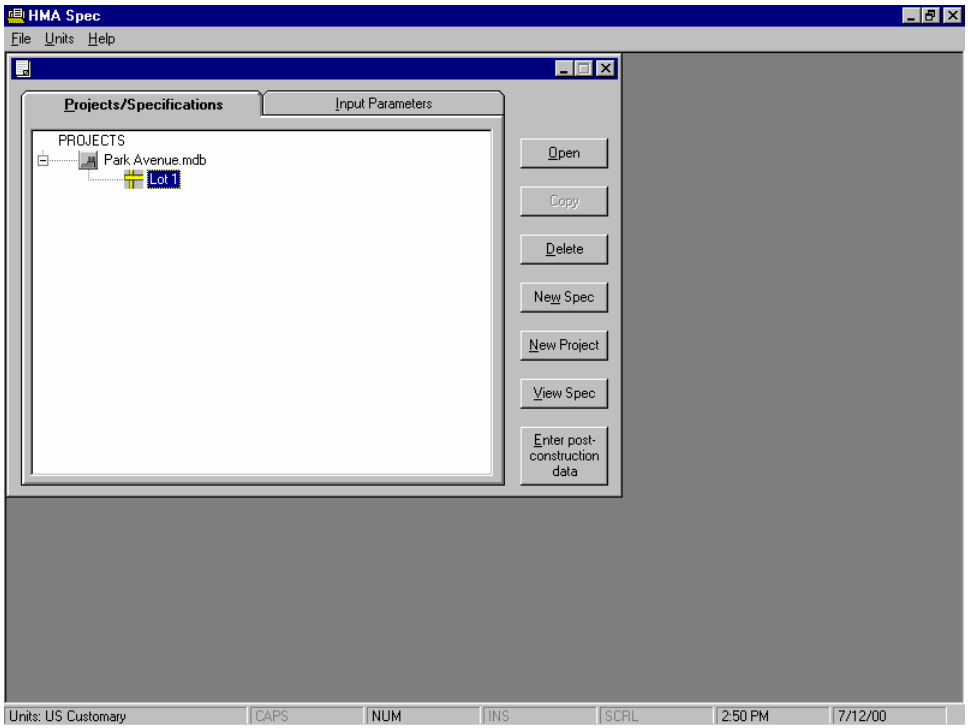

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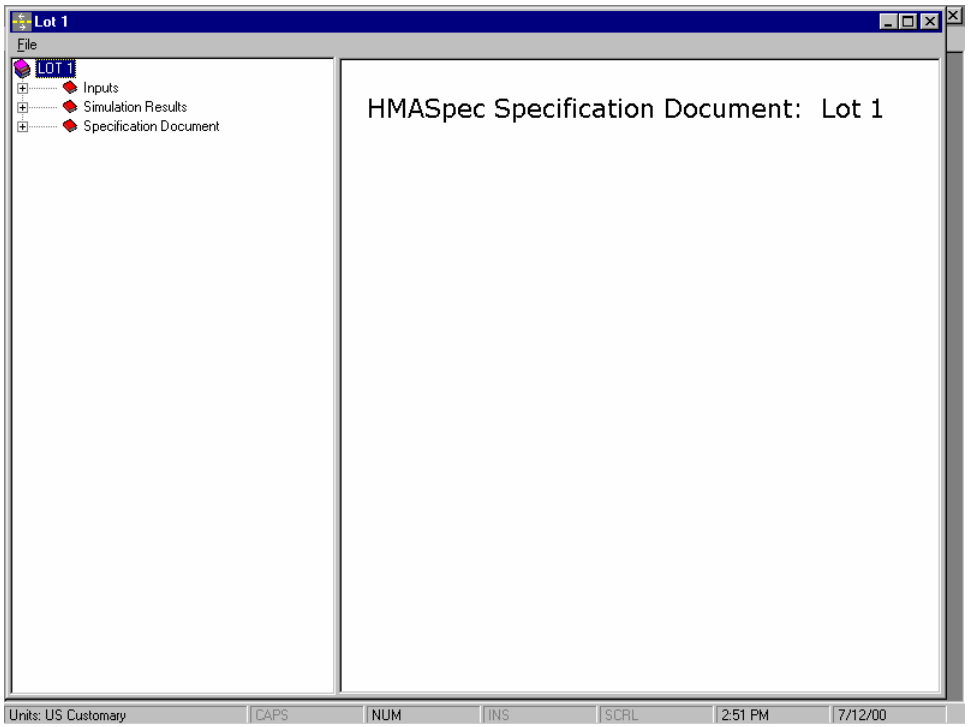

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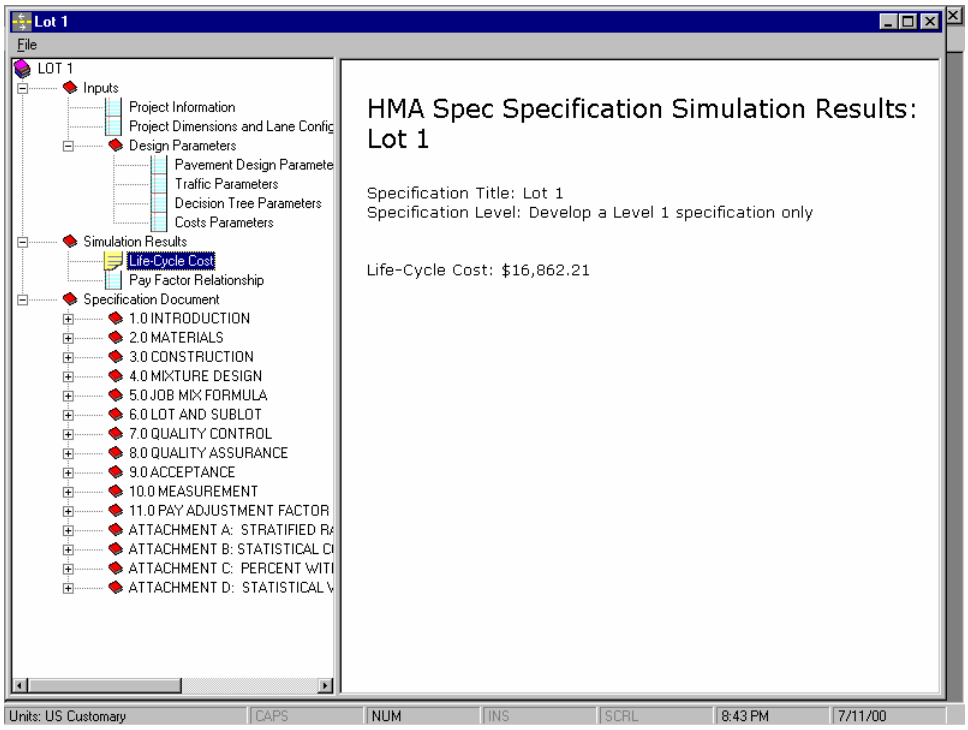

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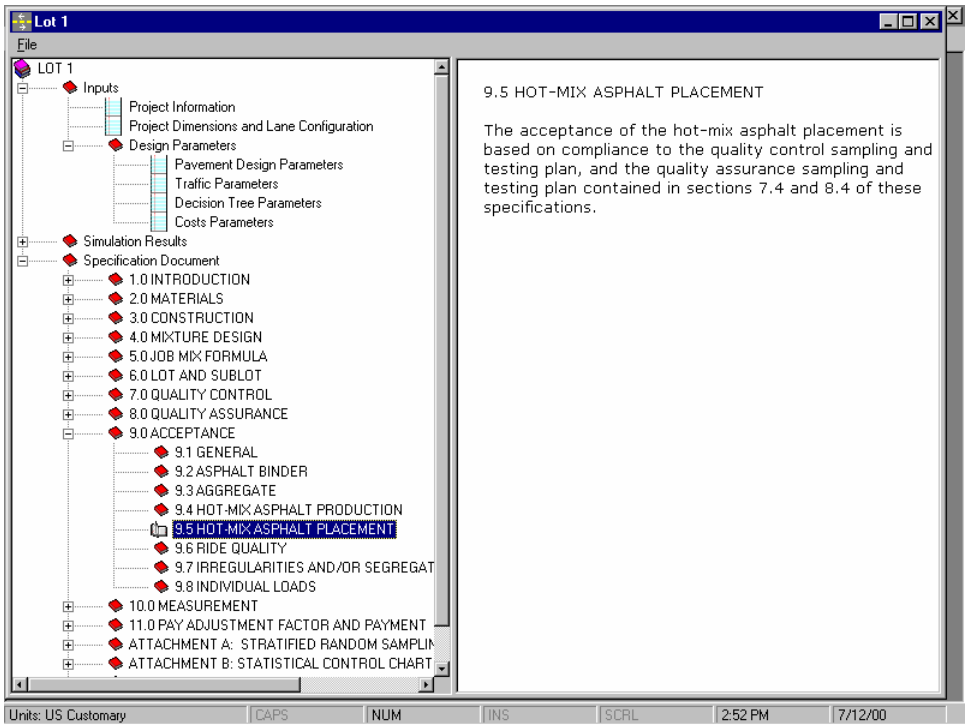

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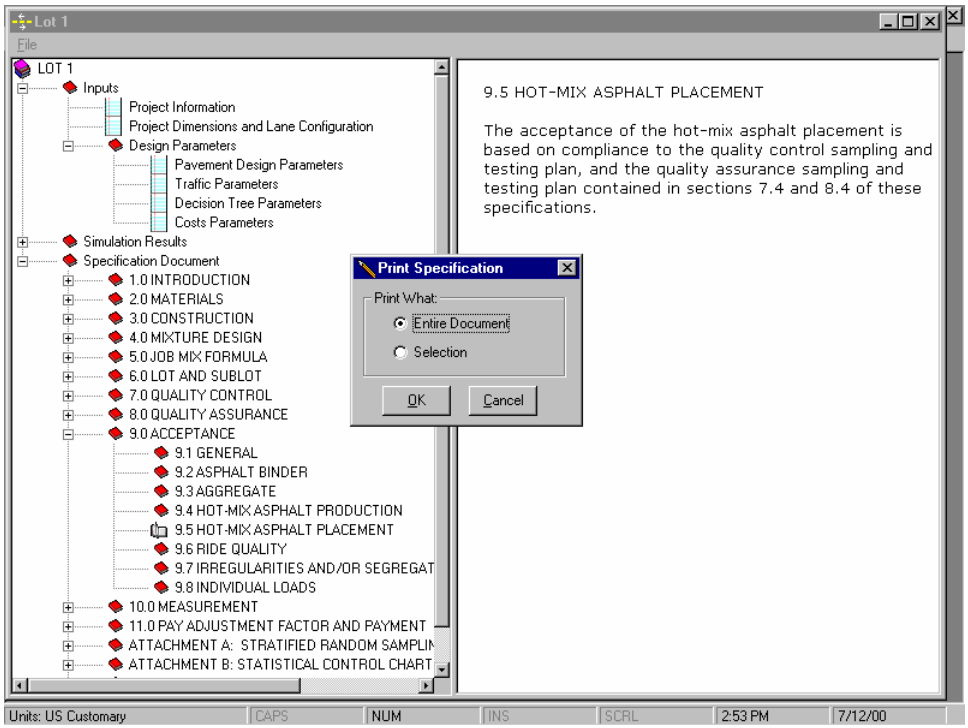

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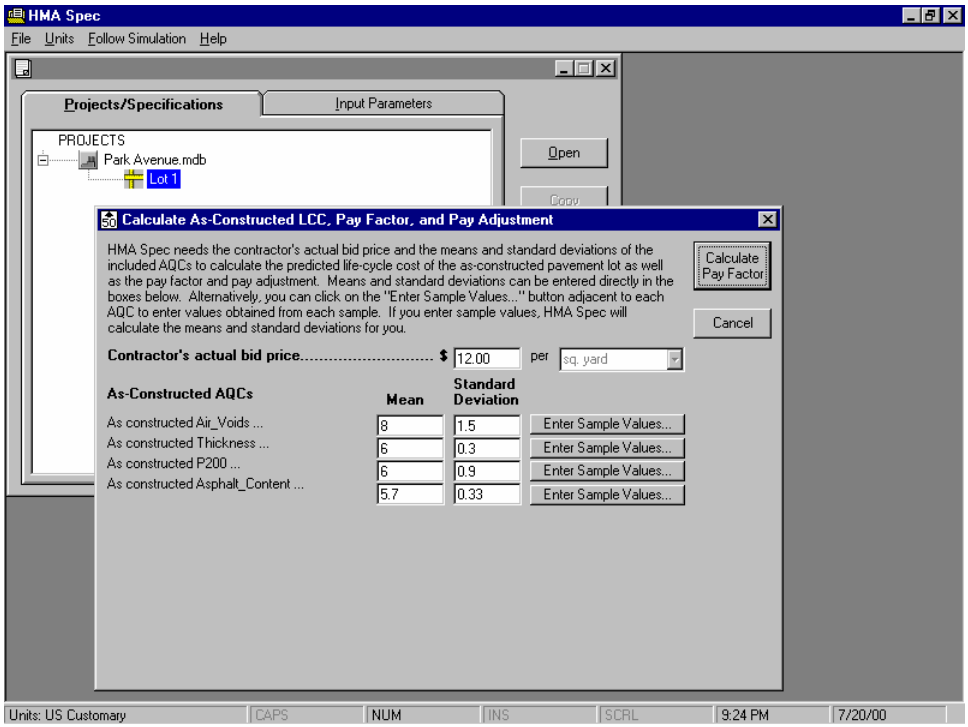

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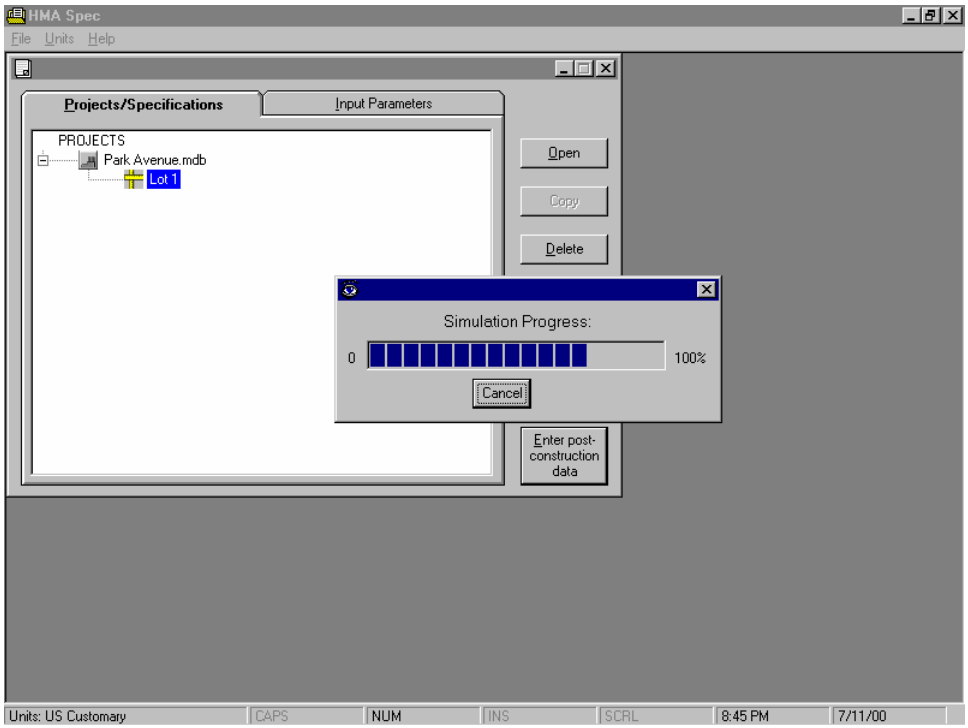

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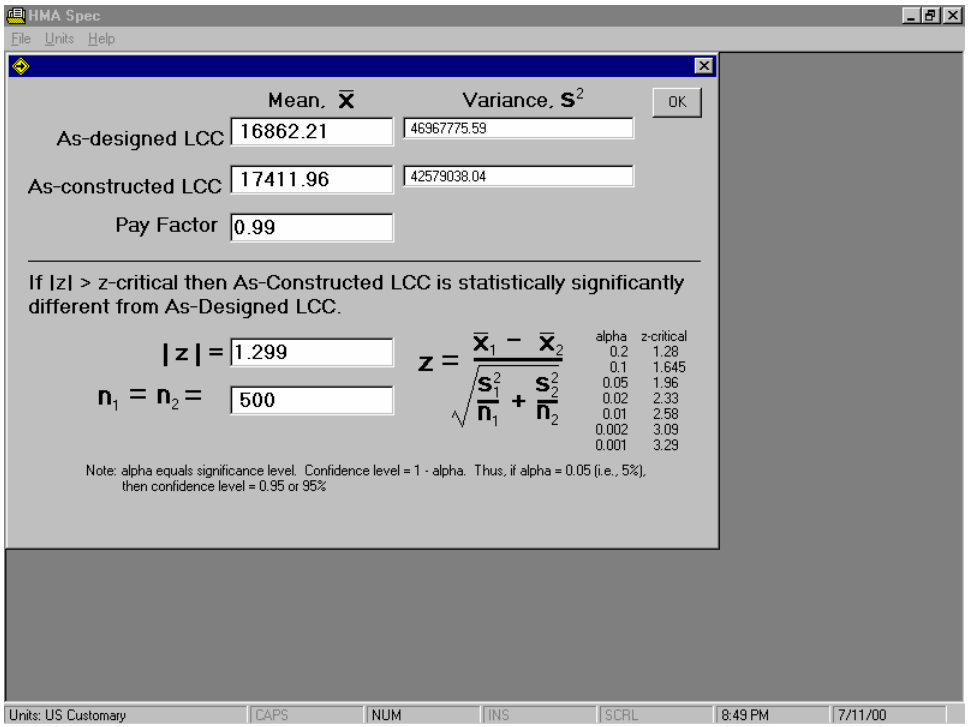

Figure 53. Form showing the postconstruction simulation results.

Low Temperature Cracking—Testing and Performance Prediction

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PERFORMANCE TESTING

Table 1 provides the experiment design for the WesTrack project. Since the primary distresses of interest for development of the performance-related specification (PRS) were permanent deformation and fatigue cracking, the asphalt cement was selected to preclude problems with low-temperature cracking. Accordingly, a single PG 64-22 binder (from two sources) was selected in accordance with Superpave guidelines.[1] Detailed information on the binder properties, both conventional and performance-related, is found elsewhere.[2]

Two test methods were used to characterize the low temperature cracking potential: the thermal stress restrained specimen test (TSRST) and the indirect tensile creep and strength test (IDT). The former was used for validation of the Superpave binder specification by SHRP researchers, and the latter is included in the Superpave mix design and analysis system. Detailed information on the development, conduct, and use of these tests may be found elsewhere. (See References 3-7) At the onset of the project, the researchers were hopeful that the IDT data could be used in the performance prediction models incorporated in the Superpave mix design and analysis system. Accordingly, the *original* test plan included comprehensive indirect tensile creep and strength testing. Midway through the project, however, the WesTrack Team was informed that the low temperature cracking model needed refinement and that it would not be available for the Team's use. Hence, the revised test plan shown in table 2, which made extensive use of the TSRST, evolved. For all low temperature cracking testing, plant-mixed materials, referred to as field-mixed, laboratory-compacted (FMLC), and field samples, referred to as field-mixed, field-compacted (FMFC cores and slabs), were taken from the top lift of the asphalt concrete. A summary of the IDT and TSRST results is included in appendices A and B. More detailed information on the IDT and TSRST results is contained in the WesTrack database elsewhere on this CD-ROM.

Typical IDT and TSRST results are shown in figures 1 and 2, respectively. Low temperature cracking test results are summarized in figures 3 through 6. TSRST results are shown in figures 3 and 4; IDT results in figures 5 and 6.

Observations made about the IDT results are qualitative in nature since a rigorous statistical analysis was not possible because of the limited number of tests conducted. As expected, and as is evident from figure 5, the creep stiffness is inversely related to test temperature. In addition, it appears that the effect of mix parameters diminishes with increasing temperature. There appears to be some effect of mix parameters at -20°C and -10°C, but this does not appear to be consistent. At -20°C, section 1 (fine gradation with optimum asphalt content and medium air voids) has the highest stiffness, whereas at -10°C and 0°C, section 25 (coarse gradation, high asphalt content and low air void content) has the highest stiffness. Since section 25 has a higher stiffness than all of the other sections tested (except for section 1 at -20°C), one might conclude that low temperature stiffness is dependent to some degree on asphalt content. Recall that section 25 was a high asphalt content section, whereas sections 1, 11, and 24 were optimum asphalt content mixes and section 26 was a low asphalt content mix. This conclusion is supported by the tensile (i.e., fracture) strength data shown in figure 6. Again, the effect of mix parameters tends to diminish with increasing temperature. However, at all test temperatures, section 25 had the greatest tensile strength.

The TSRST data shown in figure 3 indicate that there is little difference in fracture temperature between FMFC at time=0 and FMLC, although there is greater scatter in the former because of variability in air void content. The average fracture temperatures for FMFC at time=0 and FMLC specimens were -22.8 °C and -22.1 °C, respectively. As expected, the FMFC postmortem specimens had a higher fracture temperature than the FMFC at time=0 specimens. The average fracture temperatures for FMFC at time=0 and FMFC postmortem specimens were -22.8 °C and -20.6 °C, respectively. In addition, the data shown in figure 3 suggest that the fine and fine plus mixes (FMFC at time=0 specimens for sections 1 and 11, respectively) do not perform as well as the coarse mixes. The average fracture temperatures for sections 1 and 11 (FMFC at time=0 specimens) were -18.5 °C and -15.2 °C, respectively, whereas all of the coarse mixes (sections 24, 25, 26, and 35 to 39) had average fracture temperatures ranging from -20.8 °C to -28.7 °C.

The TSRST results from the aging study are shown in figure 4. The short-term oven-aged (STOA) specimens had an average fracture temperature of -27.3 °C. The long-term oven-aged specimens (LTOA) had an average fracture temperature of -25.4 °C, approximately a 2 °C difference. Interestingly, this 2 °C difference between STOA and LTOA is virtually identical to the difference in fracture temperature between the FMFC at time=0 and FMFC postmortem specimens, -22.8 °C and -20.6 °C, respectively.

To assess the difference between the various TSRST data sets, t-tests were conducted. The results shown in Table 3 indicate that there is a statistically significant difference between the STOA and LTOA specimens. For all other data sets, there are no statistically significant differences in the mean fracture temperatures. Also interesting to note is that the average fracture temperature for all the TSRST data sets was lower than -22 °C, the low temperature grade of the binder used at WesTrack (PG 64-22). The fact that there was no low temperature cracking observed at WesTrack may be interpreted in two ways: the pavement temperature did not reach -22 °C so the binder was not tested; or pavement temperature dropped to or below -22°C but the binder selection was appropriate or perhaps somewhat conservative. The overall mean fracture temperature for TSRST specimens made with plant-mixed material (i.e., FMFC or FMLC) was -21.8 °C. This is a conservative estimate of the fracture temperature of the mix since it is well documented that fracture temperature increases with cooling rate.[4,6] The TSRST cooling rate of 10 °C/hour exceeds the typical 2 °C/hour cooling measured in the field such that a more realistic estimate of the fracture temperature might be 3 °C to 5 °C cooler than that measured in the TSRST, i.e., -25 °C to -28 °C. This suggests that the binder selection was in fact conservative, i.e., that it should provide low temperature cracking resistance to temperatures of -25 °C to -28 °C.

Numerous regression models were considered in an attempt to predict TSRST fracture temperature as a function of mix parameters such as asphalt content, air void content, aggregate gradation and age conditioning. Interaction terms were also included in several models.[8] Because none of the models yielded an explained variation in excess of 20 percent, this rigorous analysis is not included here.

PERFORMANCE PREDICTION

COLD Program

As previously noted, the Superpave low temperature cracking performance prediction model was not yet available. Accordingly, other analytical tools were used to extend the WesTrack results to other materials and climatic regions. Specifically, the COLD (Computations of Low Temperature Damage) program with Minnesota Road Research Project (MnROAD) materials and field performance data was used. A FORTRAN version of a previously written program, COLD, was used as an analytical tool to evaluate its applicability to a range of material behaviors, pavement structures, and climatic conditions.

COLD calculates the pavement temperature, strength, and concurrent thermal stress at specified depth increments and time intervals throughout a specified analysis period. This period was selected to represent the 20 days with the lowest average daily temperature. Using material thermal properties, known heat sources, and principles of thermodynamics, the model computes pavement temperatures using finite difference equations. Assuming one-dimensional heat transfer, the equation has the general form:

$$T(x,t+\Delta t) = a_1 T(x-\Delta x,t) + \left[1-(a_1+a_2)\right]T(x,t) + a_2 T(x+\Delta x,t) \quad \textbf{(1)}$$

At the interface of two layers,

$$a_1 = \frac{2K_i \Delta t}{I} \quad \textbf{(2)}$$

$$a_2 = \frac{2K_{i+1} \Delta t}{I} \quad \textbf{(3)}$$

$$I = \Delta x^2 \left(\gamma_i C_i + \gamma_{i+1} C_{i+1}\right) \quad \textbf{(4)}$$

and within a given layer, the following applies:

$$a_1 = a_2 = \frac{\alpha_i \Delta t}{\Delta x^2} \quad \textbf{(5)}$$

At the pavement surface/air interface,

$$T(x,t+\Delta t) = a_1 T(x-\Delta x,t) + \left(1-a_2\right)T(x,t) + a_2 T(x+\Delta x,t) + a_3 Q \quad \textbf{(6)}$$

$$a_2 = \frac{2\alpha_0 \Delta t}{\Delta x^2} \quad \textbf{(7)}$$

$$a_3 = \frac{2\alpha_0 \Delta t}{K_0 \Delta x} \quad \textbf{(8)}$$

$$Q = u_c \left(T_{air} - T_{pvmt}\right) + e\sigma\left(T_{air}^4 - T_{pvmt}^4\right) + aH \quad \textbf{(9)}$$

Terms in the preceding equations are defined as follows:

T = temperature
x = depth
t = time
α = K/C = thermal diffusivity
K_i = thermal conductivity of ith layer
γ_i = dry unit weight of ith layer
C_i = dry mass heat capacity of ith layer
Q = total heat flux from convection and radiation
u_c = convection coefficient of pavement surface
e = emissivity of pavement surface
σ = Stefan-Boltzmann constant
a = absorptivity
H = solar insolation

Moreover, mass heat capacity and thermal conductivity vary with temperature, with a marked distinction apparent between the frozen and unfrozen states. Thus the following constants must be applied with respect to the state of the layer in question:

K_u = unfrozen thermal conductivity
K_f = frozen thermal conductivity
C_u = unfrozen dry mass heat capacity
C_f = frozen dry mass heat capacity

Other inputs to the model include transition temperatures, listed below:

t_f = the temperature below which a percent of the water in the subgrade is frozen
t_b = the temperature at which freezing begins in the subgrade

COLD assumes the pavement to be a pseudo-elastic beam or slab, infinite and longitudinally restrained, and computes the thermal stress. The general form of the equation of stress as a function of depth is given as:

$$\sigma_x(t) = -\alpha \int_{t_o}^{t} S(\Delta t, T)\, dT(t) \qquad \textbf{(10)}$$

where S(Δt, T) is the time and temperature dependent stiffness, or creep modulus, and α is the coefficient of thermal expansion, assumed to be temperature independent. Beginning at the pavement surface, the stress at depth increment i is calculated numerically according to the following finite difference equation:

$$\sigma_x(t_i) = \sigma_x(t_{i-1}) + (\Delta\sigma_x)_i \qquad \textbf{(11)}$$

where stress increments are computed using a trapezoidal approximation based on the stiffness and temperature T at times t_i and t_{i-1}:

$$(\Delta\sigma_x)_i = \frac{-\alpha(S_i + S_{i-1})(T_i + T_{i-1})}{2(1-\nu)} \quad \textbf{(12)}$$

This method assumes (1) the induced stress is elastic, uniaxial, and uniformly distributed within a given depth increment and (2) the pavement is homogeneous and initially uncracked. Using a pseudo-elastic beam method requires Poisson's ratio to be equal to zero; if a non-zero value is selected, slab analysis is performed.

An arithmetic stress/strength comparison during any segment of the diurnal thermal loading cycle yields the periods of predicted distress; whenever stress exceeds strength, cracking occurs. COLD provides reliability-based outputs, including expected values, as well as results corresponding to 99, 95, 90, and 75 percent reliability. Furthermore, a direct consequence of using the Van der Poel nomograph to estimate stiffness is that the calculated stress is also accurate only to within a factor of two. Whenever the stress is equal to half the corresponding strength, cracking may occur. Strength-temperature inputs were obtained from indirect diametral tension test results and likely possess less uncertainty.

COLD is intended to be adequate in predicting the onset of cracking, but it has no protocol for determining the propagation of cracks throughout the pavement structure, either vertically or horizontally. The task of quantifying the overall extent of cracking gives rise to a number of complex types of behavior such as crack healing, notching, and contact elements which are beyond the scope of this work.[9] On a more basic level, some binder material properties normally assumed as constants may instead be considered as variables. In particular, the coefficient of thermal expansion (α) for an asphalt cement varies with crude oil source and has been found to vary among three distinct values within the temperature domain.[10] As a general trend, α decreases with temperature. Despite these effects, thermal expansion of the mix is not greatly affected and a constant value of 1.5×10^{-5} is considered a fair approximation.

Wherever possible, measured values are used as inputs instead of estimated or predicted quantities. It should also be noted here that all of the above equations are fundamentally independent of the system of units used. COLD is, however, programmed with the English system in mind and is not metric compatible.

COLD Analysis of WesTrack and MnROAD Test Pavements

Two separate pavement test tracks were selected (WesTrack, located approximately 100 km (60 mi) southeast of Reno, Nevada, and MnROAD, sited roughly 65 km (40 mi) northwest of St. Paul, Minnesota) as the basis for all field verification of performance predictions made from laboratory data sets. Schematics of the WesTrack and MnROAD facilities are shown in figures 7 and 8, respectively. Pavement condition surveys at both sites were used to ascertain levels of thermal cracking distress for multiple test sections. Two sections at each test track were selected as the basis for comparison. It would have been desirable to examine a wider variety of binder

types in mixes, but only two binders were used at MnROAD. Therefore, investigating the performance of more than two sections at MnROAD would yield information about design parameters other than binder type. A single binder was used in all WesTrack sections, but two sections were selected for analysis based on volumetric differences: one section consisted of a mix with a high asphalt content and low air void content (section 25), while the other consisted of a low asphalt, high air void mix (section 26). If any of the sections at WesTrack failed in thermal cracking, conventional wisdom dictates that it should have been the latter.

As a final segment of the COLD analysis, it was anticipated that a reasonable amount of information could be gained by analyzing the WesTrack binder's performance in a climate such as Minnesota's. Therefore, a "hybrid" pavement was conceived, one with properties that would combine the binder contribution from WesTrack with all other mix properties and structural specifications from a MnROAD pavement.

WesTrack

The pavement sections at WesTrack were all constructed using the same binder, a PG 64-22. This effectively eliminated binder variation as a source of scatter in other analyses performed at WesTrack. Fortunately, a number of mixes with different volumetric parameters were constructed allowing for different levels of thermal distress to occur. Climatic data were collected for the period of December 11 through 30, 1997, to partially assess the validity of the thermal crack prediction model COLD. This period represents the 20-day time span with the lowest average daily minimum temperature. These data included daily maximum and minimum air temperatures and total daily solar radiation, gathered by WesTrack personnel.[11] Pavement temperatures also were measured by thermocouples embedded at several depths within the asphalt concrete layer (13, 38, 89, 114, and 140 mm – 0.5, 1.5, 3.5, 4.5, and 5.5 inches). Thermocouple data were used to verify the pavement temperature predictions generated by COLD.

MnROAD

Test pavements at MnROAD include two segments parallel to Interstate 94: a 4.0-km (2.5-mi) low volume road (LVR) loop carrying simulated rural traffic and a 5.6-km (3.5-mi) mainline (ML) road carrying actual interstate traffic. Test sections from the mainline were analyzed in this paper, as it alone contains pairs of identically designed sections differing only by binder type. The length of each section, or cell, is approximately 152 m (500 ft). Two cells were selected for comparison: 14 and 15. Cells 14 and 15 consist of 273 mm (10.75 inches) of hot-mix asphalt (HMA) over a silty clay subgrade. The asphalt concrete mix in cell 14 uses an AC-120/150 binder, graded as a PG 58-28. The mix in cell 15 contains an AC-20, also graded as a PG 58-22 . Detailed material properties for all layers in the pavements may be found in table 4. Thermocouple data were used to check pavement surface temperature calculations performed by COLD.

Climatic data for a 20-day cold period, January 18 through February 6, 1996, were selected as inputs to COLD and comprised the coldest period to occur since construction. Initially, concern was expressed about the potential effects of traffic loading on distress that would otherwise be considered to be the result of thermal effects. However, an examination of the distress showed

little or no change between 1996 and 1998, despite continual traffic loading. Specifically, over 90 percent of the cumulative observed cracking occurred during February 1996.[12] Whether traffic can be categorically stricken from the analysis or not is a matter for discussion.

The "Hybrid" Pavement

As for the other pavements, creep stiffness of the binder was calculated from the Van der Poel nomograph using the BANDS software. The hybrid is assumed to have air void and asphalt contents of 3.9 and 5.4 percent, respectively. These are directly calculated as averages of MnROAD section 14 and 15 mix properties. In combination with "average" volumetric properties of the two MnROAD mixes – namely, asphalt content and volume fraction of aggregate – the mix stiffness-temperature curve was generated using BANDS.

Mix strength at low temperature is predominantly a function of binder properties. Previous studies have assumed the strength curve takes on the form of a fourth-order polynomial, the independent variable of which is the logarithm of binder stiffness.[13] As a first-order approximation, strength properties were determined by selecting a characteristic WesTrack mix with a similar aggregate gradation and asphalt content. Although aggregate absorption, rather than gradation, is considered a more significant predictor of low temperature performance,[6,8] some strength differences are apparent among the three WesTrack gradations. Air void content, another widely used mix property, has been shown to be a relatively poor predictor of strength, and was thus eliminated from the selection criteria equation.[8] The job mix formula used at MnROAD would be most closely matched by any of the mixes composed of a fine gradation used at WesTrack. Of the fine mixes, section 1 has an asphalt content of 5.6 percent, roughly identical to that of the average MnROAD mix. Thus the strength-temperature curve derived from IDT results for section 1 was used as an estimate of the hybrid mix's behavior.[11]

Through COLD, the hybrid pavement was then subjected to the same 20 days of cold weather that MnROAD experienced. Stress, strength, and temperature results were then compared to those of the other pavements studied.

COLD Analysis

The output generated by COLD provides a reasonable estimate of whether or not thermal cracking is imminent. Predicted pavement temperatures seemed to be more moderate than thermocouple data indicated, with occasional periods in which measured and predicted values were in close agreement. This is due in part to the linear averaging of temperature and solar radiation received by the pavement. Often, the time at which a minimum or maximum temperature actually occurs does not coincide with the simplified triangular insolation distribution or temperature pattern assumed by COLD. This approximation is acceptable in lieu of writing a computer model that takes individual hourly air temperature and insolation values as direct inputs. Other specific aspects of the analysis are discussed below.

MnROAD Pavements

Pavement condition survey data, used here as a benchmark, are presented in Table 5. The data from which COLD MnROAD input files were generated include the following: material thermal properties, climatic data, pavement temperature data, stiffness data, and strength data. The actual input files appear in appendix C. The abridged COLD output files – only *expected* stress and strength values are tabulated – also appear in appendix C. Fortunately, researchers at MnDOT collected a wealth of thermocouple data about the thermal regime within the cells to a depth of roughly 2.5 m (8 ft). This aided in assembling an accurate temperature profile for the COLD input file, although COLD output reports only surface temperature.

Outputs show that pavement temperatures rarely differ with respect to section at a given site, and the magnitude of the difference is consistently 0.05°C or less. This indicates that minor changes in thermal property inputs between pavement sections resulted in even smaller differences in temperature results, i.e., the model is relatively insensitive to thermal property changes. Immediately evident from the analysis is that COLD pavement temperatures fluctuate much more moderately than recorded field values. A field temperature swing of 20°C to 30°C corresponds to a predicted daily range of 5°C to 7°C (figure 9). COLD minimum temperatures were also on the order of 3°C to 12°C higher than field values during the coldest days. On the single coldest day, February 2, COLD predicted a low temperature of -17.3°C, whereas the measured value was -24.2°C. In general, the modeled pavement reacted much more slowly to changes in air temperature than did the actual pavement.

On several occasions, the time of occurrence for an extreme temperature on a given day differed between COLD and field results. This is unavoidable unless the actual times of occurrence are the same from one day to the next; it is necessary to specify in the input file one time of day that must represent the entire period. In this analysis, the occurrence of the minimum daily temperature was selected as 5:30 a.m. Midnight or 1:00 a.m. also may be appropriate. Figure 10 shows COLD pavement temperature *versus* approximated air temperature, providing a qualitative view of how pavement temperature naturally lags air temperature.

To the credit of its creators, COLD predicted pavement temperatures that resulted in a visible qualitative difference in cracking levels between the pavements of cells 14 and 15. Plots of stress and strength against time throughout the analysis period are provided for cell 14 (figures 11 and 12) and cell 15 (figures 13 and 14). The AC-120/150 asphalt mix of cell 14 should fail first, during the single coldest morning, February 2. COLD makes no predictions about the extent of cracking due to repeated episodes of failure, i.e., on February 3 and 4, although intuition leads one to equate the area between the stress and strength curves with cracking density. The AC-20 mix of cell 15 is predicted to crack first on January 20, then remain intact until January 30, when another episode of cracking commences. A state of failure persists throughout the entire period of January 31 to February 4.

A pavement condition survey conducted on February 13, 1996,[(12)] recorded the total number of cell 14 cracks as 15 in each lane, comprising a combined length of 53 m (174 ft) in the passing lane and 54.5 m (179 ft) in the driving lane. The same survey reports 30 cracks of 107-m (350-ft) combined length in the passing lane and 35 cracks totaling 114 m (375 ft) in length for the AC-20 pavement of cell 15. Not only is this total length some 100 to 109 percent greater than

that for the AC-120/150 cell, but the cracks are more numerous, forming a much more jagged, irregular pattern.[12] While the higher distress levels in the driving lane of both cells suggest that traffic loading contributes to transverse cracking, the difference is 3 to 7 percent and is thus arguably a minor effect.

WesTrack Pavements

Complete input files for the WesTrack pavements appear in appendix C. As expected, COLD predicts no thermal cracking distress for sections 24 and 25. Very close agreement was obtained for pavement temperatures, with the measured value being no higher than 3.5°C above the value predicted by COLD (figures 15 and 16). Pavement temperatures were nearly identical for both sections.

For both sections, the stress remained negative for most of the analysis period, becoming slightly positive only during a few hours on six separate days. Since it seems unreasonable to suggest that a pavement at near-freezing temperatures is either in compression or a state of neutral stress, the results are suspicious. As the analysis period was selected, because it represented the time interval with the coldest average minimum daily temperatures and incidentally included the coldest day of the year, the pavement should, in theory, have cooled down and remained in tension for the majority of the cold period.

A casual but systematic sensitivity analysis of the model with regard to the values set for its input parameters was conducted, revealing at least three interesting details: (1) pavement layer thermal properties have an almost imperceptible effect on the calculated pavement temperature (even unrealistically extreme conductivity and heat capacity values did not seem to change the output significantly); (2) modifying the solar insolation input had a minor but discernible effect on the results; and (3) adjusting either of the stiffness or strength curves by any small increment only changed the magnitude of the respective output parameter by a similarly small amount. Other than using a time-dependent creep stiffness, COLD is a linear elastic model relying on the notion that stress is proportional to strain by a constant (i.e., stiffness). Recall that there is an additional assumed initial condition that no stress is initially acting on the pavement. Thus, any temperature increase over an increment of time (e.g., from -25°C to -20°C) will result in a computed stress that is, however improbable in practical reality, compressive.

To induce a non-zero initial stress, the initial pavement temperature profile was modified to reflect much warmer conditions (roughly 10°C above actual). It was thought that the original climatic data would, over the next few days of the analysis period, effectively impose a tensile stress on the pavement. This was not the case. Within a day, the calculated pavement surface temperature was nearly identical to that produced by using the unadjusted data. No other attempts were made to resolve the apparent contradiction.

Hybrid Pavement

The hypothetical hybrid mix constructed with the WesTrack binder and all other MnROAD mix properties, and subjected to MnROAD climatic conditions (i.e., during the period of January 18 through February 6, 1996), showed cracking to occur by a smaller margin than the MnROAD AC-20 mix but significantly more than the AC-120/150 mix (figures 17 and 18). The hybrid

performed most like the AC-20 mix. In principle, one would expect failure at a pavement temperature of -22°C, or slightly below. The first failure event was predicted to occur on the morning of February 1 at a COLD pavement temperature of -23.3°C (-9.9°F) (figure 18 and appendix C). This agrees closely with the low temperature specification suggested by the SHRP PG binder grading system. The measured temperature at that time was -26.4°C (-15.6°F), approximately 3°C lower than COLD estimated. Agreement between measured and calculated temperature was very good for this time increment but inconsistent throughout the analysis period.

CONCLUSION

TSRST results are useful as a predictive tool only insofar as fracture temperature is concerned. It was found that an acceptably strong relationship exists between T_f and $S(t)$, which is directly linked to low temperature mix stiffness and thus to cracking potential, as seen in the results of COLD analysis.

With respect to the performance of the hypothetical hybrid pavement constructed with the asphalt cement used at WesTrack, it appears that all of the information required to judge a pavement's low temperature performance is adequately captured by knowledge of material rheological properties acquired in the laboratory, knowledge about likely climatic conditions, and application of a suitable pavement temperature prediction model.

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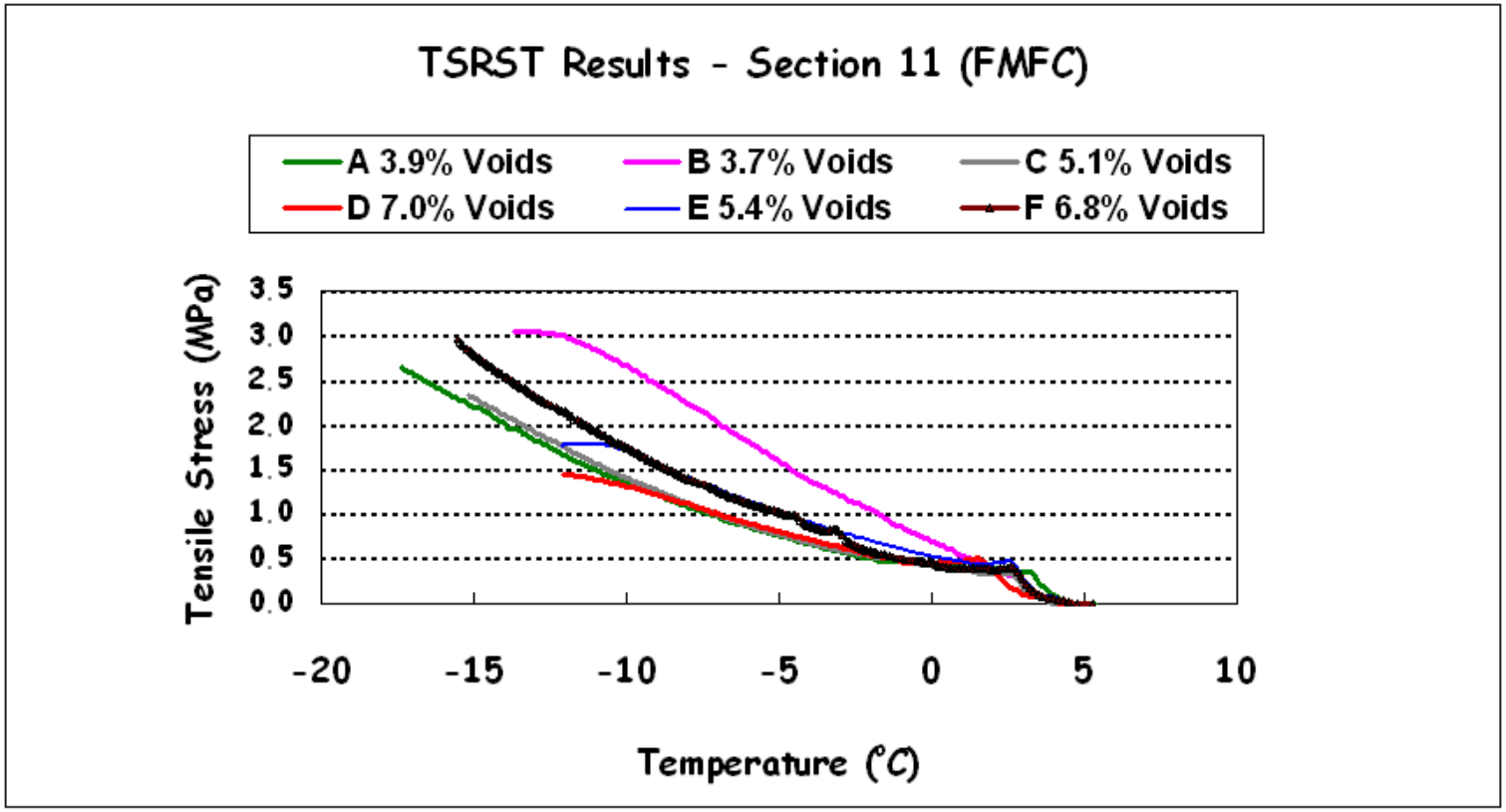
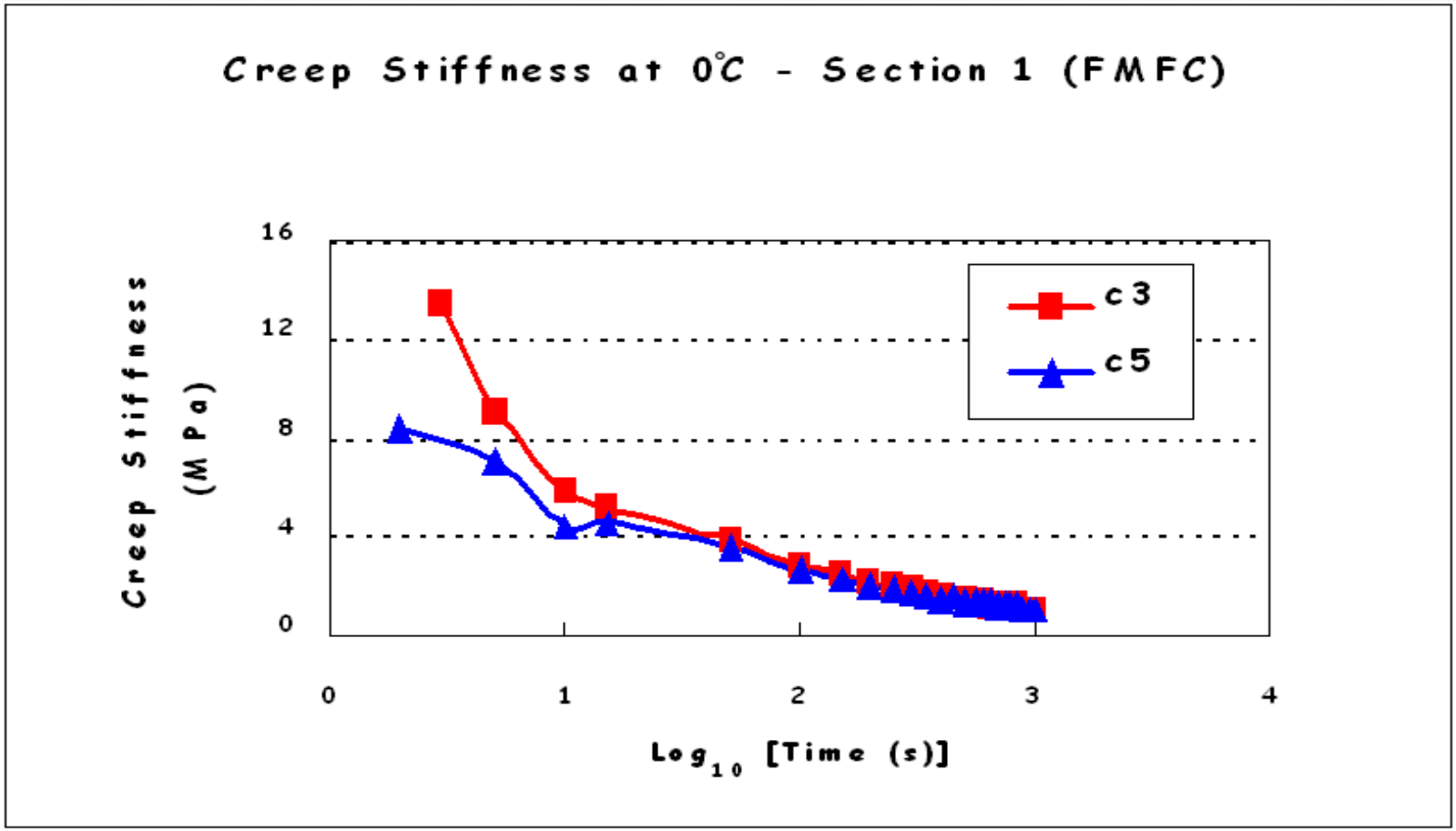


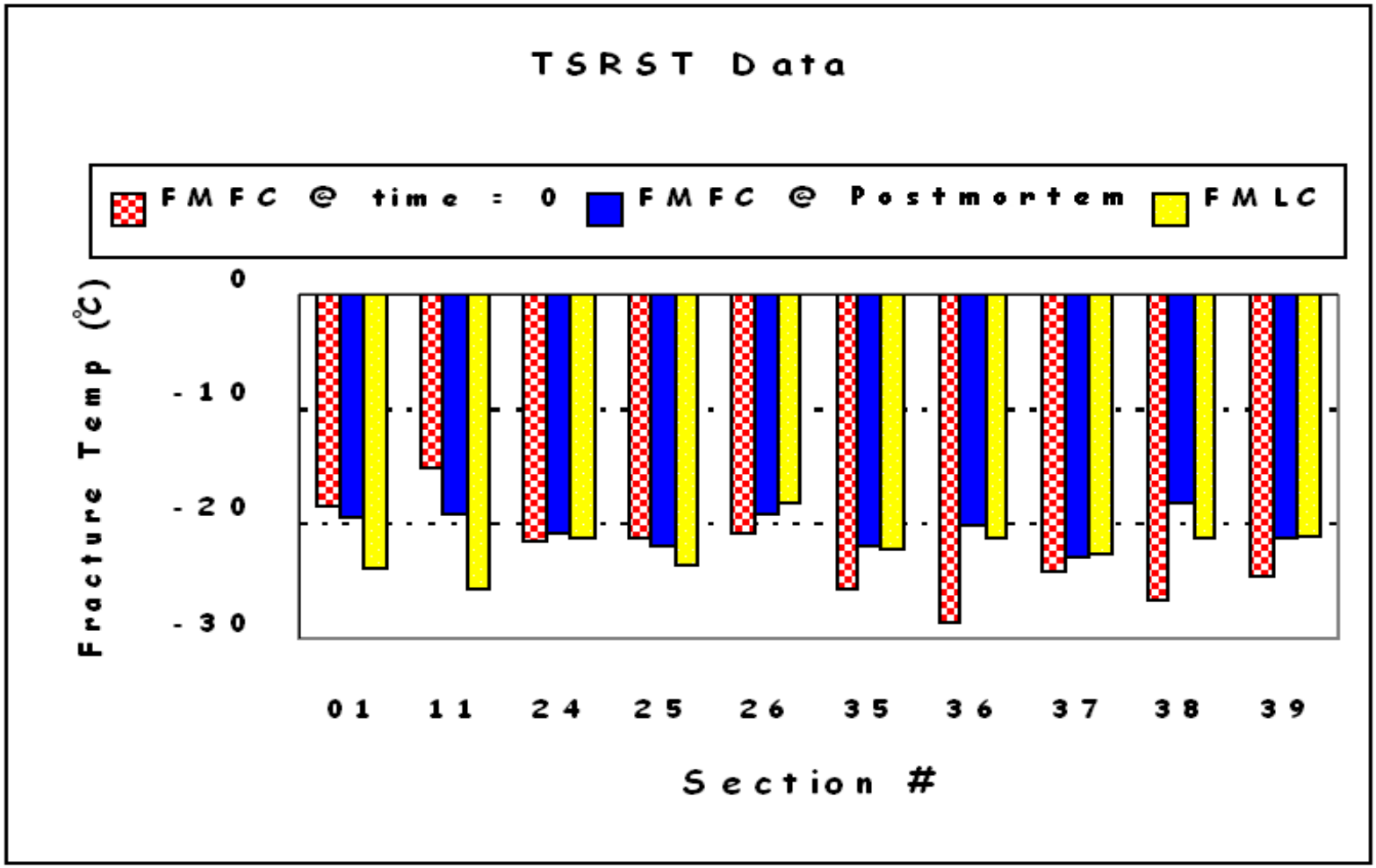
°F = 1.8 °C + 32
1 ksi = 6.9 MPa

Figure 1. Typical TSRST results.



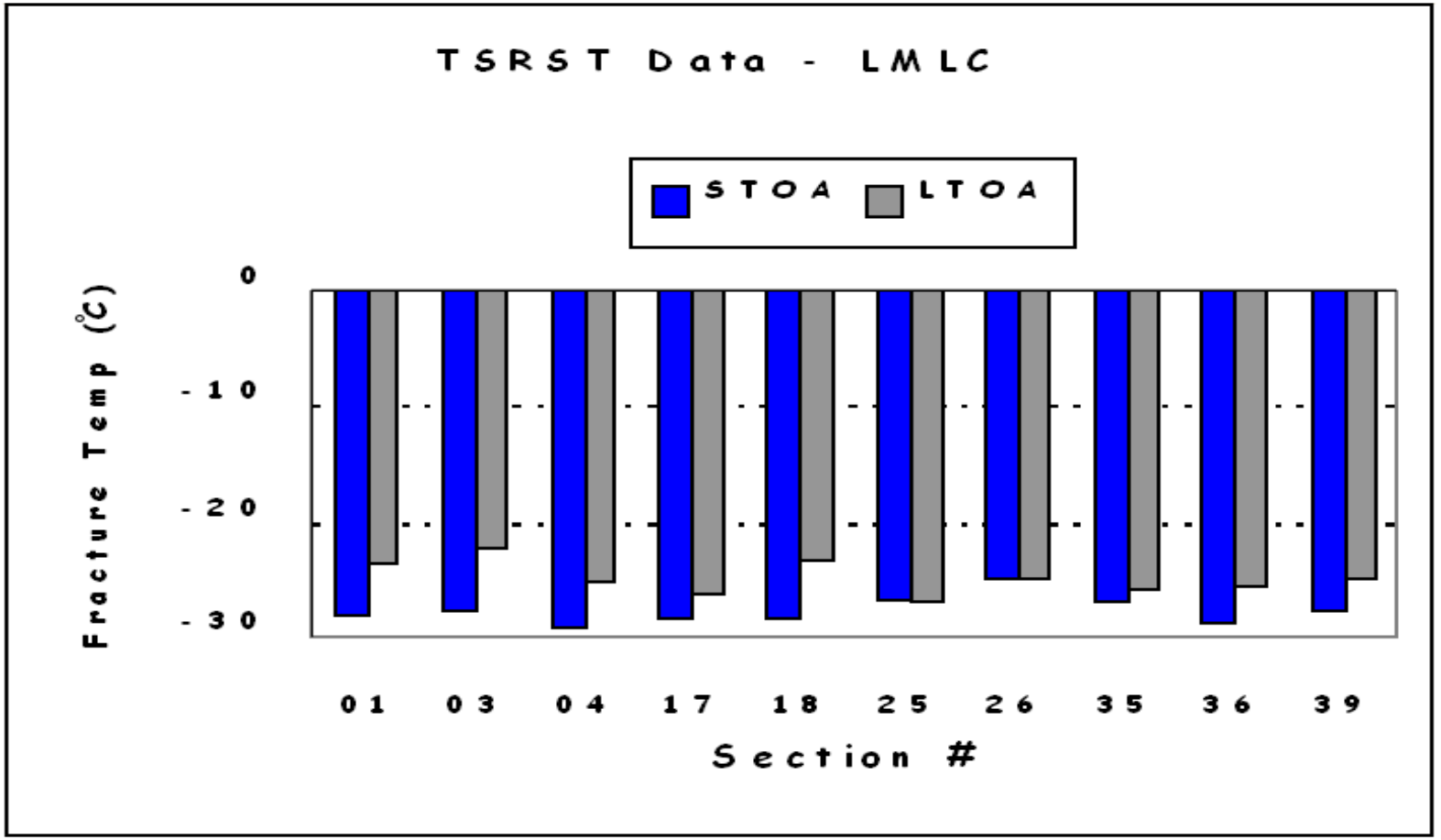
°F = 1.8 °C + 32
1 ksi = 6.9 MPa

Figure 2. Typical IDT creep results.



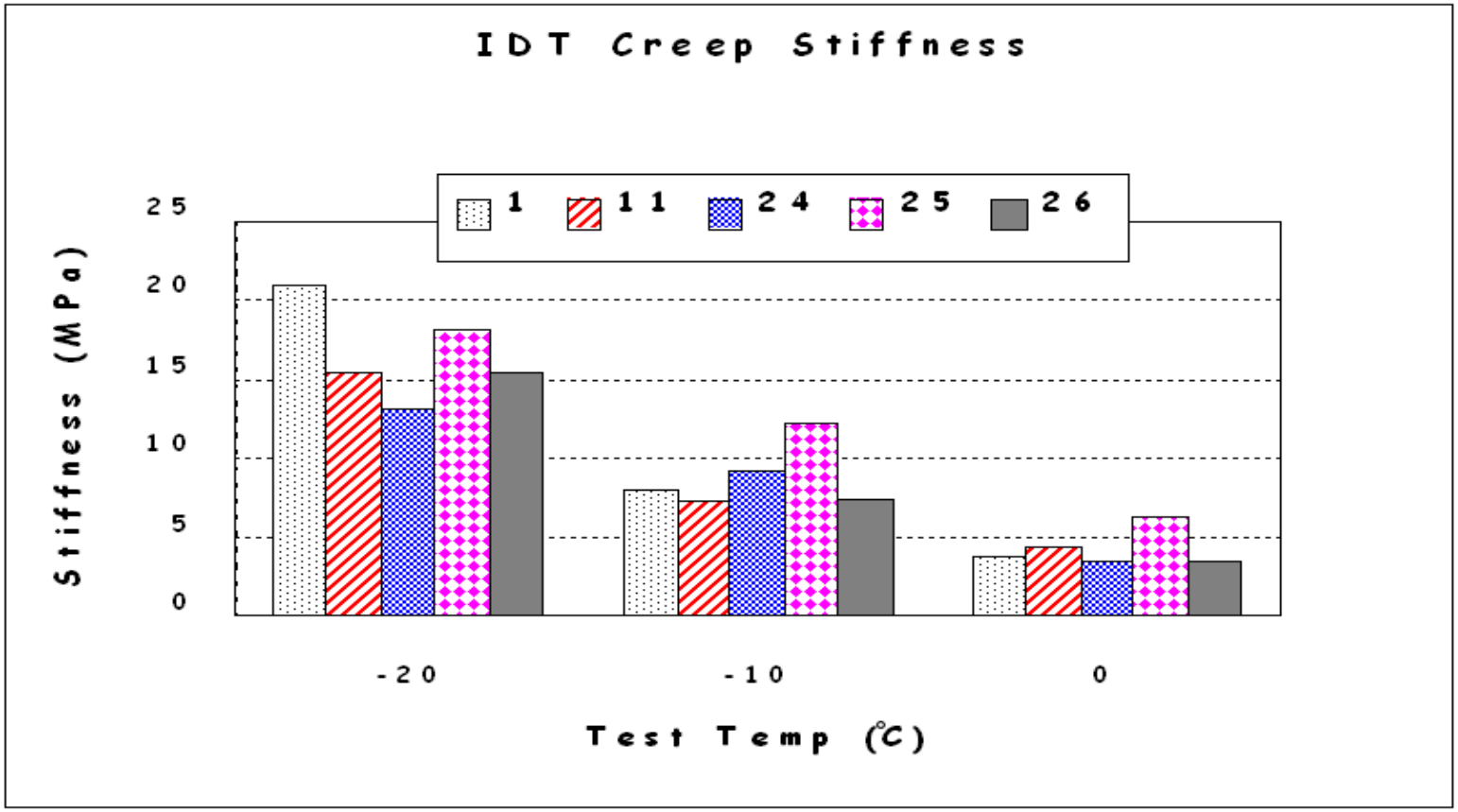
°F = 1.8 °C + 32

Figure 3. Summary of TSRST results.



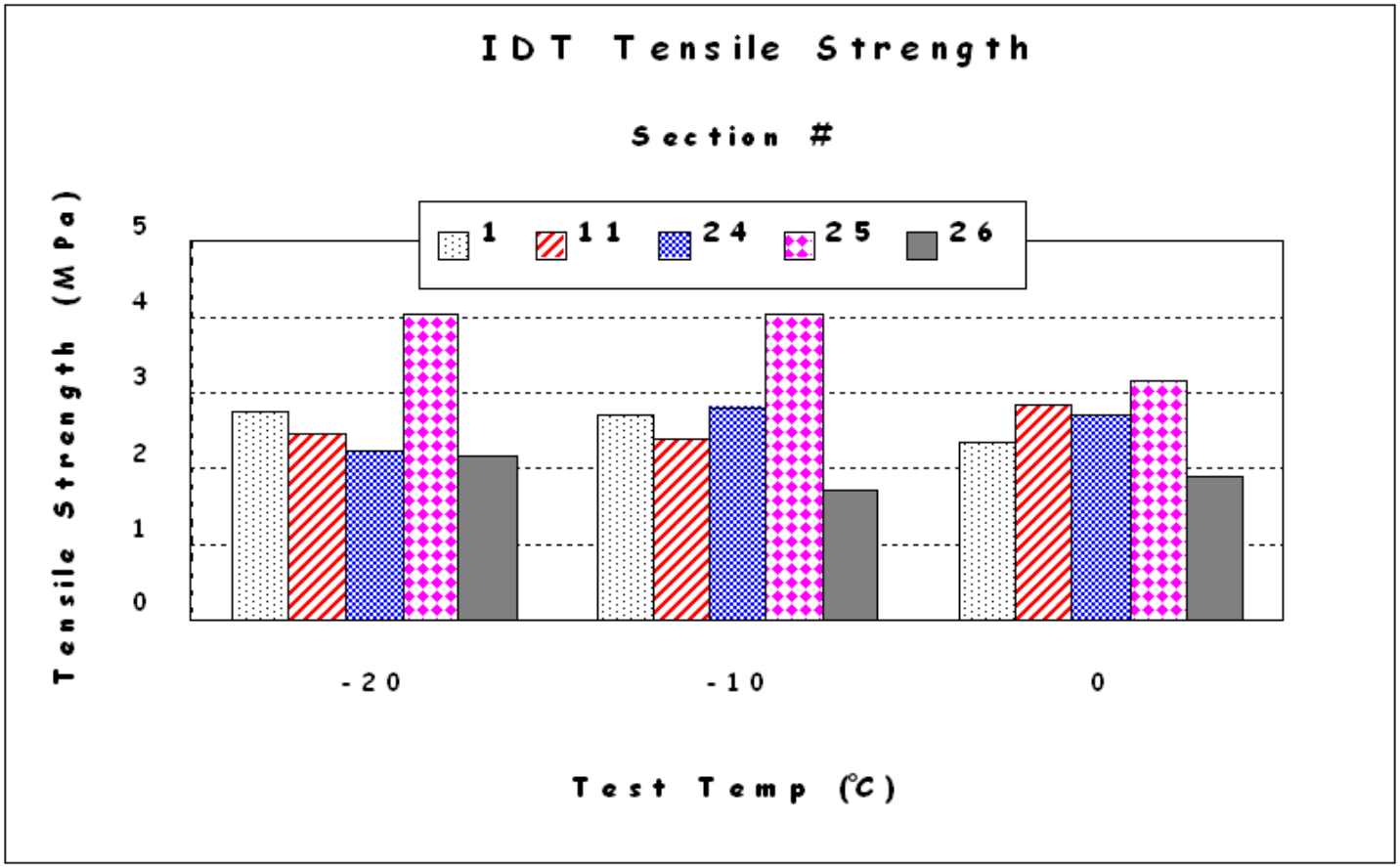
°F = 1.8 °C + 32

Figure 4. Summary of TSRST results from aging study.



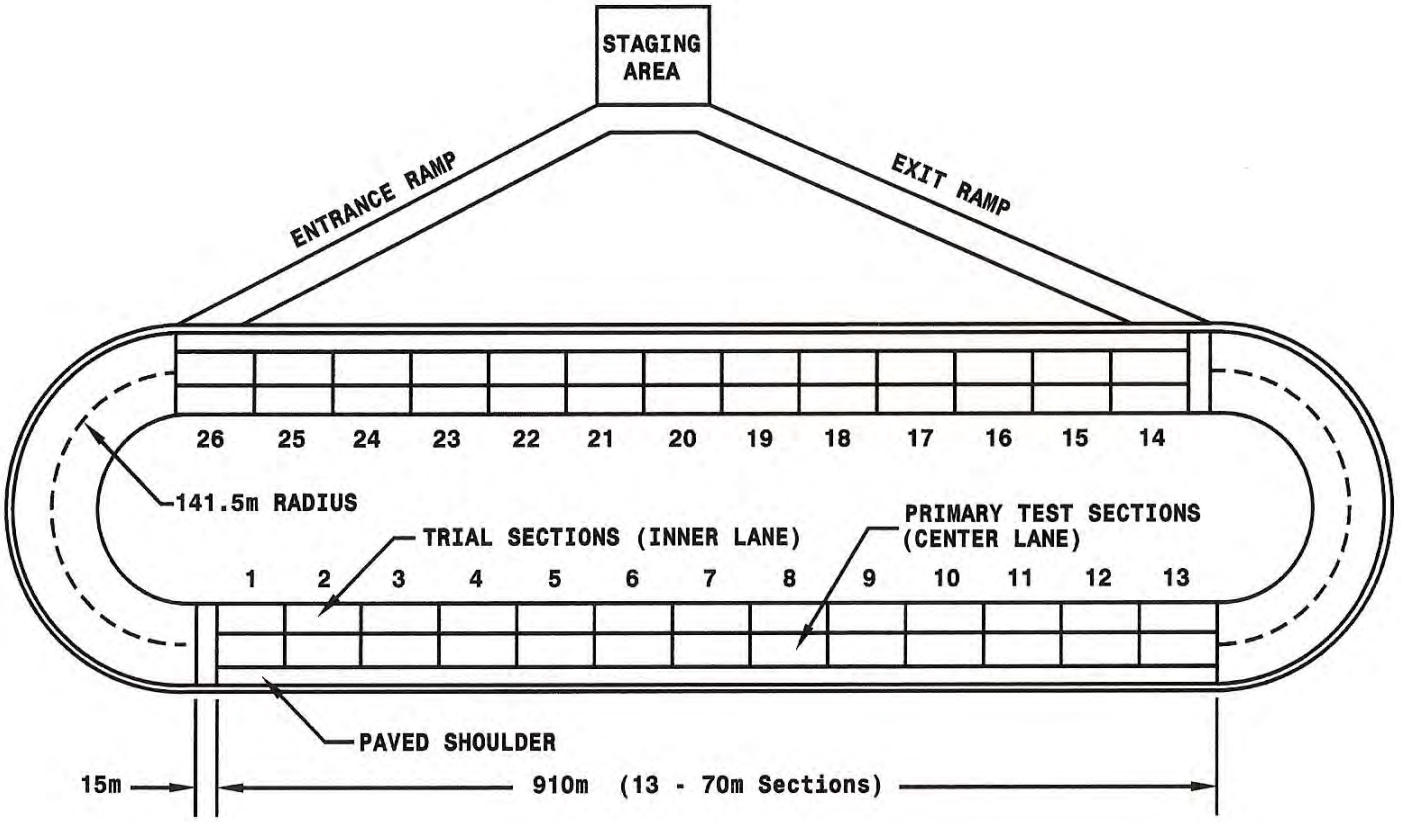
°F = 1.8 °C + 32
1 ksi = 6.9 MPa

Figure 5. Summary of IDT results (stiffness).



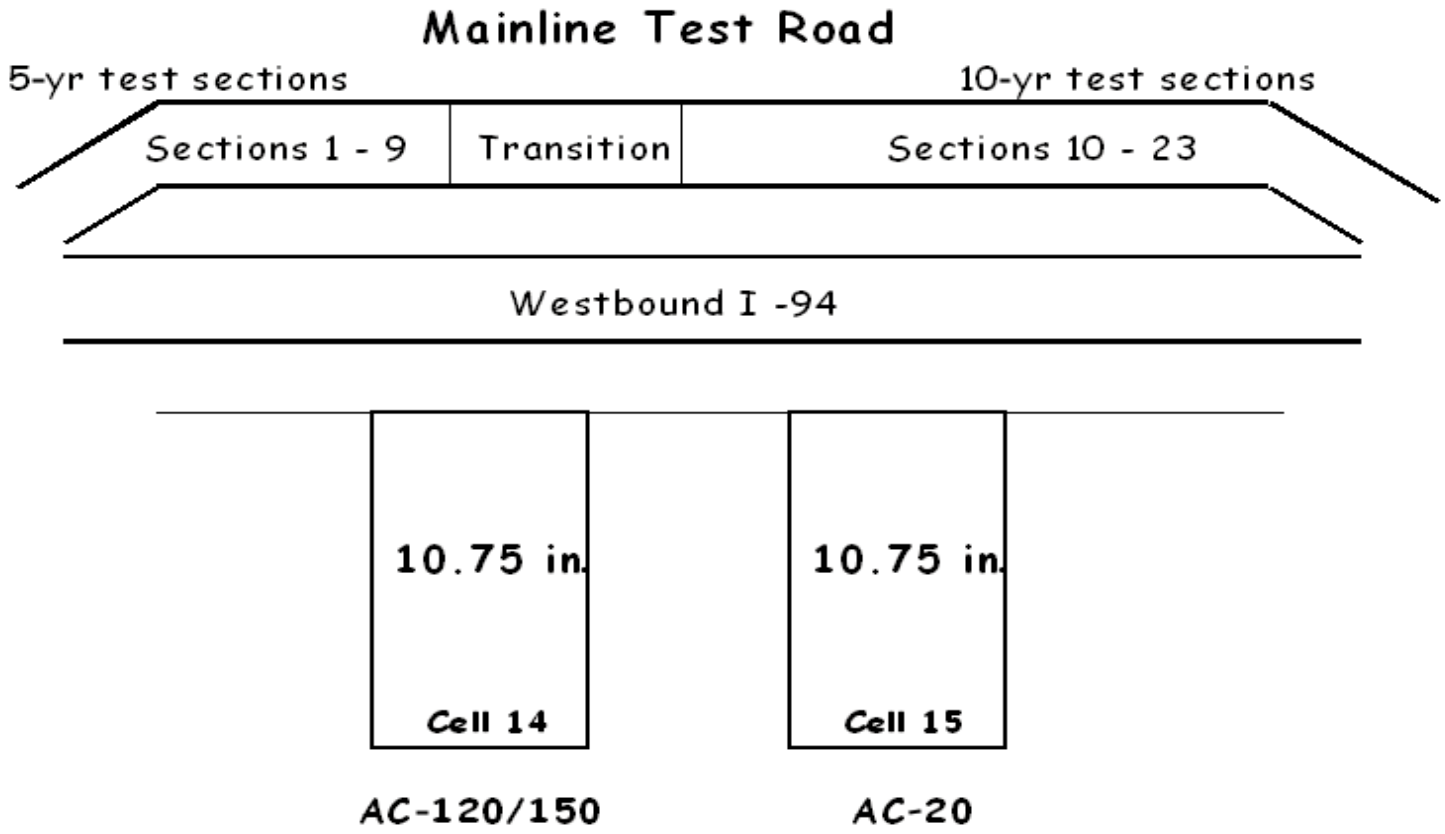
°F = 1.8 °C + 32
1 ksi = 6.9 MPa

Figure 6. Summary of IDT results (tensile strength).



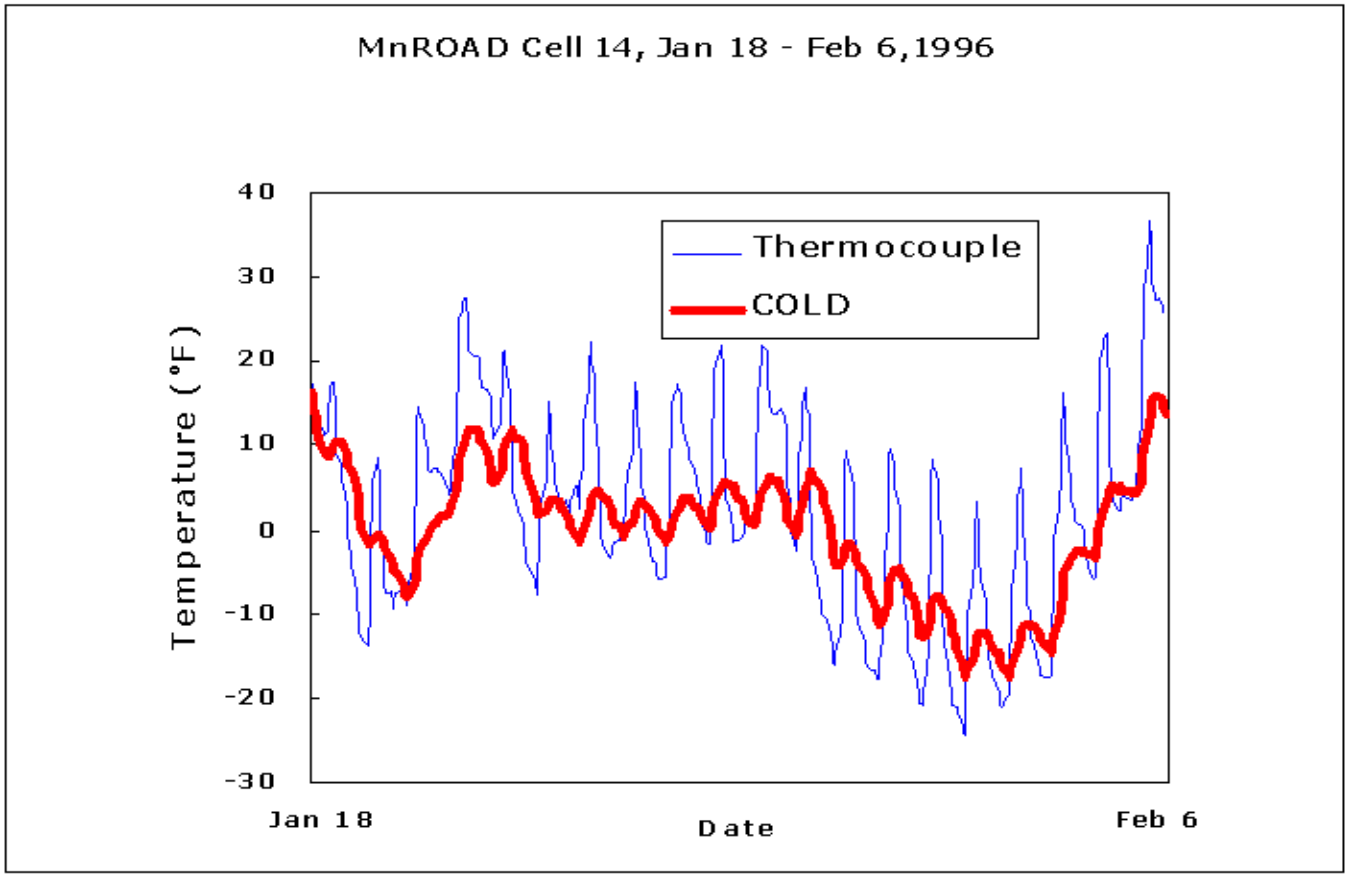
1 ft = 0.305 m

Figure 7. Schematic of WesTrack.



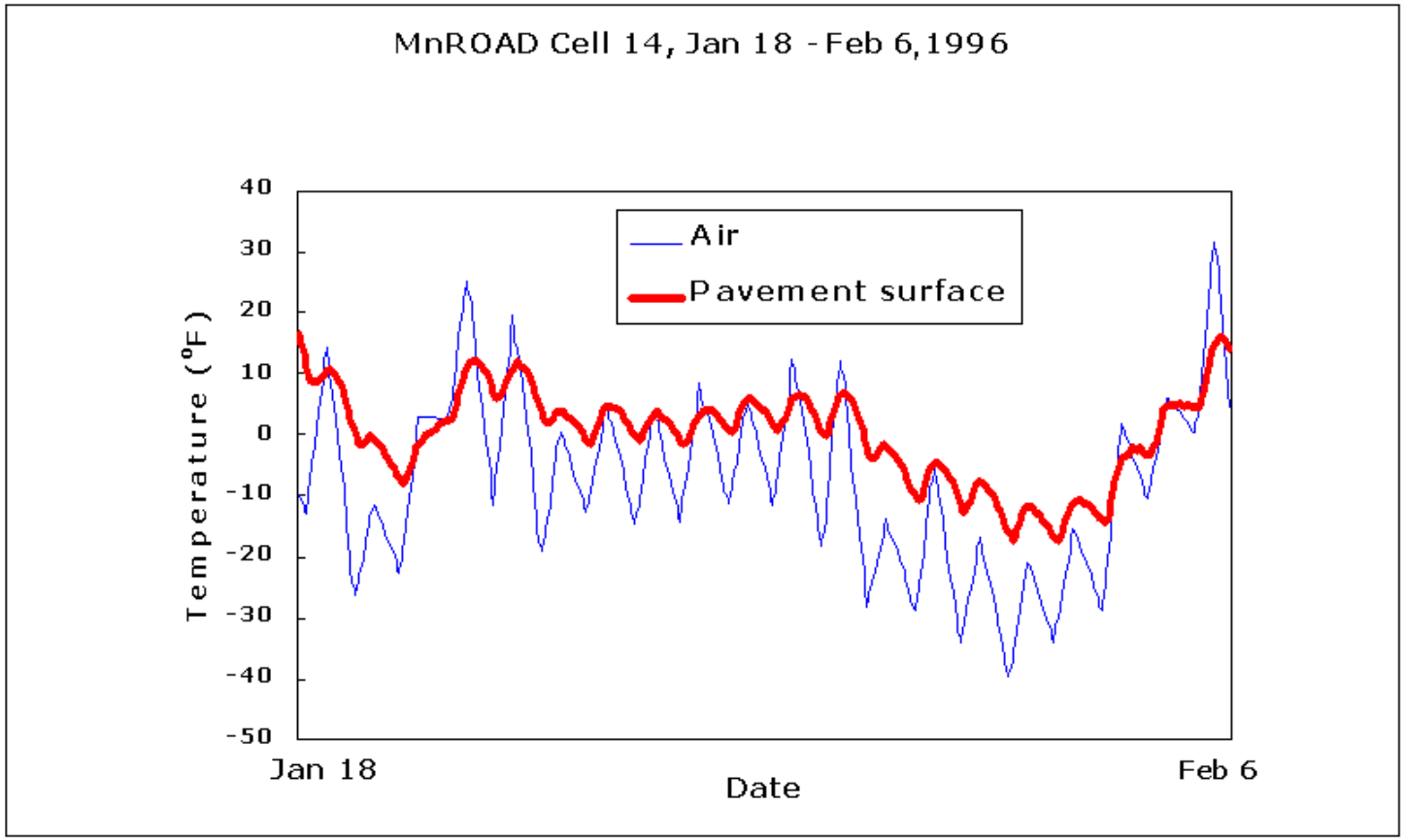
1 inch = 25.4 mm

Figure 8. Schematic of MnRoad.



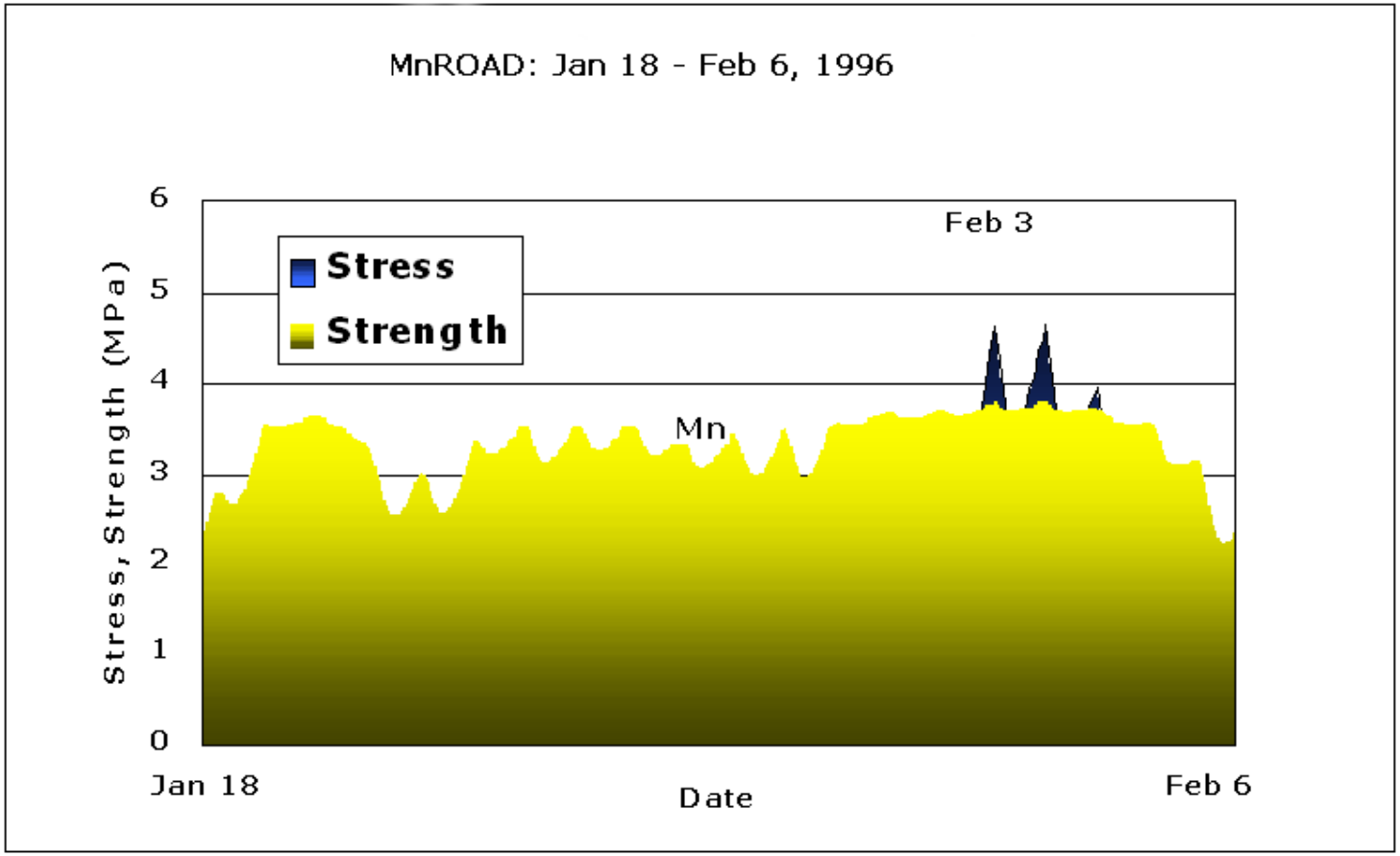
°F = 1.8 °C + 32

Figure 9. MnROAD temperature data (COLD vs. thermocouple).



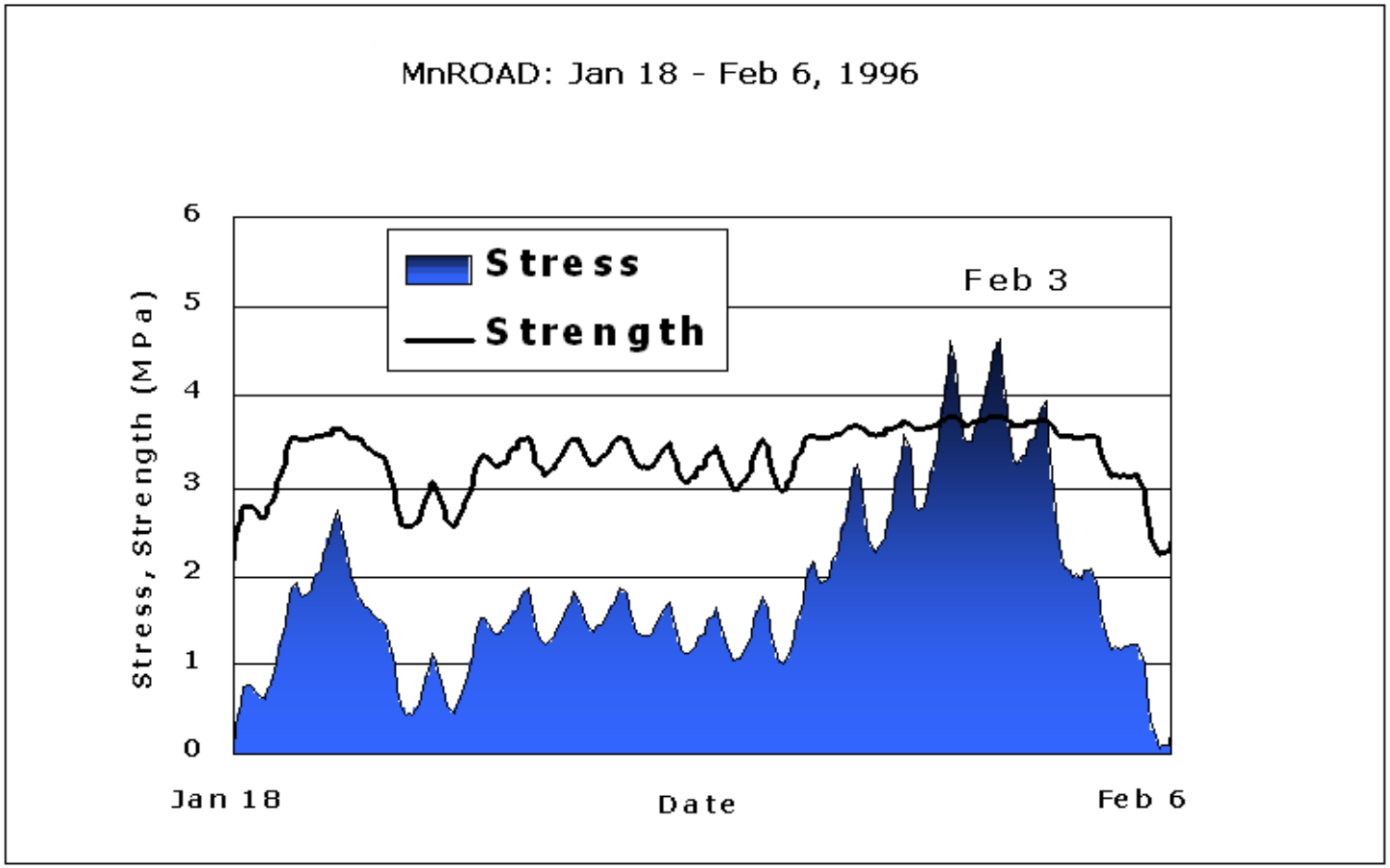
°F = 1.8 °C + 32

Figure 10. MnROAD temperature data (air vs. pavement surface).



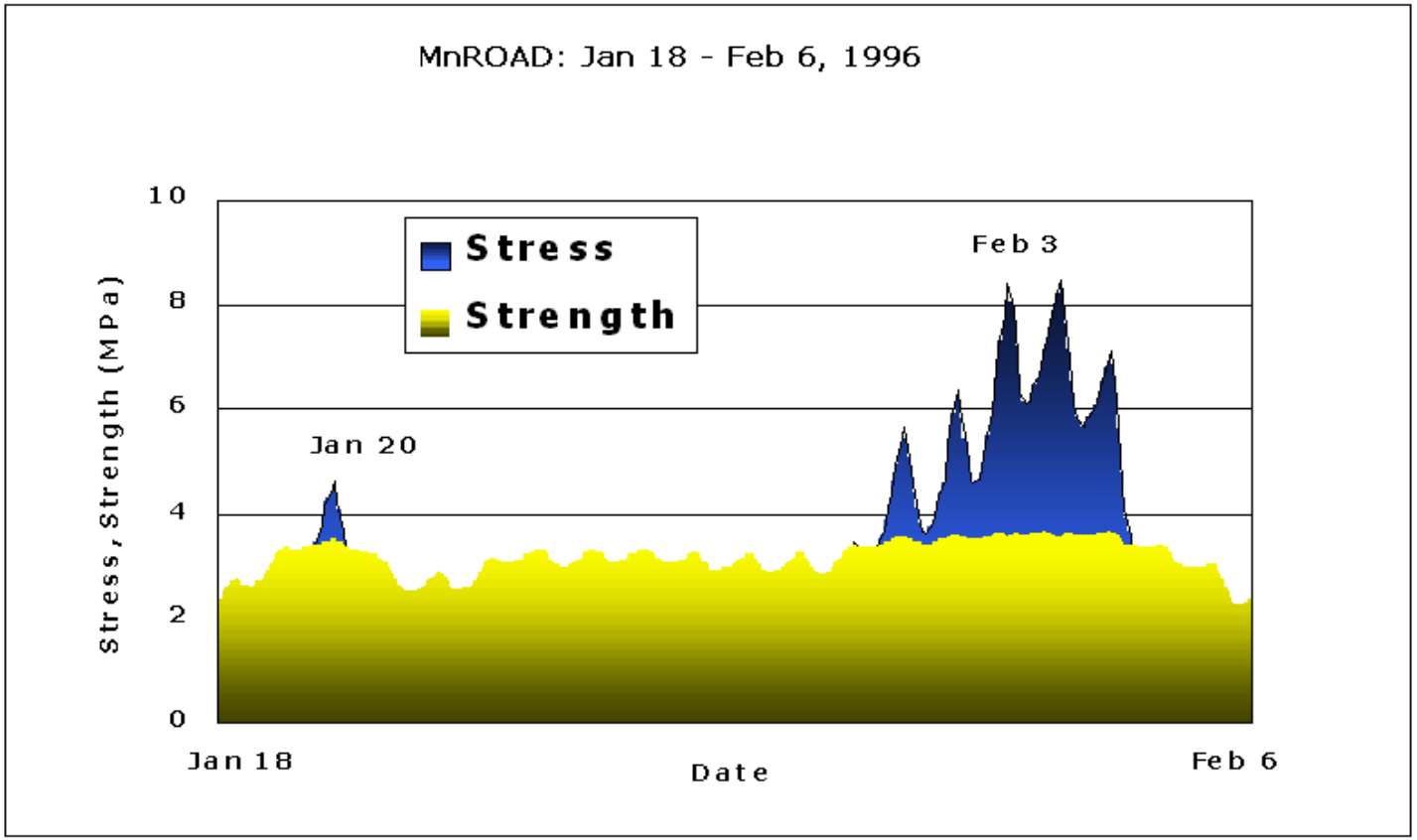
1 ksi = 6.9 MPa

Figure 11. Area plot of COLD stress and strength output (cell 14).



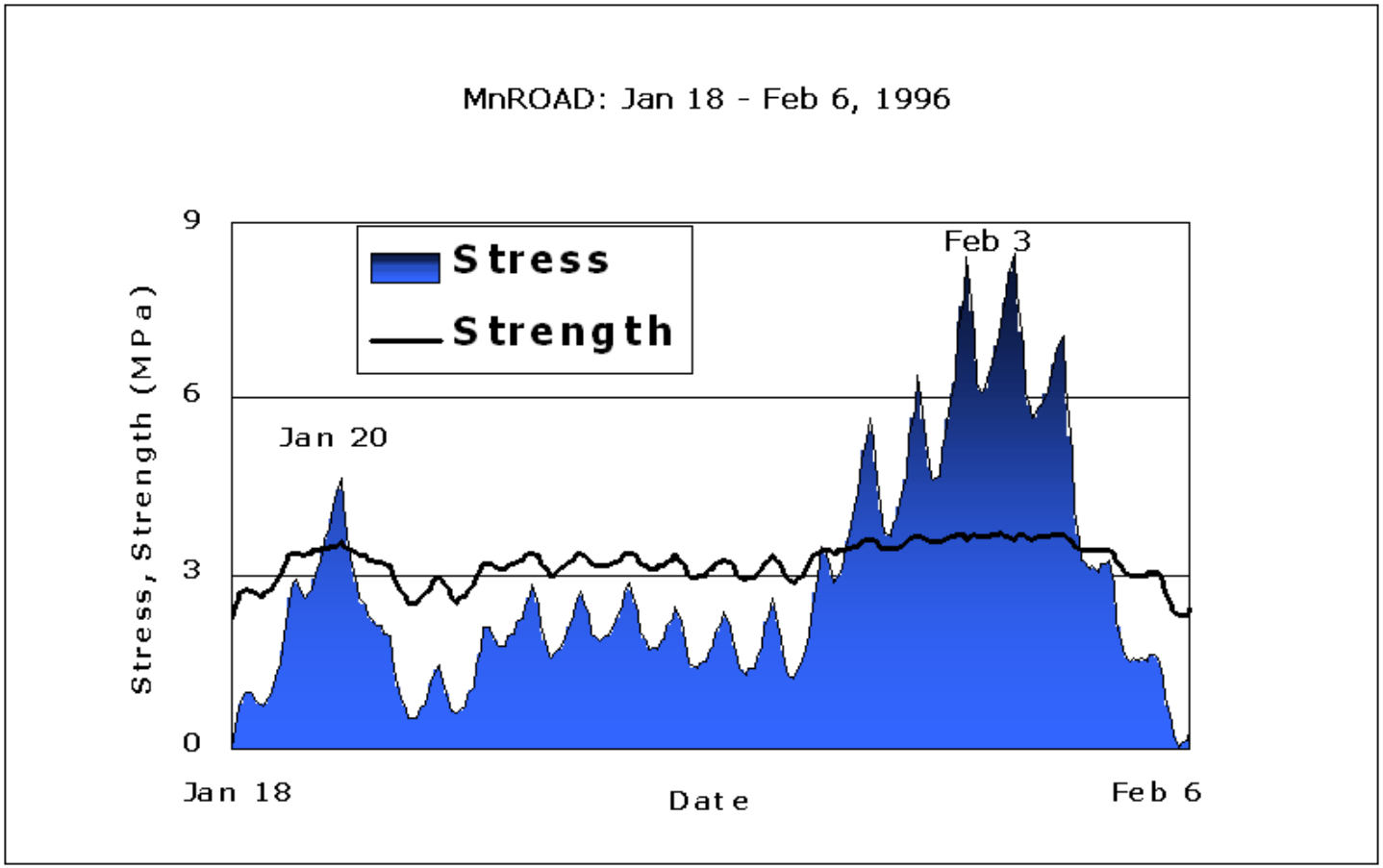
1 ksi = 6.9 MPa

Figure 12. COLD stress and strength output (cell 14).



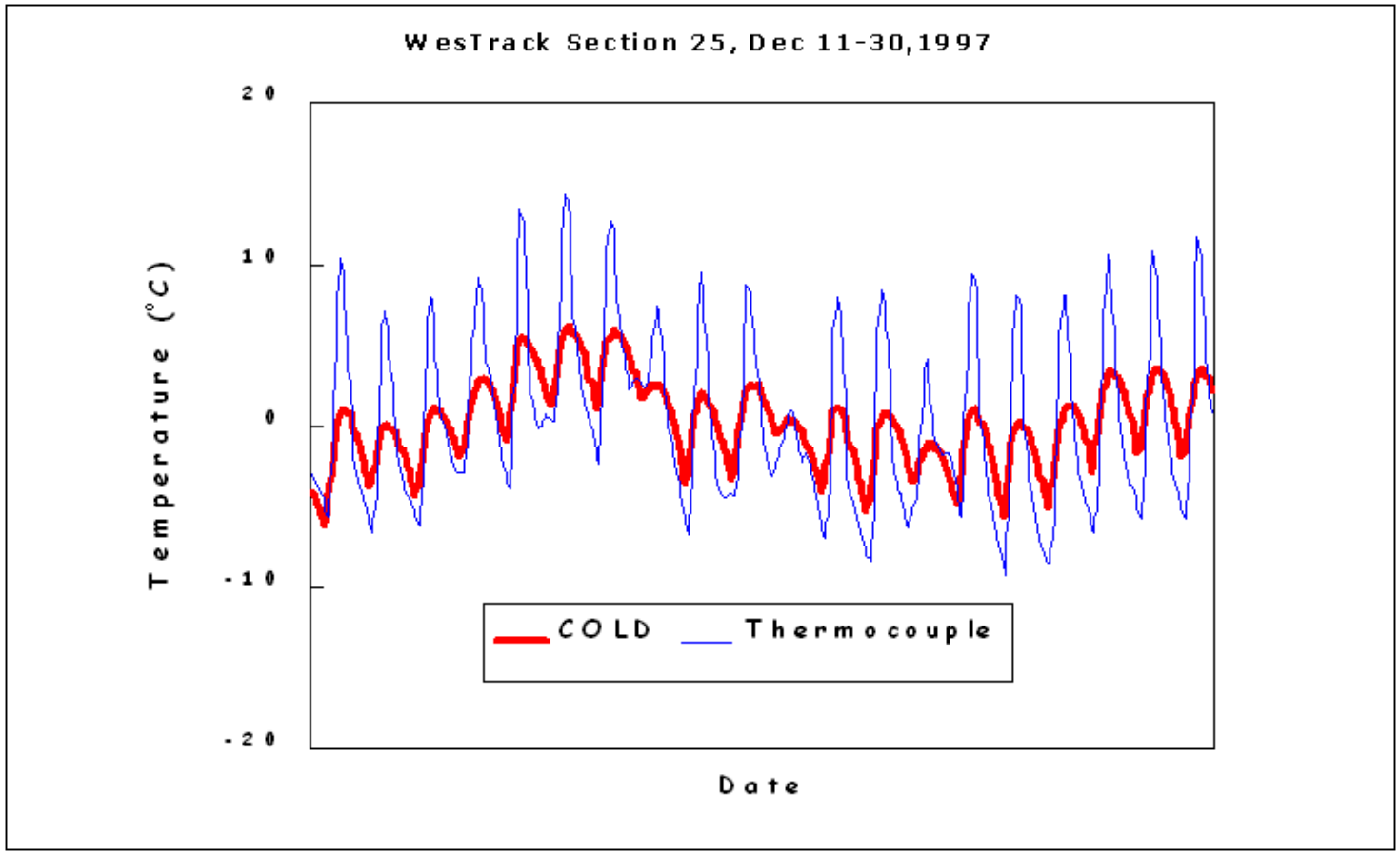
1 ksi = 6.9 MPa

Figure 13. Area plot of COLD stress and strength output (cell 15).



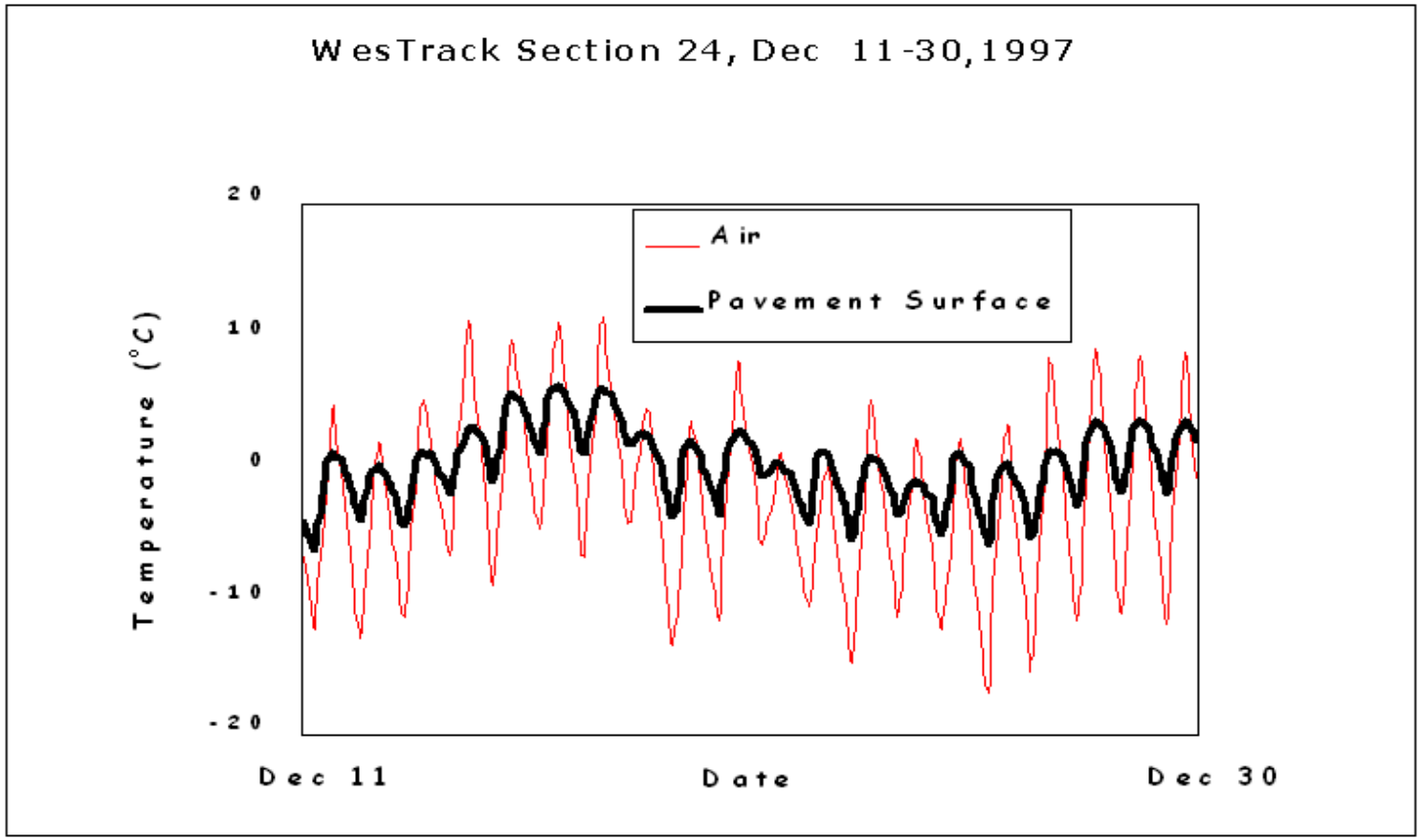
1 ksi = 6.9 MPa

Figure 14. COLD and strength output (cell 15).



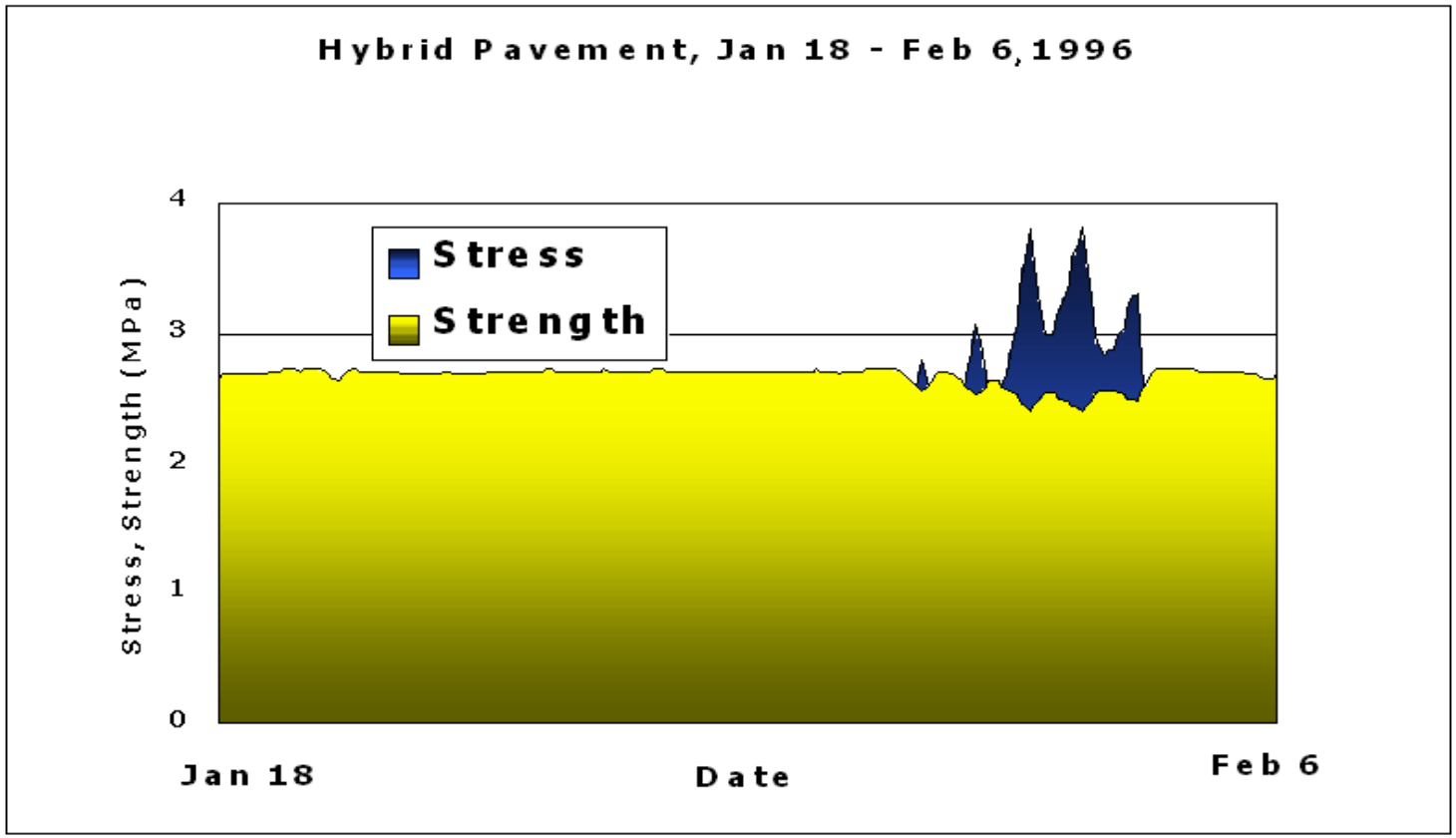
°F = 1.8 °C + 32

Figure 15. WesTrack temperature data (COLD vs. thermocouple).



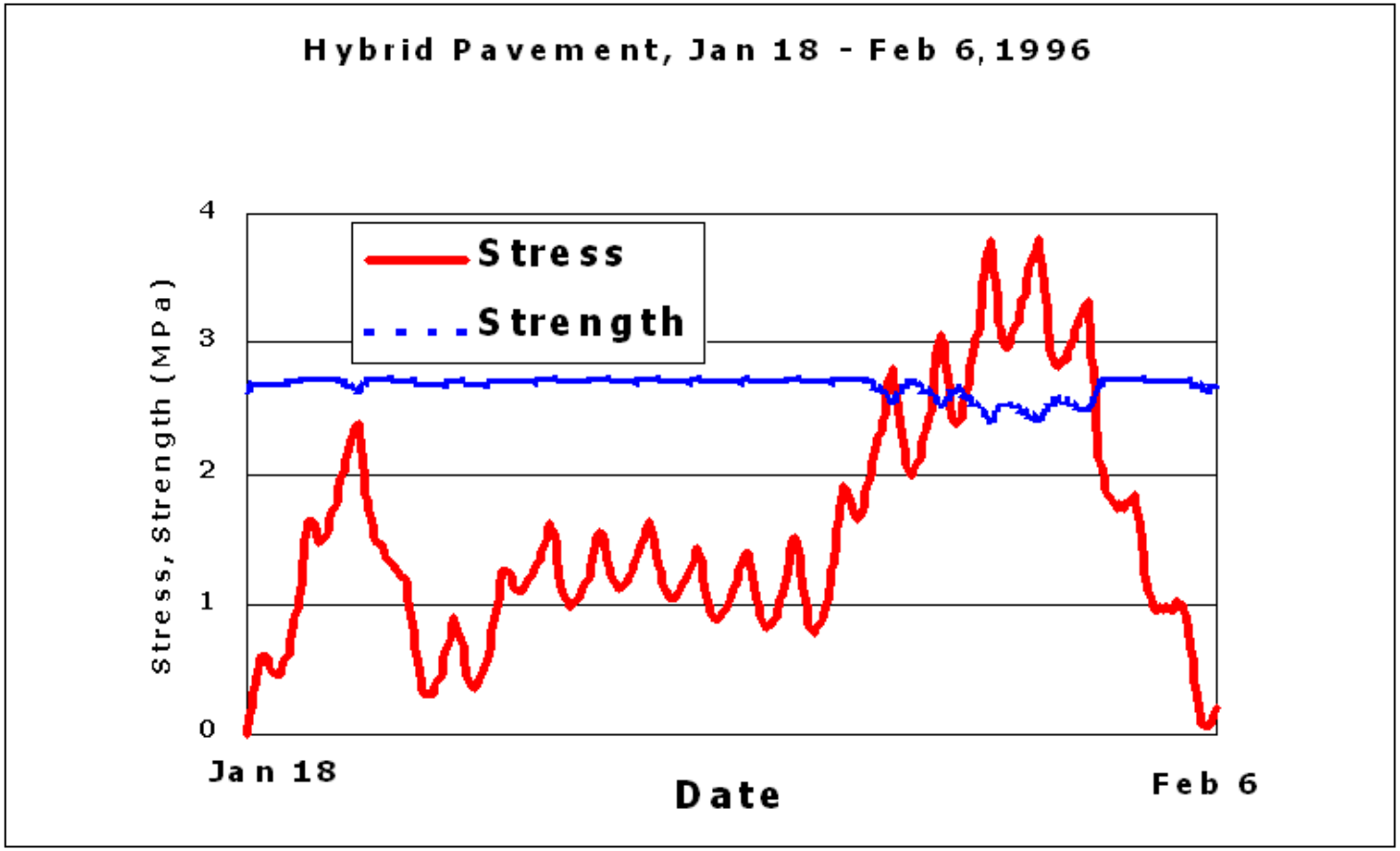
°F = 1.8 °C + 32

Figure 16. WesTrack temperature data (air vs. pavement surface).



1 ksi = 6.9 MPa

Figure 17. Area plot of COLD stress and strength output (hybrid pavement).



1 ksi = 6.9 MPa

Figure 18. COLD stress and strength output (hybrid pavement).

Table 1. Experiment design.

Design Air Void Content	Aggregate Gradation Designation								
	Fine			Fine Plus			Coarse		
	Design Asphalt Contents (%)								
(%)	Low	Optimum	High	Low	Optimum	High	Low	Optimum	High
Low		04	18		12	09/21		23 (39)	25 (55)
Medium	02	01/15	14	22	11/19	13	08 (38)	05/24 (35/54)	07 (37)
High	03/16	17		10	20		26 (56)	06 (36)	

Note: (xx) = Replacement Section

Table 2. Low temperature cracking test plan.

	Section Number	
	TSRST	IDT
FMFC: time = 0	1, 11, 24, 25, 26 35 - 39	1, 11, 24, 25, 26
FMFC: postmortem	1, 11, 24, 25, 26 35 - 39	
FMLC	1, 11, 24, 25, 26 35 - 39	1, 11, 24, 25, 26
LMLC	1, 3, 4, 17, 18, 25, 26, 35, 36, 39 **	
FMFC: field-mixed, field-compacted FMLC: field-mixed, laboratory-compacted LMLC: laboratory-mixed, laboratory-compacted		** STOA & LTOA

Table 3. Results of t-tests from TSRST data (fracture temperature).

Data Set	t - Statistic	t - Critical	Means Different?
FMFC time = 0 vs postmortem	1.577	2.101	no
FMFC @ time = 0 vs FMLC	0.446	2.101	no
FMFC postmortem vs FMLC	1.900	2.101	no
LMLC STOA vs LTOA	4.529	2.101	yes

Table 4. Pavement layer properties at MnROAD.

Cell	Layer	K_u	K_f	C_u	C_f	γ_d(pcf)	w(%)	Air Voids (%)	Asphalt Content (%)	V_s (%)
14	AC	0.85	0.85	0.22	0.22	147.3	2.0	3.85	5.34	90.81
	Subgrade	1.06	1.29	0.30	0.22	113.9	17.8	--	--	--
15	AC	0.85	0.85	0.22	0.22	147.1	2.0	3.90	5.50	90.60
	Subgrade	1.00	1.19	0.29	0.22	112.4	16.7	--	--	--

Table 5. Pavement condition survey: MnROAD cells 14 and 15.

Cell	Lane	Survey Date	Transverse Cracks	
			Number	Combined Length (ft) (1 ft = 0.305 m)
14	Passing	2/11/94	0	0
	Driving	2/11/94	0	0
	Passing	10/21/94	0	0
	Driving	10/21/94	0	0
	Passing	4/20/95	0	0
	Driving	4/20/95	0	0
	Passing	11/4/95	0	0
	Driving	11/4/95	0	0
	Passing	**2/13/96**	**15**	**174**
	Driving	**2/13/96**	**15**	**179**
	Passing	3/1/96	15	174
	Driving	3/1/96	17	203
	Passing	3/13/96	17	192
	Driving	3/13/96	20	232
	Passing	4/18/96	17	192
	Driving	4/18/96	29	262
	Passing	11/13/96	17	192
	Driving	11/13/96	29	262
	Passing	4/30/97	17	192
	Driving	4/30/97	29	262
	Passing	11/15/97	17	192
	Driving	11/15/97	29	262
	Passing	4/29/98	17	194
	Driving	4/29/98	30	266
	Passing	10/2/98	17	194
	Driving	10/2/98	30	266
15	Passing	2/11/94	0	0
	Driving	2/11/94	0	0
	Passing	10/21/94	0	0
	Driving	10/21/94	0	0
	Passing	4/20/95	0	0
	Driving	4/20/95	0	0
	Passing	11/4/95	0	0
	Driving	11/4/95	0	0
	Passing	**2/13/96**	**30**	**350**
	Driving	**2/13/96**	**35**	**375**
	Passing	3/1/96	30	350
	Driving	3/1/96	40	408
	Passing	3/13/96	32	361
	Driving	3/13/96	44	436
	Passing	4/18/96	53	447
	Driving	4/18/96	57	490
	Passing	11/13/96	53	447
	Driving	11/13/96	57	490
	Passing	4/30/97	53	447
	Driving	4/30/97	57	490
	Passing	11/15/97	53	447
	Driving	11/15/97	57	490
	Passing	4/29/98	55	451
	Driving	4/29/98	57	492
	Passing	10/2/98	55	451
	Driving	10/2/98	57	492

APPENDIX A

SUMMARY OF TSRST RESULTS

Summary of TSRST results.

Section #	FMFC at Time = 0			FMFC Postmortem			FMLC		
	% Air Voids	Fracture Temperature (°C)	Fracture Strength (MPa)	% Air Voids	Fracture Temperature (°C)	Fracture Strength (MPa)	% Air Voids	Fracture Temperature (°C)	Fracture Strength (MPa)
01	9.1	-18.5	1.81	5.8	-19.5	2.64	8.4	-24.0	1.48
03									
04									
11	5.3	-15.2	2.51	4.3	-19.2	3.32	5.4	-25.7	1.54
17									
18									
24	4.8	-21.8	2.92	6.4	-20.9	2.71	7.6	-21.3	2.21
25	2.6	-21.3	2.88	6.1	-22.0	2.20	2.7	-23.5	2.51
26	8.4	-20.8	2.35	9.0	-19.2	2.26	7.4	-18.2	0.61
35	8.0	-25.8	1.95	5.5	-22.0	2.40	7.8	-22.2	2.14
36	12.4	-28.7	1.16	11.1	-20.4	1.53	7.6	-21.3	2.20
37	9.1	-24.3	1.80	7.8	-23.1	2.49	7.6	-22.7	2.07
38	7.2	-26.8	2.54	7.0	-18.3	1.76	8.1	-21.3	2.72
39	3.9	-24.6	2.98	3.0	-21.5	3.00	8.1	-21.2	1.66

Summary of TSRST results (continued).

Section #	LMLC STOA			LMLC LTOA		
	% Air Voids	Fracture Temperature (°C)	Fracture Strength (MPa)	% Air Voids	Fracture Temperature (°C)	Fracture Strength (MPa)
01	8.5	-28.0	2.16	8.3	-23.7	2.45
03	12.4	-27.5	1.72	12.8	-22.2	1.33
04	4.7	-29.2	2.89	4.6	-25.1	3.23
11						
17	12.1	-28.5	1.90	12.4	-26.2	1.84
18	4.6	-28.3	3.08	4.5	-23.2	2.94
24						
25	4.8	-26.9	3.02	4.0	-27.1	2.98
26	12.8	-24.9	1.99	12.5	-24.8	2.05
35	8.0	-27.1	2.70	8.4	-26.0	2.58
36	12.5	-29.0	2.24	12.3	-25.8	2.27
37						
38						
39	4.0	-27.6	3.42	4.0	-25.0	3.31

°F = 1.8 °C + 32
1 ksi = 6.9 MPa

APPENDIX B

SUMMARY OF WESTRACK IDT DATA

Summary of WesTrack IDT data.

Specimen ID	Temperature (°C)	Poisson's Ratio	Creep Compliance (1/MPa)	Creep Stiffness (MPa)	Tensile Strength (MPa)
01-D2	-20	0.38	0.0478	20.92	2.73
01-C2	-10	0.36	0.1202	8.32	3.06
01-D1	-10	0.19	0.1748	5.72	2.35
01-D3	-10	0.29	0.1048	9.54	2.63
01-C3	0	0.42	0.2606	3.84	2.17
01-C5	0	0.32	0.2792	3.58	2.48
11-C3	-20	0.24	0.0778	12.85	2.47
11-D4	-20	0.59	0.0556	17.99	2.46
11-C2	-10	0.13	0.1374	7.28	2.40
11-C4	0	0.18	0.2317	4.32	2.85
24-C3	-20	0.51	0.0789	12.67	1.90
24-C5	-20	0.19	0.0745	13.42	2.54
24-C1	-10	0.16	0.1085	9.22	2.82
24-C4	0	0.18	0.2709	3.69	2.04
24-C4	0	0.20	0.3292	3.04	2.10
25-C1	-20	0.38	0.0478	20.92	4.08
25-C5	-20	0.07	0.0655	15.27	4.00
25-C3	-10	0.22	0.0856	11.68	4.11
25-D4	-10	0.47	0.0785	12.74	3.96
25-C4	0	0.39	0.2412	4.15	3.53
25-D3	0	0.42	0.1096	9.12	3.42
25-D2	0	0.36	0.1891	5.29	2.56
26-C2	-20	0.39	0.0855	11.70	2.11
26-C5	-20	0.40	0.0532	18.80	2.20
26-C3	-10	0.32	0.1318	7.59	1.51
26-D2	-10	0.21	0.1392	7.18	1.89
26-C4	0	0.24	0.4035	2.48	1.25
26-D3	0	0.35	0.3231	3.10	1.97
26-D4	0	0.50	0.2176	4.60	1.76

°F = 1.8 °C + 32
1 ksi = 6.9 MPa

APPENDIX C

COLD DATA FILES

MnROAD Cell 14 COLD input file

test_run....DELTA_T=2-hours
number_of_days= 20
delta_t= 2
number_of_layers= 2
delta_x= 2.0
begin_freezing(b)= 29.0
partially_frozen(f)= 24.0
absorptivity= .900
emissivity= .850
convection_coefficient= 3.000

Ku____Kf____Cu____Cf____density_thickness__moisture_%frozen
0.850 0.850 0.220 0.220 147.300 10.000 2.000
1.060 1.290 0.300 0.220 113.900 134.000 17.800 90.00

number_of_extreme_temps= 2
initial_temp= -10.0
final_temp= -2.5
sunrise= 7.6
sunset= 17.2

times_for_extreme_temperatures
5.5
15.5

title_____	radiation__	temp1_...	
18-Jan-96	42.8	-13.1	14.3
19-Jan-96	98.1	-26.1	-11.6
20-Jan-96	84.3	-22.5	3.2
21-Jan-96	60.4	2.5	25.1
22-Jan-96	83	-11.4	19.5
23-Jan-96	68.4	-19.3	0.3
24-Jan-96	103.8	-12.8	4.8
25-Jan-96	71.3	-14.5	3.5
26-Jan-96	59.3	-14.3	8.3
27-Jan-96	105.4	-11.3	5.1
28-Jan-96	63.2	-11.5	12.2
29-Jan-96	112	-18.1	12
30-Jan-96	119.9	-28	-13.9
31-Jan-96	106.9	-28.8	-5.7
1-Feb-96	133.9	-34	-16.8
2-Feb-96	131.9	-39.5	-21
3-Feb-96	109.6	-33.7	-15.2
4-Feb-96	127.4	-28.8	1.7
5-Feb-96	122.6	-10.5	5.8
6-Feb-96	91	0.3	31.5

initial_temp_profile
19.0 22.9 24.1 25.0 25.7 26.4 26.8 27.1
27.4 27.9 28.3 28.7 28.5 28.9 29.2 29.6
29.9 30.2 30.6 30.9 31.3 31.6 32.0 32.3

32.6 33.0 33.3 33.7 34.0 34.4 34.7 35.1
35.4 35.7 36.1 36.4 36.8 37.1 37.5 37.8
38.1 38.5 38.8 39.2 39.5 39.9 40.2 40.5
40.9 41.5 41.9 42.3 42.6 43.0 43.4 43.7
44.1 44.5 44.8 45.2 45.6 45.9 46.3 46.7
47.0 47.4 47.8 48.1 48.5 48.9 49.2 49.6
50

Poisson's_ratio= 0.35
coefficient_of_expansion= 0.000015

number_points_in_stiffness-temp_relation= 6
coefficient_of_variation= .25

temp__stiffness
-20.0 1780000
-17.0 1520000
-13.0 1300000
-9.0 1070000
-2.0 716000
0.0 657000

number_of_points_in_strength-temp_relation= 4
coefficient_of_variation= .25

temp__strength
-29.0 493
-18.0 551
0.0 509
34.0 112

MnROAD Cell 15 COLD input file

test_run....DELTA_T=2-hours
number_of_days= 20
delta_t= 2
number_of_layers= 2
delta_x= 2.0
begin_freezing(b)= 29.0
partially_frozen(f)= 24.0
absorptivity= .900
emissivity= .850
convection_coefficient= 3.000

Ku____Kf____Cu____Cf____density_thickness__moisture_%frozen
0.850 0.850 0.220 0.220 147.100 10.000 2.000
1.000 1.190 0.290 0.220 112.400 134.000 16.700 90.00

number_of_extreme_temps= 2
initial_temp= -10.0
final_temp= -2.5
sunrise= 7.6
sunset= 17.2

times_for_extreme_temperatures
5.5
15.5

title_____	radiation__	temp1_...		
18-Jan-96	42.8	-13.1	14.3	
19-Jan-96	98.1	-26.1	-11.6	
20-Jan-96	84.3	-22.5	3.2	
21-Jan-96	60.4	2.5	25.1	
22-Jan-96	83	-11.4	19.5	
23-Jan-96	68.4	-19.3	0.3	
24-Jan-96	103.8	-12.8	4.8	
25-Jan-96	71.3	-14.5	3.5	
26-Jan-96	59.3	-14.3	8.3	
27-Jan-96	105.4	-11.3	5.1	
28-Jan-96	63.2	-11.5	12.2	
29-Jan-96	112	-18.1	12	
30-Jan-96	119.9	-28	-13.9	
31-Jan-96	106.9	-28.8	-5.7	
1-Feb-96	133.9	-34	-16.8	
2-Feb-96	131.9	-39.5	-21	
3-Feb-96	109.6	-33.7	-15.2	
4-Feb-96	127.4	-28.8	1.7	
5-Feb-96	122.6	-10.5	5.8	
6-Feb-96	91	0.3	31.5	

initial_temp_profile
19.0 22.9 24.1 25.0 25.7 26.4 26.8 27.1
27.4 27.9 28.3 28.7 28.5 28.9 29.2 29.6
29.9 30.2 30.6 30.9 31.3 31.6 32.0 32.3

32.6 33.0 33.3 33.7 34.0 34.4 34.7 35.1
35.4 35.7 36.1 36.4 36.8 37.1 37.5 37.8
38.1 38.5 38.8 39.2 39.5 39.9 40.2 40.5
40.9 41.5 41.9 42.3 42.6 43.0 43.4 43.7
44.1 44.5 44.8 45.2 45.6 45.9 46.3 46.7
47.0 47.4 47.8 48.1 48.5 48.9 49.2 49.6
50

Poisson's_ratio= 0.35
coefficient_of_expansion= 0.000015

number_points_in_stiffness-temp_relation= 10
coefficient_of_variation= .25

temp__stiffness
-20.0 3233500
-17.0 2958000
-13.0 2610000
-9.0 2189500
-6.0 1856000
-2.0 1566000
-0.0 1407950
1.4 1271650
5.0 1035300
9.0 803300

number_of_points_in_strength-temp_relation= 4
coefficient_of_variation= .25

temp__strength
-29.0 421
-15.0 537
0.0 481
34.0 159

WesTrack Section 24 COLD input file

test_run....DELTA_T=2-hours
number_of_days= 20
delta_t= 2
number_of_layers= 3
delta_x= 2.0
begin_freezing(b)= 29.0
partially_frozen(f)= 24.0
absorptivity= .800
emissivity= .900
convection_coefficient= 3.000

Ku	Kf	Cu	Cf	density	_thicknes s	__moisture_	%frozen
0.830	0.830	0.220	0.220	139.600	6	2	
0.670	1.010	0.200	0.180	126.000	12	4.000	80.00
0.780	0.860	0.270	0.210	105.100	126	14.100	90.00

number_of_extreme_temps= 2
initial_temp= 20.0
final_temp= 25.0
sunrise= 7.3
sunset= 16.7

times_for_extreme_temperatures
7.3
16

title_____	radiation	__temp1_…	
11-Dec-97	259.0	10.2	40.8
12-Dec-97	190.1	9.2	35.7
13-Dec-97	203.7	11.9	41.3
14-Dec-97	124.7	20.2	52.4
15-Dec-97	260.0	16.2	49.7
16-Dec-97	199.5	23.8	52.1
17-Dec-97	201.0	20.0	52.5
18-Dec-97	83.2	24.6	40.1
19-Dec-97	258.4	7.9	38.3
20-Dec-97	220.2	11.4	46.7
21-Dec-97	86.3	21.8	33.9
22-Dec-97	243.5	13.6	32.3
23-Dec-97	236.5	5.8	41.2
24-Dec-97	113.2	12.0	36.3
25-Dec-97	252.0	10.2	36.2
26-Dec-97	252.4	1.6	38.1
27-Dec-97	219.4	4.5	47.0
28-Dec-97	237.3	11.3	48.3
29-Dec-97	215.6	12.1	47.4

30-Dec-97 218.3 10.9 48.1

initial_temp_profile

25.0	34.9	39.4	42.4	42.5	42.6	42.7
43.0	43.1	43.2	43.3	43.4	43.5	43.6
43.8	43.9	44.1	44.2	44.3	44.4	44.5
44.7	44.8	44.9	45.0	45.2	45.3	45.4
45.6	45.7	45.8	45.9	46.0	46.1	46.3
46.5	46.6	46.7	46.8	46.9	47.0	47.1
47.4	47.5	47.6	47.7	47.8	47.9	48.0
48.2	48.3	48.5	48.6	48.7	48.8	48.9
49.1	49.2	49.3	49.4	49.6	49.7	49.8
50.0						

Poisson's_ratio= 0.35
coefficient_of_expansion= 0.00015

number_points_in_stiffness-temp_relation=6
coefficient_of_variation= .25

temp__stiffness
-4.0 2540000
3.2 1860000
10.4 1160000
17.6 685000
23.0 455000
45.0 150000

number_of_points_in_strength-temperature_relation= 4
coefficient_of_variation= .25

temp__strength
-4.0 322
14.0 409
32.0 300
50.0 165

WesTrack Section 25 COLD input file

test_run....DELTA_T=2-hours
number_of_days= 20
delta_t= 2
number_of_layers= 3
delta_x= 2.0
begin_freezing(b)= 29.0
partially_frozen(f)= 24.0
absorptivity= .900
emissivity= .850
convection_coefficient= 3.000

Ku____Kf____Cu____Cf____density_thickness__moisture_%frozen
0.850 0.850 0.220 0.220 144.800 6.000 2.000
0.670 1.010 0.200 0.180 126.000 12.000 4.000 80.00
0.780 0.860 0.270 0.210 105.100 126.000 14.100 90.00

number_of_extreme_temps= 2
initial_temp= 20.0
final_temp= 25.0
sunrise= 7.3
sunset= 16.7

times_for_extreme_temperatures
7.2
16

title_____radiation__temp1_...

11-Dec-97	259	10.2	40.8
12-Dec-97	190.1	9.2	35.7
13-Dec-97	203.7	11.9	41.3
14-Dec-97	124.7	20.2	52.4
15-Dec-97	260	16.2	49.7
16-Dec-97	199.5	23.8	52.1
17-Dec-97	201	20	52.5
18-Dec-97	83.2	24.6	40.1
19-Dec-97	258.4	7.9	38.3
20-Dec-97	220.2	11.4	46.7
21-Dec-97	86.3	21.8	33.9
22-Dec-97	243.5	13.6	32.3
23-Dec-97	236.5	5.8	41.2
24-Dec-97	113.2	12	36.3
25-Dec-97	252	10.2	36.2
26-Dec-97	252.4	1.6	38.1
27-Dec-97	219.4	4.5	47
28-Dec-97	237.3	11.3	48.3
29-Dec-97	215.6	12.1	47.4
30-Dec-97	218.3	10.9	48.1

initial_temp_profile

25	34.9	39.4	42.4	42.5	42.6	42.7	42.8
43	43.1	43.2	43.3	43.4	43.5	43.6	43.7
43.8	43.9	44.1	44.2	44.3	44.4	44.5	44.6
44.7	44.8	44.9	45	45.2	45.3	45.4	45.5
45.6	45.7	45.8	45.9	46	46.1	46.3	46.4
46.5	46.6	46.7	46.8	46.9	47	47.1	47.2
47.4	47.5	47.6	47.7	47.8	47.9	48	48.1
48.2	48.3	48.5	48.6	48.7	48.8	48.9	49
49.1	49.2	49.3	49.4	49.6	49.7	49.8	49.9
50							

Poisson's_ratio= 0.35
coefficient_of_expansion= 0.000015

number_points_in_stiffness-temp_relation= 6
coefficient_of_variation= .25

temp__stiffness

-4.0	3280000
3.2	2470000
10.4	1490000
17.6	867000
23.0	567000
45.0	160000

number_of_points_in_strength-temp_relation= 4
coefficient_of_variation= .25

temp__strength

-4.0	586
14.0	586
32.0	459
50.0	300

Hybrid pavement COLD input file

test_run....DELTA_T=2-hours
number_of_days= 20
delta_t= 2
number_of_layers= 2
delta_x= 2.0
begin_freezing(b)= 29.0
partially_frozen(f)= 24.0
absorptivity= .900
emissivity= .850
convection_coefficient= 3.000

Ku____Kf____Cu____Cf____density_thickness__moisture_%frozen
0.850 0.850 0.220 0.220 147.200 10.000 2.000
1.060 1.290 0.300 0.220 113.900 134.000 17.800 90.00

number_of_extreme_temps= 2
initial_temp= -10.0
final_temp= -2.5
sunrise= 7.6
sunset= 17.2

times_for_extreme_temperatures
 5.5
 15.5

title_____radiation__temp1_...
JAN.18,1996 44.0 -13.1 14.3
JAN.19,1996 101.4 -26.1 -11.6
JAN.20,1996 86.9 -22.5 3.2
JAN.21,1996 62.0 2.5 25.1
JAN.22,1996 84.9 -11.4 19.5
JAN.23,1996 69.7 -19.3 0.3
JAN.24,1996 105.4 -12.8 4.8
JAN.25,1996 72.1 -14.5 3.5
JAN.26,1996 59.7 -14.3 8.3
JAN.27,1996 105.6 -11.3 5.1
JAN.28,1996 63.1 -11.5 12.2
JAN.29,1996 111.5 -18.1 12.0
JAN.30,1996 118.7 -28.0 -13.9
JAN.31,1996 105.4 -28.8 -5.7
FEB.01,1996 131.4 -34.0 -16.8
FEB.02,1996 129.0 -39.5 -21.0
FEB.03,1996 106.4 -33.7 -15.2
FEB.04,1996 123.4 -28.8 1.7
FEB.05,1996 118.3 -10.5 5.8
FEB.06,1996 87.3 0.3 31.5

initial_temp_profile
19.0 22.9 24.1 25.0 25.7 26.4 26.8 27.1
27.4 27.9 28.3 28.7 28.5 28.9 29.2 29.6
29.9 30.2 30.6 30.9 31.3 31.6 32.0 32.3

32.6 33.0 33.3 33.7 34.0 34.4 34.7 35.1
35.4 35.7 36.1 36.4 36.8 37.1 37.5 37.8
38.1 38.5 38.8 39.2 39.5 39.9 40.2 40.5
40.9 41.5 41.9 42.3 42.6 43.0 43.4 43.7
44.1 44.5 44.8 45.2 45.6 45.9 46.3 46.7
47.0 47.4 47.8 48.1 48.5 48.9 49.2 49.6
50

Poisson's_ratio= 0.35
coefficient_of_expansion= 0.000015

number_points_in_stiffness-temp_relation= 8
coefficient_of_variation= .25

temp__stiffness
-40.0 1740000
-31.0 1440000
-22.0 1190000
-13.0 944000
-4.0 743000
0.0 674000
23.0 392000
41.0 254000

number_of_points_in_strength-temp_relation= 5
coefficient_of_variation= .25

temp__strength
-26.0 320
-4.0 396
14.0 389
32.0 338
50.0 245

COLD output: MnROAD Cell 14

Day	Time period	Air temp (°F)	Pavement temp (°F)	Solar insolation (Langleys)	Expected values			
					Strength		Stress	
					(lb/in^2)	(MPa)	(lb/in^2)	(MPa)
1/18/96	1	-10.0	16.4	0	317.3	2.19	0.0	0.00
	2	-11.6	13.4	0	352.6	2.43	45.8	0.32
	3	-13.1	11.2	0	378.3	2.61	79.2	0.55
	4	-7.6	9.2	0	402.1	2.77	110.1	0.76
	5	-2.1	8.9	16.2	404.9	2.79	113.8	0.78
	6	3.3	9.1	32.4	403.5	2.78	111.9	0.77
	7	8.8	10.0	21.6	392.6	2.71	97.8	0.67
	8	14.3	10.4	10.8	387.6	2.67	91.3	0.63
	9	8.5	10.6	0	385.8	2.66	88.9	0.61
	10	2.8	9.6	0	397.4	2.74	104.1	0.72
	11	-3.0	8.8	0	406.9	2.81	116.4	0.80
	12	-8.8	6.9	0	428.6	2.96	144.5	1.00
1/19/96	1	-14.6	5.4	0	446.8	3.08	168.2	1.16
	2	-20.3	2.8	0	476.2	3.28	206.3	1.42
	3	-26.1	0.7	0	501.3	3.46	238.9	1.65
	4	-23.2	-1.5	0	512.7	3.53	273.8	1.89
	5	-20.3	-1.6	37.4	512.9	3.54	275.3	1.90
	6	-17.4	-0.9	74.8	511.5	3.53	265.7	1.83
	7	-14.5	-0.2	49.8	509.8	3.51	254.4	1.75
	8	-11.6	-0.6	24.9	510.6	3.52	260.1	1.79
	9	-13.2	-1.1	0	511.9	3.53	268.5	1.85
	10	-14.7	-2.3	0	514.7	3.55	288.5	1.99
	11	-16.3	-3.0	0	516.2	3.56	299.1	2.06
	12	-17.8	-4.3	0	519.2	3.58	322.6	2.22
1/20/96	1	-19.4	-4.9	0	520.7	3.59	335.6	2.31
	2	-20.9	-6.3	0	523.9	3.61	363.1	2.50
	3	-22.5	-7.0	0	525.6	3.62	378.8	2.61
	4	-17.4	-7.8	0	527.3	3.64	396.1	2.73
	5	-12.2	-6.5	32	524.4	3.62	367.8	2.54
	6	-7.1	-4.6	64.1	520.1	3.59	330.0	2.28
	7	-1.9	-2.5	42.7	515.1	3.55	291.1	2.01
	8	3.2	-1.3	21.4	512.3	3.53	271.4	1.87
	9	3.1	-0.2	0	509.9	3.52	254.8	1.76
	10	3.0	0.1	0	509.1	3.51	249.9	1.72
	11	2.9	0.9	0	499.3	3.44	236.6	1.63
	12	2.8	1.1	0	497.4	3.43	234.2	1.61
1/21/96	1	2.7	1.8	0	488.9	3.37	223.1	1.54
	2	2.6	1.8	0	488.5	3.37	222.5	1.53
	3	2.5	2.4	0	481.2	3.32	213.1	1.47
	4	7.0	2.8	0	476.9	3.29	207.5	1.43
	5	11.5	4.8	22.9	454.0	3.13	177.8	1.23
	6	16.1	7.0	45.7	428.7	2.96	145.0	1.00
	7	20.6	9.5	30.5	399.4	2.75	106.9	0.74

	8	25.1	11.1	15.2	380.5	2.62	82.3	0.57
	9	19.9	12.2	0	367.2	2.53	65.1	0.45
	10	14.7	12.1	0	368.2	2.54	66.4	0.46
	11	9.5	12.2	0	367.7	2.54	65.7	0.45
	12	4.2	11.1	0	379.9	2.62	81.6	0.56
1/22/96	1	-1.0	10.3	0	389.3	2.68	93.7	0.65
	2	-6.2	8.5	0	410.2	2.83	120.9	0.83
	3	-11.4	7.0	0	427.2	2.95	143.0	0.99
	4	-5.2	5.7	0	442.6	3.05	163.0	1.12
	5	1.0	6.6	31.3	432.5	2.98	149.9	1.03
	6	7.1	8.2	62.6	414.0	2.85	125.9	0.87
	7	13.3	10.2	41.7	390.7	2.69	95.5	0.66
	8	19.5	11.4	20.9	377.0	2.60	77.8	0.54
	9	14.0	11.9	0	370.6	2.56	69.5	0.48
	10	8.4	11.3	0	378.0	2.61	79.0	0.54
	11	2.9	10.8	0	383.4	2.64	86.1	0.59
	12	-2.7	9.3	0	401.2	2.77	109.2	0.75
1/23/96	1	-8.2	8.0	0	415.9	2.87	128.3	0.88
	2	-13.8	5.8	0	441.8	3.05	162.0	1.12
	3	-19.3	3.9	0	463.6	3.20	190.3	1.31
	4	-15.4	2.0	0	485.7	3.35	218.9	1.51
	5	-11.5	2.0	25.7	485.6	3.35	218.8	1.51
	6	-7.5	2.5	51.4	480.2	3.31	211.8	1.46
	7	-3.6	3.4	34.3	469.6	3.24	198.1	1.37
	8	0.3	3.5	17.1	468.5	3.23	196.6	1.36
	9	-1.6	3.6	0	468.0	3.23	196.0	1.35
	10	-3.4	2.8	0	476.6	3.29	207.1	1.43
	11	-5.3	2.6	0	479.2	3.30	210.5	1.45
	12	-7.2	1.6	0	490.5	3.38	225.2	1.55
1/24/96	1	-9.1	1.2	0	495.5	3.42	231.6	1.60
	2	-10.9	0.0	0	508.9	3.51	249.1	1.72
	3	-12.8	-0.5	0	510.3	3.52	258.0	1.78
	4	-9.3	-1.3	0	512.2	3.53	270.5	1.87
	5	-5.8	0.0	38.9	509.2	3.51	250.3	1.73
	6	-2.2	1.9	77.7	487.4	3.36	221.0	1.52
	7	1.3	3.9	51.8	465.0	3.21	192.0	1.32
	8	4.8	4.6	25.9	456.8	3.15	181.3	1.25
	9	2.0	4.8	0	453.7	3.13	177.4	1.22
	10	-0.7	4.2	0	461.1	3.18	186.9	1.29
	11	-3.5	4.0	0	463.5	3.20	190.1	1.31
	12	-6.2	2.9	0	475.6	3.28	205.8	1.42
1/25/96	1	-9.0	2.3	0	482.3	3.33	214.5	1.48
	2	-11.7	1.0	0	498.2	3.43	235.1	1.62
	3	-14.5	0.1	0	508.1	3.50	248.0	1.71
	4	-10.9	-0.9	0	511.2	3.52	263.8	1.82
	5	-7.3	-0.1	26.6	509.4	3.51	251.8	1.74
	6	-3.7	1.0	53.2	497.8	3.43	234.5	1.62
	7	-0.1	2.5	35.4	480.8	3.31	212.5	1.47
	8	3.5	3.0	17.7	474.7	3.27	204.6	1.41
	9	1.0	3.3	0	470.7	3.25	199.4	1.37
	10	-1.6	2.8	0	477.0	3.29	207.6	1.43

	11	-4.1	2.7	0	478.2	3.30	209.2	1.44
	12	-6.7	1.7	0	489.1	3.37	223.3	1.54
1/26/96	1	-9.2	1.3	0	494.4	3.41	230.2	1.59
	2	-11.8	0.0	0	508.9	3.51	248.9	1.72
	3	-14.3	-0.7	0	510.7	3.52	260.1	1.79
	4	-9.8	-1.5	0	512.6	3.53	273.2	1.88
	5	-5.3	-0.6	22	510.5	3.52	258.8	1.78
	6	-0.7	0.6	44	502.1	3.46	240.0	1.65
	7	3.8	2.3	29.3	482.4	3.33	214.4	1.48
	8	8.3	3.2	14.7	471.8	3.25	200.7	1.38
	9	5.5	3.9	0	463.3	3.19	189.6	1.31
	10	2.7	3.7	0	465.8	3.21	192.9	1.33
	11	-0.1	3.9	0	464.0	3.20	190.6	1.31
	12	-2.9	3.1	0	472.5	3.26	201.6	1.39
1/27/96	1	-5.7	2.8	0	476.0	3.28	206.1	1.42
	2	-8.5	1.7	0	489.1	3.37	223.2	1.54
	3	-11.3	1.1	0	496.7	3.42	233.0	1.61
	4	-8.0	0.2	0	506.8	3.49	246.1	1.70
	5	-4.7	1.4	38.9	492.6	3.40	227.7	1.57
	6	-1.5	3.3	77.9	470.9	3.25	199.5	1.38
	7	1.8	5.1	51.9	449.6	3.10	171.9	1.19
	8	5.1	5.7	26	442.8	3.05	163.0	1.12
	9	2.7	5.9	0	440.7	3.04	160.3	1.11
	10	0.4	5.2	0	448.4	3.09	170.3	1.17
	11	-2.0	5.0	0	450.8	3.11	173.4	1.20
	12	-4.4	4.0	0	462.4	3.19	188.5	1.30
1/28/96	1	-6.8	3.5	0	468.3	3.23	196.1	1.35
	2	-9.1	2.2	0	483.0	3.33	215.2	1.48
	3	-11.5	1.5	0	491.5	3.39	226.2	1.56
	4	-6.8	0.7	0	500.9	3.45	238.4	1.64
	5	-2.0	1.7	23.3	489.4	3.37	223.6	1.54
	6	2.7	3.0	46.5	473.7	3.27	203.2	1.40
	7	7.5	4.8	31	452.8	3.12	176.0	1.21
	8	12.2	5.8	15.5	441.2	3.04	161.0	1.11
	9	7.9	6.4	0	433.7	2.99	151.3	1.04
	10	3.5	6.0	0	438.9	3.03	157.9	1.09
	11	-0.8	5.8	0	441.0	3.04	160.7	1.11
	12	-5.1	4.7	0	454.6	3.13	178.4	1.23
1/29/96	1	-9.4	3.8	0	464.3	3.20	190.9	1.32
	2	-13.8	2.1	0	484.5	3.34	217.2	1.50
	3	-18.1	0.8	0	499.9	3.45	237.2	1.64
	4	-12.1	-0.4	0	510.0	3.52	255.8	1.76
	5	-6.1	0.8	41.1	499.6	3.44	236.8	1.63
	6	0.0	3.0	82.2	474.0	3.27	203.5	1.40
	7	6.0	5.3	54.8	446.8	3.08	168.3	1.16
	8	12.0	6.5	27.4	432.3	2.98	149.4	1.03
	9	6.3	7.0	0	427.6	2.95	143.3	0.99
	10	0.6	6.2	0	436.7	3.01	155.1	1.07
	11	-5.1	5.6	0	443.8	3.06	164.3	1.13
	12	-10.9	3.9	0	463.3	3.19	189.6	1.31
1/30/96	1	-16.6	2.5	0	479.6	3.31	210.8	1.45

	2	-22.3	0.1	0	507.2	3.50	246.6	1.70
	3	-28.0	-1.9	0	513.3	3.54	278.4	1.92
	4	-25.2	-4.0	0	518.3	3.57	315.2	2.17
	5	-22.4	-3.8	43.8	517.7	3.57	311.0	2.14
	6	-19.5	-2.7	87.5	515.2	3.55	291.7	2.01
	7	-16.7	-1.7	58.4	512.8	3.54	274.9	1.90
	8	-13.9	-2.0	29.2	513.5	3.54	279.4	1.93
	9	-16.0	-2.6	0	515.0	3.55	290.4	2.00
	10	-18.2	-4.0	0	518.2	3.57	314.9	2.17
	11	-20.3	-4.8	0	520.1	3.59	330.1	2.28
	12	-22.4	-6.3	0	523.6	3.61	360.7	2.49
1/31/96	1	-24.5	-7.2	0	525.8	3.63	380.8	2.63
	2	-26.7	-8.8	0	529.5	3.65	418.5	2.89
	3	-28.8	-9.8	0	531.9	3.67	444.0	3.06
	4	-24.2	-10.9	0	534.4	3.68	472.3	3.26
	5	-19.6	-9.8	38.9	531.7	3.67	441.3	3.04
	6	-14.9	-7.8	77.7	527.1	3.63	393.6	2.71
	7	-10.3	-5.8	51.8	522.4	3.60	349.6	2.41
	8	-5.7	-4.9	25.9	520.3	3.59	332.0	2.29
	9	-9.7	-4.6	0	519.7	3.58	326.7	2.25
	10	-13.8	-5.4	0	521.4	3.59	341.0	2.35
	11	-17.8	-5.8	0	522.4	3.60	349.5	2.41
	12	-21.9	-7.1	0	525.5	3.62	378.1	2.61
2/1/96	1	-25.9	-8.1	0	527.7	3.64	399.9	2.76
	2	-30.0	-9.9	0	532.0	3.67	444.6	3.07
	3	-34.0	-11.3	0	535.2	3.69	481.2	3.32
	4	-30.6	-12.7	0	538.7	3.71	523.9	3.61
	5	-27.1	-11.8	48.4	536.4	3.70	495.8	3.42
	6	-23.7	-9.9	96.9	531.9	3.67	443.4	3.06
	7	-20.2	-8.2	64.6	527.9	3.64	401.2	2.77
	8	-16.8	-7.9	32.3	527.1	3.63	393.7	2.71
	9	-20.0	-8.2	0	527.9	3.64	401.5	2.77
	10	-23.3	-9.4	0	530.7	3.66	430.4	2.97
	11	-26.5	-10.1	0	532.4	3.67	449.6	3.10
	12	-29.8	-11.7	0	536.1	3.70	491.8	3.39
2/2/96	1	-33.0	-12.7	0	538.6	3.71	522.8	3.60
	2**	-36.3	-14.6	0	542.9	3.74	579.6	4.00
	3**	-39.5	-15.9	0	546.0	3.76	623.1	4.30
	4**	-35.8	-17.3	0	549.3	3.79	672.5	4.64
	5**	-32.1	-16.3	47.6	546.9	3.77	636.5	4.39
	6**	-28.4	-14.4	95.1	542.3	3.74	570.8	3.94
	7	-24.7	-12.6	63.4	538.0	3.71	515.9	3.56
	8	-21.0	-12.2	31.7	537.0	3.70	503.3	3.47
	9	-22.8	-12.2	0	537.2	3.70	505.7	3.49
	10	-24.6	-13.1	0	539.2	3.72	530.5	3.66
	11**	-26.4	-13.3	0	539.9	3.72	539.8	3.72
	12**	-28.3	-14.4	0	542.3	3.74	572.0	3.94
2/3/96	1**	-30.1	-14.9	0	543.5	3.75	587.5	4.05
	2**	-31.9	-16.0	0	546.3	3.77	626.9	4.32
	3**	-33.7	-16.7	0	547.7	3.78	648.1	4.47
	4**	-30.0	-17.5	0	549.6	3.79	676.4	4.66

	5**	-26.3	-16.1	39.2	546.4	3.77	629.2	4.34
	6**	-22.6	-14.1	78.5	541.6	3.73	562.4	3.88
	7	-18.9	-12.1	52.3	536.9	3.70	502.4	3.46
	8	-15.2	-11.4	26.2	535.2	3.69	481.0	3.32
	9	-17.1	-11.0	0	534.4	3.68	471.5	3.25
	10	-19.1	-11.5	0	535.5	3.69	484.6	3.34
	11	-21.0	-11.5	0	535.5	3.69	484.5	3.34
	12	-23.0	-12.2	0	537.3	3.70	506.5	3.49
2/4/96	1	-24.9	-12.5	0	537.9	3.71	514.2	3.55
	2**	-26.9	-13.5	0	540.3	3.73	544.4	3.75
	3**	-28.8	-13.9	0	541.4	3.73	559.0	3.85
	4**	-22.7	-14.4	0	542.4	3.74	573.2	3.95
	5	-16.6	-12.4	45.5	537.6	3.71	510.5	3.52
	6	-10.5	-9.3	91	530.4	3.66	427.3	2.95
	7	-4.4	-6.3	60.7	523.3	3.61	358.0	2.47
	8	1.7	-4.6	30.3	519.2	3.58	323.0	2.23
	9	0.0	-3.4	0	516.6	3.56	302.4	2.08
	10	-1.8	-3.2	0	516.1	3.56	298.5	2.06
	11	-3.5	-2.5	0	514.6	3.55	287.5	1.98
	12	-5.3	-2.7	0	515.1	3.55	291.0	2.01
2/5/96	1	-7.0	-2.5	0	514.5	3.55	286.5	1.98
	2	-8.8	-3.0	0	515.7	3.56	295.6	2.04
	3	-10.5	-3.0	0	515.8	3.56	296.1	2.04
	4	-7.2	-3.3	0	516.5	3.56	301.8	2.08
	5	-4.0	-1.5	43.6	512.2	3.53	270.2	1.86
	6	-0.7	1.1	87.2	494.5	3.41	229.5	1.58
	7	2.5	3.4	58.2	466.9	3.22	193.7	1.34
	8	5.8	4.3	29.1	455.9	3.14	179.3	1.24
	9	5.0	4.9	0	449.7	3.10	171.4	1.18
	10	4.2	4.7	0	452.2	3.12	174.6	1.20
	11	3.4	5.1	0	448.2	3.09	169.4	1.17
	12	2.7	4.7	0	452.6	3.12	175.1	1.21
2/6/96	1	1.9	4.9	0	450.2	3.10	172.0	1.19
	2	1.1	4.4	0	456.0	3.14	179.6	1.24
	3	0.3	4.5	0	455.0	3.14	178.2	1.23
	4	6.5	4.6	0	454.3	3.13	177.4	1.22
	5	12.8	6.7	32.2	429.1	2.96	144.6	1.00
	6	19.0	9.5	64.4	396.3	2.73	102.0	0.70
	7	25.3	12.5	42.9	360.9	2.49	56.0	0.39
	8	31.5	14.5	21.5	337.2	2.32	25.2	0.17
	9	24.7	15.7	0	323.9	2.23	7.9	0.05
	10	17.9	15.5	0	326.5	2.25	11.4	0.08
	11	11.1	15.3	0	329.2	2.27	14.8	0.10
	12	4.3	13.8	0	345.9	2.38	36.6	0.25

°F = 1.8 °C + 32

** Periods in which stress exceeds strength.

COLD output: MnROAD Cell 15

Day	Time period	Air temp (°F)	Pavement temp (°F)	Solar insolation (Langleys)	Expected values			
					Strength		Stress	
					(lb/in^2)	(MPa)	(lb/in^2)	(MPa)
1/18/96	1	-10.0	16.4	0	325.5	2.24	0.0	0.00
	2	-11.6	13.4	0	354.2	2.44	56.0	0.39
	3	-13.1	11.2	0	375.1	2.59	96.9	0.67
	4	-7.6	9.1	0	394.4	2.72	134.7	0.93
	5	-2.1	8.9	15.8	396.7	2.74	139.3	0.96
	6	3.3	9.0	31.6	395.5	2.73	136.9	0.94
	7	8.8	10.0	21.0	386.7	2.67	119.7	0.83
	8	14.3	10.4	10.5	382.6	2.64	111.6	0.77
	9	8.5	10.5	0	381.1	2.63	108.7	0.75
	10	2.8	9.5	0	390.6	2.69	127.3	0.88
	11	-3.0	8.7	0	398.3	2.75	142.5	0.98
	12	-8.8	6.9	0	415.8	2.87	179.6	1.24
1/19/96	1	-14.6	5.3	0	430.7	2.97	214.6	1.48
	2	-20.3	2.8	0	454.5	3.13	278.1	1.92
	3	-26.1	0.6	0	474.9	3.27	340.6	2.35
	4	-23.2	-1.6	0	486.9	3.36	414.5	2.86
	5	-20.3	-1.7	36.2	487.2	3.36	417.5	2.88
	6	-17.4	-1.1	72.3	485.0	3.34	396.7	2.74
	7	-14.5	-0.3	48.2	482.3	3.33	372.2	2.57
	8	-11.6	-0.7	24.1	483.6	3.33	384.4	2.65
	9	-13.2	-1.2	0	485.6	3.35	402.6	2.78
	10	-14.7	-2.5	0	490.2	3.38	446.1	3.08
	11	-16.3	-3.1	0	492.5	3.40	469.1	3.23
	12	-17.8	-4.4	0	497.3	3.43	519.1	3.58
1/20/96	1	-19.4	-5.0	0	499.8	3.45	546.6	3.77
	2	-20.9	-6.4	0	504.8	3.48	603.5	4.16
	3	-22.5	-7.1	0	507.5	3.50	635.9	4.38
	4	-17.4	-7.9	0	510.4	3.52	671.4	4.63
	5	-12.2	-6.6	31.1	505.6	3.49	613.2	4.23
	6	-7.1	-4.7	62.2	498.7	3.44	534.4	3.68
	7	-1.9	-2.6	41.4	490.7	3.38	451.3	3.11
	8	3.2	-1.4	20.7	486.3	3.35	408.7	2.82
	9	3.1	-0.4	0	482.4	3.33	372.6	2.57
	10	3.0	0.0	0	481.2	3.32	362.1	2.50
	11	2.9	0.8	0	473.1	3.26	334.4	2.31
	12	2.8	1.0	0	471.6	3.25	329.6	2.27
1/21/96	1	2.7	1.7	0	464.6	3.20	307.9	2.12
	2	2.6	1.8	0	464.3	3.20	306.9	2.12
	3	2.5	2.4	0	458.4	3.16	289.3	1.99
	4	7.0	2.8	0	454.9	3.14	279.2	1.92
	5	11.5	4.7	22.3	436.3	3.01	228.7	1.58
	6	16.1	6.9	44.5	415.8	2.87	179.5	1.24
	7	20.6	9.4	29.7	392.0	2.70	129.5	0.89

	8	25.1	11.0	14.8	376.6	2.60	99.4	0.69
	9	19.9	12.2	0	365.9	2.52	78.4	0.54
	10	14.7	12.1	0	366.7	2.53	80.0	0.55
	11	9.5	12.1	0	366.3	2.53	79.2	0.55
	12	4.2	11.1	0	376.2	2.59	98.6	0.68
1/22/96	1	-1.0	10.3	0	383.8	2.65	113.5	0.78
	2	-6.2	8.5	0	400.8	2.76	147.3	1.02
	3	-11.4	7.0	0	414.7	2.86	176.8	1.22
	4	-5.2	5.7	0	427.2	2.95	205.7	1.42
	5	1.0	6.6	30.6	419.0	2.89	186.4	1.29
	6	7.1	8.1	61.2	404.0	2.79	153.7	1.06
	7	13.3	10.1	40.8	385.0	2.65	115.6	0.80
	8	19.5	11.3	20.4	373.9	2.58	93.9	0.65
	9	14.0	11.9	0	368.7	2.54	83.7	0.58
	10	8.4	11.2	0	374.7	2.58	95.4	0.66
	11	2.9	10.8	0	379.1	2.61	104.1	0.72
	12	-2.7	9.2	0	393.6	2.71	132.4	0.91
1/23/96	1	-8.2	8.0	0	405.5	2.80	156.5	1.08
	2	-13.8	5.7	0	426.6	2.94	203.8	1.41
	3	-19.3	3.9	0	444.3	3.06	249.0	1.72
	4	-15.4	2.0	0	462.1	3.19	299.8	2.07
	5	-11.5	2.0	25.2	462.1	3.19	299.7	2.07
	6	-7.5	2.5	50.4	457.7	3.16	286.6	1.98
	7	-3.6	3.4	33.6	449.1	3.10	262.2	1.81
	8	0.3	3.5	16.8	448.2	3.09	259.7	1.79
	9	-1.6	3.5	0	447.8	3.09	258.6	1.78
	10	-3.4	2.8	0	454.8	3.14	278.1	1.92
	11	-5.3	2.6	0	456.8	3.15	284.2	1.96
	12	-7.2	1.6	0	466.0	3.21	311.6	2.15
1/24/96	1	-9.1	1.2	0	470.1	3.24	324.1	2.23
	2	-10.9	0.0	0	481.0	3.32	360.0	2.48
	3	-12.8	-0.6	0	483.2	3.33	379.3	2.62
	4	-9.3	-1.4	0	486.1	3.35	406.4	2.80
	5	-5.8	-0.1	38.3	481.3	3.32	362.6	2.50
	6	-2.2	1.9	76.5	463.5	3.20	303.5	2.09
	7	1.3	3.8	51	445.3	3.07	251.5	1.73
	8	4.8	4.5	25.5	438.6	3.02	233.8	1.61
	9	2.0	4.7	0	436.2	3.01	227.5	1.57
	10	-0.7	4.1	0	442.1	3.05	243.0	1.68
	11	-3.5	3.9	0	444.1	3.06	248.3	1.71
	12	-6.2	2.9	0	454.0	3.13	275.6	1.90
1/25/96	1	-9.0	2.3	0	459.4	3.17	291.3	2.01
	2	-11.7	0.9	0	472.2	3.26	330.9	2.28
	3	-14.5	0.1	0	480.3	3.31	357.7	2.47
	4	-10.9	-0.9	0	484.5	3.34	391.5	2.70
	5	-7.3	-0.2	26.3	481.7	3.32	365.8	2.52
	6	-3.7	1.0	52.6	471.9	3.25	329.8	2.27
	7	-0.1	2.4	35.1	458.1	3.16	287.7	1.98
	8	3.5	2.9	17.5	453.2	3.12	273.4	1.88
	9	1.0	3.3	0	449.9	3.10	264.3	1.82
	10	-1.6	2.7	0	455.0	3.14	278.7	1.92

	11	-4.1	2.6	0	456.0	3.14	281.6	1.94
	12	-6.7	1.7	0	464.9	3.21	307.8	2.12
1/26/96	1	-9.2	1.2	0	469.2	3.23	321.1	2.21
	2	-11.8	0.0	0	480.9	3.32	359.6	2.48
	3	-14.3	-0.7	0	483.7	3.33	383.6	2.64
	4	-9.8	-1.5	0	486.7	3.36	412.0	2.84
	5	-5.3	-0.6	21.9	483.4	3.33	380.8	2.63
	6	-0.7	0.6	43.7	475.4	3.28	341.2	2.35
	7	3.8	2.3	29.2	459.4	3.17	291.3	2.01
	8	8.3	3.2	14.6	450.8	3.11	266.7	1.84
	9	5.5	3.9	0	443.9	3.06	247.7	1.71
	10	2.7	3.7	0	445.9	3.07	253.2	1.75
	11	-0.1	3.9	0	444.5	3.06	249.3	1.72
	12	-2.9	3.1	0	451.4	3.11	268.3	1.85
1/27/96	1	-5.7	2.8	0	454.2	3.13	276.3	1.90
	2	-8.5	1.7	0	464.9	3.21	307.7	2.12
	3	-11.3	1.1	0	471.0	3.25	326.8	2.25
	4	-8.0	0.2	0	479.2	3.30	353.8	2.44
	5	-4.7	1.4	38.9	467.7	3.22	316.4	2.18
	6	-1.5	3.3	77.7	450.1	3.10	264.6	1.82
	7	1.8	5.1	51.8	432.8	2.98	218.9	1.51
	8	5.1	5.7	25.9	427.2	2.95	205.2	1.41
	9	2.7	5.9	0	425.5	2.93	201.1	1.39
	10	0.4	5.2	0	431.8	2.98	216.4	1.49
	11	-2.0	5.0	0	433.8	2.99	221.3	1.53
	12	-4.4	4.0	0	443.2	3.06	245.9	1.70
1/28/96	1	-6.8	3.5	0	448.0	3.09	258.7	1.78
	2	-9.1	2.2	0	459.9	3.17	292.8	2.02
	3	-11.5	1.5	0	466.8	3.22	313.6	2.16
	4	-6.8	0.7	0	474.4	3.27	337.8	2.33
	5	-2.0	1.7	23.3	465.2	3.21	308.5	2.13
	6	2.7	3.0	46.6	452.4	3.12	271.0	1.87
	7	7.5	4.8	31.1	435.4	3.00	225.3	1.55
	8	12.2	5.8	15.5	426.0	2.94	202.1	1.39
	9	7.9	6.4	0	419.9	2.90	187.8	1.29
	10	3.5	6.0	0	424.1	2.92	197.5	1.36
	11	-0.8	5.8	0	425.8	2.94	201.7	1.39
	12	-5.1	4.7	0	436.9	3.01	229.2	1.58
1/29/96	1	-9.4	3.8	0	444.7	3.07	249.9	1.72
	2	-13.8	2.1	0	461.1	3.18	296.4	2.04
	3	-18.1	0.8	0	473.7	3.27	335.5	2.31
	4	-12.1	-0.4	0	482.6	3.33	374.2	2.58
	5	-6.1	0.8	41.3	473.4	3.26	334.6	2.31
	6	0.0	3.0	82.6	452.6	3.12	271.4	1.87
	7	6.0	5.3	55.1	430.5	2.97	213.0	1.47
	8	12.0	6.6	27.5	418.8	2.89	185.0	1.28
	9	6.3	7.0	0	414.9	2.86	176.4	1.22
	10	0.6	6.2	0	422.3	2.91	193.2	1.33
	11	-5.1	5.6	0	428.1	2.95	207.0	1.43
	12	-10.9	3.9	0	443.9	3.06	247.5	1.71
1/30/96	1	-16.6	2.5	0	457.2	3.15	284.6	1.96

	2	-22.3	0.1	0	479.6	3.31	355.1	2.45
	3	-28.0	-1.9	0	488.0	3.36	423.5	2.92
	4	-25.2	-4.0	0	495.8	3.42	503.0	3.47
	5	-22.4	-3.7	44.2	495.0	3.41	493.9	3.41
	6	-19.5	-2.7	88.4	490.9	3.38	452.3	3.12
	7	-16.7	-1.6	58.9	487.1	3.36	415.8	2.87
	8	-13.9	-1.9	29.5	488.2	3.37	425.6	2.93
	9	-16.0	-2.6	0	490.6	3.38	449.5	3.10
	10	-18.2	-4.0	0	495.8	3.42	502.1	3.46
	11	-20.3	-4.8	0	498.8	3.44	534.4	3.68
	12	-22.4	-6.3	0	504.4	3.48	597.9	4.12
1/31/96	1	-24.5	-7.2	0	507.9	3.50	639.3	4.41
	2	-26.7	-8.8	0	513.9	3.54	716.7	4.94
	3	-28.8	-9.8	0	517.7	3.57	768.9	5.30
	4	-24.2	-10.9	0	521.7	3.60	826.4	5.70
	5	-19.6	-9.7	39.4	517.3	3.57	763.1	5.26
	6	-14.9	-7.8	78.8	510.0	3.52	665.6	4.59
	7	-10.3	-5.7	52.6	502.4	3.46	574.7	3.96
	8	-5.7	-4.8	26.3	499.1	3.44	538.0	3.71
	9	-9.7	-4.6	0	498.1	3.43	526.8	3.63
	10	-13.8	-5.3	0	500.8	3.45	556.9	3.84
	11	-17.8	-5.7	0	502.4	3.46	574.5	3.96
	12	-21.9	-7.1	0	507.4	3.50	633.6	4.37
2/1/96	1	-25.9	-8.0	0	511.0	3.52	678.4	4.68
	2	-30.0	-9.9	0	517.8	3.57	769.8	5.31
	3	-34.0	-11.2	0	522.9	3.61	844.3	5.82
	4	-30.6	-12.7	0	528.5	3.64	930.6	6.42
	5	-27.1	-11.8	49.4	524.9	3.62	873.8	6.02
	6	-23.7	-9.8	98.7	517.6	3.57	767.2	5.29
	7	-20.2	-8.1	65.8	511.2	3.52	680.7	4.69
	8	-16.8	-7.8	32.9	510.0	3.52	665.5	4.59
	9	-20.0	-8.1	0	511.2	3.52	681.4	4.70
	10	-23.3	-9.3	0	515.7	3.56	740.7	5.11
	11	-26.5	-10.0	0	518.5	3.57	779.9	5.38
	12	-29.8	-11.6	0	524.3	3.61	865.6	5.97
2/2/96	1	-33.0	-12.7	0	528.4	3.64	928.2	6.40
	2**	-36.3	-14.5	0	535.3	3.69	1041.7	7.18
	3**	-39.5	-15.9	0	529.8	3.65	1127.6	7.77
	4**	-35.8	-17.3	0	517.9	3.57	1224.0	8.44
	5**	-32.1	-16.3	48.6	526.5	3.63	1153.7	7.95
	6**	-28.4	-14.3	97.3	534.2	3.68	1023.9	7.06
	7	-24.7	-12.4	64.8	527.5	3.64	914.0	6.30
	8	-21.0	-12.0	32.4	525.8	3.63	888.6	6.13
	9	-22.8	-12.1	0	526.2	3.63	893.5	6.16
	10	-24.6	-12.9	0	529.3	3.65	943.3	6.50
	11**	-26.4	-13.2	0	530.5	3.66	962.0	6.63
	12**	-28.3	-14.3	0	534.4	3.68	1026.4	7.08
2/3/96	1**	-30.1	-14.8	0	536.2	3.70	1057.1	7.29
	2**	-31.9	-16.0	0	528.9	3.65	1134.8	7.82
	3**	-33.7	-16.6	0	523.8	3.61	1176.4	8.11
	4**	-30.0	-17.4	0	517.1	3.57	1231.4	8.49

	5**	-26.3	-16.0	40.4	528.3	3.64	1139.5	7.86
	6**	-22.6	-14.0	80.8	533.2	3.68	1007.2	6.94
	7	-18.9	-12.0	53.9	525.7	3.62	886.8	6.11
	8	-15.2	-11.2	26.9	522.8	3.60	843.5	5.82
	9	-17.1	-10.9	0	521.6	3.60	824.4	5.68
	10	-19.1	-11.3	0	523.3	3.61	850.8	5.87
	11	-21.0	-11.3	0	523.3	3.61	850.8	5.87
	12	-23.0	-12.1	0	526.2	3.63	895.2	6.17
2/4/96	1	-24.9	-12.4	0	527.2	3.63	910.8	6.28
	2**	-26.9	-13.4	0	531.0	3.66	971.5	6.70
	3**	-28.8	-13.9	0	532.8	3.67	1000.7	6.90
	4**	-22.7	-14.3	0	534.5	3.69	1028.9	7.09
	5	-16.6	-12.3	47	526.8	3.63	903.4	6.23
	6	-10.5	-9.2	93.9	515.2	3.55	734.3	5.06
	7	-4.4	-6.1	62.6	503.9	3.47	592.1	4.08
	8	1.7	-4.4	31.3	497.3	3.43	519.0	3.58
	9	0.0	-3.3	0	493.2	3.40	475.4	3.28
	10	-1.8	-3.0	0	492.3	3.39	467.0	3.22
	11	-3.5	-2.4	0	490.0	3.38	443.3	3.06
	12	-5.3	-2.6	0	490.7	3.38	450.8	3.11
2/5/96	1	-7.0	-2.3	0	489.7	3.38	441.2	3.04
	2	-8.8	-2.9	0	491.7	3.39	460.9	3.18
	3	-10.5	-2.9	0	491.8	3.39	462.1	3.19
	4	-7.2	-3.2	0	493.1	3.40	474.4	3.27
	5	-4.0	-1.4	45.2	486.1	3.35	406.0	2.80
	6	-0.7	1.3	90.4	469.1	3.23	321.7	2.22
	7	2.5	3.6	60.3	446.8	3.08	256.1	1.77
	8	5.8	4.6	30.1	437.8	3.02	232.3	1.60
	9	5.0	5.1	0	432.8	2.98	219.6	1.51
	10	4.2	4.9	0	434.9	3.00	224.7	1.55
	11	3.4	5.2	0	431.6	2.98	216.6	1.49
	12	2.7	4.8	0	435.2	3.00	225.5	1.55
2/6/96	1	1.9	5.0	0	433.3	2.99	220.8	1.52
	2	1.1	4.5	0	438.0	3.02	232.8	1.61
	3	0.3	4.6	0	437.2	3.01	230.6	1.59
	4	6.5	4.7	0	436.6	3.01	229.3	1.58
	5	12.8	6.8	33.6	416.2	2.87	180.0	1.24
	6	19.0	9.7	67.1	389.5	2.69	124.0	0.85
	7	25.3	12.7	44.7	360.7	2.49	67.7	0.47
	8	31.5	14.7	22.4	341.5	2.35	30.0	0.21
	9	24.7	15.9	0	330.7	2.28	8.9	0.06
	10	17.9	15.6	0	332.9	2.30	13.2	0.09
	11	11.1	15.4	0	335.1	2.31	17.4	0.12
	12	4.3	14.0	0	348.6	2.40	44.0	0.30

°F = 1.8 °C + 32

** Periods in which stress exceeds strength.

COLD output: WesTrack Section 24

Day	Time period	Air temp (^{o}F)	Pavement temp (^{o}F)	Solar Insolation (Langleys)	Expected values			
					Strength		Stress	
					(lb/in^2)	(MPa)	(lb/in^2)	(MPa)
12/11/97	1	20.0	24.8	0	343.7	2.37	0.0	0.00
	2	16.7	23.3	0	352.5	2.43	14.5	0.10
	3	13.5	22.7	0	356.5	2.46	21.4	0.15
	4	10.2	20.8	0	367.6	2.53	42.5	0.29
	5	16.3	23.6	95.5	351.0	2.42	11.7	0.08
	6	22.4	28.4	191	321.6	2.22	-32.4	-0.22
	7	28.6	32.3	127.3	297.4	2.05	-60.9	-0.42
	8	34.7	33.6	63.7	288.3	1.99	-68.7	-0.47
	9	40.8	34.3	0	282.7	1.95	-73.2	-0.50
	10	36.3	33.6	0	288.2	1.99	-68.7	-0.47
	11	31.8	33.4	0	289.2	1.99	-67.8	-0.47
	12	27.3	31.9	0	300.4	2.07	-58.1	-0.40
12/12/97	1	22.7	31.1	0	305.4	2.11	-52.5	-0.36
	2	18.2	29.0	0	318.1	2.19	-37.1	-0.26
	3	13.7	27.7	0	326.2	2.25	-26.4	-0.18
	4	9.2	25.1	0	341.6	2.36	-3.7	-0.03
	5	14.5	26.4	70.1	333.9	2.30	-15.4	-0.11
	6	19.8	29.2	140.2	317.2	2.19	-38.2	-0.26
	7	25.1	31.7	93.5	302.1	2.08	-56.3	-0.39
	8	30.4	32.0	46.7	299.7	2.07	-58.9	-0.41
	9	35.7	32.5	0	296.4	2.04	-61.8	-0.43
	10	32.3	31.6	0	302.5	2.09	-55.8	-0.38
	11	28.9	31.4	0	303.6	2.09	-54.6	-0.38
	12	25.5	30.0	0	312.2	2.15	-44.5	-0.31
12/13/97	1	22.1	29.3	0	316.1	2.18	-39.7	-0.27
	2	18.7	27.5	0	327.2	2.26	-25.0	-0.17
	3	15.3	26.5	0	333.2	2.30	-16.5	-0.11
	4	11.9	24.4	0	346.2	2.39	3.4	0.02
	5	17.8	26.2	75.1	335.0	2.31	-13.8	-0.10
	6	23.7	29.7	150.2	314.2	2.17	-42.1	-0.29
	7	29.5	32.7	100.1	294.6	2.03	-63.5	-0.44
	8	35.4	33.6	50.1	288.2	1.99	-68.8	-0.47
	9	41.3	34.4	0	282.3	1.95	-73.6	-0.51
	10	38.3	33.8	0	286.4	1.97	-70.3	-0.48
	11	35.3	34.0	0	285.1	1.97	-71.3	-0.49
	12	32.3	32.9	0	293.2	2.02	-64.6	-0.45
12/14/97	1	29.2	32.6	0	295.5	2.04	-62.6	-0.43
	2	26.2	31.1	0	305.5	2.11	-52.5	-0.36
	3	23.2	30.4	0	309.5	2.13	-47.8	-0.33
	4	20.2	28.6	0	320.6	2.21	-34.0	-0.23
	5	26.6	29.9	46	312.5	2.15	-44.2	-0.30
	6	33.1	32.1	92	299.1	2.06	-59.5	-0.41
	7	39.5	34.7	61.3	279.6	1.93	-75.7	-0.52

	8	46.0	35.8	30.7	271.7	1.87	-81.7	-0.56
	9	52.4	37.4	0	259.7	1.79	-90.2	-0.62
	10	47.2	37.3	0	260.0	1.79	-89.9	-0.62
	11	42.1	37.7	0	257.1	1.77	-91.9	-0.63
	12	36.9	36.6	0	265.3	1.83	-86.2	-0.59
12/15/97	1	31.7	36.1	0	269.3	1.86	-83.4	-0.58
	2	26.5	34.2	0	283.6	1.96	-72.6	-0.50
	3	21.4	33.0	0	292.8	2.02	-65.0	-0.45
	4	16.2	30.4	0	309.5	2.13	-47.8	-0.33
	5	22.9	32.6	95.9	295.3	2.04	-62.8	-0.43
	6	29.6	37.1	191.7	262.0	1.81	-88.6	-0.61
	7	36.3	40.7	127.8	234.9	1.62	-105.7	-0.73
	8	43.0	41.7	63.9	227.4	1.57	-109.9	-0.76
	9	49.7	42.3	0	222.9	1.54	-112.4	-0.77
	10	46.0	41.5	0	228.8	1.58	-109.2	-0.75
	11	42.3	41.4	0	229.5	1.58	-108.8	-0.75
	12	38.6	40.0	0	240.0	1.65	-102.8	-0.71
12/16/97	1	34.9	39.4	0	244.7	1.69	-99.9	-0.69
	2	31.2	37.5	0	258.7	1.78	-90.9	-0.63
	3	27.5	36.5	0	266.6	1.84	-85.5	-0.59
	4	23.8	34.2	0	283.2	1.95	-73.0	-0.50
	5	29.5	35.9	73.6	270.4	1.86	-82.7	-0.57
	6	35.1	39.2	147.1	246.0	1.70	-99.2	-0.68
	7	40.8	42.1	98.1	224.1	1.55	-111.8	-0.77
	8	46.4	42.8	49	218.7	1.51	-114.6	-0.79
	9	52.1	43.5	0	213.5	1.47	-117.2	-0.81
	10	47.5	42.7	0	219.4	1.51	-114.2	-0.79
	11	42.9	42.5	0	220.9	1.52	-113.5	-0.78
	12	38.3	41.0	0	232.6	1.60	-107.1	-0.74
12/17/97	1	33.8	40.1	0	239.1	1.65	-103.3	-0.71
	2	29.2	38.0	0	255.3	1.76	-93.3	-0.64
	3	24.6	36.6	0	265.7	1.83	-86.1	-0.59
	4	20.0	34.0	0	285.3	1.97	-71.4	-0.49
	5	26.5	35.4	74.1	274.2	1.89	-79.9	-0.55
	6	33.0	38.6	148.2	250.6	1.73	-96.3	-0.66
	7	39.5	41.5	98.8	229.0	1.58	-109.1	-0.75
	8	46.0	42.2	49.4	223.2	1.54	-112.3	-0.77
	9	52.5	43.0	0	217.2	1.50	-115.4	-0.80
	10	48.5	42.4	0	221.9	1.53	-113.0	-0.78
	11	44.5	42.4	0	221.9	1.53	-113.0	-0.78
	12	40.5	41.1	0	231.8	1.60	-107.6	-0.74
12/18/97	1	36.6	40.5	0	236.4	1.63	-104.9	-0.72
	2	32.6	38.6	0	250.4	1.73	-96.4	-0.66
	3	28.6	37.5	0	258.5	1.78	-91.1	-0.63
	4	24.6	35.3	0	275.6	1.90	-78.9	-0.54
	5	27.7	35.4	30.7	274.5	1.89	-79.8	-0.55
	6	30.8	35.8	61.4	271.5	1.87	-82.0	-0.57
	7	33.9	36.8	40.9	264.1	1.82	-87.3	-0.60
	8	37.0	36.4	20.5	266.9	1.84	-85.3	-0.59
	9	40.1	36.7	0	264.5	1.82	-87.0	-0.60
	10	35.5	35.6	0	272.9	1.88	-81.0	-0.56

	11	30.9	35.1	0	276.5	1.91	-78.3	-0.54
	12	26.3	33.3	0	290.1	2.00	-67.5	-0.47
12/19/97	1	21.7	32.2	0	298.3	2.06	-60.5	-0.42
	2	17.1	29.9	0	312.8	2.16	-44.0	-0.30
	3	12.5	28.3	0	322.3	2.22	-31.9	-0.22
	4	7.9	25.6	0	339.0	2.34	-8.1	-0.06
	5	14.0	27.5	95.3	327.4	2.26	-25.0	-0.17
	6	20.1	31.6	190.5	302.5	2.09	-56.2	-0.39
	7	26.1	34.9	127	278.5	1.92	-76.8	-0.53
	8	32.2	35.5	63.5	273.5	1.89	-80.6	-0.56
	9	38.3	35.8	0	271.6	1.87	-82.0	-0.57
	10	34.5	34.7	0	279.8	1.93	-75.8	-0.52
	11	30.6	34.3	0	282.8	1.95	-73.5	-0.51
	12	26.8	32.6	0	295.3	2.04	-63.2	-0.44
12/20/97	1	22.9	31.7	0	301.5	2.08	-57.3	-0.40
	2	19.1	29.7	0	314.2	2.17	-42.4	-0.29
	3	15.2	28.4	0	321.9	2.22	-32.6	-0.22
	4	11.4	26.0	0	336.6	2.32	-11.9	-0.08
	5	18.5	27.8	81.2	325.1	2.24	-28.2	-0.19
	6	25.5	31.6	162.4	302.3	2.08	-56.6	-0.39
	7	32.6	35.0	108.3	277.6	1.91	-77.6	-0.54
	8	39.6	36.1	54.1	269.4	1.86	-83.7	-0.58
	9	46.7	37.1	0	261.9	1.81	-89.0	-0.61
	10	43.1	36.7	0	265.0	1.83	-86.9	-0.60
	11	39.6	36.9	0	263.2	1.81	-88.1	-0.61
	12	36.0	35.8	0	271.3	1.87	-82.3	-0.57
12/21/97	1	32.5	35.5	0	274.0	1.89	-80.4	-0.55
	2	28.9	33.9	0	285.9	1.97	-71.0	-0.49
	3	25.4	33.1	0	292.0	2.01	-66.1	-0.46
	4	21.8	31.1	0	305.6	2.11	-52.8	-0.36
	5	24.2	31.4	31.8	303.4	2.09	-55.3	-0.38
	6	26.6	32.0	63.6	300.1	2.07	-59.0	-0.41
	7	29.1	33.0	42.4	292.3	2.02	-65.8	-0.45
	8	31.5	32.6	21.2	295.5	2.04	-63.1	-0.44
	9	33.9	32.8	0	294.1	2.03	-64.3	-0.44
	10	31.0	31.7	0	301.6	2.08	-57.3	-0.40
	11	28.1	31.5	0	303.3	2.09	-55.5	-0.38
	12	25.2	30.0	0	312.1	2.15	-45.1	-0.31
12/22/97	1	22.3	29.4	0	315.9	2.18	-40.4	-0.28
	2	19.4	27.6	0	326.6	2.25	-26.3	-0.18
	3	16.5	26.7	0	332.0	2.29	-18.8	-0.13
	4	13.6	24.7	0	344.1	2.37	-0.4	0.00
	5	17.3	26.9	89.8	330.9	2.28	-20.3	-0.14
	6	21.1	30.9	179.6	306.8	2.12	-51.4	-0.35
	7	24.8	33.9	119.7	285.8	1.97	-71.3	-0.49
	8	28.6	34.2	59.9	283.4	1.95	-73.2	-0.50
	9	32.3	34.0	0	284.7	1.96	-72.2	-0.50
	10	28.5	32.6	0	295.6	2.04	-63.1	-0.44
	11	24.7	31.9	0	300.7	2.07	-58.4	-0.40
	12	20.9	29.9	0	312.4	2.15	-44.8	-0.31
12/23/97	1	17.2	28.8	0	319.2	2.20	-36.3	-0.25

	2	13.4	26.5	0	333.0	2.30	-17.3	-0.12
	3	9.6	25.1	0	341.7	2.36	-4.3	-0.03
	4	5.8	22.5	0	357.2	2.46	21.8	0.15
	5	12.9	24.5	87.2	345.5	2.38	1.7	0.01
	6	20.0	28.5	174.4	321.2	2.21	-33.7	-0.23
	7	27.0	31.9	116.3	300.4	2.07	-58.9	-0.41
	8	34.1	33.0	58.1	292.6	2.02	-65.8	-0.45
	9	41.2	33.8	0	286.2	1.97	-71.1	-0.49
	10	37.0	33.2	0	290.7	2.00	-67.3	-0.46
	11	32.9	33.2	0	290.6	2.00	-67.4	-0.46
	12	28.7	31.9	0	300.6	2.07	-58.7	-0.40
12/24/97	1	24.5	31.3	0	304.5	2.10	-54.3	-0.37
	2	20.3	29.4	0	316.0	2.18	-40.4	-0.28
	3	16.2	28.2	0	322.9	2.23	-31.5	-0.22
	4	12.0	25.9	0	337.1	2.32	-11.3	-0.08
	5	16.9	26.5	41.7	333.6	2.30	-16.6	-0.11
	6	21.7	27.7	83.5	325.9	2.25	-27.5	-0.19
	7	26.6	29.4	55.6	315.5	2.18	-41.0	-0.28
	8	31.4	29.7	27.8	314.2	2.17	-42.7	-0.29
	9	36.3	30.4	0	309.4	2.13	-48.5	-0.33
	10	32.6	29.8	0	313.2	2.16	-44.0	-0.30
	11	28.8	29.9	0	312.9	2.16	-44.3	-0.31
	12	25.1	28.6	0	320.6	2.21	-34.5	-0.24
12/25/97	1	21.4	28.1	0	323.8	2.23	-30.2	-0.21
	2	17.7	26.3	0	334.6	2.31	-15.1	-0.10
	3	13.9	25.3	0	340.5	2.35	-6.2	-0.04
	4	10.2	23.2	0	353.6	2.44	15.1	0.10
	5	15.4	25.4	92.9	339.7	2.34	-7.4	-0.05
	6	20.6	29.7	185.8	313.8	2.16	-43.3	-0.30
	7	25.8	33.1	123.9	291.7	2.01	-66.7	-0.46
	8	31.0	33.8	61.9	286.3	1.97	-71.1	-0.49
	9	36.2	34.1	0	284.4	1.96	-72.7	-0.50
	10	31.3	32.9	0	293.3	2.02	-65.3	-0.45
	11	26.3	32.3	0	297.8	2.05	-61.5	-0.42
	12	21.4	30.4	0	309.9	2.14	-48.1	-0.33
12/26/97	1	16.4	29.1	0	317.4	2.19	-38.8	-0.27
	2	11.5	26.6	0	332.6	2.29	-18.1	-0.12
	3	6.5	24.9	0	343.1	2.37	-2.2	-0.02
	4	1.6	21.9	0	361.0	2.49	28.6	0.20
	5	8.9	23.7	93.1	350.1	2.41	9.2	0.06
	6	16.2	27.8	186.1	325.4	2.24	-28.2	-0.19
	7	23.5	31.2	124.1	304.7	2.10	-54.1	-0.37
	8	30.8	32.2	62	298.9	2.06	-60.4	-0.42
	9	38.1	32.8	0	294.0	2.03	-64.7	-0.45
	10	33.3	32.0	0	300.2	2.07	-59.2	-0.41
	11	28.5	31.7	0	301.8	2.08	-57.4	-0.40
	12	23.7	30.1	0	311.7	2.15	-45.9	-0.32
12/27/97	1	18.9	29.1	0	317.5	2.19	-38.6	-0.27
	2	14.1	26.9	0	331.1	2.28	-20.2	-0.14
	3	9.3	25.4	0	340.2	2.35	-6.8	-0.05
	4	4.5	22.6	0	356.7	2.46	20.6	0.14

	5	13.0	24.4	80.9	346.0	2.39	2.5	0.02
	6	21.5	28.2	161.8	323.0	2.23	-31.4	-0.22
	7	30.0	31.7	107.9	301.7	2.08	-57.5	-0.40
	8	38.5	33.1	53.9	291.8	2.01	-66.6	-0.46
	9	47.0	34.5	0	281.2	1.94	-75.2	-0.52
	10	41.9	34.3	0	282.8	1.95	-73.9	-0.51
	11	36.8	34.6	0	280.8	1.94	-75.5	-0.52
	12	31.7	33.3	0	289.9	2.00	-68.1	-0.47
12/28/97	1	26.6	32.7	0	294.5	2.03	-64.2	-0.44
	2	21.5	30.7	0	307.6	2.12	-50.8	-0.35
	3	16.4	29.5	0	315.4	2.17	-41.4	-0.29
	4	11.3	26.9	0	331.0	2.28	-20.5	-0.14
	5	18.7	28.9	87.5	319.0	2.20	-36.8	-0.25
	6	26.1	32.9	175	292.9	2.02	-65.7	-0.45
	7	33.5	36.5	116.7	266.5	1.84	-86.3	-0.60
	8	40.9	37.6	58.3	257.8	1.78	-92.3	-0.64
	9	48.3	38.6	0	250.5	1.73	-97.0	-0.67
	10	43.1	38.0	0	255.0	1.76	-94.1	-0.65
	11	38.0	37.9	0	255.7	1.76	-93.7	-0.65
	12	32.8	36.4	0	267.1	1.84	-85.8	-0.59
12/29/97	1	27.6	35.5	0	273.8	1.89	-80.9	-0.56
	2	22.4	33.3	0	290.6	2.00	-67.7	-0.47
	3	17.3	31.7	0	301.6	2.08	-57.8	-0.40
	4	12.1	29.0	0	318.4	2.20	-37.6	-0.26
	5	19.2	30.5	79.5	309.1	2.13	-49.1	-0.34
	6	26.2	33.9	159	285.7	1.97	-71.7	-0.49
	7	33.3	37.0	106	262.6	1.81	-89.0	-0.61
	8	40.3	37.9	53	256.0	1.77	-93.5	-0.64
	9	47.4	38.7	0	249.6	1.72	-97.6	-0.67
	10	42.2	38.0	0	254.9	1.76	-94.2	-0.65
	11	37.0	37.8	0	256.3	1.77	-93.3	-0.64
	12	31.8	36.2	0	268.4	1.85	-84.9	-0.59
12/30/97	1	26.5	35.2	0	275.8	1.90	-79.5	-0.55
	2	21.3	32.9	0	293.1	2.02	-65.6	-0.45
	3	16.1	31.3	0	304.1	2.10	-55.1	-0.38
	4	10.9	28.5	0	321.3	2.22	-33.9	-0.23
	5	18.3	30.0	80.5	311.9	2.15	-45.8	-0.32
	6	25.8	33.5	161	288.6	1.99	-69.4	-0.48
	7	33.2	36.7	107.3	265.0	1.83	-87.4	-0.60
	8	40.7	37.6	53.7	257.7	1.78	-92.4	-0.64
	9	48.1	38.6	0	250.6	1.73	-97.1	-0.67
	10	42.3	37.9	0	255.7	1.76	-93.8	-0.65
	11	36.6	37.7	0	257.3	1.77	-92.7	-0.64
	12	30.8	36.0	0	270.0	1.86	-83.8	-0.58

$°F = 1.8\ °C + 32$

COLD output: WesTrack Section 25

Day	Time period	Air temp (°F)	Pavement temp (°F)	Solar insolation (Langleys)	Expected values			
					Strength		Stress	
					(lb/in^2)	(MPa)	(lb/in^2)	(MPa)
1/18/96	1	20.0	24.8	0	509.8	3.51	0.0	0.00
	2	16.7	23.4	0	519.9	3.58	17.5	0.12
	3	13.5	22.7	0	524.3	3.61	25.7	0.18
	4	10.2	21.0	0	536.9	3.70	51.3	0.35
	5	16.3	23.6	95.5	518.3	3.57	14.5	0.10
	6	22.4	28.2	191	485.5	3.35	-37.5	-0.26
	7	28.6	32.1	127.3	458.5	3.16	-70.7	-0.49
	8	34.7	33.2	63.7	448.0	3.09	-79.7	-0.55
	9	40.8	34.0	0	441.3	3.04	-85.0	-0.59
	10	36.3	33.3	0	447.4	3.08	-80.1	-0.55
	11	31.8	33.2	0	448.3	3.09	-79.4	-0.55
	12	27.3	31.8	0	460.7	3.18	-68.4	-0.47
1/19/96	1	22.7	31.0	0	466.1	3.21	-62.2	-0.43
	2	18.2	29.0	0	480.4	3.31	-44.4	-0.31
	3	13.7	27.7	0	489.4	3.37	-32.1	-0.22
	4	9.2	25.2	0	506.9	3.49	-5.4	-0.04
	5	14.5	26.4	70.1	498.2	3.43	-19.1	-0.13
	6	19.8	29.1	140.2	479.7	3.31	-45.4	-0.31
	7	25.1	31.5	93.5	462.6	3.19	-66.3	-0.46
	8	30.4	31.9	46.7	459.9	3.17	-69.3	-0.48
	9	35.7	32.3	0	456.3	3.15	-72.7	-0.50
	10	32.3	31.4	0	462.9	3.19	-65.9	-0.45
	11	28.9	31.3	0	463.9	3.20	-64.7	-0.45
	12	25.5	29.9	0	473.7	3.27	-53.1	-0.37
1/20/96	1	22.1	29.3	0	478.0	3.30	-47.7	-0.33
	2	18.7	27.5	0	490.5	3.38	-30.6	-0.21
	3	15.3	26.6	0	497.3	3.43	-20.7	-0.14
	4	11.9	24.5	0	512.0	3.53	3.0	0.02
	5	17.8	26.3	75.1	499.5	3.44	-17.2	-0.12
	6	23.7	29.6	150.2	476.3	3.28	-49.9	-0.34
	7	29.5	32.5	100.1	454.4	3.13	-74.5	-0.51
	8	35.4	33.3	50.1	447.1	3.08	-80.5	-0.56
	9	41.3	34.1	0	440.2	3.04	-86.1	-0.59
	10	38.3	33.6	0	444.7	3.07	-82.5	-0.57
	11	35.3	33.8	0	443.1	3.06	-83.8	-0.58
	12	32.3	32.8	0	452.3	3.12	-76.2	-0.53
1/21/96	1	29.2	32.5	0	454.7	3.13	-74.1	-0.51
	2	26.2	31.0	0	465.9	3.21	-62.6	-0.43
	3	23.2	30.4	0	470.3	3.24	-57.3	-0.40
	4	20.2	28.6	0	482.8	3.33	-41.4	-0.29
	5	26.6	29.9	46	473.8	3.27	-53.0	-0.37
	6	33.1	32.0	92	459.0	3.16	-70.5	-0.49
	7	39.5	34.5	61.3	436.7	3.01	-88.8	-0.61

	8	46.0	35.5	30.7	427.7	2.95	-95.5	-0.66
	9	52.4	37.1	0	413.8	2.85	-105.0	-0.72
	10	47.2	37.1	0	414.2	2.86	-104.8	-0.72
	11	42.1	37.5	0	410.5	2.83	-107.2	-0.74
	12	36.9	36.4	0	419.9	2.90	-101.0	-0.70
1/22/96	1	31.7	35.9	0	424.2	2.92	-98.0	-0.68
	2	26.5	34.1	0	440.5	3.04	-85.9	-0.59
	3	21.4	32.9	0	450.9	3.11	-77.5	-0.53
	4	16.2	30.5	0	469.8	3.24	-58.0	-0.40
	5	22.9	32.6	95.9	453.9	3.13	-74.9	-0.52
	6	29.6	36.8	191.7	416.2	2.87	-103.6	-0.71
	7	36.3	40.4	127.8	385.2	2.66	-122.4	-0.84
	8	43.0	41.3	63.9	376.5	2.60	-127.0	-0.88
	9	49.7	42.0	0	371.1	2.56	-129.7	-0.89
	10	46.0	41.2	0	377.6	2.60	-126.4	-0.87
	11	42.3	41.1	0	378.2	2.61	-126.1	-0.87
	12	38.6	39.8	0	390.0	2.69	-119.7	-0.83
1/23/96	1	34.9	39.2	0	395.3	2.73	-116.7	-0.80
	2	31.2	37.4	0	411.2	2.84	-106.9	-0.74
	3	27.5	36.4	0	420.0	2.90	-101.0	-0.70
	4	23.8	34.3	0	439.1	3.03	-87.1	-0.60
	5	29.5	35.9	73.6	424.6	2.93	-97.9	-0.67
	6	35.1	39.0	147.1	397.0	2.74	-115.7	-0.80
	7	40.8	41.8	98.1	372.0	2.56	-129.4	-0.89
	8	46.4	42.6	49	365.8	2.52	-132.4	-0.91
	9	52.1	43.2	0	359.7	2.48	-135.3	-0.93
	10	47.5	42.5	0	366.3	2.53	-132.2	-0.91
	11	42.9	42.3	0	367.7	2.54	-131.5	-0.91
	12	38.3	40.8	0	381.0	2.63	-124.7	-0.86
1/24/96	1	33.8	40.0	0	388.3	2.68	-120.7	-0.83
	2	29.2	37.9	0	406.7	2.80	-109.8	-0.76
	3	24.6	36.6	0	418.5	2.89	-102.1	-0.70
	4	20.0	34.0	0	441.0	3.04	-85.7	-0.59
	5	26.5	35.4	74.1	428.5	2.95	-95.1	-0.66
	6	33.0	38.5	148.2	401.9	2.77	-112.8	-0.78
	7	39.5	41.3	98.8	377.3	2.60	-126.7	-0.87
	8	46.0	42.0	49.4	370.7	2.56	-130.0	-0.90
	9	52.5	42.8	0	363.6	2.51	-133.5	-0.92
	10	48.5	42.2	0	369.0	2.54	-130.9	-0.90
	11	44.5	42.2	0	368.7	2.54	-131.0	-0.90
	12	40.5	40.9	0	380.1	2.62	-125.2	-0.86
1/25/96	1	36.6	40.4	0	385.1	2.66	-122.5	-0.84
	2	32.6	38.6	0	401.1	2.77	-113.3	-0.78
	3	28.6	37.5	0	410.3	2.83	-107.6	-0.74
	4	24.6	35.3	0	429.9	2.96	-94.1	-0.65
	5	27.7	35.4	30.7	428.6	2.96	-95.0	-0.65
	6	30.8	35.8	61.4	425.5	2.93	-97.3	-0.67
	7	33.9	36.7	40.9	417.1	2.88	-103.1	-0.71
	8	37.0	36.4	20.5	420.4	2.90	-100.8	-0.69
	9	40.1	36.7	0	417.7	2.88	-102.7	-0.71
	10	35.5	35.6	0	427.3	2.95	-96.0	-0.66

	11	30.9	35.1	0	431.4	2.97	-93.0	-0.64
	12	26.3	33.4	0	447.0	3.08	-80.9	-0.56
1/26/96	1	21.7	32.3	0	456.3	3.15	-73.0	-0.50
	2	17.1	30.0	0	473.0	3.26	-54.2	-0.37
	3	12.5	28.5	0	483.8	3.34	-40.3	-0.28
	4	7.9	25.8	0	502.8	3.47	-12.4	-0.09
	5	14.0	27.6	95.3	489.9	3.38	-31.7	-0.22
	6	20.1	31.5	190.5	462.2	3.19	-67.2	-0.46
	7	26.1	34.7	127	435.0	3.00	-90.5	-0.62
	8	32.2	35.4	63.5	429.4	2.96	-94.6	-0.65
	9	38.3	35.6	0	427.1	2.94	-96.3	-0.66
	10	34.5	34.6	0	436.4	3.01	-89.4	-0.62
	11	30.6	34.2	0	439.6	3.03	-86.9	-0.60
	12	26.8	32.6	0	453.8	3.13	-75.3	-0.52
1/27/96	1	22.9	31.7	0	460.9	3.18	-68.7	-0.47
	2	19.1	29.7	0	475.2	3.28	-51.6	-0.36
	3	15.2	28.5	0	483.9	3.34	-40.3	-0.28
	4	11.4	26.1	0	500.6	3.45	-16.1	-0.11
	5	18.5	27.9	81.2	487.8	3.36	-34.9	-0.24
	6	25.5	31.5	162.4	462.3	3.19	-67.2	-0.46
	7	32.6	34.8	108.3	434.4	3.00	-91.0	-0.63
	8	39.6	35.8	54.1	425.1	2.93	-97.8	-0.67
	9	46.7	36.8	0	416.3	2.87	-103.9	-0.72
	10	43.1	36.4	0	419.7	2.89	-101.6	-0.70
	11	39.6	36.7	0	417.5	2.88	-103.1	-0.71
	12	36.0	35.7	0	426.7	2.94	-96.7	-0.67
1/28/96	1	32.5	35.3	0	429.5	2.96	-94.7	-0.65
	2	28.9	33.8	0	443.2	3.06	-84.2	-0.58
	3	25.4	33.0	0	449.9	3.10	-78.7	-0.54
	4	21.8	31.1	0	465.4	3.21	-63.6	-0.44
	5	24.2	31.4	31.8	462.9	3.19	-66.5	-0.46
	6	26.6	31.9	63.6	459.4	3.17	-70.5	-0.49
	7	29.1	33.0	42.4	450.6	3.11	-78.2	-0.54
	8	31.5	32.5	21.2	454.3	3.13	-75.1	-0.52
	9	33.9	32.7	0	452.6	3.12	-76.5	-0.53
	10	31.0	31.7	0	461.2	3.18	-68.5	-0.47
	11	28.1	31.4	0	463.0	3.19	-66.5	-0.46
	12	25.2	30.0	0	473.0	3.26	-54.5	-0.38
1/29/96	1	22.3	29.4	0	477.2	3.29	-49.2	-0.34
	2	19.4	27.7	0	489.4	3.37	-32.8	-0.23
	3	16.5	26.8	0	495.5	3.42	-23.9	-0.16
	4	13.6	24.9	0	509.3	3.51	-2.1	-0.01
	5	17.3	27.0	89.8	494.6	3.41	-25.3	-0.17
	6	21.1	30.8	179.6	467.7	3.22	-61.0	-0.42
	7	24.8	33.7	119.7	444.0	3.06	-83.7	-0.58
	8	28.6	34.0	59.9	441.3	3.04	-85.9	-0.59
	9	32.3	33.9	0	442.5	3.05	-84.9	-0.59
	10	28.5	32.5	0	455.0	3.14	-74.6	-0.51
	11	24.7	31.8	0	460.4	3.17	-69.5	-0.48
	12	20.9	29.9	0	473.6	3.27	-53.9	-0.37
1/30/96	1	17.2	28.9	0	481.2	3.32	-44.2	-0.30

	2	13.4	26.6	0	496.9	3.43	-22.0	-0.15
	3	9.6	25.2	0	506.7	3.49	-6.7	-0.05
	4	5.8	22.7	0	524.3	3.61	24.5	0.17
	5	12.9	24.6	87.2	511.2	3.52	0.9	0.01
	6	20.0	28.4	174.4	484.2	3.34	-40.3	-0.28
	7	27.0	31.8	116.3	460.7	3.18	-69.4	-0.48
	8	34.1	32.8	58.1	452.1	3.12	-77.2	-0.53
	9	41.2	33.6	0	444.6	3.07	-83.4	-0.58
	10	37.0	33.0	0	449.7	3.10	-79.2	-0.55
	11	32.9	33.1	0	449.5	3.10	-79.4	-0.55
	12	28.7	31.8	0	460.5	3.17	-69.6	-0.48
1/31/96	1	24.5	31.2	0	464.8	3.20	-64.7	-0.45
	2	20.3	29.3	0	477.8	3.29	-48.7	-0.34
	3	16.2	28.2	0	485.5	3.35	-38.5	-0.27
	4	12.0	26.0	0	501.6	3.46	-14.8	-0.10
	5	16.9	26.5	41.7	497.7	3.43	-20.9	-0.14
	6	21.7	27.7	83.5	489.2	3.37	-33.3	-0.23
	7	26.6	29.4	55.6	477.5	3.29	-49.1	-0.34
	8	31.4	29.6	27.8	476.1	3.28	-50.9	-0.35
	9	36.3	30.3	0	470.7	3.25	-57.7	-0.40
	10	32.6	29.7	0	474.9	3.27	-52.5	-0.36
	11	28.8	29.8	0	474.5	3.27	-52.9	-0.36
	12	25.1	28.6	0	483.3	3.33	-41.6	-0.29
2/1/96	1	21.4	28.1	0	486.8	3.36	-36.7	-0.25
	2	17.7	26.3	0	499.0	3.44	-18.9	-0.13
	3	13.9	25.4	0	505.6	3.49	-8.5	-0.06
	4	10.2	23.3	0	520.5	3.59	17.1	0.12
	5	15.4	25.5	92.9	505.0	3.48	-9.4	-0.06
	6	20.6	29.6	185.8	476.0	3.28	-51.2	-0.35
	7	25.8	32.9	123.9	451.3	3.11	-78.1	-0.54
	8	31.0	33.6	61.9	445.2	3.07	-83.2	-0.57
	9	36.2	33.9	0	442.7	3.05	-85.2	-0.59
	10	31.3	32.7	0	452.8	3.12	-76.8	-0.53
	11	26.3	32.2	0	457.6	3.15	-72.7	-0.50
	12	21.4	30.3	0	471.1	3.25	-57.4	-0.40
2/2/96	1	16.4	29.1	0	479.4	3.31	-46.9	-0.32
	2	11.5	26.7	0	496.6	3.42	-22.8	-0.16
	3	6.5	25.0	0	508.4	3.51	-4.1	-0.03
	4	1.6	22.1	0	528.7	3.65	32.8	0.23
	5	8.9	23.8	93.1	516.5	3.56	9.9	0.07
	6	16.2	27.7	186.1	489.0	3.37	-33.8	-0.23
	7	23.5	31.0	124.1	465.7	3.21	-63.8	-0.44
	8	30.8	31.9	62	459.4	3.17	-71.0	-0.49
	9	38.1	32.6	0	453.7	3.13	-76.1	-0.52
	10	33.3	31.8	0	460.4	3.17	-69.9	-0.48
	11	28.5	31.6	0	462.0	3.19	-68.1	-0.47
	12	23.7	30.0	0	473.2	3.26	-54.8	-0.38
2/3/96	1	18.9	29.1	0	479.6	3.31	-46.6	-0.32
	2	14.1	26.9	0	495.1	3.41	-25.1	-0.17
	3	9.3	25.4	0	505.2	3.48	-9.3	-0.06
	4	4.5	22.8	0	523.9	3.61	23.4	0.16

	5	13.0	24.5	80.9	512.1	3.53	2.0	0.01
	6	21.5	28.1	161.8	486.4	3.35	-37.6	-0.26
	7	30.0	31.5	107.9	462.4	3.19	-67.8	-0.47
	8	38.5	32.9	53.9	451.4	3.11	-78.1	-0.54
	9	47.0	34.2	0	439.1	3.03	-88.0	-0.61
	10	41.9	34.1	0	440.8	3.04	-86.7	-0.60
	11	36.8	34.3	0	438.4	3.02	-88.6	-0.61
	12	31.7	33.2	0	448.6	3.09	-80.4	-0.55
2/4/96	1	26.6	32.6	0	453.7	3.13	-76.2	-0.53
	2	21.5	30.7	0	468.3	3.23	-60.9	-0.42
	3	16.4	29.5	0	477.0	3.29	-50.2	-0.35
	4	11.3	27.0	0	494.6	3.41	-25.9	-0.18
	5	18.7	28.9	87.5	481.1	3.32	-44.7	-0.31
	6	26.1	32.8	175	452.1	3.12	-77.6	-0.54
	7	33.5	36.2	116.7	421.9	2.91	-100.8	-0.69
	8	40.9	37.3	58.3	412.0	2.84	-107.5	-0.74
	9	48.3	38.3	0	403.4	2.78	-112.9	-0.78
	10	43.1	37.7	0	408.4	2.82	-109.8	-0.76
	11	38.0	37.7	0	408.9	2.82	-109.5	-0.75
	12	32.8	36.2	0	421.8	2.91	-100.9	-0.70
2/5/96	1	27.6	35.4	0	429.3	2.96	-95.6	-0.66
	2	22.4	33.2	0	448.4	3.09	-80.8	-0.56
	3	17.3	31.7	0	460.8	3.18	-69.7	-0.48
	4	12.1	29.0	0	479.8	3.31	-46.6	-0.32
	5	19.2	30.5	79.5	469.4	3.24	-59.6	-0.41
	6	26.2	33.8	159	443.2	3.06	-85.0	-0.59
	7	33.3	36.8	106	416.9	2.87	-104.3	-0.72
	8	40.3	37.6	53	409.4	2.82	-109.3	-0.75
	9	47.4	38.5	0	401.9	2.77	-113.9	-0.79
	10	42.2	37.8	0	407.8	2.81	-110.2	-0.76
	11	37.0	37.6	0	409.2	2.82	-109.4	-0.75
	12	31.8	36.1	0	423.0	2.92	-100.2	-0.69
2/6/96	1	26.5	35.2	0	431.2	2.97	-94.3	-0.65
	2	21.3	32.9	0	451.0	3.11	-78.7	-0.54
	3	16.1	31.4	0	463.4	3.19	-66.9	-0.46
	4	10.9	28.6	0	482.9	3.33	-42.6	-0.29
	5	18.3	30.1	80.5	472.5	3.26	-56.0	-0.39
	6	25.8	33.4	161	446.4	3.08	-82.5	-0.57
	7	33.2	36.5	107.3	419.4	2.89	-102.7	-0.71
	8	40.7	37.4	53.7	411.2	2.84	-108.2	-0.75
	9	48.1	38.4	0	402.9	2.78	-113.4	-0.78
	10	42.3	37.7	0	408.6	2.82	-109.8	-0.76
	11	36.6	37.5	0	410.2	2.83	-108.8	-0.75
	12	30.8	35.9	0	424.7	2.93	-99.0	-0.68

$°F = 1.8\ °C + 32$

COLD output: hybrid pavement, Jan. 18 to Feb. 6 1996

Day	Time period	Air temp (^oF)	Pavement temp (^oF)	Solar insolation (Langleys)	Expected values			
					Strength		Stress	
					(lb/in^2)	(MPa)	(lb/in^2)	(MPa)
1/18/96	1	-10.0	16.4	0	382.2	2.64	0.0	0.00
	2	-11.6	13.4	0	389.2	2.68	33.1	0.23
	3	-13.1	11.2	0	390.1	2.69	58.8	0.41
	4	-7.6	9.2	0	390.9	2.70	83.7	0.58
	5	-2.1	8.9	16.2	391.0	2.70	86.7	0.60
	6	3.3	9.1	32.4	390.9	2.70	84.8	0.58
	7	8.8	10.0	21.6	390.6	2.69	73.1	0.50
	8	14.3	10.4	10.8	390.4	2.69	67.7	0.47
	9	8.5	10.6	0	390.3	2.69	65.9	0.45
	10	2.8	9.6	0	390.7	2.69	78.2	0.54
	11	-3.0	8.8	0	391.0	2.70	88.5	0.61
	12	-8.8	6.9	0	391.8	2.70	112.5	0.78
1/19/96	1	-14.6	5.3	0	392.4	2.71	133.6	0.92
	2	-20.3	2.8	0	393.3	2.71	169.2	1.17
	3	-26.1	0.7	0	394.2	2.72	201.4	1.39
	4	-23.2	-1.6	0	395.0	2.72	236.5	1.63
	5	-20.3	-1.6	37.4	395.1	2.72	237.4	1.64
	6	-17.4	-1.0	74.8	394.8	2.72	226.8	1.56
	7	-14.5	-0.2	49.8	394.5	2.72	214.9	1.48
	8	-11.6	-0.6	24.9	394.7	2.72	220.5	1.52
	9	-13.2	-1.1	0	394.9	2.72	229.3	1.58
	10	-14.7	-2.3	0	395.4	2.73	249.2	1.72
	11	-16.3	-3.0	0	395.6	2.73	259.7	1.79
	12	-17.8	-4.3	0	395.1	2.72	281.7	1.94
1/20/96	1	-19.4	-5.0	0	392.7	2.71	293.7	2.02
	2	-20.9	-6.3	0	388.0	2.68	317.9	2.19
	3	-22.5	-7.0	0	385.5	2.66	331.4	2.28
	4	-17.4	-7.8	0	382.8	2.64	345.9	2.38
	5	-12.2	-6.5	32	387.3	2.67	321.9	2.22
	6	-7.1	-4.6	64.1	393.9	2.72	287.9	1.98
	7	-1.9	-2.5	42.7	395.4	2.73	251.3	1.73
	8	3.2	-1.3	21.4	394.9	2.72	232.0	1.60
	9	3.1	-0.2	0	394.5	2.72	215.5	1.49
	10	3.0	0.1	0	394.4	2.72	210.7	1.45
	11	2.9	0.9	0	394.1	2.72	197.5	1.36
	12	2.8	1.1	0	394.0	2.72	195.2	1.35
1/21/96	1	2.7	1.8	0	393.7	2.71	184.4	1.27

	2	2.6	1.8	0	393.7	2.71	184.0	1.27
	3	2.5	2.4	0	393.5	2.71	174.9	1.21
	4	7.0	2.8	0	393.4	2.71	169.6	1.17
	5	11.5	4.8	22.9	392.6	2.71	141.5	0.98
	6	16.1	7.0	45.7	391.7	2.70	111.9	0.77
	7	20.6	9.5	30.5	390.8	2.69	79.5	0.55
	8	25.1	11.1	15.2	390.1	2.69	59.7	0.41
	9	19.9	12.2	0	389.7	2.69	46.4	0.32
	10	14.7	12.1	0	389.7	2.69	47.5	0.33
	11	9.5	12.2	0	389.7	2.69	47.2	0.33
	12	4.2	11.1	0	390.1	2.69	59.6	0.41
1/22/96	1	-1.0	10.3	0	390.4	2.69	69.4	0.48
	2	-6.2	8.5	0	391.1	2.70	91.8	0.63
	3	-11.4	7.0	0	391.7	2.70	110.8	0.76
	4	-5.2	5.7	0	392.2	2.70	128.5	0.89
	5	1.0	6.6	31.3	391.9	2.70	116.7	0.80
	6	7.1	8.2	62.6	391.2	2.70	95.5	0.66
	7	13.3	10.2	41.7	390.5	2.69	70.3	0.48
	8	19.5	11.4	20.9	390.0	2.69	56.2	0.39
	9	14.0	11.9	0	389.8	2.69	49.8	0.34
	10	8.4	11.3	0	390.0	2.69	57.4	0.40
	11	2.9	10.8	0	390.2	2.69	63.1	0.44
	12	-2.7	9.3	0	390.8	2.69	82.0	0.57
1/23/96	1	-8.2	8.0	0	391.3	2.70	98.0	0.68
	2	-13.8	5.8	0	392.2	2.70	127.5	0.88
	3	-19.3	3.9	0	392.9	2.71	153.5	1.06
	4	-15.4	2.0	0	393.7	2.71	180.9	1.25
	5	-11.5	2.0	25.7	393.6	2.71	180.7	1.25
	6	-7.5	2.5	51.4	393.5	2.71	173.6	1.20
	7	-3.6	3.4	34.3	393.1	2.71	160.3	1.11
	8	0.3	3.5	17.1	393.1	2.71	158.9	1.10
	9	-1.6	3.6	0	393.1	2.71	158.4	1.09
	10	-3.4	2.8	0	393.3	2.71	169.2	1.17
	11	-5.3	2.6	0	393.4	2.71	172.5	1.19
	12	-7.2	1.6	0	393.8	2.72	186.9	1.29
1/24/96	1	-9.1	1.2	0	394.0	2.72	193.4	1.33
	2	-10.9	0.0	0	394.4	2.72	211.1	1.46
	3	-12.8	-0.5	0	394.7	2.72	220.3	1.52
	4	-9.3	-1.3	0	395.0	2.72	233.0	1.61
	5	-5.8	0.0	38.9	394.5	2.72	212.3	1.46
	6	-2.2	1.9	77.7	393.7	2.71	182.5	1.26
	7	1.3	3.9	51.8	392.9	2.71	154.5	1.07
	8	4.8	4.6	25.9	392.7	2.71	144.5	1.00
	9	2.0	4.8	0	392.6	2.71	141.1	0.97

	10	-0.7	4.2	0	392.8	2.71	150.0	1.03
	11	-3.5	4.0	0	392.9	2.71	153.0	1.05
	12	-6.2	2.9	0	393.3	2.71	168.1	1.16
1/25/96	1	-9.0	2.3	0	393.5	2.71	176.5	1.22
	2	-11.7	1.0	0	394.1	2.72	196.9	1.36
	3	-14.5	0.1	0	394.4	2.72	210.1	1.45
	4	-10.9	-0.9	0	394.8	2.72	226.2	1.56
	5	-7.3	-0.1	26.6	394.5	2.72	214.0	1.48
	6	-3.7	1.0	53.2	394.1	2.72	196.2	1.35
	7	-0.1	2.5	35.4	393.5	2.71	174.5	1.20
	8	3.5	3.0	17.7	393.3	2.71	166.9	1.15
	9	1.0	3.3	0	393.2	2.71	162.0	1.12
	10	-1.6	2.8	0	393.4	2.71	169.9	1.17
	11	-4.1	2.7	0	393.4	2.71	171.5	1.18
	12	-6.7	1.7	0	393.8	2.72	185.3	1.28
1/26/96	1	-9.2	1.3	0	393.9	2.72	192.2	1.33
	2	-11.8	0.0	0	394.4	2.72	211.2	1.46
	3	-14.3	-0.7	0	394.7	2.72	222.6	1.53
	4	-9.8	-1.5	0	395.0	2.72	235.8	1.63
	5	-5.3	-0.6	22	394.7	2.72	221.3	1.53
	6	-0.7	0.6	44	394.2	2.72	202.2	1.39
	7	3.8	2.3	29.3	393.5	2.71	176.8	1.22
	8	8.3	3.2	14.7	393.2	2.71	163.6	1.13
	9	5.5	3.9	0	392.9	2.71	153.2	1.06
	10	2.7	3.7	0	393.0	2.71	156.3	1.08
	11	-0.1	3.9	0	392.9	2.71	154.2	1.06
	12	-2.9	3.1	0	393.2	2.71	164.6	1.13
1/27/96	1	-5.7	2.8	0	393.3	2.71	169.0	1.17
	2	-8.5	1.7	0	393.8	2.72	185.6	1.28
	3	-11.3	1.1	0	394.0	2.72	195.4	1.35
	4	-8.0	0.2	0	394.4	2.72	208.7	1.44
	5	-4.7	1.4	38.9	393.9	2.72	190.1	1.31
	6	-1.5	3.3	77.9	393.2	2.71	162.7	1.12
	7	1.8	5.1	51.9	392.5	2.71	137.0	0.94
	8	5.1	5.7	26	392.2	2.70	128.9	0.89
	9	2.7	5.9	0	392.2	2.70	126.5	0.87
	10	0.4	5.2	0	392.4	2.71	135.6	0.93
	11	-2.0	5.0	0	392.5	2.71	138.4	0.95
	12	-4.4	4.0	0	392.9	2.71	152.4	1.05
1/28/96	1	-6.8	3.5	0	393.1	2.71	159.5	1.10
	2	-9.1	2.2	0	393.6	2.71	177.9	1.23
	3	-11.5	1.5	0	393.9	2.72	188.7	1.30
	4	-6.8	0.7	0	394.2	2.72	200.9	1.39
	5	-2.0	1.7	23.3	393.8	2.72	186.2	1.28

	6	2.7	3.0	46.5	393.3	2.71	166.4	1.15
	7	7.5	4.8	31	392.6	2.71	140.9	0.97
	8	12.2	5.8	15.5	392.2	2.70	127.3	0.88
	9	7.9	6.4	0	391.9	2.70	118.7	0.82
	10	3.5	6.0	0	392.1	2.70	124.6	0.86
	11	-0.8	5.8	0	392.2	2.70	127.1	0.88
	12	-5.1	4.7	0	392.6	2.71	143.2	0.99
1/29/96	1	-9.4	3.8	0	393.0	2.71	154.8	1.07
	2	-13.8	2.1	0	393.6	2.71	179.9	1.24
	3	-18.1	0.8	0	394.1	2.72	199.8	1.38
	4	-12.1	-0.4	0	394.6	2.72	218.6	1.51
	5	-6.1	0.8	41.1	394.1	2.72	199.5	1.38
	6	0.0	3.0	82.2	393.3	2.71	166.9	1.15
	7	6.0	5.3	54.8	392.4	2.71	134.1	0.92
	8	12.0	6.5	27.4	391.9	2.70	117.3	0.81
	9	6.3	7.0	0	391.7	2.70	112.0	0.77
	10	0.6	6.2	0	392.0	2.70	122.3	0.84
	11	-5.1	5.6	0	392.3	2.70	130.5	0.90
	12	-10.9	3.9	0	392.9	2.71	153.8	1.06
1/30/96	1	-16.6	2.5	0	393.5	2.71	173.9	1.20
	2	-22.3	0.1	0	394.4	2.72	209.5	1.44
	3	-28.0	-1.9	0	395.2	2.72	241.5	1.67
	4	-25.2	-4.0	0	396.0	2.73	276.7	1.91
	5	-22.4	-3.8	43.8	395.9	2.73	273.0	1.88
	6	-19.5	-2.7	87.5	395.5	2.73	255.0	1.76
	7	-16.7	-1.7	58.4	395.1	2.72	238.7	1.65
	8	-13.9	-2.0	29.2	395.2	2.72	243.2	1.68
	9	-16.0	-2.6	0	395.5	2.73	253.9	1.75
	10	-18.2	-4.0	0	396.0	2.73	277.0	1.91
	11	-20.3	-4.8	0	393.3	2.71	290.9	2.01
	12	-22.4	-6.3	0	388.0	2.68	317.8	2.19
1/31/96	1	-24.5	-7.2	0	384.9	2.65	334.9	2.31
	2	-26.7	-8.8	0	379.3	2.62	365.6	2.52
	3**	-28.8	-9.9	0	375.8	2.59	385.7	2.66
	4**	-24.2	-10.9	0	372.1	2.57	407.4	2.81
	5**	-19.6	-9.8	38.9	376.1	2.59	383.7	2.65
	6	-14.9	-7.8	77.7	382.8	2.64	346.0	2.39
	7	-10.3	-5.8	51.8	389.8	2.69	308.8	2.13
	8	-5.7	-4.9	25.9	392.8	2.71	293.1	2.02
	9	-9.7	-4.6	0	393.8	2.72	288.1	1.99
	10	-13.8	-5.4	0	391.3	2.70	300.9	2.07
	11	-17.8	-5.8	0	389.9	2.69	308.3	2.13
	12	-21.9	-7.1	0	385.2	2.66	332.8	2.29
2/1/96	1	-25.9	-8.1	0	381.9	2.63	350.8	2.42

	2**	-30.0	-9.9	0	375.7	2.59	386.4	2.66
	3**	-34.0	-11.3	0	370.9	2.56	414.4	2.86
	4**	-30.6	-12.8	0	365.8	2.52	446.1	3.08
	5**	-27.1	-11.8	48.4	369.1	2.54	425.8	2.94
	6**	-23.7	-9.9	96.9	375.6	2.59	386.6	2.67
	7	-20.2	-8.2	64.6	381.5	2.63	353.3	2.44
	8	-16.8	-7.9	32.3	382.6	2.64	347.3	2.39
	9	-20.0	-8.2	0	381.5	2.63	353.3	2.44
	10	-23.3	-9.4	0	377.4	2.60	376.4	2.60
	11**	-26.5	-10.1	0	374.8	2.58	391.2	2.70
	12**	-29.8	-11.7	0	369.5	2.55	423.2	2.92
2/2/96	1**	-33.0	-12.7	0	365.8	2.52	446.0	3.08
	2**	-36.3	-14.6	0	359.4	2.48	486.9	3.36
	3**	-39.5	-15.9	0	354.8	2.45	517.4	3.57
	4**	-35.8	-17.3	0	349.9	2.41	551.5	3.80
	5**	-32.1	-16.3	47.6	353.4	2.44	527.2	3.63
	6**	-28.4	-14.4	95.1	360.2	2.48	482.0	3.32
	7**	-24.7	-12.6	63.4	366.3	2.53	442.6	3.05
	8**	-21.0	-12.2	31.7	367.8	2.54	433.3	2.99
	9**	-22.8	-12.2	0	367.6	2.53	434.8	3.00
	10**	-24.6	-13.1	0	364.7	2.51	452.6	3.12
	11**	-26.4	-13.3	0	363.7	2.51	459.1	3.17
	12**	-28.3	-14.4	0	360.1	2.48	482.1	3.32
2/3/96	1**	-30.1	-14.9	0	358.5	2.47	492.9	3.40
	2**	-31.9	-16.0	0	354.4	2.44	520.4	3.59
	3**	-33.7	-16.7	0	352.3	2.43	535.0	3.69
	4**	-30.0	-17.5	0	349.5	2.41	554.3	3.82
	5**	-26.3	-16.1	39.2	354.1	2.44	522.4	3.60
	6**	-22.6	-14.1	78.5	361.0	2.49	476.3	3.28
	7**	-18.9	-12.1	52.3	367.9	2.54	432.9	2.98
	8**	-15.2	-11.4	26.2	370.5	2.55	416.9	2.87
	9**	-17.1	-11.0	0	371.8	2.56	409.3	2.82
	10**	-19.1	-11.5	0	370.2	2.55	418.8	2.89
	11**	-21.0	-11.5	0	370.3	2.55	418.5	2.89
	12**	-23.0	-12.2	0	367.6	2.53	434.6	3.00
2/4/96	1**	-24.9	-12.5	0	366.7	2.53	440.1	3.03
	2**	-26.9	-13.5	0	363.3	2.50	462.0	3.19
	3**	-28.8	-13.9	0	361.6	2.49	472.3	3.26
	4**	-22.7	-14.4	0	360.1	2.48	482.3	3.33
	5**	-16.6	-12.4	45.5	367.2	2.53	437.4	3.02
	6	-10.5	-9.3	91	377.6	2.60	375.2	2.59
	7	-4.4	-6.3	60.7	387.9	2.67	318.4	2.20
	8	1.7	-4.6	30.3	394.0	2.72	287.1	1.98
	9	0.0	-3.4	0	395.8	2.73	267.5	1.84

	10	-1.8	-3.2	0	395.7	2.73	263.4	1.82
	11	-3.5	-2.5	0	395.4	2.73	252.5	1.74
	12	-5.3	-2.7	0	395.5	2.73	255.6	1.76
2/5/96	1	-7.0	-2.5	0	395.4	2.73	251.0	1.73
	2	-8.8	-3.0	0	395.6	2.73	259.6	1.79
	3	-10.5	-3.0	0	395.6	2.73	259.9	1.79
	4	-7.2	-3.3	0	395.7	2.73	265.2	1.83
	5	-4.0	-1.5	43.6	395.0	2.72	234.9	1.62
	6	-0.7	1.1	87.2	394.0	2.72	195.3	1.35
	7	2.5	3.4	58.2	393.1	2.71	161.0	1.11
	8	5.8	4.3	29.1	392.8	2.71	147.6	1.02
	9	5.0	4.9	0	392.5	2.71	139.9	0.96
	10	4.2	4.7	0	392.6	2.71	142.5	0.98
	11	3.4	5.1	0	392.5	2.71	137.5	0.95
	12	2.7	4.7	0	392.6	2.71	142.4	0.98
2/6/96	1	1.9	4.9	0	392.5	2.71	139.4	0.96
	2	1.1	4.4	0	392.7	2.71	146.2	1.01
	3	0.3	4.5	0	392.7	2.71	144.8	1.00
	4	6.5	4.6	0	392.7	2.71	143.8	0.99
	5	12.8	6.7	32.2	391.8	2.70	114.8	0.79
	6	19.0	9.5	64.4	390.8	2.69	79.4	0.55
	7	25.3	12.5	42.9	389.6	2.69	43.3	0.30
	8	31.5	14.5	21.5	387.5	2.67	20.3	0.14
	9	24.7	15.7	0	384.2	2.65	7.7	0.05
	10	17.9	15.5	0	384.8	2.65	9.9	0.07
	11	11.1	15.3	0	385.4	2.66	12.2	0.08
	12	4.3	13.8	0	389.1	2.68	27.8	0.19

°F = 1.8 °C + 32

** Periods in which stress exceeds strength.

Moisture Sensitivity Testing

U.S. Department of Transportation
Federal Highway Administration

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WesTrack Report OSU-2
HRDI-11/04-06(CD-ROM)E

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MOISTURE SENSITIVITY TESTING

The experiment design for the WesTrack Project is shown in table 1. The materials used in the construction of the track included a single PG 64-22 binder (from two sources) and two aggregates, a partially crushed gravel and a crushed andesite. Detailed information on the properties of the binder and aggregates are found elsewhere.[1] The primary distresses of interest for development of the performance-related specification (PRS) were permanent deformation and fatigue cracking. Accordingly, materials used for the track construction (i.e., asphalt cement and aggregate) were selected to preclude problems with low temperature cracking and moisture sensitivity. The aggregates selected for this experiment were (and continue to be) frequently used by the Nevada Department of Transportation. They are not known to be "strippers." Still, lime was added to all mixes as a precaution. Specifically, lime was included in all of the asphalt concrete mixes at a rate of 1.5 percent by dry weight of aggregate. For the laboratory portion of the experiment, the lime was added in accordance with Nevada test method T343A.

Since one objective of the WesTrack experiment was to provide the early field verification of Superpave volumetric mix design, moisture sensitivity testing was conducted in accordance with American Association of State Highway and Transportation Officials (AASHTO) Test T283 using 150-mm (6-in.) diameter samples. Samples fabricated in the laboratory were approximately 95 mm (3.75 in.) in height, whereas field cores were approximately 50 mm (2 in.) in height (i.e., the thickness of the asphalt concrete layer). For moisture sensitivity testing, field cores consisting of field-mixed, field-compacted (FMFC) material were taken from the bottom lift of the asphalt concrete. Table 2 is an outline of the moisture sensitivity testing conducted. All T283 test results from Oregon State University (OSU) and the University of Nevada, Reno (UNR), are included in appendix A. More detailed information on the T283 results is contained in the WesTrack database elsewhere on this CD-ROM.

Moisture sensitivity test results are summarized in figures 1 through 4. Figures 1 and 3 show T283 test results from specimens taken immediately after construction and before traffic loading (at time = 0). Postmortem test results are shown in figures 2 and 4. Note that there is tremendous scatter in the T283 data for the FMFC specimens taken immediately after construction at time = 0. The range in tensile strength ratio (TSR) is 45 to 102. Note also that the Superpave-recommended minimum TSR of 80 percent would lead one to conclude that more than half of the sections at WesTrack were likely to have stripping problems. Condition surveys conducted throughout the loading of the track, however, did not reveal any evidence of moisture-related distress. The TSRs for specimens made with plant-mixed material (i.e., FMFC and field-mixed, laboratory-compacted (FMLC) specimens) were lower than the TSRs for laboratory-mixed, laboratory-compacted (LMLC) specimens. The mean TSRs for FMFC and FMLC specimens were 75 percent and 62 percent, respectively, whereas the mean TSR for LMLC specimens was 80 percent.

Table 3 shows results from t-tests conducted on various pairs of the data (e.g., FMFC vs. FMLC). As is evident from the results shown in Table 3, the mean TSR for the plant-mixed material (FMFC and FMLC) is statistically different from the mean TSR for the lab-produced

(LMLC) material. Specifically, T283 results from specimens made with the plant-mixed material suggest that stripping at WesTrack would be a problem, whereas the results from the lab-fabricated specimens suggest exactly the opposite. There is no statistically significant difference between the results from the time = 0 and postmortem specimens. Finally, there is a statistically significant difference between OSU and UNR results of tests on the FMFC specimens.

Figure 5 shows the relationship between air void content and indirect tensile strength, as measured in T283. Intuitively, one would expect tensile strength to be inversely proportional to air void content. However, regression of indirect tensile strength on air void content for both conditioned and unconditioned samples revealed an explained variation of barely 30 percent (R^2 = 0.30).

The scatter in the data and the obvious discrepancy between the T283 results and field performance are, to say the least, somewhat disconcerting. Though several states (Nevada, Utah) have some degree of confidence in T283 results, recently completed research from the National Cooperative Highway Research Program (NCHRP Project 9-13) tends to reinforce the observations reported here.[2] The objective of NCHRP 9-13 was to investigate the use of T283 with Superpave. Researchers at UNR considered the following variables: compaction device, sample size, saturation level, aging, freeze-thaw cycles, and aggregate sources. Very briefly, five aggregates were included in the experiment; two of these were reported to be good performers, and three were reported as poor performers. The two aggregates reported to perform well with respect to moisture sensitivity were from Alabama and Texas; the poor performers were from Colorado, Maryland, and Nevada. Given the preceding information, one would expect the aggregates from Alabama and Texas to have TSRs greater or equal to 0.80, and the aggregates from Colorado, Maryland, and Nevada to have TSRs less than 0.80. The results shown in table 4 reflect the obvious discrepancy between “reported performance” and “predicted performance” as measured by T283.

Given the WesTrack data and the results of NCHRP 9-13 research, NCHRP hosted a moisture sensitivity focus group meeting on July 28, 1999. The minutes of this meeting are provided in appendix B. The consensus of the group was that a major research effort on moisture sensitivity was desperately needed. Accordingly, a two-phase program effort to include a literature search, comprehensive laboratory testing, and field validation was proposed.

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1. Hand, A., "Relationships Between Laboratory-Measured HMA Material and Mixture Properties and Pavement Performance at WesTrack," University of Nevada, Civil Engineering, Ph.D. Thesis, Reno, NV, August 1998.

2. Epps, J., Sebaaly, P., Penaranda, J., Maher, M., McCann, M., and Hand, A., "Evaluation of Water Sensitivity Results," draft report, NCHRP 9-13, Transportation Research Board, National Cooperative Highway Research Program, Washington, D.C., April 1999.

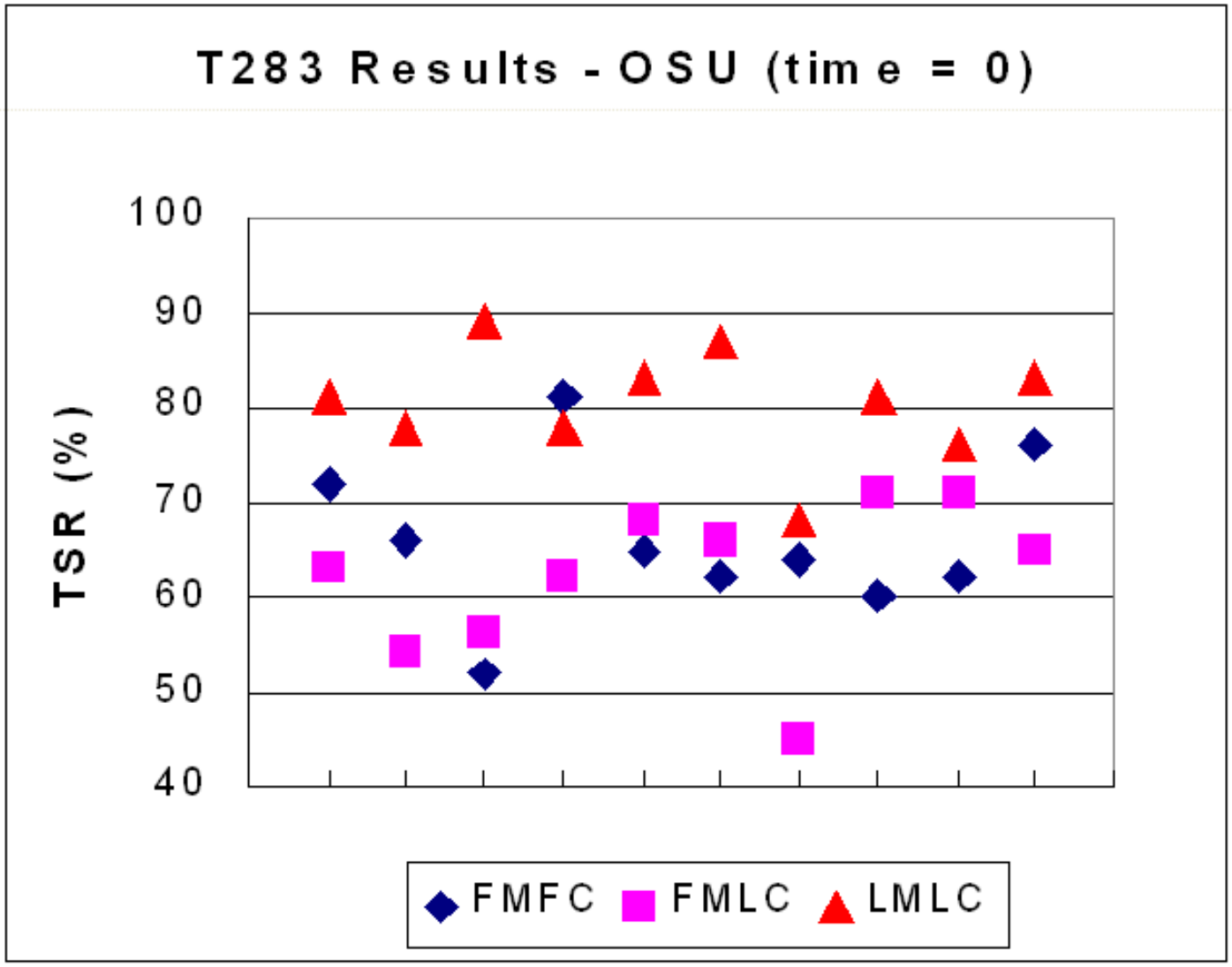


Figure 1. Comparison of T283 results for lab and field materials.

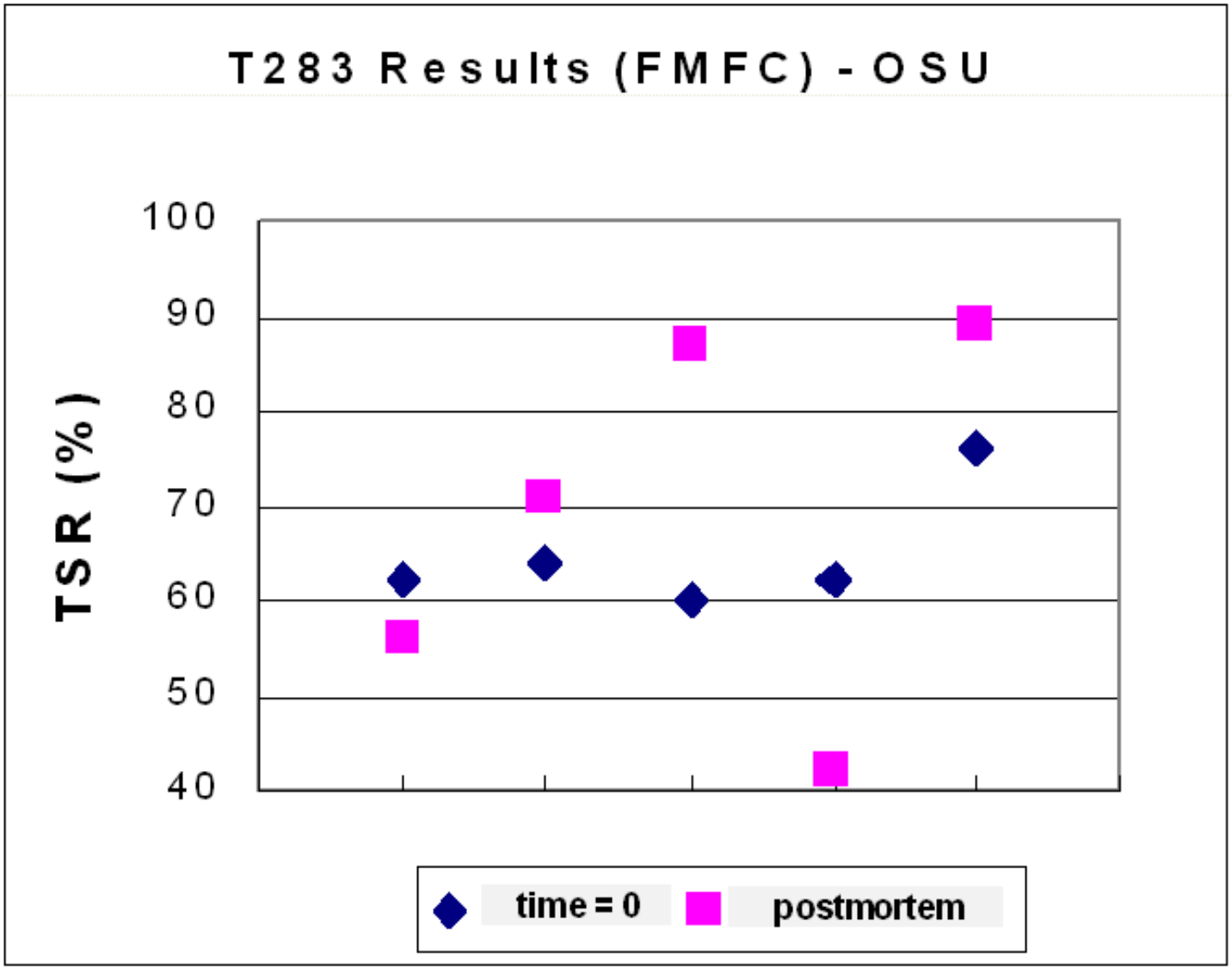


Figure 2. Comparison of T283 results for "time = 0" and postmortem specimens (OSU).

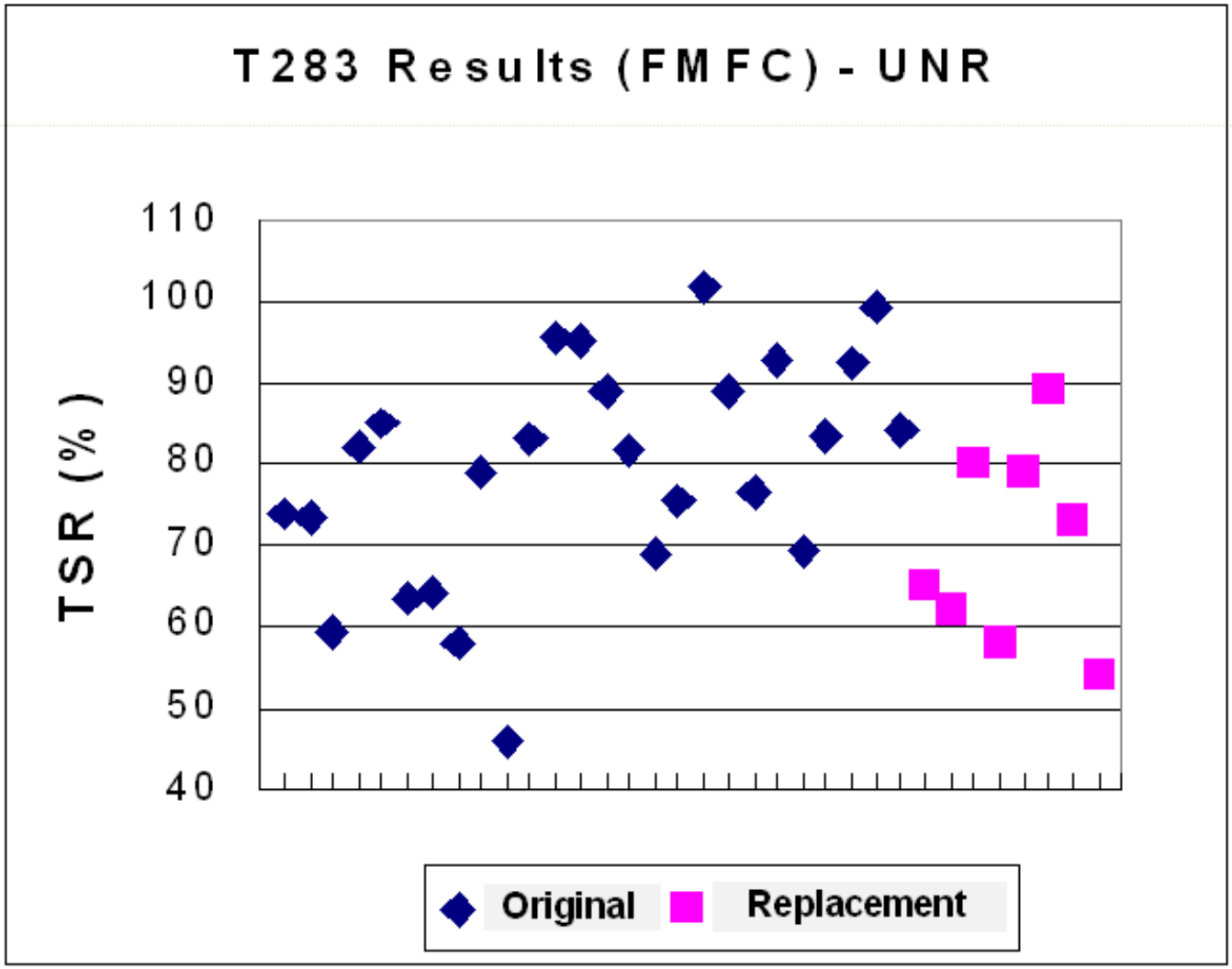


Figure 3. T283 results for FMFC specimens.

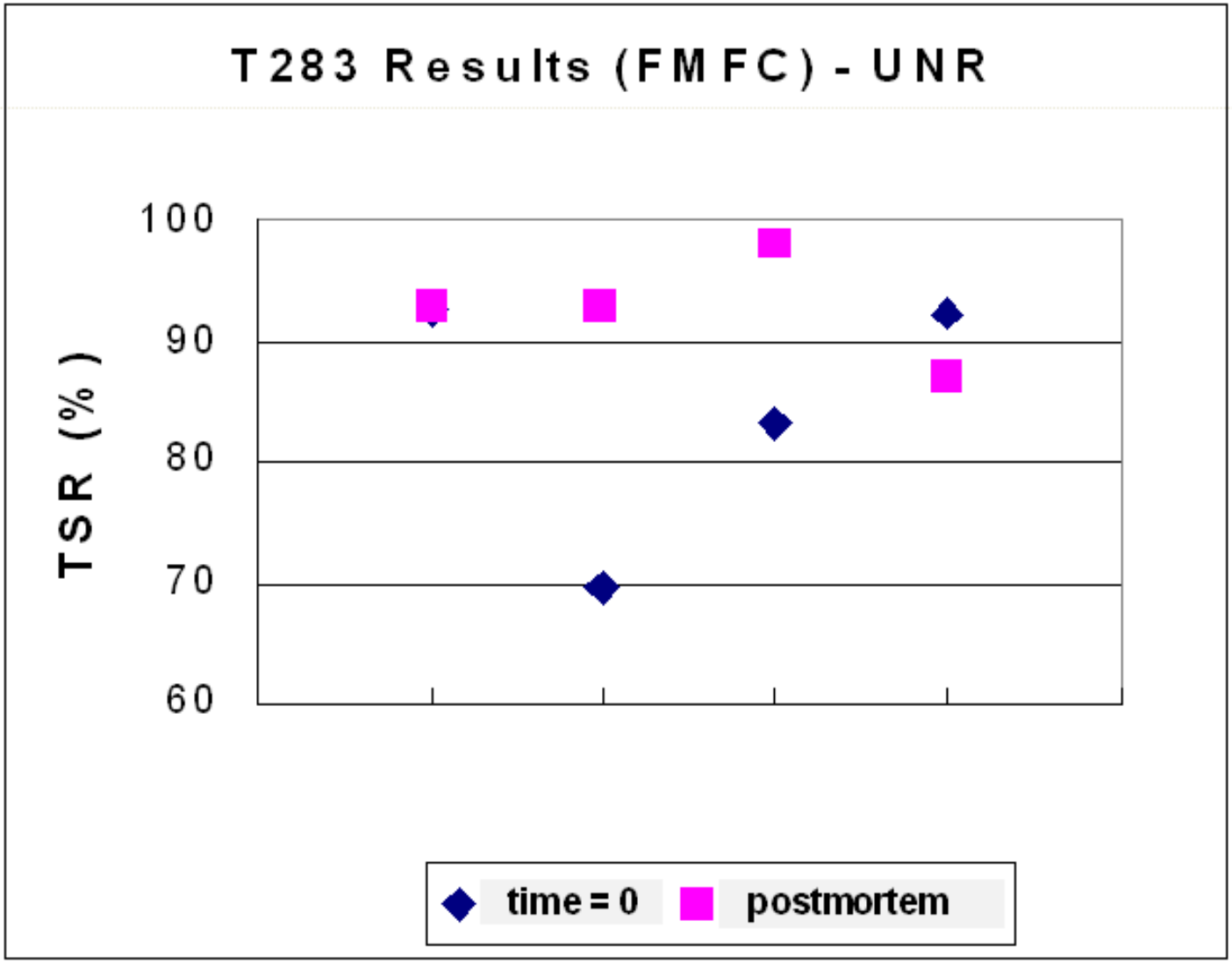
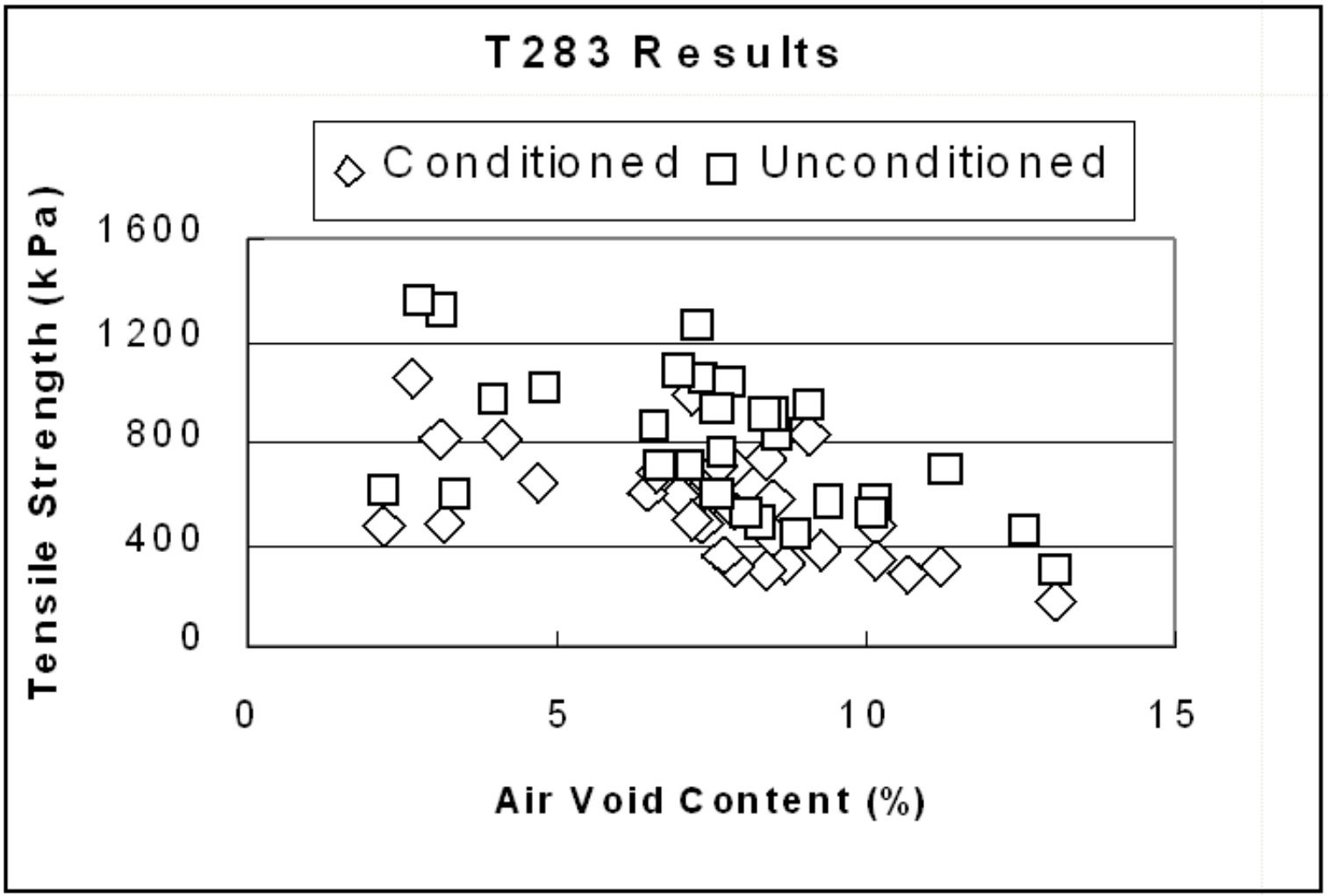


Figure 4. Comparison of T283 results for "time = 0" and postmortem specimens (UNR).



1 psi = 6.9 kPa

Figure 5. Relationship between air void content and indirect tensile strength.

Table 1. Experiment design.

Design Air Void Content	Aggregate Gradation Designation								
	Fine			Fine Plus			Coarse		
	Design Asphalt Contents (%)								
(%)	Low	Optimum	High	Low	Optimum	High	Low	Optimum	High
Low		04	18		12	09/21		23 (39)	25 (55)
Medium	02	01/15	14	22	11/19	13	08 (38)	05/24 (35/54)	07 (37)
High	03/16	17		10	20		26 (56)	06 (36)	

Note: (xx) = Replacement Section

Table 2. Moisture sensitivity testing.

	Section Number	
	OSU	UNR
FMFC: time = 0	1, 11, 24, 25, 26 35 - 39	1 - 26 35 - 39 54 - 56
FMFC: postmortem	35 - 39	21 - 25
FMLC	1, 11, 24, 25, 26 35 - 39	
LMLC	1, 11, 24, 25, 26 35 - 39	
FMFC: field-mixed, field-compacted FMLC: field-mixed, laboratory-compacted LMLC: laboratory-mixed, laboratory-compacted		

Table 3. Results of t-tests.

Data Set	t - statistic	t - critical	Means Different?
FMFC @ time = 0 vs. FMLC	1.049	2.101	no
FMFC @ time = 0 vs. LMLC	4.441	2.101	yes
FMLC vs. LMLC	5.695	2.101	yes
FMFC @ time = 0 vs. FMFC @ postmortem	0.416	2.160	no
FMFC (OSU) vs. FMFC (UNR)	2.826	2.032	yes

Table 4. Summary of NCHRP 9-13 T283 test results.

	No Freeze-Thaw Cycle				
	Aggregate Source				
Compaction – sample diameter	AL	CO	MD	NV	TX
G150			✔		
G100					
M100	✔		✔		
H100					
	Freeze-Thaw Cycle				
	Aggregate Source				
Compaction – sample diameter	AL	CO	MD	NV	TX
G150			✔		
G100			✔		
M100	✔		✔		
H100					
✔ TSR ≥ 0.80					

APPENDIX A

SUMMARY OF T283 TEST RESULTS

T283 test results, OSU.

	FM FC at Time = 0						FM FC Postmortem					
	Conditioned			Unconditioned			Conditioned			Unconditioned		
Section No.	% Air Voids	% Saturation	Tensile Strength (kPa)	% Air Voids	Tensile Strength (kPa)	TSR (%)	% Air Voids	% Saturation	Tensile Strength (kPa)	% Air Voids	Tensile Strength (kPa)	TSR (%)
01	8.7	57.7	326	8.9	446	72						
11	7.4	67.4	494	7.7	756	66						
24	8.5	61.2	432	8.6	837	52						
25	3.2	74.9	485	3.4	593	81						
26	10.7	64.9	285	12.6	450	65						
35	8.4	71.1	300	8.3	483	62	6.6	67.0	349	6.6	624	56
36	13.1	69.7	191	13.1	298	64	13.1	62.7	310	13.2	436	71
37	7.9	76.8	314	8.1	519	60	6.4	65.7	383	6.4	440	87
38	7.7	72.1	364	7.6	589	62	7.8	64.0	377	7.8	889	42
39	2.2	80.6	464	2.2	609	76	2.1	52.9	509	2.1	572	89

	FM LC						LM LC					
	Conditioned			Unconditioned			Conditioned			Unconditioned		
Section No.	% Air Voids	% Saturation	Tensile Strength (kPa)	% Air Voids	Tensile Strength (kPa)	TSR (%)	% Air Voids	% Saturation	Tensile Strength (kPa)	% Air Voids	Tensile Strength (kPa)	TSR (%)
01	8.5	60.2	575	8.5	910	63	8.4	76.4	740	8.4	911	81
11	7.2	67.5	565	7.4	1046	54	7.2	73.5	989	7.3	1261	78
24	7.0	61.2	598	7.0	1078	56	9.1	75.5	837	9.1	939	89
25	3.1	75.2	820	3.2	1319	62	2.7	73.6	1053	2.8	1350	78
26	7.9	62.2	706	7.8	1037	68	10.2	67.4	470	10.2	563	83
35	9.3	72.1	371	9.4	561	66	6.5	67.5	618	6.7	711	87
36	11.2	66.8	313	11.3	694	45	10.2	73.4	350	10.1	514	68
37	7.2	68.9	498	7.2	705	71	6.6	65.1	696	6.6	865	81
38	7.9	63.8	535	7.7	756	71	7.6	71.5	701	7.6	922	76
39	4.7	71.7	647	4.8	998	65	4.1	71.0	808	4.0	972	83

1 psi = 6.9 kPa

T283 test results, UNR.

Section No.	UNR at Time = 0 Original Construction				UNR Post Mortem Original Construction				UNR at Time = 0 Traffic Replacement Sections			
	% A.V. (Parafilm)	Unconditioned Tensile Strength (psi)	Conditioned Tensile Strength (psi)	TSR (%)	% A.V. (Parafilm)	Unconditioned Tensile Strength (psi)	Conditioned Tensile Strength (psi)	TSR (%)	% A.V. (Parafilm)	Unconditioned Tensile Strength (psi)	Conditioned Tensile Strength (psi)	TSR (%)
01	10.4	104	77	74								
02	9.2	128	94	73								
03	13.5	93	55	59								
04	6.1	170	140	82								
05	11.4	114	97	85								
06	15.8	79	50	63								
07	10.0	114	73	64								
08	13.2	117	68	58								
09	4.6	156	123	79								
10	14.7	81	37	46								
11	7.5	151	125	83								
12	4.2	192	184	96								
13	7.6	132	126	95								
14	8.5	130	116	89								
15	9.2	143	117	82								
16	12.8	107	74	69								
17	12.6	99	75	76								
18	3.8	165	168	102								
19	9.3	120	107	89								
20	11.3	98	75	77								
21	3.4	149	138	93	2.6	161	150	93				
22	8.2	148	103	70	5.5	152	142	93				
23	5.1	150	125	83	9.0	123	120	98				
24	9.6	119	110	92	8.9	117	102	87				
25	3.6	123	122	99								
26	13.0	83	70	84								
35									7.8	79	51	65
36									12.5	45	28	62
37									8.9	59	47	80
38									10.1	98	57	58
39									6.0	92	73	79
54									8.9	83	74	89
55									5.9	86	63	73
56									13.4	74	40	54

1 psi = 6.9 kPa

APPENDIX B

MINUTES OF TRB MOISTURE SENSITIVITY FOCUS GROUP

Memo to the TRB Superpave Committee

[date]

TO: Members of the TRB Superpave Committee

SUBJECT: Moisture Sensitivity Focus Group
Summary of Activities

Enclosed please our report of the July 28th Moisture Sensitivity Focus Group. The Group did recommend more research in this area. Attached is a an outline of what will eventually conclude in a Second Stage Problem Statement. We will include this in our Staff Recommendations to you for the FY 2001 program, at which time it will be open for discussion.

Thanks.

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Director, Special Programs
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Fax: 202-334-3471
Email: nhawks@nas.edu

Final Report

TRB SUPERPAVE COMMITTEE
July 28, 1999
Cecil and Ida Green Building, Washington, DC

Background:

At the first TRB Superpave Committee meeting, members elected to defer any work on moisture sensitivity, looking at the anticipated output from NCHRP 9-13 and the minimal effort proposed by FHWA. SCOR said no to the deferral, quoting NCHRP 9-13 and its recommendation that a "patch" would not be adequate for addressing the moisture sensitivity issue.

At the second TRB Superpave Committee meeting, the Superpave Support Team proposed a new project for moisture sensitivity, based on recommendations from the NCHRP 9-13 panel. This led to Committee questions concerning the original and subsequent expenditures on this subject, acknowledging there has been little technical breakthrough from the standard AASHTO T-283. The Committee recommended that TRB and NCHRP consider a forum or brainstorming session on the subject prior to recommending a new project. The recommendation was accepted; the Forum was held on July 28, 1999.

Attendees – Mike Anderson, Ron Collins, John D'Angelo, Jon Epps, Gerry Huber, Rita Leahy, Rebecca McDaniel, Gale Page, Haleem Tahir, Ron Terrel, Chris Williams, Tom White, John Bukowski, Fred Garrott, Kent Hansen, Gary Hicks, Tom Kennedy, Peter Sebaaly, Mary Stroup-Gardiner, Kevin Stuart, Magshoud Tahmoressi, Don Watson, Dean Weitzel, Jack Youtcheff, Larry Michael, Gloria Burke, Ed Harrigan, Ted Ferragut, and Neil Hawks.

General Session

Gale Page opened the meeting, followed by Neil Hawks, Ed Harrigan, and Ted Ferragut. All discussed the various aspects of the group's mission to determine if more moisture sensitivity research would be fruitful, and if so, to prepare a problem statement for inclusion in the TRB Superpave Committee recommendations for FY 2001.

Rita Leahy, University of Oregon, gave a background presentation on what the Strategic Highway Research Program had accomplished on this subject. SHRP examined the issue, developed a new conditioning and test method, but did not believe that the new method gave better results than the T283. And it was expensive.

Jon Epps reported on the findings of NCHRP 9-13; his report basically found little in the way of correlating known strippers with lab mix testing with T283. He did propose some modifications to the test, but in reality only providing incremental improvement. His overall conclusion is that the T283 test is not the final solution – possibly the best available but not the final solution.

Larry Michael then moderated an open session where the participants could present overall thoughts and concepts on the subject.

Breakout Groups

The participants were divided into two groups with moderators and staff present in each. The participants came together at the end of the day. Each presented their overall approach to the problem. The two groups then discussed their individual reports and came to general consensus on the following:

Q. Is more research needed?
A. Yes. Most definitely.

Q. In what areas?
A. Three areas were recommended.

· The first would be a definitive paper on what is known and present the gaps (in detail) in the current technology. This would then lead to the development of an overall long-range experimental plan.
· The second would be a series of laboratory tests. The researcher would be expected to work from the existing technology and look for incremental improvements and regional solutions to the problem. The Group recommended that the research concentrate on the mixture, using both the Environmental Conditioning System and AASHTO T283 as the base for the research.
· The third would be field validation.

Q. How much money and how long would the research take?
A. The estimates ranged from 3-5 years and $1-2,000,000 dollars. Nearly 50% of any estimate would be for field validation.

Additional Group Comments

- Moisture sensitivity shows up in several distress types – stripping, rutting, for example. It also could result from adhesion, cohesion, or aging mechanisms.
- Fundamental or basic research, while possible, would not be beneficial or enlightening.
- Research on individual constituents – aggregate or binder – would not prove beneficial. All research should be on the mixture.

- While a new test could be developed, consensus was that existing tests – modified, improved, or regionalized – should probably dominate any research effort.
- Whatever the laboratory program, the final test procedures need to be simple, reasonably fast, and cost effective. The test should address quality control factors also. Overriding all of that, however, is that the test should be accurate and effective in predicating moisture sensitivity.

Action

Subsequent to the meeting, Superpave Support Staff developed the following outline and problem statement.

Outline of Recommended Structure

First Contract – Literature Search, Experimental Plans, and Laboratory Testing

Phase 1
- Conduct Literature Search
  - From SHRP Literature Search Forward
- Develop Critical Review Position Paper
  - Gaps in the Fundamental Knowledge
  - Failure Mechanisms, including development of a decision tree
  - Discussion of Testing Mix versus Constituents – Binder— Aggregate — Mix
- Confirmation of Need for Further Lab and Field Testing

Phase 2
- Development of Experimental Plan
  - Laboratory Plan
  - Field Validation Plan

Phase 3
- Execution of Laboratory Plan

Second Contract - Field Validation

Phase 1
- Field Validation

Phase 2
- Precision and Bias
- Implementation/Education
- Protocol Development

Possible Framework for Laboratory Test Program
1. Select Material Ranges
   - Aggregate, Binder, Mix
   - Select mixes with known history
2. Conduct Torture Test
   - Consider Hamburg, LCPC, etc.
   - Test w/ and w/o antistrip
   - Determine rank
3. Conduct mix design tests
   - Use AASHTO T283, Gyratory, ECS
   - Vary test variables to develop equivalent rank as torture test
   - Test w/ and w/o antistrip
4. Product – equivalent ranking that identifies test variables

Possible Framework for Field Validation Test Program
1. Field Testing
   - Produce additional hot-mix samples from same mixes used in the laboratory program.
   - Test in accordance with new test protocols
   - Determine ranking and variability
2. In-service evaluation
   - Place mixes on active roadways or accelerated loading tests.
   - Consider cutting samples and testing with torture test protocols.
   - Monitor stripping of field mixes.

Timeline & Estimates

Contract 1

- Award June 01
- Complete Dec 03
- Cost Estimate $800,000

Contract 2

- Award Dec 03
- Complete Oct 05[1]
- Cost Estimate $750,000

[1] Exclusive of the field monitoring program. Assume 3 additional years with evaluation by individual States, one serving as lead state.

Performance Models for Permanent Deformation and Fatigue

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UCB-1
HRDI-11/04-06(CD-ROM)E

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EXECUTIVE SUMMARY

This report discusses the development of performance models for *permanent deformation* (rutting) and *fatigue cracking* for hot-mix asphalt (HMA) that can be used in performance-related specifications (PRS). The models are based on the results of the WesTrack full-scale accelerated pavement tests to evaluate the effect of HMA construction variables, including asphalt content, air-void content (degree of compaction), and aggregate gradation, on pavement performance.

The performance models use mix test data resulting from the testing of cores and beams. Tests developed by the Strategic Highway Research Program (SHRP) for permanent deformation cores [repeated simple shear test at constant height (RSST-CH)] and stiffness and fatigue response on beams (flexural fatigue) were utilized. The core and beam specimens were obtained from:

1. In situ pavement test sections, termed *field-mixed, field-compacted* (FMFC);
2. Slabs prepared with asphalt and aggregate mixed in the laboratory and compacted using rolling wheel compaction, termed *laboratory-mixed, laboratory-compacted* (LMLC); and
3. Slabs prepared in the laboratory with loose mix obtained at the time of construction using rolling wheel compaction, termed *field-mixed, laboratory-compacted* (FMLC).

The data obtained from these tests, combined with periodic performance measurements of deflection, rutting, and cracking, have been used subsequently to develop the performance models. LMLC data have been combined with FMFC data to define the effects of aggregate grading on rutting.

The resulting performance models developed using the above information are of two general types: those based on direct regressions between the specific performance measure (rut

depth or fatigue cracking) and 80-kN (18,000-lb) equivalent single-axle loads (ESALs) and mix characteristics, and those based on mechanistic-empirical analyses assuming the pavement behaves as a multi-layer elastic system. The first category has been termed *Level 1*, and the second, *Level 2*. The general framework is illustrated in Figure 1.2.

Chapter 1 provides an overall description of the contents of the report. It includes a brief summary of the RSST-CH and flexural fatigue and stiffness tests together with a brief description of the models shown in the framework illustrated in Figure 1.2.

For the mechanistic-empirical analyses, the assumption has been made that multi-layer elastic analysis can produce sufficiently accurate estimates of stresses, strains, and deflections in the pavement structures. Chapter 2 summarizes the moduli determined for the three pavement components: HMA, base, and engineered fill and foundation soil. It includes the analysis procedures used to obtain the specific values that combine the results of field measurements of pavement response (falling weight deflectometer) and laboratory measurements (flexural and shear stiffnesses on the HMA and triaxial compression resilient modulus tests on the base and subgrade materials).

Chapter 3 describes the methodology used to develop the performance models for permanent deformation (rutting). For the *Level 1* models, two categories, termed *Level 1A* and *Level 1B*, are presented in Figure 1.2.

The *Level 1A* model is based on direct regressions between observed rutting and mix variables and utilizes performance data from both the 26 original and 8 replacement sections. The *Level 1B* model was obtained using mechanistic-empirical analyses of the pavements. In this instance, relationships between rut depth and ESALs were developed theoretically for a 10-year period for 23 sections in which little or no fatigue cracking was observed. The 23 sections

included both original and replacement sections. For the analyses, the traffic was uniformly distributed throughout a 24-hour period and the yearly temperature environment was assumed to be the same for each year of the 10-year period. This procedure reduces the impact of early rutting that occurred in some of the sections.

The *Level 1A* model is limited to mixes and an environment similar to the WesTrack experiment. The *Level 1B* model can, however, be used for other traffic and environmental (temperature) conditions.

Two *Level 2* models are presented in Figure 1.2. The *Level 2A* model can be used for other traffic and temperature environments but is limited to mixes with aggregate gradings similar to those at WesTrack. The *Level 2B* model can be used for other types of mixes as long as they are characterized by means of the RSST-CH.

Regression models are also presented relating ESALs to specific rut depths with asphalt content, air-void content, and aggregate gradation [defined by the percent passing the 0.074 mm (No. 200) sieve and the percent of aggregate between the 2.36 mm (No. 8) and 0.074 mm (No. 200) sieves]. The equations utilize the results of RSST-CH tests on both FMFC and LMLC specimens. These regressions were developed using the *Level 2* approach. They are suitable in determining pay factors by Monte Carlo simulations as long as a specific rut depth is chosen and the simulations are constrained to the range of parameters used for the regression analysis.

Chapter 4 describes the development of the performance models for fatigue. For *Level 1* (regression modeling), a Probit model has been used to define the probability of cracking. This type of model was selected since it permits use of observed performance data for all 26 original sections. (Note: the eight replacement sections were not utilized because of the limited time period during which these sections were in service.) In the Probit model, the dependent variable

is the indicator of cracking, termed INDCR. If cracking is observed, INDCR=1; otherwise, INDCR has a value of zero.

Three *Level 2* fatigue models are presented. These have not been characterized in the same manner as those for rutting. Rather, since the procedure is the same for the three categories shown in Figure 1.2, selection is based on the engineer's choice of mix fatigue and stiffness characteristics. Three options are available:

- use WesTrack mix data,
- use stiffness and fatigue data from published information, or
- use laboratory-determined stiffness and fatigue response data obtained for the specific area in which the mix(es) is (are) to be used.

A brief description of how the performance models developed in Chapters 3 and 4 can be used to develop pay factors, a part of PRS, is presented in Chapter 5. The resulting pay factors are applicable to HMA pavement construction in which both fatigue and rutting distress may occur during the expected period of performance.

In this approach, bonuses for superior construction and penalties for inferior construction reflect full agency cost increments. The sole determining factor for construction quality is the date of the first rehabilitation. Both fatigue and rutting distress are reflected in the pay-factor schedule. Each entry in the schedule is based on the distress yielding the most beneficial consequence to the agency (i.e., smaller bonus and larger penalty). Pay factors are computed independently for each pay quantity and combined pay factors are determined that incorporate the influence of air-void content, asphalt content, HMA thickness, and aggregate gradation (as defined in Chapter 3 for rutting).

The cost model is based on the difference in present worth of rehabilitation costs *as constructed* versus *as specified* and *as expected*. This approach provides a rational basis for setting the level of penalty/bonus for inferior/superior construction quality. It requires an estimate of future rehabilitation cost and it considers annual inflation of rehabilitation costs, traffic growth, expected years of the constructed-life of the asphalt concrete, and a discount rate representing the time-value of money.

While the *Level 1* direct regression models are limited to mixes and environments similar to WesTrack conditions, the information presented in Chapters 2, 3, and 4 provides the basis for development of performance models for other regions or site-specific projects. Chapter 6 describes the requisite information and steps to do this.

The approach, shown in Figure 1.3, requires:

1. definition of HMA characteristics, including stiffness, fatigue, and permanent deformation response as a function of mix variables;
2. representative environmental (temperature) data;
3. expected traffic characteristics including loading expressed as ESALs and expected temporal distributions and growth rates; and
4. representative pavement cross-sections and material characteristics of the other pavement components.

The performance models that are used are based on a mix analysis and design system that was: originally developed as a part of SHRP and extended to efficiently treat in situ temperatures; initially calibrated for fatigue to the Caltrans flexible pavement design system and extended to incorporate construction variability; used in interpreting results of California heavy vehicle simulator (HVS) testing in the Caltrans/Accelerated Pavement Testing (CAL/APT)

Program; and, most recently, used for analyzing WesTrack data. As applied here, it considers the means and variances of asphalt content, air-void content, asphalt-concrete thickness, and aggregate gradation. In estimating damaging stresses and strains under traffic loading, it treats the pavement as a multi-layer, elastic system. The performance models compute the distribution of pavement lives, expressed as ESALs, using Monte Carlo simulation techniques similar to those described in Chapter 5.

Chapter 7 contains a summary of the information and some specific recommendations for the use or development of performance models for rutting and fatigue cracking.

For permanent deformation, the performance model based solely on regression that is recommended is that termed *Level 1B*. The expression for this model is shown as Equation 3.14. For the mechanistic-empirical analysis, the use of the RSST-CH is recommended, following the format as described in Chapter 3, since this permits the use of local mixes as well as local traffic and environmental conditions.

For fatigue, if a regression model is to be used, either Equation 4.1 for *fine* and *fine-plus* mixes or Equation 4.2 for *coarse* mixes should provide satisfactory results. It is expected that Equation 4.1 should be applicable to conventional dense-graded mixes as well as the *fine* mixes.

As with rutting, for the *Level 2* procedure, laboratory test data for local mixes (flexural fatigue test data) are preferred for use. If these data are not available and the local mix utilizes a dense-graded aggregate, the Asphalt Institute expression (Equation 6.5) that considers both the asphalt and air-void contents is suitable.

In the development of pay factors, it is likely that aggregate gradation has only a small effect on fatigue response and pay factors for the "reasonable" deviations from a target gradation may not be necessary for controlling this mode of distress. In contrast, gradation should be

considered when defining pay factors for rutting; the procedure described in Chapter 3 considering asphalt content, air-void content, and aggregate gradation is recommended for use at this time.

In the approach to pay-factor determination described in Chapter 5, the cost model (i.e., the time to the first rehabilitation activity) differs from that used in the PRS developed by Nichols Consulting Engineers for the WesTrack Project. The Nichols procedure considers lifecycle costs for some prescribed period of time. In the opinion of the authors, the procedure presented in Chapter 5 is a rational and defensible method for assigning penalties and bonuses. Accordingly, it is strongly recommended for use to establish pay factors for HMA construction.

While guidelines are presented for the use of existing information in developing the requisite performance models, it is strongly recommended that the performance models be based on fatigue and permanent deformation tests on either site-specific materials or tests on materials representative of a given region.

This report contains 11 appendices, A through K, providing data summaries and justification for some of the developments discussed in the paper. The contents of the appendices are as follows:

- *Appendix A* – tabulations of the measured downward rut depth versus ESALs for both the original and replacement sections.
- *Appendix B* – a summary of RSST-CH data for both the original and replacement sections for FMFC cores obtained prior to and after trafficking.
- *Appendix C* – a summary of RSST-CH data for LMLC specimens.
- *Appendix D* – a summary of an analytical study conducted by Symplectic Engineering Corporation to evaluate the influence of traffic wander on rut-depth development.

- *Appendix E* – a comparison of rut depth versus ESALs for the 23 sections used to develop the empirical (regression analysis) procedure.
- *Appendix F* – a comparison of rut depth versus ESALs for the 23 sections used to develop the mechanistic-analysis procedure.
- *Appendix G* – comparisons of simulations using the regression equation summarized in Table 3.13, including the effects of aggregate gradation.
- *Appendix H* – a summary of fatigue test data for both original and replacement sections, FMFC specimens obtained from slabs obtained prior to trafficking, and LMLC specimens. Also included are results of studies on FMFC specimens (obtained prior to trafficking) to evaluate the effects of temperature and frequency of loading on fatigue response.
- *Appendix I* – estimates of variability on fatigue response using WesTrack data (*Level 1* model) and thickness effects deduced from Caltrans data.
- *Appendix J* – a summary of the Shell and Witczak procedures to estimate the stiffness of HMA using mix volumetric and asphalt and aggregate properties.
- *Appendix K* – a summary of the steps in the development of an RSST-CH inelastic strain model based on data obtained using LMLC specimens containing one WesTrack *coarse* mix.

1.0 INTRODUCTION

One of the major purposes of WesTrack has been to develop performance models defining the influence of asphalt mix variables on pavement performance, models that can be used in performance-related specifications (PRS). Mix variables have included asphalt content, air-void content (degree of compaction), and aggregate gradation. The role of the Pavement Research Center at the University of California, Berkeley, in this phase of the program has been to develop performance models for *permanent deformation* (rutting) and *fatigue cracking.*

The program to accomplish these objectives has included: (1) testing of cores and beams (sawed from slabs) from the test sections, referred to as *field-mixed, field compacted* (FMFC) specimens; (2) testing of cores and beams obtained from slabs prepared in the laboratory by rolling wheel compaction, referred to as *laboratory-mixed, laboratory compacted* (LMLC); and (3) testing of a limited number of specimens obtained from slabs prepared in the laboratory with loose mix obtained from the field at the time of construction, referred to as *field-mixed, laboratory-compacted* (FMLC). Results of the FMLC tests are not discussed in this report. The data obtained from the FMFC and LMLC tests combined with performance measurements of deflection, rutting, and cracking have been used to develop the performance models described in Chapters 3 and 4 for rutting and fatigue cracking, respectively. The LMLC data have been combined with the FMFC data to define the effects of aggregate grading on rutting.

This introductory section contains a brief description of the laboratory tests utilized and presents a framework for the performance models that have been developed. In addition, the use of these models to develop pay factors based on the mix variables influencing rutting investigated in the WesTrack experiment, together with factors influencing fatigue cracking developed in another project (*1*), is introduced. Finally, the section contains a brief discussion of the applicability of this approach to other pavement applications.

1.1 Laboratory Tests

The laboratory tests program consisted of permanent deformation measurements on cores using the repeated simple shear test at constant height (RSST-CH) (*2*) and determination of stiffness and fatigue response of beam specimens using a flexural fatigue test (*3*).

1.1.1 Repeated Simple Shear Test at Constant Height (RSST-CH)

This test was performed on cylindrical specimens (cores) 150 mm (6 in.) diameter × 50 mm (2 in.) height. Each specimen had cut surfaces on the top and bottom as well as on the vertical face. Three test temperatures were used for the RSST-CH: 40°C, 50°C, and 60°C (104ºF, 122ºF, and 140ºF), with the majority of tests being performed at 50°C (122ºF).

Shear loading was applied in the form of a haversine with a time of loading of 0.1 sec. and a time interval between loadings of 0.6 sec. A relationship between permanent shear strain, γ_p, and stress repetitions, N, is shown in Figure 1.1. Each curve is adjusted by defining the intercept of γ_p at $N = 0$ and subtracting this value from all measurements of γ_p. An equation of the form:

$$\gamma_p = aN^b \qquad \textbf{(1.1)}$$

is then fit to the data, usually for values of $N \geq 100$. In this expression, the coefficients a and b result from the regression analysis.

Shear stiffness, G, is also determined from the data according to the relation:

$$G = \frac{\tau}{\gamma_{recov}} = \frac{\text{shear stress } \left[69 \text{ kPa } (10\, psi)\right]}{\text{recoverable shear strain at } N = 100} \qquad \textbf{(1.2)}$$

Data obtained from this test are summarized in Appendices B and C.

1.1.2 Flexural-Fatigue Tests

Beam specimens, 63 mm (2.5 in.) wide × 50 mm (2.0 in.) high × 381 mm (15.0 in.) long, were tested in repeated flexure in the controlled-strain mode of loading at a frequency of 10 Hz. While the majority of the tests were performed at 20°C (68ºF), a limited number of specimens were tested at 5°C (41ºF) and 30°C (86ºF) to define the influence of temperature on fatigue behavior. The data provided both a measure of flexural stiffness and fatigue response, expressed in terms of the number of load repetitions for a 50 percent reduction in flexural stiffness versus applied strain. Two strain levels were used for the majority of the test series: 200×10^{-6} and 400×10^{-6} mm/mm (in./in.). Reference (*3*) describes the equipment and procedures followed.

For a specific mix at a given temperature, the results of the fatigue tests can be expressed in the following form:

$$N = K_1 \varepsilon_t^{K_2} \qquad \textbf{(1.3)}$$

where:

N = number of strain repetitions to a 50-percent reduction in mix stiffness

ε_t = tensile strain, repeatedly applied

K_1, K_2 = experimentally determined coefficients

Test data used for the analyses presented herein are contained in summary form in Appendix H. Data include results for the 26 original and 8 replacement sections. Results of tests on specimens sawed from slabs taken immediately after construction (FMFC) are reported in Appendix H as well. Appendix H also includes data for LMLC specimens, although they are not used for the performance models discussed in this study.

1.2 Performance Models

The performance models developed here are of two general types: those based on direct regressions between the specific performance measure (rut depth or fatigue cracking) and equivalent single axle loads (ESALs) and mix characteristics; and those based on mechanistic-empirical analyses assuming the pavement behaves as a multi-layer elastic system. The first category has been termed *Level 1*, and the second, *Level 2*. The general framework is illustrated in Figure 1.2.

1.2.1 *Level 1* Models

For rutting, there are two categories of *Level 1* models termed, *Level 1A* and *Level 1B*. The *Level 1A* models are based on direct regressions between observed rutting or observed cracking as seen in Figure 1.2. For rutting, the model utilizes performance data from both the 26 original and 8 replacement sections, but for fatigue, the model utilizes only the fatigue data for the 26 original sections.

The *Level 1B* model was obtained using mechanistic-empirical analyses of the pavements. In this instance, rut depth versus ESALs relationships were developed theoretically for a 10-year period for 23 sections in which little or no fatigue cracking was observed. The 23 sections included both original and replacement sections. For the analyses, the traffic was uniformly distributed throughout a 24-hour period and the yearly temperature environment was assumed to be the same for each year of the 10-year period. As will be seen, this procedure tended to reduce the impact of early rutting that occurred in some of the sections.

For fatigue, a Probit model has been used to define the probability of cracking.

As seen in Figure 1.2, the *Level 1* models are based on specific WesTrack mixes. The *Level 1B* model for rutting can, however, be used for other traffic and environmental (temperature) conditions.

1.2.2 Level 2 Models

For rutting, two *Level 2* models have been developed. The *Level 2A* model can be used for other traffic and temperature environments but is limited to mixes with aggregate gradings similar to those at WesTrack. The *Level 2B* model can be used for other types of mixes as long as they are characterized by means of the repeated simple shear test at constant height (RSST-CH).

Although not shown in Figure 1.2, regression models have been developed relating ESALs to specific rut depths with asphalt content, air-void content, and aggregate gradation [defined by the percent passing the 0.074-mm (No. 200) sieve and the percent of aggregate between the 2.36-mm (No. 8) and 0.074-mm (No. 200) sieves]. The equations utilize the results of RSST-CH tests on both FMFC and LMLC specimens. These regressions were developed using the *Level 2* approach. As will be noted in Chapter 3, models of this type are suitable for the determination of pay factors for permanent deformation as long as the bounds of the regression are not exceeded.

There were a total of three *Level 2* models for fatigue, and these have not been characterized in the same manner as the rutting models. Rather, since the procedure is the same for the three categories shown in Figure 1.2, selection is based on the engineer's choice of mix fatigue and stiffness characteristics. Three options are available:

- use WesTrack mix data,

- use stiffness and fatigue data from published information, or
- use laboratory-determined stiffness and fatigue response data obtained for the specific area in which the mix(es) is (are) to be used.

These guidelines also are shown in Figure 1.2.

A subsequent section describes the requisite information needed for utilization of the *Level 2* models, including the results of temperature simulations, moduli determinations for the pavement components, laboratory-determined rutting and fatigue characteristics, and detailed truck traffic data.

1.3 Pay Factors

While the development of PRS is a part of another phase of the WesTrack Project, this report includes a brief description of how the performance models presented here can be used to develop the pay factors included in PRS (*4*). In the material to be presented subsequently in Chapter 5, the pay factors are applicable to HMA pavement construction in which both fatigue and rutting distress may occur during the expected period of performance.

In this approach, bonuses for superior construction and penalties for inferior construction reflect full agency cost increments. The sole determining factor for construction quality is the date of the first rehabilitation. Both fatigue and rutting distress are reflected in the pay-factor schedule. Each entry in the schedule is based on the distress yielding the most beneficial consequence to the agency (i.e., smaller bonus and larger penalty). Pay factors are determined independently for each pay quantity and combined pay factors are computed according to the following (*4*):

$$Combined\ \ pay\ \ factor = (1 + pf_{ac})(1 + pf_{av})(1 + pf_{t})(1 + pf_{p200})(1 + pf_{fa}) - 1 \qquad \textbf{(1.4)}$$

where:

pf_{ac} = pay factor for asphalt content

pf_{av} = pay factor for air-void content

pf_{t} = pay factor for thickness

pf_{p200} = pay factor for percent passing 0.074-mm (No. 200) sieve

pf_{fa} = pay factor for material passing 2.36-mm (No. 8) sieve and retained on 0.074-mm (No. 200) sieve

1.4 Applicability to Other Conditions

Based on the results presented in Chapters 2 through 5, Chapter 6 describes the requisite information and steps required to develop performance models for a region or specific site. The approach requires: (1) definition of HMA characteristics, including stiffness, fatigue, and permanent deformation response; (2) representative environmental (temperature) data; (3) expected traffic characteristics including loading expressed as ESALs and expected temporal distributions and growth rates; and (4) representative pavement cross sections and material characteristics of the other pavement components. The general framework is illustrated in Figure 1.3.

The performance models described are based on a mix analysis and design system that was: originally developed as a part of SHRP (*5*) and extended to efficiently treat in situ temperatures (*6*); initially calibrated for fatigue to the Caltrans flexible pavement design system (*1*) and extended to incorporate construction variability (*7*); used in interpreting results of California heavy vehicle simulator (HVS) testing in the CAL/APT program (*8*); and, most recently, used for analyzing WesTrack data. As applied here, it considers both permanent deformation and fatigue and specifically considers the means and variances of the following

asphalt-concrete construction quantities: asphalt content, air-void content, asphalt-concrete thickness, and aggregate gradation. In estimating damaging stresses and strains under traffic loading, it treats the pavement as a multi-layer, elastic system. The performance models compute the distribution of pavement lives, expressed as ESALs, using Monte Carlo simulation techniques.

2.0 MODULUS DETERMINATION

2.1 Introduction

The purpose of this evaluation was to establish elastic moduli of the pavement components at WesTrack to permit determination of stresses, strains, and deflections in the test pavement sections. The results of the investigation provided the necessary input for the evaluation of observed pavement performance and the establishment of performance models for the performance-related specifications, a major WesTrack product.

The assumption was that multi-layer elastic analysis could produce sufficiently accurate estimates of stresses, strains, and deflections in the pavement structures. In turn, this formed the basis for the establishment of performance models for permanent deformation (rutting) and load-associated cracking (fatigue).

The sources from which the moduli were obtained included both field and laboratory measurements. The field data included an extensive series of falling weight deflectometer (FWD) measurements taken at intervals throughout the traffic loading. Laboratory data included test results from the following:

- *Asphalt concrete* – flexural fatigue, RSST-CH, and resilient modulus (indirect tension) tests.
- *Untreated base* – triaxial-compression resilient modulus tests.
- *Engineered fill and foundation soil* – triaxial-compression resilient modulus tests.

This section describes the methodology used to arrive at the various moduli and a summary of the values used in the analyses to establish performance models.

2.2 Analyses of Field Data, Original Sections

In the analyses of the FWD data to determine moduli, best estimates of these parameters were considered to be those minimizing the sum of the squared differences between measurements and simulations of FWD surface deflections. In these analyses, simulations were based on regression equations relating the deflection at each of the seven sensor locations of the FWD to the layer moduli. The Microsoft® Excel solver routine was used to determine the best-fit moduli.

Regression equations, based on the assumption of a three-layer system for WesTrack, took the following form:

$$\begin{aligned}\ln D = {} & d_0 + d_1 \ln E_1 + d_2 \ln E_2 + d_3 \ln E_3 \\ & + d_4 (\ln E_1)^2 + d_5 (\ln E_2)^2 + d_6 (\ln E_3)^2 \\ & + d_7 \ln E_1 \cdot \ln E_2 + d_8 \ln E_1 \cdot \ln E_3 + d_9 \ln E_2 \cdot \ln E_3\end{aligned} \quad \textbf{(2.1)}$$

where:

D = surface deflection, mils

E_1 = modulus of the asphalt concrete

E_2 = modulus of untreated aggregate base

E_3 = modulus of engineered fill and foundation base

$d_0 \ldots d_9$ = regression coefficients

Simulations were performed to examine the effects of all possible combinations of five levels of modulus for each of the three layers. Only one load level was simulated, 44.4 kN (10,000 lbf) having a radius of 150 mm (5.9 in.). Parameters used for the simulations are summarized in Table 2.1.

Examples of the results of these analyses are shown in Figures 2.1 through 2.3; Table 2.2 summarizes the regression equations (form of Equation 2.1) for the seven sensor locations (0, 12, 18, 24, 36, 46, and 60 in.).

In the best-fit analyses, assumptions were made as to how the moduli were likely to vary as a function of external influences such as temperature. These included:

1. the asphalt concrete modulus, E_1, is related to the average surface temperature, T, (based on Section 12 data):

$$E_1 = \exp\left(A_0 + A_1 T\right) \quad \textbf{(2.2)}$$

   where A_0 and A_1 are regression coefficients;

2. the base modulus, E_2, is independent of temperature and season; and
3. the foundation soil modulus, E_3, is sensitive to seasonal, but not to temperature, influences and was investigated as a discreet function of the measurement period and a sinusoidal function as follows:

$$E_3 = D_0 + D_1\left[\sin\left(doy - D_2\right) \Big/ 365 \times 2 \times \pi\right] \quad \textbf{(2.3)}$$

   where:

doy = day of the year

D_0, D_1, D_2 = regression coefficients

Preprocessing of the FWD data was accomplished by:

1. removing unnecessary information,
2. adjusting surface deflections for each drop of a 44.4-kN (10,000-lbf) load assuming linearity between surface deflection and load level, and

3. using the average of 20 sets (five locations and four drops) of FWD deflection measurements for each test section and analysis period.

Figure 2.4 illustrates the framework utilized for the simulations; modulus values for the three layers are summarized in Tables 2.3 and 2.4. Table 2.4 also lists the measurement periods utilized in the analyses. Note in Table 2.3 that the slope of the ln E_1 versus T relationship was assumed to be constant for all mixes.[1]

FWD-determined moduli for the asphalt concrete as a function of temperature are shown in Figure 2.5 for the sections evaluated in the south tangent and in Figure 2.6 for sections from the north tangent.

Table 2.5 compares mixes based on moduli at a temperature of 40°C (104°F) to examine the effects of asphalt content and air-void content. The table shows the influence of air-void content is significant, with an increase in air-void content resulting in a reduction in mix stiffness. Note also that replicate sections have comparable stiffnesses.

The base modulus was assumed to be unaffected by both temperature and season. The values for the south and north tangents were estimated to be 104 MPa (15,100 psi) and 93.2 MPa (13,500 psi), respectively. The modulus for the south tangent is about the same as that for the foundation soil, but it is less than that for the north tangent. Considering also other investigations which suggest that conventional back-calculation routines may underestimate base moduli, additional investigation appears warranted to determine suitable means for back-calculating untreated base moduli. This was, however, beyond the scope of this study.

[1] This simplification seemed reasonable since all of the mixes contained the same asphalt binder and aggregate, and the gradations were reasonably uniform among the mixes.

The influence of season on foundation soil modulus is illustrated in Figures 2.7 and 2.8 for the south and north tangents, respectively. In these figures it will be noted that the modulus varies throughout the year with a high value in mid-December and a low value about mid-May. The minimum value is about 70 percent of the maximum.

There is a significant difference in foundation moduli between the sections of the south and north tangents, with the north tangent sections being considerably stiffer than those in the south tangent. Also, the annual range in modulus is larger for the north tangent than for the south tangent sections.

As noted earlier, sinusoidal functions also were applied to the foundation-soil moduli to define seasonal variations. Figures 2.9 and 2.10 indicate that such functions are reasonably well suited to define the influence of seasonal variations on modulus for the WesTrack foundation.

For the analysis reported subsequently, the decision was made to use the moduli shown in Figures 2.9 and 2.10 for the foundation soil in order to evaluate both the permanent deformation and fatigue performance of the test sections.

2.3 Comparisons of Field- and Laboratory-Determined Moduli

A limited opportunity was provided to compare laboratory-determined moduli from the flexural fatigue tests at 20°C (68°F) and the RSST-CH at 50°C (122°F) for the asphalt mixes with those determined from evaluation of the FWD measurements.

In the laboratory, flexural stiffness measurements were obtained during fatigue testing of mixes from the bottom portion of each of the test sections. Results of a comparison of these stiffness values for a number of the test sections with those determined from the analysis of the FWD results are shown in Figure 2.11.

Similarly, in the RSST-CH to define the permanent deformation response of the various mixes, shear stiffnesses were determined at 50°C (122°F) for mixes from each of the test sections. Comparison of stiffnesses determined from the shear moduli with those estimated from the FWD measurements are shown in Figure 2.12. For comparisons with the FWD estimates, the laboratory shear stiffnesses were converted according to the following expression:

$$E = G \cdot 2(1+\nu) \quad \textbf{(2.4)}$$

where:

G = shear modulus

ν = Poisson's ratio

For this conversion, the Poisson's ratio, ν, for the asphalt concrete was assumed to be equal to 0.35.

The correlations shown in Figures 2.11 and 2.12 also were used to determine moduli for use in analyses of the responses of the replacement sections.

A brief comparison also was made between the FWD- and laboratory-determined moduli (*9*) for the base and foundation soils. These results are shown in Table 2.6.

2.4 Moduli Used for Permanent Deformation and Fatigue Analyses

The results presented in the previous sections established the bases for selection of moduli for use in developing the performance models for both permanent deformation and fatigue. To reflect seasonal variations in stiffness, the subgrade moduli for the south and north tangents shown in Figure 2.9 and 2.10 have been used.

Earlier indications were that the moduli of the base courses in the north and south tangents were constant but of slightly different magnitudes. It also had been noted that back-

calculation procedures result, at times, in estimated moduli for untreated bases that are lower than expected. This was assumed to be the case for the base moduli shown in Table 2.6. In the Shell pavement design procedure, for example, untreated aggregate layers are assumed to be of the order of two times the subgrade modulus (*10*). Also, data summarized in Reference (*11*)[2] suggest larger values for materials similar to the WesTrack untreated base material. Accordingly, a modulus value of 138 MPa (20,000 psi) was used in the *Level 1B* and *Level 2A* analyses for permanent deformation and 172 MPa (25,000 psi) in the *Level 2* analysis for fatigue.

For the asphalt concrete, moduli at 20°C (68°F) from the flexural fatigue tests and the temperature slope (A_1) from the back-calculations shown in Table 2.3 were used to represent the stiffness moduli in the permanent deformation analyses to be described subsequently. The values for both A_0 and A_1 for the mixes used in these analyses are summarized in Table 2.7. Comparison of some of the A_0 values for Sections 1-25 with those shown in Table 2.3 reflect the inclusion of additional flexural stiffness data from the fatigue test program.

For the permanent deformation analyses of Sections 35-55, the coefficients A_0 and A_1 were established from the regressions shown in Figures 2.11 and 2.12 using the flexural fatigue test stiffnesses at 20°C (68°F) and the shear stiffnesses at 50°C (122°F) for the RSST-CH. The flexural stiffnesses were divided by the factor 0.9 and shear stiffnesses were multiplied by the product of a factor of 3 (Equation 2.4 with ν=0.5) and the regression factor 5.832. When the data were plotted as shown in Figures 2.5 and 2.6, the average slope of –0.0610 shown in Table 2.7 was obtained. This procedure was followed in lieu of FWD analyses of these test sections.

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[2] Table 6 in Reference (*11*) shows values for untreated granular bases ranging from 150 to 500 MPa (22×10^3 to 72×10^3 psi), for example.

2.5 Additional Stiffness Analyses

For the mechanistic analyses used to assess fatigue response, the mix stiffnesses obtained from the flexural fatigue tests were utilized (see Appendix H). With these data, regression analyses were performed on the results of 186 fatigue tests on the FMFC mix, primarily at 20°C (68°F) and with limited data at 5°C (41°F) and 30°C (84°F).

Results of the analyses are represented by the following equations:

1. *fine* and *fine-plus* mixes (127 tests)

$$\ln(Stiff) = 11.4677 - 0.0827V_{air} - 0.2285P_{Wasp} - 0.0579T \quad \left(R^2 = 0.85\right) \qquad \textbf{(2.5)}$$

2. *coarse* mixes (59 tests)

$$\ln(Stiff) = 11.4707 - 0.0576V_{air} - 0.2142P_{Wasp} - 0.0606T \quad \left(R^2 = 0.79\right) \qquad \textbf{(2.6)}$$

where:

$Stiff$ = mix stiffness, MPa

V_{air} = air-void content, percent

P_{Wasp} = asphalt content, percent, by weight of mix

T = temperature, °C

Comparison of the mix stiffnesses for the original sections in Table 2.7, with those predicted by the regression equations for specific asphalt and air-void contents, are shown in Figure 2.13.

2.6 Summary

The asphalt mix moduli utilized in Chapters 3 and 4 have been developed from laboratory-determined stiffnesses (measured both in flexural and shear) and from

back-calculation of FWD data determined over a period of time on the test sections. As seen in Figure 2.13, the stiffness moduli for both types of analyses are compatible for the range in temperatures that occurred at WesTrack and will be used in the distress analyses to develop the performance models.

The stiffness moduli for the base and "subgrade" materials reflect the results of measurements, both with the FWD and laboratory triaxial tests, together with engineering judgment that is based on experience with tests on a range of untreated materials and values reported by a number of investigators (*11*).

3.0 PERMANENT DEFORMATION

3.1 Introduction

The purpose of this phase of the investigation was to develop models that can be incorporated in the PRS program and that define the influence of asphalt content, air-void content, and aggregate gradation on the accumulation of permanent deformation in the asphalt-bound layer.

Two levels of models have been developed: those based on regressions between measured performance, rut depth,[3] and traffic loading and mix variables (termed, *Level 1*); and those based on mechanistic-empirical analyses using the same parameters (termed, *Level 2*).

Data used to develop these models, include the following:

1. measured downward rut depths and associated traffic (in terms of ESALs) – Appendix A,
2. RSST-CH data on FMFC specimens prior to the start of and at the conclusion of traffic (termed, *postmortem*)[4] for the specific tests sections – Appendix B, and
3. RSST-CH on LMLC specimens including:
    a. study of specimens representing Sections 4 and 25 to determine effects of temperature and shear stress level on mix performance – Appendix C1 and

[3] All performance models are based on rut depths measured from the original pavement surface, i.e., baseline to valley. Those values are somewhat less than those measured from peak to valley in each rut.

[4] For example, Sections 7, 9, 13, 21, and 25 were removed from consideration at about 1,460,000 ESALs due to excessive rutting.

b. aggregate gradation study at North Carolina State University (NCSU) to define the effects of aggregate grading variations on the performance of specimens over ranges in air-void contents, asphalt contents, and aggregate gradations representing reasonable specification tolerances for both the fine and coarse gradings–Appendix C2.

To assist in the development of the mechanistic-empirical (M-E) models, a special study of the effects of traffic wander on rut depth accumulations also was performed. This analytical study was conducted by Dr. S. Weissman of Symplectic Engineering Corporation using finite element simulations for different traffic wander patterns including that used at WesTrack. A brief summary of this study is included in Appendix D.

3.2 Regression Modeling (*Level 1*)

Two approaches, based on regression, have been followed to develop relationships between rut depth and traffic, environment, and mix variables including asphalt content, air-void content, and aggregate gradation. Although the two methods involve different approaches to arrive at the performance relationship, an expression of the following form has served as the basis for both approaches:

$$\begin{aligned}\ln(rd) = {} & a_0 + a_1 \cdot P_{Wasp} + a_2 \cdot V_{air} + a_3 \cdot P_{Wasp}^2 + a_4 \cdot V_{air}^2 + a_5 \cdot P_{200} \\ & + a_6 \cdot fa + a_7 \cdot \ln ESALs + a_8 \cdot T \cdots + (\textit{interaction terms} \\ & \textit{among the variables}) \cdots + (\textit{indicator variables representing} \\ & \textit{the three aggregate gradings used at Wes Track}) \cdots + (\textit{indicator} \\ & \textit{variable for aggregate type, replacement sections})\end{aligned} \quad \textbf{(3.1)}$$

where:

rd = rut depth, in. or mm

$ESALs$ = number of 80-kN (18,000-lb) ESALs

P_{200} = percent aggregate finer than 0.074-mm (No. 200) sieve

fa = percent aggregate passing the 2.36-mm (No. 8) sieve and retained on the 0.074-mm (No. 200) sieve

T = a measure of temperature, e.g., average temperature to the time of rut depth measurement

$a_0 \ldots a_n$ = regression constants

The *first approach* (*Level 1A*) involved a direct regression between rut depth and traffic, environment (temperature), and mix parameters. Using the individual rut depth measurements up to about 2.0×10^6 ESALs, the ESALs corresponding to each rut depth measurement, and the mix parameters, this approach resulted in the following expressions:

For the *fine* and *fine-plus* mixes in the original experiment, the expression for rut depth (in inches) is:

$$\ln(rd) = -5.257 + 0.357 \cdot \ln ESALs + 0.185 P_{Wasp} + 0.041 V_{air} + 0.916 P_{200} + 0.005 T \qquad (R^2 = 0.67) \qquad \textbf{(3.2)}^5$$

where:

T = 90th percentile air temperature during the period for which rut depths were measured

[5] If the temperature term is not included (because the regressions were not significantly improved with it), the following expressions are obtained:

a. for *fine* and *fine-plus* mixes (~1.8×10^6 ESALs):
$\ln(rd) = -4.966 + 0.343 \ln ESALs + 0.192 P_{Wasp} + 0.042 \cdot V_{air} + 0.196 \cdot P_{200}$ ($R^2 = 0.66$)

b. for *coarse* mixes (~0.85×10^6 ESALs):
$\ln(rd) = -6.852 + 0.449 \ln ESALs + 0.504 \cdot P_{Wasp} + 0.045 \cdot V_{air}$ ($R^2 = 0.76$)

For the original *coarse* mix, the expression (in inches) is:

$$\ln(rd) = -4.939 + 0.212 \cdot \ln ESALs + 0.439 \cdot P_{Wasp} + 0.044 \cdot V_{air} + 0.034 \cdot T \qquad (R^2 = 0.80) \qquad \textbf{(3.3)}^{5}$$

For the replacement *coarse* mix (and for ESALs to 0.6×10^6 rather than 2.0×10^6 as above), the expression (in inches) is:

$$\ln(rd) = -6.204 + 0.190 \cdot \ln ESALs + 0.829 \cdot P_{Wasp} + 0.207 \cdot V_{air} \qquad (R^2 = 0.63) \quad \textbf{(3.4)}$$

It will be noted that temperature does not appear in Equation 3.4 for the replacement sections since the time interval of measurement was comparatively short for the number of ESALs used to develop the expression.

The *second approach* (*Level 1B*) utilized the M-E model described in the next section to develop regressions relating rut depth to traffic (ESALs) and mix properties described earlier. A total of 23 of the 34 test sections, those with *no* or *little* fatigue cracking, were used in the analysis; these included 17 original and 6 replacement sections.[6]

For each section, the parameters *a* and *c* (see Equation 3.5) were determined to provide the best fit between measured rut depths and traffic for the WesTrack conditions of traffic and temperature. Using these parameters, the accumulation of rut depth in each section was then determined for a period of 10 years with the traffic (WesTrack axle loading) applied at the rate of 60 vehicles per hour continuously throughout the 10 years. The temperature environment was that for WesTrack and was assumed the same for each year of the analysis period.

ESALs were then determined for each of the 23 sections for rut depths of 2.5 to 17.8 mm (0.1 to 0.7 in.) in increments of 2.5 mm (0.1 in.). Table 3.1 contains a summary of these results.

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[6] Original Sections 1, 4, 7, 9, 11, 12, 13, 14, 15, 18, 19, 20, 21, 22, 23, 24, and 25; Replacement Sections 35, 37, 38, 39, 54, and 55.

Various regressions were then applied to the data to obtain the effects of traffic and mix parameters on rut-depth accumulation. Results of six regressions considered most suitable are summarized in Table 3.2. Comparisons of rut depths predicted by three of the regressions in Table 3.2[7] (the *Level 1B-1*, *1B-2*, and *1B-3* curves) and Equations 3.2, 3.3, and 3.4 (the *Level 1A* curve) are shown in Figures 3.1, 3.2, and 3.3 for three sections,[8] while all comparisons are contained in Appendix E.

3.3 Mechanistic-Empirical Modeling (*Level 2*)

Mechanistic-empirical (M-E) models have been developed to represent the behavior of the pavement sections at WesTrack using the procedure described in this section. As will be seen subsequently, these models provide a basis for extending the results of WesTrack to other traffic conditions and environments and for developing regression models for use in the *Level 1* analyses. Results of the latter were presented in the previous section.

3.3.1 Approach

For the analyses reported herein, the pavement is assumed to behave as a multi-layered elastic system. The pavement structure representative of the WesTrack pavement is shown in Figure 3.4. Moduli for the different asphalt concrete sections and layers were developed as described in Chapter 2 of this report. Equation 2.2 was used to determine the moduli with the coefficients A_0 and A_1 obtained from Table 2.7; a constant Poisson's ratio of 0.35 was assumed. Moduli for the base courses for the south and north tangents were assumed to be the same, 138

[7] Defined by their R^2 values.

[8] In Figures 3.1, 3.2, and 3.3, Level 1B-1 corresponds to regression 3, Level 1B-2 to Regression 5, and Level 1B-3 to Regression 6, all in Table 3.2.

MPa (20,000 psi); a Poisson's ratio of 0.40 was used for this material. Representative values of the subgrade moduli for each month of the year were obtained from Equation 2.3; values for that are shown in Figures 2.9 and 2.10. Poisson's ratio for the subgrade was assumed to be 0.45.

The analysis consisted of determining three parameters τ, γ^e, and ε_v on an hour-by-hour basis.[9] Measured temperature distributions were used to define the moduli of the asphalt concrete, which was subdivided into three layers from top to bottom with thicknesses 25 mm (1 in.), 50 mm (2 in.), and 75 mm (3 in.) to simulate the effects of temperature gradients on mix stiffness.

In this modeling, rutting in the asphalt concrete was assumed to be controlled by shear deformations. Accordingly the computed values for τ and γ^e at a depth of 50 mm (2 in.) beneath the edge of the tire were used for the rutting estimates (Figure 3.4). Densification of the asphalt concrete was excluded in these estimates, since it had a comparatively small influence on surface rutting.

In simple loading, permanent shear strain in the AC was assumed to accumulate according to the following expression:

$$\gamma^i = a \cdot \exp(b\tau)\gamma^e n^c \qquad \textbf{(3.5)}$$

where:

γ^j = permanent (inelastic) shear strain at a 50-mm (2-in.) depth

τ = shear stress determined at this depth using elastic analysis

γ^e = corresponding elastic shear strain

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[9] τ, γ^e = elastic shear stress and strain, respectively, at a depth of 50 mm (2 in.) below outside edge of tire
ε_v = elastic vertical compressive strain at the subgrade surface

n = number of axle load repetitions

a, b, c = regression coefficients

The time-hardening principle was used to estimate the accumulation of inelastic strains in the asphalt concrete under in situ conditions. The resulting equations are as follows:

$$a_j = a \times exp(b\tau)\gamma_j^e \quad \textbf{(3.6)}$$

$$\gamma_1^i = a_1[\Delta n_1]^c \quad \textbf{(3.7)}$$

$$\gamma_j^i = a_j[(\gamma_{j-1}^i / a_j)^{(1/c)} + \Delta n_1]^c \quad \textbf{(3.8)}$$

where:

j = jth hour of trafficking

γ_j^e = elastic shear strain at the jth hour

Δn = number of axle load repetitions applied during the jth hour

The concept is illustrated schematically in Figure 3.5.

Rutting in the AC layer due to the shear deformation was determined from the following:

$$rd_{AC} = K\gamma_j^i \quad \textbf{(3.9)}$$

For a 150-mm (6-in.) layer, the value of K has been determined to be 5.5 when the rut depth (rd_{AC}) is expressed in inches (*2*).

To estimate the contribution to rutting from base and subgrade deformations, a modification to the Asphalt Institute subgrade strain criteria (*12*) was utilized. The equation expressing the criterion for 13 mm (0.5 in.) of surface rutting is:

$$N = 1.05 \times 10^{-9}\ \varepsilon_v^{-4.484} \quad \textbf{(3.10)}$$

where:

N = the allowable number of repetitions

ε_v = the compressive strain at the top of the subgrade

Since these criteria do not address rutting accumulation in the pavement structure, rut depth (*rd*) contributed by the unbound layers was assumed to accumulate as follows:

$$rd = dn^e \quad \textbf{(3.11)}$$

where:

D, e = experimentally determined coefficients

Least squares analyses for the WesTrack data suggest that the value for *d* in Equation 3.11 using the Asphalt Institute criteria is:

$$d = f/[1.05 \times 10^{-9}\ \varepsilon_v^{-4.484}]^e \quad \textbf{(3.12)}$$

where:

f = 3.548

e = 0.372

Using the time-hardening principle, as was used for the asphalt concrete, rut-depth accumulation can be expressed in a form similar to Equation 3.8, i.e.:

$$rd_j = d_j[(rd_{j-1}/d_j)^{1/0.372} + \Delta n_j]^{0.372} \quad \textbf{(3.13)}$$

The framework for rut-depth estimation, using Equations 3.5, 3.8, and 3.13, is illustrated in Figure 3.6. This approach (*Level 2*) has a distinct advantage over the direct regression approach (*Levels 1A* and *B*) in that it permits prediction of rut depth as a function of traffic and environment as well as a function of the mix parameters.

Initially, 13 sections[10] were used to calibrate the coefficients of Equations 3.5 and 3.11. While a value of *b* in Equation 3.5 of 0.0487, based on RSST-CH (the results of which are

[10] These 13 sections were Sections 1, 2, 4, 5, 7, 9, 13, 14, 15, 18, 21, 23, and 25.

summarized in Appendix C1) was used initially, subsequently a value of b = 0.071 (10.28 in metric units)[11] was determined to provide better correspondence between measured and computed rut depths. This latter value has been adopted for all subsequent analyses.

Using the procedure illustrated in Figure 3.6, least squares regression provided values of a and c for each of the 23 sections. These are summarized in Table 3.3. It will be noted that the average root mean square error (RMSE) for rut depth for the 24 sections is 0.051 in. (1.3 mm). Figures 3.7, 3.8, 3.9, and 3.10 illustrate comparisons between computed and measured rut depths for Section 4 (*fine*), Section 19 (*fine-plus*), Section 7 (*coarse*), and Section 38 (*replacement*, *coarse*). All of the comparisons are included in Appendix F.

Using the values of a and c shown in Table 3.3, the relationships of rut depth versus ESALs for the 23 sections were then determined by applying a uniform traffic load of 60 trucks per hour for a 10-year period and the temperature environment of WesTrack. This temperature distribution was assumed to be the same for each year of the 10-year period.

Regressions using different mix parameters have already been presented in Table 3.2 and comparisons of the results determined using direct regression and the regressions based on the M-E analysis have been summarized in Appendix E. Based on these results, it is strongly recommended that Regression 3 of Table 3.2 should be used, i.e.:

$$\begin{aligned}\ln(rd) = {} & -6.1651 + 0.309941 \ln ESALs + 0.00294305\ V_{air}^2 + 0.0688276\ P_{Wasp}^2 \\ & - 0.0657803\ P_{Wasp} \cdot P_{200} + 0.600498\ (fine\ plus) - 1.59167\ (coarse) \\ & + 2.35276\ (replace) + 0.21327 \ln ESALs\ (coarse) - 0.140386 \ln ESALs\ (replace)\end{aligned} \quad \textbf{(3.14)}$$

[11] Initially, the computations were done in English units.

On the one hand, the results of this equation and those of Equations 3.2, 3.3, and 3.4 correspond for a number of the sections. On the other hand, the direct regression using these equations may be overly influenced by early rutting that occurred in some of the sections at WesTrack. This is illustrated by the results for Sections 1, 14, and 15 from the original 26 and for the replacement sections, Appendix E.

To support the recommendation for the use of Equation 3.14, a comparison was made between the results of the WesTrack loading (e.g., Figures 3.7 through 3.10) and those using the extended time period analysis. The comparisons are shown in Figure 3.11. Analyses of the data shown in this Figure indicate the following:

ESALs for Slower Rates

- 0-1,000 Faster estimates exceed slower by average of 147%.
- 1,000-10,000 Faster estimates exceed slower by average of 25%.
- 10,000-100,000 Faster estimates exceed slower by average of 36%.
- 100,000-1,000,000 Slower estimates exceed faster by average of 4%.
- 1,000,000-10,000,000 The two averages are the same.

Rut Depth in inches

- 0.1 Faster estimates exceed slower by average of 55%.
- 0.2 Faster estimates exceed slower by average of 38%.
- 0.3 Slower estimates exceed faster by average of 16%.
- 0.4 Slower estimates exceed faster by average of 6%.

At the larger ESAL levels and higher rut depths, the rate of trafficking has little influence.

To illustrate the influence of air-void and asphalt contents on mix performance, computations have been made using Equation 3.14 for the *fine* mix with a value of P_{200} of 5.5 percent. These results are shown in Figure 3.12.

To be able to use mixes like those at WesTrack in different traffic and temperature environments, the *Level 2* procedure can be followed. This requires the use of values of *a* and *c* (termed, *field a* and *field c*) from Equation 3.5 that are dependent on mix properties (e.g., asphalt content, air-void content, and aggregate gradation).

To this end, calibrations were performed with the data that resulted from the analyses of the 23 test sections (see Table 3.3), and represented by the results shown in Figures 3.7 through 3.10 and included in Appendix F. Results of these calibrations provided the following expressions:

$$\ln(\textit{field a}) = -10.0792 + -0.788273P_{Wasp} + 0.0846995V_{air} - 0.358081\textit{fine} + 0.225354\textit{coarse} - 4.52386\ln(\textit{field c}) \quad (R^2 = 0.93) \qquad \textbf{(3.15)}$$

$$\ln(\textit{field c}) = -7.58344 + 1.051941P_{Wasp} + 0.95641\textit{fine plus} + 0.66471\textit{coarse} \quad (R^2 = 0.62) \qquad \textbf{(3.16)}$$

Use of parameters based on these equations to estimate rutting is termed the *Level 2A methodology*.

The approach described in this section thus far allows the designer to use any traffic loading and temperature environment in the PRS (for pay factors), as long as the grading of the aggregate use in the mix conforms to one of those used at WesTrack. For wider application, it would be desirable to have relationships that are not limited solely to the WesTrack mix types.

An approach that is recommended utilizes the results of the laboratory RSST-CH and the mix variables – asphalt content and air-void content – to determine the *field a* and *c* values. To obtain the requisite parameters, a series of regressions were performed, the results of which are

shown in Tables 3.4 and 3.5. From these analyses, Regression 6 in both Tables 3.4 and 3.5 is recommended for use to define *a* and *c* for the *Level 2* procedure if mixes differing from the WesTrack mixes are used. This approach is referred to as *Level 2B.*

3.3.2 Effects of Aggregate Gradation

The effects of variations in aggregate gradings on permanent deformation have been difficult to ascertain from only the results of the performance data for the field test sections. Accordingly, a study was conducted to define the influence of this parameter on mix rutting performance as measured using the RSST-CH.

For this study, test specimens were prepared by rolling wheel compaction for mixes containing the target gradings for both the *coarse* and *fine* mixes and variations relative to these gradings. Appendix C2 contains the grading curves as well as the resulting test data. For each mix, i.e., *coarse* and *fine,* the experiment consisted of (3 gradings)×(3 asphalt contents)×(3 air-void contents)×(3 replicates) resulting in a total of 162 shear test specimens. The tests were performed at NCSU. Results of this test program, as well as the shear tests on cores from the various test sections prior to trafficking, have been used in the analyses described in this section.

Using the 23 sections, and relating the *field a* to RSST parameters and asphalt content and air-void content as necessary, several models were investigated. For this effort, a constant value for the *field c* was assumed; values for the *field a* are shown in Table 3.6. With these values and the other mix data including asphalt content, air-void content (V_{air}), mineral filler (P_{200}) – percent passing 0.074-mm (No. 200) sieve, and fine aggregate (*fa*) – percent passing 2.36-mm (No. 8) sieve and retained on 0.074-mm (No. 200) sieve, together with the RSST data, various regressions were performed. Table 3.6 also lists the data used for these regressions.

Several models including asphalt content, air-void content, their squares, and the four RSST measurements [repetitions to 5 percent strain, lab "*a*" and lab "*b*" (Figure 1.1), and *G** at 100 repetitions] were examined. Six calibrations were accomplished with this model, each succeeding one recalibrated with one fewer section from the previous, discarding the most offending outlier. Table 3.7 shows the results of these calibrations. From this evaluation, the most promising model was selected; it included the parameters asphalt content (P_{Wasp}), asphalt content squared (P_{Wasp}^2), and *G**.

The results of the RSST-CH shown in Table 3.7 are based on tests on FMFC cores taken prior to trafficking. In order to utilize the NCSU data, it was necessary to recalibrate the models relating RSST results to mix parameters. Four of the models used are shown in Table 3.8.[12] The G* results were then adjusted as shown in Table 3.9 and new *field a* values were determined to define the effects of P_{200} and *fa* on mix rutting performance; Table 3.9 lists these values as well. The model in Table 3.8 with $R^2 = 0.767$ was used because it showed the largest impact of the independent variables, particularly fine aggregate, *fa*. This is illustrated in Table 3.10.

With these *a* values and the fixed *c* value, ESALs versus rut depth (*rd*) relationships were generated for the range in P_{200} and *fa* values shown in Table 3.9 for one asphalt content, 5.5 percent, and one air-void content, 6.5 percent. An example of influence of these parameters on ESALs to a rut depth of 10 mm (0.4 in.) is shown in Figure 3.13. A regression was then generated between ln(*rd*) and the following independent variables: ln(*ESALs*), P_{200}, *fa*, P_{200}^2, fa^2, $P_{200} \cdot fa$, $P_{200} \cdot \ln(ESALs)$, and $fa \cdot \ln(ESALs)$. With an adjusted R^2 of 0.973 and showing only variables statistically significant at the 5 percent level, the resulting equation is:

[12] As seen from Table 3.7, it was only necessary to treat *G**.

$$\ln(rd) = a_0 + a_1(\ln ESALs) + a_2 \cdot P_{200} + a_3 \cdot fa^2 \quad \textbf{(3.17)}$$

where:

a_0, a_1, a_2, a_3 = regression coefficients summarized in the following table

	Value	Standard Error	P-Value
Constant, a_0	-1.78448	0.0993823	
ln(*ESALs*), a_1	0.344720	0.00470789	0.0000
P_{200}, a_2	-0.0937563	0.0116117	0.0000
fa^2, a_3	-0.0001397256	0.00002577412	0.0000

In this equation, *rd* is the downward rut depth expressed in mm. The P_{200} and *fa* contents are expressed as percentages by weight of aggregate. The data set used for the calibration encompassed rut depths from 2 to 18 mm (0.08 to 0.71 in.), P_{200} contents from 5 to 7 percent, and fine-aggregate contents from 20 to 36 percent. *The equation cannot be used with confidence outside these ranges.*

The effects of this model are demonstrated in Figures 3.14 through 3.17. The influence of mineral filler and fine aggregate on ESALs to a given rut depth are illustrated by Figures 3.14 and 3.15. The effect seems to be significant, at least for the P_{200}. One might envision a contractor missing the P_{200} target by 2 percent and, hence, reducing the rutting life by about 50 percent.

As indicated by Figures 3.16 and 3.17, the effect of P_{200} and *fa* on the rut depth at a given level of ESALs is much less dramatic. For trafficking at a level of 10 million ESALs, the rut depth decreases from 25.5 mm (1.00 in.) at 5 percent P_{200} to 21.3 mm (0.84 in.) at 7 percent P_{200} (both for 28 percent *fa*). For the same level of trafficking, the rut depth decreases from 24.7 mm (0.97 in.) at 20 percent *fa* to 21.6 mm (0.85 in.) at 36 percent *fa* (both for 6 percent P_{200}).

3.3.3 A Performance Model for Rutting Combining Effects of Asphalt Content, Air-Void Content, Mineral Filler, and Fine-Aggregate Content

This section briefly describes the development of a complete rutting model, which captures not only the effects of aggregate gradation but also the effects of asphalt content and air-void content. To develop the model, a simulation experiment was completed using information presented earlier.

The simulations used the multi-layered elastic program, CIRCLY (*13*). Layer thicknesses were 25.4 mm (1 in.), 50.8 mm (2 in.), and 76.2 mm (3 in.) to represent the 152.4-mm (6-in.) asphalt concrete, and 152.4 mm (6 in.) for the base. The base modulus was held constant, and the subgrade modulus was varied monthly. Values representative of the *Section 11 tangent* were used. The asphalt-concrete moduli were temperature dependent and were computed from Equation 2.2 (with E expressed in MPa and T in ° Celsius). Moduli at 20°C (68°F) were simulated by the equation in Table 3.11 (without G^*).[13] A_1 was taken to be -0.0587 (Table 2.4).

To compute the critical stresses and strains, regression equations shown in Table 3.12 were used. In the equations, E_1, E_2, and E_3 are average moduli for the top 25.4 mm (1 in.), middle 50.8 mm (2 in.), and lower 76.2 mm (3 in.) of the asphalt layer, respectively, and E_5 is the subgrade modulus. Critical conditions included the shear stress and shear strain at a depth of 50.8 mm (2 in.) beneath the edge of the loaded area and the maximum normal strain at the top of

[13] Ranges for the variables are as follows:

	Asphalt Content	Air-Void Content	Mineral Filler	Fine Aggregate Content
Maximum	6.62	15.96	7.00	36.30
Average	5.56	8.38	5.70	27.89
Minimum	4.33	2.45	4.40	18.40

The use of G^* in the regression did not produce a significant increase in accuracy as noted in Table 3.11.

the foundation soil. Graphically, the correlations for these parameters are shown in Figures 3.18, 3.19, and 3.20.

The algorithm for simulating the accumulation of rutting is that which was described earlier (*Level 2,* Equations 3.5 through 3.13) making use of the following values: "b" = 10.2805, "c" = 0.34, "e" = 0.3716, and "f" = 3.54838. A brief study indicated that the use of the regression equations rather than a more detailed set of calculations with CIRCLY did not influence the accuracy of the simulations.

To expand the simulation illustrated in Figures 3.14 through 3.17, five asphalt contents ranging from 4.5 to 6.5 percent and five air-void contents ranging from 4.5 to 8.5 percent were added. These variables, coupled with the five mineral filler contents and five fine-aggregate contents used earlier, resulted in a simulation experiment evaluating 625 mixes comprised of all possible combinations of the four variables.

The simulations used actual WesTrack trafficking and temperature data from February 26, 1996, to March 6, 1999, over which time approximately 5 million ESALs had been accumulated. They were artificially extended from March 7, 1999, to March 5, 2002, by reproducing the first approximately 3-year data set, thus covering approximately 6 years of trafficking with ESAL accumulations of approximately 10 million. To extend beyond this 6-year period, the temperature and trafficking data were replicated every 3 years, as necessary. These simulations were designed to produce estimates of the ESALs resulting in downward rut depths of 3, 6, 9, 12, 15, and 18 mm (0.12, 0.24, 0.35, 0.47, 0.59, and 0.71 in.). Altogether, 3,750 (625 × 6) estimates were calculated.

Results of the expanded simulation experiment were used to calibrate by regression a fit between ln(*rd*) (mm) and the following independent variables: P_{Wasp}, V_{air}, P_{200}, *fa*, P_{Wasp}^2, P_{200}^2,

fa^2, $P_{Wasp} \cdot V_{air}$, $P_{Wasp} \cdot P_{200}$, $P_{Wasp} \cdot fa$, $V_{air} \cdot P_{200}$, $V_{air} \cdot fa$, $P_{200} \cdot fa$, ln(*ESALs*), P_{Wasp} ·ln(*ESALs*), V_{air}·ln(*ESALs*), P_{200}·ln(*ESALs*), and *fa*·ln(*ESALs*). With an adjusted R^2 of 0.983 and showing only variables statistically significant at the 5 percent level, the regression coefficients are shown in Table 3.13. Typical results of the simulations are shown in Figures 3.21 through 3.24. Appendix G contains plots of simulated rut depths using the regression represented by Table 3.13 with measured rut depths for the 23 sections used earlier.

To consider only mix variables (i.e., eliminating ESALs as an independent variable), the performance models were then recalibrated. Table 3.14 provides a summary of the coefficients necessary to estimate the ESALs required to produce rut depths ranging from 3 to 18 mm (0.12 to 0.71 in.) as a function of the four mix variables. Figure 3.25 illustrates how the rut depth develops for a mix with an asphalt content of 5.5 percent, an air-void content of 6.5 percent, a mineral filler content of 6.0 percent, and a fine-aggregate content of 28 percent.

Figures 3.26 through 3.34 illustrate the influence of the mix variables on ESALs to a rut depth of 15 mm (0.59 in.). It should be noted that a regression equation involving the four mix variables can be established for any limiting rut depth selected by the specifying agency. At this time, the coefficients representing either a rut depth of 12 mm (0.47 in.) or 15 mm (0.59 in.) would seem appropriate and can be taken directly from Table 3.14.

3.4 Summary and Recommendations

In this section, a series of models have been presented to define the effects of mix variables on permanent deformation. These models have been divided into two levels: *Level 1*, based on direct regression, and *Level 2*, based on a combination of mechanistic-empirical modeling and regression.

For the *Level 1* analyses, Equation 3.14 is recommended for use because it tends to minimize the effects of some of the early rutting observed in some of the WesTrack sections.

The *Level 2* analysis, utilizing a mechanistic-empirical procedure incorporating layered elastic analysis, permits the use of temperature regimes and traffic distributions different from those occurring at WesTrack.

The *Level 2A* procedure provides a direct use of mix parameters to define the parameters *a* and *c* to be used in the rutting procedure for a specific mix representative of one of the types used at WesTrack. This procedure requires the use of Equations 3.15 and 3.16 to define the *a* and *c* parameters for the specific mix under consideration as long as it conforms to one of the three general mix types used at WesTrack.

Level 2B requires that the RSST-CH be performed on the specific mix that is intended for use in the pavement system and the use of the regression equations for *a* and *c* shown in Tables 3.4 and 3.5 (Regression No. 6).

Finally, a procedure was presented whereby mix variables, including asphalt content, air-void content, and aggregate gradation [as defined by P_{200} and the 2.36-mm (No. 8) × 0.074-mm (No. 200) fraction], can be combined to develop a performance relation suitable for use in determining pay factors by Monte Carlo simulations as long as a specific rut depth is specified. It must be emphasized, however, that this relation is constrained to the ranges of the parameters used for the regression analysis. It makes use of the RSST-CH data from both the field cores (FMFC) and from the laboratory-prepared specimens (LMLC) tested at NCSU.

4.0 FATIGUE CRACKING

4.1 Introduction

As with permanent deformation, the objective has been to provide models that can be incorporated in the PRS program and that define the influence of asphalt content, air-void content, and aggregate gradation on the development of fatigue cracking in the asphalt concrete layer.

Two levels of models have been developed: those based on regressions between fatigue cracking, traffic loading, and mix variables (*Level 1*); and those based on mechanistic-empirical analyses to predict performance based on laboratory-measured fatigue response and stiffnesses of the pavement layers (*Level 2*). Appendix H contains a summary of the fatigue test and flexural stiffness data for specimens of FMFC mixes obtained from slabs from both the original (used for the *Level 2* analyses) and replacement sections prior to trafficking.[14]

4.2 Regression Modeling (*Level 1*)

In the next section, describing the mechanistic-empirical approach, it will be noted that linear regression was used to relate load repetitions associated with fatigue damage and mix variables in the laboratory tests. For direct comparisons of field performance (cracking) and mix variables, however, linear regression was not considered appropriate because of sample bias; that is, linear regression only considers mixes that exhibited fatigue cracking. Accordingly, two models were developed: a Probit model for crack initiation and a continuous model for crack

[14] Appendix H contains data on specimens obtained after trafficking although these data have not been used in the analyses reported herein.

propagation in which the dependent variable is the expected value of wheelpath cracking. For crack initiation, the Probit model was selected since it permits the use of observed field performance data for all 26 original test sections. In the Probit model, the dependent variable is the indication of cracking (INDCR). For each condition survey, if cracking is observed, INDCR = 1; otherwise it has a zero value.

For a 10 percent probability of cracking, the model for *fine* and *fine-plus* mixes from the original sections is:

$$Prob(INCR=1)=\Phi\begin{bmatrix}-49.502+4.788\cdot\ln(ESALs)\\ -5.245\cdot P_{Wasp}+1.148\cdot V_{air}-2.301P_{200}\end{bmatrix} \quad \textbf{(4.1)}^{15}$$

where Φ is the cumulative density function of the normal distribution.

For the *coarse* mixes in the original sections, the model is as follows:

$$Prob(INCR=1)=\Phi[-47.151+5.293\cdot\ln(ESALs)-5.996\cdot P_{Wasp}+0.450\cdot V_{air}] \quad \textbf{(4.2)}$$

Examples of the performance predicted by these equations are shown in Figures 4.1, 4.2, and 4.3. Note that both asphalt content and degree of compaction (as measured by air-void content) have a significant influence on fatigue performance.

For crack propagation a continuous regression model has been utilized in which the dependent variable is the expected value, $|E|$, of wheelpath cracking (*CRX*), that is:

$$|E|=\left[\log(CRX)\middle|INDCR=1\right] \quad \textbf{(4.3)}$$

[15] An alternative relation that does not include the P_{200} term is:
$Prob(INCR=1)=\Phi\left[-75.832+5.234\cdot\ln(ESALs)-3.072\cdot P_{Wasp}+1.050\cdot V_{air}\right]$.

This equation is a function of the same variables as the model for crack initiation and includes a correction term for selectivity bias. Parameters for this model for the *fine* and *fine-plus* and c*oarse* mixes are as follows:

	Fine and Fine-Plus		Coarse	
	Value	P-value	Value	P-value
Constant	-7.98	0.000	116	0.000
ESALs	+0.176E-05	0.000	+0.105E-5	0.000
P_{Wasp}	-1.23	0.000	+10.5	0.000
V_{air}	+0.659	0.000	-2.13	0.000
P_{200}	+0.382	0.016	-27.1	0.016
Correction, λ	+2.2	0.000	-0.604	0.130
R^2	0.56		0.51	

The progression model for the *coarse* mixes has a limited set of data points (55 versus approximately 200 for the *fine* and *fine-plus* mixes). Only the crack initiation model has been used in the PRS program at the time this report was written.

In developing a performance model for fatigue, the thickness of the asphalt concrete also must be considered. While this parameter can be incorporated in the *Level 2* approach as seen in the next section, the regression model presented in this section does not include thickness since only one pavement thickness (150 mm [6 in.]) was used at WesTrack.

To attempt to build a thickness parameter into the regression equation (e.g., Equation 4.1), results of thickness effects reported in Reference (*1*) have been combined with the WesTrack results. Appendix I describes an approach used to arrive at a model, based on regression, combining the results of both studies.

4.3 Mechanistic-Empirical Modeling

The approach used to predict fatigue cracking within the mechanistic-empirical (M-E) framework is similar to that described in Reference (*1*). The approach includes several

components: flexural fatigue testing of the *fine, fine-plus,* and *coarse* mixes; performance predictions based on the models developed as part of SHRP (*14*) but extended to efficiently treat in situ temperatures (*6*); and calibration to the Caltrans flexible-pavement design methodology (*1*). The refined models have been used previously in interpreting the results of the California HVS testing from pavement sections in the CAL/APT program.

As with the permanent deformation analyses, the pavement is treated as a multi-layer elastic system. Figure 4.4 represents the idealization of the WesTrack pavement structure for the analyses performed here. Modulus values for the base and subgrade are those reported in Chapter 2 for the north and south tangents of the test track. Stiffness moduli for the asphalt concrete were represented by Equations 2.5 and 2.6 for the *fine and fine-plus* and *coarse* mixes, respectively.

The damage determinant for fatigue that was used is the principal tensile strain, ε_t, at the underside of the asphalt-bound layer, Figure 4.4. Results of the laboratory fatigue tests on the three FMFC mixes from the original sections are as follows (Note: the P_{200} term does not appear in the regressions):

Fine mixes:

$$\ln N_f = -\underset{(1.5343)}{27.0265} - \underset{(0.0230)}{0.1439} V_{air} + \underset{(0.1245)}{0.4148} P_{Wasp} - \underset{(0.1632)}{4.6894} \ln \varepsilon_t \qquad R^2 = 0.88 \qquad \textbf{(4.4)}$$

Fine-plus mixes:

$$\ln N_f = -\underset{(1.5658)}{27.3409} - \underset{(0.0231)}{0.1431} V_{air} + \underset{(0.1247)}{0.4219} P_{Wasp} + \underset{(0.0126)}{0.0128} \ln T - \underset{(0.1632)}{4.6918} \ln \varepsilon_t \qquad R^2 = 0.88 \qquad \textbf{(4.5)}$$

Coarse mixes:

$$\ln N_f = -\underset{(2.3308)}{27.6723} - \underset{(0.0299)}{0.0941} V_{air} + \underset{(0.2853)}{0.6540} P_{Wasp} + \underset{(0.0174)}{0.0331} T - \underset{(0.1878)}{4.5402} \ln \varepsilon_t \qquad R^2 = 0.92 \qquad \textbf{(4.6)}$$

where:

N_f = fatigue life

V_{air} = air-void content, percent

P_{Wasp} = asphalt content, percent

T = temperature at 150 mm (6 in.), °C

ε_t = maximum tensile strain

Simulation of performance of the 26 sections covered the time period March 3, 1996, through October 2, 1998. The approach followed is briefly summarized in the following section.

4.3.1 Approach to Performance Simulation

The framework for the analysis of the performance of the test section is illustrated in Figure 4.5. The simulations attempted to reflect not only the influence of mix variables on the stiffness and fatigue characteristics of the 26 mixes, but also the following: for traffic, hourly variations and wander; for temperature, hourly variations with depth; and variations in subgrade stiffness according to Figures 2.9 and 2.10.

The *stiffness and fatigue response* for the various WesTrack mixes are represented by Equations 2.5, 2.6, 4.4, 4.5, and 4.6. It will be noted for the *fine* and *fine-plus* mixes that only one stiffness relationship has been developed but separate fatigue relationships are used.

Temperature data for the WesTrack site were obtained from the temperature database developed by NCE (15). Temperature at the bottom of the 150-mm (6-in.) asphalt concrete layer, T_b, was determined on an hourly basis, as was the temperature gradient, defined in this instance as:

$$g = \frac{T_{50} - T_{150}}{100} \quad \textbf{(4.7)}$$

where:

T_{50} = temperature at 50-mm (2-in.) depth, °C

T_{150} = temperature at 150-mm (6-in.) depth, °C

Equation (2.3) was used to determine the *subgrade stiffness* on a daily basis.

To stratify the data in cells, subintervals were identified for each of the variables with limits as follows:

1. for $T_{b,}$ °C : -10, 0, 10, 20, 30, 40, and 50
2. for g : -0.15, -0.1, -0.05, 0, 0.05, 0.1, and 0.15
3. for E_{sub}, MPa : 90, 95, 100, 105, 110, 115, 120

While a total of 216 cases (6 x 6 x 6) were identified, not every combination contained observed field data, so the number was reduced to 110 cases. Mean values were then developed based on the frequency of occurrence of specific values in each of the cells for the three parameters. It should be noted that E_{sub} would be the same for 24 hours in a single day.

To evaluate the *maximum principal tensile strain* at the underside of the asphalt concrete, this layer was subdivided into three sublayers, each with a thickness of 50 mm (2 in.) to reflect change in stiffness with temperature change with depth. While the stiffness of the asphalt concrete changed with temperature and subgrade stiffness varied with season, the modulus of the base was maintained at a constant value of 172.4 MPa (25,000 psi). Strains were calculated using the multi-layer elastic analysis program, CIRCLY (*13*).

Since the stiffness of the asphalt concrete mixes varied both with air-void content and asphalt content (Equations 2.5 and 2.6), a range of these parameters was selected that encompassed the measured values (Appendix H). This required 110 × 3 × 3 = 990 cases for both the *fine and fine-plus* mixes and the *coarse* mix. For each case, strains were determined at 51 points on the underside of the asphalt concrete. Figure 4.6 illustrates the variation of tensile

strain throughout the asphalt concrete layer and Figure 4.7 shows the variation of strain with offset from the centerline of the dual wheels at the underside of this layer.

To simplify the computations of damage, a function was fit to the strain distribution, an example of which is shown in Figure 4.7. This was accomplished by superimposing the strain distribution for each tire (assuming normal distributions of strain resulting from both tires). The equation defining this superposition has the following form:

$$f(m_1, m_2, \sigma) = \frac{A}{\sigma\sqrt{2\pi}}\left[\exp\left(-\frac{(x-m_1)^2}{2\sigma^2}\right)+\exp\left(-\frac{(x-m_2)^2}{2\sigma^2}\right)\right] \quad \textbf{(4.8)}$$

where:

x = offset (m)

A = multiplication factor

m_1 = mean position of the left tire strain distribution

m_2 = mean position of the right tire strain distribution

σ = standard deviation for both normal distributions

From Figure 4.7 it will be noted that an expression based on Equation 4.8 is suitable to represent the tensile strain distribution using the parameters m_1, m_2, A, and σ.

The next step was to relate these four parameters to the parameters T_b, g, E_{sub}, V_{air}, and P_{Wasp} to define a strain function representative of all possible combinations of the material and environmental variables for the WesTrack pavements.

Results of the regressions for the four parameters of Equation 4.8 as a function of the five material and environmental variables are summarized in Table 4.1 for the coarse mix and Table 4.2 for the fine and fine-plus mixes. Some of the terms shown in these tables are defined as follows:

$T_b \cdot g$	=	product of the temperature at the bottom of the AC and the temperature gradient
$T_b \cdot E_{sub}$	=	product of AC temperature (at bottom) and subgrade modulus
$(T_b \cdot g)^2$	=	square of product of bottom AC temperature and temperature gradient
$(T_b \cdot E_{sub})^2$	=	square of product of bottom AC temperature and subgrade modulus
$T_b \cdot g \cdot V_{air}$	=	interaction of bottom AC temperature, temperature gradient, and air-void content
$T_b \cdot g \cdot P_{Wasp}$	=	interaction of bottom AC temperature, temperature gradient, and asphalt content
$T_b \cdot E_{sub} \cdot V_{air}$	=	interaction of bottom AC temperature, subgrade modulus, and air-void content
$T_b \cdot E_{sub} \cdot P_{Wasp}$	=	interaction of bottom AC temperature, subgrade modulus, and asphalt content

To illustrate the *fatigue performance* simulation, results for Section 8 will be used as an example.

The first step is to construct the basic input matrix that contains T_b, g, E_{sub}, V_{air}, and P_{Wasp} on an hourly basis, i.e.:

$$T_b g E_{sub} = \begin{vmatrix} T_b & g & E_{sub} & V_{air} & P_{asp} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \end{vmatrix}_{21943\times5} \quad \textbf{(4.9)}$$

The number 21943 represents the total number of hours during which traffic was applied at WesTrack.

The ε_t function for each hour can be generated, i.e.:

$$T_b gE_{sub} coef = \begin{vmatrix} m_1 & m_2 & \sigma & A \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \end{vmatrix}_{21943\times 4} \quad \textbf{(4.10)}$$

The four parameters define the shape of the tensile strain versus offset relationship that is a continuous function. Thus the tensile strain can be determined for wander with any offset. The location that incurs the most damage is defined as the local maximum when the applied traffic is in a no-wander position. To determine the location of the local maximum tensile strain the Newton-Raphson algorithm has been utilized.

For the WesTrack wander pattern, a strain matrix, *strn*(i), for a particular section (in this case, *Section 8*) can thus be formed:

$$strn(8) = \begin{vmatrix} 5L & 4L & 3L & 2L & 1L & Center & 1R & 2R & 3R & 4R & 5R \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{vmatrix}_{21943\times 11} \quad \textbf{(4.11)}$$

Once the strain has been calculated for each point for each hour, cycles to failure are obtained from the laboratory fatigue relationship:

$$\left(N_f\right)_{Section8} = \exp\left\{-27.6723 - 0.0941\begin{vmatrix} V_{air} \\ \vdots \\ \vdots \\ \vdots \end{vmatrix} + 0.654\begin{vmatrix} P_{Wasp} \\ \vdots \\ \vdots \\ \vdots \end{vmatrix} + 0.0331\begin{vmatrix} T_b \\ \vdots \\ \vdots \\ \vdots \end{vmatrix} - 4.5402\cdot\log\left(\varepsilon_t\right)_{Section8}\right\}$$

(4.12)

This, like the other matrices, has a dimension of 21943 × 11.

The next step was to form the ESALs matrix with the same dimensions as Equation 4.12, i.e.:

$$ESALs = \begin{vmatrix} E_{5L} & E_{4L} & E_{3L} & E_{2L} & E_{1L} & E_{center} & E_{1R} & E_{2R} & E_{3R} & E_{4R} & E_{5R} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{vmatrix}_{21943\times 11} \quad \textbf{(4.13)}^{16}$$

Cumulative damage was then determined using the linear sum of cycle ratios cumulative damage by Miner's hypothesis, i.e.:

$$\sum_{i=1}^{n} \frac{n_i}{N_i} = 1 \quad \textbf{(4.14)}$$

where:

n_i = applied ESALs for each entry of the ESALs matrix

N_i = number of load applications to failure for Section 8 from the strain matrix

The matrix for this computation was:

$$\frac{ESALs}{(N_f)_{Section8}} = \begin{vmatrix} \frac{E_{5L}}{N_{f5L}} & \frac{E_{4L}}{N_{f4L}} & \frac{E_{3L}}{N_{f3L}} & \frac{E_{2L}}{N_{f2L}} & \frac{E_{1L}}{N_{f2L}} & \frac{E_{center}}{N_{fcenter}} & \frac{E_{1R}}{N_{f1R}} & \frac{E_{2R}}{N_{f2R}} & \frac{E_{3R}}{N_{f3R}} & \frac{E_{4R}}{N_{f4R}} & \frac{E_{5R}}{N_{f5R}} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{vmatrix}_{21943\times 11} \quad \textbf{(4.15)}$$

The summation of the n_i / N_i ratios for each hour represents the damage caused by the traffic in that hour. The cumulative damage versus cumulative hourly ESALs can then be plotted as shown in Figure 4.8. In this figure, damage development for both the WesTrack wander pattern and without wander are shown. Note that a considerable difference in ESALs is obtained for the two conditions.

[16] When the trucks were operated with a driver, repetitions were uniformly distributed to the 11 positions.

The question arises as to the definition of fatigue damage as determined by this procedure. To this end it is necessary to compare the predictions of crack initiation with measurements of surface cracking in the field. Table 4.3 summarizes ESALs to crack initiation without and with wander and ESALs corresponding to observed fatigue cracking of 10 percent and 50 percent. These results are shown in Figures 4.9, 4.10, and 4.11.

In Figures 4.9 through 4.11, for a given test section, the first *diamond* point corresponds to (predicted) crack initiation based on the no-wander condition, while the second *diamond* corresponds to that (predicted) with wander. The first *x-mark* corresponds to 10 percent observed surface cracking, while the second *x-mark* corresponds to 50 percent surface cracking.

An analysis of the data shown in Figures 4.9 through 4.11 suggests that, for the *coarse* mixes in which crack initiation was predicted in the first summer, surface cracking appeared during the following winter. This suggests that crack propagation time in the coarse mixes (of the type used at WesTrack) is relatively short, particularly if a cold period follows immediately a warm period leading to crack initiation. Also, the time between crack initiation and the appearance of surface cracks is substantially longer for the *fine and fine-plus* mixes. These data also suggest that the use of a single shift factor may not be appropriate for the *coarse* and *fine and fine-plus* mixes with that factor being higher for the *fine and fine-plus* mixes than for the *coarse* mix.

In spite of these differences, the data emphasize the importance of proper compaction and a controlled asphalt content. Table 4.4 summarizes recommended targets for construction variations. This control is particularly important for the *coarse* mixes. In addition, the results

demonstrate the feasibility of the M-E approach and the breadth of its capabilities, including wander effects.

4.3.2 Suggested Procedures for Performance Prediction

To use the method described herein for a specific situation requires a measure of the *stiffness* characteristics of the asphalt-aggregate mix according to the form of Equations 2.5 and 2.6. If such an equation is not available, the general stiffness equation developed for AC mixes by Witczak (*16*) can be utilized. Stiffness characteristics of the other pavement components are also required to permit the determination of tensile strains using M-E analysis.

A fatigue relationship is required for the mix under consideration. It is recommended that this relation have the form expressed by Equations 4.4, 4.5, and 4.6. If such an expression is not available, then one of the following expressions can be used as long as dense-graded AC mixes are utilized:

- the fatigue expression used in the Asphalt Institute mix design methodology, including the correction factor for asphalt content and air-void content (*12*), or
- the fatigue expression developed during the SHRP program and representative of mixes containing 16 different asphalt cements (*14*).

With this information, the framework shown in Figure 4.12 should be followed. Rather than using traffic wander as described in the analysis of the WesTrack pavements, the use of a shift factor is recommended as seen in this figure. Some of the elements of this approach are briefly described in the following paragraphs.

The approach shown in Figure 4.12 is based on that described in Reference (*4*). This system specifically considers the mean and variance of the following construction quantities: asphalt content, air-void content, and AC layer thickness.[17]

It is recommended that the distribution of fatigue lives be determined by a Monte Carlo simulation for the specific section under consideration. This requires that a random selection be made of the variables under consideration (e.g., asphalt content, air-void content, and AC thickness).

Each of the Monte Carlo simulations produces an independent estimate of the laboratory fatigue life, *N*. The corresponding simulated in situ fatigue life is determined by applying a shift factor, *SF*, and a temperature conversion factor, *TCF*, i.e.:

$$in\ situ\ life = \left(N \cdot SF\right) / TCF \qquad \textbf{(4.16)}$$

Suggested shift factors are as follows:

- For WesTrack mixes: SF (approximate, depending on V_{air})

  coarse 2-3

  fine and *fine-plus* 10-20

- For other types of dense-graded mixes prepared with conventional asphalt cements:

$$SF = 3.2 \times 10^{-5} \varepsilon_t^{-1.38} \quad \text{for } \varepsilon_t > 0.000040 \qquad \textbf{(4.17)}$$

The *TCF* is dependent on region and appears to follow an equation of the following form (*1*):

$$TCF = a \ln\left(t_{AC}\right) + b \qquad \textbf{(4.18)}$$

where:

[17] Aggregate gradation can also be considered, although it did not appear specifically in the WesTrack gradations as defined by Equations 4.4, 4.5, and 4.6 for the three mixes used in the experiment.

t_{AC} = asphalt layer thickness, cm

a, b = coefficients dependent on region

For three California locations these coefficients are as follows (*1*):

Location	a	b
California coastal region	1.754	-2.891
High desert	2.102	-3.884
Mountains (elev. ~ 1300 m)	1.448	-2.475

It is recommended, however, that a procedure like that described in Reference (*3*) be followed to determine the *TCF* for a specific locale.

From the results of these computations, the effects of the mix parameters can be defined. For example, the effects of as-constructed air-void content on pavement performance might take the form shown in Figure 4.13.

4.4 Summary and Recommendations

For fatigue, two models have been presented to define the effects of mix and structural (HMA thickness) variables on performance. The *Level 1* model is based on direct regression using a Probit model rather than linear regression, while the *Level 2* model is based on M-E analysis.

The *Level 1* model does not include the effects of thickness since only one thickness of HMA was utilized in the test pavement. While not recommended for use at this time, a Probit regression model is included in Appendix I that does incorporate HMA thickness as a parameter. This model was developed by combining the results of the WesTrack experiment with a performance model for fatigue developed as a part of the CAL/APT program (*1*). Comparisons of the results of the WesTrack model (Equation 4.1) with the Caltrans fatigue model (not included here) indicate that the WesTrack model showed that mix performance was more

affected by asphalt content and less affected by air-void content than it was in the Caltrans model.

For the *Level 2* model, it is recommended that stiffness and fatigue response characteristics be measured in the laboratory to define the effects of mix variables for mixes representative of the area of use. If this is not feasible, guidelines are provided for data that might be used depending on the type of mix.

Simulations of mix performance at WesTrack reinforced the effects of compaction and asphalt content on fatigue performance that have been reported elsewhere [e.g., Reference (*1*)]. The simulations also indicated that cracks, once formed, appeared to propagate more quickly in the *coarse* mixes used at WesTrack than in the *fine* and *fine-plus* mixes.

Finally, the results of the analyses presented in this chapter confirm the effectiveness of the M-E approach in defining performance models for fatigue in HMA.

5.0 AN APPROACH TO THE DETERMINATION OF PAY FACTORS

The information presented in Chapters 2, 3, and 4 has been developed to permit determination of pay factors for asphalt concrete construction for use in performance-related specifications (PRS). While development of the PRS was not a part of the activities described in this report, it was considered useful, nevertheless, to demonstrate a rational and feasible method for quantitatively establishing pay incentives using the results reported here as well as earlier experience based on methodology reported in Reference (*4*).

Contractor pay incentives serve at least two objectives: (1) they encourage the contractor to construct pavements with significantly improved performance in comparison to those meeting minimum specification requirements, while at the same time maintaining costs at reasonable levels; and (2) they provide a rational alternative for dealing with marginally inadequate/adequate construction.

One approach that can be taken to the development of pay factors is to consider primarily the economic impacts to the highway agency. In this approach, the assumption is that an appropriate penalty for inferior construction should be the *added cost to the agency* and that the bonus for superior construction should be no greater than the *added savings to the agency.*

For new construction, for example, these agency costs/savings are associated primarily with subsequent pavement rehabilitation. Inferior construction hastens the need for future rehabilitation and may increase the cost of rehabilitation as well. As a result, inferior construction increases the present worth of future rehabilitation costs. Superior construction, on the other hand, reduces the present worth of these costs largely by deferring the future rehabilitation. The difference in present worth of rehabilitation costs, as-constructed versus as-specified and as-expected, provides a rational basis for setting the level of penalty/bonus for inferior/superior construction quality.

To compute the differential present worth of future rehabilitation requires two different types of models: (1) a performance model or models for determining the effect of construction quality on expected pavement performance; and (2) a cost model for translating these effects into rehabilitation dollars.

Two performance models are used in the example described here: one for rutting and the other for fatigue cracking. The rutting model utilizes the information presented in Chapter 3, while the fatigue cracking model follows the framework described in Chapter 4 but reflects the more extensive information contained in Reference (*4*). Monte Carlo simulations are used to obtain distributions of pavement lives.

The cost model considers only the time to the next rehabilitation activity (i.e., it ignores future rehabilitation measures beyond the first cycle). It requires an estimate of future rehabilitation cost; and it considers annual inflation of rehabilitation costs, traffic growth, expected years of the constructed life of the asphalt concrete, and a discount rate representing the time-value of money.

5.1 Performance Models

The process embedded within the performance models is illustrated schematically in Figure 5.1a for rutting and in Figure 5.1b for fatigue cracking. Central to the process is the random selection of air-void content, asphalt content, and aggregate gradation parameters (i.e., P_{200} and *fa*) for rutting, and random selection of air-void content, asphalt content, and asphalt concrete thickness for fatigue cracking.[18]

[18] While not shown in Figure 5.1b (fatigue cracking) because it is only incidental to the computations, a random selection was also made of the foundation modulus, a modulus representing the composite effects of base, subbase, and subgrade layers in an "equivalent" two-layer system.

The random selections assume normally distributed random variables with known or assumed means and variances. Estimates of these variances were obtained from a combination of literature review, moduli back-calculations of FWD measurements, and data obtained as a part of WesTrack (*4*). Summary results are presented in Table 5.1. This table includes materials and construction components and components resulting from sampling and testing. The latter components must be removed from the variance estimates to isolate materials and construction effects. The percentages of variance attributed to materials and construction are shown in Table 5.1 as well. Reference (*4*) describes the basis for obtaining these values.

Ranges for the variables examined for both rutting and fatigue cracking are shown in Table 5.2. For the computations included here, it has been assumed that the air-void content at maximum density of the mix is 5 percent.

5.1.1 Permanent Deformation

The performance model used for permanent deformation is based on the information presented in Chapter 3. It includes the effects of air-void content, asphalt content, and aggregate gradation. The methodology is described in Section 3.2.3.

The resulting equation, based on regression, has the following form:

$$\ln(ESALs_{rd}) = a_0 + a_1 \cdot P_{Wasp} + a_2 \cdot V_{air} + a_3 \cdot fa + a_4 \cdot P_{Wasp}^{\,2} + a_5 \cdot V_{air}^{\,2} + a_6 \cdot fa^2 + a_7 \cdot P_{Wasp} \cdot V_{air} + a_8 \cdot V_{air} \cdot fa + a_9 \cdot P_{200} \cdot fa \quad \textbf{(5.1)}$$

where:

$\ln(ESALs_{rd})$ = natural logarithm of *ESALs* to specific rut depth (mm), e.g., *rd* = 15 mm (0.6 in.)

$a_0 \ldots\ldots a_9$ = regression coefficients, Table 3.14

As seen in Table 3.14, regression coefficients are developed for a range in rut depths from 3 mm (0.12 in.) to 18 mm (0.71 in.). The effects of the target values for mix parameters listed in Table 5.2 have been plotted for ESALs to a rut depth of 15 mm (0.6 in.) and are shown in Figures 3.27, 3.29, 3.31, and 3.33. While other values for rut depth could be used in the computations, this level was considered to provide a reasonable value for computational purposes and, at the same time, is a value where remedial action is often required.

Using Equation 5.1 and the procedure shown in Figure 5.1, a series of Monte Carlo simulations were performed to define relationships between ESALs to 10 percent rutting (15 mm [0.6 in.] or more) and the various mix parameters shown in Table 5.2. Figures 5.2 and 5.3 illustrate the effects of as-constructed asphalt content and air-void content on the ESALs to 10 percent rutting (15 mm [0.6 in.] or more) for a range in standard deviations for each of the parameters. Figures 5.4 and 5.5, respectively, illustrate the same information plotted in the form of asphalt content and air-void content versus as-constructed standard deviation of the associated parameter. Isolines of ESALs to 10 percent rutting (15 mm [0.6 in.] or more) are shown in each of the figures. Also shown are the construction targets.

As described in Reference (*4*), the information presented above can serve as a basis for establishing agency costs. In the example presented in that reference, construction was assumed to be controlled by degree of compaction. In the example presented here, the control is assumed to be by air-void content[19] and maximum permissible air-void content has been set at 9.75 percent. Because this percentage is considered to be a random variable, some violation of the

[19] In the example presented in Reference (*4*), relative compaction was utilized since this was the method used by Caltrans at the time when Reference (*4*) was submitted to that agency for consideration, i.e., 1997. The minimum acceptable relative compaction was set at 95 percent. For the assumptions used in this chapter, this corresponds to an air-void content of 9.75 percent.

minimum degree of compaction (maximum air-void content) requirement during construction is anticipated. For the computations presented here, the tolerable failure level has been set at 1 percent, which provides a reasonable probabilistic interpretation. As seen in Figure 5.6, the expected performance is 9.5×10^6 ESALs, corresponding to a target air-void content of 7 percent and a standard deviation in this value of 1.2 percent. This is the ESALs value that will be the target used to define both inferior ($< 9.5 \times 10^6$ ESALs) and superior ($> 9.5 \times 10^6$ ESALs) construction.

Contractor penalties can reasonably be extracted when the air-void specification is not met *and* when performance is inferior. This penalty zone is highlighted in the upper right of Figure 5.7. Contractor bonuses can reasonably be awarded when the air-void specification is met *and* when performance is superior. This bonus zone is highlighted in the lower left of Figure 5.7. For other cases, no pay adjustment seems to be appropriate. Although the left, wedge-shaped zone of Figure 5.7 represents conditions having better-than-expected performance, a bonus should not be awarded because construction fails to meet specification requirements. The right, wedge-shaped zone of Figure 5.7 represents complying conditions, but performance fails to meet expectations and, hence, construction does not justify a contractor bonus. The presence of these two wedge-shaped zones, due in part to the probabilistic nature of both specification compliance and pavement performance, may explain traditional problems in trying to link relative-compaction specifications with performance.

The cost model to be discussed subsequently is based on a comparison between the as-constructed pavement performance and the expected performance (9.5×10^6 ESALs). A qualitative indication of the results of the use of the cost model is shown in Figure 5.8.[20]

[20] Consideration of the wedge-shaped area has not been incorporated in the pay factors to be discussed subsequently.

5.1.2 Fatigue Cracking

The performance model used for fatigue cracking follows the framework for the *Level 2* model presented in Chapter 4 (i.e., the M-E methodology illustrated schematically in Figure 5.1b). It is based, however, on data pertaining to California AC pavements containing dense-graded aggregates.[21]

The multi-layer elastic program, ELSYM5, was used to simulate the stress and strain states within the simulated pavement structures. Loading consisted of a dual-tire assembly of 9,000 pounds (40 kN) total having a center-to-center spacing of 305 mm (12 in.) and a contact pressure of 100 psi (690 kPa). The critically stressed location for fatigue was assumed to be at the bottom boundary of the AC layer.

For the analysis reported here, mix properties were developed from earlier testing of a mix considered representative of those in use in California. Constituents of this mix included an AR-4000 California Valley asphalt cement and Watsonville granite. The aggregate gradation passed between the middle limits of Caltrans 3/4 medium and coarse gradations. Stiffness and fatigue life calibrations for this mix are as follows:

$$Stiff = \exp(15.259 - 0.07577V_{air} - 0.17233P_{Wasp}) \quad \textbf{(5.2)}$$

and

$$N_f = \exp(-22.0012 - 0.164566V_{air} + 0.575199P_{Wasp} - 3.71763\ln\varepsilon_t) \quad \textbf{(5.3)}$$

[21] These gradings generally lie closer to the 0.45 curve than either the *fine* or *coarse* gradings used at WesTrack; however, the fatigue response of these mixes is likely similar to that of the mixes with the fine grading used at WesTrack.

Each of the Monte Carlo simulations produced an independent estimate of the laboratory fatigue life, N_f. The corresponding simulated in situ life, ESALs, was computed by applying a shift factor, SF, and a temperature conversion factor, TCF, as follows:

$$ESALs = \frac{N_f \cdot SF}{TCF} \quad \textbf{(5.4)}$$

The shift factor is an empirically derived factor that accounts for differences between the laboratory and the in situ pavement in the rate at which fatigue damage accumulates with each load application. For computations reported here, the shift factor was calibrated to the Caltrans design model following procedures described in Reference (*4*). Thickness replaced strain as the independent variable, however, and engineering judgment was used to develop reasonable estimates for the thickest and thinnest pavement sections. The shift factor was computed as follows:

$$SF = 30.48 + 6.44(t - 12) \qquad for\ t > 12 \quad \textbf{(5.5)}$$

$$SF = 0.3771t^2 - 2.6109t + 7.5121 \qquad for\ 3.6 \le t \le 12 \quad \textbf{(5.6)}$$

and

$$SF = 3 \qquad for\ t < 3.6 \quad \textbf{(5.7)}$$

in which t is the AC thickness in inches. The temperature conversion factor, *TCF*, is given by:

$$TCF = 1.754 \ln t - 1.256 \qquad for\ t \ge 4 \quad \textbf{(5.8)}$$

$$TCF = 1.175 \qquad for\ t < 4 \quad \textbf{(5.9)}$$

For the analyses reported herein, the 10th percentile fatigue life was used as the basic performance estimate. This life corresponds to about 10 percent fatigue cracking in the wheel paths. As verified by sensitivity analysis, incremental agency costs due to off-target construction

(of either inferior or superior quality) are not significantly affected by the chosen performance percentile (at least within a reasonable range of the 1st to the 20th percentile) (*4*).

Target values and standard deviations for asphalt content and air-void content are shown in Table 5.1. This Table also contains an expression for the standard deviation of thickness (*4*) used to develop this parameter for the sections analyzed. Table 5.3 contains a summary of the four pavement sections used in the analyses. These are typical of California construction for the range in traffic as defined by the Traffic Index (range 7-13).[22] This Table also contains the target standard deviations for thickness for the four sections, computed according to the equation in Table 5.1.

With these targets, Monte Carlo simulations were performed to quantify the effects of construction quality on simulated in situ fatigue performance.[23] Each investigation employed either 100,000 simulations (air-void content/relative compaction and asphalt-concrete thickness) or 200,000 simulations (asphalt content).

Results, for a structure identified as 11AB20 (Table 5.3), are shown in Figures 5.9 through 5.11, illustrating the effects of air-void content, asphalt content, and asphalt-concrete thickness, respectively.

Results of an analysis similar to that illustrated for permanent deformation in Figure 5.6 through 5.8 are shown in Figures 5.12 and 5.13. As shown in Figure 5.6, the two wedge-shaped zones also exist in Figure 5.13. In this case, the target value corresponding to an average

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[22] The Traffic Index provides a measure of the applied traffic expressed as ESALs according to the following relation: $ESALs = 1.2895 \times 10^{2}(TI)^{8.2919}$

[23] For fatigue, the effects of P_{200} were not included. It will be noted in Equations 4.4, 4.5, and 4.6 for the laboratory test data that the P_{200} term does not appear in the regression expressions. Also it was noted in Chapter 4 that an alternate expression for Equation 4.1 did not include the P_{200} term, with little effect on the R^2 value.

air-void content of 7 percent is about 16.5 million ESALs. Thus for pay factors for fatigue, this is the target against which inferior and superior performance will be measured subsequently.

5.2 Cost Model

The performance models yield the 10th percentile in situ lives for ruts (15 mm [0.6 in.] in depth) and fatigue cracking (10 percent in wheelpaths) for both expected or on-target construction quality as well as off-target construction quality. The relative performance, *RP*, the performance input to the cost model, is computed as follows:

$$RP = \frac{off\text{-}target\ ESALs}{on\text{-}target\ ESALs} \tag{5.10}$$

The first step in the cost model is to determine the off-target pavement life in years, *OTY*, which results from the simulated performance differential. Assuming that traffic grows geometrically, the off-target pavement life is computed as follows:

$$OTY = \frac{\ln\left(1 + RP\left[\left(1+g\right)^{TY} - 1\right]\right)}{\ln\left(1+g\right)} \tag{5.11}$$

where:

g = the annual rate of traffic growth, expressed as a decimal, and

TY = the number of years of pavement life resulting from on-target construction activity

The cost model assesses the present worth of moving the first rehabilitation cycle from its on-target position, *TY*, to its off-target position, *OTY*. The net present worth, expressed as a percentage of the rehabilitation costs (in current-year dollars) is described in the following paragraphs.

Assume that:

1. C is the resurfacing/rehabilitation cost in current-year dollars,
2. the target pavement life is 20 years
3. r is the annual rate of growth in resurfacing/rehabilitation cost, that is, the construction cost index,
4. d is the annual discount rate, and
5. OTY is the pavement life due to off-target construction.

Then on-target construction will result in:

1. a future cost of $C(F/P, r\%, 20)$ at the end of the 20-year target period or
2. an annual equivalent of $C(F/P, r\%, 20)(A/F, d\%, 20)$ for 20 years.

Off-target construction will result in:

1. a future cost of $C(F/P, r\%, OTY)$ at the end of the off-target period or
2. an annual equivalent of $C(F/P, r\%, OTY)(A/F, d\%, OTY)$ for OTY years.

In the event that the OTY is less than the target period, the off-target construction increases the agency costs over the expected life of 20 years by the present worth of the difference between these annual cost streams over the OTY period. These costs are illustrated schematically in Figure 5.14. Their present worth is:

$$\left[C(F/P, r\%, OTY)(A/F, d\%, OTY) - C(F/P, r\%, 20)(A/F, d\%, 20)\right](P/A, d\%, OTY) \quad \textbf{(5.10)}$$

The equation for this expression is:

$$\Delta PW = C\left(\frac{(1+r)^{OTY}}{(1+d)^{OTY}-1} - \frac{(1+r)^{20}}{(1+d)^{20}-1}\right)\left(\frac{(1+d)^{OTY}-1}{(1+d)^{OTY}}\right) \quad \textbf{(5.11)}$$

When OTY exceeds the target life, the service life for comparison purposes may be set at either the target life of 20 years or the longer OTY. It should be noted that if the longer period is chosen, it is beneficial to the contractor's interests.

5.3 Pay Factors

With the above information, it is then possible to determine pay factors. The examples to be illustrated are based on the following:

1. Pay factors are applicable to new construction only.
2. The final pay factor schedule is project- and distress-independent.
3. Bonuses for superior construction and penalties for inferior construction reflect full agency cost increments.
4. The sole construction quality effect is the date of first resurfacing/rehabilitation.
5. Both fatigue and rutting distress are reflected in the pay factor schedule. Each entry in the pay factor schedule is based on the distress mode yielding most beneficial consequence to agency, namely, smaller bonus or larger penalty.
6. Pay factors are determined independently for each pay quantity. The combined pay factor is computed by the following equation:

$$Combined\ pay\ factor = (1 + pf_{ac})(1 + pf_{av})(1 + pf_{mf})(1 + pf_{fa})(1 + pf_{t}) - 1 \qquad \textbf{(1.4)}$$

in which all pay factors are expressed as decimals. Reference (4) describes the basis for this simplified expression for combining pay factors.

For convenience, the definitions, which are utilized, are summarized as follows:

a) Asphalt content (*ac*): Percentage of asphalt by weight of total mixture.

b) Air-void content (*av*): Percentage of air voids by volume of total mixture.

c) Mineral filler (*mf*): Aggregate passing 0.074-mm (No. 200) sieve, expressed as a percentage by weight of aggregate.

d) Fine aggregate (*fa*): Aggregate passing 2.36-mm (No. 8) sieve and retained on 0.074-mm (No. 200) sieve, expressed as a percentage by weight of aggregate.

e) Rutting life: ESALs to 10-percent of rutting with downward depths of 15 mm (0.6 in.) or more based on WesTrack performance.

f) Fatigue life: ESALs to 10-percent cracking based on Caltrans experience as summarized by the Caltrans analysis and design model.

The cost implications of off-target construction have been calculated according to the methodology described above. Tables 5.4 through 5.7 present the results of the rutting analysis based on the WesTrack model for rutting. Tables 5.8 through 5.10 present the results for the fatigue analysis using the California model. Finally, Tables 5.11 through 5.15 present the results of the combined analyses showing results most favorable to the agency.

These computations are based on the following cost parameters:

1. 2 percent annual rate of inflation in resurfacing/rehabilitation cost (r),
2. 2.5 percent annual rate of traffic growth (g),
3. 5 percent discount rate (d),
4. 20-year expected pavement life (TY),
5. Rutting failure results in resurfacing which costs 20 percent of the cost of new pavement construction in current-year dollars, and
6. Fatigue failure results in rehabilitation which costs 50 percent of the cost of new pavement construction in current-year dollars.

With this information, it is then possible to establish pay-factor tables. These are shown in Tables 5.16 through 5.20 for each of the five factors considered. The pay factors for air-void content do not include the effects of either the area where the specification is met but the performance is inferior to that of the target or the area where the specification is not met but the performance is superior to that of the target (Figures 5.6 and 5.13).

6.0 APPLICABILITY OF APPROACH TO OTHER CONDITIONS

The *Level 1* direct regression models presented in Chapters 3 and 4 are based on mix and pavement response observed in the environment associated with WesTrack. Accordingly, their use should be limited to mixes and environments similar to the WesTrack conditions. Material presented in Chapters 2, 3, and 4 does provide, however, the basis for development of performance models for both rutting and fatigue for other regions or for site-specific projects.

To develop these models requires the following:

1. traffic characteristics including load spectra or ESALs, temporal distribution(s), and growth rates if initial estimates are used;
2. representative environmental data;
3. definition of HMA characteristics, including stiffness, fatigue behavior, and permanent deformation response; and
4. representative pavement cross-sections and material characteristics of other pavement components.

This chapter presents details associated with the framework shown in Figure 1.3 for the development of performance models for rutting and fatigue.

6.1 Traffic Characteristics

Traffic can be represented by ESALs or in more detailed form by anticipated distributions of axle loads and axle configurations (load spectra), if available, with the estimate representing that in the critical design lane. The traffic can be assumed to be uniformly applied throughout the day, month, and year during the design period. If estimates of non-uniform traffic distributions are available, these also can be used.

For fatigue evaluations, it is necessary to apply a shift factor accounting for a host of factors including traffic wander, crack propagation time, and frequency of loading, to assure that load repetitions in the field are commensurate with those applied in the laboratory. If initial estimates of traffic are used, anticipated growth rates can be applied. As seen in Chapters 3 and 4, hour-by-hour accumulations of damage (fatigue or rutting) from traffic can be determined for specific mix and pavement characteristics. To simplify the performance models for pay factor determinations, however, it is recommended that temperature conversion factors for traffic (to be discussed in the next section) be utilized.

6.2 Environmental Considerations

Both temperature and moisture effects should be considered in the development of the performance models. The effects of moisture on the stiffness characteristics of untreated materials in the pavement section in a specific region will be especially significant in defining fatigue response. Temperature effects are important considerations in both the fatigue and rutting models.

To consider the effects of *moisture changes,* information similar to that presented in Figure 2.9 and 2.10 illustrating seasonal effects on subgrade modulus should be available. In zones where freeze/thaw effects must be considered, an approach like that described in Reference (*12*) to define these effects on both subgrade and base course moduli is appropriate.

While it is possible to compute the *effects of temperature* on both fatigue and rutting on an hour-by-hour basis, when determining pay factors, it is more efficient to do this at one temperature. For this purpose, the use of a temperature conversion factor (TCF) simplifies the computations. The TCF is a multiplicative factor that converts the number of design load

repetitions accruing in the mixed temperature environment in situ to its equivalent at a single temperature.

Reference (*6*) describes a procedure for defining TCFs for both fatigue and rutting analyses. In Reference (*6*), the procedure has been applied to two hypothetical pavement structures located within nine geographic regions of the U.S. In addition, as noted in Chapter 4, this procedure has been developed for three specific sites in California (*1*).

In this approach, pavement temperatures are simulated using the climate-materials structure (CMS) pavement analysis model (*17*). Representative parameters used in this model are shown in Table 6.1.

For fatigue, it is suggested that the TCF be developed at a temperature of 20°C (68°F) since this is a convenient temperature for defining mix fatigue response in the laboratory.[24]

For rutting, it is recommended that the critical temperature at a 50-mm (2-in.) depth be determined; the critical temperature is defined as the temperature at which most permanent deformation occurs. This approach, applicable to mixes containing conventional asphalts, also represents the temperature at which the RSST-CH should be performed to define the permanent deformation characteristics of the mix under consideration. As with fatigue (see footnote), if mixes containing modified binders are used, it is desirable to perform the RSST-CH over a range in temperatures [e.g., 40 to 60°C (104 to 140°F)]. The results of these tests can then be used following the more general procedures described in Reference (*6*).

[24] This approach is recommended for mixes containing conventional asphalt binders. If modified binders are used, it is desirable to determine fatigue behavior for a range of temperatures, e.g., 10°C to 30°C (50°F to 86°F) and develop TCFs following the procedure described in Reference (*6*).

6.3 HMA Characteristics

To develop M-E performance models for both rutting and fatigue cracking, the use of layered elastic analysis is recommended at this time as illustrated in Chapters 3 and 4. This analysis requires as input both *stiffnesses (moduli)* and *Poisson's ratios* at representative temperatures and times of loading for the asphalt mix or mixes being used.

In addition, *fatigue* and *permanent deformation* response characteristics must be defined in a manner that permit their use with the performance parameters (stress, strain) determined using layered elastic analysis in order to develop the desired performance models. This section briefly summarizes the necessary data required for the methodologies described in Chapters 3 and 4.

6.3.1 Stiffness Characteristics

To determine critical stresses and strains in a pavement structure or structures to define mix performance requires a measure of the stiffness characteristics of the mix or a general class of mixes as a function of P_{Wasp}, V_{air}, P_{200}, and *fa*. In addition, the effects of temperature and time of loading on stiffness must also be defined.

Equations 2.5 and 2.6 illustrate, for the WesTrack mixes, the form of the relationship between stiffness and mix characteristics and temperature. These relationships were developed from flexure tests on beam specimens of representative mixes at a specific time (frequency) of loading, in this case, 10 Hz (time of loading 0.016 sec.).

If conventional asphalt binders are used, it is possible to estimate mix stiffness from the characteristics of the mix components rather than direct measurement as represented by the results presented as Equations 2.5 and 2.6. Appendix J contains brief descriptions of two procedures, one developed by the Shell researchers (*10*) and the other by Witczak (*16*).

For mixes containing modified binders, it is desirable to measure mix stiffness over a range in temperatures (e.g., using the flexure test as described in Chapter 1). As more experience is developed with these materials, it is possible that an expression or expressions similar to those in existence for conventional binders may become available. Table 6.2 provides suggested guidelines for establishment of mix stiffness values for use in performance models.

Poisson's ratios for mixes vary from about 0.2 at low temperatures to 0.49 at high temperatures (*18*).

6.3.2 Permanent Deformation Characteristics

The performance model represented by the regression equation (Equation 5.1, with coefficients shown in Table 3.14) based on WesTrack test data can serve as a starting point. In Chapter 5, this model was used in conjunction with the fatigue performance model representative of California conditions to develop the combined pay factors shown in Tables 5.16 through 5.20. Alternatively, results of the simple shear test can be used to develop a mechanistic-empirical model (*Level 2*) like that presented in Chapter 3.

For WesTrack, a series of LMLC specimens was prepared for the *coarse* mix representing Sections 5 and 24 (binder content of 5.7 percent and an air-void content of about 8 percent). Tests were performed at three stress levels [27.6, 55.1, and 82.7 kPa (4, 8, and 12 psi)] and at three temperatures [40, 50, and 60°C (104, 122, and 140°F)].

The data permitted a calibration to be developed for the model described in Chapter 3 according to the following process:

1. The elastic shear strain, γ^e, was measured at 100 load applications to minimize the influence of sometimes spurious initial readings.

2. A fourth-degree polynomial was fit to the inelastic shear strain, γ^i, versus number of load applications curve (first 10 applications) to determine the intercept on the y axis.
3. All inelastic shear strain measurements were reduced by the value of the intercept to correct for any initial seating irregularities or mechanical slackness in the test apparatus.
4. Least squares nonlinear curve fitting was used to determine the calibration constants, *a* and *b*, of the following permanent deformation model:

$$\gamma^i = aN^b \quad \textbf{(1.1)}$$

Data for the first 100 load applications were ignored in these calibrations. Table 6.3 shows the results of this process for the specimens used in the rutting analysis. These averages were computed as follows:

1. The arithmetic averages of the shear modulus and simulated RSST repetitions to the three strain levels were first computed.
2. The "average" elastic shear strain was calculated based on the average shear modulus.
3. The "average" values of *a* and *b* were back-calculated from the 1 percent and 5 percent shear strains and the corresponding average simulated RSST repetitions.

The laboratory test data summarized in Table 6.3 were obtained at a single temperature and a single shear stress. For analysis of the permanent deformation performance of the WesTrack pavements, it was necessary to simulate for each mix not only the effects of mix type and number of load applications, but also the effects of temperature and shear stress. The multiple-temperature, multiple-stress experiment noted above provided the means for developing a suitable first-order approximation. The experiment led to the development of an RSST-CH inelastic strain model of the following general form (as shown in Appendix K):

$$\gamma^i = a' \exp(c' \tau) \gamma^e n^{b'} \quad \textbf{(6.1)}$$

and specifically for the mix in Sections 5 and 24,

$$\gamma^i = 1.262 \exp(0.0487 \tau) \gamma^e n^{0.36} \quad \textbf{(6.2)}$$

As a first approximation it was assumed that the c' of the general relationship would be unaffected by the mix type[25] and that the a' could be estimated from the a calibrated at 50°C (122°F) and 10 psi (69 kPa) shear stress and reported in Table 6.3 as follows:

$$a' = \frac{a}{\left(\exp(0.0487 \cdot 10) \gamma^e\right)} \quad \textbf{(6.3)}$$

The inelastic strain simulation then becomes:

$$\gamma^i = a' \exp\left(0.0487 \tau\right) \gamma^e n^{b'} \quad \textbf{(6.4)}$$

Initial computations for the development of rutting were performed with the coefficient 0.0487. As noted in Chapter 3, however, this coefficient was changed to 0.071 to provide better correspondence between computed and measured rut depths. Appendix K has been included to illustrate how RSST-CH laboratory data could be used for mixes from a specific region for performance model development (note: some of the coefficients of the expression used in Chapter 3 were changed, e.g., the coefficient c in Equation 3.5 corresponds to b' in Equation 6.4).

An alternative procedure for defining the performance models, already described in Chapter 3, also makes use of the results of simple shear tests; however, the testing is less extensive than that described above. In this approach, use is made of *Regression 6* in Tables 3.4

[25] This rather arbitrary decision reflects two very important observations. First, the critical shear stress [at a 50-mm (2-in.) depth beneath the outer edge of either of the dual tires] is not highly variable at different temperatures or among different mixes. And, second, in the general formulation, the effect of the shear stress, τ, on the inelastic strain is much less significant than the effect of the elastic strain, γ^e (and, by inference, the temperature).

and 3.5 with laboratory measured parameters obtained from the simple shear test to determine the parameters *field a* and *field c*. The parameters are: (1) repetitions to 5 percent permanent strain (RSST5); and (2) the value of *a* (termed *lab a*) from the relation between permanent strain (γ^i) and stress repetitions (N) represented by Equation 1.1. The values of *field a* and *field c* can then be used in Equation 3.5 to estimate rutting. This approach necessitates the use of a fixed value of $b = 0.071$, which results from the WesTrack tests, in Equation 3.5.

6.3.3 Fatigue Characteristics

Essentially, the performance model for fatigue consists of a relationship between load applications to failure and the applied tensile strain and mix variables. Laboratory testing using a flexural fatigue test [e.g., like that described in Reference (*14*)] is recommended to define the fatigue response of a mix or mixes being utilized in construction. Equations 4.4, 4.5, and 4.6 represent examples of the form of the response developed using the laboratory fatigue test. If conventional asphalt binders are used, testing at 20°C (68°F) should be sufficient. For mixes containing modified binders, testing at temperatures in the range of 5°C to 30°C (41°F to 86°F) is recommended until more data becomes available on the effects of temperature on fatigue performance for these materials.

If fatigue testing is not possible and the mix to be used contains a conventional asphalt binder, then one of the fatigue relationships described in the following sections can be utilized.

6.3.3.1 The Asphalt Institute Fatigue Performance Model (12)

This expression was developed initially by Finn et al. (*19*) as a part of the National Cooperative Highway Research Program (NCHRP) Project 1-10B, which concerned the development of a mechanistic-empirical pavement design procedure. It was then modified to

reflect the effects of asphalt content and air-void content when incorporated in the Asphalt Institute design methodology. The resulting expression is as follows (for more than 45 percent cracking in the wheel path):

$$\log_{10} N_{field} = C\left[16.086 - 3.291\log_{10}\left(\frac{\varepsilon_t}{10^{-6}}\right) - 0.854\log_{10}\left(\frac{E^*}{10^3}\right)\right] \quad \textbf{(6.5)}$$

where:

N_{field} = ESALs to 45 percent cracking

$C = 10^M$

$$M = 4.84\left(\frac{V_{asp}}{V_{air} + V_{asp}} - 0.69\right)$$

The value of $C = 1$ when $V_{asp} = 11$ percent and $V_{air} = 5$ percent. If the repetitions to less than 10 percent cracking are desired in lieu of those to greater than 45 percent cracking, the value of N_{field} corresponding to greater than 45 percent cracking can be divided by 1.38.

6.3.3.2 SHRP-Developed Performance Model (14)

This fatigue performance model was developed from controlled strain tests on a number of mixes and conventional asphalt binders. The overall data used to calibrate the model are shown in Table 6.4. The resulting regression model is as follows:

$$N = 2.738 \cdot 10^5 \cdot e^{0.077 \cdot VFB} \cdot \varepsilon_o^{-3.624} \cdot S_o''^{-2.720} \qquad (R^2 = 0.79) \quad \textbf{(6.6)}$$

where:

N = the number of load repetitions to a 50 percent reduction in stiffness (crack initiation)

e = base of the natural logarithm

ε_o = flexural strain (in./in.)

S_o'' = initial flexural loss stiffness at the 50th loading cycle (psi)

VFB = voids filled with bitumen (percent)

To determine the field ESALs, a shift is required. Shift factors recommended for application initially depend upon the amount of cracking that is permissible so that shift factors of 10.0 for 10 percent cracking in the wheelpaths and 14.0 for 45 percent cracking in the wheelpaths are recommended.

Use of this expression requires measurement of the mix stiffness S_o and phase angle at 10 Hz in the fatigue test equipment described in Reference (*4*).

6.3.3.3 Recommendations

For large projects, it is recommended that a fatigue testing program be performed for the specific mix or mixes being utilized since the cost of testing is likely to be small in comparison to the cost of the project. Testing is also desirable if representative mixes for a specific region will form the basis for the PRS.

6.4 Other Pavement Components–Stiffness and Thickness

In order to conduct analyses of the type described in Chapters 3 and 4, it is necessary to have measures of moduli and Poisson's ratios for the other components of the pavement system, as well as their thicknesses.

For the untreated pavement components, moduli can be determined using triaxial resilient modulus testing (e.g., AASHTO TP 46-94).[26]

For these materials, the resilient modulus (analogous to an elastic modulus) is defined as:

$$M_r = \frac{\sigma_d}{\varepsilon_r} \quad \textbf{(6.7)}$$

where:

σ_d = repeatedly applied deviator stress

ε_r = recoverable axial strain, usually measured after about 100 repetitions of the applied deviator stress

For fine-grained soils, M_r is dependent on the applied stress, σ_a, according to the following relation:

$$M_r = A\sigma_a^b \quad \textbf{(6.8)}$$

where *A* and *b* are experimentally determined coefficients and are a function of the water content, dry density, and soil structure imparted by the laboratory compaction method (*20*).

M_r for granular materials also is dependent on the applied stress conditions; one form of this stress dependency is (*20*):

$$M_r = K_1\theta^{K_2} \quad \textbf{(6.9)}$$

where:

θ = first stress in variant (σ_{1+} σ_{2+} σ_3) and for the triaxial compression test is ($\sigma_d + 3\sigma_3$)

[26] "Test Method for Determining the Resilient Modulus of Soils and Aggregate Materials," AASHTO Designation TP 46-94. Method utilizes a repeated load test in triaxial compression.

σ_3 = confining pressure

K_1, K_2 = experimentally determined coefficients; Reference (*11*) contains a summary of values for K_1 and K_2 as a function of material type

Alternatively, moduli can be determined by back-calculation of the in situ pavement structure if an overlay structure is being considered. An example of this approach has been described in Chapter 2 for the WesTrack pavement.

If moduli are not measured, approximate values can be determined. For example, moduli for fine-grained soils may be estimated from the California Bearing Ratio (CBR) as follows, as suggested by the Shell investigators (*10*):

$$E_{sub} = 1500(CBR) \quad \textbf{(6.10)}$$

where:

E_{sub} = modulus of subgrade in psi

Also, the Shell investigators have suggested that the modulus of a granular layer placed on top of a subgrade is in the range 2 to 3, depending on the thickness of the granular layer (*10*).

Poisson's ratios for soils vary from about 0.3 for a partially saturated condition to 0.5 when the soil is saturated. For granular materials, values in the range of 0.3 to 0.4 are suitable for use (*20*).

Estimating key stresses/strains in the asphalt-bound layer requires knowing the thicknesses of the other pavement components as well.

6.5 Performance Models

Performance models for fatigue and rutting are required (as seen in Chapter 5) to determine the effect of construction quality on anticipated pavement performance. Approaches

have been discussed earlier in Chapters 3 and 4. This section attempts to codify those approaches for site-specific projects or regions where conditions are not represented by those for which the *Level 1* models were developed.

6.5.1 Fatigue

The process embedded within the performance model is outlined schematically in Figure 1.3. Central to the process is the random selection of air-void content, asphalt content, and HMA thickness for each simulation. Although not shown in Figure 1.3, a random selection also is made of the foundation modulus, a modulus representing the composite effects of base, subbase, and subgrade layers in an *equivalent* two-layer system.

These random selections assume normally distributed random variables with known or assumed means and variances. In Table 5.1, the quantities, which represent reasonable estimates of materials/construction variability associated with conventional construction practice, have already been summarized.[27] The basis for this information is contained in Reference (*4*). It should be noted that the equations for estimating the standard deviation of AC thickness were developed here as an approximate way to handle multi-lift construction. Among the assumptions made in their development was that the coefficient of variation of thickness in single-lift construction is about 14 percent.

A multi-layer elastic program, e.g., ELSYM5 (*20*), can be used to simulate the stress and strain states within the simulated pavement structures. It is recommended that loading consisting of a dual-tire assembly of 9,000 pounds (40 kN) total having a center-to-center spacing of 304

[27] At this time, suggested characteristics for the foundation modulus are (1) total standard deviation – 30% (coefficient of variation); (2) percentage of variance due to materials/construction – 70%; and (3) materials/construction component of standard deviation – 25%.

mm (12 in.) and a contact pressure of 100 psi (690 kPa) be used. The critically stressed location for fatigue is assumed to be at the bottom boundary of the asphalt-concrete layer.

Stiffness and fatigue life expressions are required. Section 6.3.1 and 6.3.3 provide the requisite information for both. While it has been stated before, it is strongly recommended that laboratory testing be completed for representative mixes of a specific region or site to obtain this information.

Each of the Monte Carlo simulations produces an independent estimate of the laboratory fatigue life, *N*. The corresponding simulated in situ life, *ESALs*, is computed by applying a shift factor, *SF*, and a temperature conversion factor, *TCF*, as follows:

$$ESALs = \frac{N \cdot SF}{TCF} \qquad \textbf{(6.11)}$$

The shift factor, as noted earlier, is an empirically derived factor that accounts for differences between the laboratory and the in situ pavement in the rate at which fatigue damage accumulates with each load application. Chapter 4 contains suggested *SF* values for WesTrack type mixes (*coarse* and *fine*) and conventional dense-graded mixes (Equation 4.17). Alternatively, as reported in Reference (*4*), thickness could be used instead of strain as the independent variable. An *SF* of this form is:

$$SF = 30.48 + 6.44\left(t_{AC} - 12\right) \qquad for \quad t_{AC} > 12 \qquad \textbf{(6.12)}$$

$$SF = 0.3774 t_{AC}^{\ 2} - 2.6109 t_{AC} + 7.5121 \qquad for \quad 3.6 \le t_{AC} \le 12 \qquad \textbf{(6.13)}$$

and

$$SF = 3 \qquad for \quad t_{AC} < 3.6 \qquad \textbf{(6.14)}$$

in which t_{AC} is the asphalt-concrete thickness in inches.

The procedure to develop a site-specific *TCF* or a value applicable to a specific region is briefly discussed in Section 6.2 and follows the procedure detailed in Reference (*6*).

It is recommended that the 10th percentile fatigue life obtained from the Monte Carlo simulations be used as the basic performance estimate. This life corresponds to about 10 percent fatigue cracking in the wheel paths. As verified by sensitivity analysis [Reference (*4*)], incremental agency costs due to off-target construction (of either inferior or superior quality) are not significantly affected by the chosen performance percentile (at least within a reasonable range of the 1st to the 20th percentile). By this process, information like that shown in Figures 5.9, 5.10, and 5.11 can be developed for use in the PRS.

6.5.2 Permanent Deformation

Figure 1.3 illustrates the recommended steps for the development of a performance model for permanent deformation. As with fatigue, the quantities that represent reasonable estimates of materials/construction variability are utilized and Table 5.1 provides values that are a "best estimate" for conventional construction practice. If local information is available, it should be used in lieu of the information contained in Table 5.1 For permanent deformation, the effects of HMA thickness are not as significant as for fatigue; therefore, inclusion of this parameter is not mandatory.

An M-E analysis is used to simulate the stress and strain states within the pavement structure as with fatigue. The same surface loading condition is recommended; although a higher tire pressure can be utilized if deemed appropriate.

The asphalt concrete layer should be subdivided into a series of sublayers. If the ELSYM5 program is used, three sublayers are recommended. The top sub-layer should be 25 mm (1.0 in.) in thickness, the next 50-mm (2.0-in.) thick, and the third the remainder of the

layer. This provides a thickness combination that can be used to approximate the temperature gradient that exists in the pavement.

A stiffness expression like that for fatigue is necessary to permit calculation of the critical stresses and strains in the HMA. In addition, test results obtained using the RSST-CH with the test performed at the critical temperature should be available. This will permit determination of the values for *field a* and *field c* in Equation 3.5. (*Note: it may be necessary to recalibrate the data for the particular locale to obtain an appropriate value for the coefficient b.*)

Using the time hardening principle represented by Equations 3.6, 3.7, and 3.8, Equation 3.9 for rut depth in the HMA layer, and Equations 3.12 and 3.13 for the rutting contributed by the untreated portion of the pavement structure, permits a rut depth to be estimated.

Monte Carlo simulations permit estimates of rutting life, that is the number of ESALs to the specified rut depth. As with fatigue, it is recommended that the ESALs to 10 percent rutting (of specified limiting rut depth or more) be determined. And, as with fatigue, information like that shown in Figures 5.2 through 5.5 can be developed for use in the PRS.

7.0 SUMMARY AND RECOMMENDATIONS

This report describes the approach used to develop performance models from the results of the WesTrack accelerated pavement test program for use in a performance-related specification for asphalt concrete mixes. The performance models described here are those for permanent deformation (rutting) and fatigue cracking. The models developed are at two levels, as seen in Figure 1.2.

Level 1 makes use of direct regressions between pavement performance (measured rut depths and area and extent of cracking) and applied traffic and mix properties. The latter includes asphalt content, air-void content, and aggregate gradation defined by the percent passing the 0.074-mm (No. 200) sieve (P_{200}) and the percent of fine aggregate between the 2.36-mm (No. 8) and 0.074-mm (No. 200) sieves.

Level 2 makes use of mechanistic-empirical analyses to define critical stresses and strains assuming the pavement structure behaves as a multi-layer elastic system.

Mix stiffness properties were determined from nondestructive testing of the pavement sections and from measurements on mix specimens tested in the laboratory in flexure and shear (Chapter 2).

The *rutting* characteristics of the mixes were determined by means of RSST-CH, which determined not only a shear stiffness at the temperature of the test, but also a relationship between shear stress repetitions (τ = 70 kPa [10 psi]) and plastic strain γ_p with a form defined by the following expression:

$$\gamma_p = aN^b \qquad \textbf{(1.1)}$$

Fatigue response was determined by a flexural fatigue test (third-point loading) conducted in the controlled-strain mode of loading. Results of the tests at different strain levels for individual mixes were expressed by relations of the following form:

$$N = K_1 \varepsilon_t^{K_2} \qquad \textbf{(1.3)}$$

and by a general expression for all of the mixes from the original 26 sections as follows:

$$\ln N_f = -a - bV_{air} + cP_{W_{asp}} - d \ln \varepsilon_t - e \ln T \qquad \textbf{(4.4, 4.5, 4.6)}$$

Results of the tests were then used to develop performance models as described in Chapter 3 for *permanent deformation* and in Chapter 4 for *fatigue cracking.* In these analyses, extensive use was made of regression.

For permanent deformation, the performance model based solely on regression and recommended for use in the PRS at this time is Equation 3.14.

For the mechanistic-empirical analysis, the use of RSST-CH is recommended following the format as described in Chapter 3; this permits the use of local mixes as well as local traffic and environmental conditions.

For fatigue, if a regression model is to be used, either Equation 4.1 for *fine* and *fine-plus* mixes or Equation 4.2 for *coarse* mixes should provide satisfactory results. Equation 4.1 is expected to be applicable to conventional dense-graded mixes as well as the *fine* mixes.

As with rutting, laboratory test data for local mixes (flexural fatigue test data) are preferred for use for the *Level 2* procedure. If these data are not available and the local mix utilizes a dense-graded aggregate, then the Asphalt Institute expression considering both the asphalt and air-void contents is considered suitable.

In the development of pay factors, it is likely that aggregate grading has only a small effect on fatigue response and pay factors for the “reasonable” deviations from a target gradation

may not be necessary for controlling this mode of distress. However, gradation should be considered when defining pay factors for rutting; the procedure described in Chapter 3 considering asphalt content, air-void content, and aggregate gradation is recommended for use at this time.

Chapter 5 has presented a rational and feasible method for quantitatively establishing pay incentives using the results developed from WesTrack for rutting together with results obtained from an earlier study to define the effects of fatigue. The approach taken is that the added cost to the agency should serve as the basis for a penalty for inferior construction and the savings to the agency for superior construction should serve as the basis for a bonus.

In this approach, the cost model considers only the time to the next rehabilitation activity (i.e., future rehabilitation measures beyond the first cycle are not considered). This differs from the approach used in the PRS developed by Nichols Consulting Engineers for the WesTrack Project; that approach considers lifecycle costs for some prescribed period of time.

The approach described here is, in the opinion of the authors, a rational and defensible method for assigning penalties and bonuses. Accordingly, it is strongly recommended for use to establish pay factors for HMA construction.

Based on the information presented in Chapters 2 through 5, guidelines are provided for the development of performance models for fatigue and rutting. This methodology is applicable to other regions or for site-specific projects. Although guidelines are presented for the use of existing information in developing the requisite performance models, it is strongly recommended that the performance models be based on fatigue and permanent deformation tests on either site-specific materials or tests on materials representative of a given region.

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9.0 TABLES

Table 2.1 Parameters used in simulations.

Layer	Thickness, in. (mm)	Poisson's ratio	Moduli psi (MPa)
Surface	6.0 (150)	0.35	20,000-2,000,000 (138-13,800)
Base	12.0 (300)	0.40	5,000-200,000 (34.5-1,380)
Foundation	∞	0.45	2,000-100,000 (13.8-690)

Table 2.2 Regression coefficients for predicting surface deflection in mils.

	Location of deflection measurement						
	0 in.	12 in.	18 in.	24 in.	36 in.	48 in.	60 in.
d_0	13.8648	13.0839	13.2415	10.5328	10.8222	12.7046	10.6819
d_1	-0.371352			0.319609		-0.262585	
d_2	-0.391083	-0.496013	-0.432364		0.278526		
d_3	-0.266685	-0.604232	-0.803025	-1.20533	-1.24694	-1.04706	-0.980988
d_4	0.018388	-0.022779	-0.017578	-0.018072	0.0044371	0.016013	0.0029934
d_5	0.010939	0.024924	0.031176	0.020782			-0.005306
d_6	0.050517	0.025249		-0.022723	-0.032615	-0.034235	-0.015758
d_7	0.018400	0.029459		-0.044980	-0.049409	-0.029396	-0.006990
d_8	-0.061446	0.016903	0.041682	0.063360	0.0485230	0.019796	
d_9	-0.034141	-0.069783	-0.044341		0.032084	0.040621	0.0232921
Adjusted R^2	0.993	0.992	0.991	0.984	0.993	0.991	0.997

(1 in. = 25.4 mm)

Table 2.3 FWD calibration of asphalt-concrete modulus (psi).

Section	A_0	A_1
1	14.52140	-0.05870
2	14.52709	-0.05870
3	14.15116	-0.05870
4	14.80929	-0.05870
10	14.01662	-0.05870
11	14.74919	-0.05870
12	14.78954	-0.05870
14	14.69831	-0.05870
15	14.73147	-0.05870
16	14.31987	-0.05870
17	14.24529	-0.05870
18	15.30039	-0.05870
19	14.64752	-0.05870
20	14.39871	-0.05870
22	14.54525	-0.05870

(1 psi = 6.9 kPa)

Table 2.4 FWD calibration of base and foundation-soil moduli (psi).

Period	Parameter	South tangent	North tangent
All	E_2	15,125	13,487
1	E_3	17,566	22,625
2		15,529	19,611
4		15,498	19,476
5		15,601	19,121
6		15,293	18,312
8		15,931	22,114
10		15,737	20,269
12		16,743	20,960
14		17,868	21,725
16		18,412	22,929
18		18,381	23,422
20		17,889	22,324
22		16,638	20,583
23		16,365	19,023
24		16,092	18,511
25		16,271	17,755
26		16,720	18,929
27		15,153	17,575
29		14,524	16,843
30		15,270	16,882
32		14,003	15,737
All	D_0	16,560	20,205
	D_1	1,508	2,085
	D_2	249	237

(1 psi = 6.9 kPa)

Table 2.5 Stiffness ranking of AC.

Gradation	Section	Asphalt content	Air-void content	Modulus at 40ºC, psi
South tangent				
Fines plus	12	Medium	Low	253,073
	11[a]	Medium	Medium	243,064
	10	Low	High	116,834
Fines	4	Medium	Low	258,119
	2	Low	Medium	194,654
	1[b]	Medium	Medium	193,549
	3[c]	Low	High	133,659
North tangent				
Fines plus	19[a]	Medium	Medium	219,565
	22	Low	Medium	198,222
	20	Medium	High	171,201
Fines	18	High	Low	421,795
	15[b]	Medium	Medium	238,794
	14	High	Medium	231,007
	16[c]	Low	High	158,222
	17	Medium	High	146,852

[a]Sections 11 and 19 are duplicates. (1 psi = 6.9 kPa)
[b]Sections 1 and 15 are duplicates. (°F = 1.8 °C + 32)
[c]Sections 3 and 16 are duplicates.

Table 2.6 Comparison of laboratory and FWD moduli, psi, for base and foundation soil (measurement period 12).

Layer	South tangent		North tangent	
	Laboratory	FWD	Laboratory	FWD
Base	13,000	15,100	12,100	13,500
Engineered fill, top	14,100	16,700	6,800	21,000
Engineered fill, bottom	20,000		20,400	
Foundation soil	11,000		16,800	

(1 psi = 6.9 kPa)

Table 2.7 AC modulus coefficients (units in psi).

Section	A_0	A_1
1	14.21976	-0.0587
4	14.74661	-0.0587
7	14.61647	-0.0587
9	14.89291	-0.0587
11	14.77807	-0.0587
12	14.90155	-0.0587
13	14.53573	-0.0587
14	14.50107	-0.0587
15	14.46691	-0.0587
18	14.83194	-0.0587
19	14.53123	-0.0587
20	14.43511	-0.0587
21	14.81272	-0.0587
22	14.70827	-0.0587
23	14.95398	-0.0587
24	14.66365	-0.0587
25	14.78208	-0.0587
35	14.38958	-0.061
37	14.51254	-0.061
38	14.55094	-0.061
39	14.52325	-0.061
54	14.51352	-0.061
55	14.46777	-0.061

(1 psi = 6.9 kPa)

Table 3.1 Calculated ESALs to a range in rut depths for a constant loading of 60 trucks/hour, WesTrack environment.

	ESALs to rut depth, mm									
Section	2.5 mm	5.1 mm	7.6 mm	10.2 mm	12.7 mm	15.2 mm	17.8 mm	V_{air}	P_{Wasp}	P_{200}
1	28,039	252,287	820,069	3,591,871	9,204,604	18,398,845		8.6	5.69	5.1
4	236,708	611,416	1,359,344	2,773,927	3,863,423	5,878,847	7,019,202	6.9	5.24	4.4
7	63,999	153,055	227,630	316,256	408,645	513,061	624,134	7.6	6.28	6.4
9	110,563	234,749	352,391	497,064	651,076	854,130	1,082,798	3.2	6.07	5.2
11	117,174	482,548	2,448,516	6,534,875	12,923,017			8	5.5	5.5
12	116,657	435,335	1,585,887	5,124,824	9,010,004	15,295,397		3.8	5.35	6
13	95,473	225,983	355,542	517,591	707,157	945,578	1,273,364	6	6.01	5.7
14	10,769	161,277	329,455	962,944	3,077,647	6,489,484	11,865,398	7.7	6.22	4.9
15	29,167	287,582	1,834,871	6,728,613	16,439,353			8.8	5.55	5.2
18	189,538	666,122	2,747,063	6,158,581	9,973,563	15,910,029		4.6	6.22	5.1
19	18,607	180,272	368,802	1,021,007	2,988,579	5,954,150	9,437,925	6	5.41	5.8
20	8,338	92,423	234,398	499,951	1,380,435	3,205,796	6,357,843	10.4	5.4	5.2
21	76,781	176,680	255,239	346,170	455,231	556,356	688,619	3.6	6.25	5.4
22	7,119	177,636	916,839	8,948,966				6.9	4.76	5.3
23	69,331	224,904	446,813	905,331	2,231,318	3,215,667	5,376,272	5.8	5.78	7
24	26,867	105,733	202,299	308,313	447,466	632,476	929,569	7.5	5.9	6.6
25	58,393	153,644	234,776	335,143	459,322	584,865	766,798	3.1	6.33	6.7
35		929	3,339	53,879	375,289	2,160,805	3,499,640	8.75	6.12	5.6
37		2,971	23,206	85,712	217,934	461,473	1,216,154	9.55	6.14	5.7
38	819	31,835	489,242	3,054,882	7,271,094	16,890,972		7.7	5.55	6.2
39	1,530	47,133	489,200	2,725,955	5,423,810	10,857,714		5.5	5.94	5.7
54		902	2,835	44,886	276,540	1,991,198	3,010,916	7.3	6.11	5.8
55	2,282	29,129	89,868	231,453	454,256	883,673	1,985,619	4.3	6.04	6

(1 in. = 25.4 mm)

Table 3.2 Regressions relating rut depth to ESALs and mix parameters for simulated 10-year trafficking and WesTrack environment.

	Regr. 1	Regr. 2	Regr. 3	Regr. 4	Regr. 5	Regr. 6
Constant	-4.06247	-3.88788	-6.1651	-7.13496	-8.66225	-7.93245
V_{air}	0	0	0	0	0.0516084	0.038771
P_{Wasp}	0	0	0	0	0.487042	0.039324
$V_{air}\ P_{Wasp}$	0	0	0	0	0	0
$V_{air}^{\ 2}$	0.00302745	0	0.00294305	0.00408994	0	0
$P_{Wasp}^{\ 2}$	0	0	0.0688276	0.0423931	0	0
ln *ESALs*	0.03019387	0.309198	0.30994	0.304416	0.303358	0.39695
P_{200}	-0.812031	-0.868229	0	0	0	0
$V_{air} \cdot P_{200}$	0	0.00679854	0	0	0	0
$P_{Wasp} \cdot P_{200}$	0.0818242	0.0827899	-0.0657803	0	0	0
Fine	0	0	0	0	0	-0.39695
fine-plus	0.593592	0.60387	0.600498	0.397368	0.409128	0
Coarse	-1.7751	-1.7657	-1.59167	-2.12708	-2.09736	0.08131
Replace	2.72257	2.72868	2.7797	2.35276	2.34783	0
fine ln *ESALs*	0	0	0	0	0	0
fine-plus ln *ESALs*	0	0	0	0	0	0
coarse ln *ESALs*	0.21865	0.218834	0.21327	0.200957	0.19863	0
replace ln *ESALs*	-0.13931	-0.139484	-0.140386	-0.135964	-0.135645	0
R^2	0.812	0.811	0.809	0.790	0.786	0.740

Table 3.3 Calibration results for 23 sections, conventional analysis.

Section	a	C	RMSE (in.)
1	5.41658	.022521	0.027
4	0.01392	0.66306	0.037
7	0.01509	0.77181	0.102
9	0.00410	0.83989	0.076
11	1.64235	0.29677	0.040
12	1.05802	0.33734	0.087
13	0.01186	0.75472	0.078
14	6.15197	0.25614	0.050
15	7.30191	0.20716	0.001
18	0.39160	0.41493	0.035
19	3.86629	0.29245	0.044
20	7.03048	0.26222	0.050
21	0.00973	0.81183	0.118
22	29.32602	0.10116	0.042
23	0.59761	0.43650	0.050
24	0.49708	0.49941	0.084
25	0.05564	0.67400	0.102
35	52.77398	0.12388	0.024
37	12.04868	0.26447	0.032
38	23.14986	0.13996	0.024
39	13.73983	0.18501	0.030
54	51.08506	0.12941	0.012
55	3.22487	0.35783	0.032
Average			0.051

(1 in. = 25.4 mm)

Table 3.4 Calibration of equations for simulating ln(*field a*) based on mix and RSST variables.

	Regr. 1	Regr. 2	Regr. 3	Regr. 4	Regr. 5	Regr. 6
Constant	14.9116	24.7107	24.3317	24.9718	25.3649	20.4844
P_{Wasp}	-3.67001	-5.02990	-5.04342	-5.23716	-5.71438	-5.12624
V_{air}						0.313875
$P_{Wasp} \cdot V_{air}$	0.0823738					
rsst5					6.219E-05	9.699E-05
lab a	1301.81	1622.41	1745.07	1858.91	2472.96	2264.05
R^2	0.611	0.629	0.684	0.752	0.888	0.951
Sections Omitted	None	14	14, 15	1, 14, 15	1, 14, 15, 19	1,4, 14, 15, 19

Table 3.5 Calibration of equations for simulating *field c* based on mix and RSST variables.

	Regr. 1	Regr. 2	Regr. 3	Regr. 4	Regr. 5	Regr. 6
Constant	-0.944102	-1.75309	-1.72144	-1.77798	-1.83917	-1.49931
P_{Wasp}	0.312598	0.426673	0.427803	0.444915	0.493348	0.452398
V_{air}						-0.0217923
$P_{Wasp} \cdot V_{air}$	-0.0064968					
rsst5					-6.216E-06	-8.575E-06
lab a	-87.5258	-113.452	-123.693	-133.748	-190.11	-175.759
R^2	0.556	0.591	0.648	0.728	0.890	0.936
Sections Omitted	None	14	14, 15	1, 14, 15	1, 14, 15, 19	1, 4, 14, 15, 19

Table 3.6 Values of *field a* from the 23 section using a constant value for *c*.

Section	P_{Wasp}	V_{air}	P_{200}	*fa*	Reps 5%	*G**	*lab a*	*lab b*	*field a*	*field c*
1	5.75	9.6	5.1	33.7	2,113	53.72	0.001588	0.448	1.146	0.34
4	5.63	6.5	4.4	34.8	40,093	70.52	0.000842	0.384	1.280	0.34
7	6.38	8.3	6.4	22.3	2,105	42.35	0.002276	0.407	4.114	0.34
9	5.8	2.5	5.2	32.6	2,764	45.86	0.001263	0.464	2.674	0.34
11	5.16	8.1	5.5	34.6	799	48.54	0.001948	0.486	0.913	0.34
12	5.27	3.7	6.0	32.7	37,572	67.03	0.001332	0.344	1.020	.034
13	5.76	6.5	5.7	32.9	479	44.89	0.001507	0.570	2.599	0.34
14	6.62	5.9	4.9	35.1	692	46.27	0.002473	0.461	1.979	0.34
15	5.56	8.1	5.2	35.0	6,405	47.49	0.001170	0.428	1.230	0.34
18	6.26	3.5	5.1	34.7	20,266	79.88	0.002750	0.291	1.096	0.34
19	5.48	6.0	5.8	34.5	1,303	35.86	0.000872	0.564	2.020	0.34
20	5.13	10.4	5.2	34.7	340	39.39	0.001766	0.574	2.434	0.34
21	5.84	3.7	5.4	36.1	1,707	44.31	0.001344	0.488	4.419	0.34
22	4.52	6.9	5.3	33.5	2,792	56.57	0.001130	0.477	1.279	0.34
23	5.84	4.3	7.0	22.1	50,918	62.41	0.000990	0.364	2.169	0.34
24	5.78	7.5	6.6	22.1	2,973	59.20	0.003168	0.348	4.143	0.34
25	6.24	2.8	6.7	22.7	10,012	41.09	0.003029	0.308	4.097	0.34
35	5.71	8.7	5.6	18.4	129	34.25	0.004389	0.506	3.739	0.34
37	5.94	9.6	5.7	18.9	184	34.84	0.004065	0.486	5.127	0.34
38	5.43	7.7	6.2	19.4	860	43.24	0.003505	0.397	2.003	0.34
39	5.32	5.5	5.7	18.6	1,388	52.17	0.004003	0.353	2.021	0.34
54	5.78	7.3	5.8	19.9	651	43.24	0.004622	0.373	4.964	.034
55	5.93	4.3	6.0	19.1	137	40.84	0.004372	.0502	3.956	0.34

Table 3.7 Regressions for ln *a* based on mix and laboratory shear test parameters.

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
constant	-6.40078E-01	9.28909E-01	4.20514E-01	7.35276E-01	8.72143E-01	8.30836E-01
P_{Wasp}	4.95130E-01					
P_{Wasp}^2		4.18146E-02	5.90585E-02	5.05927E-02	4.79060E-02	4.86907E-02
*G**	-2.77254E-02	-3.08302E-02	-3.11846E-02	-3.13983E-02	-3.17611E-02	-3.07348E-02
R^2	.0524	0.610	0.697	0.718	0.767	0.823
Sections Omitted		24	14, 24	11, 14, 24	11, 14, 15, 24	1, 11, 14, 15, 24

Table 3.8 Models to define *G as a function of mix variables.**

	R^2 = 0.809	R^2 = 0.804	R^2 = 0.779	R^2 = 0.767
Predicting	ln(*G**)	ln(*G**)	ln(*G**)	G*
Constant	8.13378	5.34512	4.79242	256.401
P_{Wasp}	-0.49722	-0.136602		-35.6794
V_{air}	-0.140085			-15.0318
P_{200}				6.29193
Fa	-0.116067		0.0144959	
P_{Wasp}^2		-0.0312521	-0.030895	
V_{air}^2	0.0034694	0.00355533		0.415377
P_{200}^2	0.024439			
Fa^2	0.00337748	0.00128764		0.0343932
$P_{Wasp} \cdot V_{air}$	0.0169372	0.0163597		2.15752
$P_{Wasp} \cdot P_{200}$	0.0240761	0.0304861	0.0142573	
$P_{Wasp} \cdot fa$		-0.00709602		
$V_{air} \cdot P_{200}$				
$V_{air} \cdot fa$	-0.0016362	-0.0016957	-0.00177202	-0.224379
$P_{200} \cdot fa$	-0.010578	-0.00301201		

Table 3.9 Determination of *a* values for mixes containing ranges in P_{200} and *fa* (*c* = 0.340).

P_{Wasp}	V_{air}	P_{200}	*fa*	*G**			field *a*
				NCSU	% Change	UCB	
5.5	6.5	5.0	20	73.19	-1.55	48.55	2.251714
5.5	6.5	5.0	24	73.41	-1.27	48.68	2.242338
5.5	6.5	5.0	28	74.73	0.53	49.57	2.181931
5.5	6.5	5.0	32	77.15	3.76	51.16	2.077697
5.5	6.5	5.0	36	80.67	8.20	53.35	1.942303
5.5	6.5	5.5	20	76.33	2.47	50.53	2.118575
5.5	6.5	5.5	24	76.55	2.90	50.74	2.104886
5.5	6.5	5.5	58	77.87	4.61	51.59	2.050853
5.5	6.5	5.5	32	80.29	7.65	53.08	1.958803
5.5	6.5	5.5	36	83.81	11.80	55.13	1.839263
5.5	6.5	6.0	20	79.48	6.13	52.33	2.004236
5.5	6.5	6.0	24	79.70	6.74	52.63	1.985780
5.5	6.5	6.0	28	81.02	8.38	53.44	1.937102
5.5	6.5	6.0	32	83.44	11.23	54.85	1.855183
5.5	6.5	6.0	36	86.96	15.13	56.77	1.748862
5.5	6.5	6.5	20	82.62	9.53	54.01	1.903695
5.5	6.5	6.5	24	82.84	10.29	54.39	1.881741
5.5	6.5	6.5	28	84.16	11.86	55.16	1.837606
5.5	6.5	6.5	32	86.58	14.55	56.48	1.764198
5.5	6.5	6.5	36	90.11	18.21	58.29	1.669007
5.5	6.5	7.0	20	85.77	12.69	55.57	1.814708
5.5	6.5	7.0	24	85.99	13.58	56.01	1.790207
5.5	6.5	7.0	28	87.31	15.08	56.75	1.749960
5.5	6.5	7.0	32	89.73	17.63	58.00	1.683767
5.5	6.5	7.0	36	93.25	21.08	59.70	1.598026

Table 3.10 Regression models to define the effects of mix variables on *G measured in LMLC compacted specimens.**

P_{Wasp}	V_{air}	P_{200}	*fa*	*G**			
				R^2 = 0.809	R^2 = 0.804	R^2 = 0.779	R^2 = 0.767
5.5	**6.5**	**5.5**	**20**	**78.38**	**77.62**	**77.38**	**76.33**
5.5	**6.5**	**5.5**	**24**	**67.79**	**74.59**	**78.30**	**76.55**
5.5	**6.5**	**5.5**	**28**	**65.33**	**74.69**	**79.24**	**77.87**
5.5	**6.5**	**5.5**	**32**	**70.14**	**77.94**	**80.19**	**80.29**
5.5	**6.5**	**5.5**	**36**	**83.90**	**84.75**	**81.15**	**83.81**
5.5	**6.5**	**4.5**	**28**	**60.27**	**68.72**	**73.27**	**71.58**
5.5	**6.5**	**5**	**28**	**62.37**	**71.64**	**76.20**	**74.73**
5.5	**6.5**	**5.5**	**28**	**65.33**	**74.69**	**79.24**	**77.87**
5.5	**6.5**	**6**	**28**	**69.28**	**77.87**	**82.41**	**81.02**
5.5	**6.5**	**6.5**	**28**	**74.36**	**81.18**	**85.71**	**84.16**
5.5	**4.5**	**5.5**	**28**	**72.87**	**83.38**	**87.51**	**87.63**
5.5	**5.5**	**5.5**	**28**	**68.76**	**78.63**	**83.27**	**82.34**
5.5	**6.5**	**5.5**	**28**	**65.33**	**74.69**	**79.24**	**77.87**
5.5	**7.5**	**5.5**	**28**	**62.51**	**71.45**	**75.41**	**74.24**
5.5	**8.5**	**5.5**	**28**	**60.22**	**68.84**	**71.76**	**71.44**
4.5	**6.5**	**5.5**	**28**	**84.28**	**94.69**	**99.79**	**99.53**
5	**6.5**	**5.5**	**28**	**74.20**	**84.76**	**89.61**	**88.70**
5.5	**6.5**	**5.5**	**28**	**65.33**	**74.69**	**79.24**	**77.87**
6	**6.5**	**5.5**	**28**	**57.52**	**64.80**	**69.00**	**67.04**
6.5	**6.5**	**5.5**	**28**	**50.64**	**55.35**	**59.16**	**56.22**

Table 3.11 Regression for asphalt concrete modulus as a function of mix variables.

	Without G^*	With G^*
Constant	-31,666.8	-36,619.8
P_{Wasp}		2,158.64
P_{200}	5,825.02	4,369.00
Fa	1,437.71	1,506.44
$P_{Wasp} \cdot fa$	-38.8805	-100.352
$V_{air} \cdot P_{200}$	31.0337	38.3619
$V_{air} \cdot fa$	-17.3339	-17.2588
$P_{200} \cdot fa$	-182.866	-135.246
G^*		20.8749
R^2	0.817	0.854

Table 3.12 Regression equations relating elastic moduli of pavement layers to parameters used to predict permanent deformation in the pavement structure.

	ln Shear Strain at 50.8 mm	Shear Stress at 50.8 mm (MPa)	ln Vertical Strain at Subgrade
Constant	0.8217170	0.3137060	-4.0864700
$\ln E_1$	2.0944700	0.6140080	0.0764232
$\ln E_2$	-2.8458700	-0.5066260	
$\ln E_3$		-0.1751630	0.4218020
$\ln E_5$	-1.8473700		-1.3455200
$(\ln E_1)^2$		-0.0079054	-0.0121811
$(\ln E_2)^2$		-0.0141901	0.0191260
$(\ln E_3)^2$	-0.0617350		0.0037581
$(\ln E_5)^2$		-0.0116200	0.0788732
$\ln E_1 \cdot \ln E_2$	-0.1484240		
$\ln E_1 \cdot \ln E_3$	0.0496573	-0.0296093	-0.0049935
$\ln E_1 \cdot \ln E_5$	-0.3728530	-0.0658791	0.0116570
$\ln E_2 \cdot \ln E_3$	0.1172230	0.0565259	-0.0542048
$\ln E_2 \cdot \ln E_5$	0.5552690	0.0738717	0.0131217
$lnE_3 \cdot lnE_5$			-0.0311707
R^2	0.9968	0.9851	0.9999

(1 in. = 25.4 mm)
(1 psi = 6.9 kPa)

Table 3.13 Regression coefficients relating ln(*rd*) in mm and mix and traffic variables.

	Value	Standard Error	P-Value
Constant	0.153165	0.0797641	
P_{Wasp}	-1.48931	0.0567757	0.0000
V_{air}	0.131078	0.0199003	0.0000
Fa	0.0283932	0.0038144	0.0000
P_{Wasp}^2	0.181117	0.0040089	0.0000
V_{air}^2	-0.00601424	0.0007840	0.0000
Fa^2	-0.000568699	0.0000487	0.0000
$P_{Wasp} \cdot V_{air}$	-0.0204476	0.0017979	0.0000
$P_{Wasp} \cdot P_{200}$	-0.00391608	0.0014200	0.0059
$P_{Wasp} \cdot fa$	-0.00195938	0.0003265	0.0000
$V_{air} \cdot fa$	0.00334441	0.0001634	0.0000
$P_{200} \cdot fa$	-0.00255553	0.0002757	0.0000
ln(*ESALs*)	0.126011	0.0068535	0.0000
$P_{Wasp} \cdot \ln(ESALs)$	0.395119	0.0010912	0.0000
$V_{air} \cdot \ln(ESALs)$	0.00193021	0.0005353	0.0003

Table 3.14 Regression coefficients relating ln(ESALs) to mix variables for specific levels of rutting.

	Downward Rut Depth (mm)					
	3	6	9	12	15	18
Constant	4.15659	32.1396	35.6119	26.5116	19.6304	15.5941
P_{Wasp}	4.80344	-4.13639	-4.9073	-1.07049	1.67468	3.32617
V_{air}	-0.271222	-0.9128258	-0.695417	-0.655977	-0.608102	-0.57752
fa	-0.0513972	-0.0561651	-0.060186	-0.066391	-0.0625076	-0.0665384
P_{Wasp}^2	-0.637872	0.113609	0.174723	-0.18449	-0.430036	-0.574549
V_{air}^2	0.162333	0.0152498	0.0176358	0.0161092	0.0204602	0.0197888
fa^2	0.00134321	0.00146158	0.00160422	0.00165989	0.00170736	0.00171777
$P_{Wasp} \cdot V_{air}$	0.0275229	0.143108	0.103099	0.0964891	0.0809674	0.0765997
$V_{air} \cdot fa$	-0.00849295	-0.00903533	-0.010073	-0.00935616	-0.01012	-0.00986111
$P_{200} \cdot fa$	0.00863251	0.00886307	0.00964144	0.00927116	0.00949051	0.00962141
R^2	0.993	0.991	0.992	0.991	0.996	0.997

(1 in. = 25.4 mm)

Table 4.1a The linear regression fitting results of coefficient m_1 of *coarse* mix.

Gradient	[-0.15,-0.10]	[-0.10,-0.05]	[-0.05,0.0]	[0.0,0.05]	[0.05,0.10]	[0.10,0.15]
Intercept	-0.08175863	-0.03479309	-0.03411011	-0.0431191	-0.03614109	-0.03233883
$T_b \cdot g$	0.01950062			0.03462285		
$T_b \cdot E_{sub}$		6.717861e-6	6.793519e-6		6.942432e-6	7.675834e-6
$(T_b \cdot g)^2$	0.002959697			-0.009660887		
$(T_b \cdot E_{sub})^2$		-3.21376e-11	-1.247114e-10		-2.164686e-10	-3.704025e-10
G		0.0845437	0.03453812		0.05250905	0.04367304
E_{sub}	0.0009615674		-0.00002152473	0.00002656082		-0.00003846102
V_{air}	0.001093299	0.0006746544	0.0006666258	0.0006601759	0.0006720647	0.0006863074
P_{Wasp}	0.003705114	0.00226696	0.002230678	0.002233238	0.002180534	0.002211977
$T_b \cdot g \cdot V_{air}$	0.0001268999			-0.0002971607		
$T_b \cdot E_{sub} \cdot V_{air}$		-5.584353e-8	-6.137919e-8		-7.738638e-8	-8.894092e-8
$T_b \cdot g \cdot P_{Wasp}$	0.0004663344			-0.001021566		
$T_b \cdot E_{sub} \cdot P_{Wasp}$		-2.0672e-7	-2.257651e-7		-2.846534e-7	-3.27908e-7
$V_{air} \cdot PWasp$	0.00002792679	-0.00001991557	-0.00002062941	-0.00001568069	-0.00002628364	-0.00002838366
R^2	0.9959	0.9972	0.9971	0.9875	0.9965	0.999

Table 4.1b The linear regression fitting results of coefficient m_2 of *coarse* mix.

Gradient	[-0.15,-0.10]	[-0.10,-0.05]	[-0.05,0.0]	[0.0,0.05]	[0.05,0.10]	[0.10,0.15]
Intercept	0.3562	0.3562	0.3562	0.3561	0.3562	0.3562
M_1	-1.0066	-1.0053	-1.0062	-1.0071	-1.0085	-1.0095
R^2	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000

Table 4.1c The linear regression fitting results of coefficient σ of *coarse* mix.

Gradient	[-0.15,-0.10]	[-0.10,-0.05]	[-0.05,0.0]	[0.0,0.15]	[0.15,0.10]	[0.10,0.15]
Intercept	0.1431	0.1423	0.1426	0.1445	0.1412	0.1409
M^1	-5.5021	-3.5916	-4.9619	-8.6655	-4.0365	-21.2729
M_1^2	-125.6612	-182.4311	-126.0442	-224.8148	-308.7180	-283.9384
M_1^3		-8698.2050	-668.5057		-22427.9359	15039.9723
M_1^4		-226481.9409			-873964.3969	
M_1^5		-2393516.9861			-13472803.3775	
$\sin(M_1/0.01)$	0.0216		0.0166	0.0453		0.172
R^2	0.9999	0.9998	0.9999	0.9958	0.9999	0.9998

Table 4.1d The linear regression fitting results of coefficient *A* of *coarse* mix.

Gradient	[-0.15,-0.10]	[-0.10,-0.05]	[-0.05,0.0]	[0.0,0.05]	[0.05,0.10]	[0.10,0.15]
Intercept	-13.39914	-11.58667	-11.12271	-11.49544	-12.01581	-11.10854
$T_b \cdot g$	1.53532			2.294153		
$T_b \cdot E_{sub}$		0.0005025015	0.0004804504		0.0004590989	0.0005093146
$(T_b \cdot g)^2$	0.2220458			-0.5428994		
$(T_b \cdot E_{sub})^2$		-1.161947e-9	-5.566515e-9		-1.683449e-9	-1.405131e-8
G		6.384203	0.6557571		5.63907	2.487178
E_{sub}	0.05892822		-0.006828288	-0.002321114		-0.007310587
V_{air}	0.06316996	0.04783163	0.04758049	0.04731206	0.04742552	0.04794235
P_{Wasp}	0.2173902	0.1641741	0.163119	0.1601871	0.1608133	0.1615919
$T_b \cdot g \cdot V_{air}$	0.005865289			-0.01427007		
$T_b \cdot E_{sub} \cdot V_{air}$		-3.361553e-6	-3.468244e-6		-3.921476e-6	-4.321448e-6
$T_b \cdot g \cdot P_{Wasp}$	0.02175577			-0.0527957		
$T_b \cdot E_{sub} \cdot P_{Wasp}$		-0.0000124667	-0.00001285962		-0.00001453973	-0.00001601667
$V_{air} \cdot P_{Wasp}$	-0.00146397	-0.001153217	-0.001164524	-0.001324928	-0.001308766	-0.001402494
R^2	0.9987	0.9923	0.9985	0.9962	0.9917	0.9974

Table 4.2a The linear regression fitting results of coefficient m_1 of *fine* and *fine-plus* mixes.

Gradient	[-0.15,-0.10]	[-0.10,-0.05]	[-0.05,0.0]	[0.0,0.05]	[0.05,0.10]	[0.10,0.15]
Intercept	-0.07988474	-0.03634856	-0.03691352	-0.04270346	-0.03327317	-0.03607125
$T_b \cdot g$	0.0159674			0.03393941		0.006677723
$T_b \cdot E_{sub}$		7.199499e-6	6.842651e-6		7.529676e-6	
$(T_b \cdot g)^2$	0.002579341			-8.99276e-3		-0.0003165719
$(T_b \cdot E_{sub})^2$		-1.351548e-10	-1.361373e-10		-3.466108e-10	
G		0.07178455	0.02041707			
E_{sub}	0.0008506537			2.267549e-5		0.00004793386
V_{air}	0.001564374	0.00100384	0.0009612834	0.001012483	0.0009535552	0.0009445551
P_{Wasp}	0.003935108	0.002520002	0.002413306	0.002475931	0.002344938	0.002294424
$T_b \cdot g \cdot V_{air}$	0.0001833901			-0.0004657914		-0.000101136
$T_b \cdot E_{sub} \cdot V_{air}$		-9.289788e-8	-9.387046e-8		-1.124367e-7	
$T_b \cdot g \cdot P_{Wasp}$	0.0004900334			-0.001215362		-0.0002752519
$T_b \cdot E_{sub} \cdot P_{Wasp}$		-2.543658e-7	-2.57598e-7		-3.074625e-7	
$V_{air} \cdot P_{Wasp}$	-0.000046345	-0.0000360965	-3.451985e-5	-0.0000428518	-0.0000418012	-0.00004531004
R^2	0.9929	0.9971	0.9967	0.9898	0.9943	0.9976

Table 4.2b The linear regression fitting results of coefficient m_2 of *fine* and *fine-plus* mixes.

Gradient	[-0.15,-0.10]	[-0.10,-0.05]	[-0.05,0.0]	[0.0,0.05]	[0.05,0.10]	[0.10,0.15]
Intercept	0.3562	0.3562	0.3562	0.3560	0.3562	0.3561
M_1	-1.0073	-1.0062	-1.0069	-1.0086	-1.0096	-1.0103
R^2	0.9999	1.0000	1.0000	1.0000	1.0000	0.9999

Table 4.2c The linear regression fitting results of coefficient σ of *fine* and *fine-plus* mixes.

Gradient	[-0.15,-0.10]	[-0.10,-0.05]	[-0.05,0.0]	[0.0,0.15]	[0.15,0.10]	[0.10,0.15]
Intercept	0.1425	0.1423	0.1422	0.1485	0.1411	0.1409
M_1	-6.7044	-6.4943	-6.5630	-3.3726	-4.2418	-4.4155
M_1^2	-162.0980	-157.8808	-160.1644	-57.7235	-379.9716	-503.7375
M_1^3					-31839.2312	-58146.4542
M_1^4					-1396525.8838	-3559716.1828
M_1^5					-23722319.7929	-84038344.7616
$\sin(M_1/0.01)$	0.0310	0.0294	0.0304	0.0073		
R^2	0.9999	0.9998	0.9998	0.9968	0.9998	0.9998

Table 4.2d The linear regression fitting results of coefficient *A* of *fine* and *fine-plus* mixes.

Gradient	[-0.15,-0.10]	[-0.10,-0.05]	[-0.05,0.0]	[0.0,0.05]	[0.05,0.10]	[0.10,0.15]
Intercept	-13.41943	-11.60635	-11.93162	-11.52406	-11.99708	-11.81081
$T_b \cdot g$	1.319236			2.235742		0.4622427
$T_b \cdot E_{sub}$		0.0004821816	0.0004740113		0.0004566367	
$(T_b \cdot g)^2$	0.1982441			-0.5164648		-0.01628367
$(T_b \cdot E_{sub})^2$		1.14947e-9	-2.061125e-9		-3.015393e-9	
g		5.958508	-2.517388		5.119211	
E_{sub}	0.05352491			-0.002119558		0.002269168
V_{air}	0.09092601	0.06912625	0.06805976	0.06760431	0.06782119	0.06745517
P_{Wasp}	0.2349178	0.1777141	0.1748931	0.1720754	0.1727083	0.1707851
$T_b \cdot g \cdot V_{air}$	0.008588157			-0.02108253		-0.005128277
$T_b \cdot E_{sub} \cdot V_{air}$		-5.169588e-6	-5.12326e-6		-5.737562e-6	
$T_b \cdot g \cdot P_{Wasp}$	0.02376517			-0.05790203		-0.01413554
$T_b \cdot E_{sub} \cdot P_{Wasp}$		-0.00001428444	-0.00001414514		-0.00001582453	
$V_{air} \cdot P_{Wasp}$	-0.002397742	-0.001936588	-0.001916482	-0.002129637	-0.002135857	-0.002265763
R^2	0.9975	0.9919	0.9933	0.9967	0.9926	0.9975

Table 4.3 Comparison of the results of the fatigue performance simulations and the condition survey data for WesTrack.

Section number	Mix type	V_{Air}	P_{Wasp}	ESAL@Center		ESAL@Wander		10% Fatigue cracking		50% Fatigue cracking	
				ESAL	Date	ESAL	Date	ESAL	Date	ESAL	Date
1	fine	8.8	5.55	377,281	06/17/96	407,821	06/21/96	NA	09/03/98	NA	09/03/98
2		10.4	4.92	321,777	06/08/96	339,348	06/14/96	2,899,176	07/26/97	NA	09/03/98
3		12.4	4.97	228,937	05/12/96	237,067	05/14/96	3,585,531	11/05/97	4,340,103	02/18/98
4		6.6	5.12	554,770	07/28/96	722,115	08/23/96	NA	09/03/98	NA	09/03/98
14		9	6.05	359,447	06/16/96	379,046	06/18/96	NA	09/03/98	NA	09/03/98
15		8.7	5.42	389,497	06/20/96	420,307	06/22/96	NA	09/03/98	NA	09/03/98
16		12.2	4.75	237,012	05/14/96	254,878	05/21/96	3,720,800	11/17/97	NA	09/03/98
17		11	5.74	306,473	06/06/96	313,389	06/07/96	4,227,572	01/18/98	NA	09/03/98
18		4.3	6.04	932,825	09/14/96	2,985,674	08/02/97	NA	09/03/98	NA	09/03/98
19	fine plus	7.2	5.89	522,507	07/26/96	671,603	08/07/96	NA	09/03/98	NA	09/03/98
20		10.9	5.88	311,190	06/06/96	321,934	06/08/96	NA	09/03/98	NA	09/03/98
21		4.2	6.75	1,120,796	10/07/96	3,077,371	08/10/97	NA	09/03/98	NA	09/03/98
22		8.1	5.23	477,540	07/16/96	557,757	07/28/96	NA	09/03/98	NA	09/03/98
9		3.9	6.56	2,473,892	04/23/97	3,207,338	08/21/97	NA	09/03/98	NA	09/03/98
10		11.8	5.28	281,464	05/25/96	301,208	06/03/96	1,750,322	12/29/96	4,215,885	01/17/98
11		7.9	5.99	475,939	07/16/96	564,704	07/28/96	NA	09/03/98	NA	09/03/98
12		4.6	5.84	1,120,257	10/07/96	3,051,019	08/08/97	NA	09/03/98	NA	09/03/98
13		5.9	6.51	657,852	08/04/96	1,092,379	10/03/96	NA	09/03/98	NA	09/03/98
5	coarse	8.1	5.63	1,332,219	10/24/96	3,090,234	08/11/97	1,757,238	12/30/96	2,311,472	04/08/97
6		10.8	5.71	639,137	08/03/96	994,875	09/22/96	1,668,205	12/16/96	1,794,207	02/19/97
7		6.9	6.49	3,096,162	08/11/97	NA	09/03/98	NA	09/03/98	NA	09/03/98
8		8.5	5.47	1,032,261	09/26/96	2,954,219	07/31/97	1,515,380	12/01/96	1,789,150	01/01/97
23		4.9	5.79	NA	03/09/98	NA	09/03/98	NA	09/03/98	NA	09/03/98
24		7.2	5.94	2,897,595	07/26/97	4,538,003	04/06/98	NA	09/03/98	NA	09/03/98
25		3.7	6.55	NA	09/03/98	NA	09/03/98	NA	09/03/98	NA	09/03/98
26		11	5.31	594,392	07/30/96	829,604	09/02/96	1,487,207	11/29/96	1,626,490	12/10/96

Table 4.4 Construction variations in mix and structural characteristics.

Property	Measure of variance	Value or range, WesTrack	Suggested value*
Asphalt content	standard deviation	0.1-0.4%	0.19%
Air-void content	standard deviation	0.4-1.5%	1.2%
Thickness, AC	standard deviation	0-5 mm	$0.173(t_{AC})^{0.69}$ **

* Reflects materials/construction part of standard deviation (1 in. = 25.4 mm)

** Although there was no range in thicknesses for WesTrack, this value is recommended for thickness of AC used in the project under consideration

Table 5.1 Construction targets.

	Mean	Total standard deviation (including sampling and testing)	Percent of variance attributed to materials and construction
Asphalt content (%)	5.0	0.3	40
Air-void content (%)	7.0	1.5	60
Mineral filler (%)	5.5	0.9	75
Fine aggregate (%)	30.0	3.0	85
Asphalt-concrete thickness (in.)	4 pavement structures	$0.15 \times \text{AC thickness}^{0.69}$	75

Table 5.2 Levels and ranges for variables evaluated.

Variable	Mean		As-constructed standard deviation	
	Levels	Range	Levels	Range
Asphalt content	21	4.0 to 6.0	9	0.114 to 0.266
Air-void content	21	5.00 to 9.75	9	0.684 to 1.596
Mineral filler	21	3.0 to 8.0	9	0.4674 to 1.0906
Fine aggregate	21	24.0 to 36.0	9	1.6596 to 3.8724
Thickness	21 for each of 4 pavement sections	-1.0 to 1.0	9	4.8% to 11.2%

Table 5.3 Pavement structures.

Designation	Layer	Target Thickness (in.)	Modulus (psi)	Poisson's Ratio	Target Standard Deviation
7AB20	Surface Base Subbase Subgrade	3.6 7.2 6.0 -	Variable 30,000 20,000 12,200	0.40 0.45 0.45 0.50	0.314
9AB20	Surface Base Subbase Subgrade	6.6 6.6 7.8 -	Variable 30,000 20,000 12,200	0.40 0.45 0.45 0.50	0.476
11AB20	Surface Base Subbase Subgrade	9.6 6.0 8.4 -	Variable 25,000 20,000 12,200	0.40 0.45 0.45 0.50	0.620
13AB20	Surface Base Subbase Subgrade	10.2 7.8 12.6 -	Variable 25,000 20,000 12,200	0.40 0.45 0.45 0.50	0.640

(1 in. = 25.4 mm)
(1 psi = 6.9 kPa)

Table 5.4 Effect of off-target asphalt content on future agency resurfacing cost based on rutting in WesTrack pavements (change expressed as a percent of new pavement construction cost).

As-constructed average asphalt content (%)	As-constructed standard deviation of asphalt content (multiple of 0.19%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
4.0	-13.9	-13.9	-13.8	-13.8	-13.7	-13.6	-13.5	-13.4	-13.3
4.1	-13.4	-13.4	-13.3	-13.2	-13.1	-13.0	-12.9	-12.8	-12.6
4.2	-12.8	-12.7	-12.6	-12.5	-12.4	-12.2	-12.1	-11.9	-11.7
4.3	-12.0	-11.9	-11.8	-11.6	-11.5	-11.3	-11.2	-10.9	-10.8
4.4	-11.1	-11.0	-10.8	-10.7	-10.5	-10.3	-10.0	-9.8	-9.5
4.5	-10.0	-9.9	-9.6	-9.5	-9.2	-9.0	-8.7	-8.5	-8.1
4.6	-8.7	-8.5	-8.3	-8.1	-7.8	-7.5	-7.2	-6.9	-6.5
4.7	-7.2	-7.0	-6.7	-6.5	-6.2	-5.8	-5.5	-5.0	-4.7
4.8	-5.5	-5.3	-4.9	-4.7	-4.3	-3.9	-3.5	-3.1	-2.6
4.9	-3.7	-3.3	-3.0	-2.6	-2.2	-1.8	-1.3	-0.9	-0.4
5.0	-1.6	-1.2	-0.9	-0.4	0.0	0.5	0.9	1.5	2.0
5.1	0.7	1.0	1.5	1.9	2.3	2.8	3.4	3.9	4.4
5.2	3.0	3.3	3.8	4.2	4.8	5.2	5.8	6.2	6.8
5.3	5.3	5.7	6.1	6.6	7.1	7.6	8.1	8.5	9.0
5.4	7.6	8.0	8.5	8.9	9.3	9.8	10.2	10.7	11.1
5.5	9.8	10.2	10.6	10.9	11.4	11.8	12.2	12.6	13.1
5.6	11.8	12.1	12.5	12.9	13.2	13.6	14.0	14.3	14.7
5.7	13.5	13.9	14.2	14.5	14.8	15.2	15.4	15.8	16.0
5.8	15.1	15.3	15.7	15.9	16.2	16.4	16.7	16.9	17.2
5.9	16.4	16.6	16.8	17.1	17.3	17.5	17.7	17.9	18.1
6.0	17.4	17.6	17.8	18.0	18.2	18.3	18.5	18.6	18.7

Table 5.5 Effect of off-target air-void content on future agency resurfacing cost based on rutting in WesTrack pavement (change expressed as a percent of new pavement construction cost).

As-constructed air-void content (%)	As-constructed standard deviation of air-void content (multiple of 1.2%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
5.00	-5.1	-5.0	-4.9	-4.8	-4.6	-4.3	-4.3	-4.0	-3.8
5.25	-4.5	-4.4	-4.2	-4.2	-3.9	-3.9	-3.6	-3.5	-3.2
5.50	-3.9	-3.8	-3.7	-3.5	-3.4	-3.2	-3.1	-3.0	-2.7
5.7	-3.4	-3.2	-3.1	-2.9	-2.8	-2.6	-2.6	-2.4	-2.1
6.00	-2.7	-2.7	-2.5	-2.4	-2.2	-2.2	-2.0	-1.9	-1.7
6.25	-2.2	-2.1	-2.0	-1.9	-1.7	-1.6	-1.4	-1.4	-1.2
6.4	-1.6	-1.5	-1.5	-1.3	-1.3	-1.1	-1.0	-0.9	-0.7
6.7	-1.1	-1.0	-0.9	-0.9	-0.8	-0.6	-0.6	-0.5	-0.3
6.9	-0.6	-0.5	-0.4	-0.4	-0.3	-0.3	0.0	0.0	0.1
7.1	-0.1	0.0	0.0	0.1	0.2	0.3	0.3	0.4	0.5
7.4	0.3	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.9
7.6	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.2	1.2
7.85	1.2	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.5
8.1	1.6	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9
8.3	2.0	2.0	2.0	2.0	2.1	2.1	2.1	2.2	2.1
8.6	2.3	2.3	2.4	2.4	2.4	2.4	2.5	2.5	2.4
8.8	2.6	2.7	2.6	2.7	2.7	2.7	2.7	2.7	2.7
9.0	2.9	2.9	2.9	2.9	2.9	3.0	2.9	3.0	2.9
9.3	3.2	3.1	3.2	3.1	3.2	3.1	3.2	3.1	3.1
9.5	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.3
9.75	3.6	3.6	3.6	3.7	3.5	3.6	3.5	3.6	3.5

Table 5.6 Effect of off-target mineral filler on future agency resurfacing cost based on rutting in WesTrack pavement (change expressed as a percent of new pavement construction cost).

As-constructed average mineral filler (%)	As-constructed standard deviation of mineral filler (multiple of 0.7794%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
3.00	6.9	7.0	7.0	7.2	7.3	7.4	7.5	7.7	7.8
3.25	6.2	6.3	6.4	6.5	6.6	6.7	6.9	7.0	7.1
3.50	5.5	5.5	5.7	5.8	6.0	6.0	6.2	6.3	6.5
3.75	4.7	4.9	5.0	5.1	5.2	5.4	5.5	5.7	5.8
4.00	4.1	4.1	4.2	4.4	4.4	4.6	4.8	5.0	5.0
4.25	3.4	3.4	3.6	3.6	3.8	3.9	4.0	4.2	4.4
4.50	2.6	2.7	2.8	2.9	3.0	3.1	3.3	3.4	3.6
4.75	1.9	2.0	2.0	2.2	2.3	2.5	2.5	2.8	2.8
5.00	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.1
5.25	0.4	0.4	0.6	0.7	0.8	0.9	1.1	1.2	1.4
5.50	-0.5	-0.3	-0.3	-0.1	0.0	0.2	0.3	0.5	0.6
5.75	-1.2	-1.1	-1.0	-0.8	-0.7	-0.6	-0.4	-0.2	-0.1
6.00	-1.9	-1.8	-1.7	-1.7	-1.4	-1.4	-1.2	-1.1	-0.8
6.25	-2.7	-2.5	-2.4	-2.3	-2.3	-2.1	-1.9	-1.8	-1.6
6.50	-3.4	-3.3	-3.2	-3.0	-3.0	-2.8	-2.7	-2.4	-2.4
6.75	-4.1	-4.0	-3.8	-3.8	-3.7	-3.5	-3.4	-3.3	-3.1
7.00	-4.8	-4.7	-4.6	-4.5	-4.4	-4.3	-4.1	-4.0	-3.8
7.25	-5.5	-5.3	-5.4	-5.2	-5.1	-4.9	-4.8	-4.7	-4.5
7.50	-6.1	-6.1	-6.0	-5.9	-5.8	-5.6	-5.5	-5.3	-5.2
7.75	-6.8	-6.7	-6.6	-6.6	-6.4	-6.3	-6.1	-6.1	-5.8
8.00	-7.4	-7.3	-7.3	-7.2	-7.1	-7.0	-6.8	-6.7	-6.6

Table 5.7 Effect of off-target fine aggregate on future agency resurfacing cost based on rutting in WesTrack pavement (change expressed as a percent of new pavement construction cost).

As-constructed average fine aggregate (%)	As-constructed standard deviation of fine aggregate (multiple of 2.7659%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
24.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
24.6	0.2	0.1	0.2	0.1	0.1	0.0	0.1	0.0	0.1
25.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.0	0.0
25.8	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0
26.4	0.3	0.2	0.3	0.2	0.2	0.1	0.1	0.1	0.1
27.0	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
27.6	0.2	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.0
28.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0
28.8	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1
29.4	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	-0.1
30.0	0.1	0.0	0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1
30.6	0.0	0.0	0.0	-0.1	0.0	-0.1	-0.1	-0.2	-0.1
31.2	-0.1	-0.1	-0.2	-0.1	-0.2	-0.1	-0.2	-0.2	-0.2
31.8	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	-0.2	-0.4
32.4	-0.3	-0.4	-0.3	-0.4	-0.3	-0.4	-0.3	-0.4	-0.4
33.0	-0.4	-0.4	-0.4	-0.5	-0.4	-0.5	-0.5	-0.5	-0.4
33.6	-0.6	-0.5	-0.6	-0.6	-0.6	-0.5	-0.7	-0.6	-0.7
34.2	-0.6	-0.7	-0.7	-0.7	-0.7	-0.7	-0.8	-0.7	-0.8
34.8	-0.8	-0.8	-0.8	-0.9	-0.8	-0.9	-0.8	-1.0	-0.8
35.4	-1.1	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.1	-1.1
36.0	-1.2	-1.2	-1.2	-1.2	-1.2	-1.1	-1.2	-1.1	-1.3

Table 5.8 Effect of off-target asphalt content on future agency rehabilitation cost based on Caltrans fatigue model (change expressed as a percent of new pavement construction cost).

As-constructed average asphalt content (%)	As-constructed standard deviation of asphalt content (multiple of 0.19%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
4.0	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.3
4.1	2.8	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
4.2	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
4.3	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
4.4	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0
4.5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
4.6	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
4.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
4.8	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
4.9	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.1	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
5.2	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
5.3	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
5.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4
5.5	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7
5.6	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.0
5.7	-2.5	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4
5.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.7	-2.7	-2.7	-2.7
5.9	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1
6.0	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5

Table 5.9 Effect of off-target air-void content on future agency rehabilitation cost based on Caltrans fatigue model (change expressed as a percent of new pavement construction cost).

As-constructed air-void content (%)	As-constructed standard deviation of air-void content (multiple of 1.2%)								
	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.6
5.00	-20.4	-19.9	-19.3	-18.7	-18.1	-17.4	-16.7	-15.9	-15.1
5.25	-18.7	-18.1	-17.5	-16.9	-16.2	-15.4	-14.7	-13.9	-13.0
5.50	-16.8	-16.2	-15.6	-14.9	-14.2	-13.4	-12.6	-11.8	-10.9
5.7	-14.9	-14.3	-13.6	-12.9	-12.1	-11.3	-10.5	-9.7	-8.8
6.00	-12.9	-12.2	-11.5	-10.8	-10.0	-9.2	-8.4	-7.5	-6.6
6.25	-10.8	-10.1	-9.4	-8.6	-7.9	-7.0	-6.2	-5.3	-4.3
6.4	-8.7	-8.0	-7.3	-6.5	-5.7	-4.8	-3.9	-3.0	-2.1
6.7	-6.6	-5.8	-5.1	-4.3	-3.4	-2.6	-1.7	-0.8	0.2
6.9	-4.4	-3.6	-2.8	-2.0	-1.2	-0.3	0.5	1.5	2.4
7.1	-2.2	-1.4	-0.6	0.2	1.0	1.9	2.8	3.7	4.6
7.4	0.1	0.8	1.6	2.4	3.2	4.1	5.0	5.9	6.8
7.6	2.3	3.0	3.8	4.6	5.4	6.3	7.2	8.0	9.0
7.85	4.5	5.3	6.0	6.8	7.6	8.4	9.3	10.2	11.1
8.1	6.7	7.4	8.2	8.9	9.7	10.5	11.4	12.2	13.1
8.3	8.8	9.6	10.3	11.0	11.8	12.6	13.4	14.2	15.1
8.6	10.9	11.6	12.4	13.1	13.8	14.6	15.3	16.1	16.9
8.8	13.0	13.7	14.3	15.0	15.7	16.5	17.2	17.9	18.7
9.0	15.0	15.6	16.3	16.9	17.6	18.3	19.0	19.7	20.4
9.3	16.9	17.5	18.1	18.7	19.3	20.0	20.6	21.3	21.9
9.5	18.7	19.2	19.8	20.4	21.0	21.5	22.1	22.7	23.3
9.75	20.4	20.9	21.4	21.9	22.5	23.0	23.5	24.1	24.6

Table 5.10 Effect of off-target asphalt-concrete thickness on future agency rehabilitation cost based on Caltrans fatigue model (change expressed as a percent of new pavement construction cost).

Difference between as-measured average AC thickness and design thickness (in.)	As-constructed standard deviation of AC thickness (multiple of 8%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-1.0	17.7	18.5	19.2	19.9	20.7	21.4	22.3	23.0	23.8
-0.9	15.9	16.7	17.4	18.2	19.0	19.8	20.6	21.4	22.3
-0.8	14.0	14.8	15.6	16.4	17.2	18.1	18.9	19.8	20.7
-0.7	12.0	12.8	13.6	14.5	15.3	16.2	17.1	18.0	18.9
-0.6	9.9	10.8	11.6	12.5	13.3	14.2	15.1	16.1	17.1
-0.5	7.8	8.6	9.5	10.4	11.3	12.2	13.1	14.1	15.1
-0.4	5.6	6.4	7.3	8.2	9.1	10.1	11.0	12.0	13.1
-0.3	3.3	4.2	5.0	5.9	6.9	7.9	8.9	9.9	11.0
-0.2	1.0	1.9	2.7	3.7	4.6	5.6	6.6	7.6	8.8
-0.1	-1.3	-0.5	0.5	1.4	2.3	3.3	4.3	5.3	6.4
0.0	-3.5	-2.7	-1.9	-1.0	0.0	1.0	2.0	3.0	4.1
0.1	-5.8	-5.0	-4.1	-3.2	-2.3	-1.4	-0.3	0.7	1.8
0.2	-7.9	-7.1	-6.3	-5.5	-4.6	-3.6	-2.7	-1.6	-0.6
0.3	-10.1	-9.3	-8.5	-7.7	-6.8	-5.9	-5.0	-4.0	-2.9
0.4	-12.1	-11.3	-10.6	-9.8	-8.9	-8.1	-7.1	-6.2	-5.2
0.5	-14.1	-13.3	-12.6	-11.8	-11.0	-10.2	-9.3	-8.4	-7.4
0.6	-16.0	-15.3	-14.6	-13.8	-13.0	-12.2	-11.4	-10.5	-9.5
0.7	-17.9	-17.2	-16.5	-15.8	-15.0	-14.2	-13.4	-12.5	-11.6
0.8	-20.0	-19.3	-18.5	-17.7	-17.0	-16.2	-15.4	-14.5	-13.7
0.9	-22.3	-21.4	-20.6	-19.8	-19.0	-18.2	-17.3	-16.5	-15.6
1.0	-24.8	-23.9	-22.9	-22.0	-21.2	-20.3	-19.4	-18.6	-17.7

(1 in. = 25.4 mm)

Table 5.11 Effect of off-target asphalt content on future agency resurfacing/rehabilitation costs (change expressed as a percent of new pavement construction cost).

As-constructed average asphalt content (%)	As-constructed standard deviation of asphalt content (multiple of 0.19%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
4.0	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.3
4.1	2.8	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
4.2	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
4.3	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
4.4	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0
4.5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
4.6	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
4.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
4.8	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
4.9	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
5.0	0.0	0.0	0.0	0.0	0.0	0.5	0.9	1.5	2.0
5.1	0.7	1.0	1.5	1.9	2.3	2.8	3.4	3.9	4.4
5.2	3.0	3.3	3.8	4.2	4.8	5.2	5.8	6.2	6.8
5.3	5.3	5.7	6.1	6.6	7.1	7.6	8.1	8.5	9.0
5.4	7.6	8.0	8.5	8.9	9.3	9.8	10.2	10.7	11.1
5.5	9.8	10.2	10.6	10.9	11.4	11.8	12.2	12.6	13.1
5.6	11.8	12.1	12.5	12.9	13.2	13.6	14.0	14.3	14.7
5.7	13.5	13.9	14.2	14.5	14.8	15.2	15.4	15.8	16.0
5.8	15.1	15.3	15.7	15.9	16.2	16.4	16.7	16.9	17.2
5.9	16.4	16.6	16.8	17.1	17.3	17.5	17.7	17.9	18.1
6.0	17.4	17.6	17.8	18.0	18.2	18.3	18.5	18.6	18.7

Table 5.12 Effect of off-target air-void content on future agency resurfacing/rehabilitation costs (change expressed as a percent of new pavement construction cost).

As-constructed air-void content (%)	As-constructed standard deviation of air-void content (multiple of 1.2%)								
	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.6
5.0	-5.1	-5.0	-4.9	-4.8	-4.6	-4.3	-4.3	-4.0	-3.8
5.25	-4.5	-4.4	-4.2	-4.2	-3.9	-3.9	-3.6	-3.5	-3.2
5.5	-3.9	-3.8	-3.7	-3.5	-3.4	-3.2	-3.1	-3.0	-2.7
5.7	-3.4	-3.2	-3.1	-2.9	-2.8	-2.6	-2.6	-2.4	-2.1
6.0	-2.7	-2.7	-2.5	-2.4	-2.2	-2.2	-2.0	-1.9	-1.7
6.25	-2.2	-2.1	-2.0	-1.9	-1.7	-1.6	-1.4	-1.4	-1.2
6.4	-1.6	-1.5	-1.5	-1.3	-1.3	-1.1	-1.0	-0.9	-0.7
6.7	-1.1	-1.0	-0.9	-0.9	-0.8	-0.6	-0.6	-0.5	0.2
6.9	-0.6	-0.5	-0.4	-0.4	-0.3	-0.3	0.5	1.5	2.4
7.1	-0.1	0.0	0.0	0.2	1.0	1.9	2.8	3.7	4.6
7.4	0.3	0.8	1.6	2.4	3.2	4.1	5.0	5.9	6.8
7.6	2.3	3.0	3.8	4.6	5.4	6.3	7.2	8.0	9.0
7.85	4.5	5.3	6.0	6.8	7.6	8.4	9.3	10.2	11.1
8.1	6.7	7.4	8.2	8.9	9.7	10.5	11.4	12.2	13.1
8.3	8.8	9.6	10.3	11.0	11.8	12.6	13.4	14.2	15.1
8.6	10.9	11.6	12.4	13.1	13.8	14.6	15.3	16.1	16.9
8.8	13.0	13.7	14.3	15.0	15.7	16.5	17.2	17.9	18.7
9.0	15.0	15.6	16.3	16.9	17.6	18.3	19.0	19.7	20.4
9.3	16.9	17.5	18.1	18.7	19.3	20.0	20.6	21.3	21.9
9.5	18.7	19.2	19.8	20.4	21.0	21.5	22.1	22.7	23.3
9.75	20.4	20.9	21.4	21.9	22.5	23.0	23.5	24.1	24.6

Table 5.13 Effect of off-target mineral filler on future agency resurfacing/rehabilitation costs (change expressed as a percent of new pavement construction cost).

As-constructed average mineral filler (%)	As-constructed standard deviation of mineral filler (multiple of 0.7794%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
3.00	6.9	7.0	7.0	7.2	7.3	7.4	7.5	7.7	7.8
3.25	6.2	6.3	6.4	6.5	6.6	6.7	6.9	7.0	7.1
3.50	5.5	5.5	5.7	5.8	6.0	6.0	6.2	6.3	6.5
3.75	4.7	4.9	5.0	5.1	5.2	5.4	5.5	5.7	5.8
4.00	4.1	4.1	4.2	4.4	4.4	4.6	4.8	5.0	5.0
4.25	3.4	3.4	3.6	3.6	3.8	3.9	4.0	4.2	4.4
4.50	2.6	2.7	2.8	2.9	3.0	3.1	3.3	3.4	3.6
4.75	1.9	2.0	2.0	2.2	2.3	2.5	2.5	2.8	2.8
5.00	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.1
5.25	0.4	0.4	0.6	0.7	0.8	0.9	1.1	1.2	1.4
5.50	-0.5	-0.3	-0.3	-0.1	0.0	0.2	0.3	0.5	0.6
5.75	-1.2	-1.1	-1.0	-0.8	-0.7	-0.6	-0.4	-0.2	-0.1
6.00	-1.9	-1.8	-1.7	-1.7	-1.4	-1.4	-1.2	-1.1	-0.8
6.25	-2.7	-2.5	-2.4	-2.3	-2.3	-2.1	-1.9	-1.8	-1.6
6.50	-3.4	-3.3	-3.2	-3.0	-3.0	-2.8	-2.7	-2.4	-2.4
6.75	-4.1	-4.0	-3.8	-3.8	-3.7	-3.5	-3.4	-3.3	-3.1
7.00	-4.8	-4.7	-4.6	-4.5	-4.4	-4.3	-4.1	-4.0	-3.8
7.25	-5.5	-5.3	-5.4	-5.2	-5.1	-4.9	-4.8	-4.7	-4.5
7.50	-6.1	-6.1	-6.0	-5.9	-5.8	-5.6	-5.5	-5.3	-5.2
7.75	-6.8	-6.7	-6.6	-6.6	-6.4	-6.3	-6.1	-6.1	-5.8
8.00	-7.4	-7.3	-7.3	-7.2	-7.1	-7.0	-6.8	-6.7	-6.6

Table 5.14 Effect of off-target fine aggregate on future agency resurfacing/rehabilitation costs (change expressed as a percent of new pavement construction cost).

As-constructed average fine aggregate (%)	As-constructed standard deviation of fine aggregate (multiple of 2.7659%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
24.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
24.6	0.2	0.1	0.2	0.1	0.1	0.0	0.1	0.0	0.1
25.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.0	0.0
25.8	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0
26.4	0.3	0.2	0.3	0.2	0.2	0.1	0.1	0.1	0.1
27.0	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
27.6	0.2	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.0
28.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0
28.8	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1
29.4	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	-0.1
30.0	0.1	0.0	0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1
30.6	0.0	0.0	0.0	-0.1	0.0	-0.1	-0.1	-0.2	-0.1
31.2	-0.1	-0.1	-0.2	-0.1	-0.2	-0.1	-0.2	-0.2	-0.2
31.8	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	-0.2	-0.4
32.4	-0.3	-0.4	-0.3	-0.4	-0.3	-0.4	-0.3	-0.4	-0.4
33.0	-0.4	-0.4	-0.4	-0.5	-0.4	-0.5	-0.5	-0.5	-0.4
33.6	-0.6	-0.5	-0.6	-0.6	-0.6	-0.5	-0.7	-0.6	-0.7
34.2	-0.6	-0.7	-0.7	-0.7	-0.7	-0.7	-0.8	-0.7	-0.8
34.8	-0.8	-0.8	-0.8	-0.9	-0.8	-0.9	-0.8	-1.0	-0.8
35.4	-1.1	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.1	-1.1
36.0	-1.2	-1.2	-1.2	-1.2	-1.2	-1.1	-1.2	-1.1	-1.3

Table 5.15 Effect of off-target asphalt concrete thickness on future agency resurfacing/rehabilitation costs (change expressed as a percent of new pavement construction cost).

Difference between as-measured average AC thickness and design thickness (in.)	As-constructed standard deviation of AC thickness (multiple of 8%)								
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-1.0	17.7	18.5	19.2	19.9	20.7	21.4	22.3	23.0	23.8
-0.9	15.9	16.7	17.4	18.2	19.0	19.8	20.6	21.4	22.3
-0.8	14.0	14.8	15.6	16.4	17.2	18.1	18.9	19.8	20.7
-0.7	12.0	12.8	13.6	14.5	15.3	16.2	17.1	18.0	18.9
-0.6	9.9	10.8	11.6	12.5	13.3	14.2	15.1	16.1	17.1
-0.5	7.8	8.6	9.5	10.4	11.3	12.2	13.1	14.1	15.1
-0.4	5.6	6.4	7.3	8.2	9.1	10.1	11.0	12.0	13.1
-0.3	3.3	4.2	5.0	5.9	6.9	7.9	8.9	9.9	11.0
-0.2	1.0	1.9	2.7	3.7	4.6	5.6	6.6	7.6	8.8
-0.1	-1.3	-0.5	0.5	1.4	2.3	3.3	4.3	5.3	6.4
0.0	-3.5	-2.7	-1.9	-1.0	0.0	1.0	2.0	3.0	4.1
0.1	-5.8	-5.0	-4.1	-3.2	-2.3	-1.4	-0.3	0.7	1.8
0.2	-7.9	-7.1	-6.3	-5.5	-4.6	-3.6	-2.7	-1.6	-0.6
0.3	-10.1	-9.3	-8.5	-7.7	-6.8	-5.9	-5.0	-4.0	-2.9
0.4	-12.1	-11.3	-10.6	-9.8	-8.9	-8.1	-7.1	-6.2	-5.2
0.5	-14.1	-13.3	-12.6	-11.8	-11.0	-10.2	-9.3	-8.4	-7.4
0.6	-16.0	-15.3	-14.6	-13.8	-13.0	-12.2	-11.4	-10.5	-9.5
0.7	-17.9	-17.2	-16.5	-15.8	-15.0	-14.2	-13.4	-12.5	-11.6
0.8	-20.0	-19.3	-18.5	-17.7	-17.0	-16.2	-15.4	-14.5	-13.7
0.9	-22.3	-21.4	-20.6	-19.8	-19.0	-18.2	-17.3	-16.5	-15.6
1.0	-24.8	-23.9	-22.9	-22.0	-21.2	-20.3	-19.4	-18.6	-17.7

(1 in. = 25.4 mm)

Table 5.16 Contractor pay factors for asphalt content (percentage of future resurfacing/rehabilitation cost in current-year dollars).

Difference between as-measured average asphalt content and design asphalt content (%)	As-measured standard deviation of asphalt content (%)		
	Below 0.255	0.255 to 0.345	Above 0.345
-1.10 to -0.91	-3	-3	-3
-0.90 to -0.71	-3	-3	-3
-0.70 to -0.51	-2	-2	-2
-0.50 to -0.31	-1	-1	-1
-0.30 to -0.11	-1	-1	-1
-0.10 to 0.09	0	0	-1
0.10 to 0.29	-3	-5	-6
0.30 to 0.49	-8	-9	-11
0.50 to 0.69	-12	-13	-14
0.70 to 0.89	-15	-16	-17
0.90 to 1.09	-18	-18	-19

Table 5.17 Contractor pay factors for air-void content (percentage of future resurfacing/rehabilitation cost in current-year dollars).

As-measured average air-void content (%)	As-measured standard deviation of air-void content (%)		
	Below 1.32	1.32 to 1.78	Above 1.78
4.8-5.1	5	5	4
5.15-5.7	4	3	3
5.75-6.20	3	2	2
6.25-6.65	2	1	1
6.70-7.05	1	0	-1
7.1-7.55	-1	-3	-6
7.6-8.05	-5	-8	-10
8.1-8.55	-10	-12	-14
8.6-8.95	-14	-16	-18
9.0-9.45	-17	-19	-21
9.5-10.0	-21	-22	-24

Table 5.18 Contractor pay factors for asphalt-concrete thickness (percentage of future resurfacing/rehabilitation cost in current-year dollars).

Difference between as-measured average AC thickness and design thickness (in.)	As-measured standard deviation of AC thickness (%)		
	Below 7.85	7.85 to 10.62	Above 10.62
-1.10 to -0.91	-18	-21	-23
-0.90 to -0.71	-15	-17	-20
-0.70 to -0.51	-11	-13	-16
-0.50 to -0.31	-6	-9	-12
-0.30 to -0.11	-2	-5	-8
-0.10 to 0.09	3	0	-3
0.10 to 0.29	7	5	2
0.30 to 0.49	11	9	6
0.50 to 0.69	15	13	10
0.70 to 0.89	19	17	15
0.90 to 1.09	24	21	19

(1 in. = 25.4 mm)

Table 5.19 Contractor pay factors for mineral filler (percentage of future resurfacing/rehabilitation cost in current-year dollars).

Difference between as-measured average mineral filler and design mineral filler (%)	As-measured standard deviation of mineral filler (%)		
	Below 0.765	0.765 to 1.035	Above 1.035
-2.75 to -2.26	-7	-7	-8
-2.25 to -1.76	-6	-6	-6
-1.75 to - 1.26	-4	-4	-5
-1.25 to -0.76	-3	-3	-3
-0.75 to -0.26	-1	-2	-2
-0.25 to 0.24	0	0	0
0.25 to 0.74	2	1	1
0.75 to 1.24	3	3	3
1.25 to 1.74	5	4	4
1.75 to 2.24	6	6	5
2.25 to 2.74	7	7	7

Table 5.20 Contractor pay factors for fine aggregate (percentage of future resurfacing/rehabilitation cost in current-year dollars).

Difference between as-measured average fine aggregate and design fine aggregate (%)	As-measured standard deviation of fine aggregate (%)		
	Below 2.55	2.55 to 3.45	Above 3.45
-6.6 to -5.5	0	0	0
-5.4 to -4.3	0	0	0
-4.2 to -3.1	0	0	0
-3.0 to -1.9	0	0	0
-1.8 to -0.7	0	0	0
-0.6 to 0.5	0	0	0
0.6 to 1.7	0	0	0
1.8 to 2.9	0	0	0
3.0 to 4.1	1	1	1
4.2 to 5.3	1	1	1
5.4 to 6.5	1	1	1

Table 6.1 Selected temperature simulation parameters.[28]

Layer	Property	Calibrated Value
Asphalt Mixture	Thermal Conductivity	0.8 Btu/hr-ft-°F (unfrozen, frozen, freezing)
	Heat Capacity	0.22 Btu/lb-°F (unfrozen and freezing)
	Unit Weight	145 pcf
	Water Content	2%
Subgrade	Dry Density	120 pcf
	Dry Heat Capacity	0.29 Btu/lb-°F
Other	Maximum Allowable Convection Coefficient	3 Btu/hr-ft^2-°F
	Emissivity Factor	0.85
	Absorptivity Factor	0.90
	Geiger Radiation Factor A	0.77
	Geiger Radiation Factor B	0.28
	Vapor Pressure	5 mm mercury
	Cloud Base Factor for Back Radiation	0.85

(1 Btu = 1,055 J)
(1 ft = 305 mm)
(°F = 1.8 °C + 32)
(1 pcf = 16 kg/m^3)
(1 lb = 0.454 kg)
(1 in. = 25.4 mm)

[28] The computer program was utilized with American standard units for the information reported in Chapter 4. In addition, the available temperature data files used for the temperature simulations were expressed in American standard units. Hence only these units are reported

Table 6.2 Procedures for establishing HMA stiffnesses and Poisson's ratios.

Material	Procedure	Remarks
HMA containing conventional asphalts	Direct Measurement	
	(1) Flexure on beam specimens at 20°C and representative times of loading (AASHTO TP8-94)	Preferred method; Can be extended to other temperatures using Shell (*10*) or Witczak (*16*) procedures. Shear stiffness* at higher temperatures (40-60°C) can provide a control point as well.
	(2) Axial compression on beam specimens (ASTM D3497)	Use if flexure test not available; extension to wider range in temperatures using Shell or Witczak procedures.
	(3) Diametral loading at 20°C (ASTM D4123)	Least desirable of three methods.
	Estimation	
	(1) Shell method (*10*); requires estimates of asphalt stiffness and volumetric properties of the mix.	See Appendix J.
	(2) Witczak method (*16*); requires estimates of asphalt and mix characteristics.	See Appendix J.
HMA containing modified binders	Direct Measurement	
	(1) Flexure on beam specimens 5°C to 30°C and representative times of loading.	Use of shear stiffness in range of 40°C to 60°C can be used to extend stiffness vs. temperature relationship.

*Shear stiffness can be used to extend temperature range (Chapter 2). (°F = 1.8 °C + 32)

Table 6.3 Calibration of strain models from RSST-CH testing.

Section	Specimen	Elastic shear strain	Regression coefficients		G*, psi	Simulated RSST repetitions to shear strain		
			a	b		1.00%	2.00%	5.00%
4	B2T	0.0008047	0.0007506	0.4017904	12,427	629	3,533	34,559
4	B4T	0.0012562	0.0007542	0.3908173	7,961	745	4,390	45,778
Average		**0.0009810**	**0.0007544**	**0.3956147**	**10,194**	**687**	**3,961**	**40,169**
5	B1T	0.0011777	0.0016413	0.3717509	8,491	129	833	9,802
5	B2T	0.0013740	0.0038732	0.2785549	7,278	30	363	9,729
Average		**0.0012683**	**0.0023109**	**0.3346613**	**7,885**	**80**	**598**	**9,766**
7	B1T	0.0013740	0.0023674	0.3886646	7,278	41	242	2,561
7	B2LR	0.0014721	0.0029055	0.3499988	6,793	34	248	3,394
7	B2T	0.0021722	0.0028282	0.3900961	4,604	25	151	1,577
7	B3RR	0.0011711	0.0056172	0.3702744	8,539	5	31	367
Average		**0.0014699**	**0.0029581**	**0.3726179**	**6,803**	**26**	**168**	**1,975**
9	B1T	0.0014067	0.0010746	0.4940017	7,109	91	372	2,377
9	B2LR	0.0013936	0.0043256	0.3302257	7,176	13	103	1,655
9	B2T	0.0017076	0.0010074	0.4861040	5,856	112	468	3,080
9	B4RR	0.0017992	0.0051443	0.3982810	5,558	5	30	302
Average		**0.0015565**	**0.0015861**	**0.4585926**	**6,425**	**55**	**243**	**1,853**
12	B1T	0.0010076	0.0012050	0.3339262	9,924	565	4,504	70,038
12	B2T	0.0011189	0.0018744	0.3406894	8,937	136	1,042	15,344
Average		**0.0010603**	**0.0014029**	**0.3351698**	**9,431**	**351**	**2,773**	**42,691**
13	B1T	0.0016946	0.0025780	0.4920132	5,901	16	64	414
13	B2LR	0.0011908	0.0019506	0.4521205	8,398	37	172	1,306
13	B3T	0.0014590	0.0013884	0.5702849	6,854	32	108	536
13	B4RR	0.0016291	0.0048119	0.3413204	6,138	9	65	952
Average		**0.0014657**	**0.0023865**	**0.4549278**	**6,823**	**23**	**102**	**802**
15	B1T	0.0015440	0.0006285	0.5085267	6,477	231	902	5,465
15	B2T	0.0014328	0.0007239	0.4816192	6,979	233	983	6,591
Average		**0.0014863**	**0.0006783**	**0.4940439**	**6,728**	**232**	**943**	**6,028**
19	B1T	0.0021525	0.0008531	0.5750742	4,646	72	241	1,187
19	B2T	0.0017666	0.0004615	0.6509954	5,661	113	327	1,336
Average		**0.0019406**	**0.0006150**	**0.6160045**	**5,153**	**92**	**284**	**1,261**
21	B1T	0.0020806	0.0011602	0.4860376	4,806	84	350	2,306
21	B2LR	0.0015245	0.0017208	0.4211284	6,560	65	339	2,982
21	B2T	0.0012955	0.0020773	0.4573437	7,719	31	141	1,049
21	B4RR	0.0014656	0.0035702	0.3532099	6,823	18	131	1,759
Average		**0.0015439**	**0.0018335**	**0.4342420**	**6,477**	**50**	**240**	**2,024**
22	B1T	0.0011711	0.0006404	0.5449074	8,539	155	553	2,972
22	B2T	0.0012890	0.0007456	0.5425766	7,758	120	429	2,324
Average		**0.0012272**	**0.0006875**	**0.5438858**	**8,148**	**137**	**491**	**2,648**
23	B1T	0.0012889	0.0006269	0.3986488	7,759	1,040	5,920	58,958
23	B2T	0.0010665	0.0040230	0.2267650	9,377	55	1,179	67,024
Average		**0.0011672**	**0.0011776**	**0.3392132**	**8,568**	**548**	**3,549**	**62,991**
25	B1T	0.0021002	0.0062642	0.2209037	4,761	8	192	12,126
25	B2LR	0.0018973	0.0031627	0.2533791	5,271	94	1,449	53,913
25	B2T	0.0014721	0.0040545	0.2742445	6,793	27	337	9,513
25	B4RR	0.0017731	0.0093922	0.2829962	5,640	1	14	368
Average		**0.0017805**	**0.0041441**	**0.2527979**	**5,616**	**33**	**498**	**18,980**

(1 psi = 6.9 kPa)

Table 6.4 Summary of the overall data used for the surrogate fatigue model, Equation 6.6.

Number of Asphalts	12
Number of Aggregates	5
Asphalt Content	8 – 4.5 to 6.2 percent by weight of aggregate, depending on the type of aggregate used
Air-Void Levels	Variable – 2 to 9 percent
Voids Filled with Asphalt	Variable – 54 to 90 percent
Strain Levels	Variable – 200 to 1200 micro-in./in.
Temperature	4 – 5, 10, 20, and 25 °C
Frequency	1 – 10 Hz (sinusoidal)
Specimen Size	2.0 in. height, 2.5 in. width, 15.0 in. length
Total Number of Mixes	44
Total Number of Specimens	196
Range of Fatigue Life	1000 to 5,400,000 cycles
Range of Loss of Stiffness	120,000 to 650,000 psi

(°F = 1.8 °C + 32)
(1 in. = 25.4 mm)
(1 psi = 6.9 kPa)

10.0 FIGURES

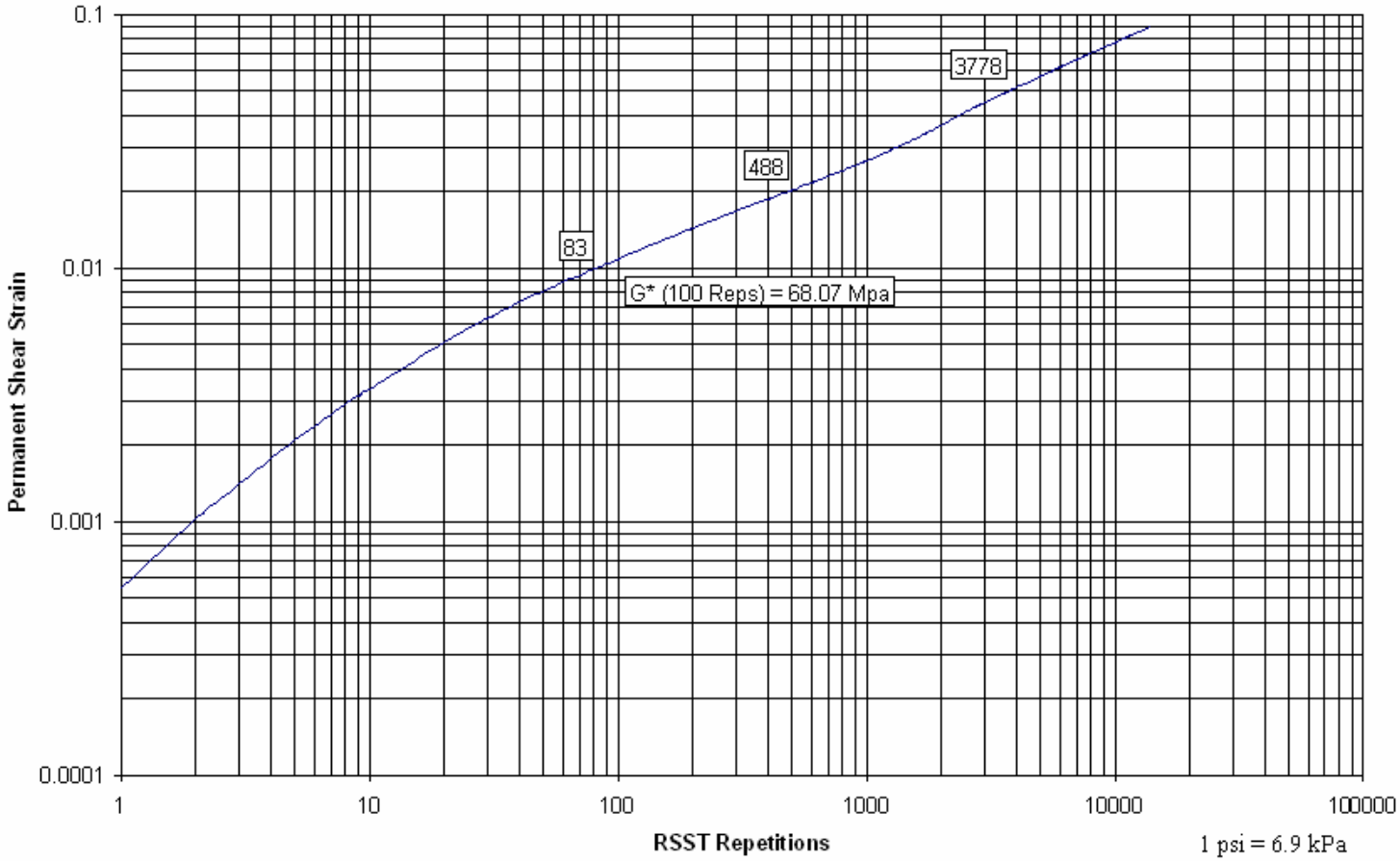


Figure 1.1. Shear strain, γ_p, versus load repetitions, N.

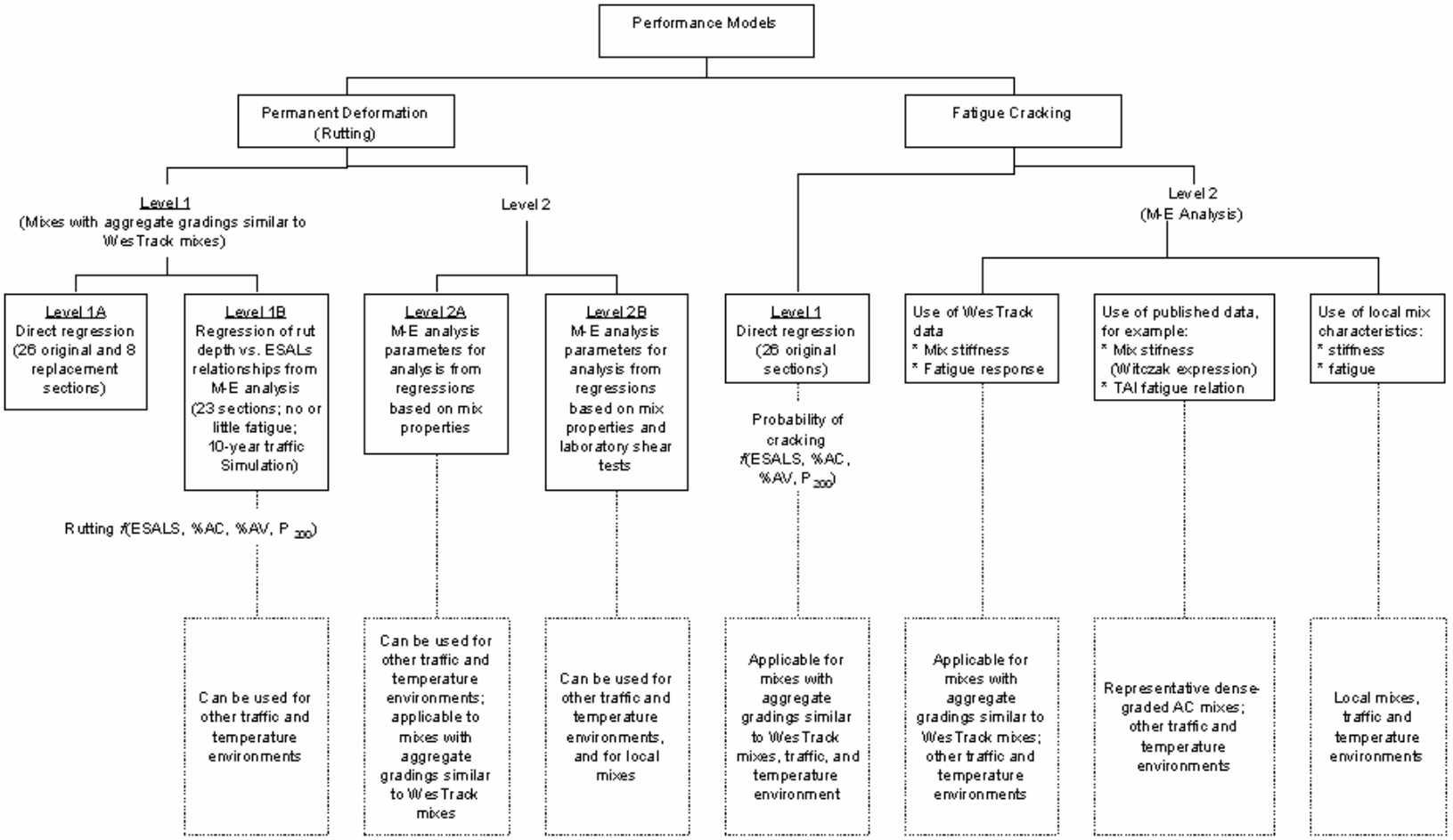


Figure 1.2. Performance model framework

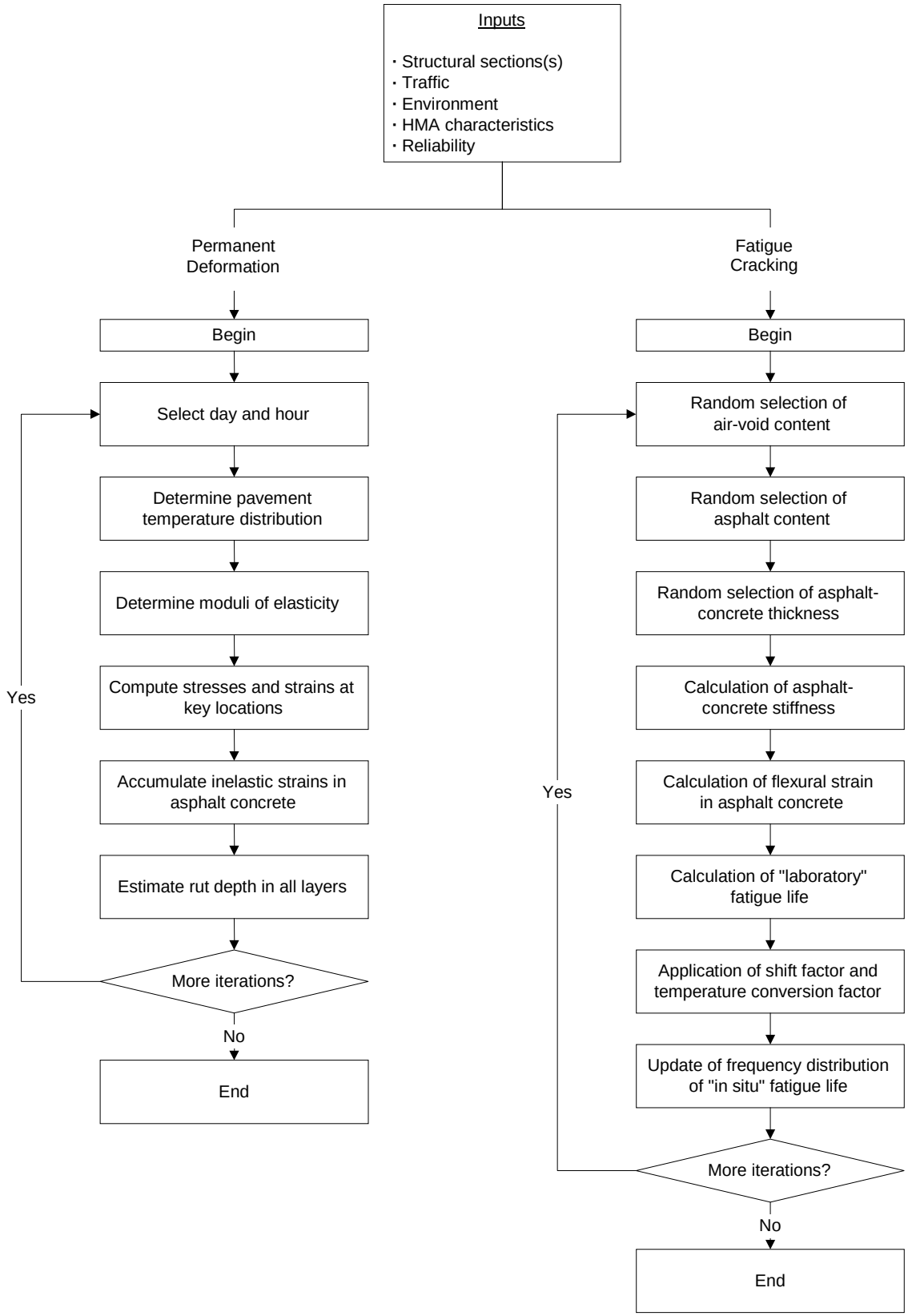


Figure 1.3. Framework for development of performance models for permanent deformation and fatigue.

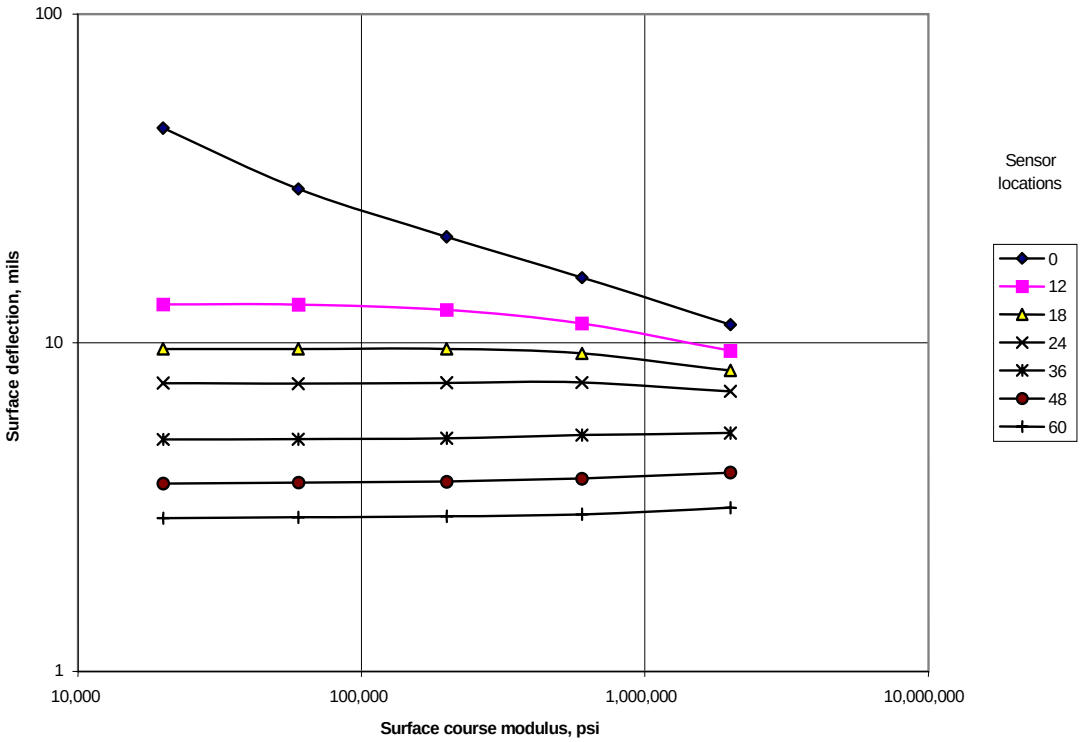


Figure 2.1. Illustration of effect of surface course modulus on surface deflection; E_2 = 30,000 psi, E_3 = 15,000 psi (1 in. = 25.4 mm, 1 psi = 6.9 kPa).

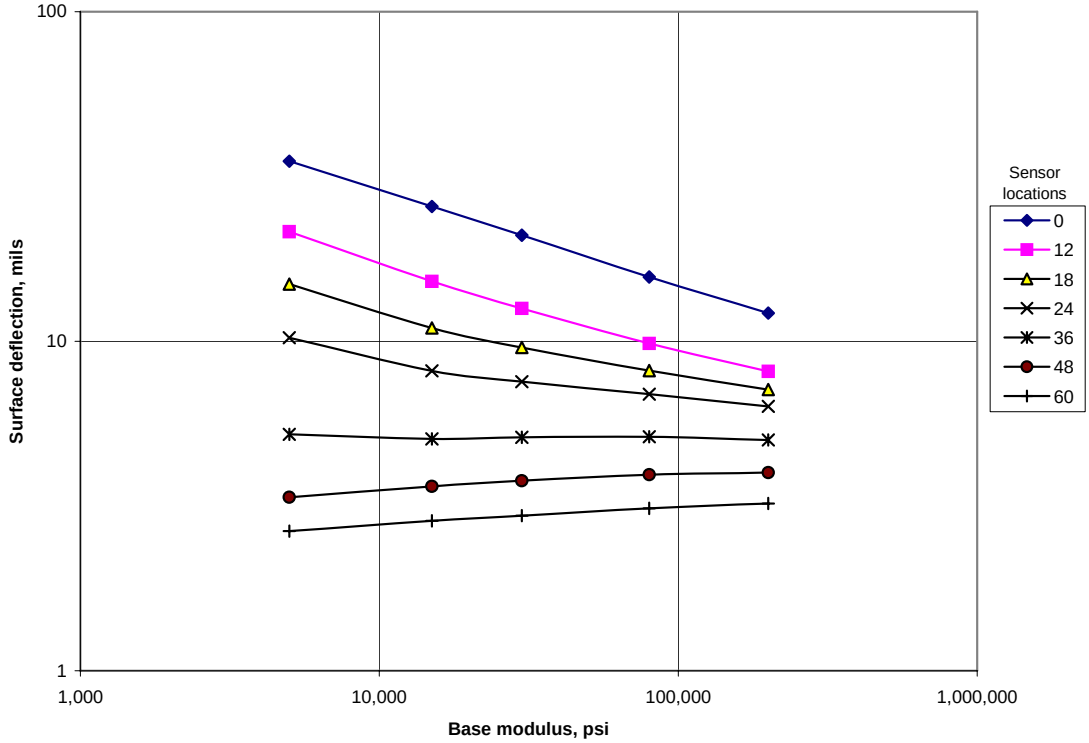


Figure 2.2. Illustration of effect of base course modulus on surface deflection; E_1 = 200,000 psi, E_3 = 15,000 psi (1 in. = 25.4 mm, 1 psi = 6.9 kPa).

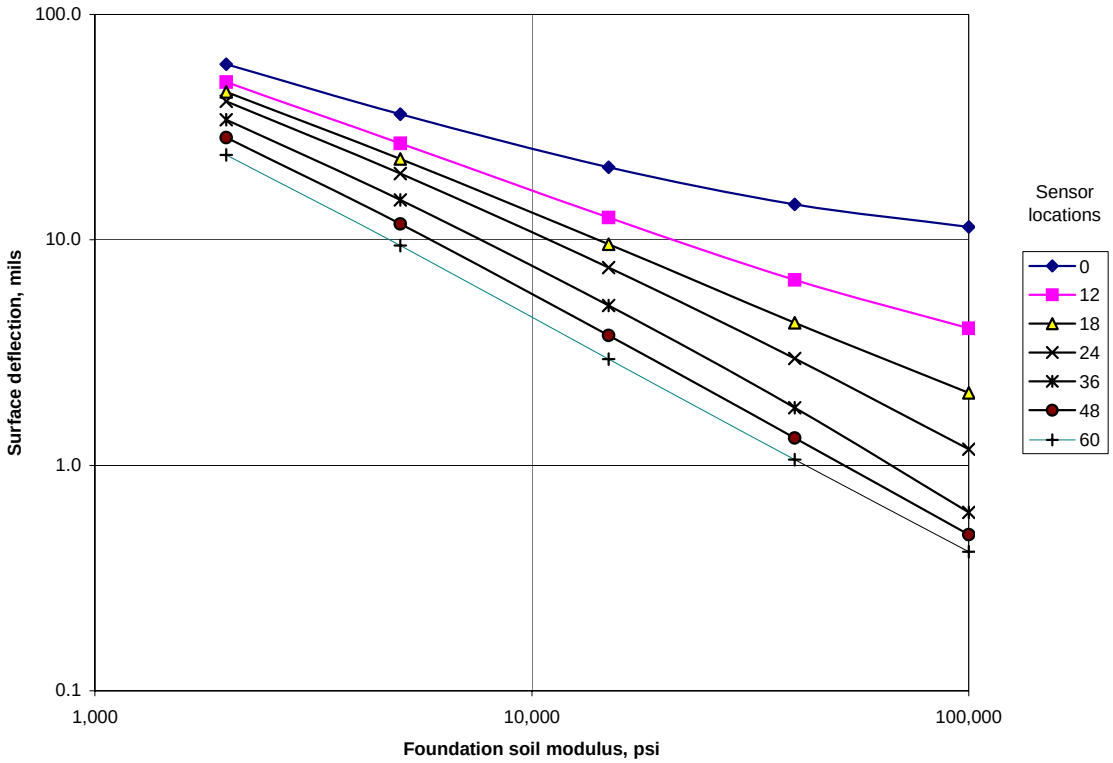


Figure 2.3. Illustration of effect of foundation soil modulus on surface deflection; E_1=200,000 psi, E_2 = 30,000 psi (1 in. = 25.4 mm; 1 psi = 6.9 kPa).

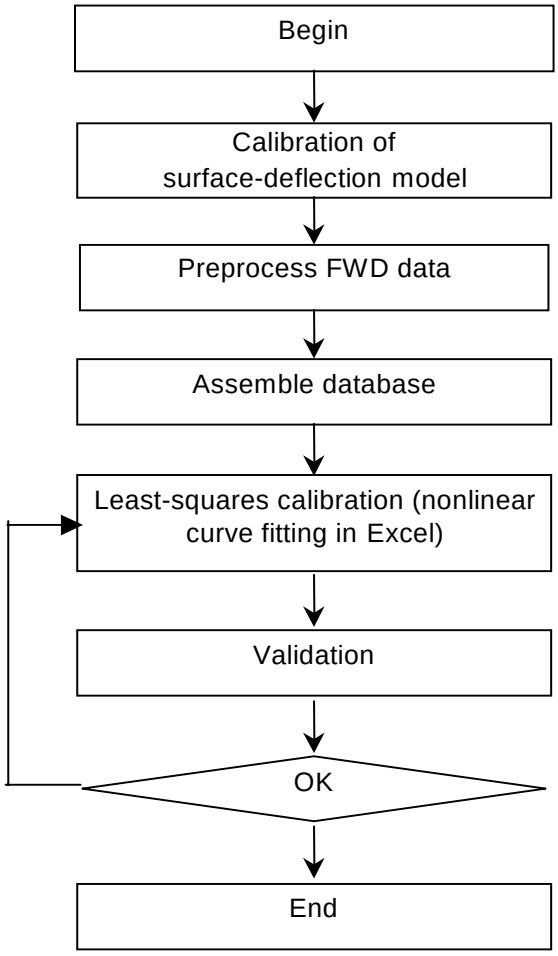


Figure 2.4. Framework for moduli determination.

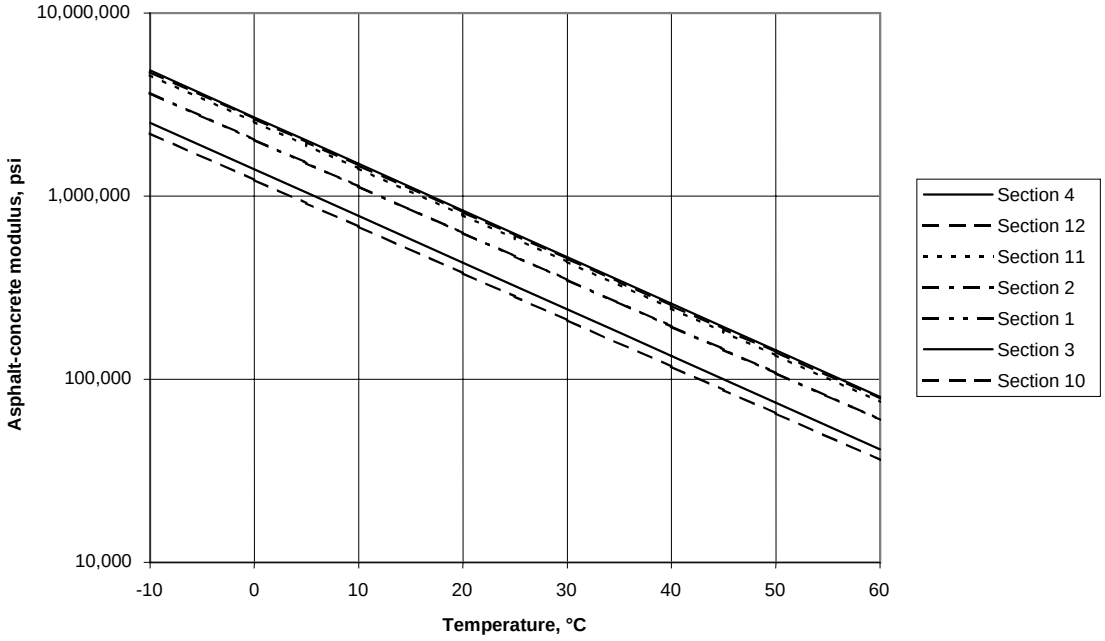


Figure 2.5. FWD-determined moduli for asphalt mixes, south tangent (1 psi = 6.9 kPa, °F = 1.8 °C + 32).

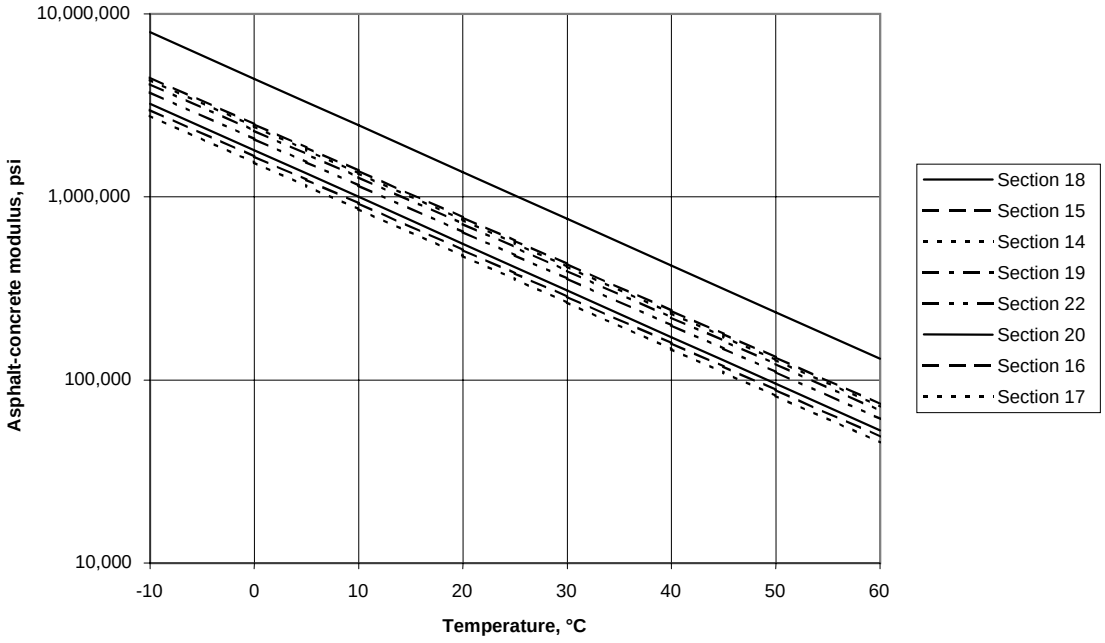


Figure 2.6. FWD-determined moduli for asphalt mixes, north tangent. (1 psi = 6.9 kPa, °F = 1.8 °C + 32).

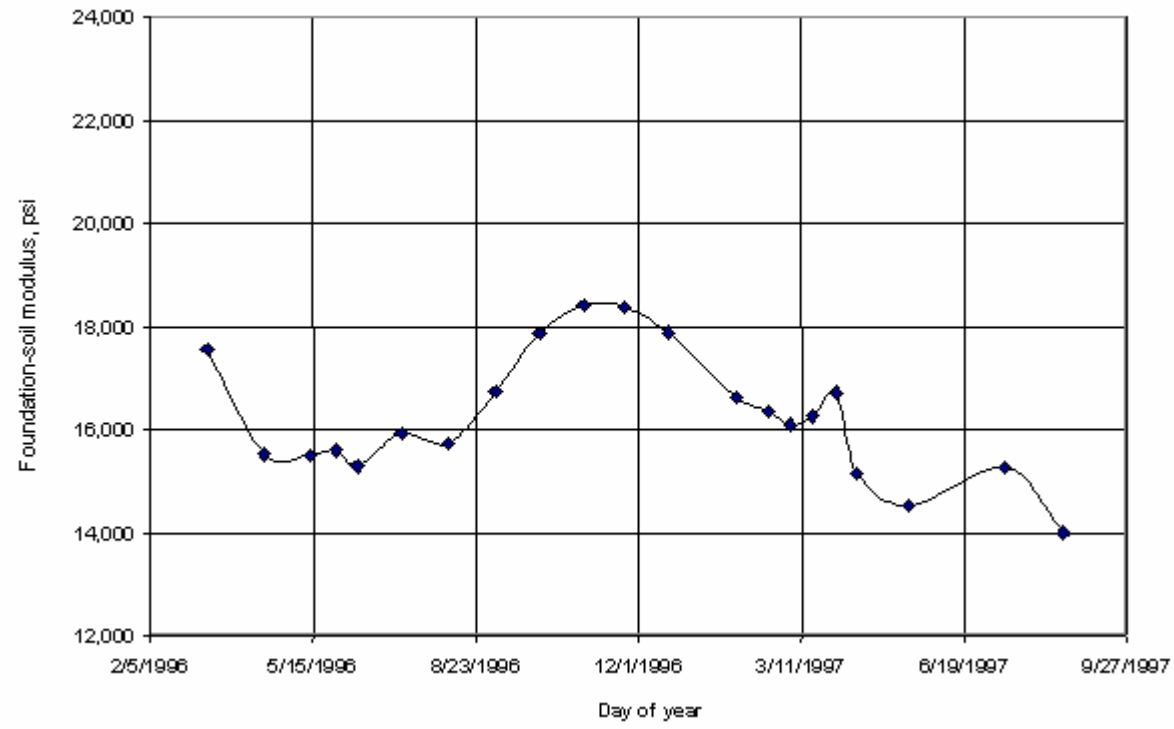


Figure 2.7. Seasonal variations of foundation-soil modulus, south tangent (1 psi = 6.9 kPa).

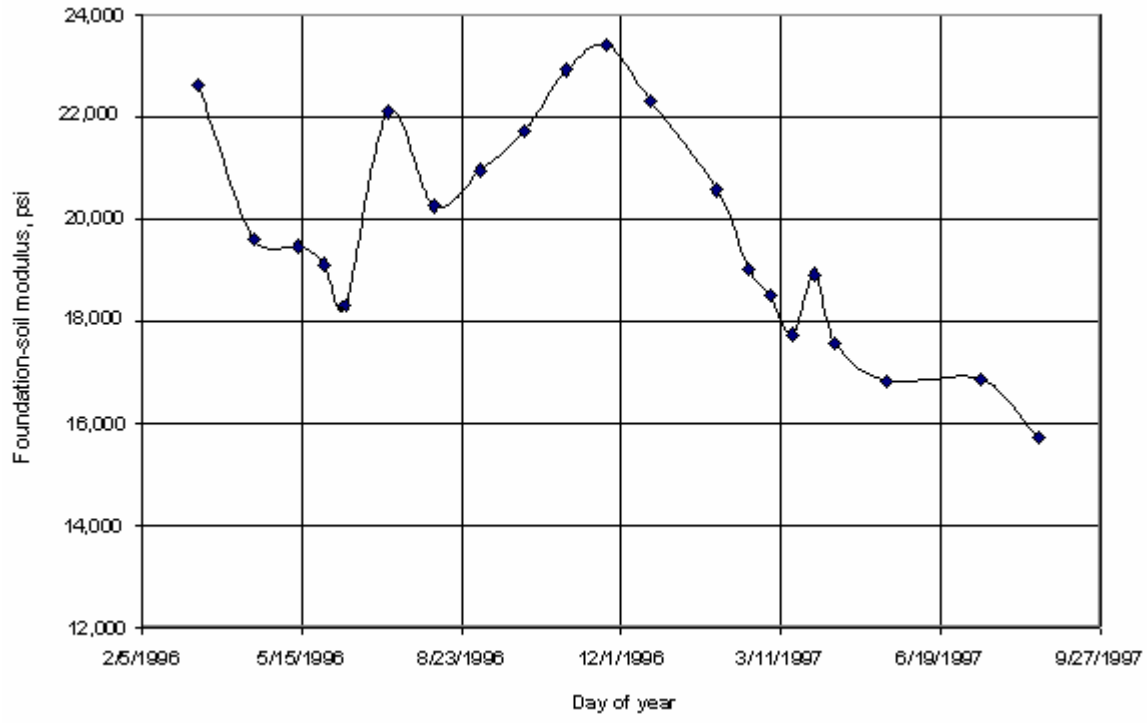


Figure 2.8. Seasonal variations of foundation-soil modulus, north tangent (1 psi = 6.9 kPa).

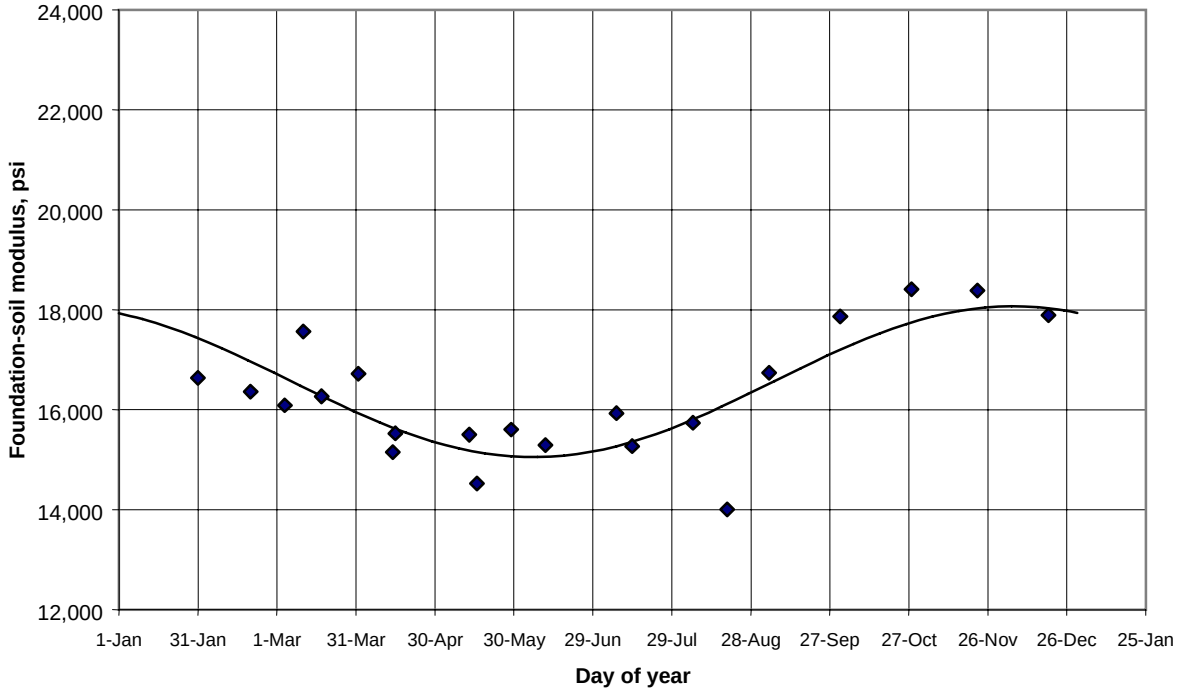


Figure 2.9. Sinusoidal influence of season on foundation-soil modulus, south tangent (1 psi = 6.9 kPa).

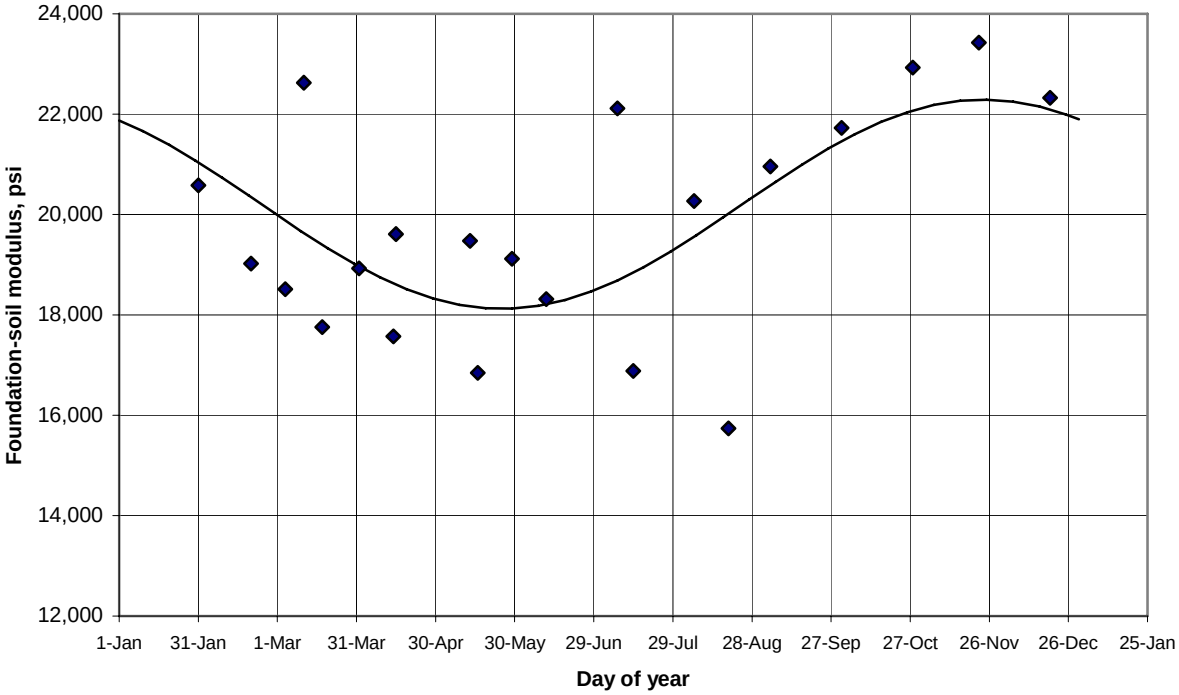


Figure 2.10. Sinusoidal influence of season on foundation-soil modulus, north tangent (1 psi = 6.9 kPa).

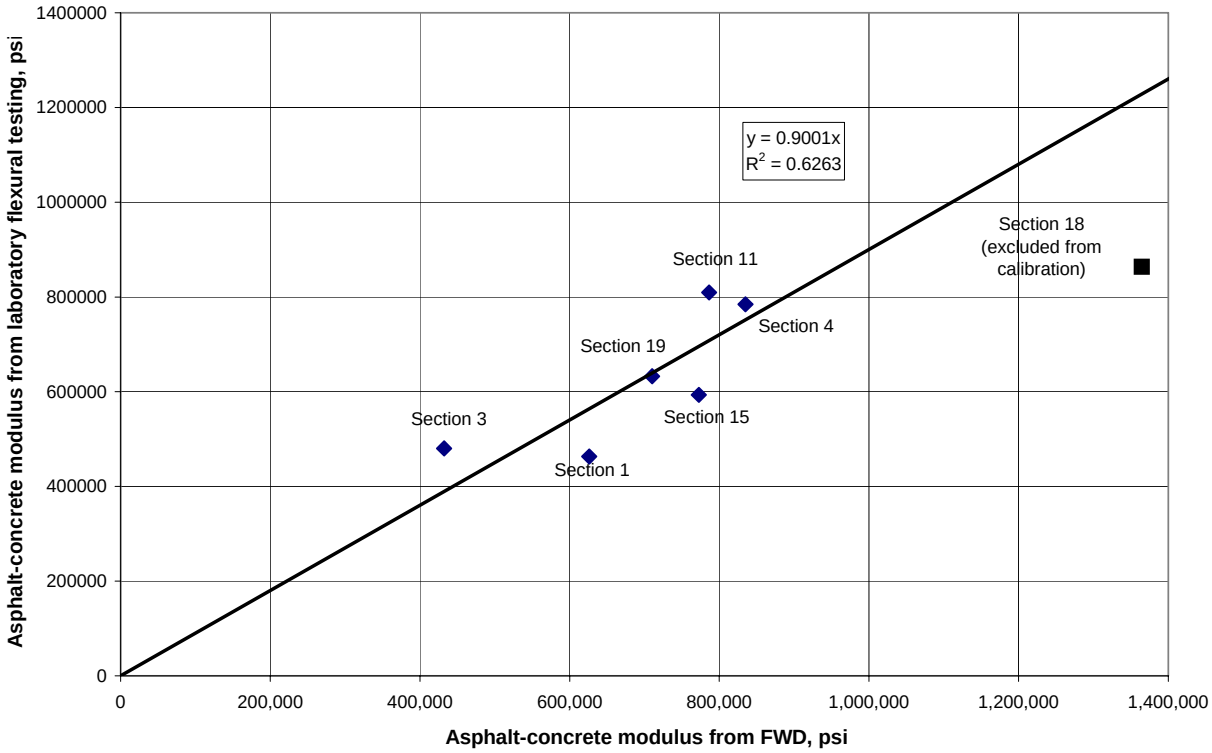


Figure 2.11. Comparison of laboratory-determined flexural stiffness moduli at 20 °C (68 °F) versus moduli determined from FWD measurements (1 psi = 6.9 kPa).

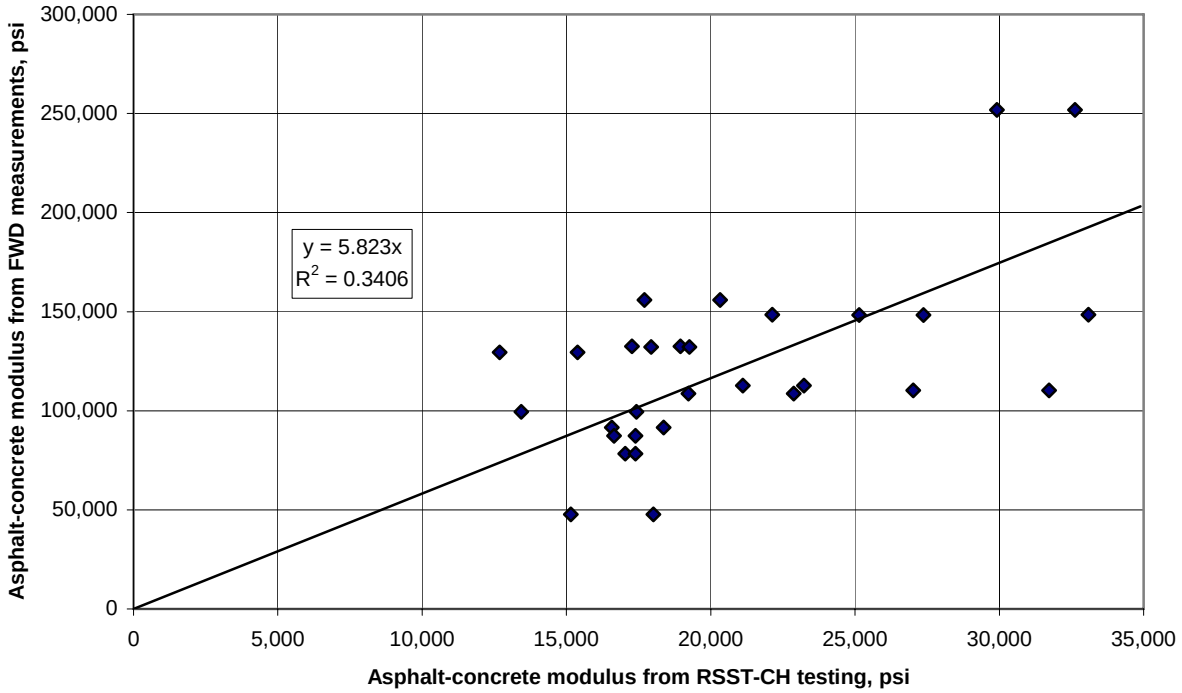
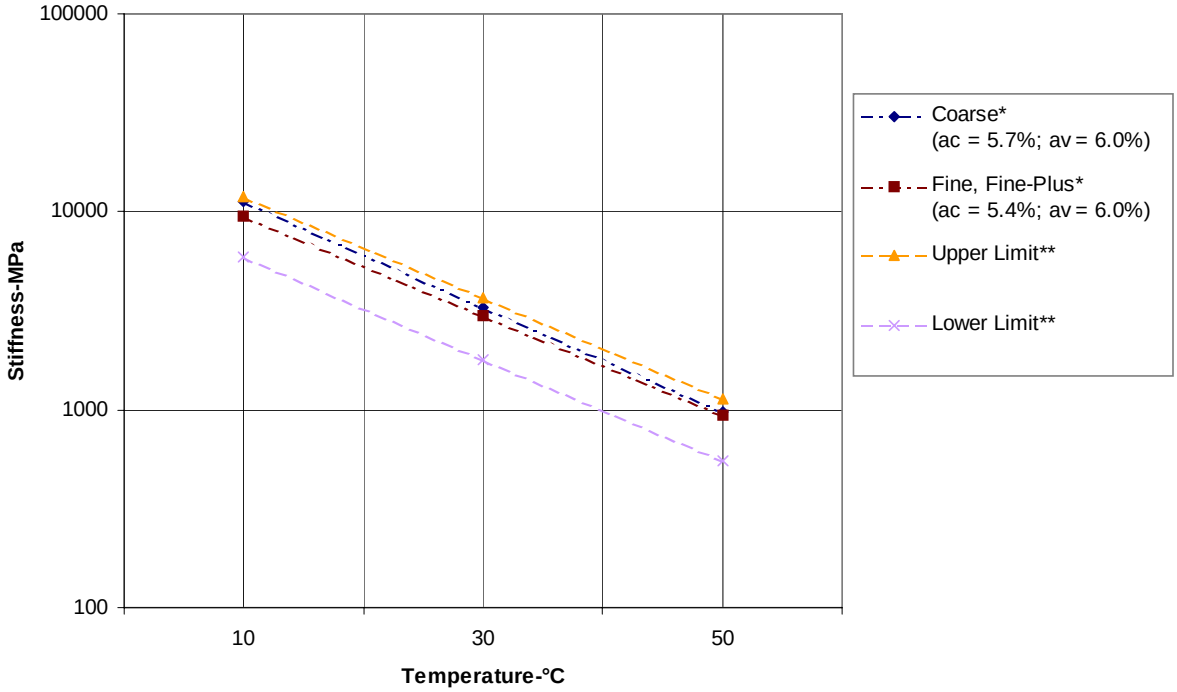


Figure 2.12. Comparison of laboratory-determined stiffness values determined from the RSST-CH tests at 50 °C (122 °F) and FWD measurements; shear stress = 10 psi (6.9 kPa) and Poisson's ratio = 0.35 (1 psi = 6.9 kPa).



*according to Equations 2.5 and 2.6

**Range in stiffness used in permanent deformation analyses; Equation 2.2

Figure 2.13. Comparison of moduli used in permanent deformation analyses with those from Equations 2.5 and 2.6 and used in fatigue analyses, original sections (1 psi = 6.9 kPa, °F = 1.8 °C + 32).

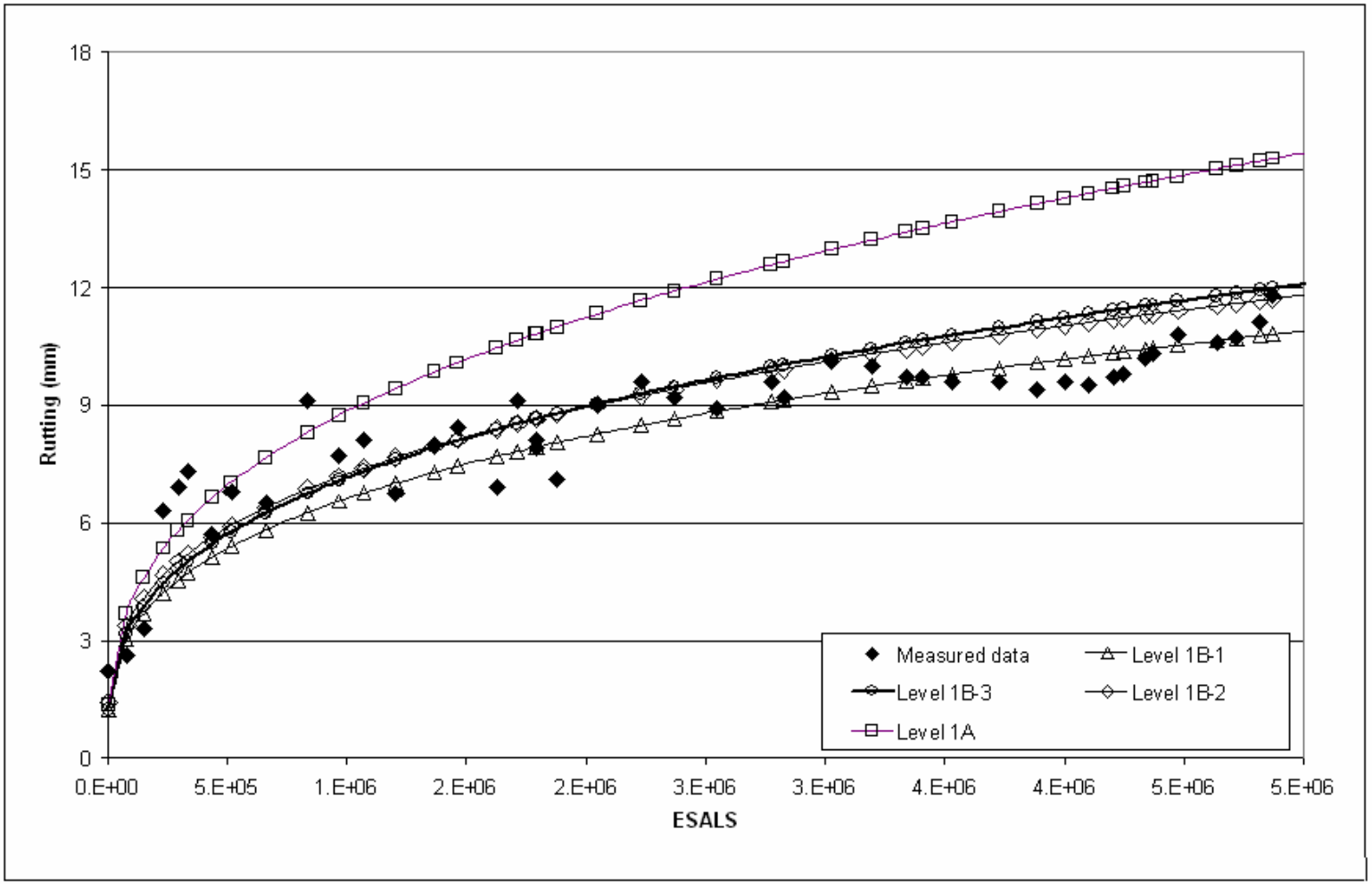


Figure 3.1. Comparison of rut depth versus ESALs for four regression models and measured rut depths, Section 1 (1 in. = 25.4 mm).

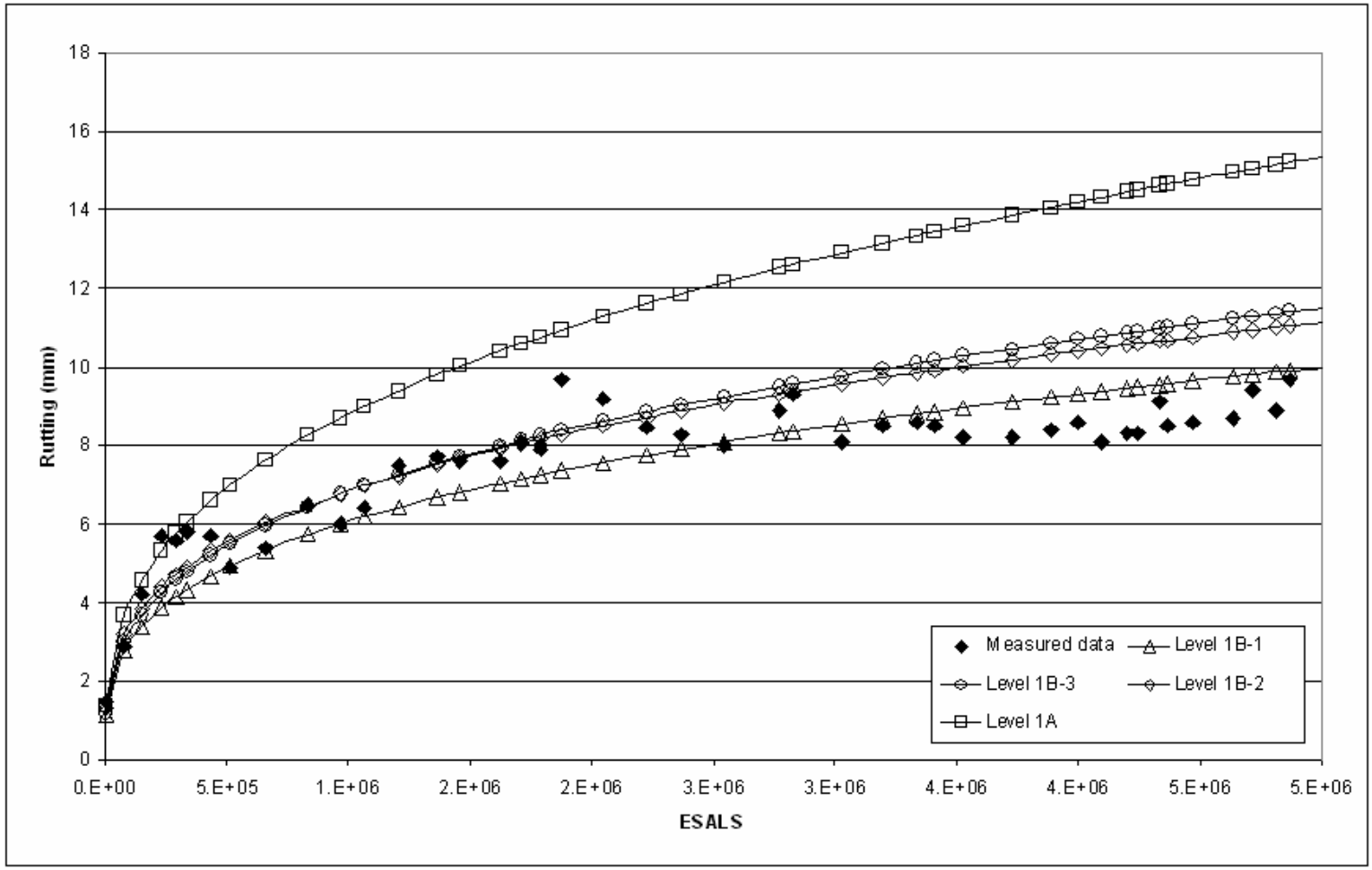


Figure 3.2. Comparison of rut depth versus ESALs for four regression models and measured rut depths, Section 15 (1 in. = 25.4 mm).

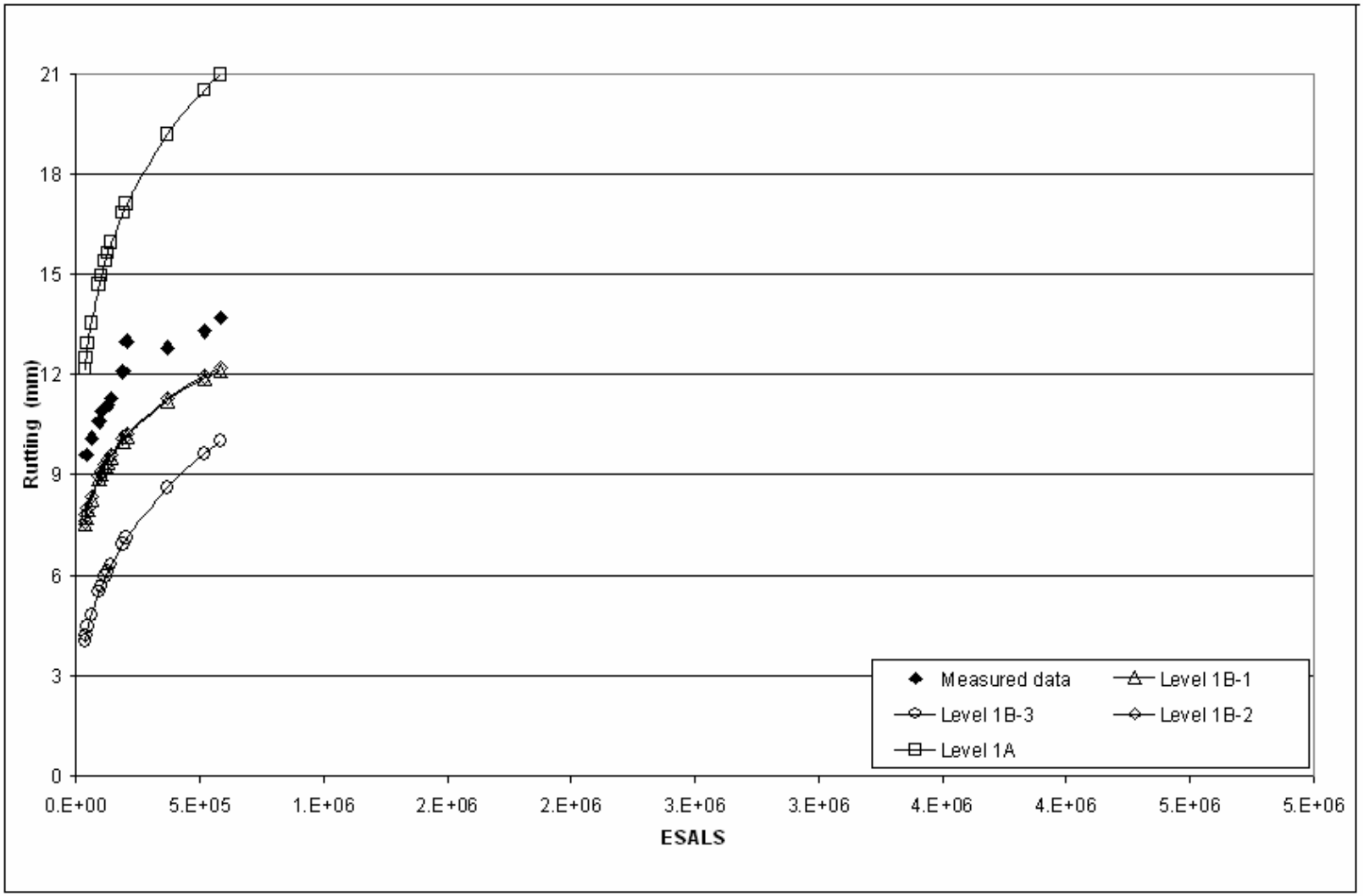


Figure 3.3. Comparison of rut depth versus ESALs for four regression models and mearsured rut depths, Section 54 (1 in. = 25.4 mm).

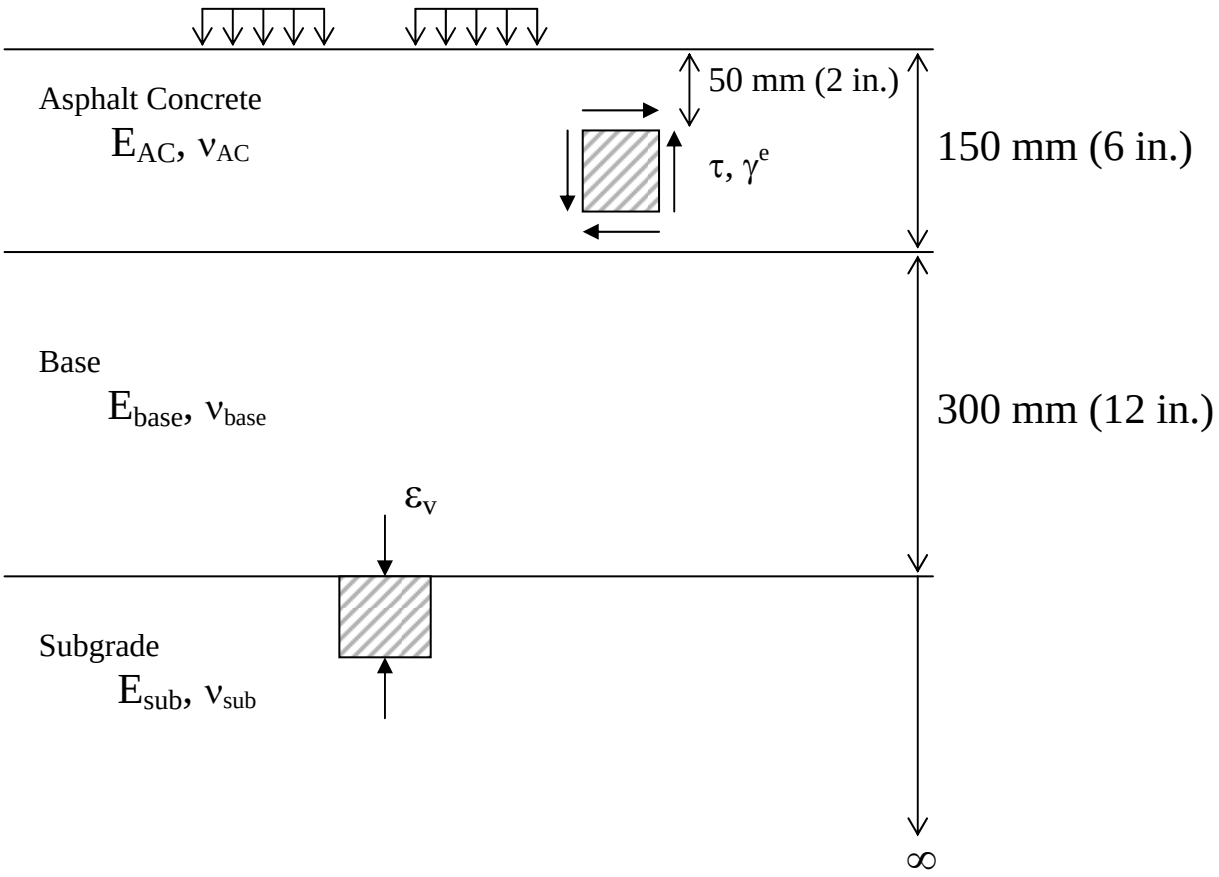


Figure 3.4. WesTrack pavement representation for mechanistic-empirical modeling for rutting.

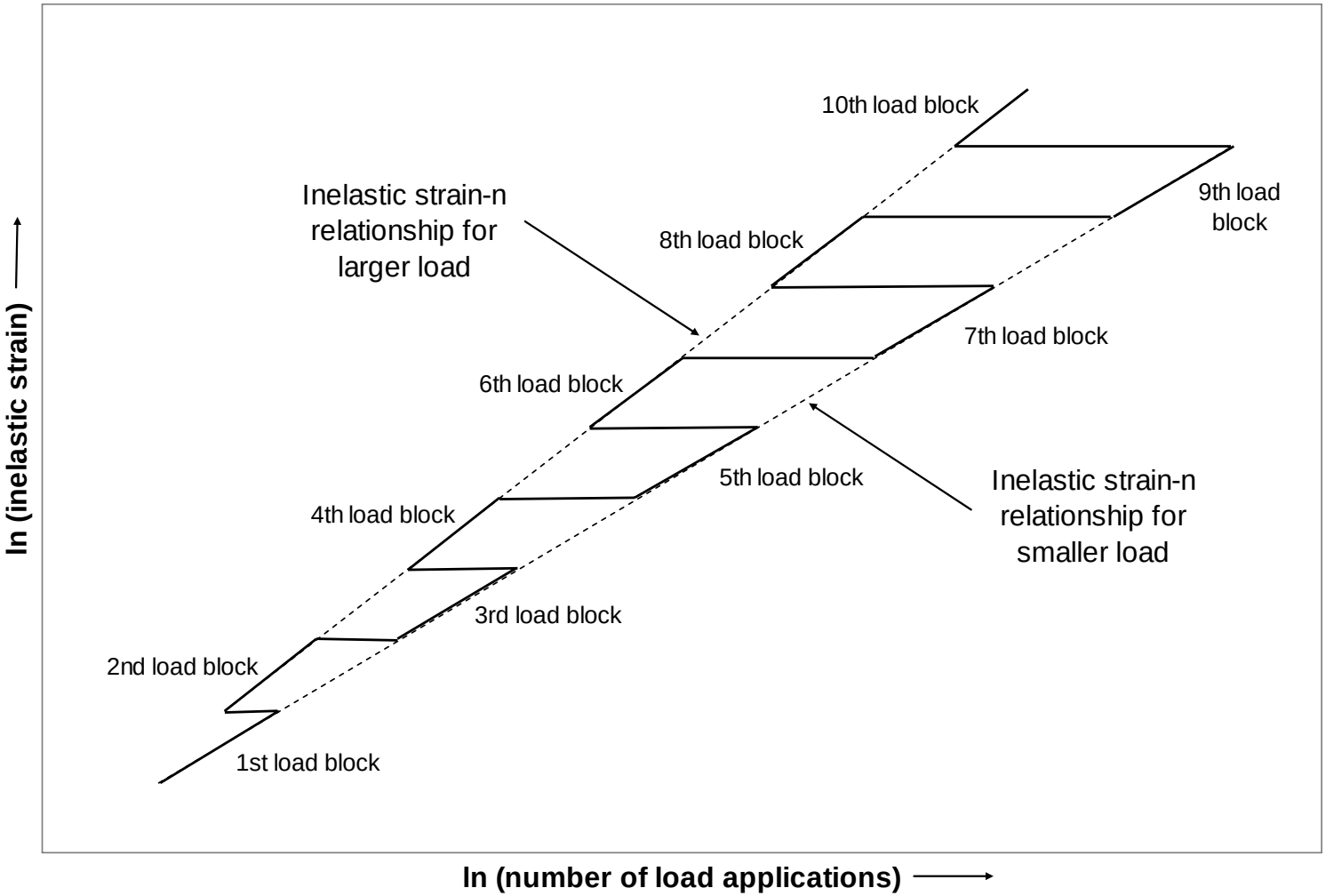


Figure 3.5 Time-hardening procedures for plastic strain accumulation under stress repetitions of different magnitudes in compounding loading.

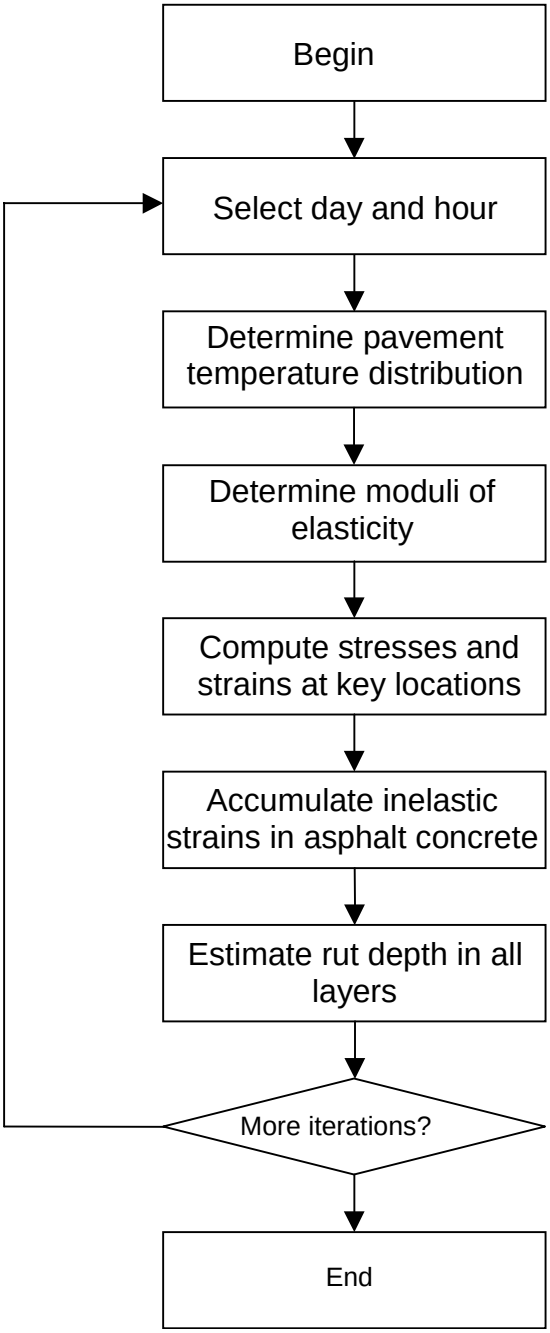


Figure 3.6. Framework for rut depth estimates.

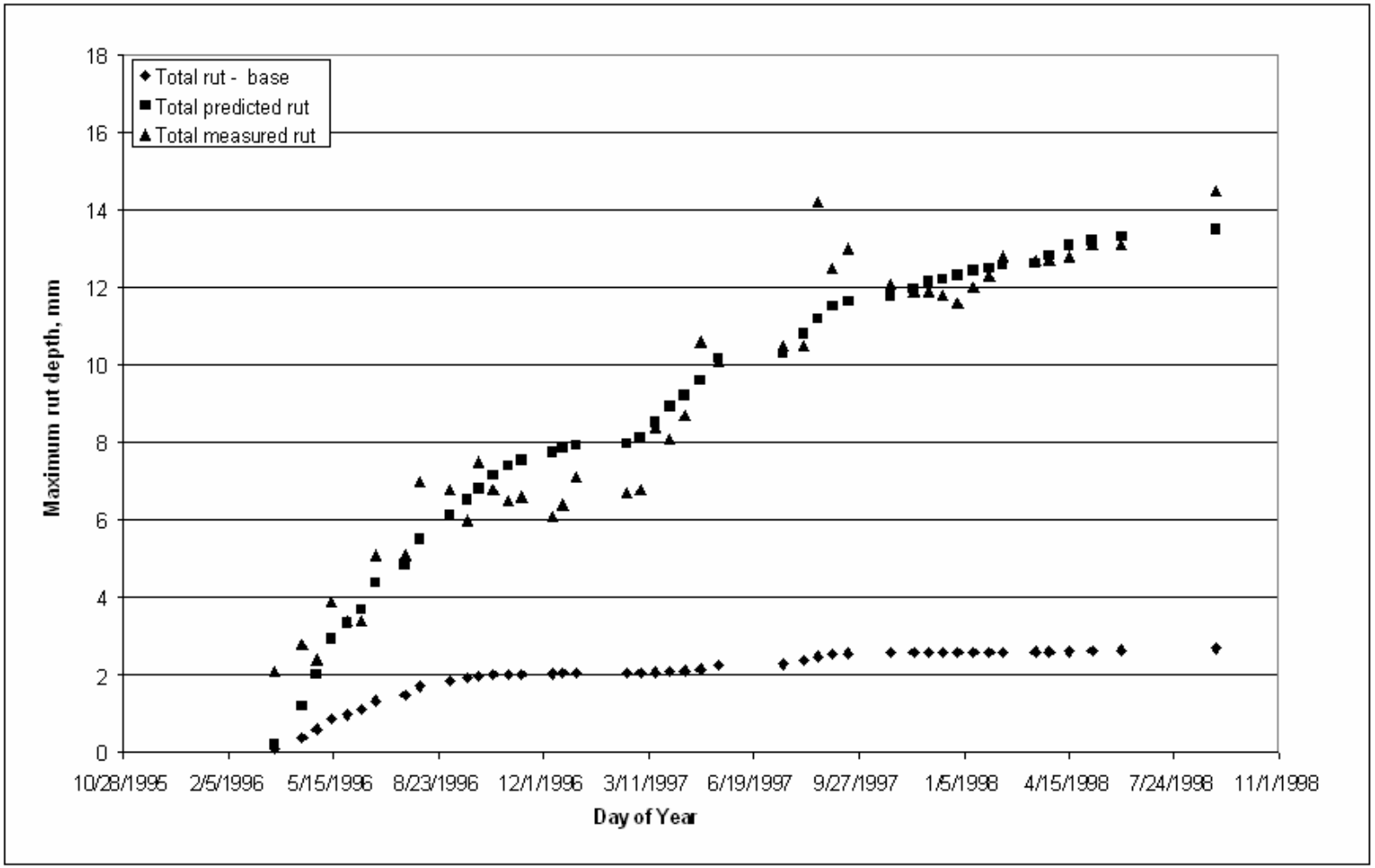


Figure 3.7. Comparison between computed and measured rut depth versus time, Section 4 (1 in. = 25.4 mm).

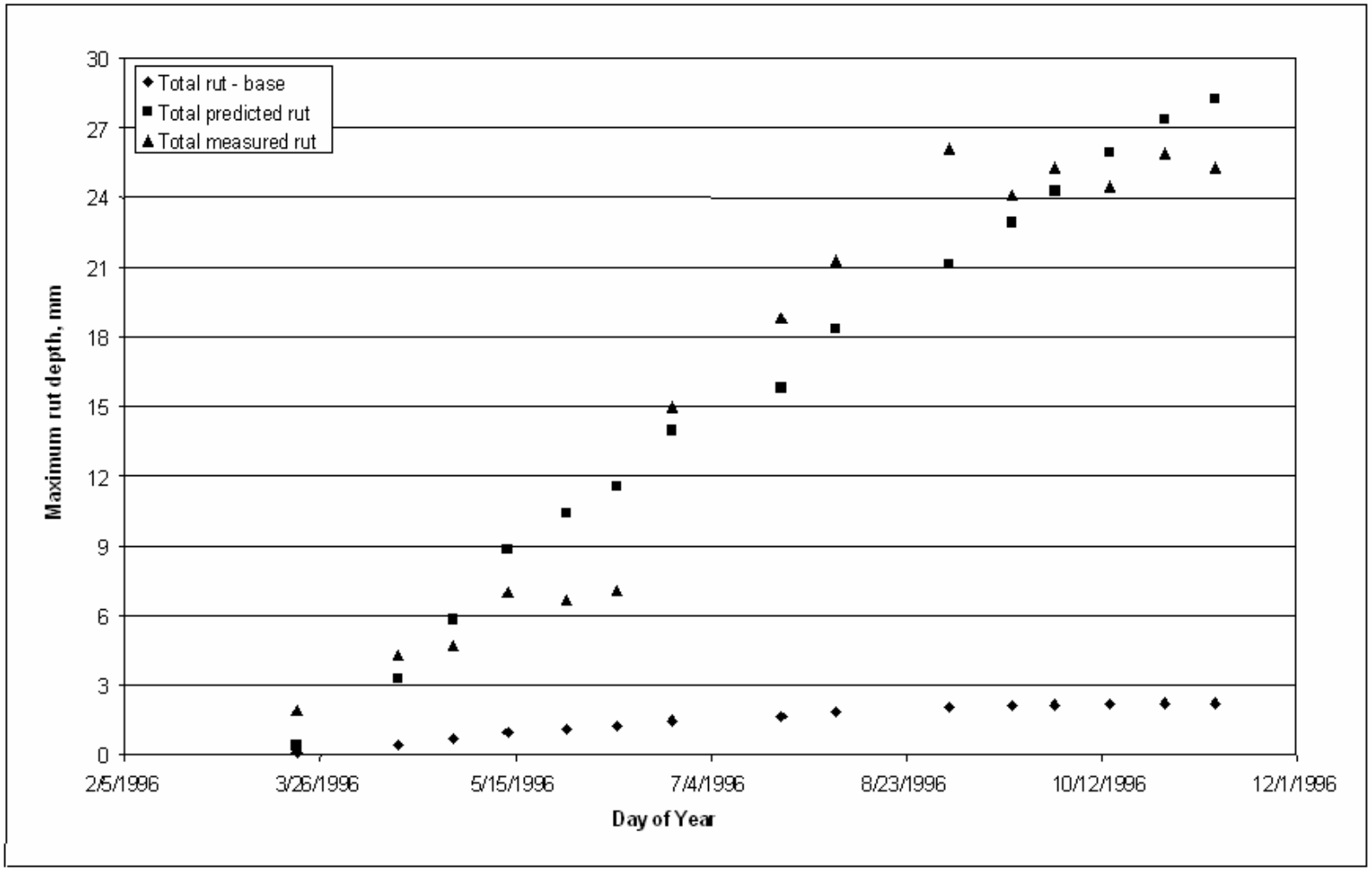


Figure 3.8. Comparison between computed and measured rut depth versus time, Section 7 (1 in. = 25.4 mm).

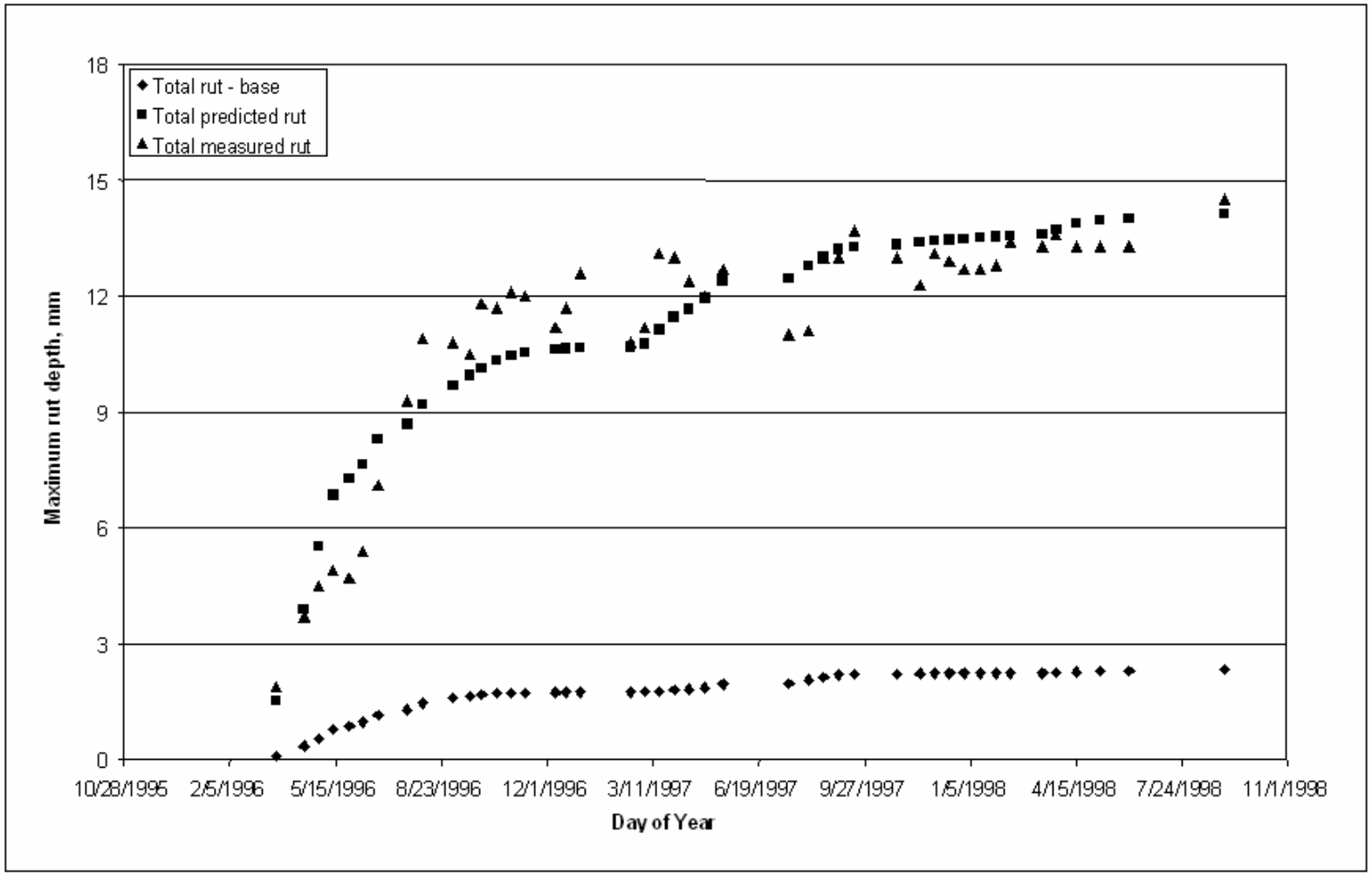


Figure 3.9. Comparison between computed and measured rut depth versus time, Section 19 (1 in. = 25.4 mm).

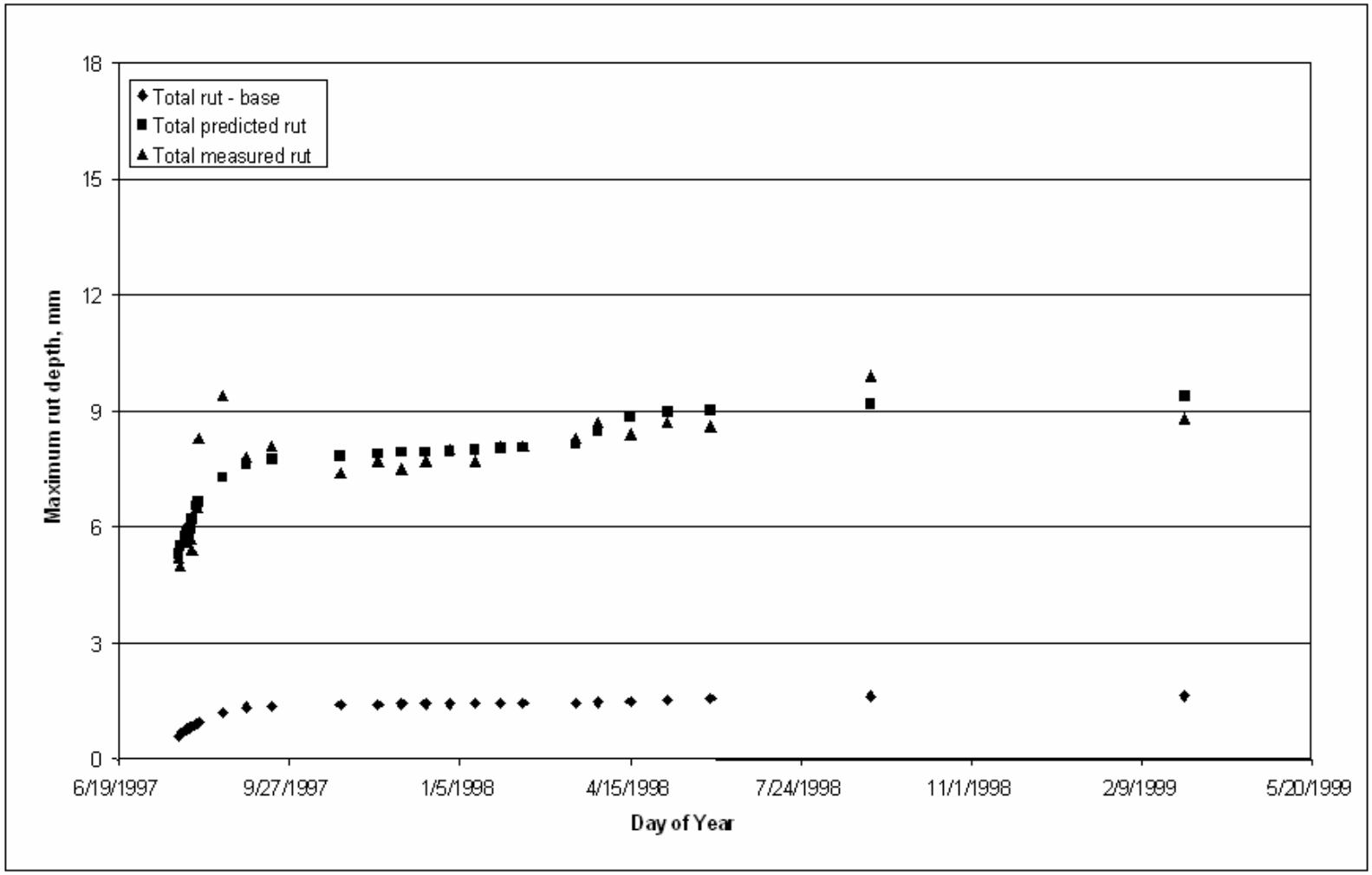


Figure 3.10. Comparison between computed and measured rut depth versus time, Section 38 (1 in. = 25.4 mm).

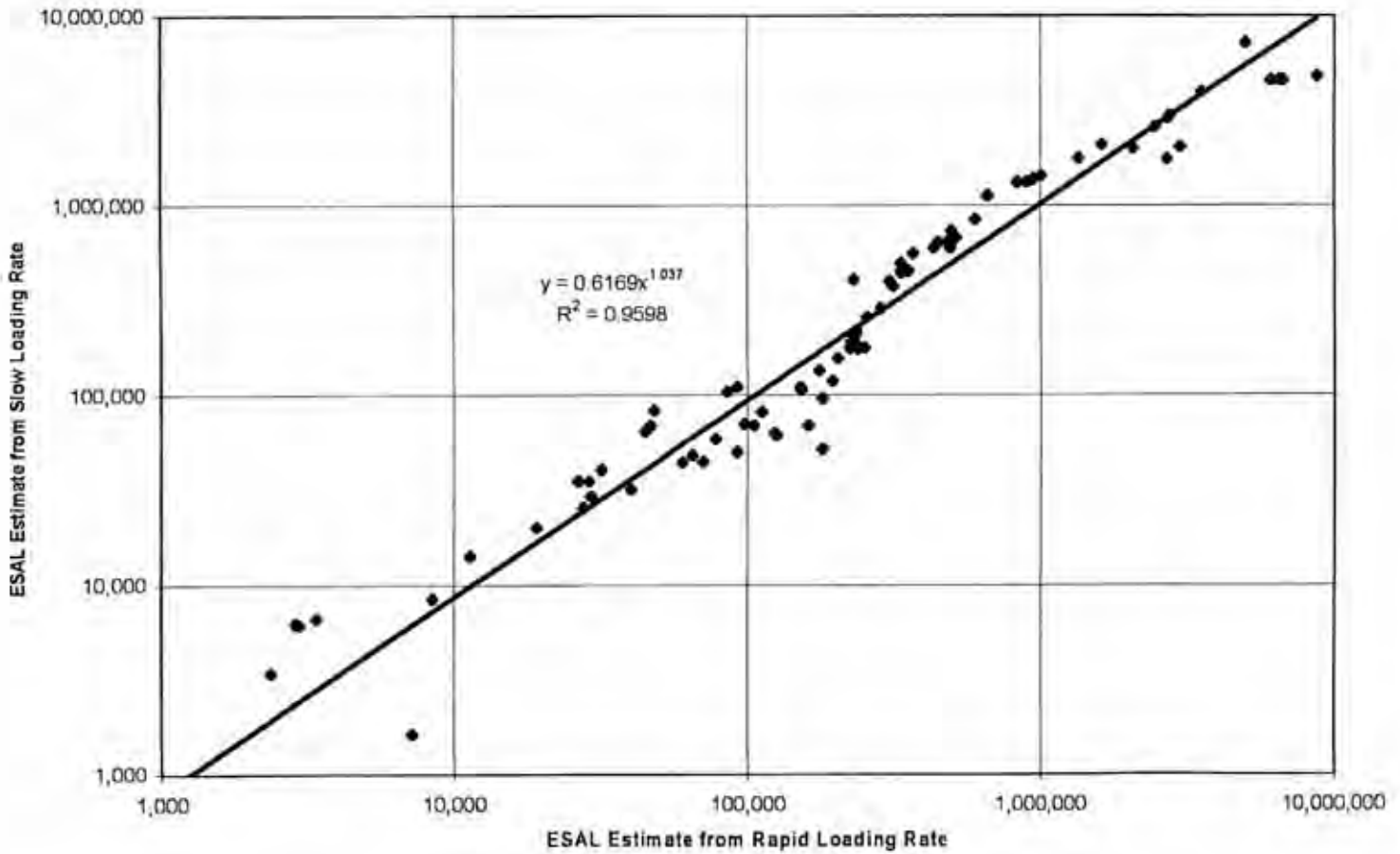


Figure 3.11. Effect of loading rate on ESAL estimates.

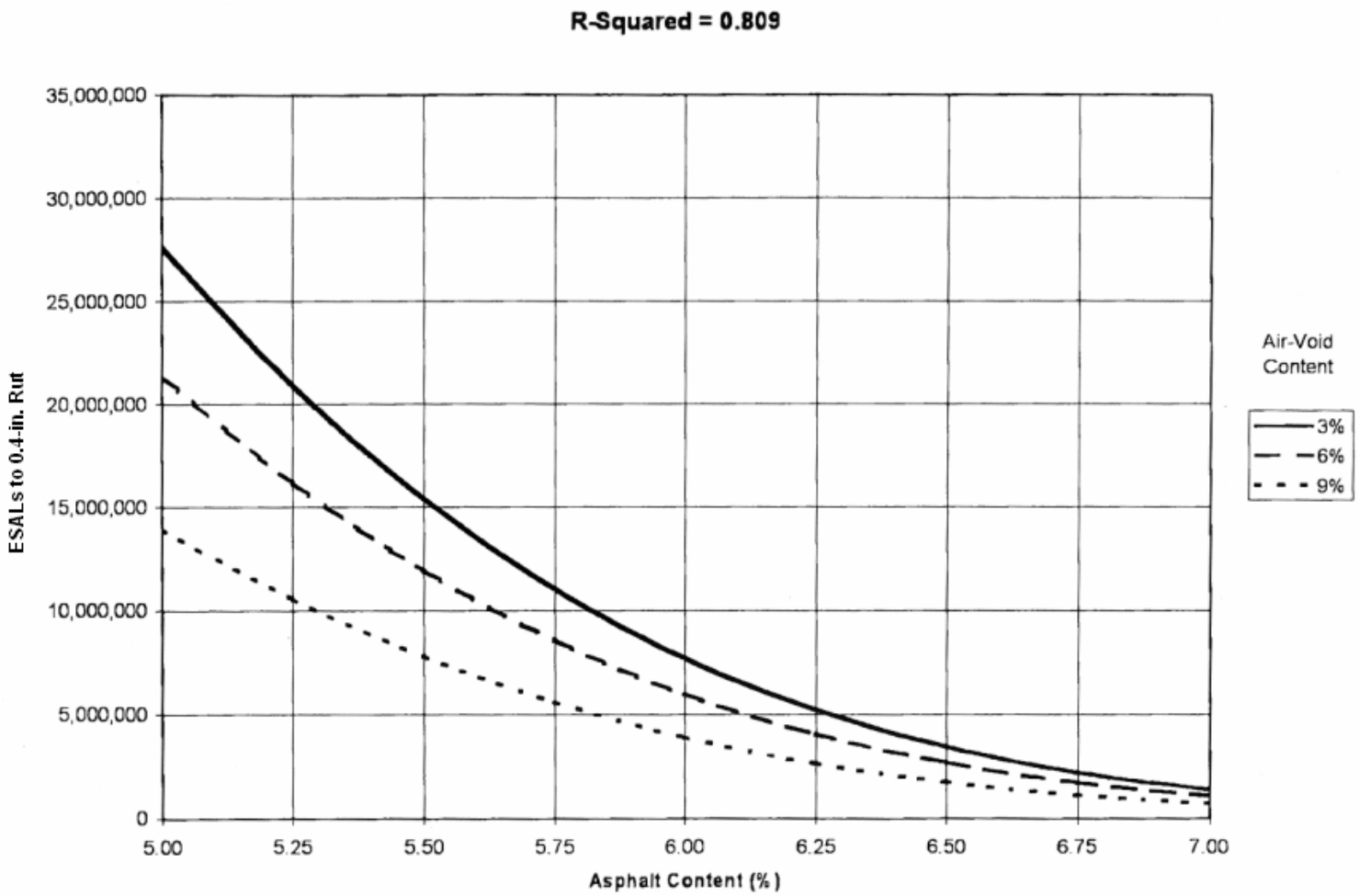


Figure 3.12. Influence of asphalt content and air-void content on computed ESALs to a rut depth of 10 mm (0.4 in.); Regression 3, Table 3.2, and P_{200} = 5.5%.

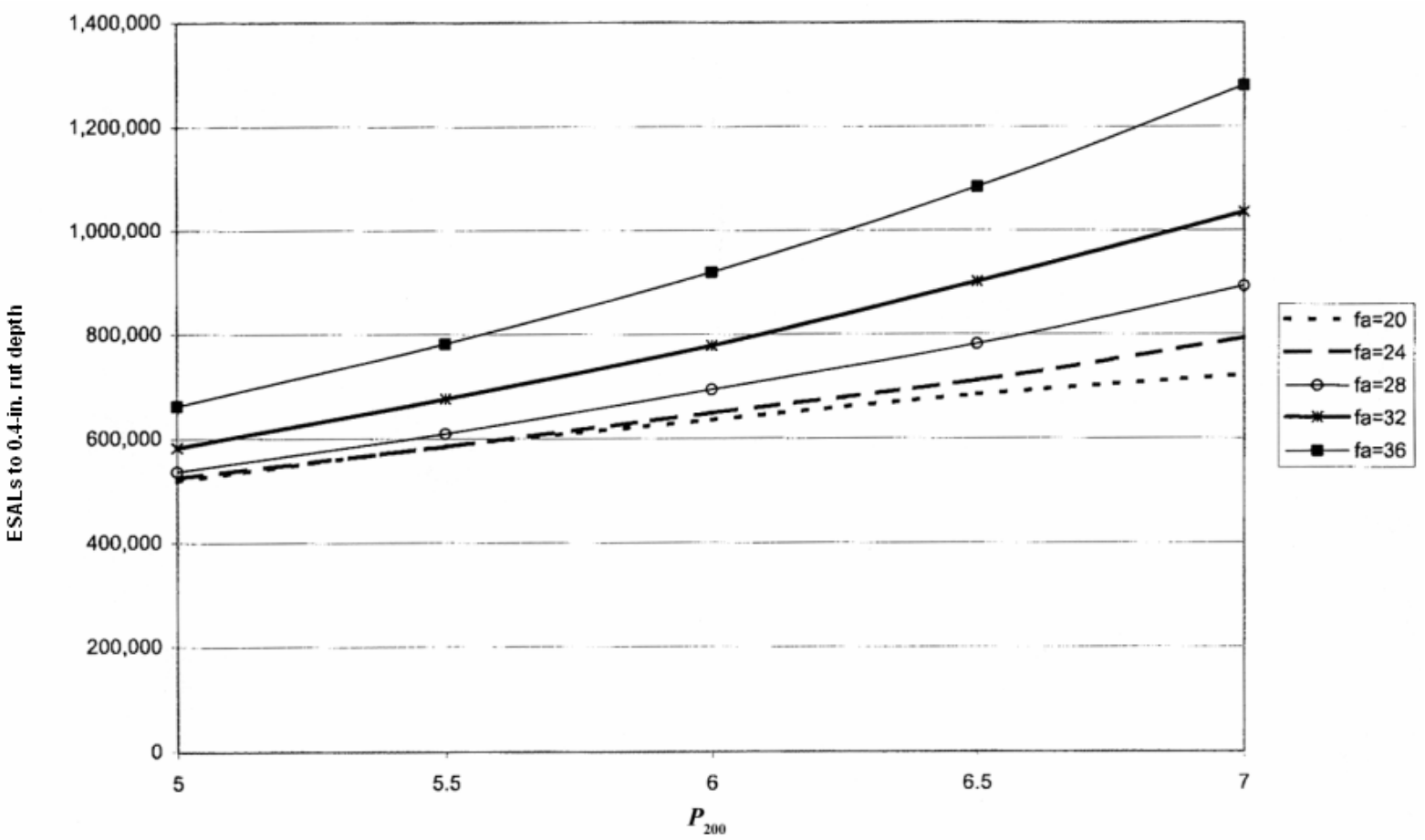


Figure 3.13. Influence of mineral filler (P_{200}) on ESALs to a rut depth of 0.4 in. (10 mm) for a range in amounts of fine aggregate (*fa*); P_{Wasp} = 5.5%; V_{air} = 6.5%.

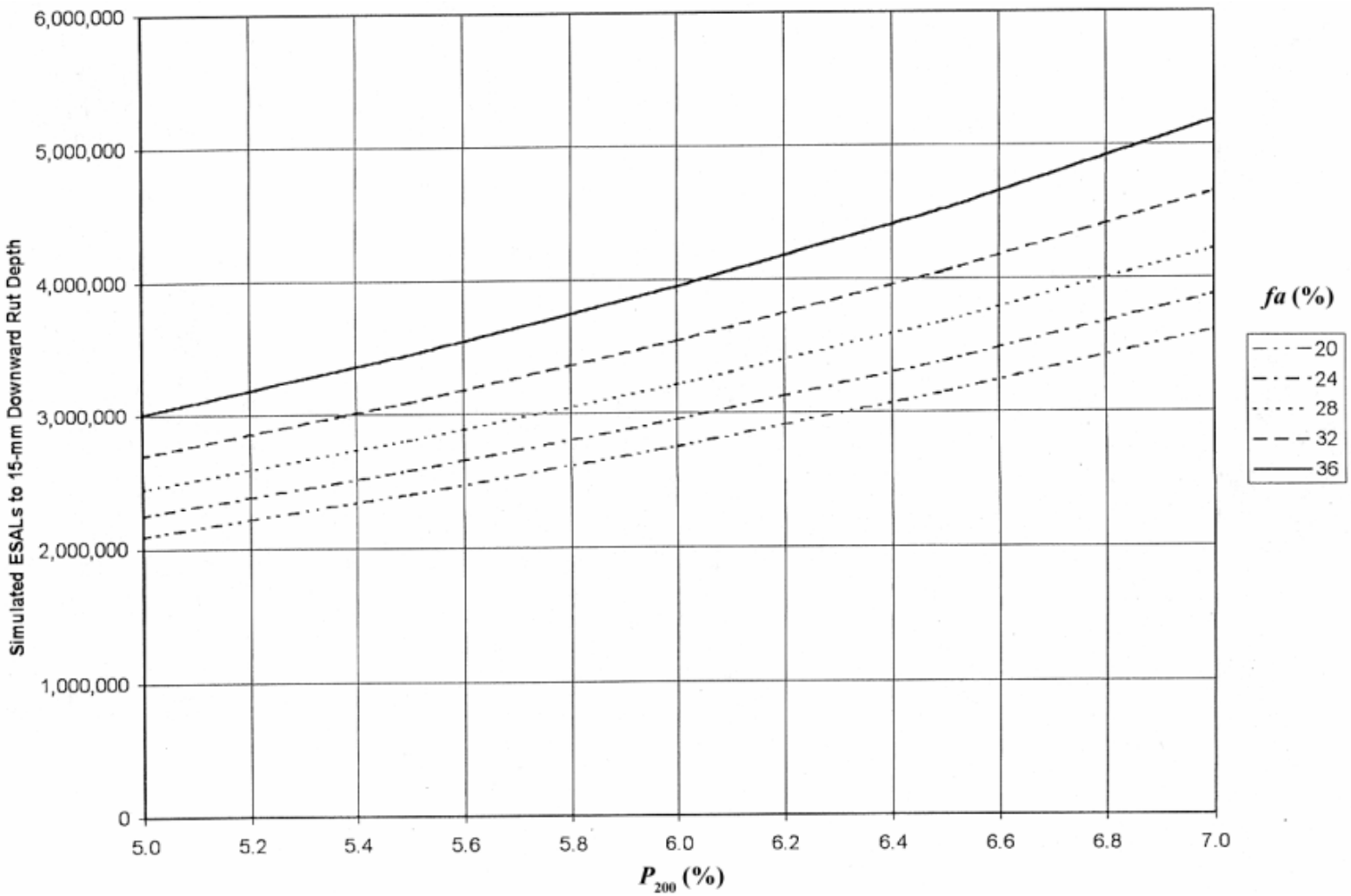


Figure 3.14. Influence of P_{200} content for a range of fine aggregate proportions on simulated ESALs to a rut depth of 15 mm (0.6 in.).

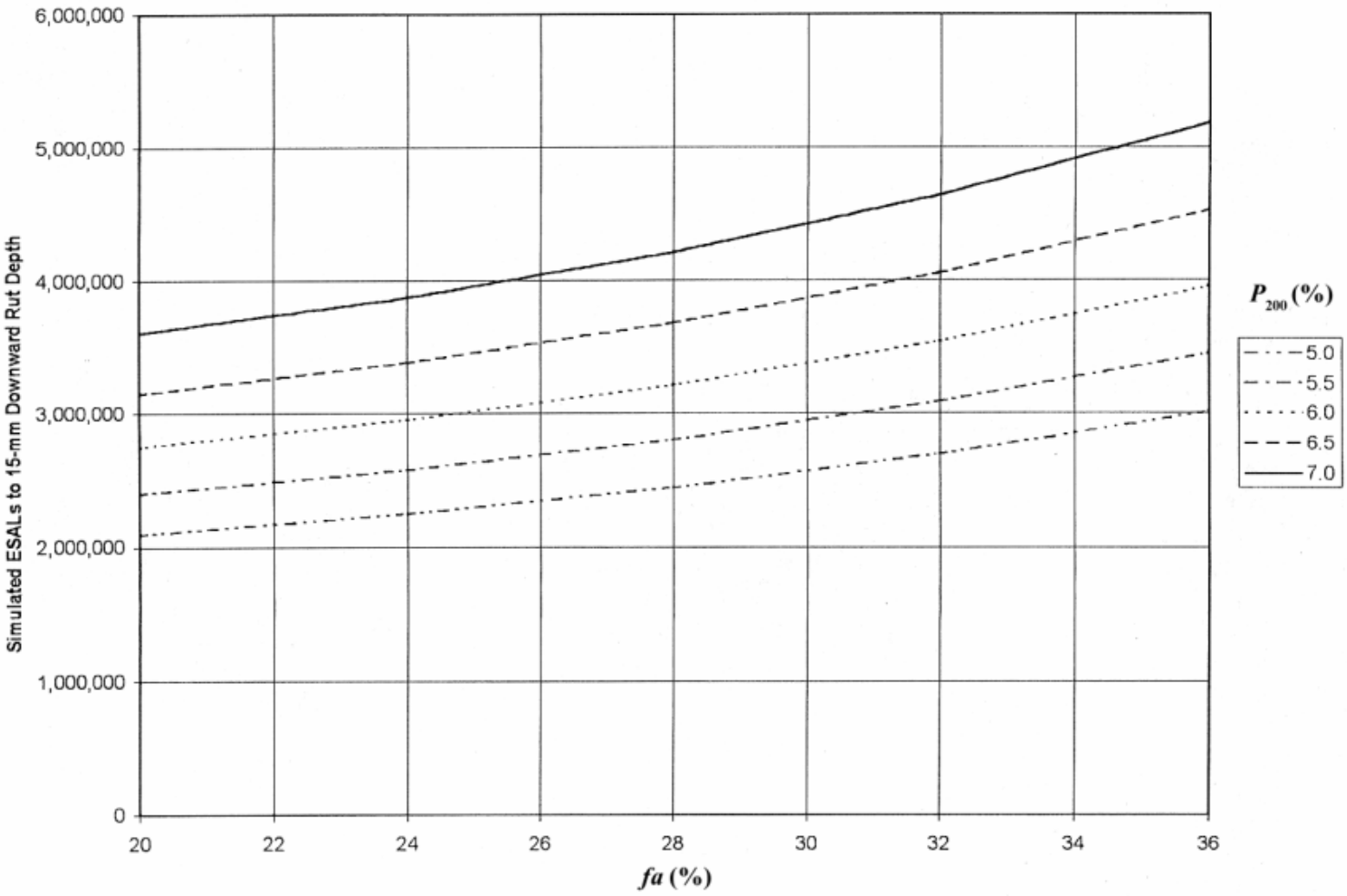


Figure 3.15. Influence of fine aggregate content for a range in P_{200} contents on simulated ESALs to a rut depth of 15 mm (0.6 in.).

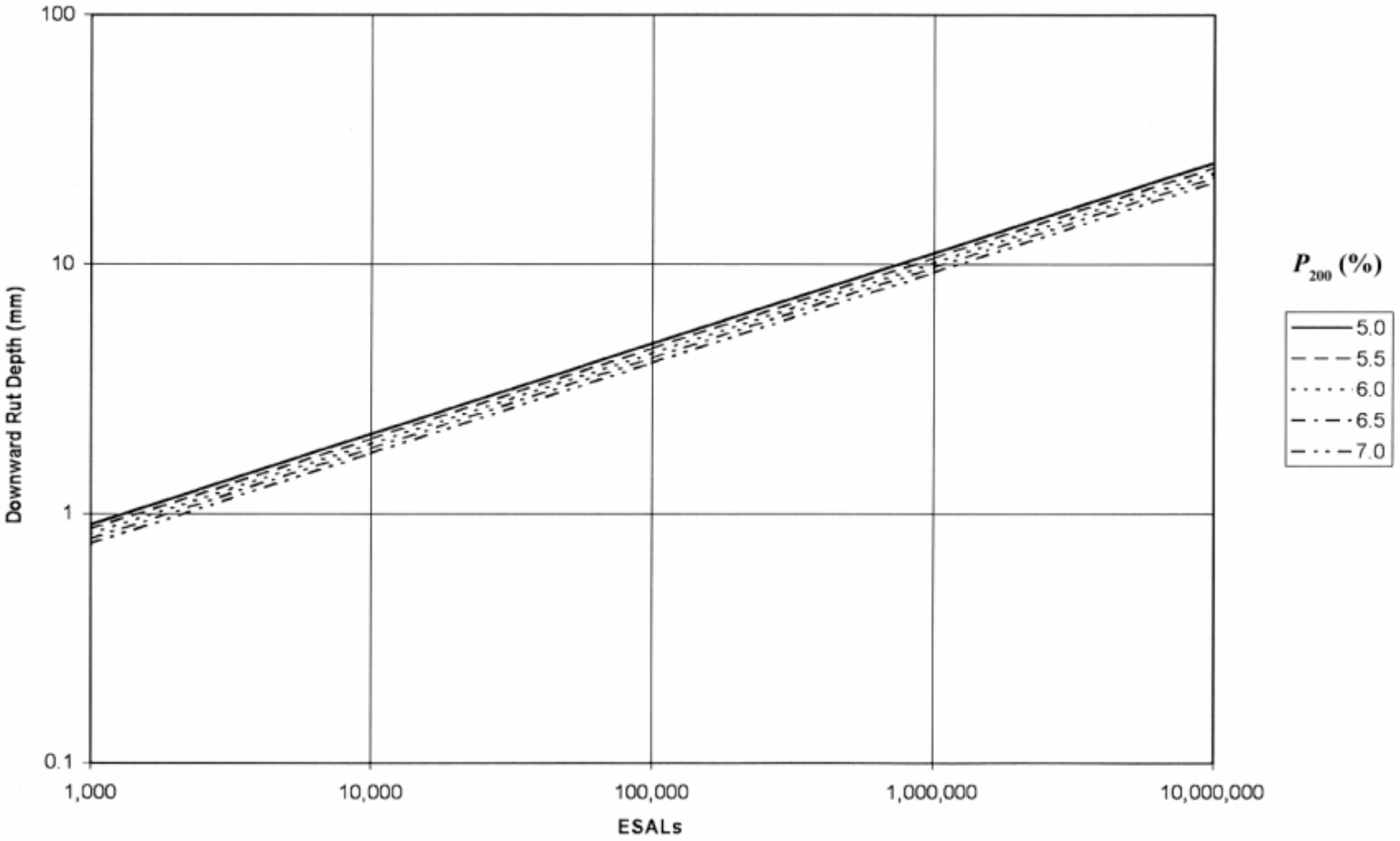


Figure 3.16. Influence of P_{200} content on rut depth for a range in ESALs; fine aggregate content = 28% (1 in. = 25.4 mm).

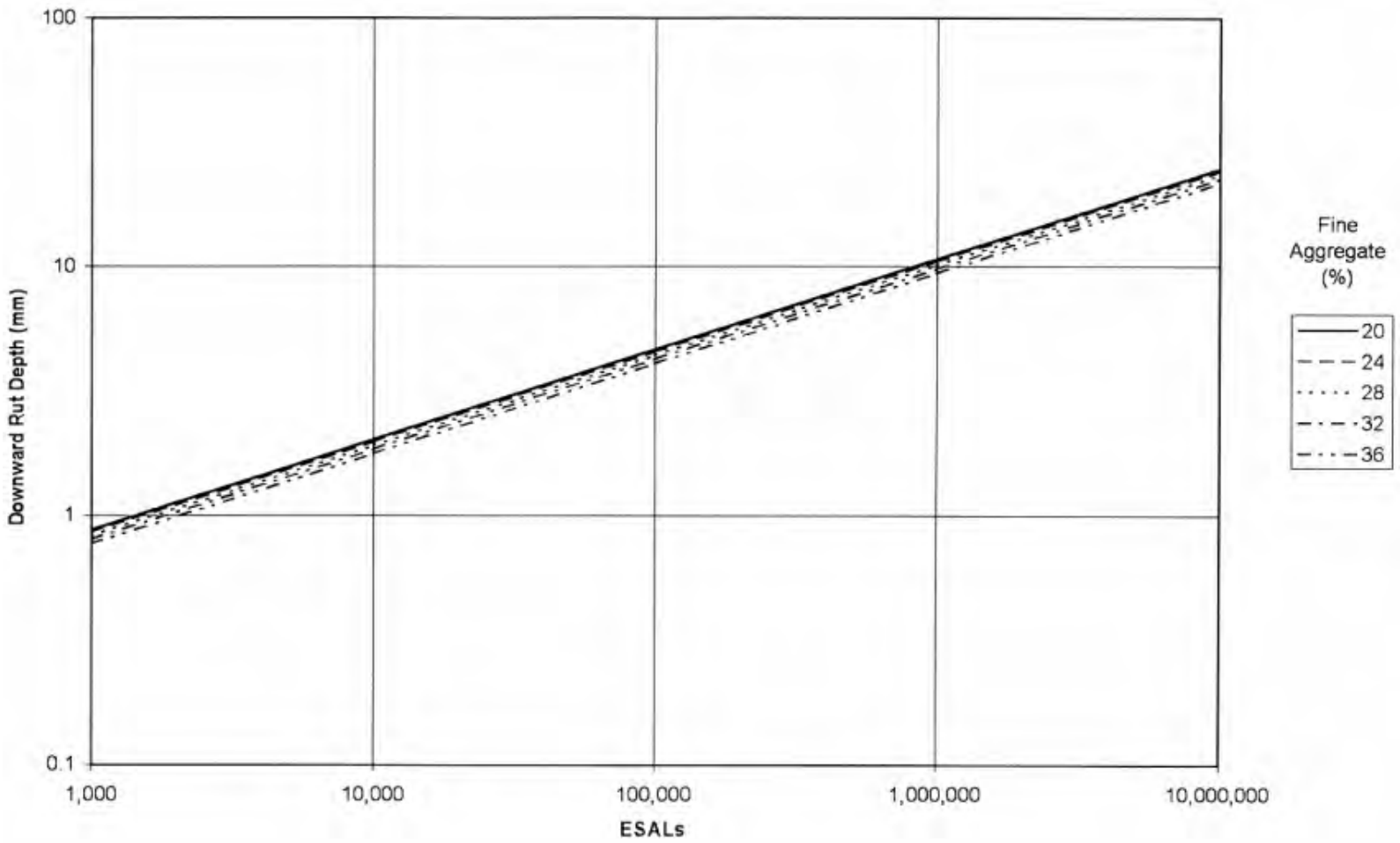


Figure 3.17. Influence of fine aggregate content on rut depth for a range in ESALs; P_{200} = 6% (1 in. = 25.4 mm).

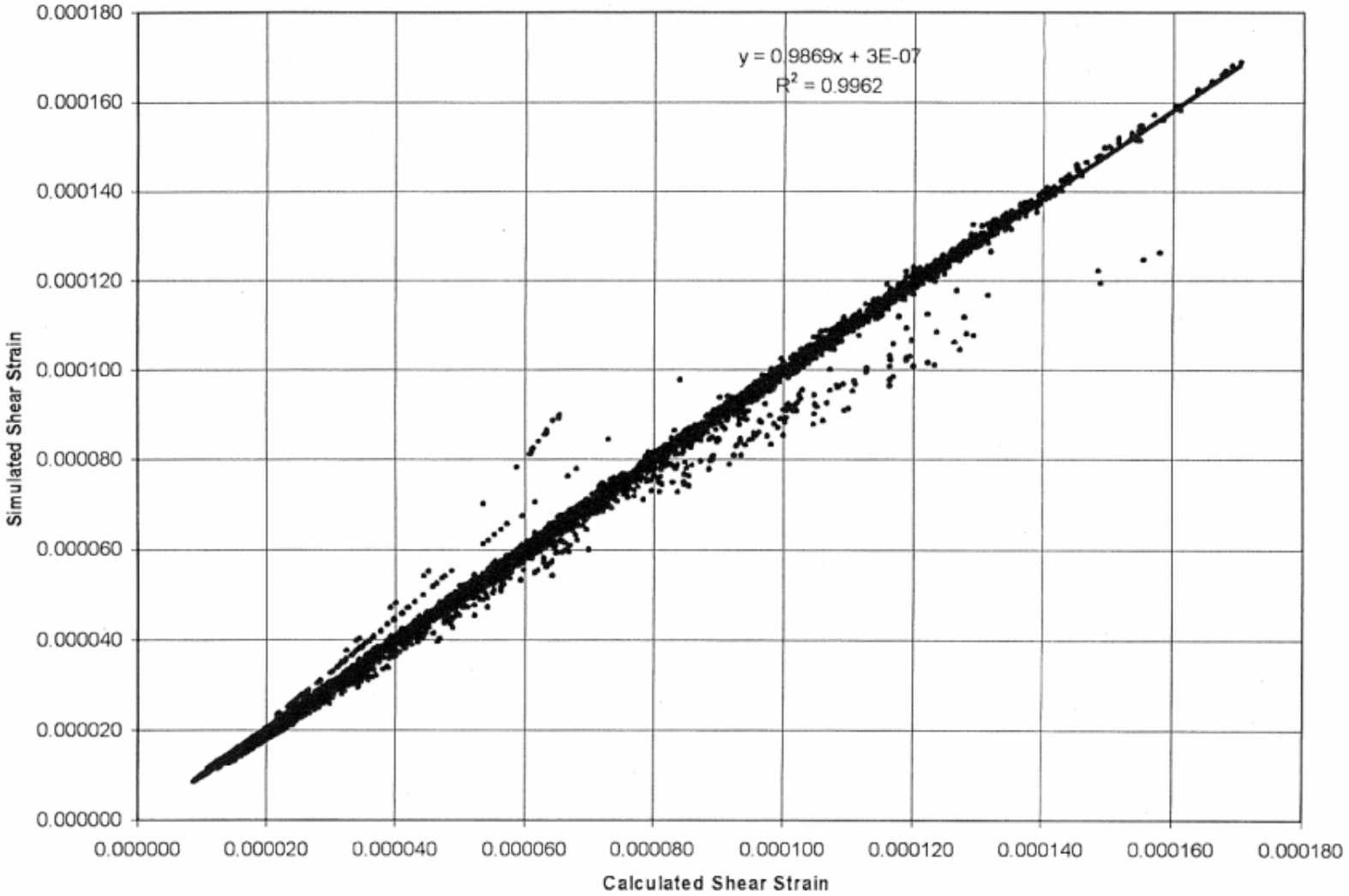


Figure 3.18. Comparison of simulated shear strain using regression equation of Table 3.12 and calculated shear strain by CIRCLY.

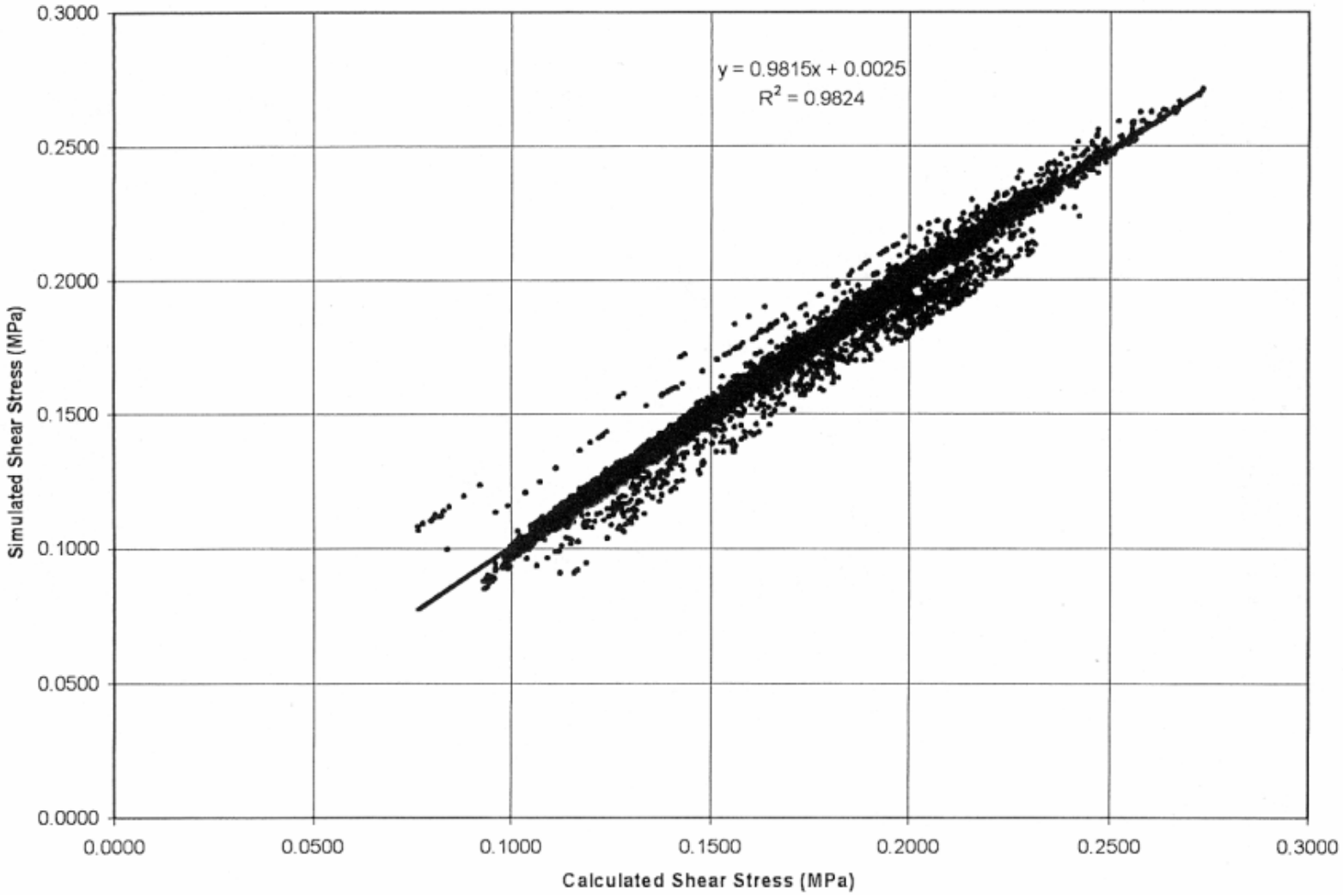


Figure 3.19. Comparison of simulated shear stress using regression equation of Table 3.12 and calculated shear stress by CIRCLY (1 psi = 6.9 kPa).

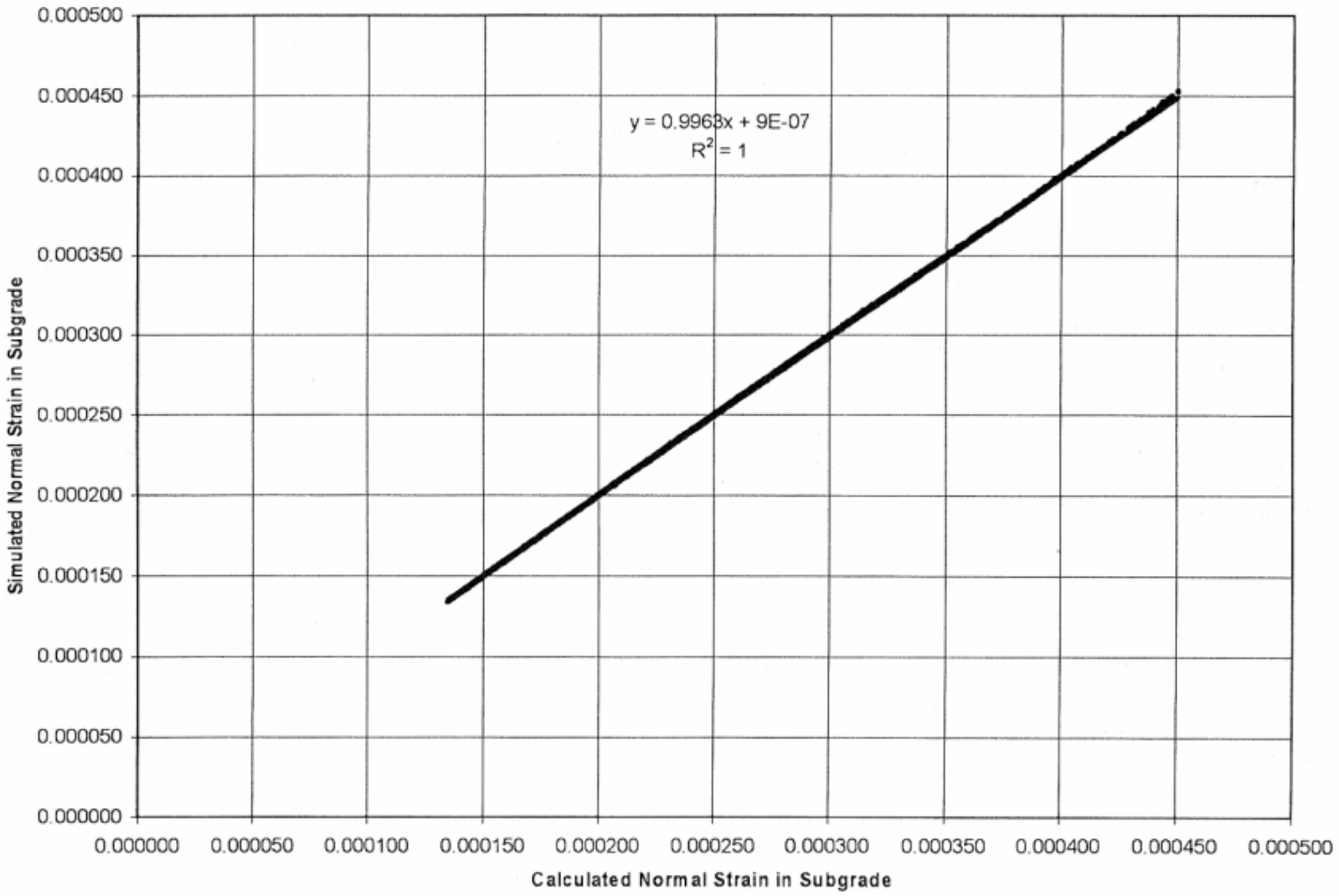


Figure 3.20. Comparison of simulated vertical compressive strain at subgrade surface using regression equation of Table 3.12 and calculated subgrade strain by CIRCLY.

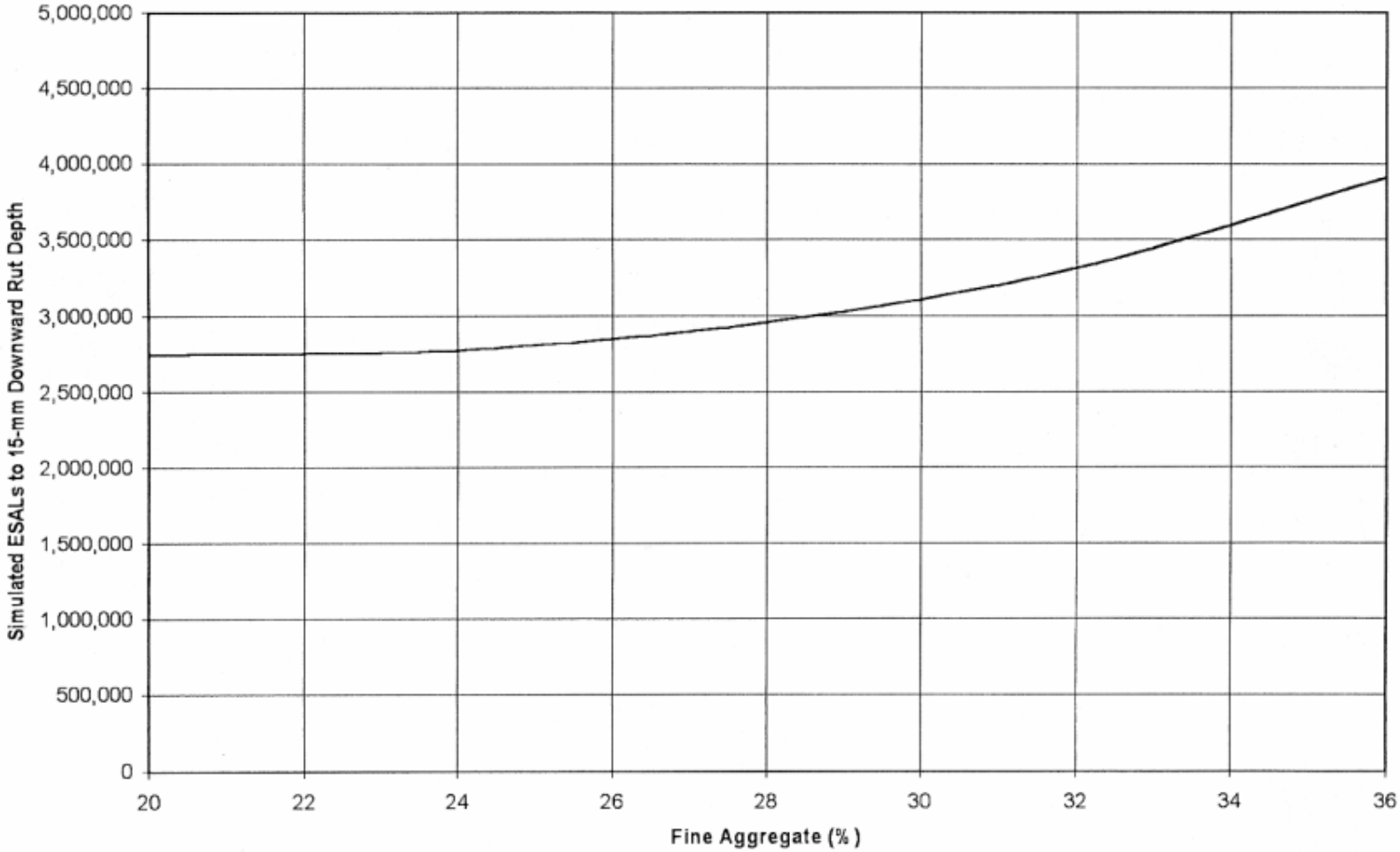


Figure 3.21. Simulated ESALs to rut depth of 15 mm (0.6 in.) versus fine aggregate content; P_{Wasp} = 5.5%, V_{air} = 6.5%; P_{200} = 6.5%.

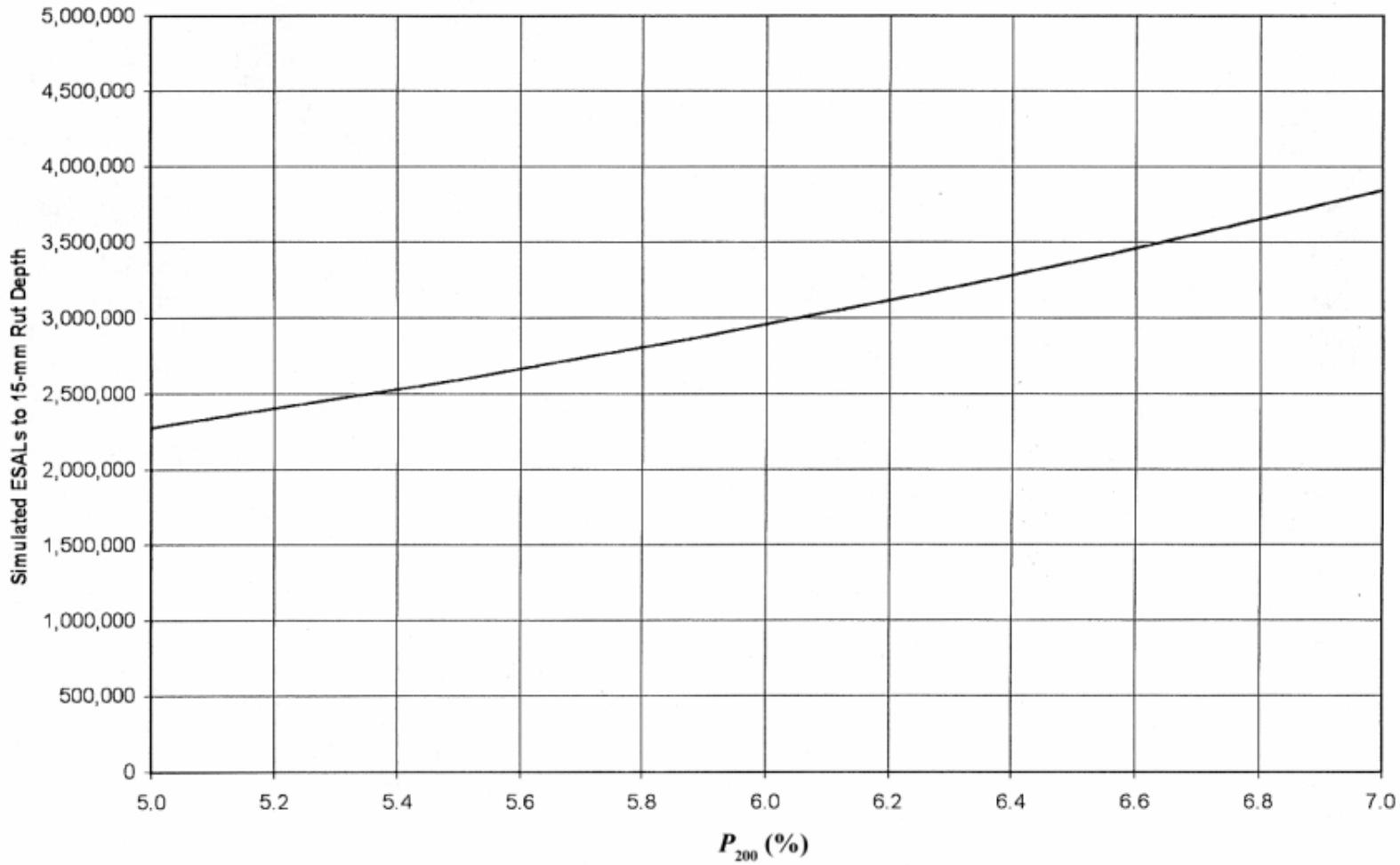


Figure 3.22. Simulated ESALs to rut depth of 15 mm (0.6 in.) versus P_{200} content; P_{Wasp} = 5.5%, V_{air} = 6.5%; fine aggregate content = 28.0%.

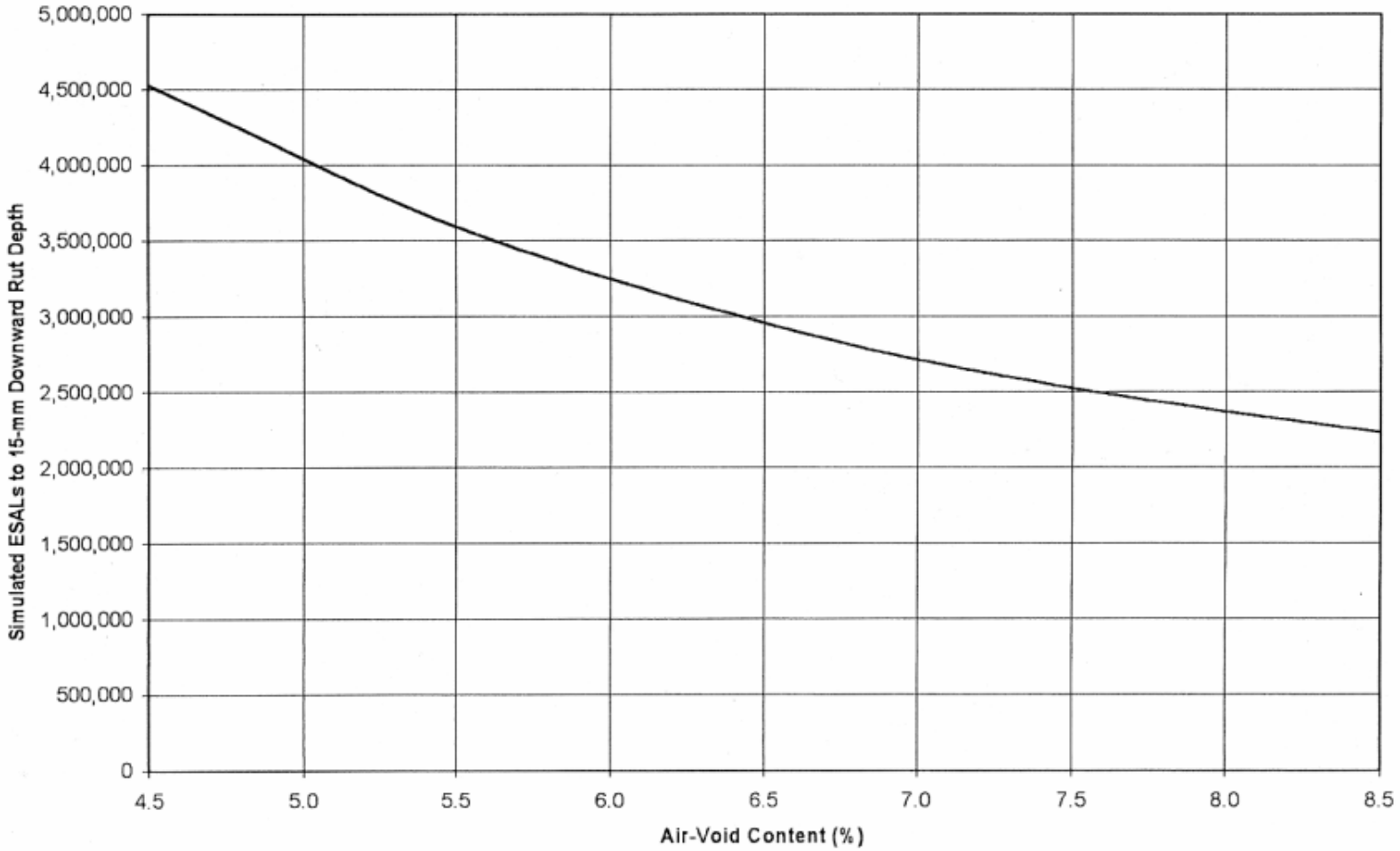


Figure 3.23. Simulated ESALs to rut depth of 15 mm (0.6 in.) versus air-void content; P_{Wasp} = 5.5%, P_{200} = content 6.0%; fine aggregate content = 28%.

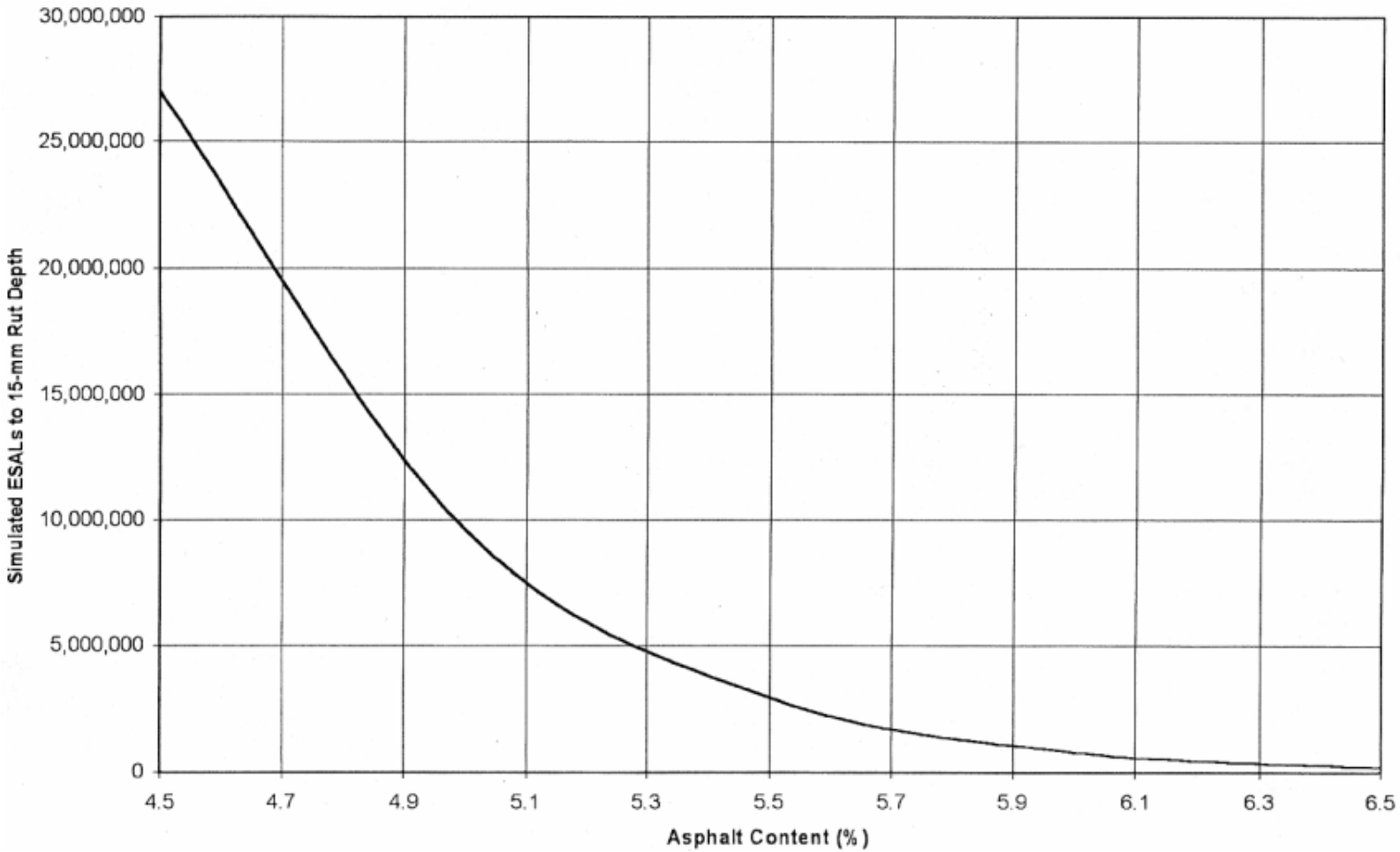


Figure 3.24. Simulated ESALs to rut depth of 15 mm (0.6 in.) versus asphalt content; V_{air} = 6.5%, P_{200} content = 6.0%; fine aggregate content = 28%.

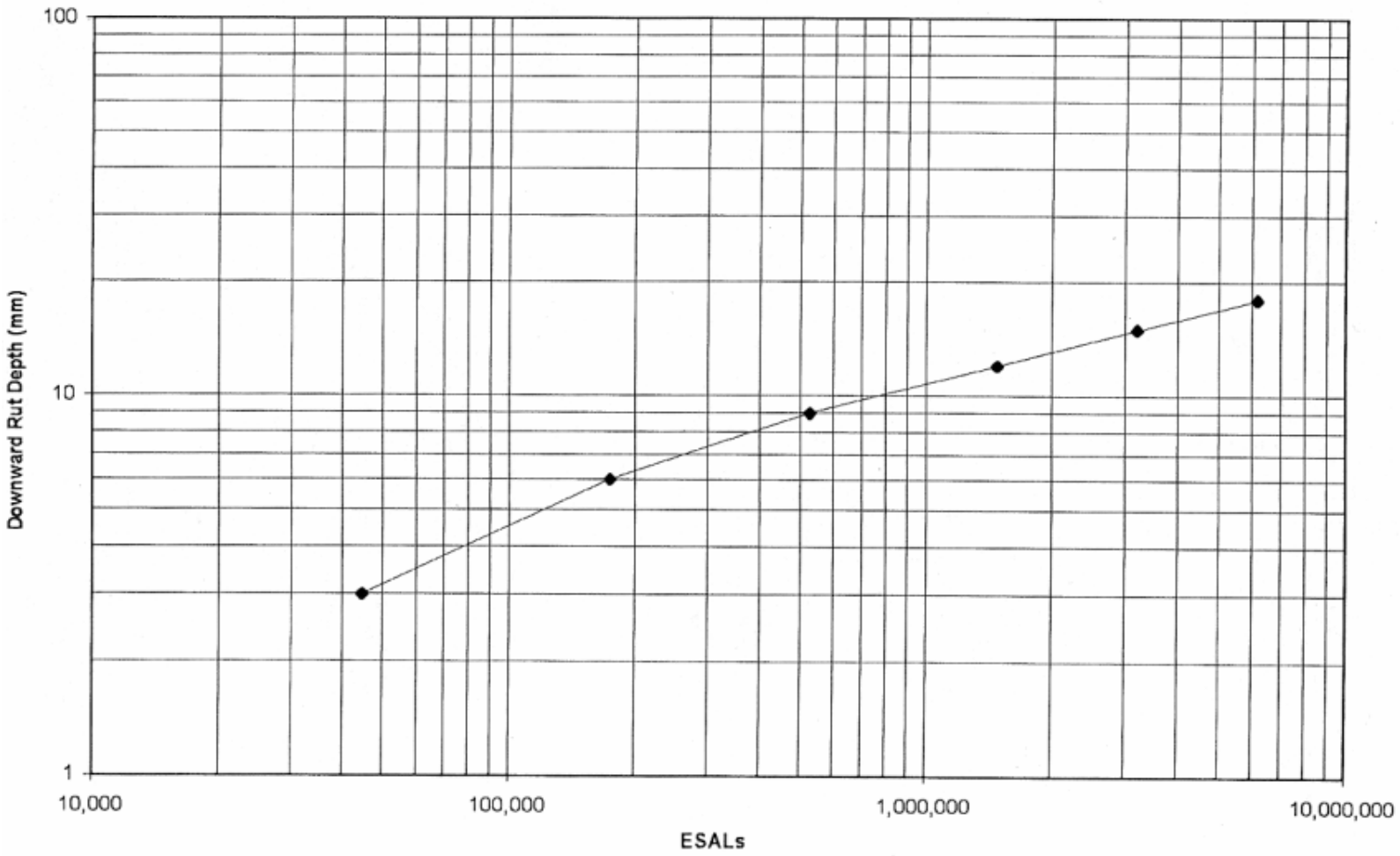


Figure 3.25. Simulated rut depth versus ESALs; P_{Wasp} = 5.5%, V_{air} = 6.5%, P_{200} 6.0%; fine aggregate content = 28% (1 in. = 25.4 mm).

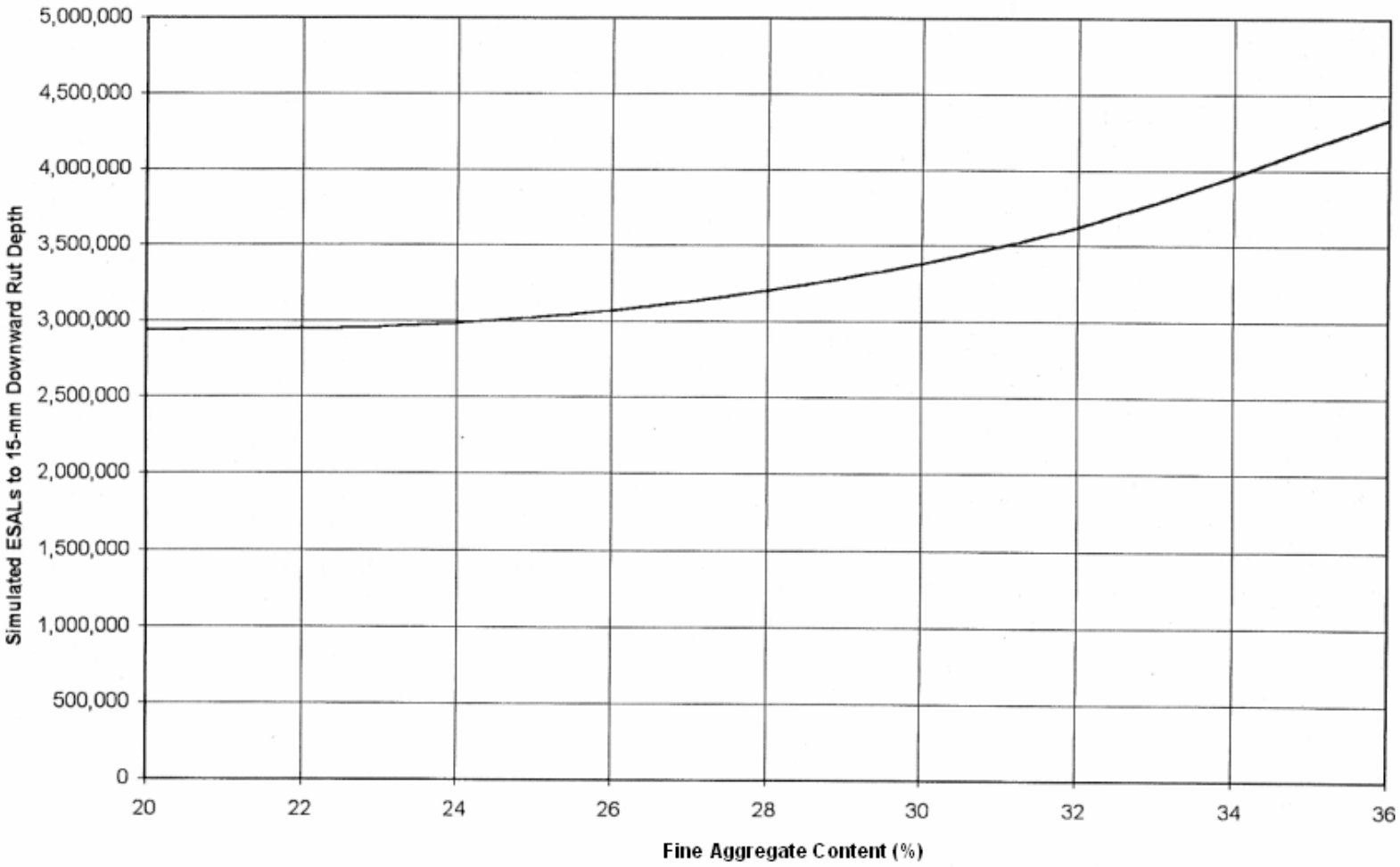


Figure 3.26. Effect of mix variables on simulated ESALs to 15-mm (0.6-in.) rut depth for a range in fine aggregate contents; P_{Wasp} = 5.5%; V_{air} = 6.5 %; P_{200} = 6.0 %.

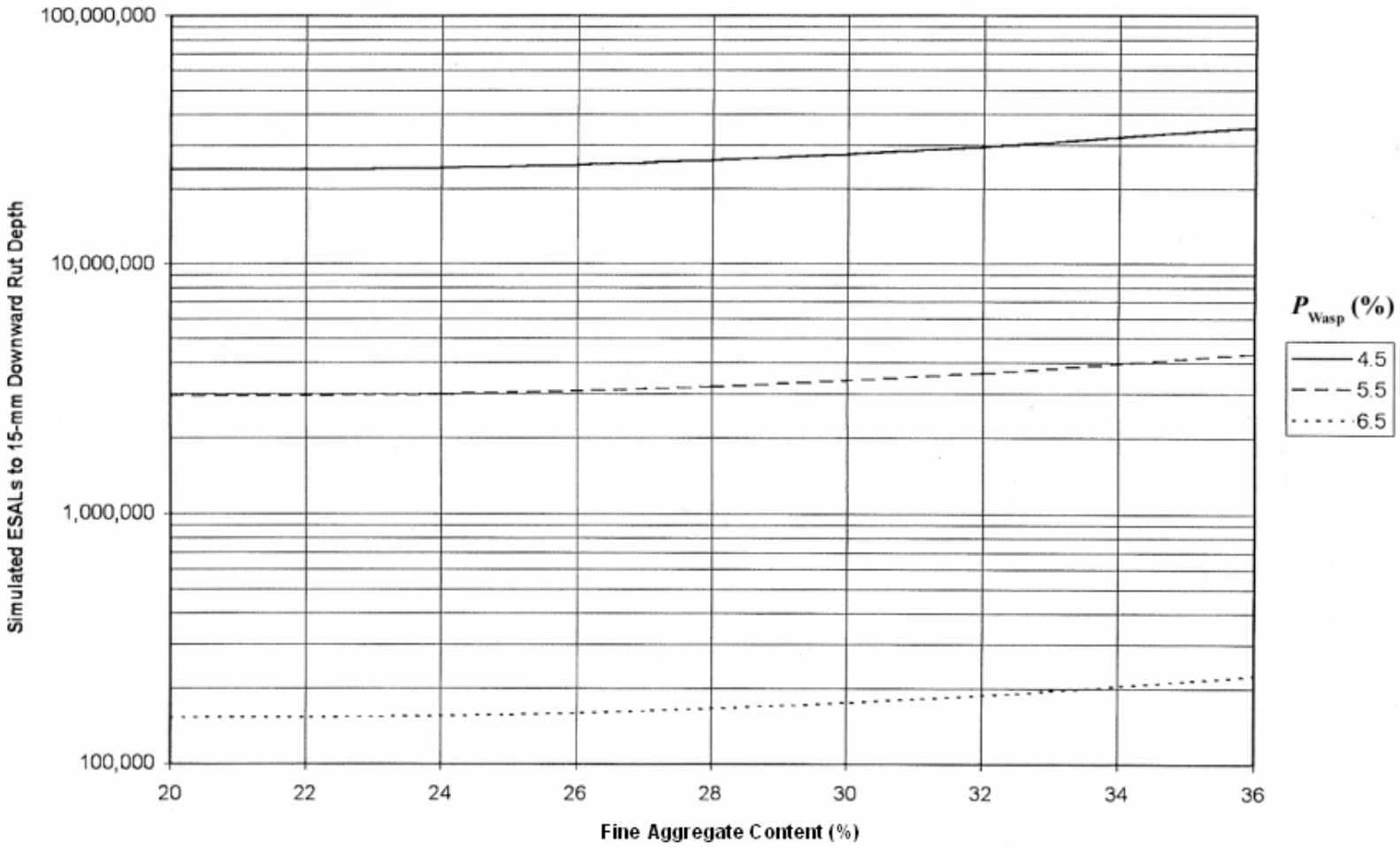


Figure 3.27. Effect of mix variables on simulated ESALs to 15-mm (0.6-in.) rut depth for a range in fine aggregate contents; V_{air} = 6.5%; P_{200} = 6.0%.

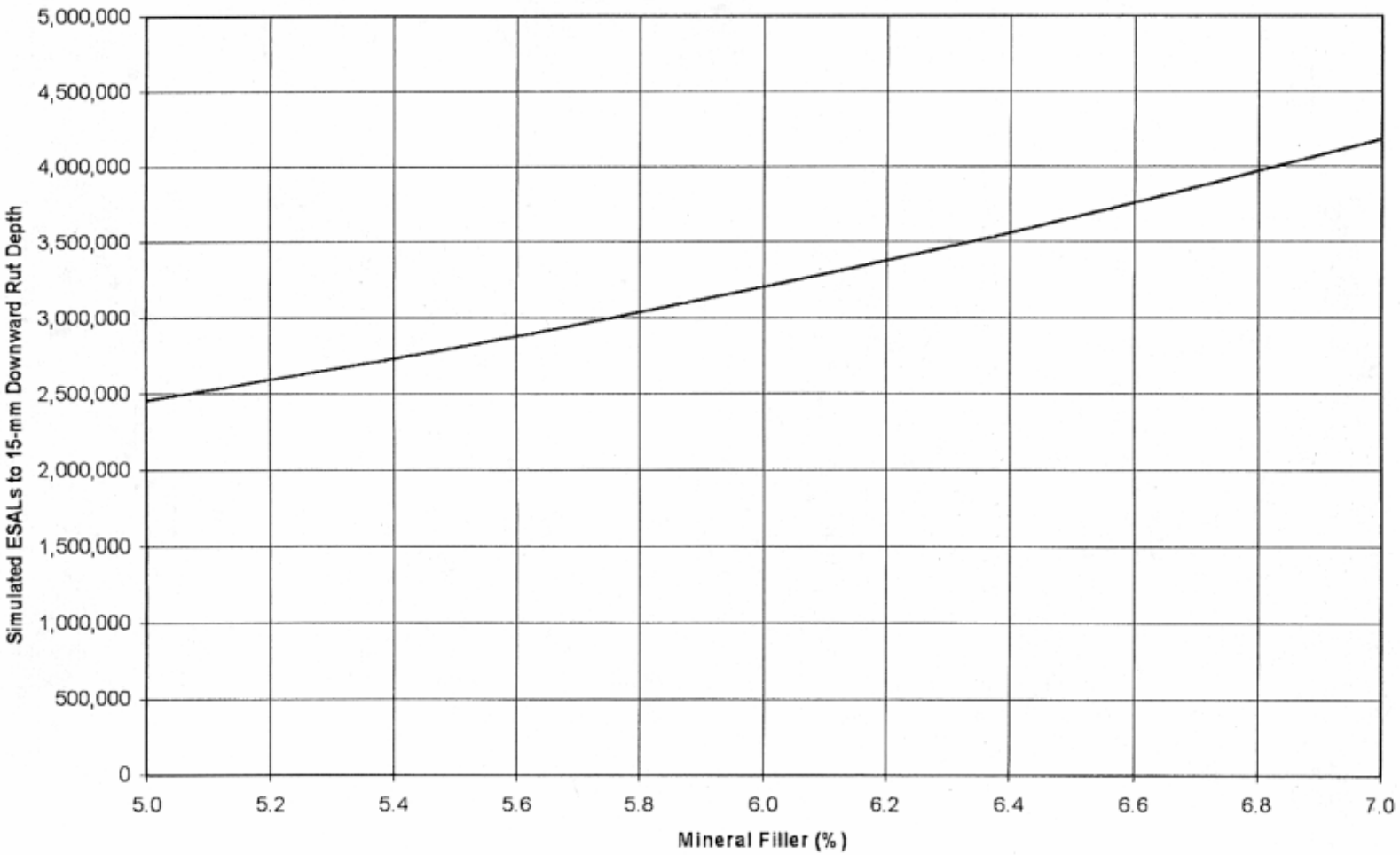


Figure 3.28. Effect of mix variables on simulated ESALs to 15-mm (0.6-in.) rut depth for a range in P_{200}; P_{Wasp} = 5.5%; V_{air} = 6.5%; fine aggregate content = 28%.

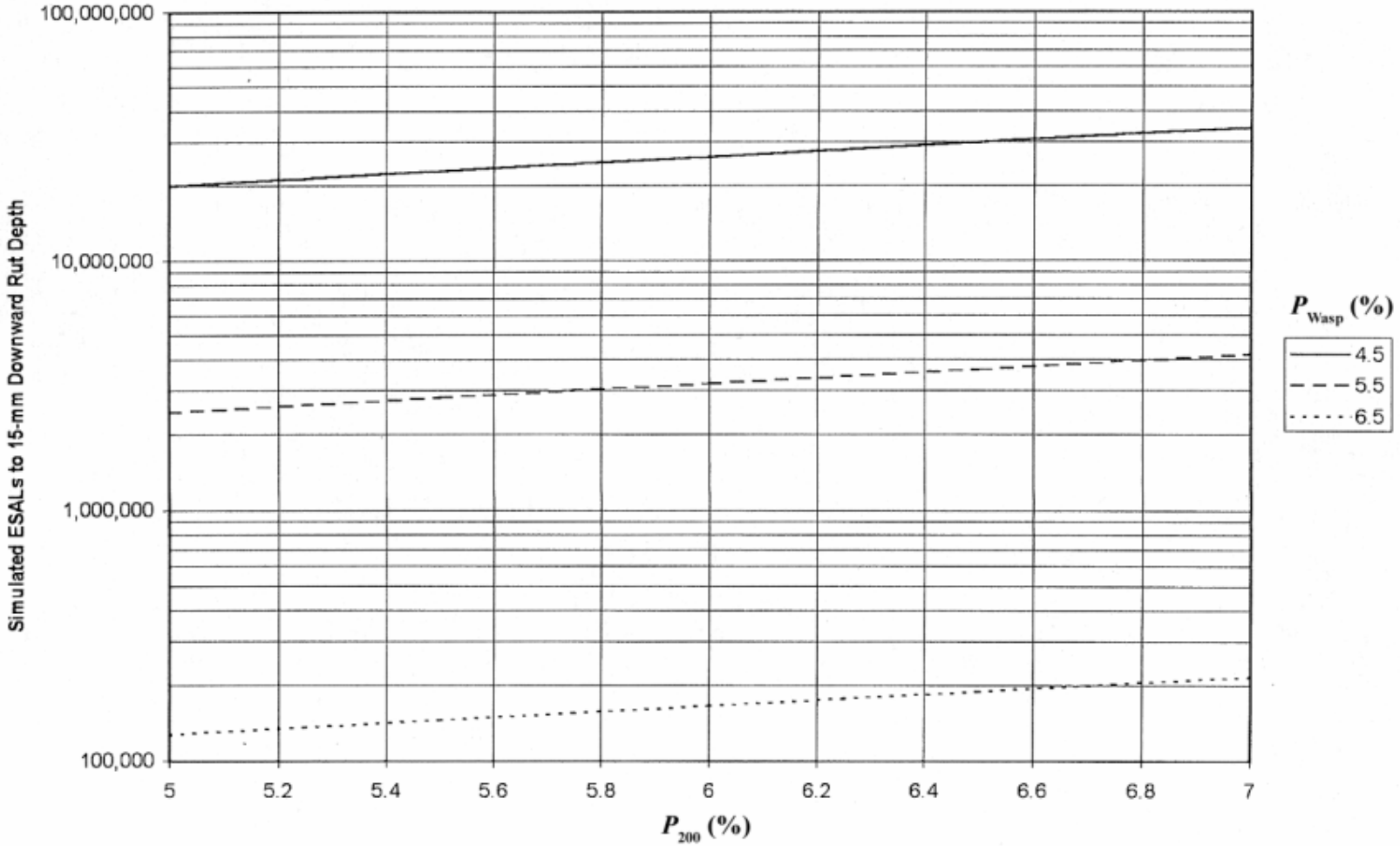


Figure 3.29. Effect of mix variables on simulated ESALs to 15-mm (0.6-in.) rut depth for a range in P_{200}; V_{air} = 6.5%; fine aggregate content = 28%.

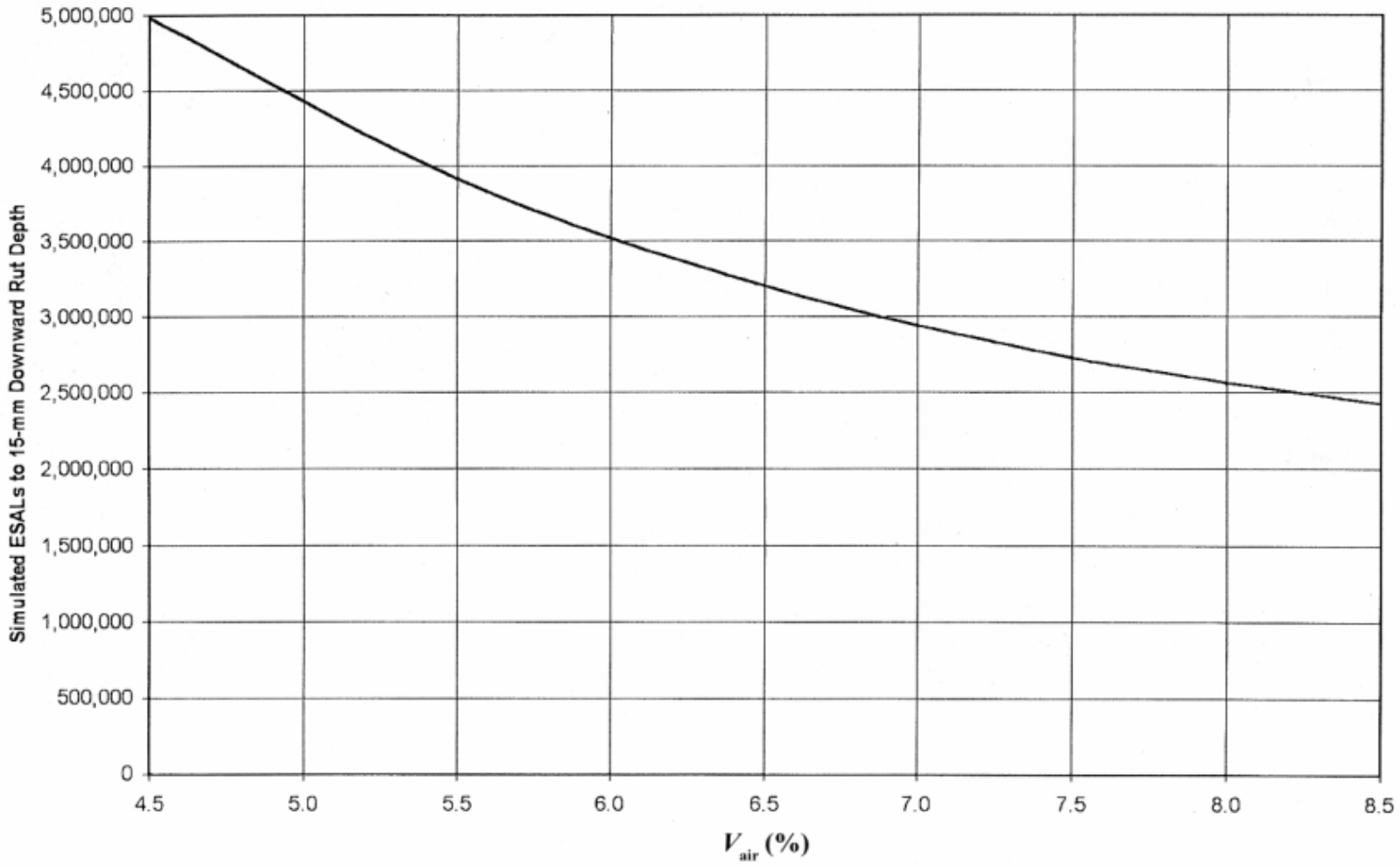


Figure 3.30. Effect of mix variables on simulated ESALs to 15-mm (0.6-in.) rut depth for a range in air-void contents; P_{Wasp} = 5.5%; P_{200} = 6.0%; fine aggregate content = 28%.

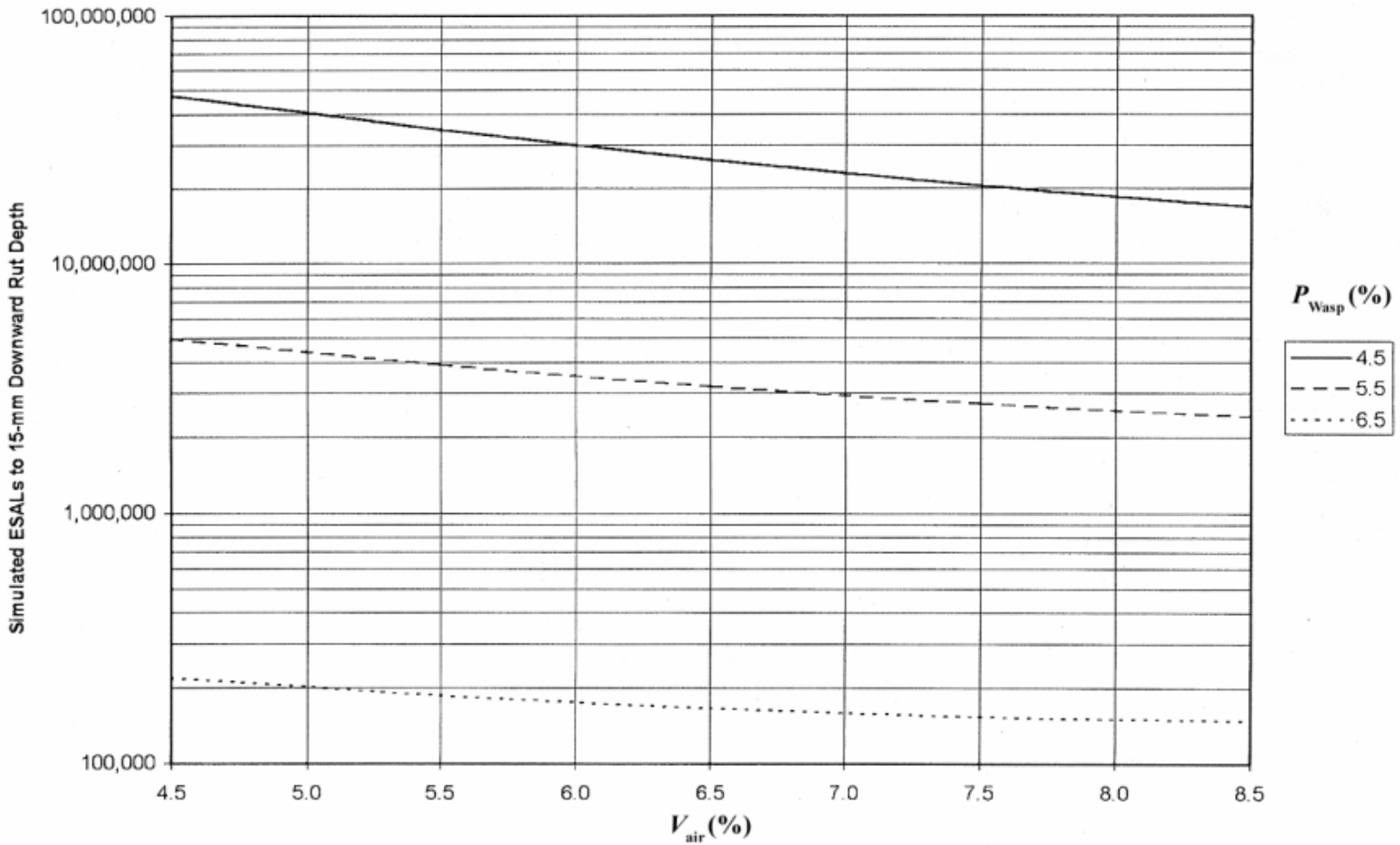


Figure 3.31. Effect of mix variables on simulated ESALs to 15-mm (0.6-in.) rut depth for a range in air-void contents; P_{200} = 6.0%; fine aggregate content = 28%.

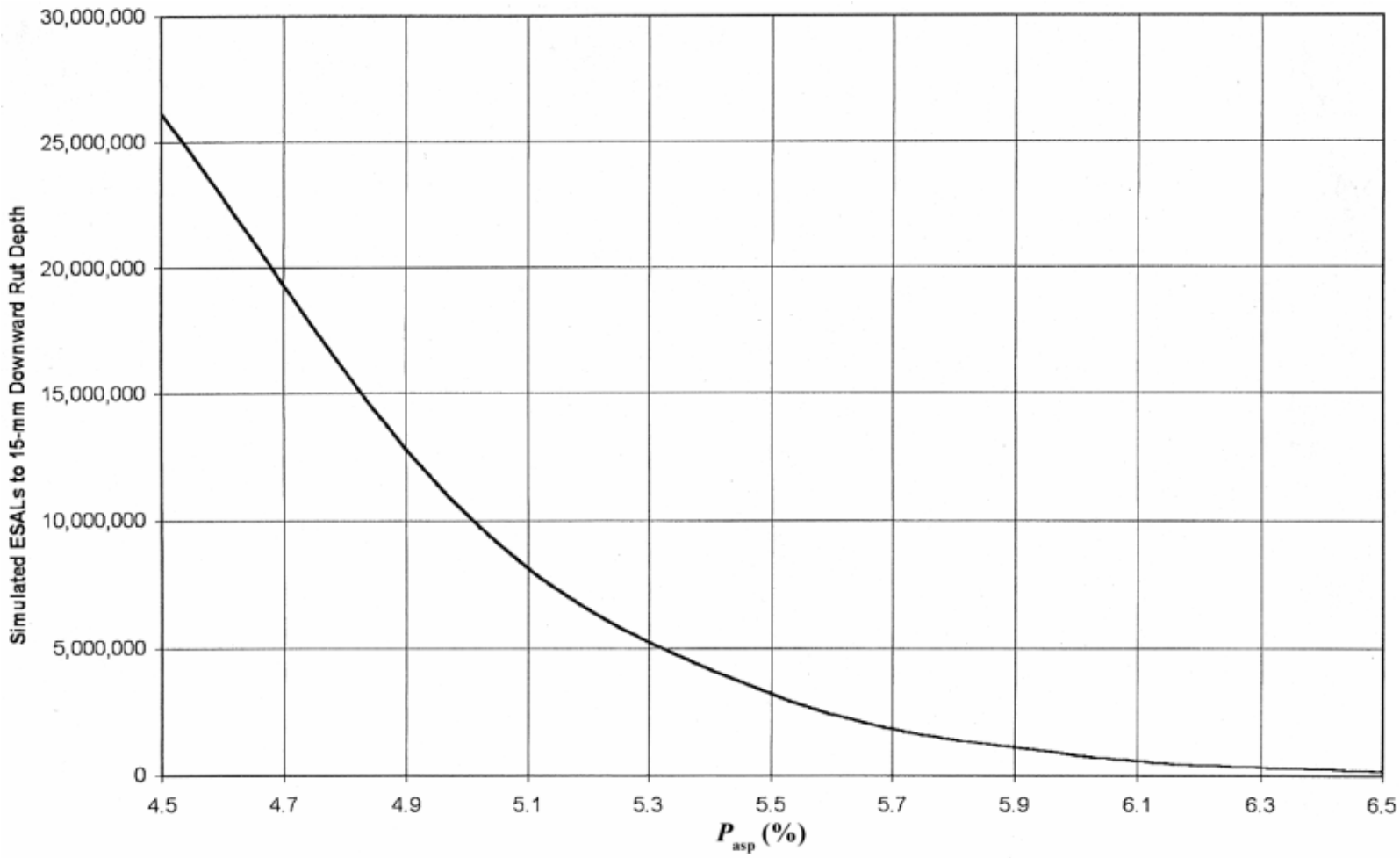


Figure 3.32. Effect of mix variables on simulated ESALs to 15-mm (0.6-in.) rut depth for a range in asphalt contents; V_{air} = 6.5%; P_{200} = 6.0 %; fine aggregate content = 28%.

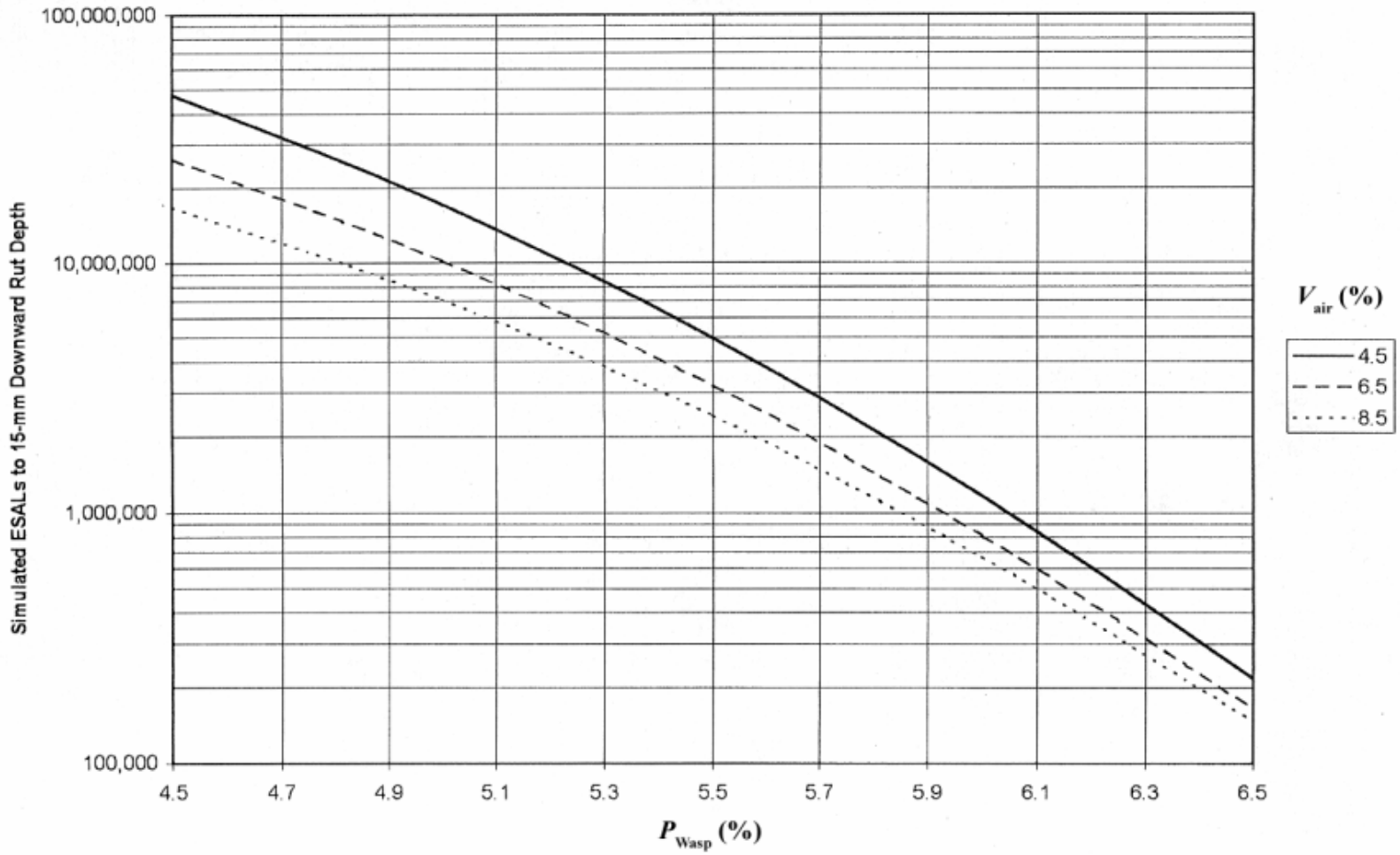


Figure 3.33. Effect of mix variables on simulated ESALs to 15-mm (0.6-in.) rut depth for a range in asphalt contents; P_{200} = 6.0%; fine aggregate content = 28%.

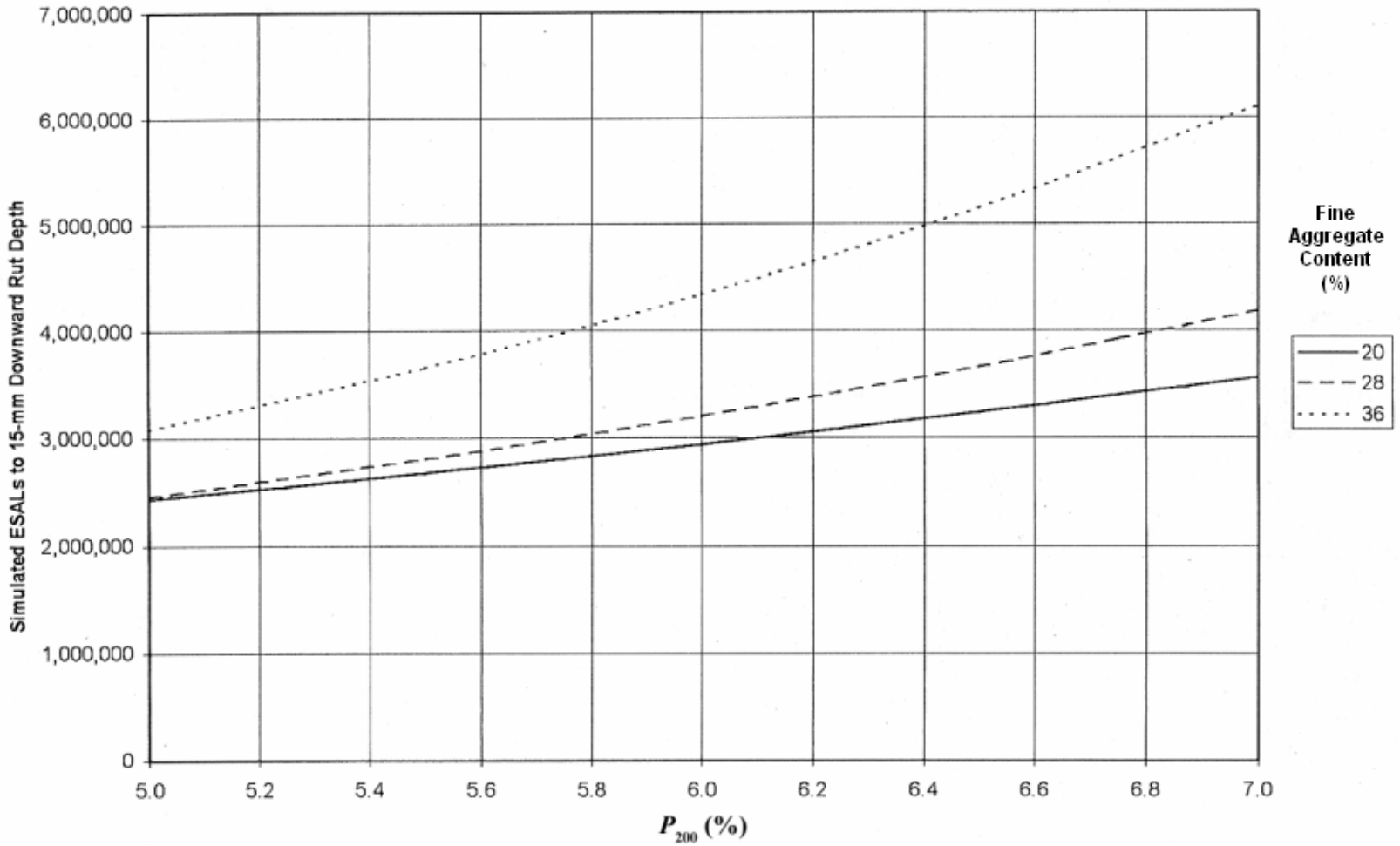


Figure 3.34. Effect of mix variables on simulated ESALs to 15-mm (0.6-in.) rut depth for a range in P_{200}; P_{Wasp} = 5.5%; V_{air} = 6.5%.

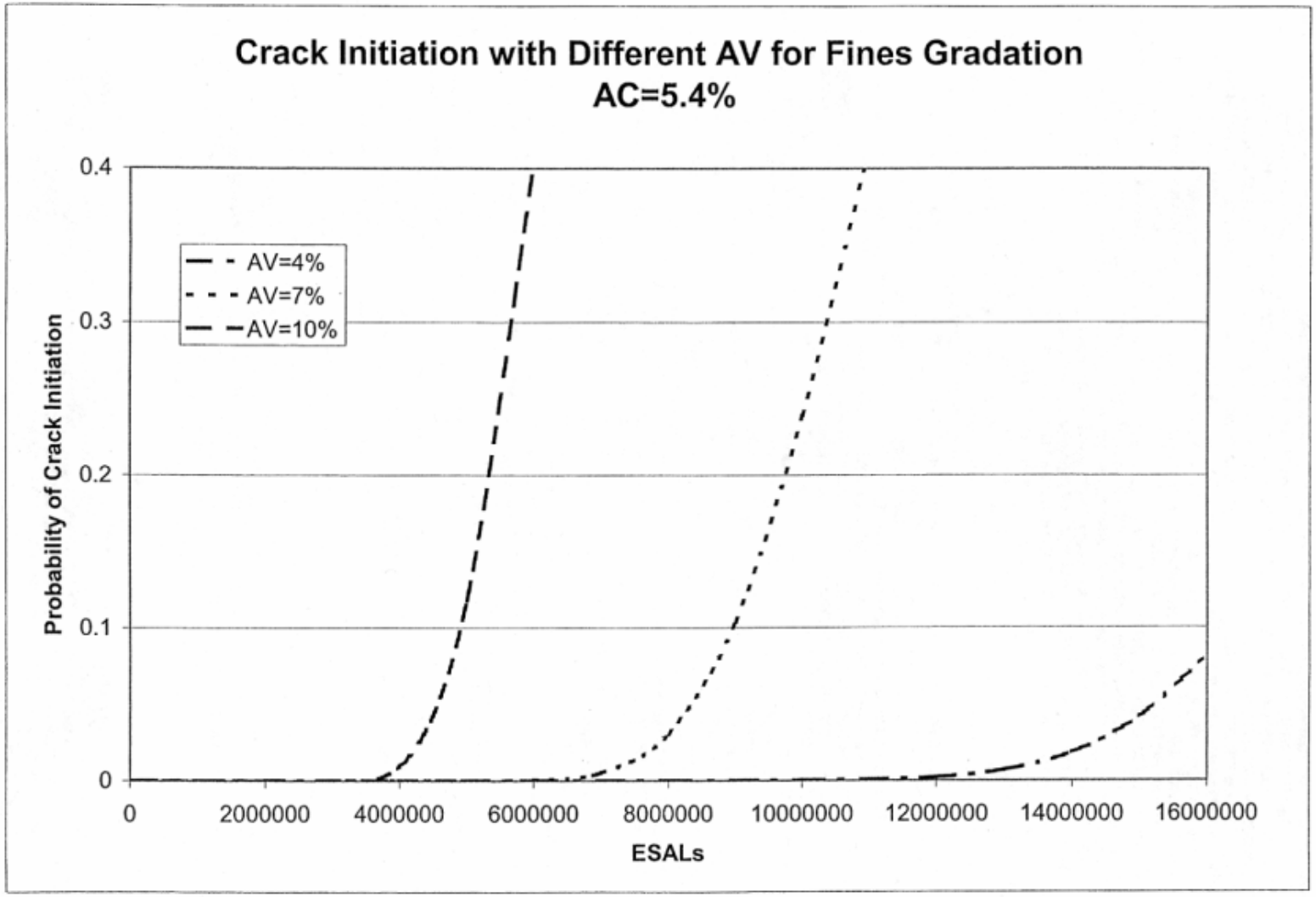


Figure 4.1. Probability of crack initiation verus ESALs for *fine* mix for a range in air-void contents; asphalt content = 5.4%.

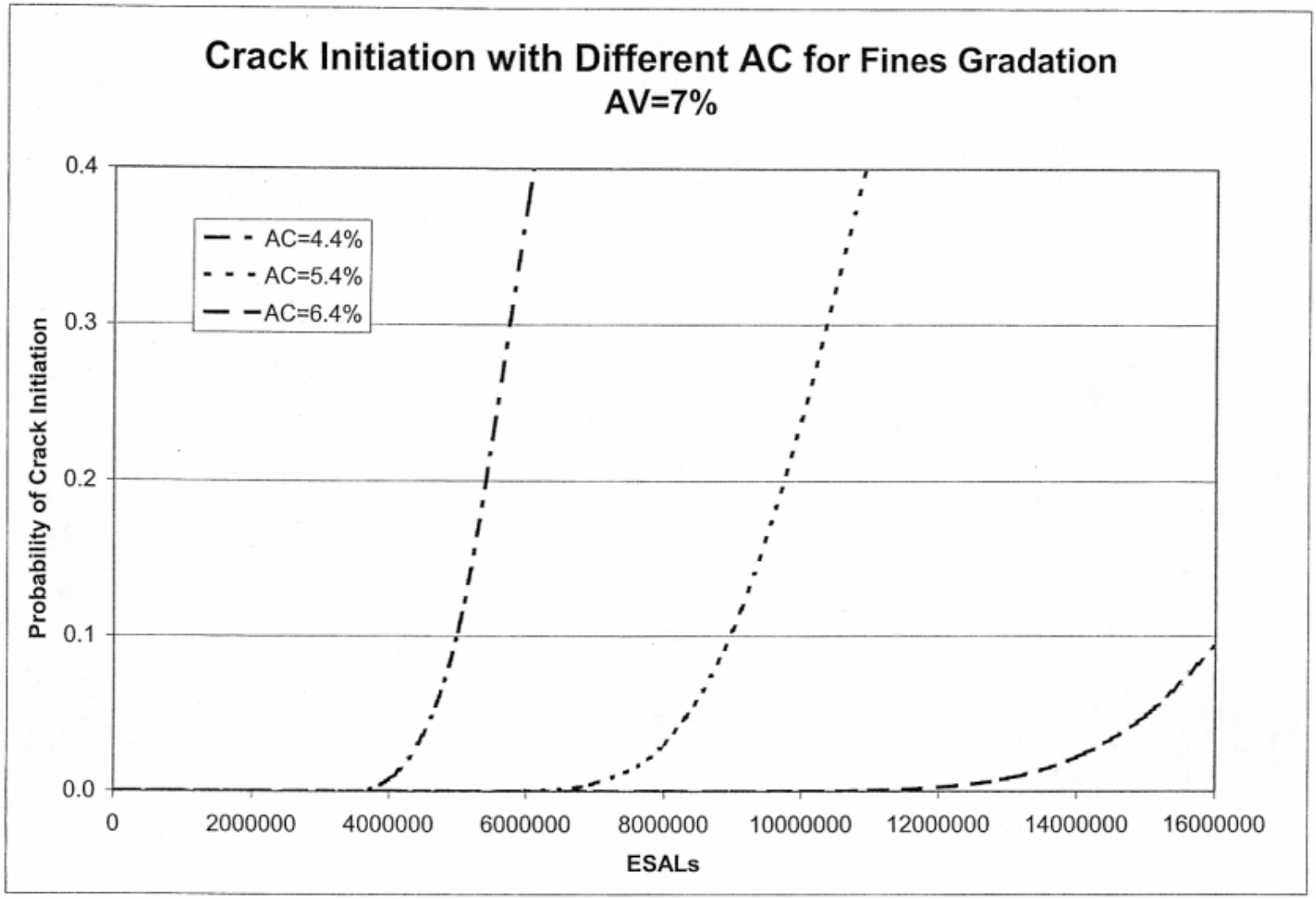


Figure 4.2. Probability of crack initiation versus ESALs for *fine* mix for a range in asphalt contents; air-void content = 7.0%.

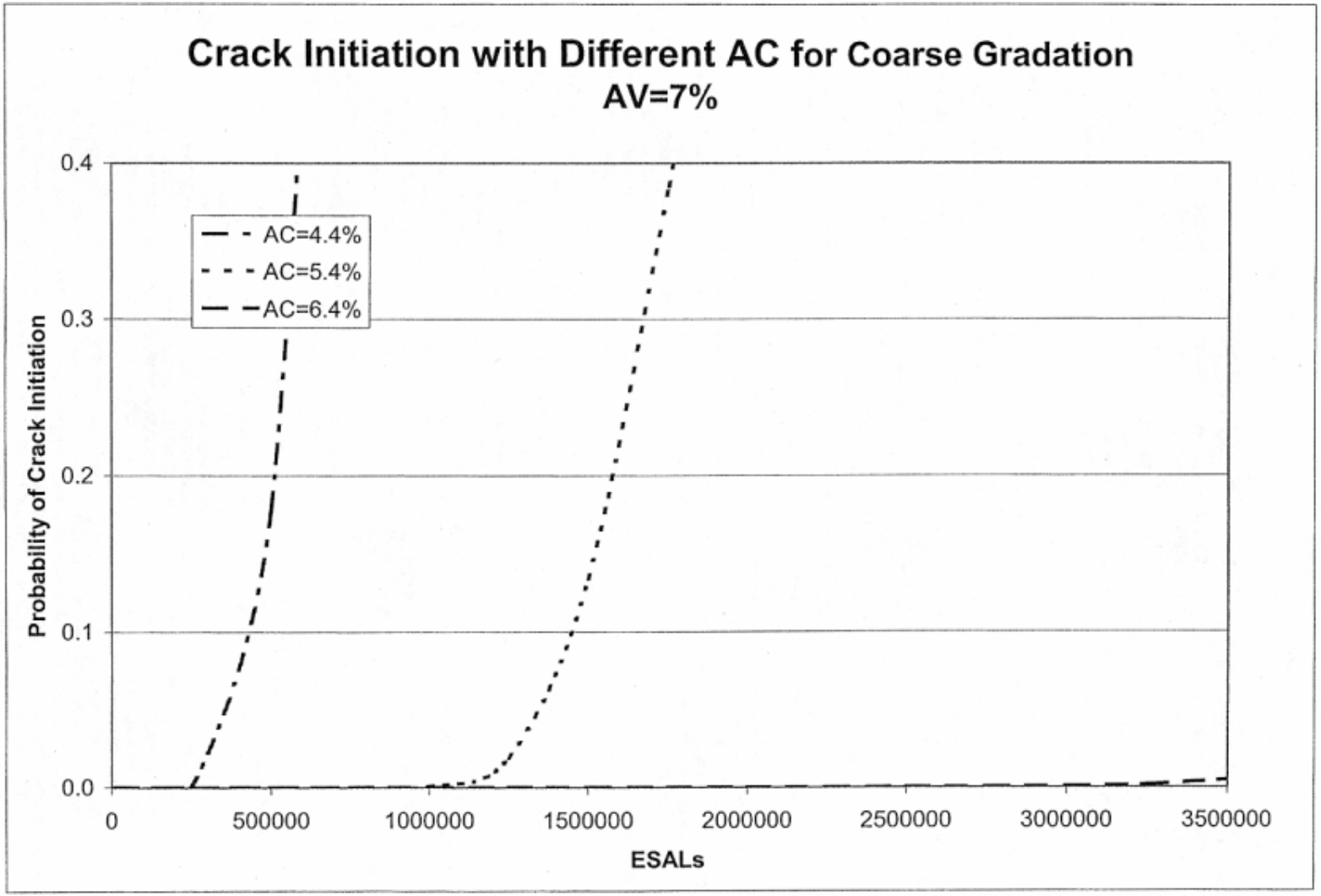


Figure 4.3. Probability of crack initiation versus ESALs for *coarse* mix for a range in asphalt contents; air-void content = 7.0%.

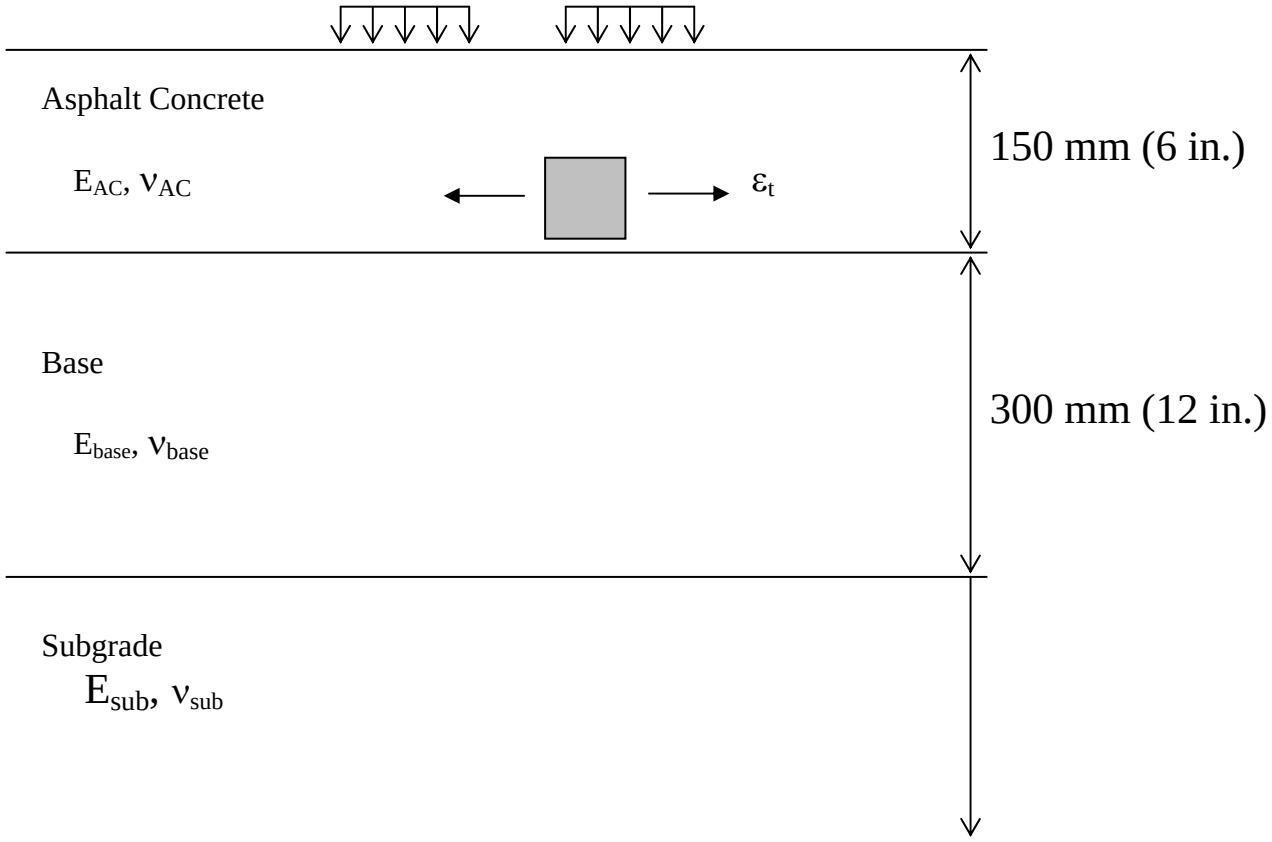


Figure 4.4. Pavement representation for mechanistic-empirical modeling for fatigue cracking.

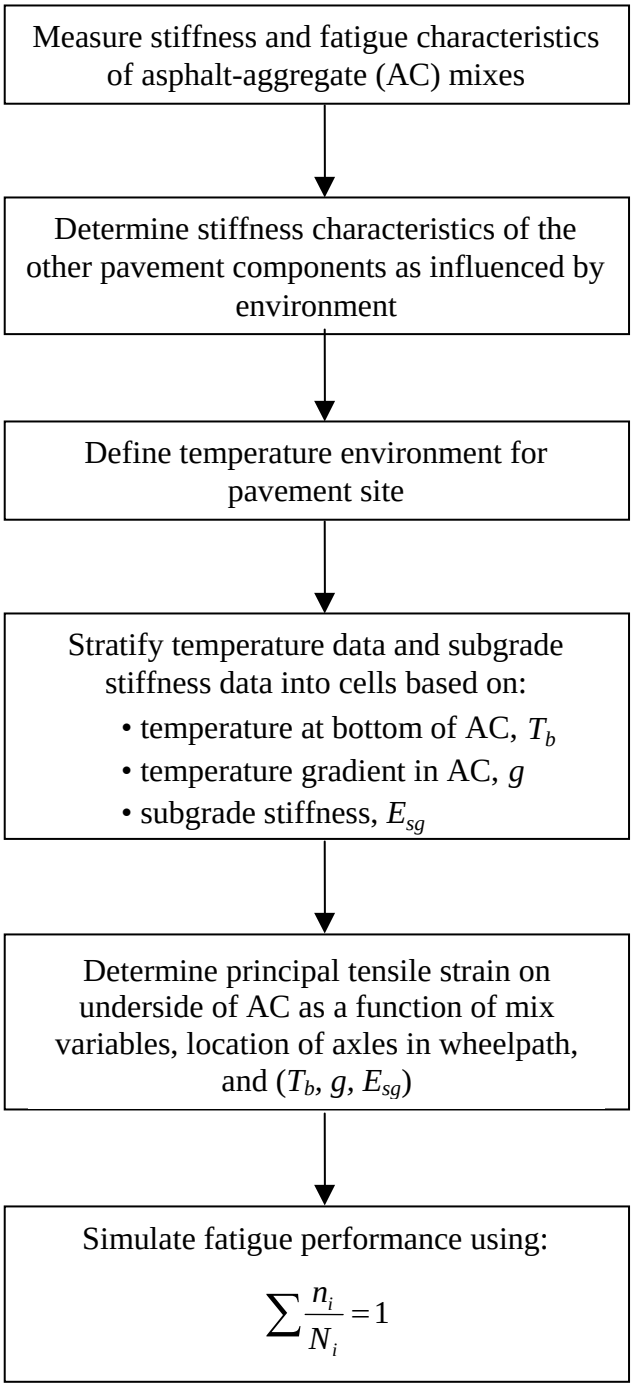


Figure 4.5. Framework for simulation of fatigue performance of 26 WesTrack sections.

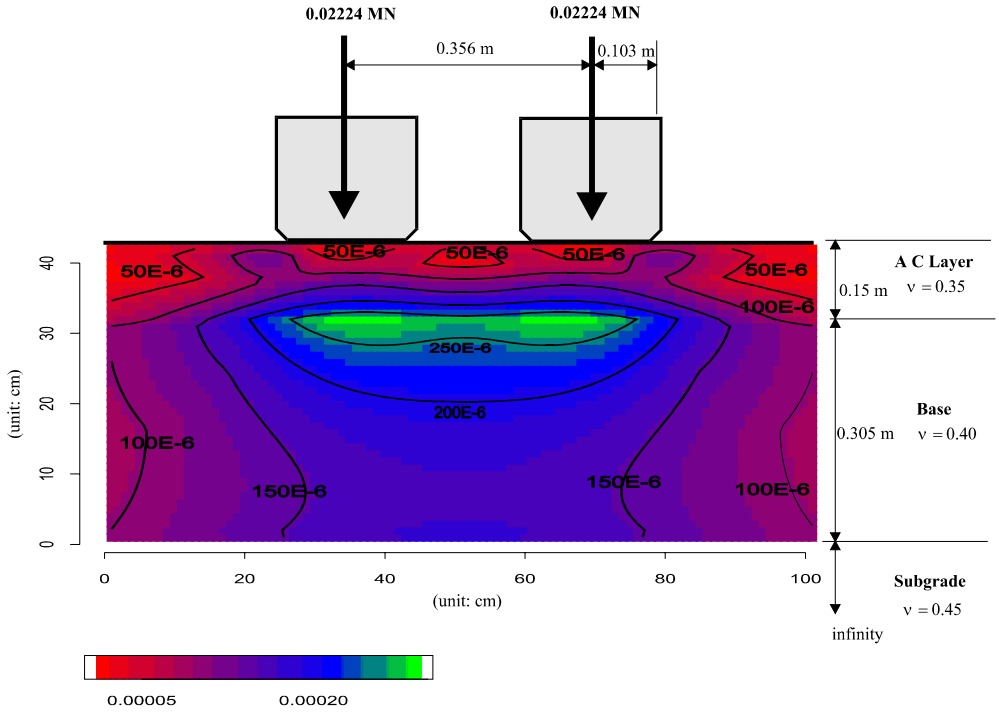


Figure 4.6. Strain distribution in pavement structure; T_b = 35 °C (95 °F) and g = 0.06 (1 in. = 25.4 mm; 1 lbf = 4.48 N).

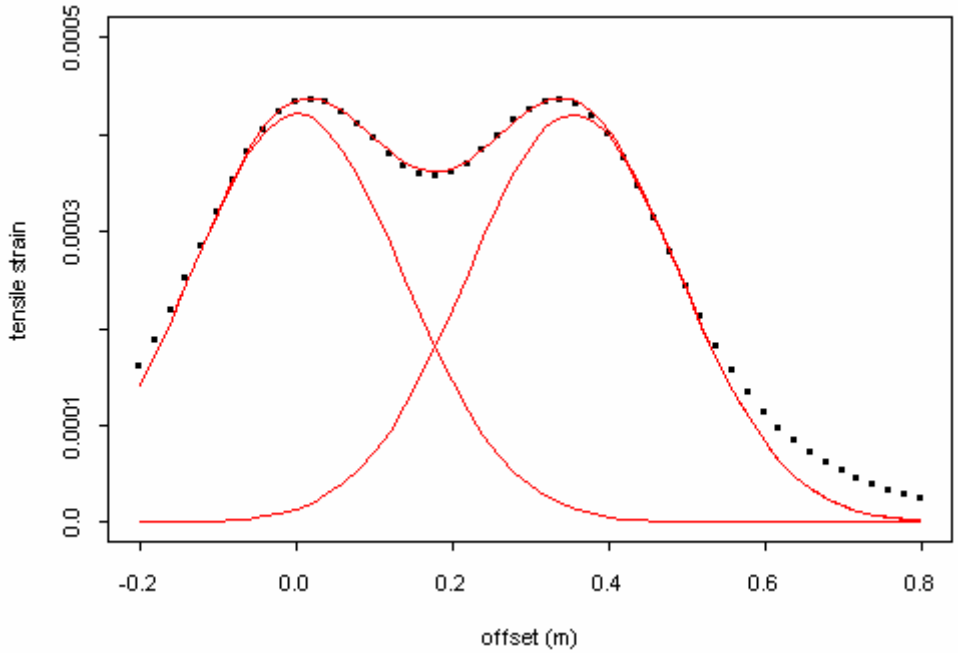


Figure 4.7. Comparison of the superimposition of two normal distributions with computed tensile strains (individual points) as a function of offset from dual wheel centerline; T_b = 41.0 °C (106 °F), g = 0.109, E_{sub} = 5.8 MPa (840 psi), V_{air} = 14.78%; P_{Wasp} = 6.22% (1 in. = 25.4 mm).

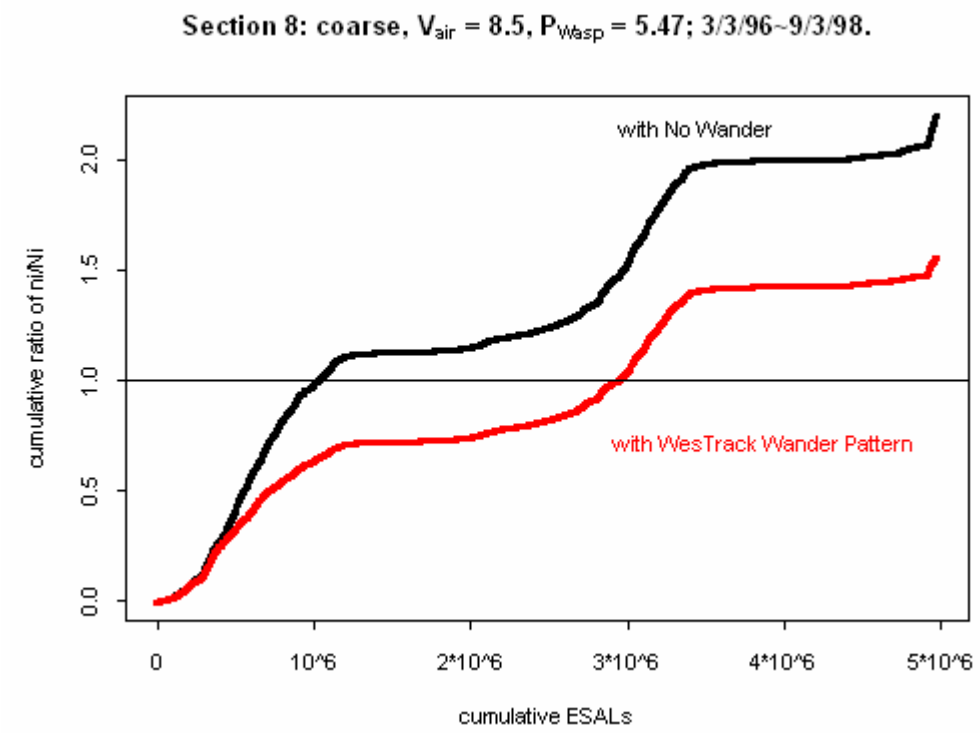


Figure 4.8. The development of fatigue damage in Section 8 with and without traffic wander.

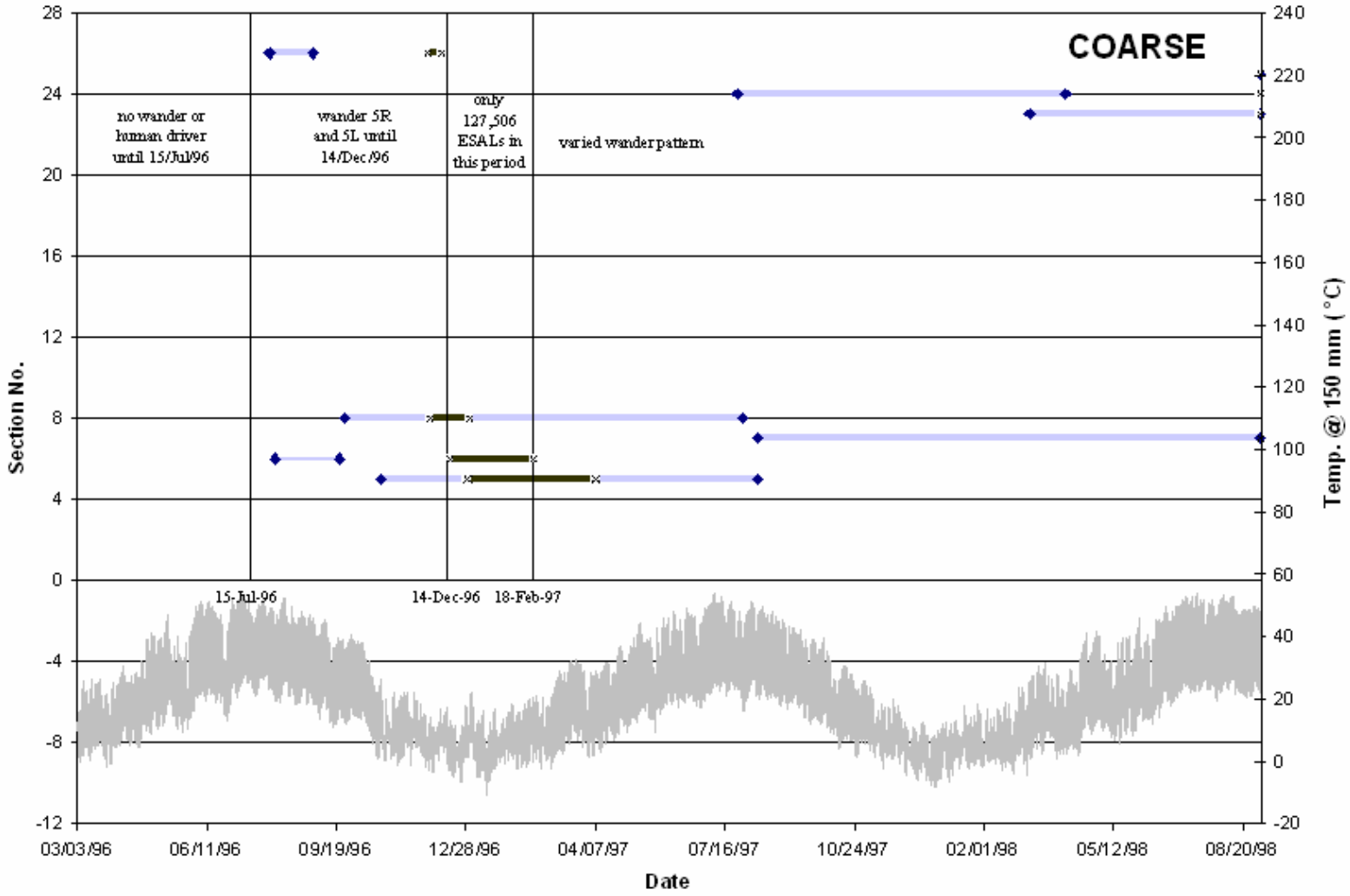


Figure 4.9. Fatigue performance prediction simulation and condition survey results for the *coarse* mixes, WesTrack (1 in. = 25.4 mm; °F = 1.8 °C + 32).

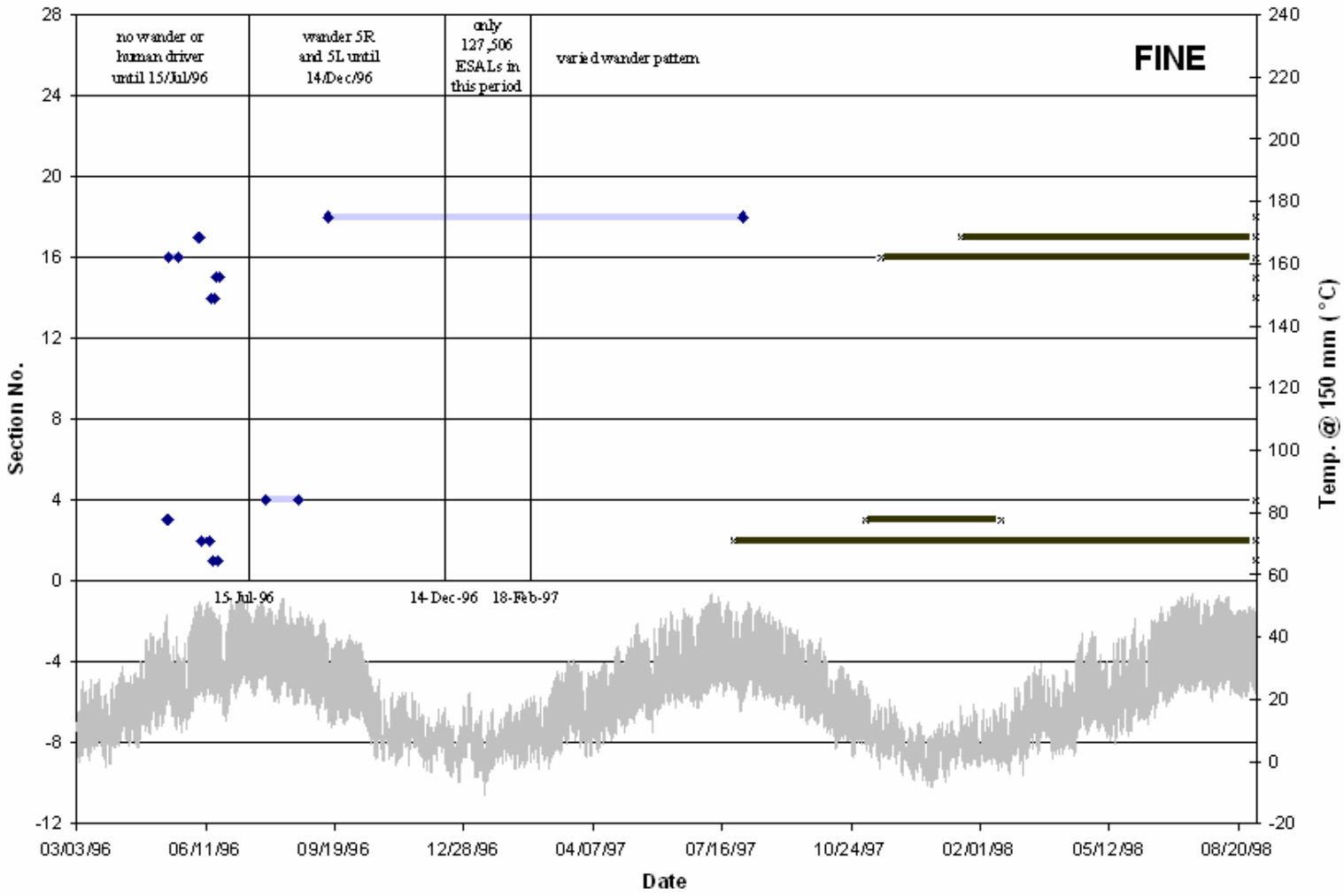


Figure 4.10. Fatigue performance prediction simulation and condition survey results for the *fine* mixes, WesTrack (1 in. = 25.4 mm; °F = 1.8 °C + 32).

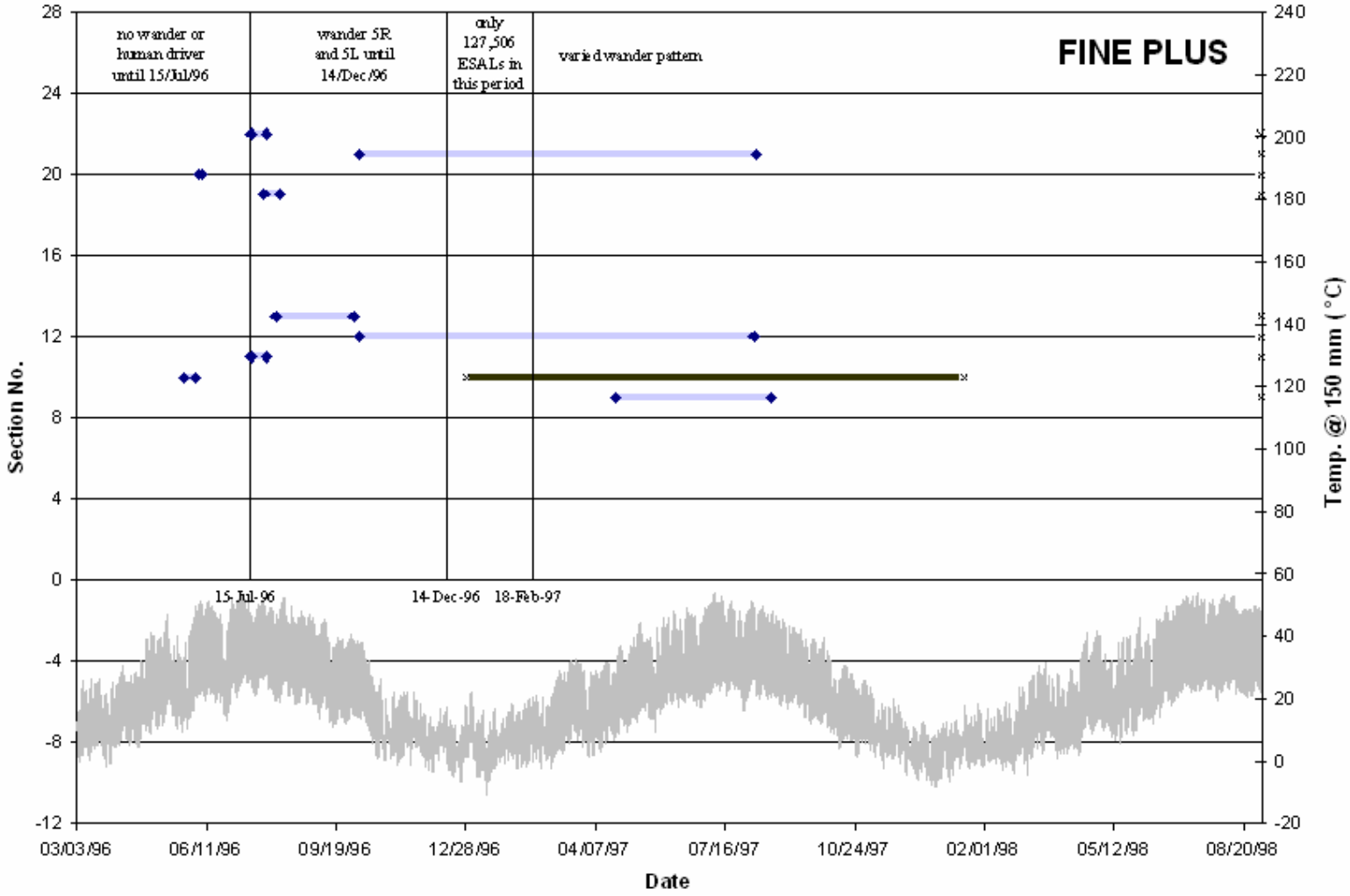


Figure 4.11. Fatigue performance prediction simulation and condition survey results for the *fine-plus* mixes, WesTrack (1 in. = 25.4 mm; °F = 1.8 °C + 32).

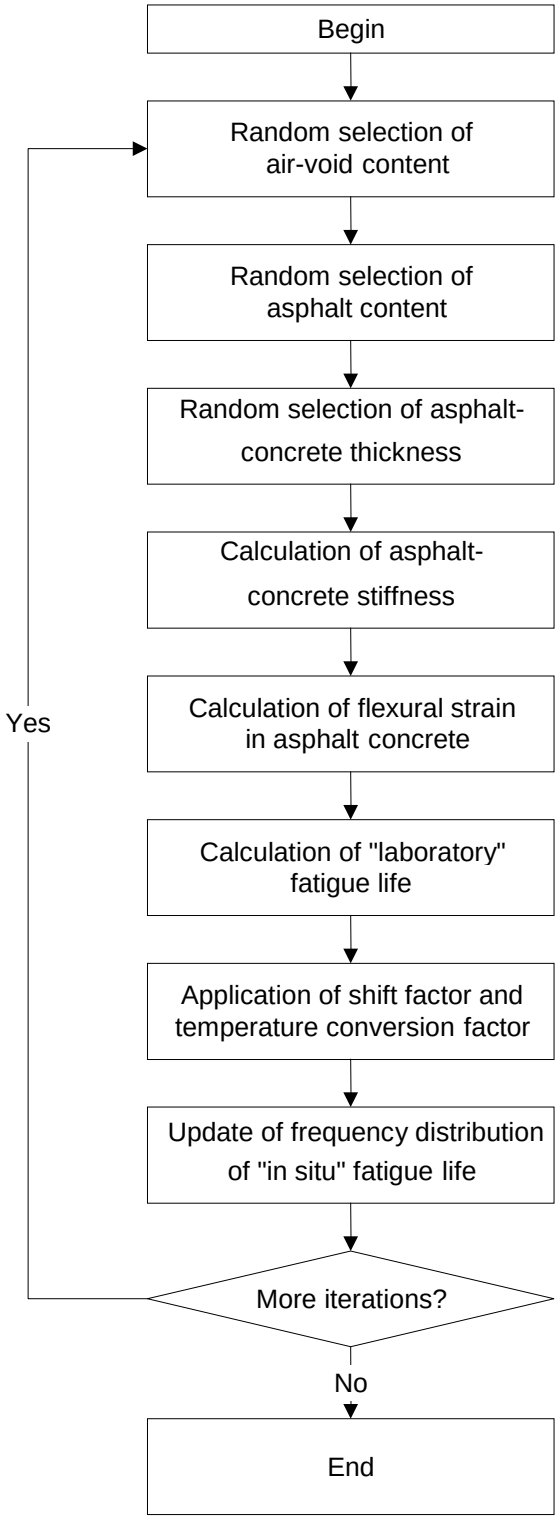


Figure 4.12. Outline of the pavement performance model simulation.

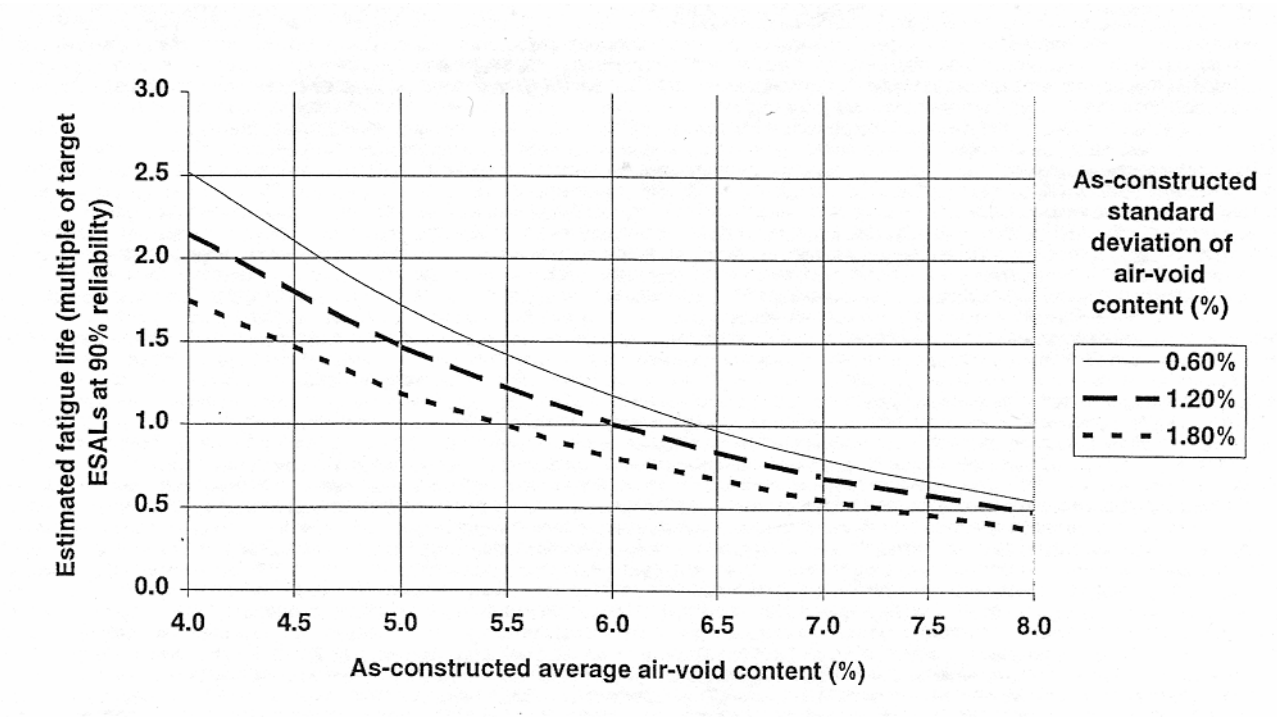
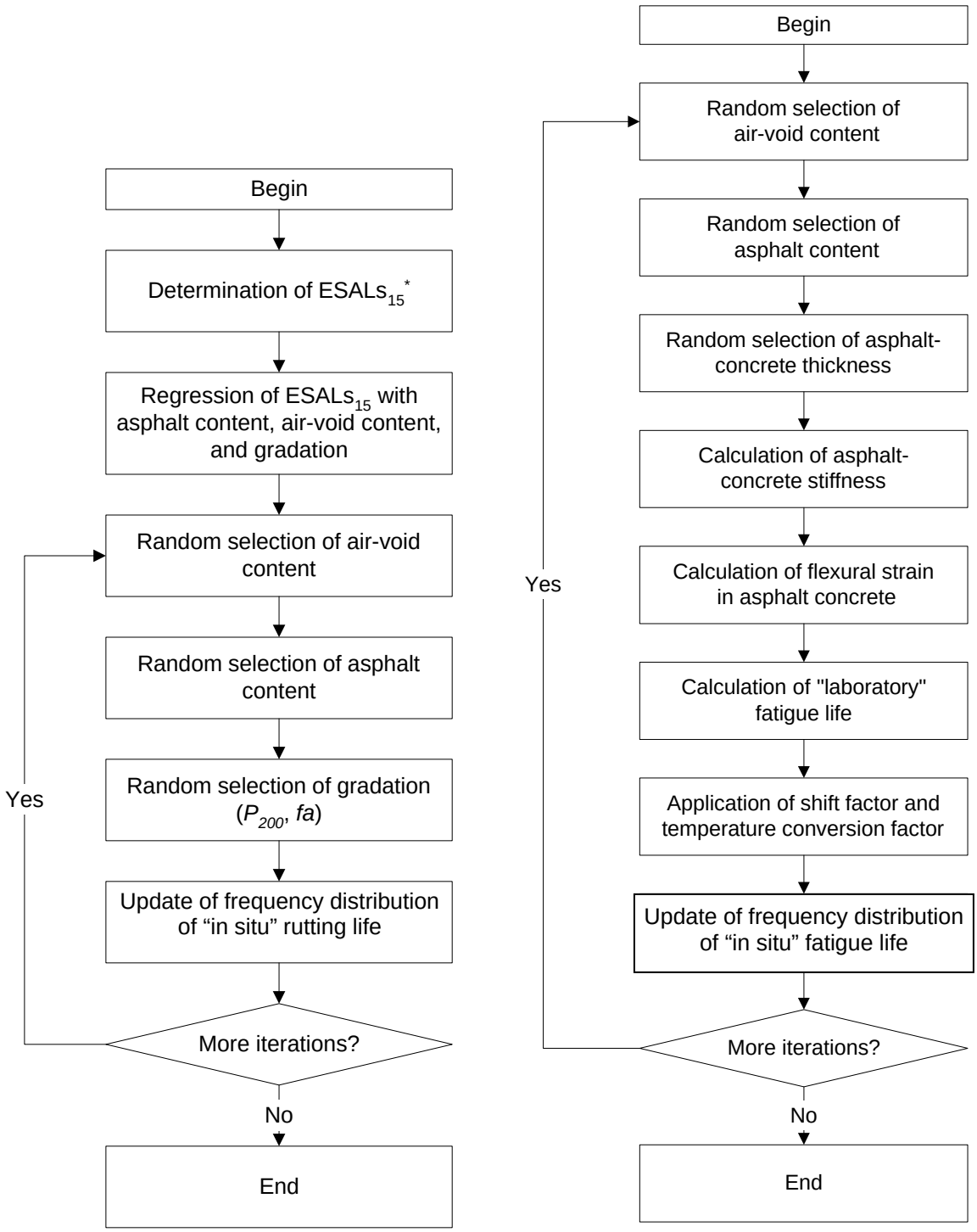


Figure 4.13. Effects of as-constructed air-void content on pavement fatigue performance.



a. Rutting **b. Fatigue Cracking**

*ESALs to a rut depth of 15 mm

Figure 5.1. Outlines of performance model simulations for rutting and fatigue cracking.

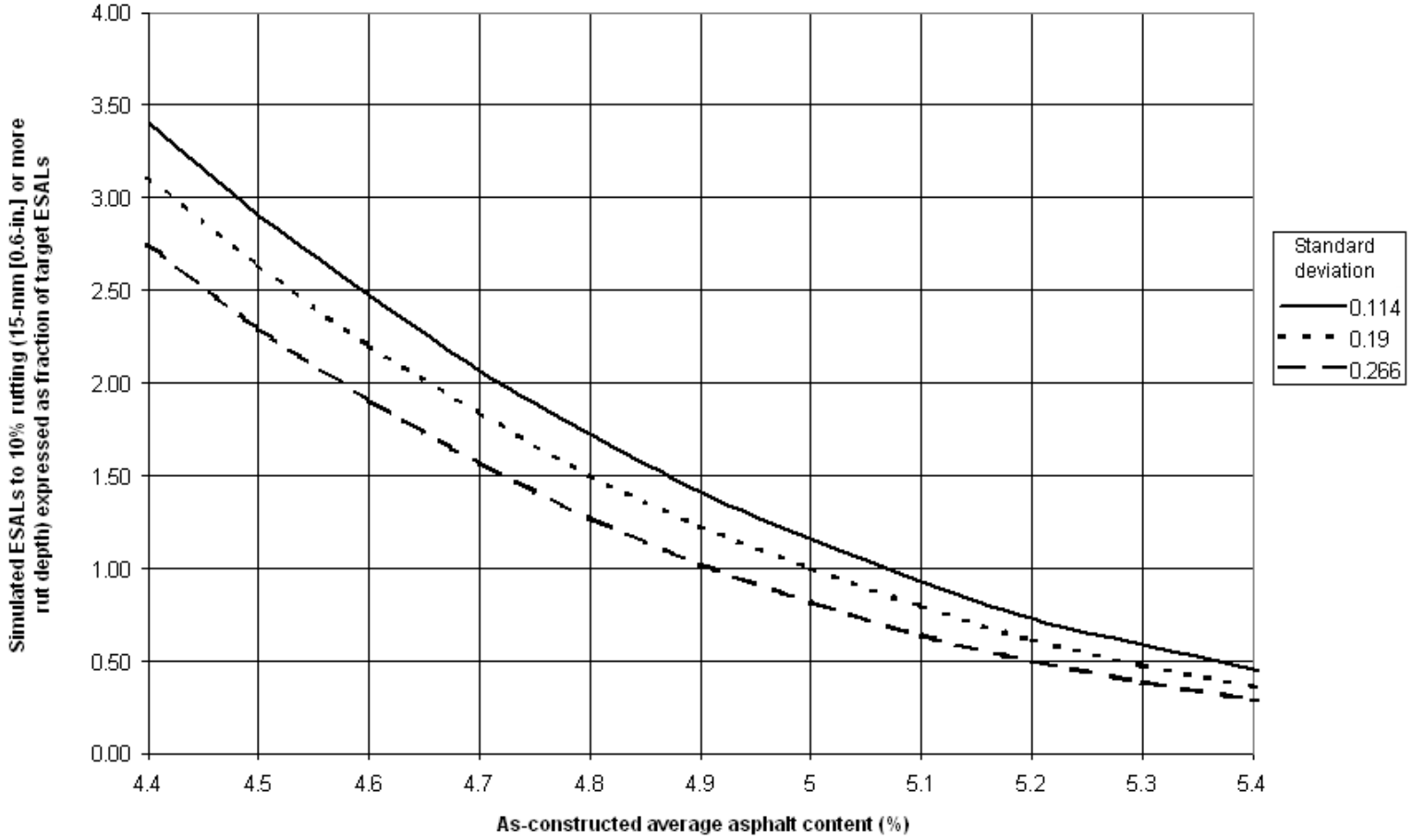


Figure 5.2. Influence of as-constructed asphalt content on rutting performance.

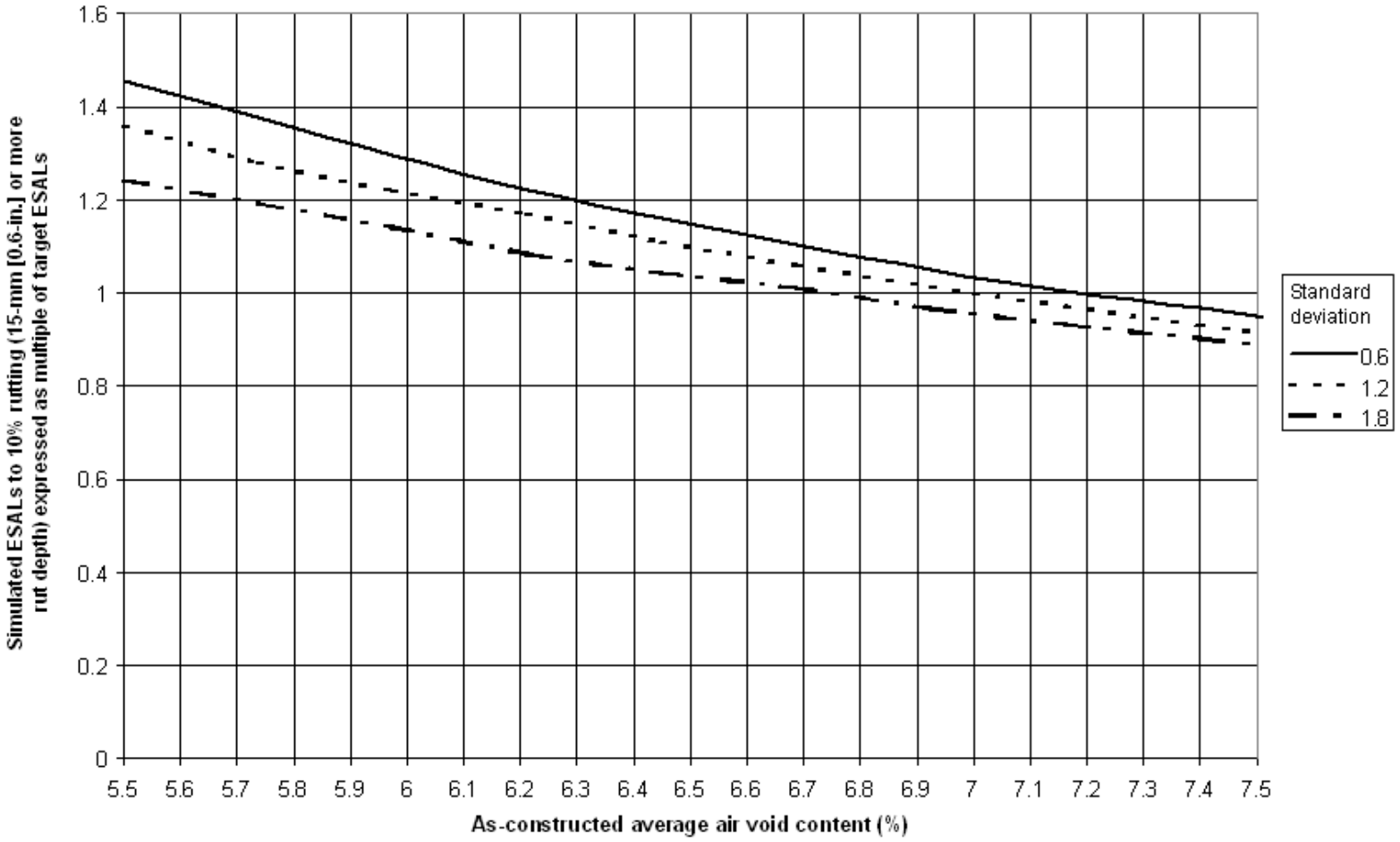


Figure 5.3. Influence of as-constructed air-void content on rutting performance.

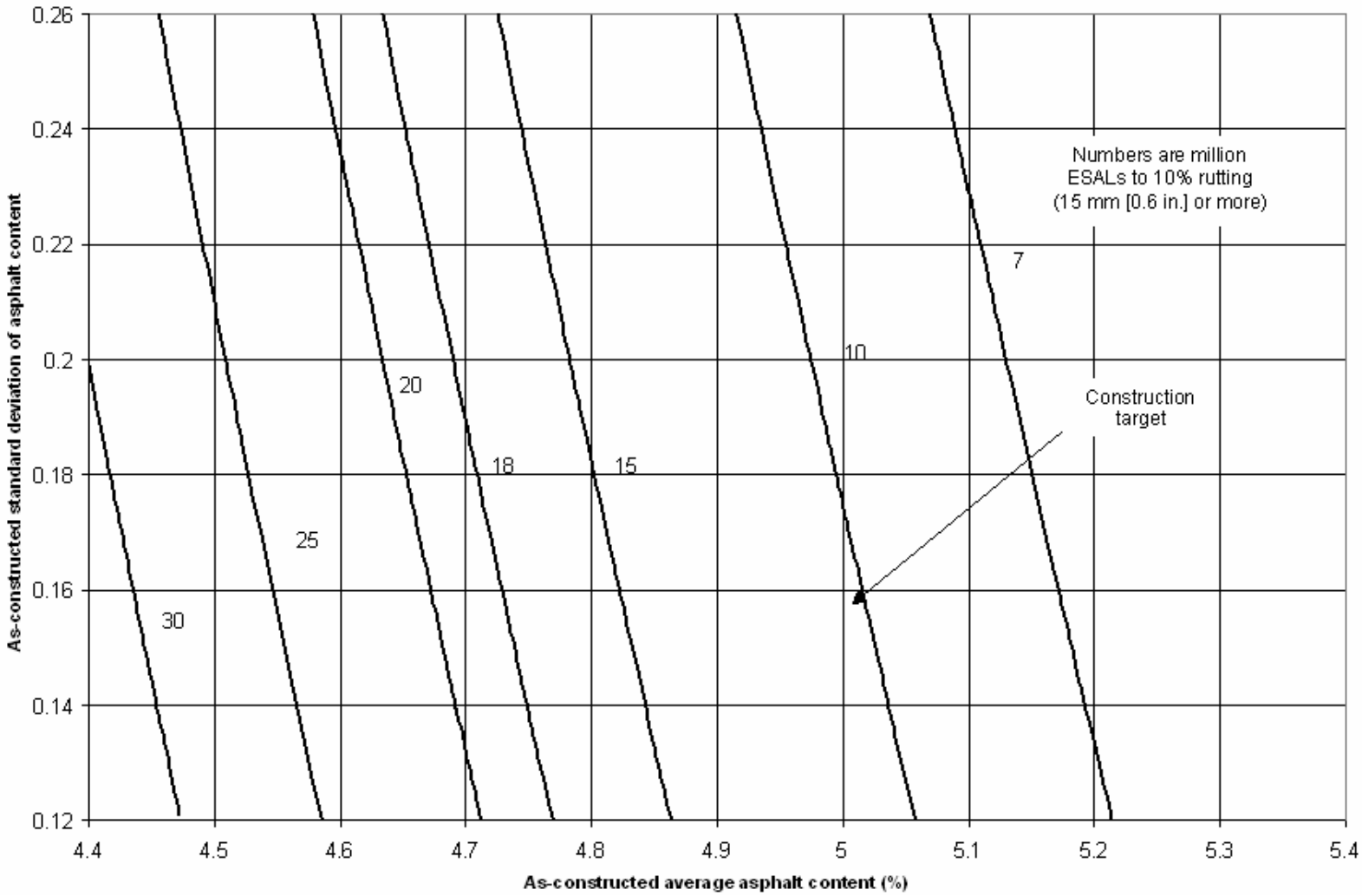


Figure 5.4. Influence of as-constructed asphalt content on pavement rutting performance.

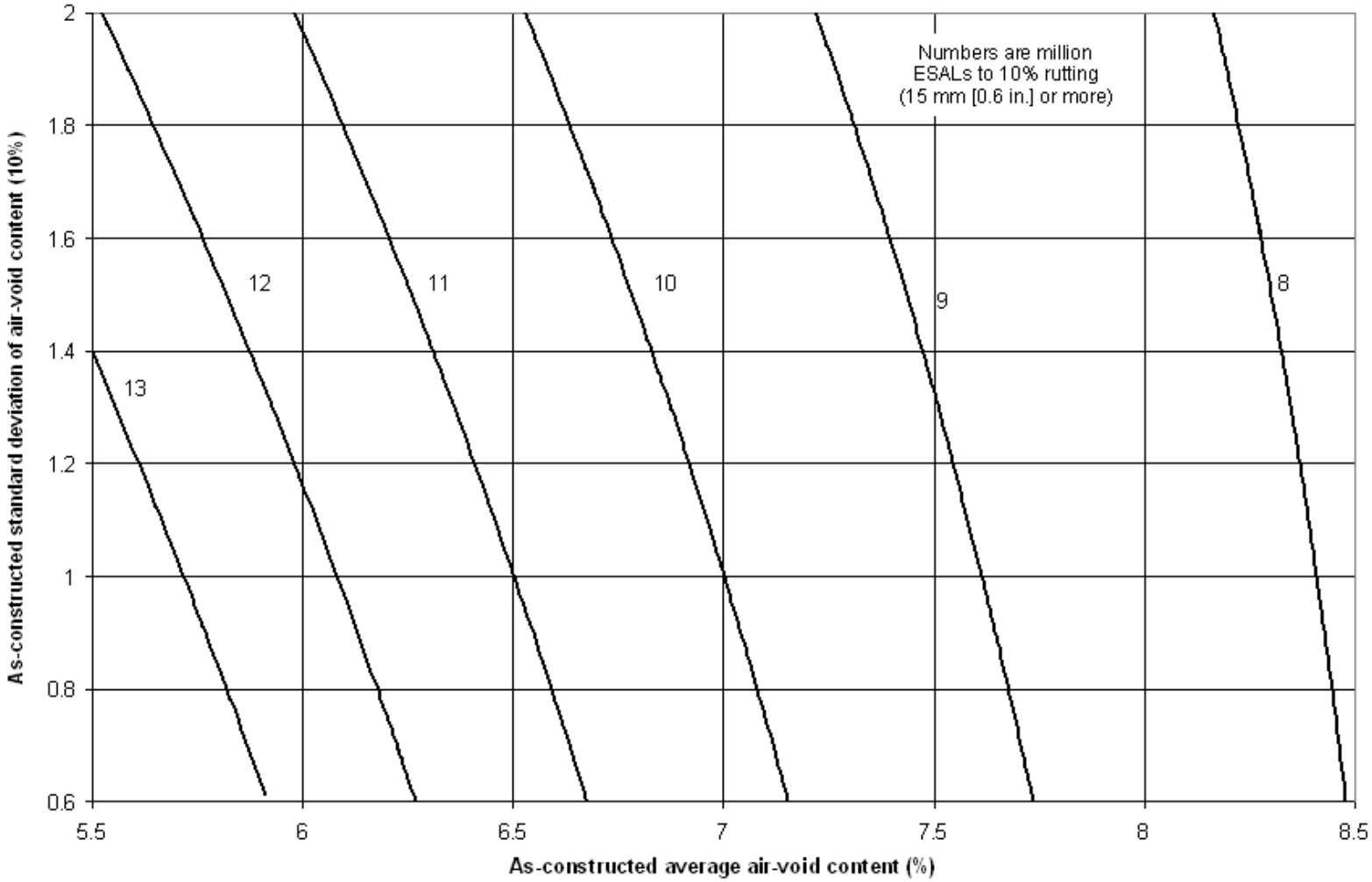


Figure 5.5. Influence of as-constructed air-void content on pavement rutting performance.

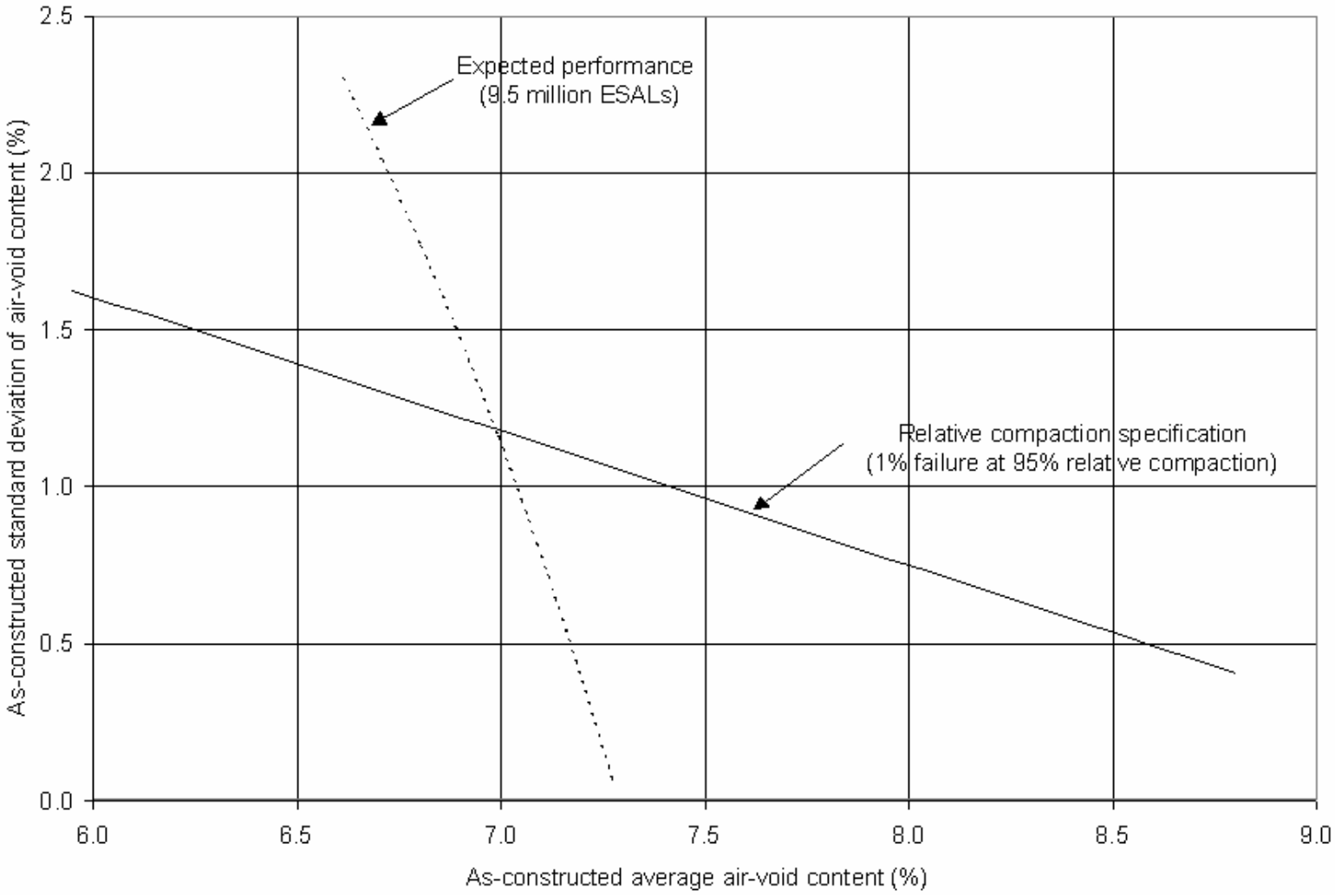


Figure 5.6. Expected pavement rutting performance.

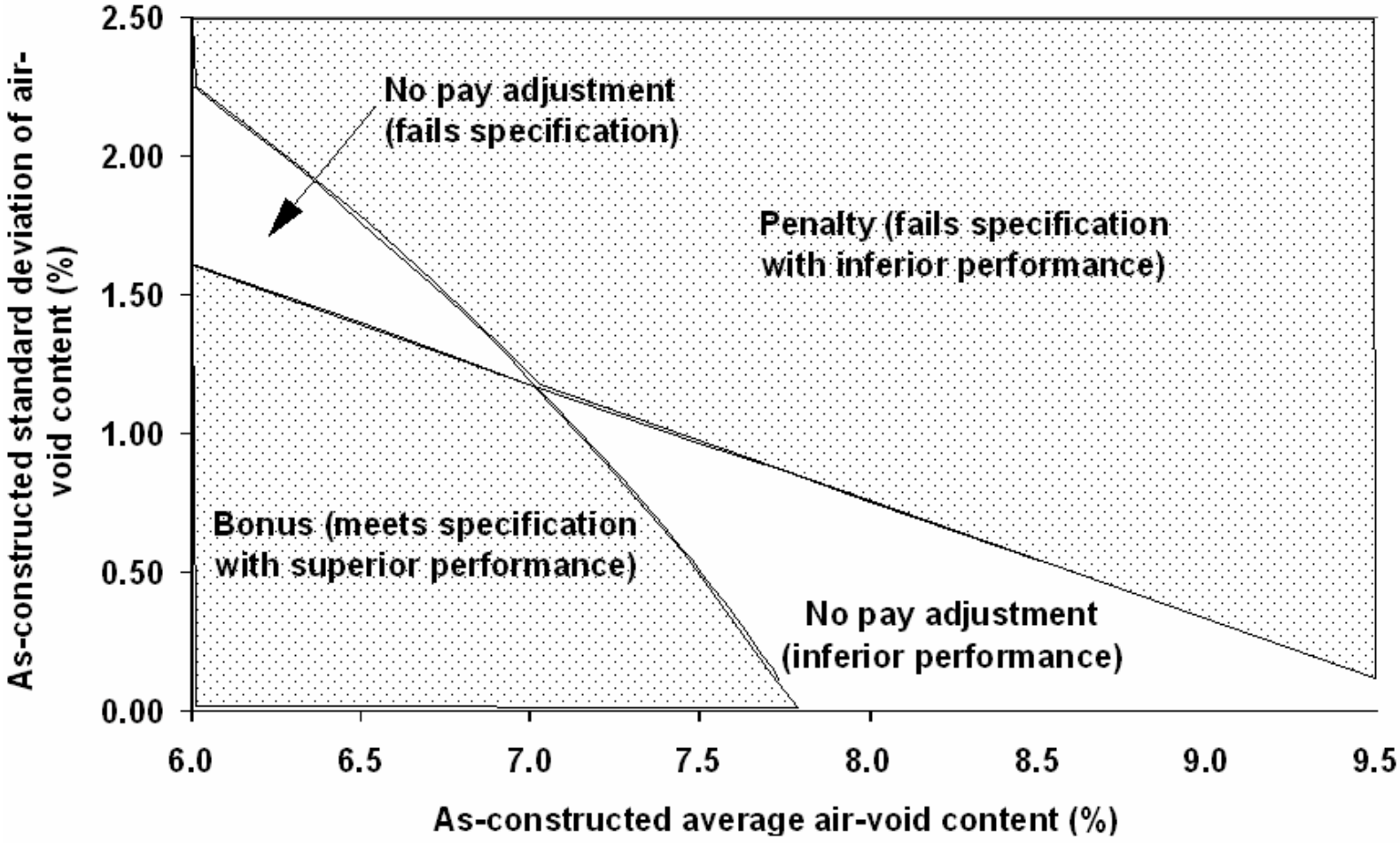


Figure 5.7. Influence of air-void content on contractor pay adjustments.

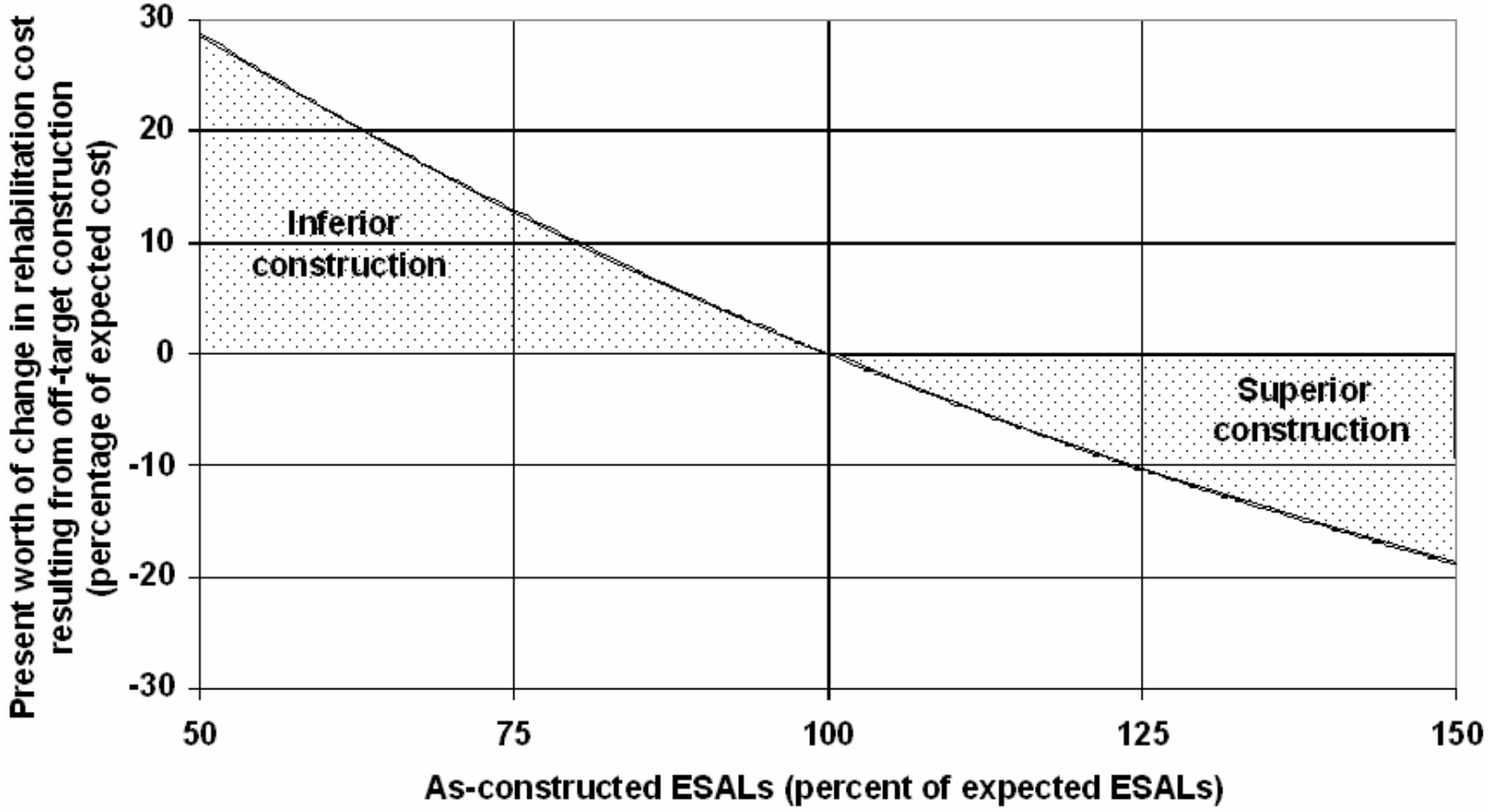


Figure 5.8. Influence of pavement performance on pay factors.

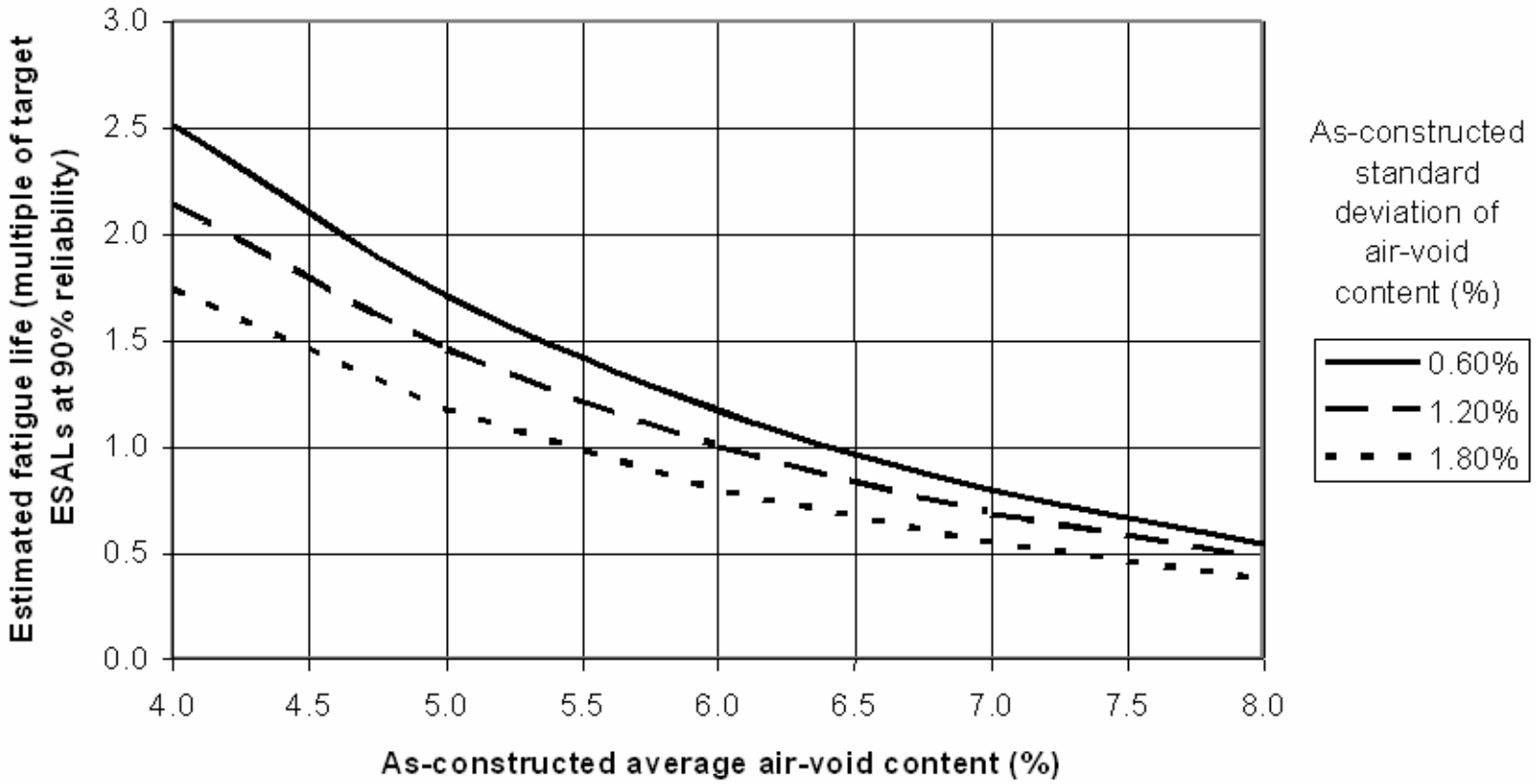


Figure 5.9. Effects of as-constructed air-void content content on pavement fatigue performance.

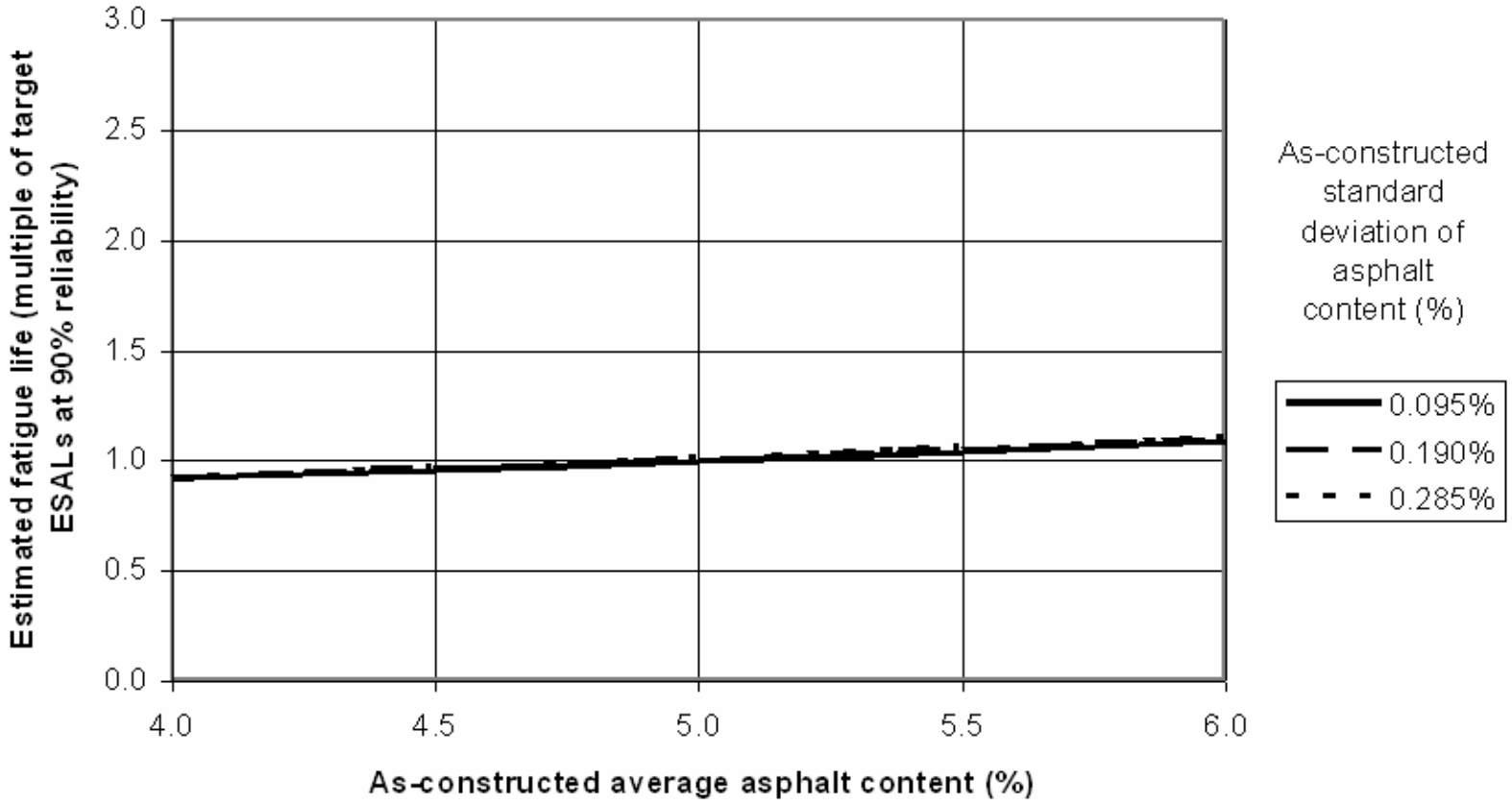


Figure 5.10. Effects of as-constructed asphalt content on pavement fatigue performance.

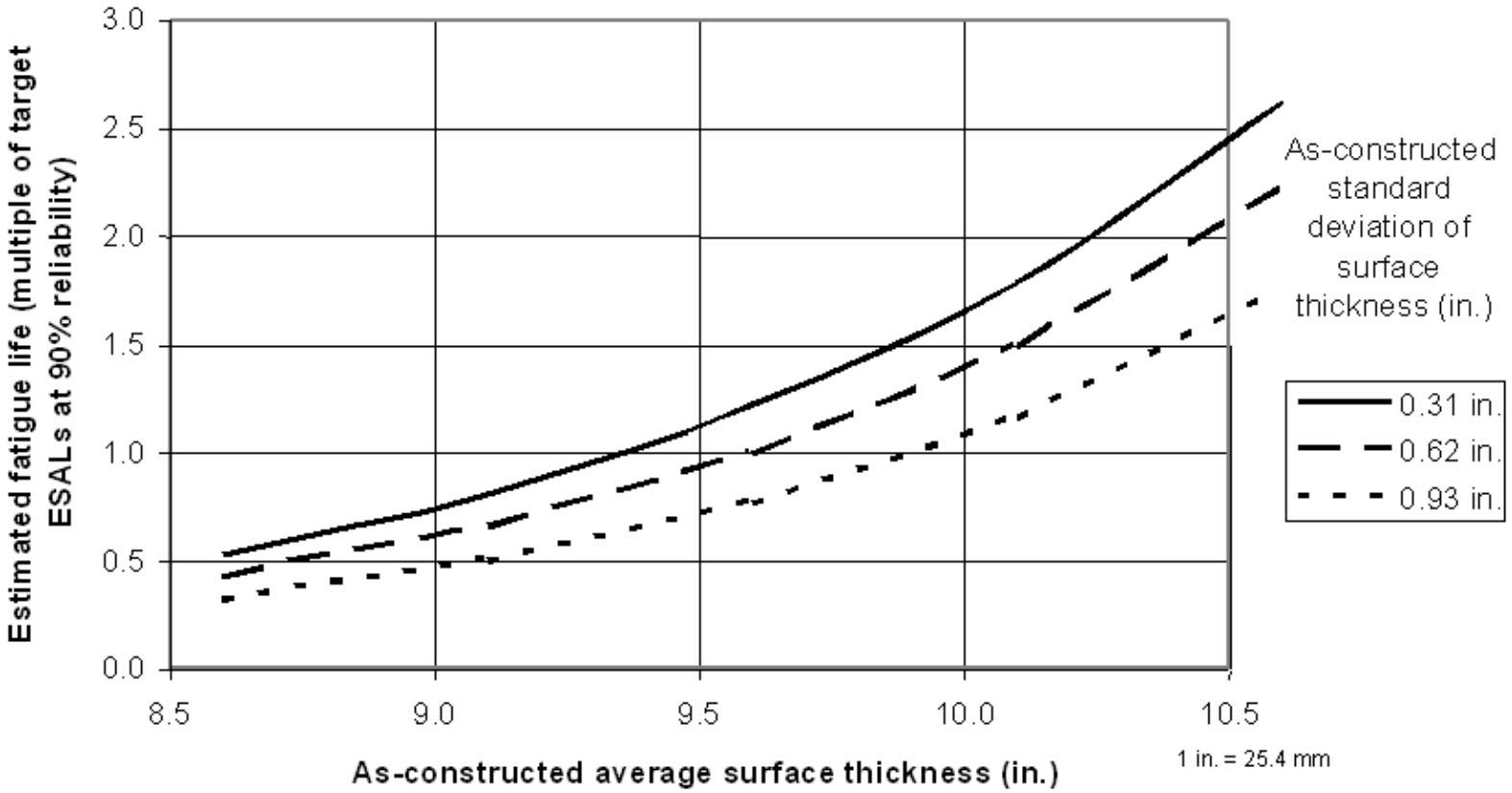


Figure 5.11. Effects of as-constructed surface thickness on pavement fatigue performance.

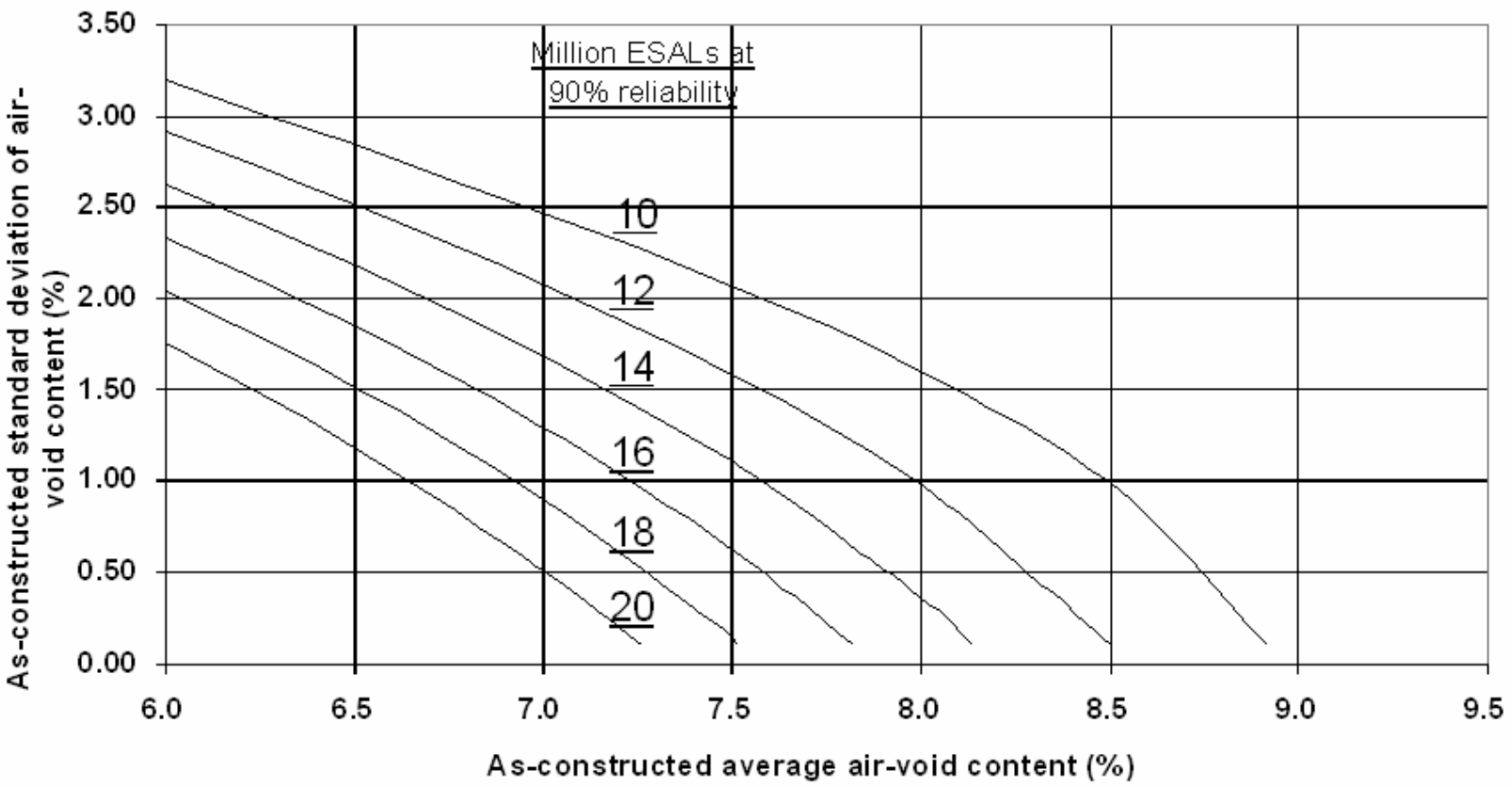


Figure 5.12. Influence of air-void content on pavement performance.

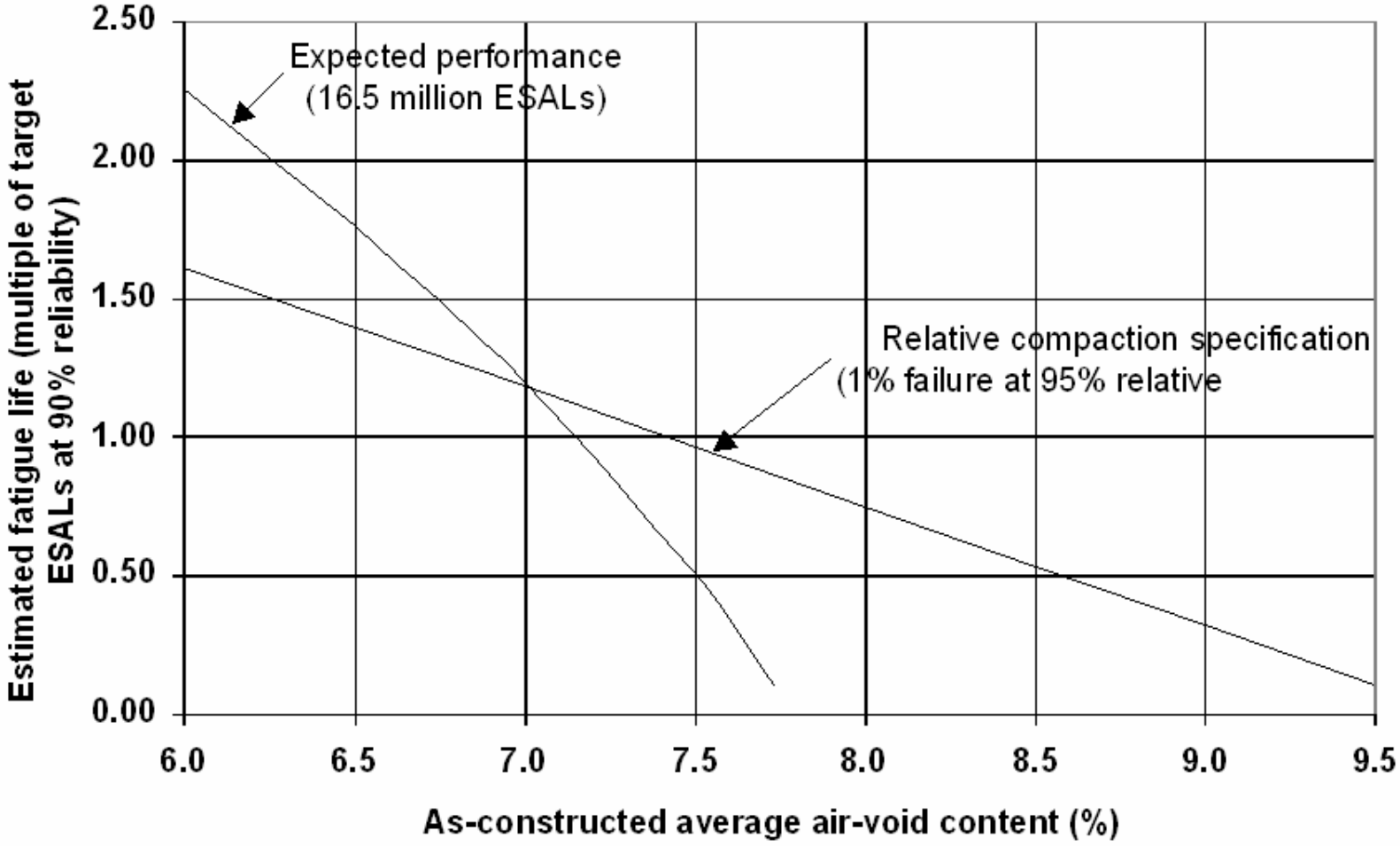


Figure 5.13. Expected pavement performance.

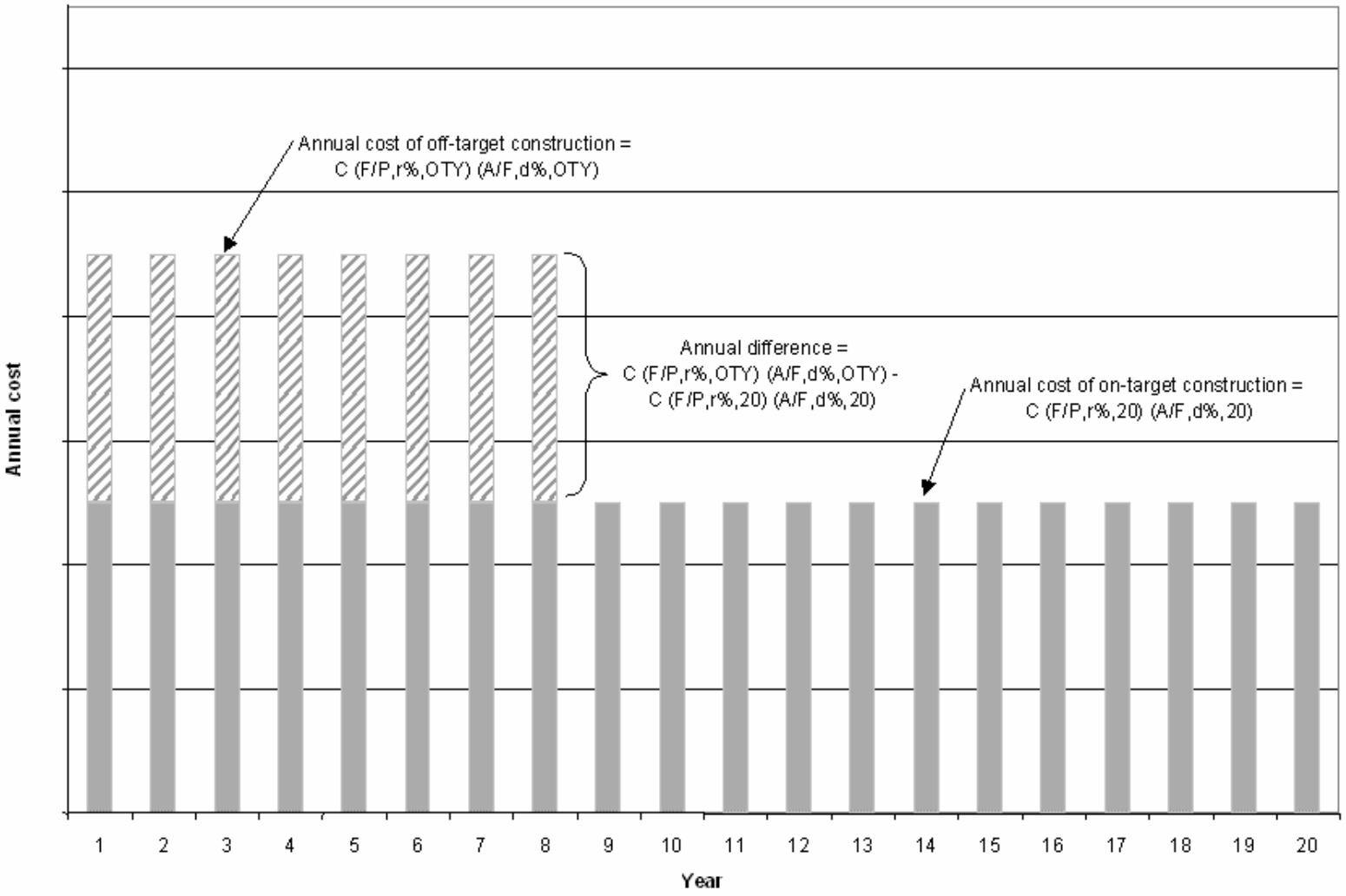


Figure 5.14. Schematic illustration of annual costs of on-target and off-target construction.

APPENDIX A

Table A.1. – Measured downward rut depth versus ESALs, original sections.

Table A.2. – Measured downward rut depth versus ESALs, replacement sections.

Table A.1. Measured downward rut depth versus ESALs, original sections.

Monitoring Session	Date	Total ESALs to Date	Average Rut Depth by Section (mm)																										Device used to obtain rut depth
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
1	3/18/96	4,518	2	0	1	2	2	1	2	2	2	1	1	2	1	2	2	1	1	1	2	2	1	3	1	2	3	3	Dipstick
2	4/15/96	80,063	3	2	3	3	3	5	4	4	3	3	2	3	3	3	3	4	3	3	4	5	4	4	2	5	4	2	Dipstick
3	4/29/96	150,644	3	3	5	2	2	6	5	4	3	5	2	2	4	4	4	6	3	2	5	5	4	5	4	5	6	4	Dipstick
4	5/13/96	233,736	6	5	7	4	7	11	7	5	5	7	3	3	5	8	6	8	5	2	5	7	7	5	6	7	8	9	Dipstick
5	5/28/96	296,504	7	5	7	3	6	10	7	5	5	6	3	3	5	6	6	7	6	2	5	8	5	5	5	7	7	9	Dipstick
6	6/10/96	336,073	7	5	7	3	7	12	7	7	4	6	2	3	4	8	6	8	6	3	5	8	5	5	5	8	7	11	Dipstick
7	6/24/96	436,966	6	4	6	5	10	13	15	10	10	8	4	4	9	8	6	7	6	4	7	9	13	7	6	13	9	9	AZ Device
9	7/22/96	516,563	7	5	7	5	13	19	19	13	13	11	7	7	13	10	5	9	9	4	9	12	18	8	9	18	19	14	AZ Device
10	8/05/96	662,883	7	5	8	7	15	22	21	15	15	11	8	7	16	10	5	8	11	6	11	11	22	8	9	18	21	14	AZ Device
12	9/03/96	835,823	9	5	9	7	16	21	26	14	18	11	7	8	17	9	7	8	10	6	11	13	24	9	12	16	21	13	AZ Device
13	9/19/96	967,780	8	5	8	6	17	21	24	15	19	10	6	8	15	9	6	8	10	6	11	14	25	8	12	20	20	14	AZ Device
14	9/30/96	1,070,221	8	5	8	8	18	21	25	15	17	12	8	7	16	11	6	9	9	6	12	13	25	9	12	20	21	14	AZ Device
15	10/14/96	1,205,574	7	5	8	7	16	21	25	15	18	12	7	8	18	12	8	8	11	6	12	12	23	8	13	22	23	15	AZ Device
16	10/28/96	1,365,970	8	6	9	7	17	21	26	16	18	12	8	8	15	11	8	10	11	7	12	15	24	9	12	23	22	13	AZ Device
17	11/11/96	1,463,101	8	6	9	7	16	21	25	16	18	13	8	7	17	10	8	9	11	7	12	15	25	8	11	22	20	15	AZ Device
19	12/09/96	1,626,437	7	5	9	6	16	21		15		10	8	7		10	8	8	10	6	11	14		9	13	22		14	AZ Device
20	12/19/96	1,711,938	9	5	8	6	19	21		14		11	8	7		13	8	10	9	7	12	14		8	12	20		17	AZ Device
21	1/09/97	1,790,400	8	6	9	7	19	21		15		13	9	8		13	8	9	11	8	13	15		9	13	21		16	AZ Device
23	2/18/97	1,794,199	8	5	8	7	18	23		16		13	8	8		13	8	9	11	8	11	14		9	10	21		17	AZ Device
24	3/03/97	1,880,144	7	5	11	7	21	24		15		12	8	9		13	10	8	12	9	11	13		10	13	22		19	AZ Device
25	3/17/97	2,047,631	9	8	10	8	20	25		19		11	8	8		12	9	9	12	7	13	12		9	13	20		18	AZ Device

Table A.1., continued.

26	3/31/97	2,229,566	10	8	9	8	22	26		20		10	8	8		13	8	8	11	7	13	13		8	12	22		18	AZ Device
27	4/14/97	2,369,909	9	6	11	9	22	28		19		12	9	10		12	8	10	11	8	12	14		10	13	22		18	AZ Device
28	4/29/97	2,546,035	9	7	12	11	20	28		22		13	9	9		11	8	9	10	7	12	12		9	12	23		20	AZ Device
29	5/16/97	2,774,052	10	7	11	10	21	29		22		13	9	9		12	9	10	12	8	13	14		8	13	23		22	AZ Device
30	7/14/97	2,825,970	9	6	10	11						12	10	8		10	9	9	12	7	11	12		7	15				AZ Device
31	8/05/97	3,027,764	10	8	11	11						13	9	8		11	8	9	11	8	11	14		8	16				AZ Device
32	8/19/97	3,194,168	10	8	10	14						12	9	10		13	9	9	11	9	13	14		8	16				AZ Device
33	9/02/97	3,338,264	10	8	10	13						13	8	9		12	9	9	10	9	13	14		8	13				Laser
34	9/16/97	3,407,976	10	8	11	13						12	8	9		12	9	9	10	8	14	15		8	14				Laser
35	10/27/97	3,530,248	10	7	10	12						12	8	9		12	8	9	11	8	13	15		7					Laser
36	11/18/97	3,727,207	10	7	10	12						12	8	8		12	8	9	10	8	12	15		8					Laser
37	12/02/97	3,886,594	9	7	10	12						11	8	9		13	8	10	10	8	13	15		8					Laser
38	12/16/97	4,000,077	10	7	11	12						12	8	9		12	9	10	11	8	13	15		8					Laser
39	12/30/97	4,100,720	10	7	11	12						12	8	9		13	8	10	11	8	13	15		8					Laser
40	1/13/98	4,203,408	10	7	12	12						12	8	9		13	8	10	10	8	13	15		8					Laser
41	1/27/98	4,247,038	10	7	11	12						13	8	9		12	8	11	11	8	13	15		8					Laser
42	2/10/98	4,339,085	10	8	12	13						13	9	9		13	9	12	11	8	13	16		8					Laser
43	3/04/98	4,369,711	10	9	12	13						14	8	10		13	9	13	12	9	13	16		8					Laser
44	3/26/98	4,473,690	11	8	12	13						15	8	8		13	9	11	12	9	14	16		9					Laser
45	4/15/98	4,635,856	11	9	13	13						13	8	8		13	9	11	12	8	13	15		9					Laser
46	5/07/98	4,719,839	11	8	13	13						15	8	9		13	9	12	11	9	13	16		10					Laser
47	6/02/98	4,817,861	11	8	13	13						15	9	9		13	9	12	11	9	13	17		10					Laser
48	9/17/98	4,871,710	12	9	15	15						16	9	14		16	10	14	11	11	15	18		11					Laser
49	3/09/99	5,003,303	11	9	14	15						17	9	13		17	9	15	12	11	14	18		11					Laser

Table A.2. Measured downward rut depth versus ESALs, replacement sections.

Monitoring Session	Date	ESALS	Average Rut Depth by Section (mm)							
			35	36	37	38	39	54	55	56
Additional Data	7/22/97	35,171		19	9					14
Additional Data	7/23/97	40,590	11					10	7	
Additional Data	7/24/97	48,334		20		5	5			
Additional Data	7/25/97	61,037	11	20	9	5	4	10	7	16
Additional Data	7/28/97	93,036	10	22	10	6	5	11	7	16
Additional Data	7/29/97	102,272	9	21	10	6	5	11	7	16
Additional Data	7/30/97	118,079	10	21	10	6	5	11	8	16
Additional Data	7/31/97	128,451	11	21	10	6	6	11	7	15
Additional Data	8/01/97	141,499	10	22	10	5	5	11	8	17
Additional Data	8/04/97	188,491	12	24	12	7	7	12	9	17
31	8/05/97	203,756	12	28	13	8	7	13	9	18
32	8/19/97	368,234	13	28	16	9	10	13	14	22
33	9/02/97	518,895	15	26	16	8	9	13	13	21
34	9/16/97	582,042	14	27	15	8	9	14	13	21
35	10/27/97	704,315	14	Milled		7	8	Milled		
36	11/18/97	913,092	14			8	8			
37	12/02/97	1,063,520	14			8	8			
38	12/16/97	1,174,138	14			8	8			
39	12/30/97	1,263,852	14			8	8			
40	1/13/98	1,377,469	14			8	8			
41	1/27/98	1,421,098	14			8	8			
42	2/10/98	1,513,145	14			8	8			
43	3/04/98	1,543,771	14			8	9			
44	3/26/98	1,647,695	15			9	8			
45	4/15/98	1,809,769	14			8	8			
46	5/07/98	1,893,843	14			9	9			
47	6/02/98	1,991,891	14			9	9			
48	9/17/98	2,045,740	16			10	10			
49	3/09/99	2,177,333	14.9			9	10			

APPENDIX B

REPEATED-LOAD SIMPLE SHEAR TESTS AT CONSTANT HEIGHT (RSST-CH) DATA; ALL TEST SECTIONS PRIOR TO AND AFTER TRAFFICKING

Table B.1. – Original sections (Sections 1-26); FMFC specimens.

Table B.2. – Replacement sections (Sections 33-39 and 54-56); FMFC specimens.

Table B.3. – Original sections (Sections 7, 9, 13, 21, and 25 after 1,460,000 ESALs); FMFC specimens.

Table B.4. – Original sections (Sections 5, 6, 8, 24, and 26 after 2,775,000 ESALs; Section 23 after 3,400,000 ESALs; Sections 1, 2, 3, 4, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, and 22 after 5,000,000 ESALs); FMFC specimens.

Table B.5. – Replacement sections, FMFC (Sections 36, 37, 54, 55, and 56 after 580,000 ESALs; Sections 35, 38, and 39 after 2,180,000 ESALs).

Table B.1. Original sections (Sections 1-26); FMFC specimens.

Specimen	Gradation	Air-Void Content	Actual AC, %	RSST Reps to Shear Strain			G* (MPa)
				0.01	0.02	0.05	@ 100 Reps
WT 01 B1	Fines	9.8	5.3	33	192	1721	49.1
WT 01 B4	Fines	9.4	5.3	82	448	2506	58.4
WT 02 B5	Fines	8.2	5.3	116	1108	16062	81.0
WT 02 B6	Fines	8.8	5.3	157	976	7905	69.0
WT 03 B3	Fines	13.2	4.8	28	104	566	43.5
WT 03 B6	Fines	13.5	4.8	33	114	569	44.4
WT 04 B2	Fines	6.3	5.3	484	3823	38584	84.5
WT 04 B4	Fines	6.7	5.3	718	4546	41602	56.5
WT 05 B1	Coarse	8.3	6.7	121	791	10023	58.3
WT 05 B2	Coarse	6.3	6.7	50	313	9950	49.6
WT 06 B1	Coarse	14.7	6.4	16	60	485	37.6
WT 06 B4	Coarse	15.7	6.4	16	56	375	38.2
WT 07 B1	Coarse	8.7	7.4	42	207	2622	52.4
WT 07 B2	Coarse	8.0	7.4	41	155	1587	32.3
WT 08 B2	Coarse	10.0	5.9	84	539	8797	73.3
WT 08 B3	Coarse	9.5	5.9	51	256	4638	71.5
WT 09 B1	Fines Plus	2.5	7.2	70	325	2457	51.1
WT 09 B2	Fines Plus	2.5	7.2	101	468	3071	40.7
WT 10 B1	Fines Plus	13.8	5.3	27	88	403	46.0
WT 10 B2	Fines Plus	12.2	5.3	20	70	356	38.7
WT 11 B1	Fines Plus	8.3	6.0	33	154	1209	51.9
WT 11 B3	Fines Plus	7.8	6.0	25	82	388	45.2
WT 12 B1	Fines Plus	4.1	6.0	544	4463	59711	69.9
WT 12 B2	Fines Plus	3.4	6.0	152	921	15434	64.2
WT 13 B1	Fines Plus	6.7	6.6	20	65	418	41.2
WT 13 B3	Fines Plus	6.2	6.6	38	106	541	48.6
WT 14 B1	Fines	9.7	6.2	20	92	671	48.4
WT 14 B6	Fines	8.2	6.2	22	90	713	44.1
WT 15 B1	Fines	8.6	5.5	124	692	5938	45.8
WT 15 B2	Fines	7.7	5.5	174	836	6872	49.2
WT 16 B1	Fines	13.8	4.6	27	109	633	42.3

Table B.1., continued.

Specimen	Gradation	Air-Void Content	Actual AC, %	RSST Reps to Shear Strain			G* (MPa)
				0.01	0.02	0.05	@ 100 Reps
TW 16 B6	Fines	13.3	4.6	21	76	400	46.9
WT 17 B1	Fines	11.5	5.4	18	66	423	44.4
WT 17 B4	Fines	10.8	5.4	17	59	389	42.5
WT 18 B5	Fines	3.3	6.2	70	898	24419	76.4
WT 18 B6	Fines	3.8	6.2	88	1208	16113	83.3
WT 19 B1	Fines Plus	6.9	6.0	59	227	1223	32.4
WT 19 B2	Fines Plus	5.2	6.0	91	291	1382	39.3
WT 20 B5	Fines Plus	10.8	5.8	16	47	248	34.3
WT 20 B6	Fines Plus	9.9	58.	25	87	433	44.5
WT 21 B1	Fines Plus	4.2	6.9	96	337	2332	34.0
WT 21 B2	Fines Plus	3.3	6.9	32	132	1082	54.6
WT 22 B1	Fines Plus	7.1	5.4	109	470	3122	59.3
WT 22 B2	Fines Plus	6.6	5.4	83	362	2461	53.9
WT 23 B1	Coarse	5.1	6.8	1204	5239	37897	58.5
WT 23 B2	Coarse	3.5	6.8	97	1009	63940	66.5
WT 24 B4	Coarse	9.3	6.4	35	180	3746	57.5
WT 24 B5	Coarse	5.6	6.4	28	141	2201	60.9
WT 25 B1	Coarse	3.1	7.1	73	386	10001	33.6
WT 25 B2	Coarse	2.5	7.1	47	275	10022	48.6
WT 26 B2	Coarse	14.4	6.0	28	106	687	53.5
WT 26 B3	Coarse	13.1	6.0	22	83	569	45.8

(1 psi = 6.9 kPa)

Table B.2. Replacement sections (Sections 33-39 and 54-56); FMFC specimens.

Specimen	Gradation	Air-Void Content	Actual AC, %	RSST Reps to Shear Strain			G* (MPa)
				0.01	0.02	0.05	@ 100 Reps
WT 35 B1-T	Coarse	8.6	M	6	19	155	32.1
WT 35 B2-T	Coarse	8.9	M	5	15	104	36.4
WT 36 B1-T	Coarse	15.7	M	7	19	83	27.3
WT 36 B2-T	Coarse	15.4	M	5	13	53	27.2
WT 37 B1-T	Coarse	8.9	H	7	24	209	33.8
WT 37 B2-T	Coarse	10.2	H	7	21	158	35.9
WT 38 B1-T	Coarse	7.3	L	16	66	831	44.3
WT 38 B2-T	Coarse	8.1	L	15	67	888	42.2
WT 39 B1-T	Coarse	4.9	M	12	53	1088	54.4
WT 39 B2-T	Coarse	6.1	M	19	103	1688	49.9
WT 54 B1-T	Coarse	7.0	M	7	23	271	38.9
WT 54 B2-T	Coarse	7.6	M	13	50	1032	47.6
WT 55 B1-T	Coarse	4.0	H	6	16	99	40.8
WT 55 B2-T	Coarse	4.6	H	6	18	176	40.9
WT 56 B1-T	Coarse	11.1	L	16	44	266	32.6
WT 56 B2-T	Coarse	16.0	L	8	22	96	27.0

Note: Specimens were tested prior to trafficking. (1 psi = 6.9 kPa)

Table B.3. Original sections FMFC (section 7, 9, 13, 21, and 25 after 1,460,000 ESALs); FMFC specimens.

Specimen	Gradation	Air-Void Content	RSST Reps to Shear Strain			G* (MPa)
			0.01	0.02	0.05	@ 100 Reps
07-B2	Coarse	1.46	54	244	3435	48.0
07-B3	Coarse	1.30	16	46	364	61.0
09-B2	Fines plus	0.03	33	128	1628	51.4
09-B4	Fines plus	0.63	18	48	292	40.2
13-B2	Fines plus	3.56	46	167	1335	59.4
13-B4	Fines plus	2.66	32	100	905	44.3
21-B2	Fines plus	1.94	51	280	3121	48.2
21-B4	Fines plus	2.02	35	145	1741	49.7
25-B2	Coarse	1.34	110	1374	54541	37.9
25-B4	Coarse	1.51	12	37	355	41.1

(1 psi = 6.9 kPa)

Table B.4. Original sections (Sections 5, 6, 8, 24, and 26 after 2,775,000 ESALs; Section 23 after 3,400,000 ESALs; Sections 1, 2, 3, 4, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, and 22 after 5,000,000 ESALs); FMFC specimens.

Specimen	Gradation	Air-Void Content	RSST Reps to Shear Strain					G* (MPa) @ 100 Reps
			0.01	0.02	0.03	0.04	0.05	
1 L 1	Fines	5.9	503	40,965	529,023	3,185,649	12,823,258	85.6
1 L 2	Fines	5.5	2,000	70,537	611,319	2,829,343	9,285,893	94.3
2 L 1	Fines	7.7	7,891	317,073	2,519,075	10,961,233	34,293,373	141.6
2 L 2	Fines	8.0	10,270	235,626	1,299,616	4,364,989	11,171,484	130.4
3 L 1	Fines	7.4	5,063	76,094	389,399	1,240,138	3,045,691	113.9
3 L 2	Fines	6.9	22,569	443,961	2,566,202	8,910,457	23,400,704	136.0
4 L 1	Fines	4.9	15,566	1,536,496	22,265,827	148,408,108	646,340,142	115.7
4 L 2	Fines	4.4	153	1,276	3,671	6,575	9,705	56.3
5 T 1	Coarse	8.2	82	460	1,662	4,273	8,808	70.3
5 T 2	Coarse	7.9	76	651	3,263	9,224	18,554	65.9
6 T 1	Coarse	9.9	127	733	2,397	6,302	13,625	80.0
6 T 2	Coarse	15.2	129	1,037	3,827	9,920	17,926	66.7
8 T 1	Coarse	8.2	412	4,736	15,792	33,796	72,090	118.2
8 T 2	Coarse	8.5	389	5,249	16,000	29,430	62,013	90.0
10 L 1	Fines Plus	5.3	156,308	7,120,011	66,472,288	324,324,724	1,108,913,317	121.5
10 L 2	Fines Plus	7.6	7,819	286,910	2,526,543	11,826,592	39,157,070	101.9
11 L 1	Fines Plus	2.2	60,187	5,782,406	83,533,208	555,539,922	2,415,305,445	106.0
11 L 2	Fines Plus	2.2	113,960	1,652,325	7,896,563	23,957,379	56,664,165	106.9
12 L 1	Fines Plus	1.6	1,908	23,818	112,901	340,988	803,689	62.2
12 L 2	Fines Plus	1.4	6,572	171,287	1,263,730	5,217,479	15,671,745	68.2
14 L 1	Fines	2.2	1,714	44,900	352,734	1,399,643	4,076,660	91.3
14 L 2	Fines	2.1	7,502	578,714	7,358,417	44,700,465	181,160,412	89.9
15 L 1	Fines	6.1	4,054	214,542	2,215,792	11,614,092	41,979,664	101.0
15 L 2	Fines	6.7	5,632	151,080	1,028,263	4,009,162	11,519,393	78.8
16 L 1	Fines	8.1	1,338	57,360	457,841	1,998,796	6,269,492	75.9
16 L 2	Fines	8.3	1,418	24,711	134,484	439,536	1,101,373	132.4
17 L 1	Fines	6.7	14,486	304,207	1,861,064	6,727,558	18,228,475	118.8
17 L 2	Fines	6.3	24,565	927,564	7,933,535	36,376,286	118,522,977	121.3

Table B.4., continued.

Specimen	Gradation	Air-Void Content	RSST Reps to Shear Strain					G* (MPa) @ 100 Reps
			0.01	0.02	0.03	0.04	0.05	
18 L 1	Fines	1.9	261	9,305	39,035	179,579	493,337	42.9
18 L 2	Fines	2.3	515	12,026	41,788	174,800	436,691	44.6
19 L 1	Fines Plus	1.9	19,048	1,471,658	18,965,994	116,319,569	474,922,414	77.8
19 L 2	Fines Plus	3.0	42,552	4,866,004	77,834,213	556,443,083	2,558,754,909	91.1
20 L 1	Fines Plus	1.2	2,181	53,515	366,326	1,434,138	4,133,735	62.0
20 L 2	Fines Plus	4.6	3,476	615,324	12,794,871	110,185,288	585,374,732	78.2
22 L 1	Fines Plus	5.1	7,258	84,148	323,940	843,001	1,770,147	70.8
22 L 2	Fines Plus	4.7	5,282	149,070	1,089,366	4,467,223	13,347,866	113.1
23 L 1	Coarse	2.1	572	10,377	33,174	106,655	239,932	59.3
23 L 2	Coarse	3.2	395	11,707	89,724	372,790	1,125,258	58.8

(1 psi = 6.9 kPa)

Table B.5. Replacement sections, FMFC (Sections 36, 37, 54, 55, and 56 after 580,000 ESALs; Sections 35, 38, and 39 after 2,180,000 ESALs).

Specimen	Gradation	Air-Void Content	RSST Reps to Shear Strain					G* (MPa) @ 100 Reps
			0.01	0.02	0.03	0.04	0.05	
35 L 1	Coarse	1.9	1.11E+02	4.70E+03	1.99E+04	3.67E+04	1.28E+05	40.1
35 L 2	Coarse	1.7	2.21E+01	5.29E+02	2.85E+03	5.62E+03	8.54E+03	42.6
36 R 1	Coarse	2.8	3.85E+01	3.01E+02	1.38E+03	3.62E+03	5.15E+03	49.8
36 R 2	Coarse	2.2	3.10E+01	5.94E+02	3.27E+03	7.15E+03	1.18E+04	45.0
37 L 1	Coarse	9.7	3.01E+01	9.72E+02	5.71E+03	1.07E+04	1.51E+04	43.7
37 L 2	Coarse	0.4	5.77E+01	2.34E+03	9.17E+03	3.66E+04	9.83E+04	46.1
38 L 1	Coarse	4.0	3.39E+01	3.00E+02	2.12E+03	6.69E+03	1.33E+04	43.4
38 L 2	Coarse	4.3	7.07E+01	1.21E+03	4.73E+03	9.87E+03	1.58E+04	65.1
39 L 1	Coarse	-0.4	7.69E+02	1.83E+04	3.53E+04	1.70E+05	3.85E+05	45.0
39 L 2	Coarse	0.2	4.60E+02	1.57E+04	3.52E+04	1.60E+05	3.79E+05	53.1
43 L 1	Coarse	-1.0	7.48E+04	3.17E+12	9.16E+16	1.34E+20	3.82E+22	38.1
43 L 2	Coarse	-0.9	1.69E+04	1.98E+09	1.86E+12	2.39E+14	1.03E+16	40.6
51 L 1	Coarse	3.2	5.20E+05	1.37E+08	3.58E+09	3.62E+10	2.18E+11	52.5
51 L 2	Coarse	4.1	8.21E+05	6.24E+08	3.02E+10	4.75E+11	4.02E+12	60.3
54 L 1	Coarse	2.2	1.19E+02	1.52E+04	1.14E+05	5.57E+05	1.90E+06	53.2
54 L 2	Coarse	1.8	6.39E+02	9.41E+04	1.77E+06	1.42E+07	7.15E+07	52.4
55 L 1	Coarse	-0.5	7.83E+01	5.98E+03	3.00E+04	1.35E+05	4.04E+05	48.2
55 L 2	Coarse	-0.3	7.18E+01	4.56E+03	2.13E+04	7.89E+04	2.18E+05	44.6
56 C 1	Coarse	14.4	3.08E+02	1.86E+03	5.16E+03	9.05E+03	1.29E+04	79.6
56 C 2	Coarse	13.9	8.42E+01	3.52E+02	9.34E+02	1.83E+03	2.94E+03	61.6
56 R 1	Coarse	7.8	7.11E+01	1.27E+03	7.68E+03	1.84E+04	4.80E+04	50.3
56 R 2	Coarse	7.7	1.28E+02	2.76E+03	1.33E+04	2.97E+04	7.63E+04	76.5

(1 psi = 6.9 kPa)

APPENDIX C1

RSST-CH DATA; TESTS AT UC BERKELEY ON LMLC SPECIMENS REPRESENTATIVE OF SECTIONS 5 AND 24.

APPENDIX C2

RSST-CH DATA; TESTS AT NCSU ON LMLC SPECIMENS TO EVALUATE THE INFLUENCE OF AGGREGATE GRADATION ON PERMANENT DEFORMATION.

Appendix C1

Table C1.1.

SPECIMEN	AV	TEST PARAMETERS		TEST RESULTS: RSST Reps to Shear Strain					G* (MPa)	a	b
		Temp, °C	Stress, kPa (psi)	1.0% Strain	2.0% Strain	3.0% Strain	4.0% Strain	5.0% Strain			
WTNMM5-3	7.34	60	84 (12)	15	68	214	495	927	41.9	4.62E-03	0.349
WTNMM6-3	8.83	60	84 (12)	12	48	124	246	423	42.7	4.05E-03	0.416
WTNMM7-1	8.18	60	84 (12)	13	66	191	478	1020	43.0	5.85E-03	0.311
WTNMM4-1	7.71	60	56 (8)	22	122	451	1084	2161	31.2	4.30E-03	0.319
WTNMM4-3	8.92	60	56 (8)	18	86	248	540	986	34.4	3.87E-03	0.371
WTNMM5-2	7.60	60	56 (8)	100	641	1554	2960	4731	48.2	1.28E-03	0.431
WTNMM3-1	8.22	60	28 (4)	63	291	796	1548	2624	22.4	1.78E-03	0.424
WTNMM3-2	7.79	60	28 (4)	41	196	709	1657	3128	22.1	3.18E-03	0.343
WTNMM6-1	7.62	60	28 (4)	105	635	2208	5744	10599	16.4	2.23E-03	0.336
WTNMM8-1	8.58	50	84 (12)	67	321	811	1578	2870	53.9	1.70E-03	0.427
WTNMM8-3	8.83	50	84 (12)	32	153	466	988	1779	66.3	2.99E-03	0.376
WTNMM9-1	7.84	50	84 (12)	78	532	1739	3913	7735	68.3	2.33E-03	0.343
WTNMM9-2	8.71	50	56 (8)	158	1112	4351	10078	19632	51.0	1.93E-03	0.329
WTNMM10-3	7.71	50	56 (8)	281	1585	4435	9138	15888	60.9	1.12E-03	0.392
WTNMM12-1	8.47	50	56 (8)	1236	9192	30685	78001	156559	53.1	1.08E-03	0.320
WTNMM18-1	8.94	50	28 (4)	15619	73697	159374	275473	421138	36.8	5.52E-05	0.526
WTNMM13-2	7.88	50	28 (4)	5066	46042	155606	369202	721641	52.0	5.60E-04	0.333
WTNMM13-3	7.46	50	28 (4)	9182	66625	176725	353094	604015	54.8	1.98E-04	0.416
WTNMM19-1	8.69	40	84 (12)	597	7216	28956	76154	164165	166.8	1.53E-03	0.291
WTNMM20-1	8.60	40	84 (12)	514	3408	10111	21267	38475	177.3	8.77E-04	0.383
WTNMM15-3	7.80	40	84 (12)	953	6219	29453	53328	101505	163.2	9.19E-04	0.347
WTNMM21-1	8.86	40	56 (8)	604	6140	25792	63321	132051	185.5	1.39E-03	0.304
WTNMM21-2	8.55	40	56 (8)	2102	20965	67236	161840	319883	186.4	7.87E-04	0.328
WTNMM21-3	7.57	40	56 (8)	2201	27322	82129	206150	420925	162.0	8.73E-04	0.313
WTNMM22-1	7.61	40	28 (4)	20499	166774	568435	1356851	2664506	134.9	3.75E-04	0.331
WTNMM22-2	9.03	40	28 (4)	11856	86040	274290	624388	1181830	199.3	3.76E-04	0.350
WTNMM22-3	7.18	40	28 (4)	44497	185413	646358	1567708	3116972	98.9	3.90E-04	0.325

(°F = 1.8 °C + 32; 1 psi = 6.9 kPa)

Appendix C2

Table C2.1. Final course gradations.

Final Gradation with lime

Final Coarse High Gradation

Sieve Size (mm)	w/o lime Percent Passing	Gradation of Lime
19	100.0	100
12.5	88.0	100
9.5	80.0	100
4.8	45.8	100
2.4	30.9	100
1.2	23.7	100
0.6	17.2	99.8
0.3	12.7	97.2
0.2	9.2	90.2
0.1	6.0	81.3

Final Coarse High Gradation

Sieve Size (mm)	Percent Passing
19	100.0
12.5	88.2
9.5	80.3
4.8	46.6
2.4	32.0
1.2	24.9
0.6	18.4
0.3	14.0
0.2	10.5
0.1	7.1

Final Coarse Med Gradation

Sieve Size (mm)	w/o lime Percent Passing	Gradation of Lime
19	100.0	100
12.5	80.6	100
9.5	61.7	100
4.8	38.3	100
2.4	24.6	100
1.2	16.0	100
0.6	10.5	99.8
0.3	7.58	97.2
0.2	5.043	90.2
0.1	3.7	81.3

Final Coarse Med Gradation

Sieve Size (mm)	Percent Passing
19	100.0
12.5	80.9
9.5	62.2
4.8	39.2
2.4	25.7
1.2	17.2
0.6	11.9
0.3	8.9
0.2	6.3
0.1	4.8

Final Coarse Low Gradation

Sieve Size (mm)	w/o lime Percent Passing	Gradation of Lime
19	100	100
12.5	65.918	100
9.5	53.460	100
4.8	35.948	100
2.4	18.993	100
1.2	11.124	100
0.6	5.004	99.8
0.3	3.595	97.2
0.2	2.530	90.2
0.1	2.033	81.3

Final Coarse Low Gradation

Sieve Size (mm)	Percent Passing
19	100.0
12.5	66.4
9.5	54.2
4.8	36.9
2.4	20.2
1.2	12.5
0.6	6.4
0.3	5.0
0.2	3.8
0.1	3.2

(1 in. = 25.4 mm)

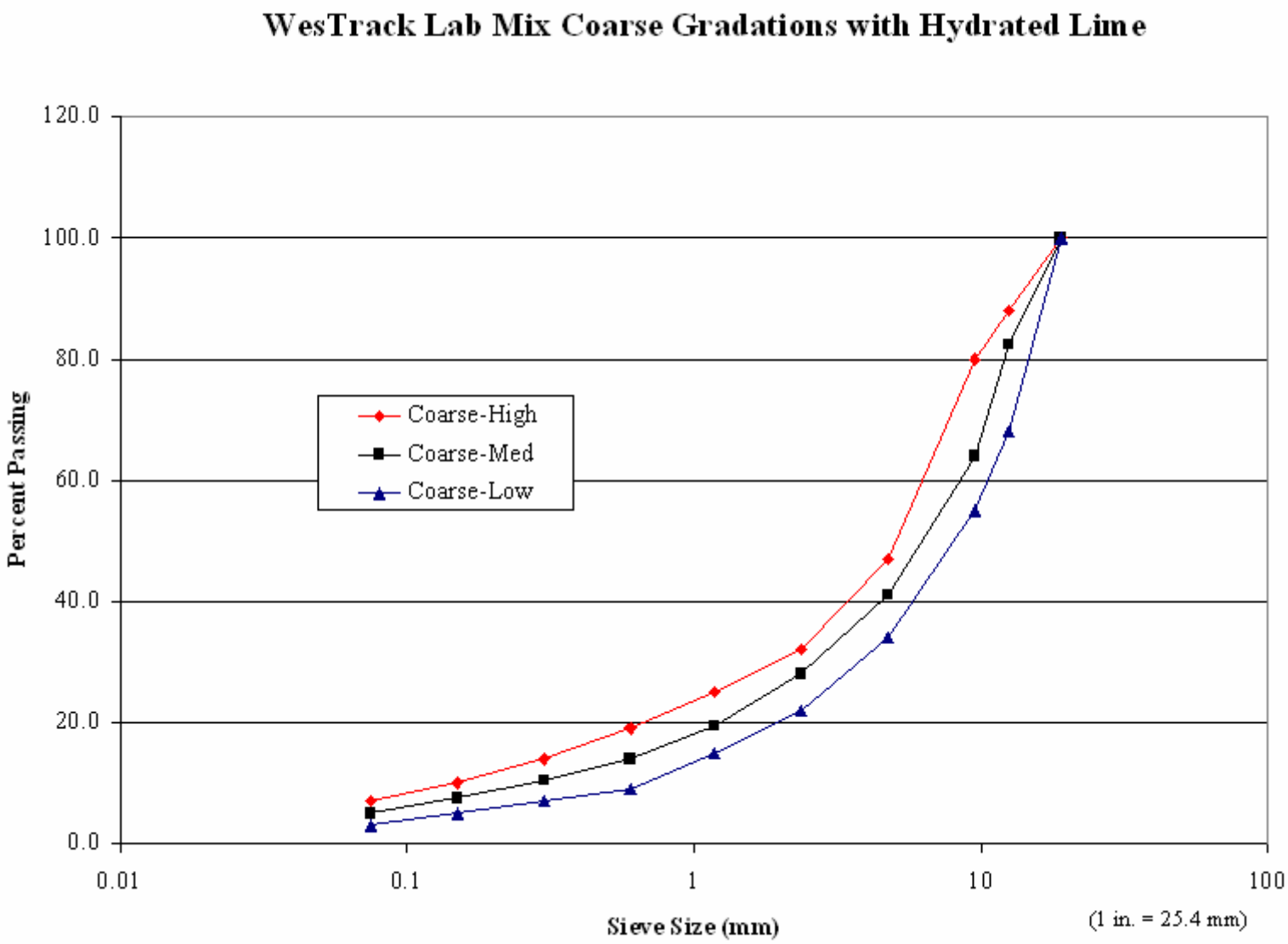

WesTrack Lab Mix Coarse Gradations with Hydrated Lime
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Percent Passing
Coarse-High
Coarse-Med
Coarse-Low
0.01
0.1
1
10
100
Sieve Size (mm)
(1 in. = 25.4 mm)

Figure C2.1.

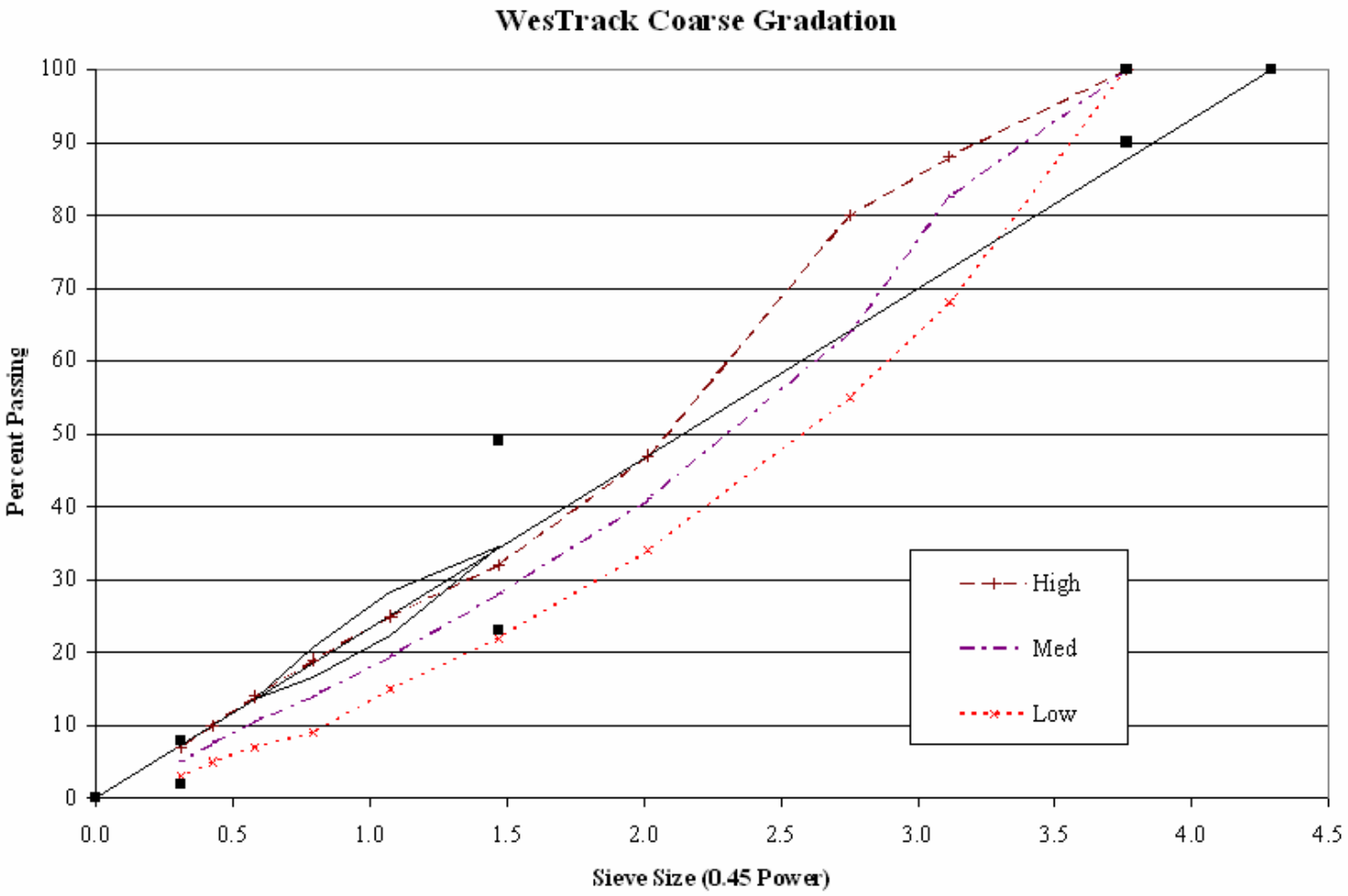

WesTrack Coarse Gradation
Percent Passing
Sieve Size (0.45 Power)
0
10
20
30
40
50
60
70
80
90
100
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
High
Med
Low

Figure C2.2.

Table C2.2. Lab mix/lab compacted specimens, low.

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Lab mix/lab compacted specimen

8/12/1999

			RSST-CH Test Results Reps to Shear Strain					Extrapolation from Rep 100 G* (MPa)	γ= a*(N^b):	
Specimen	**AVwp**	**Rice SpG**	**1.0%**	**2.0%**	**3.0%**	**4.0%**	**5.0%**	**@100 Reps**	**a**	**b**
WTCL50-41	2.3	2.434	77	435	3397	*16049*	*49621*	94.6	5.90E-03	0.198
WTCL50-42	2.4	2.434	91	563	4562	*17303*	*49231*	85.8	4.98E-03	0.213
WTCL50-43	2.8	2.434	74	408	2404	*10295*	*28547*	89.0	5.30E-03	0.219
WTCL50-21	5.8	2.434	151	2211	*15993*	*60454*	*169575*	75.6	3.69E-03	0.216
WTCL50-32	5.1	2.434	50	248	1044	3471	*8264*	64.4	4.91E-03	0.257
WTCL50-33	6.0	2.434	57	478	4093	*18525*	*58573*	75.0	5.95E-03	0.194
WTCL50-11	9.1	2.434	34	128	350	874	*1649*	53.9	3.88E-03	0.345
WTCL50-12	9.9	2.434	47	181	516	1494	*3191*	61.4	4.23E-03	0.306
WTCL50-13	9.5	2.434	35	183	592	1648	*3356*	52.0	4.06E-03	0.309
Averages	**5.9**	**2.4**	**68**	**537**	**3661**	**14457**	**41334**	**72.4**	**4.77E-03**	**0.25**
St Dev	**3.1**	**0.0**	**37**	**646**	**4897**	**18700**	**53154**	**15.4**	**8.49E-04**	**0.06**
WTCL57-51	2.9	2.425	36	92	628	3926	*9684*	64.9	7.56E-03	0.206
WTCL57-52	3.0	2.425	49	308	2124	*9787*	*29821*	76.0	6.35E-03	0.200
WTCL57-53	2.6	2.425	79	599	3398	*11063*	*27477*	79.9	4.08E-03	0.245
WTCL57-31	6.6	2.425	54	311	2209	*11226*	*35764*	60.0	6.64E-03	0.193
WTCL57-32	5.9	2.425	66	523	5389	*24142*	*79239*	63.5	6.01E-03	0.188
WTCL57-33	6.6	2.425	43	221	1449	*8509*	*29380*	65.5	7.84E-03	0.180
WTCL57-11	8.9	2.425	59	358	1671	5949	*14187*	52.1	4.56E-03	0.250
WTCL57-12	8.8	2.425	62	389	1782	5592	*12442*	48.1	3.96E-03	0.269
WTCL57-21	10.8	2.425	42	250	1611	*8896*	*29444*	60.5	7.34E-03	0.186
Averages	**6.2**	**2.4**	**54**	**339**	**2251**	**9899**	**29715**	**63.4**	**6.04E-03**	**0.21**
St Dev	**3.0**	**0.0**	**14**	**154**	**1389**	**5903**	**20722**	**10.1**	**1.50E-03**	**0.03**
WTCL64-41	2.8	2.363	34	271	2408	*10525*	*33785*	59.7	6.80E-03	0.191
WTCL64-42	3.3	2.363	34	172	1413	*10520*	*44178*	59.3	9.48E-03	0.156
WTCL64-43	3.5	2.363	39	521	7046	*38225*	*149875*	51.6	7.14E-03	0.163
WTCL64-31	7.8	2.363	78	499	2996	*10534*	*27488*	52.6	4.64E-03	0.233
WTCL64-32	8.3	2.363	24	116	426	1352	*3149*	48.2	5.94E-03	0.265
WTCL64-33	8.3	2.363	36	228	1228	5186	*13818*	56.5	6.24E-03	0.218
WTCL64-11	9.5	2.363	68	789	4267	*15795*	*41912*	57.5	4.39E-03	0.229
WTCL64-12	9.1	2.363	61	903	9171	*37375*	*120636*	54.6	5.39E-03	0.190
WTCL64-13	9.0	2.363	68	842	*10094*	*52216*	*186826*	48.9	5.97E-03	0.175
Averages	**6.9**	**2.4**	**49**	**482**	**4339**	**20192**	**69074**	**54.3**	**6.22E-03**	**0.20**
St Dev	**2.8**	**0.0**	**20**	**305**	**3586**	**17768**	**65940**	**4.3**	**1.52E-03**	**0.04**

(1 psi = 6.9 kPa)

Table C2.3. Lab mix/lab compacted specimens, medium.

University of California, Berkeley

Pavement Research Center
Lab mix/lab compacted specimen
7/26/1999

			RSST-CH Test Results Reps to Shear Strain					Extrapolation from Rep 100 G* (MPa)	γ= a*(N^b):	
Specimen	**AVwp**	**Rice SpG**	**1.0%**	**2.0%**	**3.0%**	**4.0%**	**5.0%**	**@100 Reps**	**a**	**b**
WTCM50-61	3.3	2.429	124	998	8619	*24596*	*64698*	97.5	3.88E-03	0.231
WTCM50-12	2.1	2.429	82	335	1183	6043	*13421*	102.4	4.94E-03	0.243
WTCM50-13	2.1	2.429	76	442	2551	*10122*	*27034*	101.4	4.92E-03	0.227
WTCM50-51	7.1	2.429	202	3453	*19496*	*66166*	*170715*	88.5	2.93E-03	0.235
WTCM50-52	6.5	2.429	80	957	7979	*28696*	*82996*	84.1	4.63E-03	0.210
WTCM50-53	7.1	2.429	120	2036	*13136*	*48459*	*133384*	76.2	3.71E-03	0.220
WTCM50-31	7.7	2.429	111	981	4190	*11456*	*24966*	87.0	2.75E-03	0.286
WTCM50-71	9.1	2.429	92	946	5708	*18764*	*47731*	68.4	3.81E-03	0.239
WTCM50-33	7.4	2.429	137	1471	8723	*25413*	*62032*	87.8	3.17E-03	0.250
Averages	**5.8**	**2.4**	**114**	**1291**	**7954**	**26635**	**69664**	**88.2**	**3.86E-03**	**0.24**
St Dev	**2.6**	**0.0**	**40**	**956**	**5650**	**19487**	**52431**	**11.3**	**8.29E-04**	**0.02**
WTCM57-21	3.8	2.421	66	371	1632	6161	*13899*	88.8	4.46E-03	0.253
WTCM57-22	3.2	2.421	61	230	799	3078	*7423*	66.3	5.19E-03	0.254
WTCM57-23	3.2	2.421	64	329	1521	6487	*15140*	80.1	5.05E-03	0.238
WTCM57-31	5.8	2.421	51	246	996	3517	*7823*	61.5	4.77E-03	0.262
WTCM57-32	5.4	2.421	34	134	429	1327	*2836*	64.9	5.19E-03	0.285
WTCM57-33	6.5	2.421	32	166	648	2027	*4583*	65.3	5.15E-03	0.270
WTCM57-51	9.4	2.421	129	1399	5814	*16190*	*35754*	53.8	2.61E-03	0.282
WTCM57-52	9.7	2.421	70	657	2910	7264	*16261*	53.0	3.03E-03	0.289
WTCM57-53	11.6	2.421	54	332	1387	3497	*7286*	47.8	3.34E-03	0.304
Averages	**6.5**	**2.4**	**62**	**429**	**1793**	**5505**	**12334**	**64.6**	**4.31E-03**	**0.27**
St Dev	**3.1**	**0.0**	**28**	**394**	**1676**	**4501**	**9965**	**13.1**	**1.03E-03**	**0.02**
WTCM64-11	2.3	2.39	49	252	1535	*8948*	*29830*	81.1	7.41E-03	0.185
WTCM64-12	1.6	2.39	25	87	235	626	*1301*	57.0	5.46E-03	0.309
WTCM64-13	1.9	2.39	37	188	779	3526	*9583*	66.4	6.69E-03	0.219
WTCM64-22	5.8	2.39	40	259	1420	5090	*12897*	52.7	5.40E-03	0.235
WTCM64-41	7.2	2.39	39	241	882	2201	*4413*	42.6	3.49E-03	0.317
WTCM64-43	7.5	2.39	63	500	2174	5994	*13415*	42.1	3.45E-03	0.281
WTCM64-31	8.3	2.39	49	345	1264	2992	*5967*	53.5	2.99E-03	0.324
WTCM64-61	9.8	2.39	25	128	388	861	*1589*	42.9	3.44E-03	0.363
WTCM64-33	9.6	2.39	62	351	1320	3274	*6464*	56.0	2.98E-03	0.321
Averages	**6.0**	**2.4**	**43**	**261**	**1111**	**3724**	**9495**	**54.9**	**4.59E-03**	**0.28**
St Dev	**3.3**	**0.0**	**14**	**126**	**605**	**2627**	**8786**	**12.7**	**1.69E-03**	**0.06**

(1 psi = 6.9 kPa)

Table C2.4.

University of California, Berkeley

Pavement Research Center
Lab mix/lab compacted specimen
8/12/1999

			RSST-CH Test Results					Extrapolation from Rep 100		
			Reps to Shear Strain					G* (MPa)	γ= a*(N^b):	
Specimen	**AVwp**	**SpG**	**1.0%**	**2.0%**	**3.0%**	**4.0%**	**5.0%**	**@100 Reps**	**a**	**b**
WTCH47-21	4.2	2.425	170	1686	*9.67E+03*	*3.04E+04*	*7.40E+04*	82.0	3.00E-03	0.251
WTCH47-22	3.2	2.425	523	5613	*2.01E+04*	*5.13E+04*	*1.06E+05*	101.5	1.45E-03	0.306
WTCH47-23	4.0	2.425	170	1346	*8.42E+03*	*2.64E+04*	*6.40E+04*	96.3	3.08E-03	0.252
WTCH47-31	7.7	2.425	7248	*4.57E+04*	*1.32E+05*	*2.81E+05*	*5.05E+05*	96.6	3.33E-04	0.382
WTCH47-32	6.4	2.425	470	4187	*1.51E+04*	*3.71E+04*	*7.46E+04*	110.3	1.38E-03	0.320
WTCH47-33	6.4	2.425	193	2266	*1.28E+04*	*4.09E+04*	*1.01E+05*	92.8	2.88E-03	0.248
WTCH47-11	10.1	2.425	483	7709	*3.46E+04*	*1.04E+05*	*2.44E+05*	112.6	1.96E-03	0.261
WTCH47-12	9.8	2.425	1212	*1.50E+04*	*6.13E+04*	*1.67E+05*	*3.63E+05*	117.6	1.26E-03	0.287
WTCH47-13	10.1	2.425	515	*1.22E+04*	*7.18E+04*	*2.53E+05*	*6.72E+05*	118.0	2.33E-03	0.228
Averages			**1220**	**10626**	**40669**	**110124**	**244789**	**103.1**	**1.96E-03**	**0.28**
St Dev			**2283**	**13975**	**41350**	**99899**	**222041**	**12.3**	**9.39E-04**	**0.05**
WTCH54-31	3.0	2.403	209	3246	*2.08E+04*	*7.49E+04*	*2.02E+05*	106.9	3.22E-03	0.225
WTCH54-32	2.9	2.403	660	*8.99E+03*	*3.82E+04*	*1.07E+05*	*2.37E+05*	134.6	1.56E-03	0.280
WTCH54-33	3.1	2.403	513	9710	*3.86E+04*	*1.17E+05*	*2.74E+05*	110.2	1.92E-03	0.260
WTCH54-1A	5.8	2.403	274	2529	*1.03E+04*	*2.70E+04*	*5.68E+04*	93.7	1.89E-03	0.299
WTCH54-52	6.6	2.403	260	2098	*9.18E+03*	*2.40E+04*	*5.07E+04*	92.3	1.96E-03	0.299
WTCH54-42	7.1	2.403	524	6135	*2.39E+04*	*6.36E+04*	*1.36E+05*	84.3	1.55E-03	0.294
WTCH54-2A	9.3	2.403	219	1482	4830	*1.09E+04*	*2.06E+04*	96.1	1.51E-03	0.352
WTCH54-2B	8.7	2.403	199	1337	4464	9787	*1.87E+04*	86.1	1.58E-03	0.352
WTCH54-2C	9.2	2.403	128	919	3798	*9.78E+03*	*2.05E+04*	88.8	2.49E-03	0.302
Averages			**332**	**4049**	**17123**	**49238**	**112924**	**99.2**	**1.96E-03**	**0.30**
St Dev			**185**	**3378**	**13983**	**42431**	**101775**	**15.9**	**5.64E-04**	**0.04**
WTCH61-11	2.3	2.389	226	1940	*1.01E+04*	*2.89E+04*	*6.55E+04*	99.7	2.43E-03	0.273
WTCH61-12	2.0	2.389	83	381	1646	8229	*1.69E+04*	81.0	4.69E-03	0.243
WTCH61-13	2.5	2.389	103	632	3674	*1.23E+04*	*3.03E+04*	92.5	3.93E-03	0.247
WTCH61-21	5.7	2.389	154	1417	6906	*1.86E+04*	*4.16E+04*	82.7	2.62E-03	0.277
WTCH61-22	5.0	2.389	114	1124	6005	*1.81E+04*	*4.33E+04*	80.5	3.26E-03	0.256
WTCH61-23	6.3	2.389	112	779	3085	7490	*1.50E+04*	80.9	2.36E-03	0.317
WTCH61-31	10.8	2.389	101	611	1818	3721	*6.78E+03*	72.4	1.73E-03	0.382
WTCH61-32	8.8	2.389	101	560	1843	4326	*8.06E+03*	69.1	2.14E-03	0.350
WTCH61-33	8.8	2.389	115	731	2483	5956	*1.13E+04*	77.9	2.11E-03	0.339
Averages			**123**	**908**	**4171**	**11952**	**26521**	**81.9**	**2.81E-03**	**0.30**
St Dev			**43**	**498**	**2901**	**8406**	**20091**	**9.4**	**9.67E-04**	**0.05**

(1 psi = 6.9 kPa)

Table C2.5. Final fine gradations.

Final Gradation with lime

Final Fine High Gradation

Sieve Size (mm)	w/o lime Percent Passing	Gradation of Lime
19	100.0	100
12.5	90.4	100
9.5	82.4	100
4.8	53.2	100
2.4	40.4	100
1.2	37.1	100
0.6	30.1	99.8
0.3	16.6	97.2
0.2	8.3	90.2
0.1	6.4	81.3

Final Fine High Gradation

Sieve Size (mm)	Percent Passing
19	100.0
12.5	90.5
9.5	82.7
4.8	53.9
2.4	41.3
1.2	38.1
0.6	31.1
0.3	17.8
0.2	9.5
0.1	7.5

Final Fine Med Gradation

Sieve Size (mm)	w/o lime Percent Passing	Gradation of Lime
19	100.0	100
12.5	88.3	100
9.5	73.5	100
4.8	47.3	100
2.4	36.3	100
1.2	31.3	100
0.6	24.2	99.8
0.3	12.5	97.2
0.2	4.8	90.2
0.1	2.8	81.3

Final Fine Med Gradation

Sieve Size (mm)	Percent Passing
19	100.0
12.5	88.5
9.5	73.9
4.8	48.1
2.4	37.3
1.2	32.4
0.6	25.4
0.3	13.8
0.2	6.0
0.1	4.0

Final Fine Low Gradation

Sieve Size (mm)	w/o lime Percent Passing	Gradation of Lime
19	100.0	100
12.5	71.3	100
9.5	57.1	100
4.8	39.4	100
2.4	29.0	100
1.2	23.6	100
0.6	15.5	99.8
0.3	6.0	97.2
0.2	2.1	90.2
0.1	1.4	81.3

Final Fine Low Gradation

Sieve Size (mm)	Percent Passing
19	100.0
12.5	71.8
9.5	57.7
4.8	40.4
2.4	30.1
1.2	24.7
0.6	16.8
0.3	7.4
0.2	3.5
0.1	2.6

(1 in. = 25.4 mm)

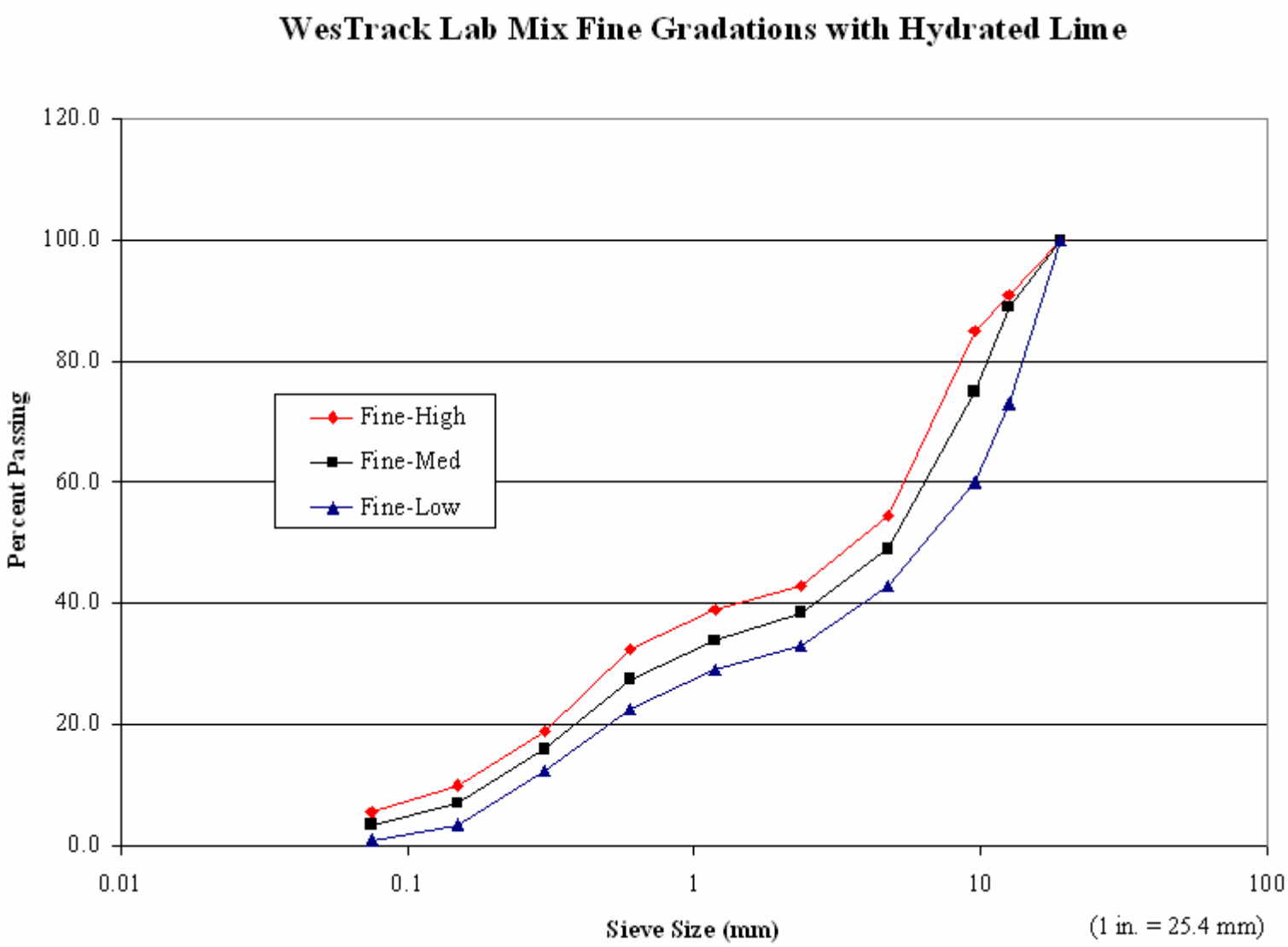

WesTrack Lab Mix Fine Gradations with Hydrated Lime
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Percent Passing
Fine-High
Fine-Med
Fine-Low
0.01
0.1
1
10
100
Sieve Size (mm)
(1 in. = 25.4 mm)

Figure C2.3.

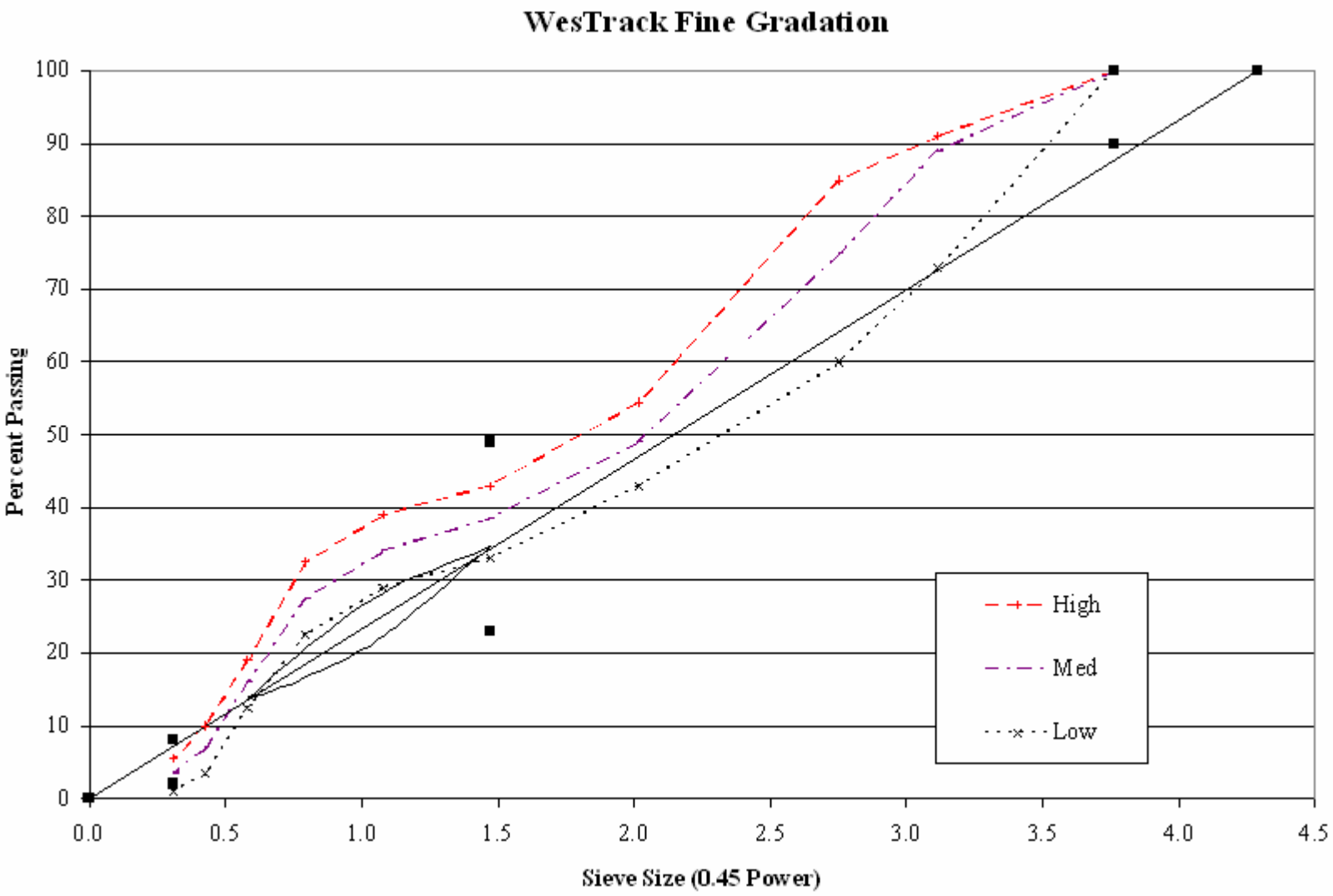

WesTrack Fine Gradation
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Sieve Size (0.45 Power)
High
Med
Low

Figure C2.4.

Table C2.6.

University of California, Berkeley

Pavement Research Center

Lab mix/lab compacted specimen

8/12/1999

			RSST-CH Test Results					Extrapolation from Rep 100		
			Reps to Shear Strain					G* (MPa)	γ= a*(N^b):	
Specimen	**AVwp**	**SpG**	**1.0%**	**2.0%**	**3.0%**	**4.0%**	**5.0%**	**@100 Reps**	**a**	**b**
WTFL47-11	2.8	2.454	287	8248	*49538*	*193579*	*557168*	104.1	3.06E-03	0.211
WTFL47-12	2.5	2.454	271	2269	*11844*	*33421*	*74725*	102.1	2.23E-03	0.277
WTFL47-13	3.0	2.454	569	*12226*	*68894*	*234938*	*608419*	111.7	2.20E-03	0.235
WTFL47-21	7.2	2.454	204	2394	*11941*	*35887*	*84258*	64.0	2.58E-03	0.261
WTFL47-22	6.5	2.454	261	4289	*21968*	*70148*	*172634*	83.3	2.52E-03	0.248
WTFL47-23	6.6	2.454	486	7159	*31896*	*94372*	*218910*	84.5	1.92E-03	0.265
WTFL47-31	10.3	2.454	144	1281	4813	*12460*	*25820*	63.6	2.23E-03	0.306
WTFL47-32	9.4	2.454	180	1445	5350	*13106*	*26445*	54.8	1.96E-03	0.318
WTFL47-33	10.5	2.454	199	2498	9499	*27114*	*59597*	70.2	2.22E-03	0.283
Averages	**6.5**	**2.5**	**289**	**4645**	**23971**	**79447**	**203108**	**82.0**	**2.32E-03**	**0.27**
St Dev	**3.2**	**0.0**	**144**	**3771**	**22231**	**81514**	**224905**	**20.4**	**3.52E-04**	**0.03**
WTFL54-41	2.8	2.425	92	606	3479	*11747*	*29322*	79.8	4.07E-03	0.244
WTFL54-42	3.3	2.425	83	441	1864	6422	*13738*	69.5	3.78E-03	0.271
WTFL54-43	2.9	2.425	105	879	4930	*15015*	*36137*	62.2	3.47E-03	0.254
WTFL54-31	6.9	2.425	109	789	3828	*11160*	*25312*	66.5	3.16E-03	0.272
WTFL54-32	6.9	2.425	121	766	2931	7539	*14813*	64.2	2.38E-03	0.317
WTFL54-33	6.0	2.425	164	1238	5107	*12783*	*26530*	58.4	2.22E-03	0.306
WTFL54-21	10.6	2.425	230	1604	4773	*10348*	*18962*	57.1	1.33E-03	0.368
WTFL54-22	8.9	2.425	182	1305	4465	*10533*	*20403*	48.9	1.76E-03	0.338
WTFL54-23	10.1	2.425	173	1007	2794	5298	*9588*	55.7	1.24E-03	0.404
Averages	**6.5**	**2.4**	**140**	**959**	**3797**	**10094**	**21645**	**62.5**	**2.60E-03**	**0.31**
St Dev	**3.0**	**0.0**	**49**	**368**	**1118**	**3134**	**8438**	**9.0**	**1.06E-03**	**0.05**
WTFL61-11	2.5	2.414	76	402	2020	8801	*19358*	51.2	4.68E-03	0.240
WTFL61-12	2.2	2.414	47	170	568	2211	*5598*	39.4	6.07E-03	0.244
WTFL61-13	2.7	2.414	71	265	1001	3697	*8264*	50.7	4.61E-03	0.264
WTFL61-32	6.4	2.414	132	843	2875	6523	*12438*	42.3	1.94E-03	0.345
WTFL61-42	7.0	2.414	131	1084	4665	*12096*	*25816*	45.1	2.51E-03	0.294
WTFL61-43	6.0	2.414	199	1498	5998	*14540*	*30767*	51.7	2.31E-03	0.298
WTFL61-53	10.2	2.414	145	848	2651	6026	*10869*	39.4	1.71E-03	0.363
WTFL61-62	9.4	2.414	110	576	1656	3388	*5908*	50.0	1.58E-03	0.397
WTFL61-63	10.3	2.414	120	698	2020	4243	*7610*	54.5	1.62E-03	0.383
Averages	**6.3**	**2.4**	**115**	**709**	**2606**	**6836**	**14070**	**47.1**	**3.00E-03**	**0.31**
St Dev	**3.3**	**0.0**	**45**	**418**	**1737**	**4205**	**9162**	**5.7**	**1.67E-03**	**0.06**

(1 psi = 6.9 kPa)

Table C2.7.

University of California, Berkeley

Pavement Research Center

Lab mix/lab compacted specimen

8/5/1999

			RSST-CH Test Results Reps to Shear Strain					Extrapolation from Rep 100 G* (MPa)	γ= a*(N^b):	
Specimen	**AVwp**	**SpG**	**1.0%**	**2.0%**	**3.0%**	**4.0%**	**5.0%**	**@100 Reps**	**a**	**b**
WTFM47-11	3.9	2.45	553	9677	*39429*	*118105*	*276589*	115.1	1.87E-03	0.262
WTFM47-12	3.6	2.45	362	8576	*40849*	*139753*	*362825*	126.4	2.50E-03	0.234
WTFM47-13	3.8	2.45	315	5531	*28387*	*93312*	*234860*	126.0	2.52E-03	0.242
WTFM47-21	6.7	2.45	100	794	4679	*14946*	*36947*	69.6	3.74E-03	0.247
WTFM47-22	6.5	2.45	159	1548	*8572*	*26636*	*64181*	92.2	3.01E-03	0.254
WTFM47-23	6.8	2.45	181	1618	9776	*24658*	*56838*	70.8	2.68E-03	0.267
WTFM47-31	8.8	2.45	137	1014	3961	*9927*	*20339*	78.4	2.28E-03	0.311
WTFM47-32	9.2	2.45	175	1271	4047	8844	*16937*	74.9	1.61E-03	0.353
WTFM47-33	10.5	2.45	149	1260	4028	8328	*16943*	78.3	1.71E-03	0.347
Averages	**6.6**	**2.5**	**237**	**3477**	**15970**	**49390**	**120718**	**92.4**	**2.44E-03**	**0.28**
St Dev	**2.5**	**0.0**	**146**	**3516**	**15704**	**52464**	**133159**	**23.7**	**6.76E-04**	**0.05**
WTFM54-11	2.7	2.418	281	4739	*24070*	*78043*	*194352*	98.6	2.54E-03	0.245
WTFM54-12	2.5	2.418	295	5263	*27027*	*88960*	*224143*	105.7	2.55E-03	0.241
WTFM54-13	2.2	2.418	288	5771	*32216*	*112329*	*295951*	113.9	2.75E-03	0.230
WTFM54-41	6.1	2.418	261	4158	*20511*	*64125*	*155243*	89.2	2.45E-03	0.252
WTFM54-51	6.7	2.418	417	3520	*11158*	*25982*	*50050*	84.6	1.26E-03	0.340
WTFM54-52	5.5	2.418	451	3422	*11045*	*25227*	*47873*	83.6	1.17E-03	0.348
WTFM54-31	9.1	2.418	155	977	2770	5548	*10164*	62.5	1.40E-03	0.387
WTFM54-32	8.7	2.418	198	798	1746	3398	*5727*	65.2	1.25E-03	0.426
WTFM54-33	9.5	2.418	139	915	2772	5988	*11113*	65.9	1.67E-03	0.365
Averages	**5.9**	**2.4**	**276**	**3285**	**14813**	**45511**	**110513**	**85.5**	**1.89E-03**	**0.32**
St Dev	**2.9**	**0.0**	**106**	**1942**	**11503**	**41053**	**108880**	**18.5**	**6.64E-04**	**0.07**
WTFM61-11	2.7	2.385	220	2748	*13114*	*38930*	*90535*	76.7	2.45E-03	0.264
WTFM61-12	1.8	2.385	137	834	3972	*11368*	*25142*	66.7	2.90E-03	0.281
WTFM61-13	2.2	2.385	171	1403	7486	*19571*	*43876*	82.2	2.61E-03	0.276
WTFM61-43	6.7	2.385	177	1273	3544	6429	*12868*	71.7	1.31E-03	0.385
WTFM61-51	5.8	2.385	148	949	2782	5320	*10077*	65.7	1.44E-03	0.385
WTFM61-41	5.8	2.385	171	1216	3600	7319	*13864*	62.6	1.45E-03	0.372
WTFM61-33	10.1	2.385	107	535	1415	2676	*4556*	51.4	1.36E-03	0.428
WTFM61-22	9.4	2.385	79	389	959	1643	*2781*	52.1	1.32E-03	0.459
WTFM61-31	8.5	2.385	258	1475	4095	7748	*13845*	57.4	1.02E-03	0.408
Averages	**5.9**	**2.4**	**163**	**1203**	**4552**	**11223**	**24172**	**65.2**	**1.76E-03**	**0.36**
St Dev	**3.1**	**0.0**	**54**	**690**	**3713**	**11658**	**27783**	**10.6**	**6.88E-04**	**0.07**

(1 psi = 6.9 kPa)

Table C2.8.

University of California, Berkeley

Pavement Research Center
Lab mix/lab compacted specimen
8/27/1999

			RSST-CH Test Results				Extrapolation from Rep 100			
			Reps to Shear Strain					G* (MPa)	γ= a*(N^b):	
Specimen	**AVwp**	**SpG**	**1.0%**	**2.0%**	**3.0%**	**4.0%**	**5.0%**	**@100 Reps**	**a**	**b**
WTFH47-73	4.2	2.44	888	*18866*	*105175*	*355938*	*916337*	132.7	1.96E-03	0.235974
WTFH47-81	3.6	2.454	849	*17668*	*90448*	*288137*	*707802*	172.1	1.76E-03	0.248
WTFH47-82	3.1	2.454	1054	*27732*	*158814*	*547817*	*1431347*	204.3	1.86E-03	0.232
WTFH47-12	6.9	2.44	319	3107	*12511*	*32910*	*69684*	109.2	1.81E-03	0.297
WTFH47-22	6.0	2.44	131	1896	*15583*	*62652*	*184351*	98.4	4.08E-03	0.207
WTFH47-23	6.9	2.44	154	2222	*15276*	*55583*	*151374*	102.9	3.51E-03	0.223
WTFH47-51	10.6	2.44	235	2725	9022	*26665*	*56593*	94.7	1.95E-03	0.297
WTFH47-52	8.7	2.44	96	930	3999	*11269*	*24997*	70.6	2.93E-03	0.280
WTFH47-53	9.9	2.44	305	3286	11872	*30556*	*63615*	90.6	1.73E-03	0.304
Averages	**6.7**	**2.4**	**448**	**8715**	**46967**	**156836**	**400678**	**119.5**	**2.40E-03**	**0.26**
St Dev	**2.7**	**0.0**	**373**	**9943**	**56439**	**193103**	**501767**	**43.0**	**8.82E-04**	**0.04**
WTFH54-21	3.6	2.424	170	1750	*9470*	*29073*	*69395*	106.2	2.87E-03	0.256
WTFH54-22	2.9	2.424	126	776	4856	*14695*	*35485*	105.1	3.53E-03	0.253
WTFH54-23	3.9	2.424	109	942	5573	*17081*	*41906*	98.2	3.55E-03	0.249
WTFH54-11	6.7	2.424	300	2996	*10560*	*26185*	*52963*	97.1	1.59E-03	0.317
WTFH54-12	6.8	2.424	257	2737	*10638*	*28053*	*59516*	92.3	1.92E-03	0.297
WTFH54-13	7.0	2.424	107	902	4024	*11208*	*24904*	85.5	2.95E-03	0.279
WTFH54-31	9.2	2.424	167	994	2918	5519	*10406*	72.4	1.35E-03	0.390
WTFH54-32	9.2	2.424	220	1284	3534	6540	*11902*	74.0	1.09E-03	0.408
WTFH54-42	9.4	2.424	199	1245	2996	5499	*9841*	67.7	1.06E-03	0.420
Averages	**6.5**	**2.4**	**184**	**1514**	**6063**	**15984**	**35146**	**88.7**	**2.21E-03**	**0.32**
St Dev	**2.5**	**0.0**	**67**	**821**	**3246**	**9717**	**22438**	**14.5**	**1.02E-03**	**0.07**
WTFH61-31	3.4	2.412	231	4377	*25154*	*87492*	*230079*	96.7	2.89E-03	0.231
WTFH61-32	2.8	2.412	178	2214	*14335*	*49603*	*129922*	110.4	3.27E-03	0.232
WTFH61-33	3.3	2.412	129	1021	8393	*24187*	*62901*	98.3	3.79E-03	0.233
WTFH61-11	6.3	2.412	114	1244	6679	*20764*	*50616*	79.8	3.32E-03	0.250
WTFH61-41	6.3	2.412	212	1369	3817	7281	*13655*	90.1	1.19E-03	0.392
WTFH61-43	5.7	2.412	168	1359	5592	*14056*	*29281*	75.5	2.19E-03	0.304
WTFH61-73	9.5	2.414	191	1091	2907	5444	*9752*	74.5	1.12E-03	0.413
WTFH61-82	9.8	2.414	76	379	913	1566	*2649*	61.5	1.28E-03	0.465
WTFH61-83	8.7	2.414	51	319	1038	2195	*4139*	65.1	2.49E-03	0.360
Averages	**6.2**	**2.4**	**150**	**1486**	**7648**	**23621**	**59222**	**83.5**	**2.39E-03**	**0.32**
St Dev	**2.7**	**0.0**	**61**	**1222**	**7771**	**28279**	**75773**	**16.4**	**1.01E-03**	**0.09**

(1 psi = 6.9 kPa)

APPENDIX D

Summary of Traffic Wander Study Conducted by Symplectic Engineering Corporation entitled, "The Effect of Traffic Wander on Rut Evolution in Asphalt Concrete Surface Layers"

The objective of this study has been to evaluate the influence of traffic wander on the development of rut depth in asphalt concrete surface layers, including those representative of the WesTrack pavement. A series of nonlinear plane strain finite element simulations were utilized to compare rut depth evolution for three different traffic wander patterns with that evolution under channelized traffic (a total of four loading patterns). Included in the evaluations were the influence of temperature of the asphalt concrete layer and stiffness of the underlying layer(s) ("flexible" and "rigid").

The underlying layers were assumed to exhibit linear elastic behavior. Accordingly, the rutting was confined to the asphalt concrete layer, modeled as a viscoplastic material. The model incorporated a linear viscoelastic component to reflect temperature and rate of loading dependency in parallel with a rate-independent elastoplastic part to allow large residual strains (as a percentage of the strains during loading) and a Bauchinger-type effect.

Small deformation theory was utilized and rut evolution during the first 1,000 load cycles was determined for the four loading patterns, Table D.1, and the two base types as noted above. Three different temperature distributions were utilized:

1. uniform temperature of 50°C (122°F),
2. linearly varying temperature between 60°C (140°F) at the surface and 40°C (104°F) at the bottom of the asphalt concrete layer, and
3. uniform temperature of 35°C (95°F).

Forty-two finite element simulations were developed; Table D.2 summarizes these. Figures D.1 and D.2 contain examples of the results of these simulations.

A main conclusion of this study is that the importance of wander depends on the type of base materials and on the thickness of the asphalt concrete layer. Specifically, for the case of

flexible base, three of the four patterns studied led to similar rut depths for thick layers of asphalt concrete pavements. The fourth wander pattern, channeled traffic, differed from the other three in that a smaller rut depth was obtained. For the case of rigid base, all four wander patterns led to similar rut depths when the asphalt concrete layer was thin, but differing rut depths resulted for the case of thick asphalt concrete layers (with channeled traffic yielding the largest rut depth).

With regard to quantifying the importance of traffic wander, the study is inconclusive. After 1,000 loading cycles, the maximal difference among the four wander patterns was roughly 25 percent, which some may not consider a significant variance. However, it should be noted that the ruts continue to develop, and the rut evolution plots suggest, in some cases, that the difference may increase after a larger number of repetitions.

Table D.1. Traffic patterns.

Four different patterns were utilized:

1. channelized traffic (all loads applied at the same location (W0)

2. wander among five locations (W1)

Transverse distance from center (m)	Percentage of traffic
±0.4	5
±0.2	25
0.0	40

3. wander among nine locations representing highway conditions (W2)

Transverse distance from center (m)	Percentage of traffic
±0.51	3.5
±0.38	6.5
±0.25	12.5
±0.13	17.5
0.00	20.0

4. wander among eleven locations based on WesTrack data (W3)

Transverse distance from center (m)	Percentage of traffic
-0.127	16.67
-0.102	5.64
-0.076	8.05
-0.051	9.06
-0.25	2.94
0.0	9.97
0.025	9.90
0.051	7.74
0.076	7.22
0.102	6.56
0.127	16.25

(1 in. = 25.4 mm)

Table D.2. Configurations of system analyzed.

AC thickness (m)	Base type	Environment distribution	Load distribution
0.10	Flexible	1	1,2,3,4
0.15	Flexible	1,2	1,2,3,4
0.15	Flexible	3	1
0.20	Flexible	1	1,2,3,4
0.25	Flexible	1	1,2,3,4
0.10	Rigid	1	1,2,3,4
0.15	Rigid	1,2	1,2,3,4
0.15	Rigid	3	1
0.20	Rigid	1	1,2,3,4
0.25	Rigid	1	1,2,3,4

(1 in. = 25.4 mm)

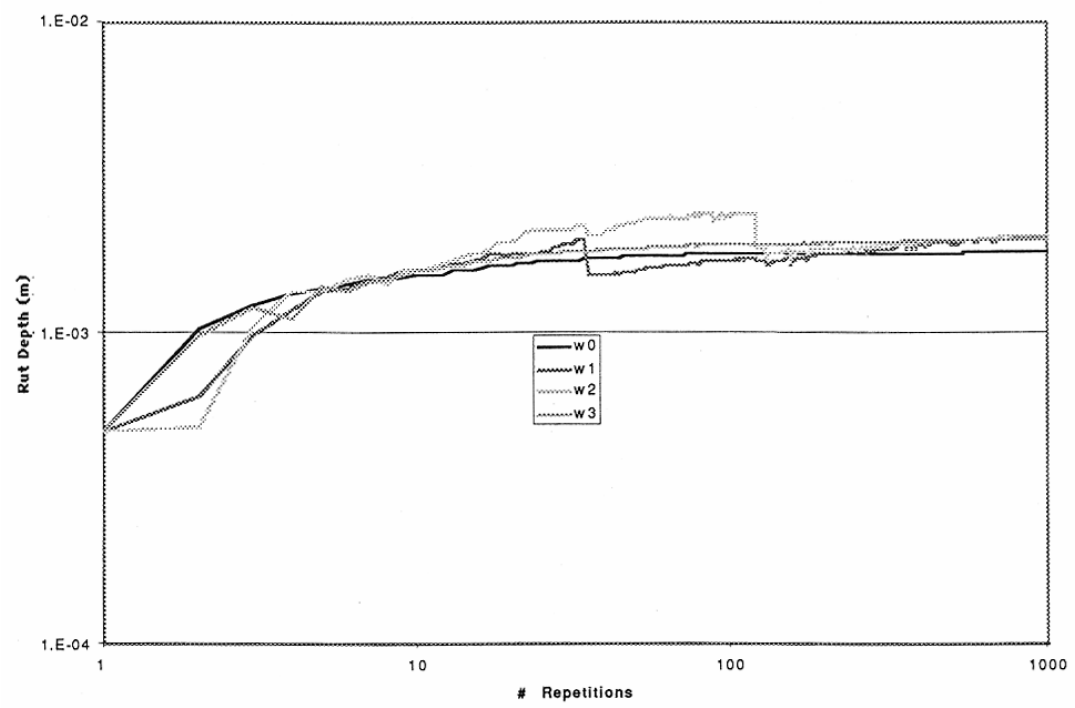


Figure D.1. Evolution of rut depth for 0.15-m (6-in.) AC layer on a flexible base, 50°C (122°F).

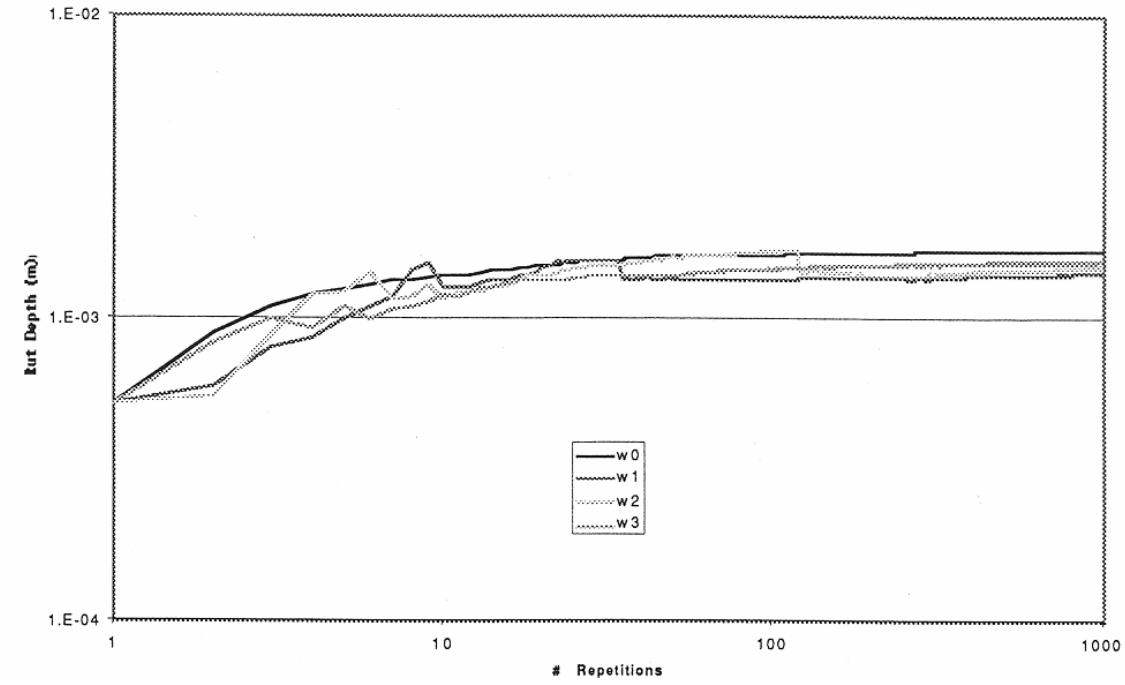
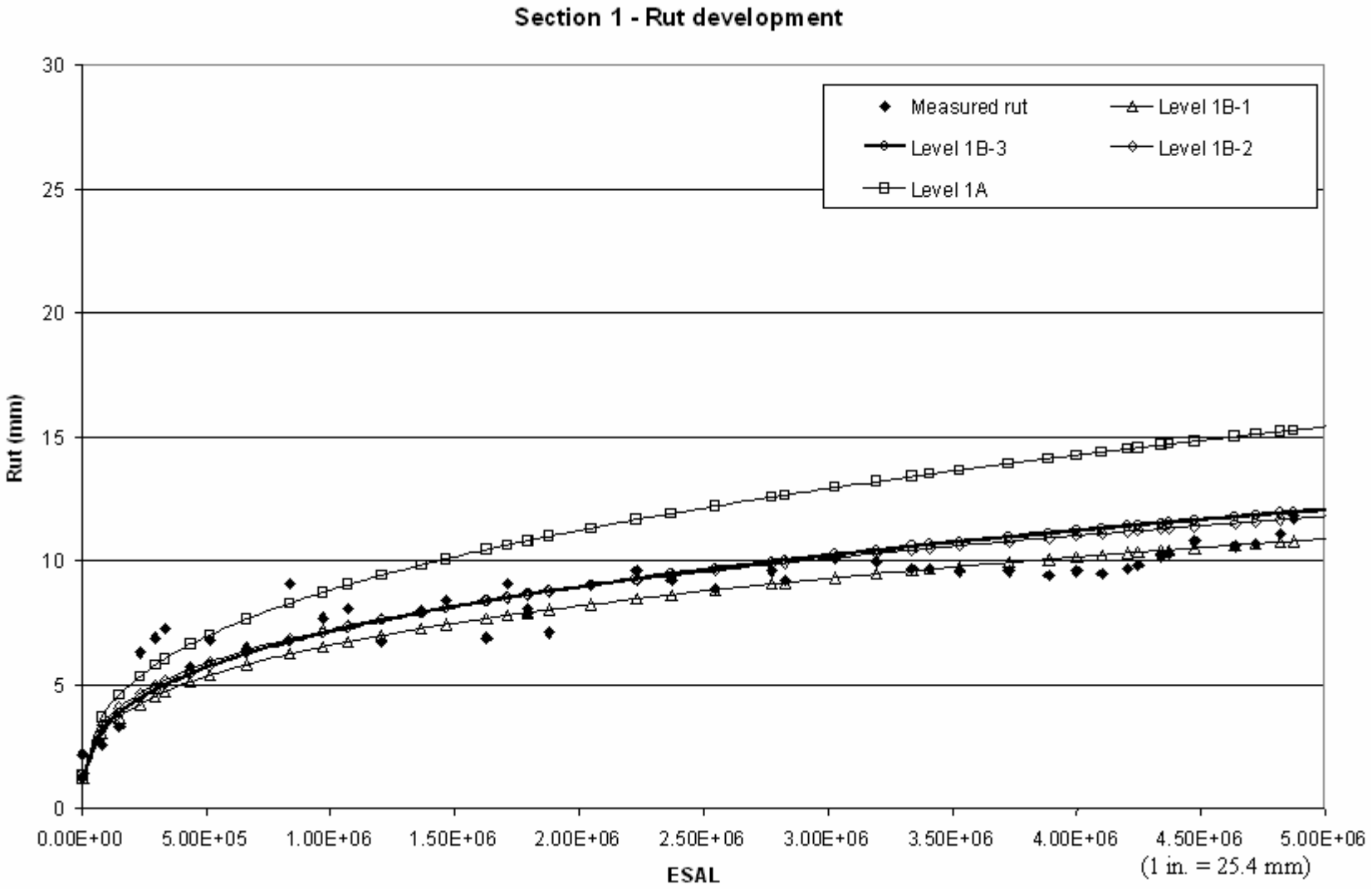


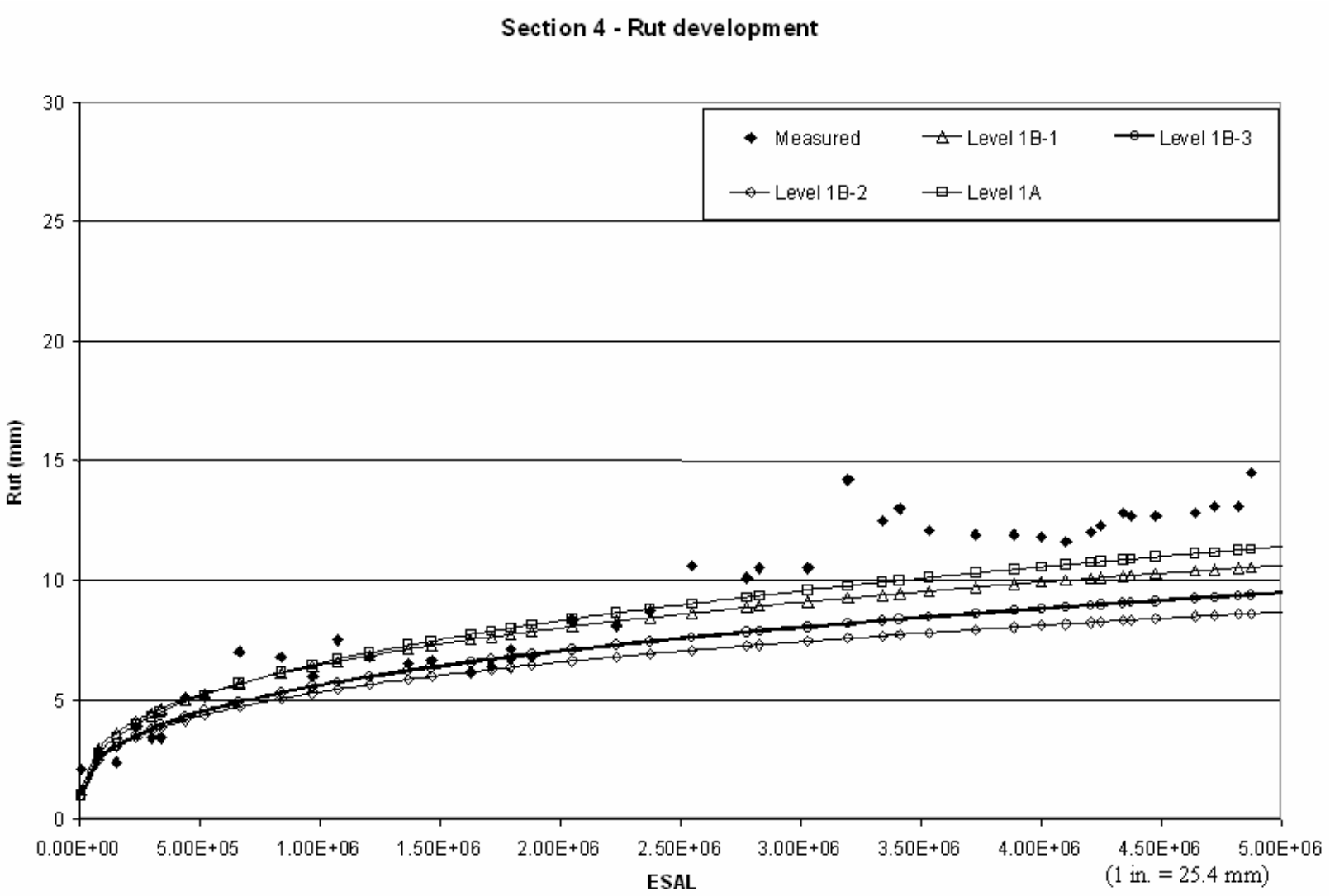
Figure D.2. Evolution of rut depth for 0.15-m (6-in.) AC layer on a rigid base, 50°C (122°F).

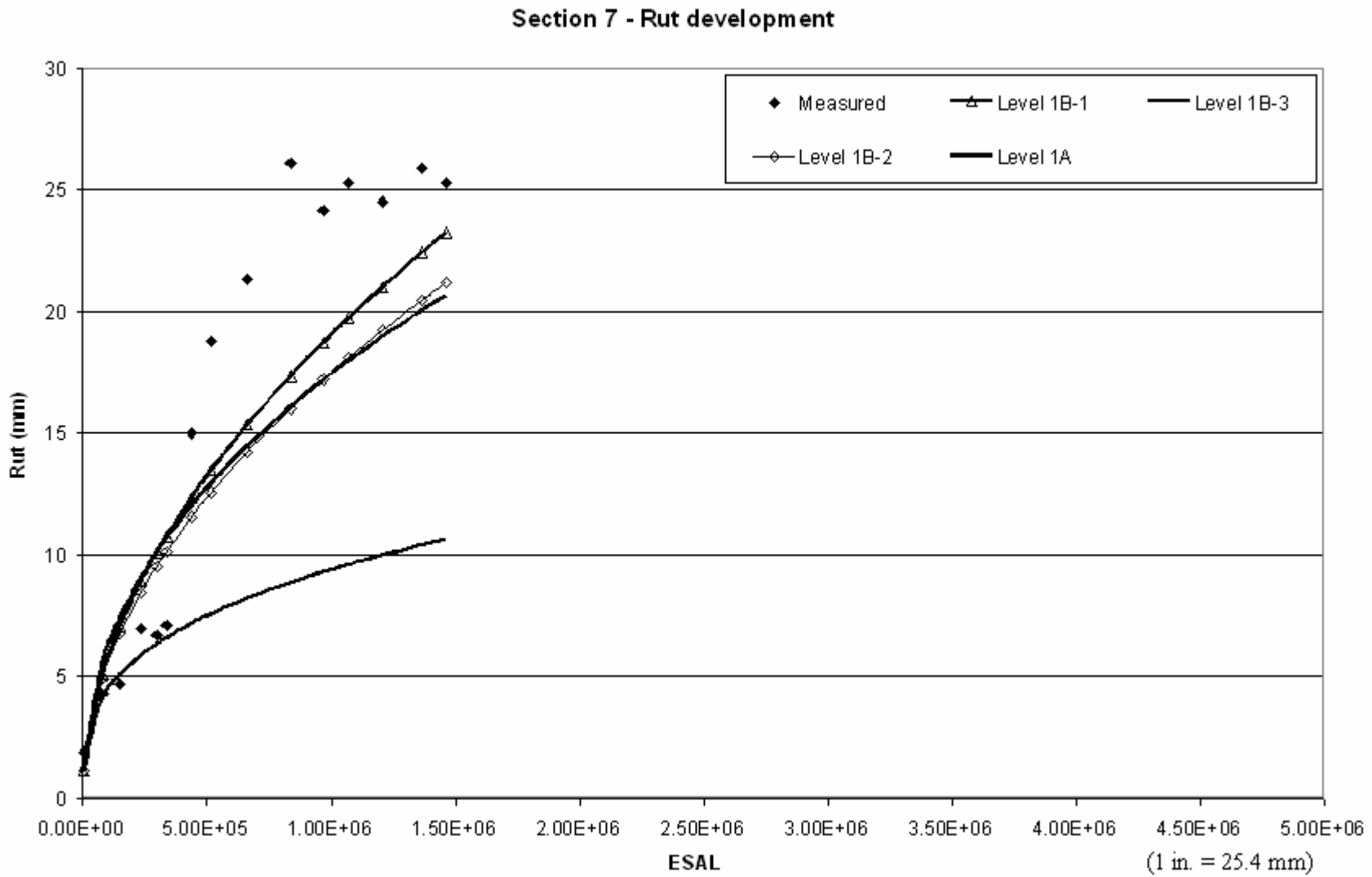
APPENDIX E

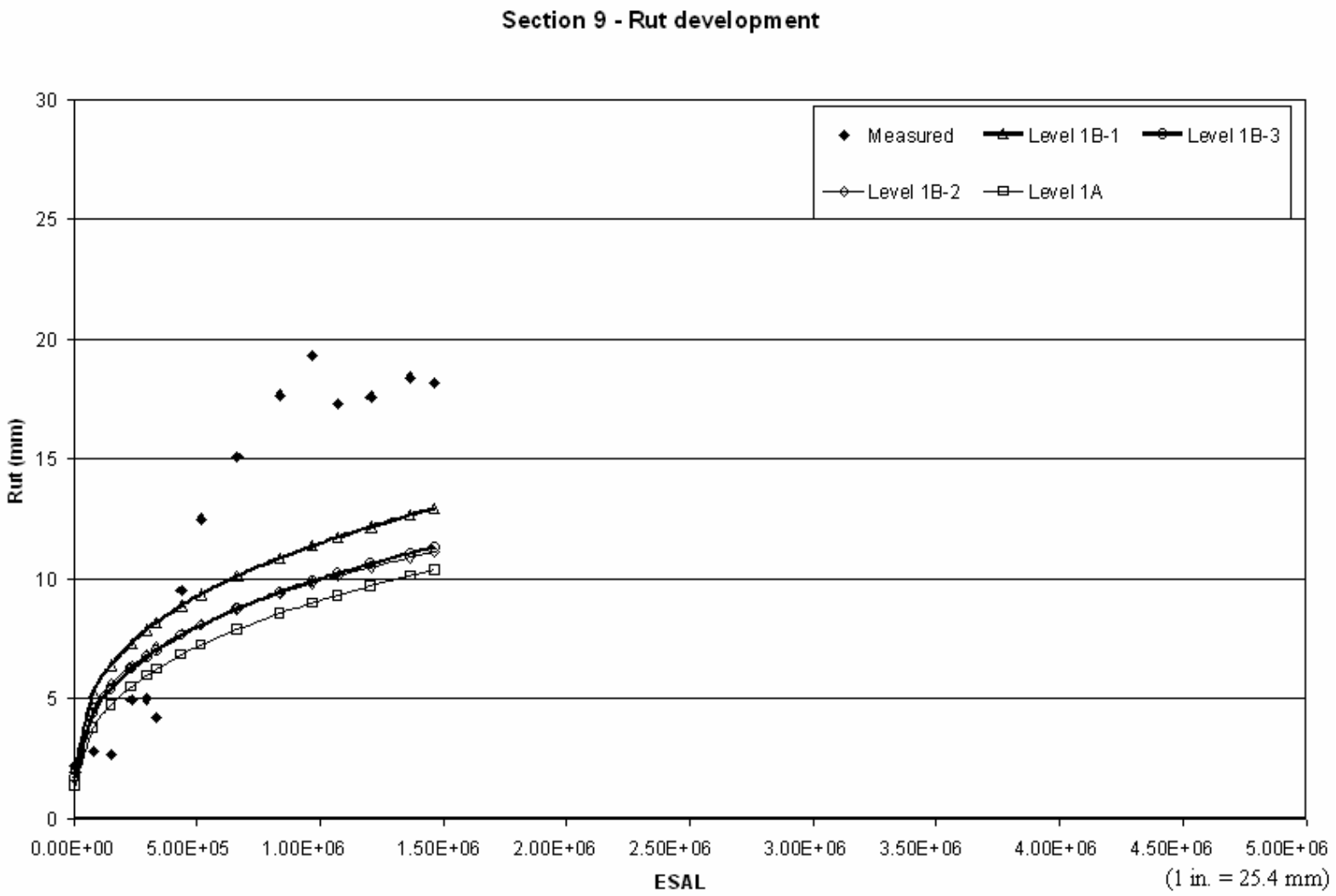
Comparison of Level 1A and Level 1B Regressions with Measured Rut Depths (as a Function of ESALs)

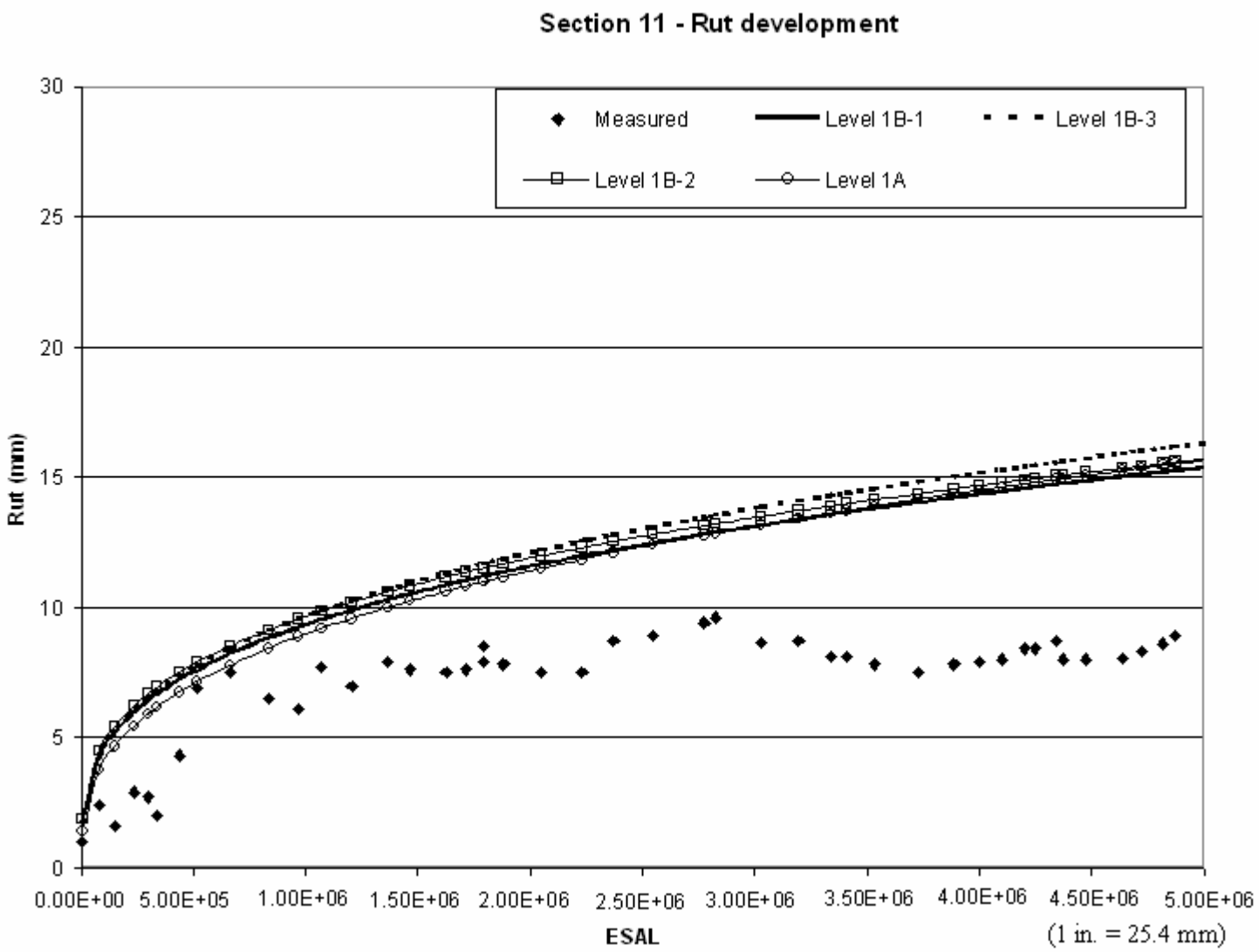
Rut Development – Sections 1, 4, 7, 9, 11-15, 18-25, 35, 37-39, 54, and 55

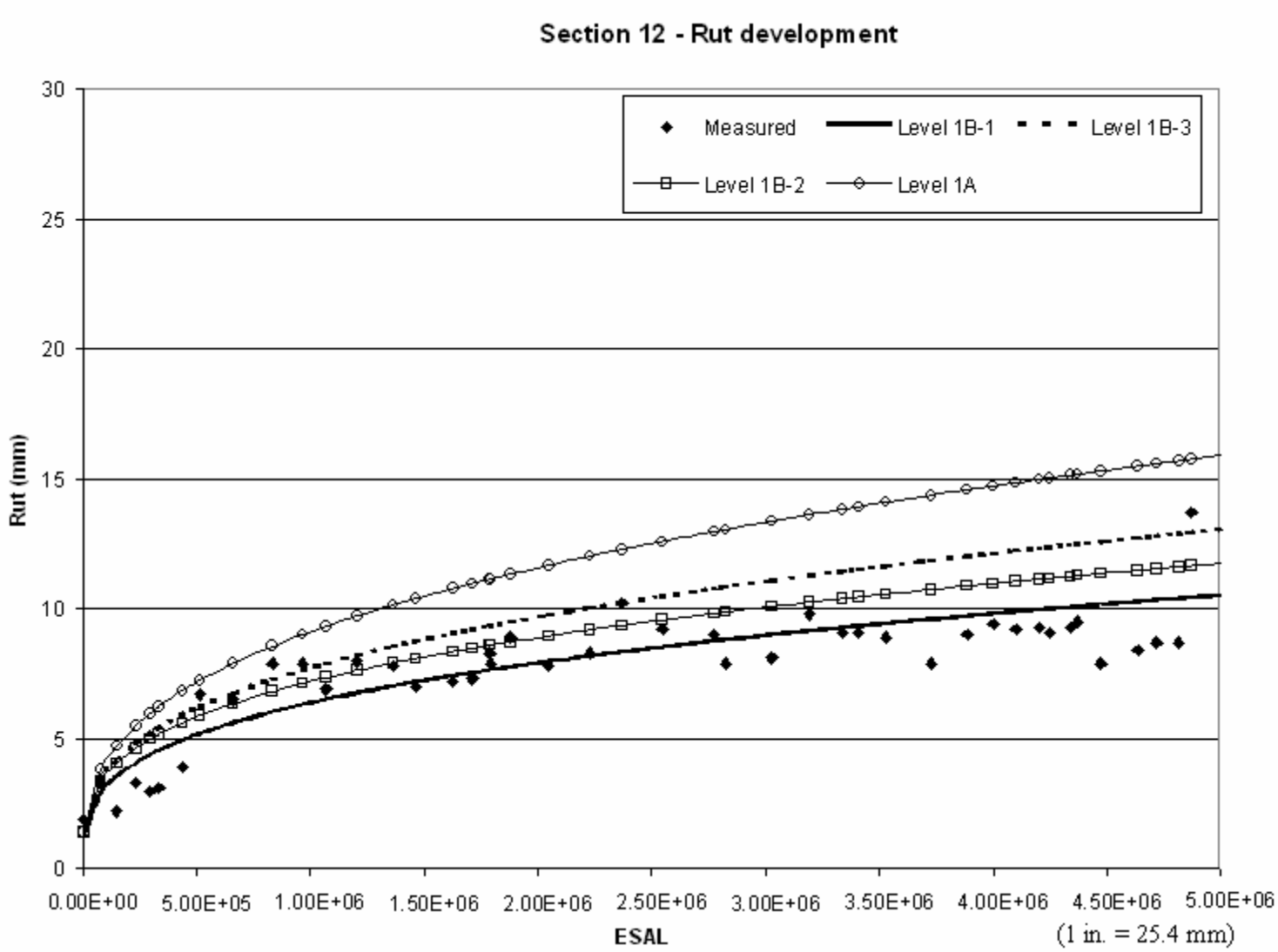

Section 1 - Rut development
Measured rut
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

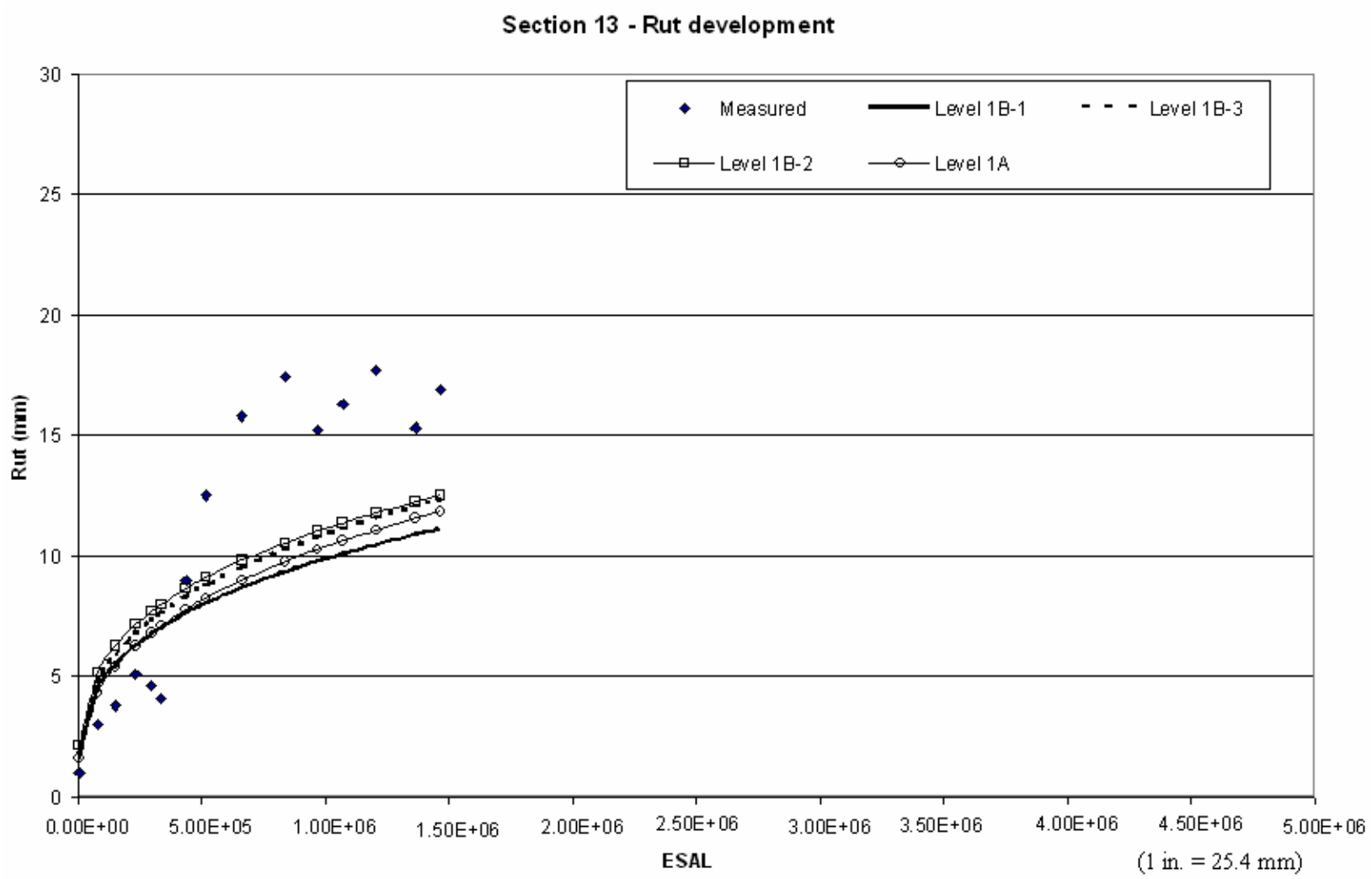

Section 4 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

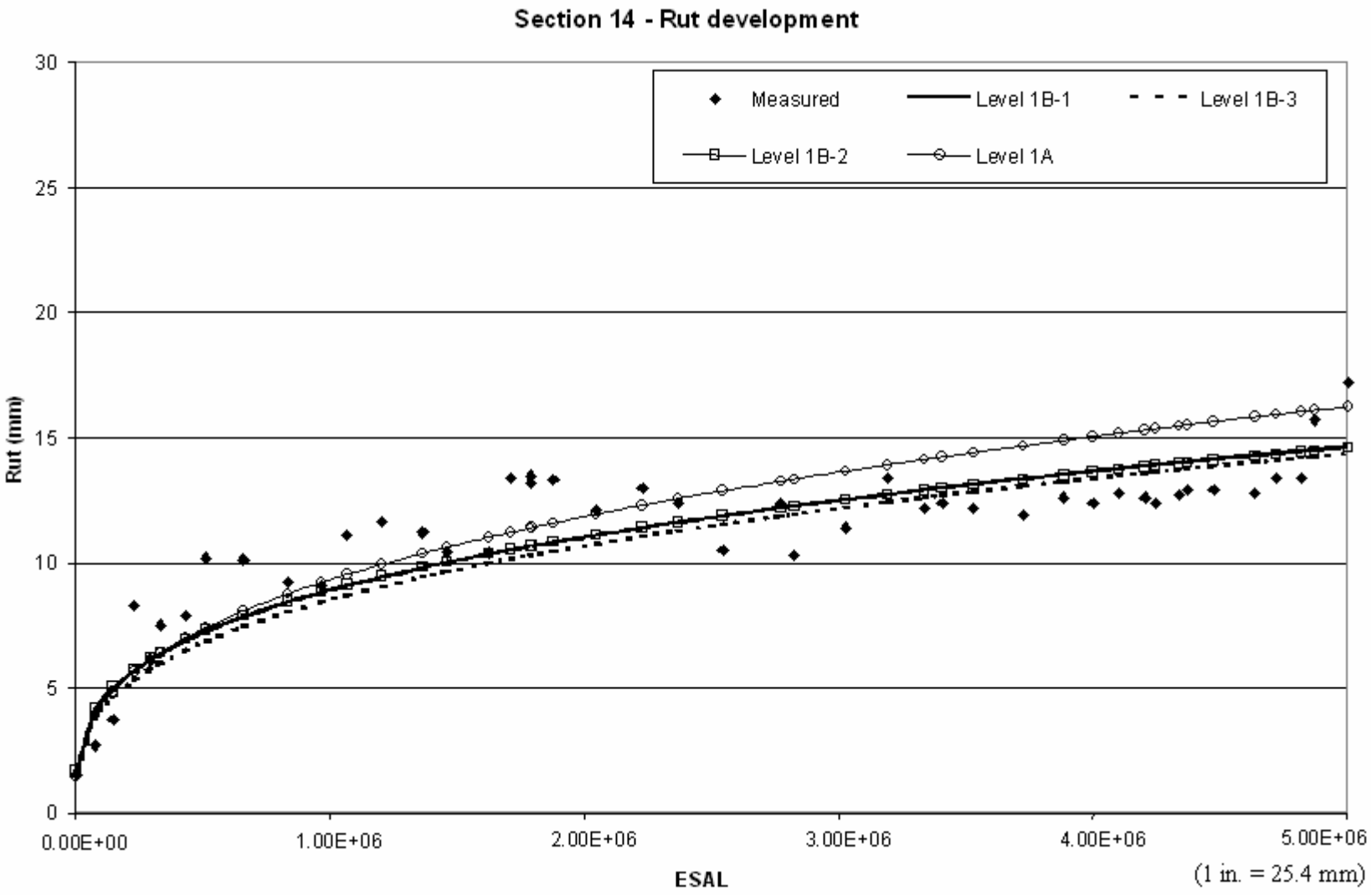

Section 7 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

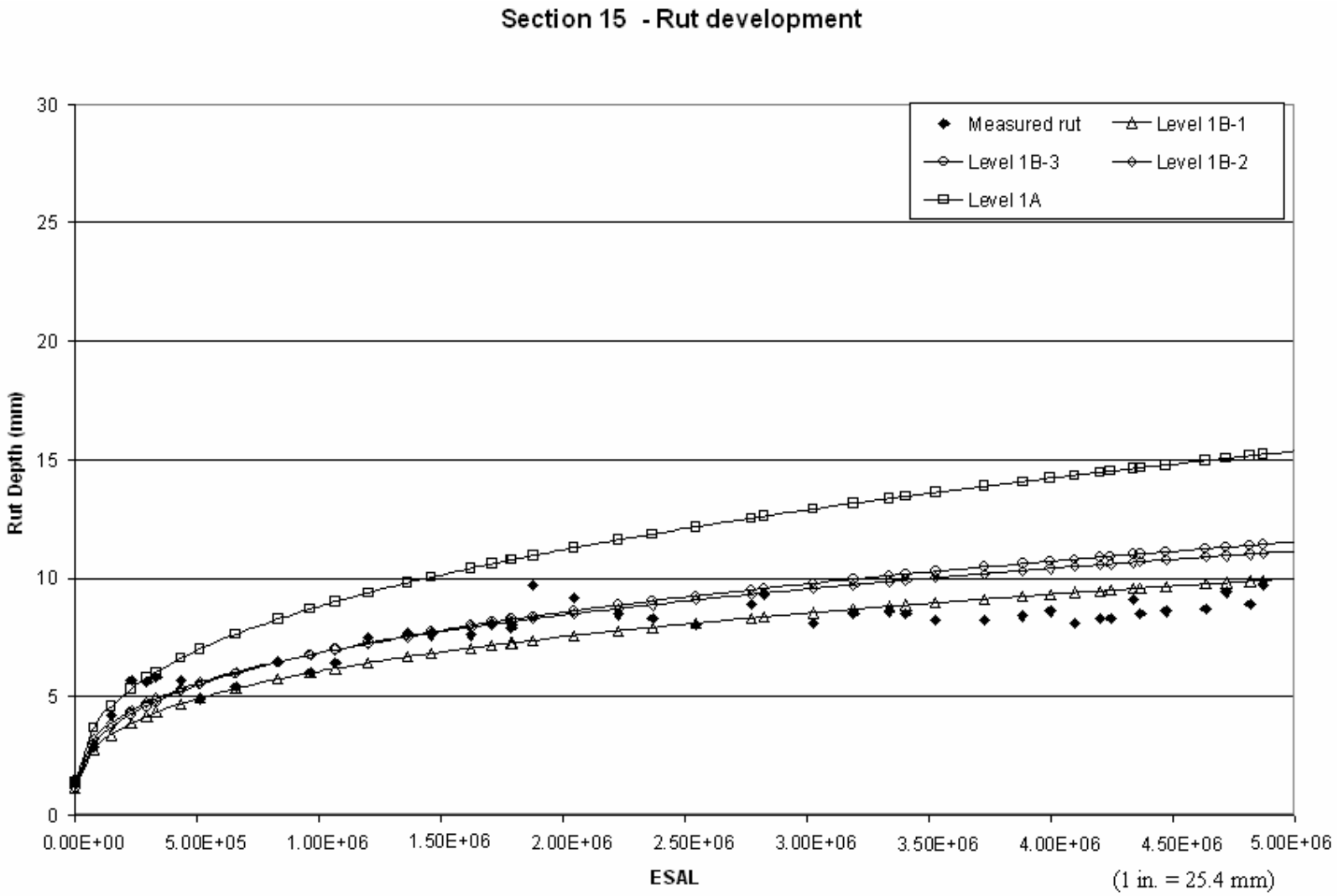

Section 9 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

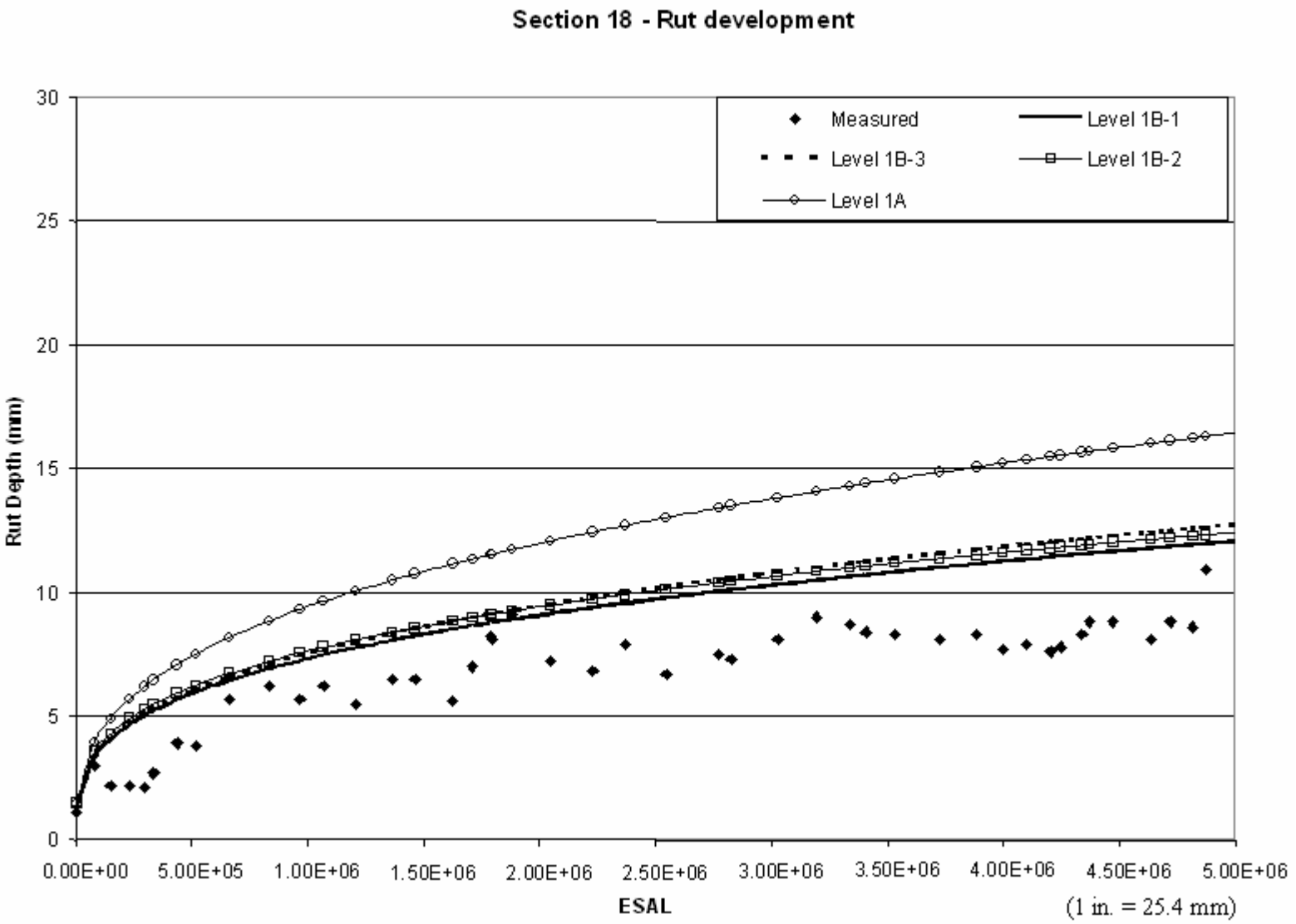

Section 11 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

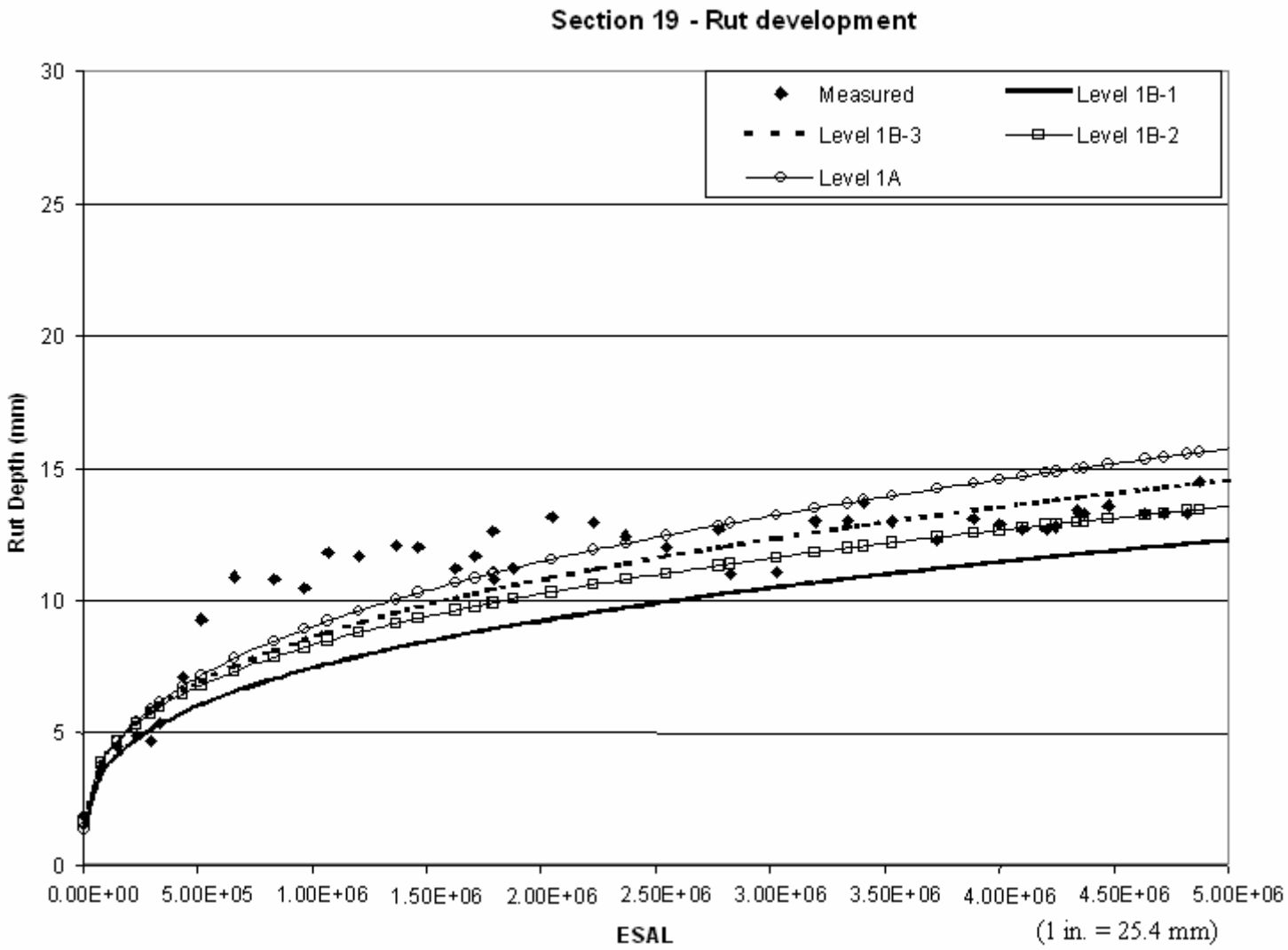

Section 12 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

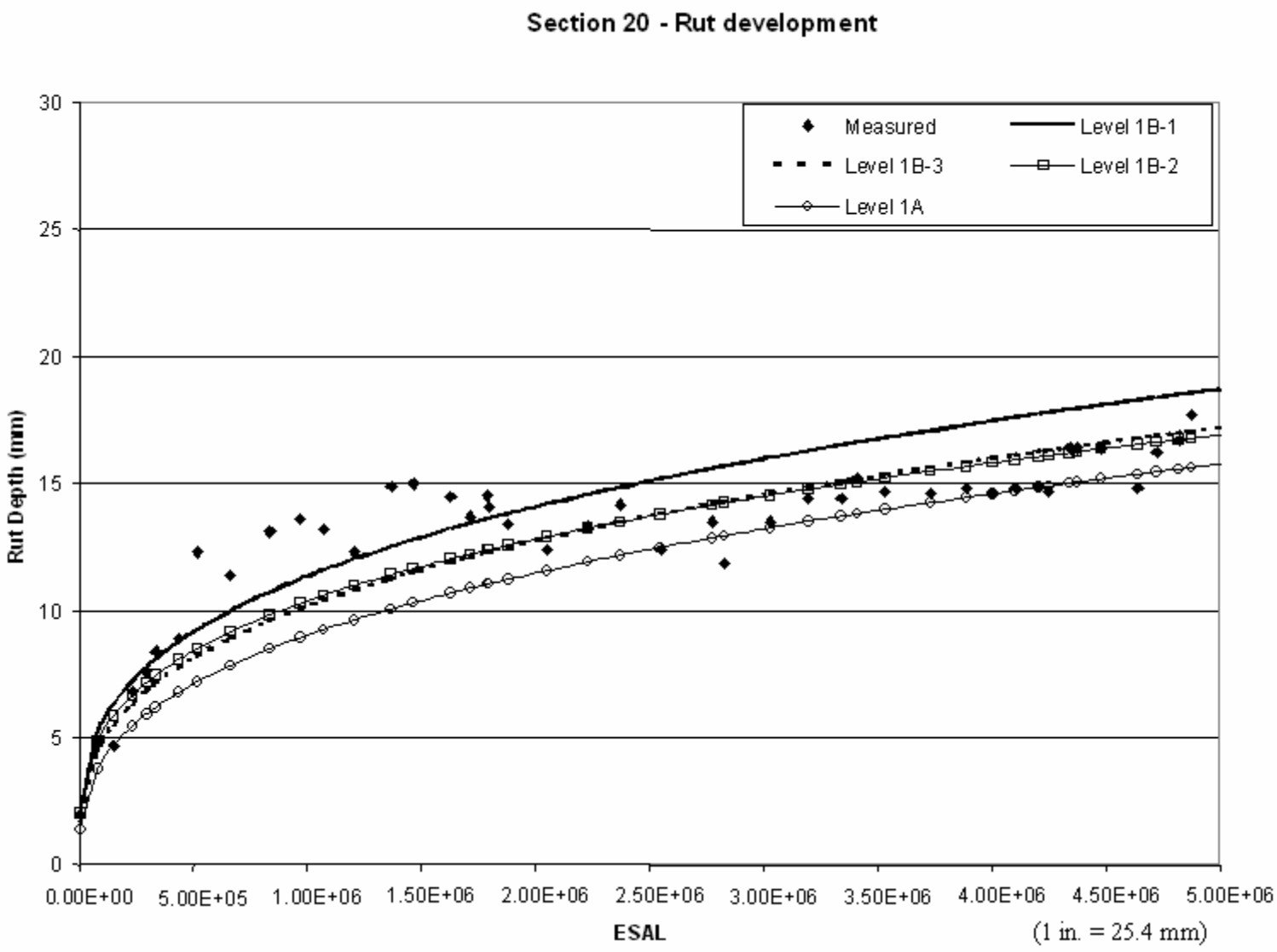

Section 13 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

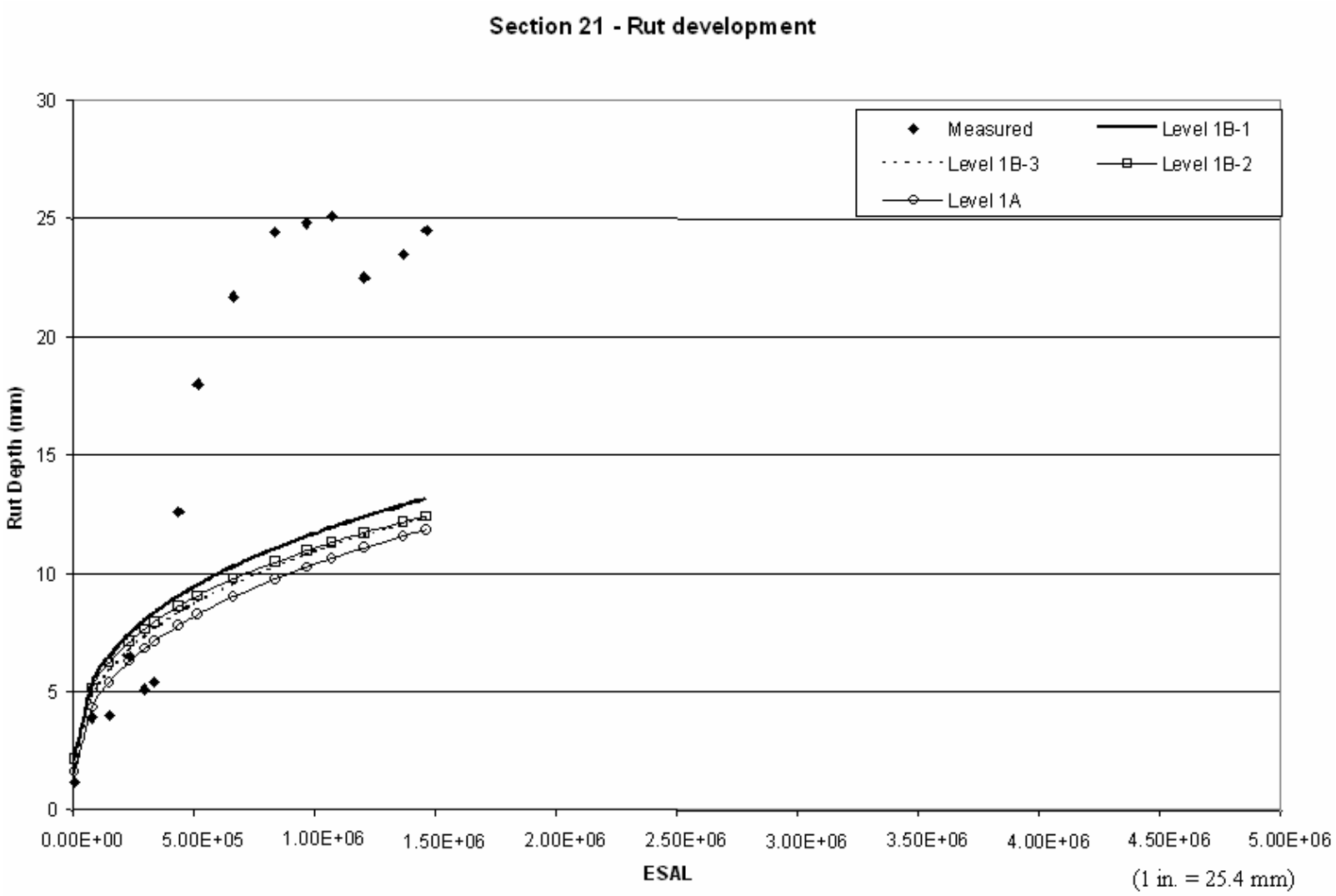

Section 14 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut (mm)
30
25
20
15
10
5
0
0.00E+00
1.00E+06
2.00E+06
3.00E+06
4.00E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

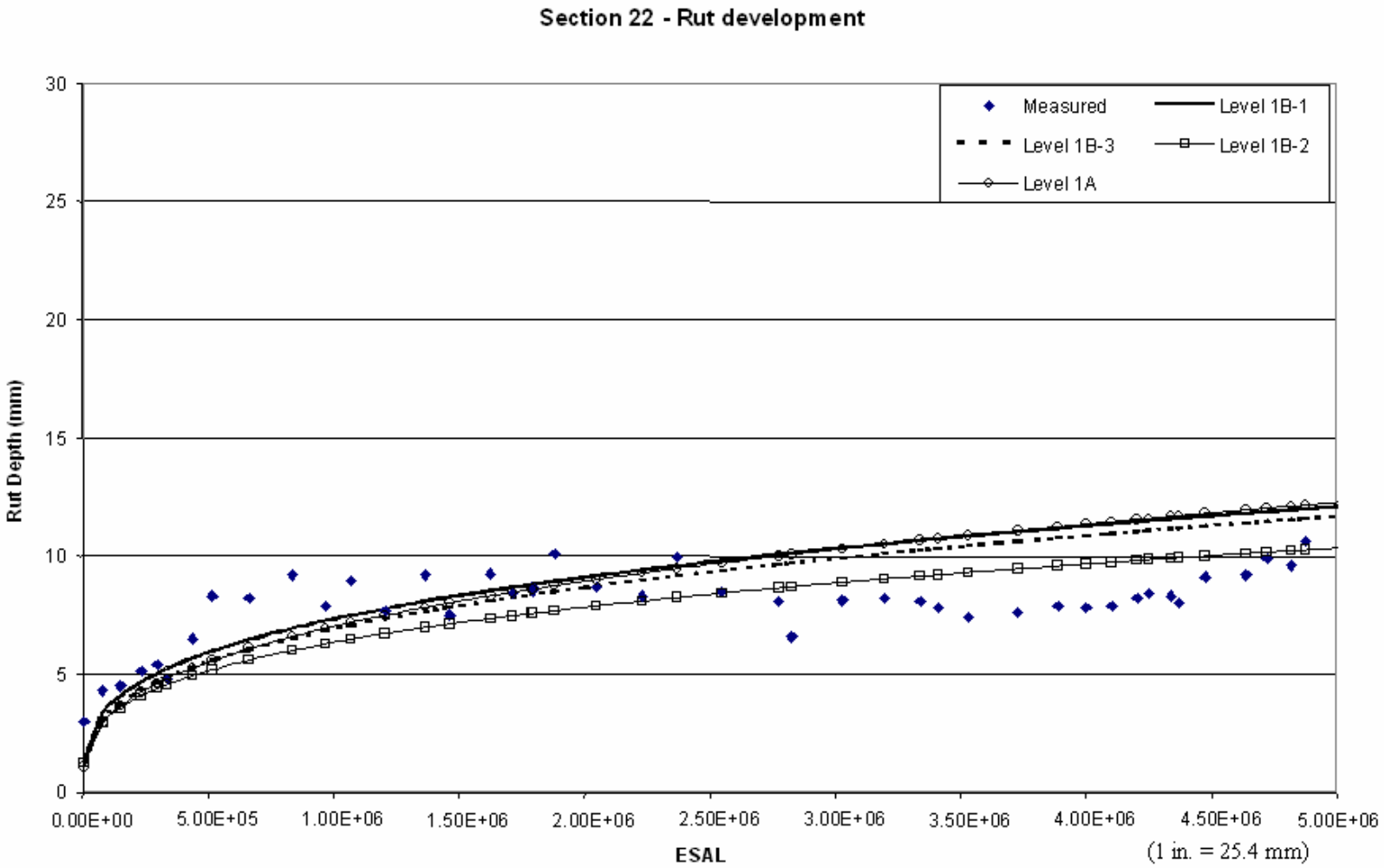

Section 15 - Rut development
Measured rut
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

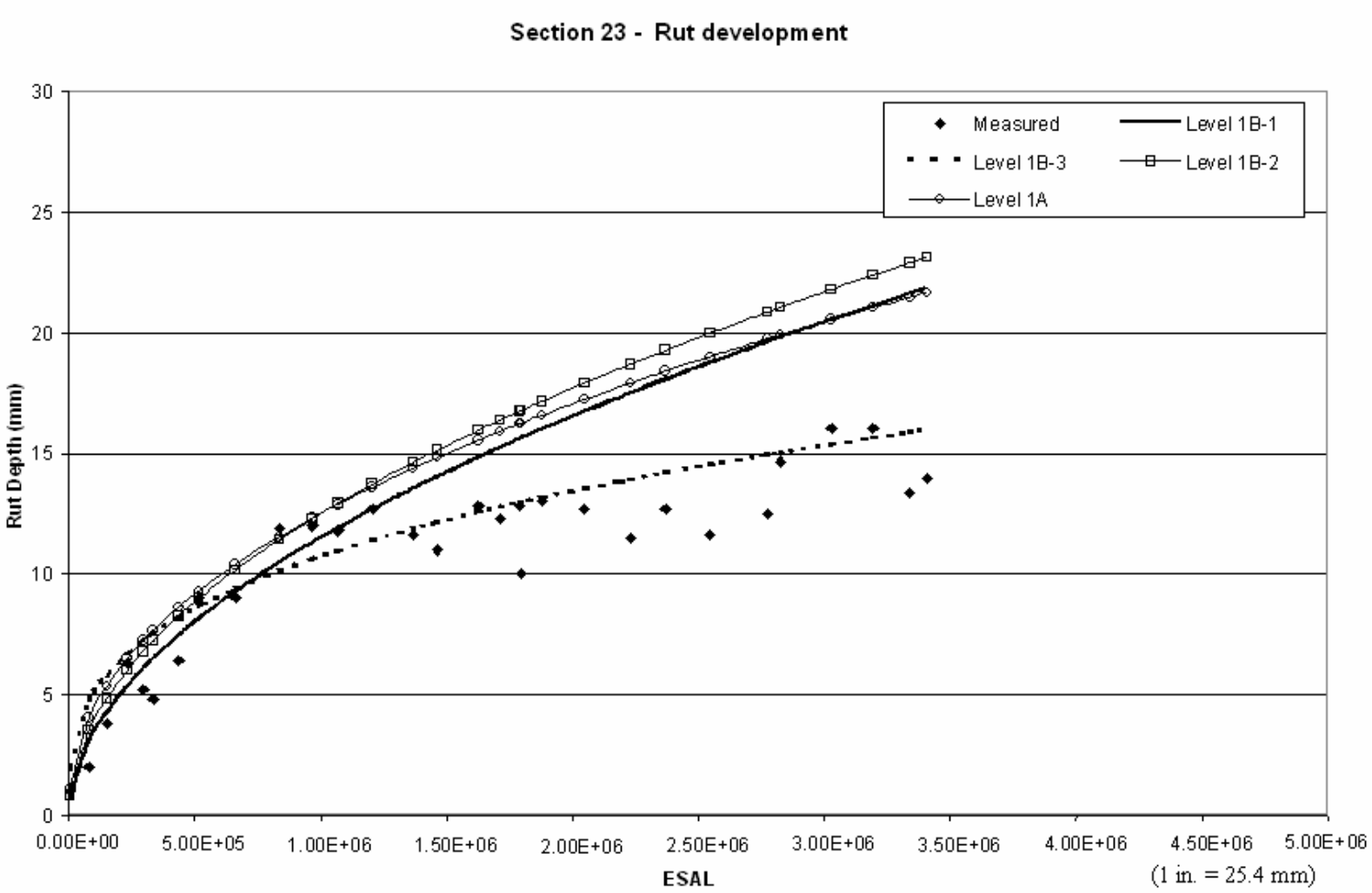

Section 18 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

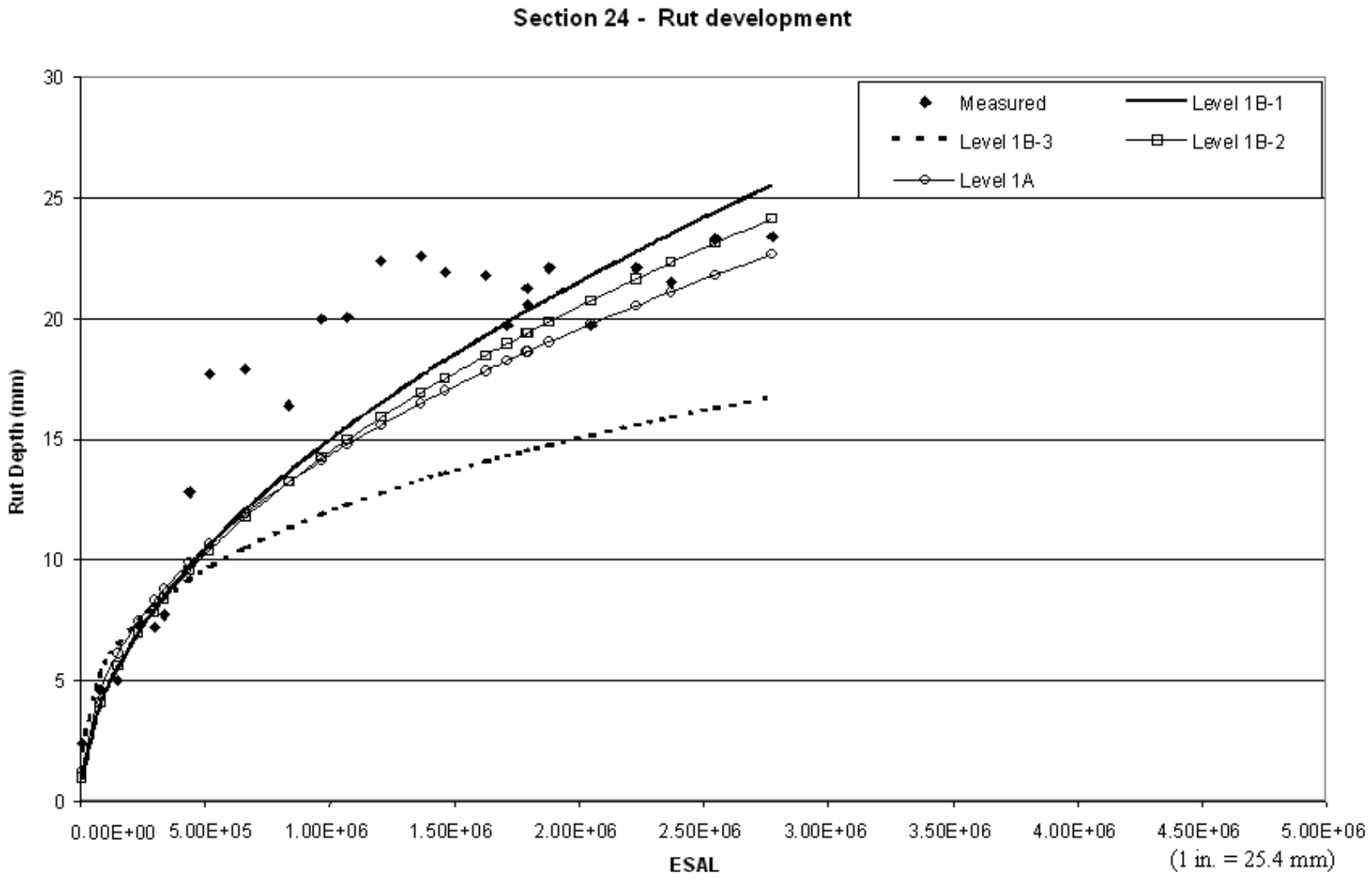

Section 19 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

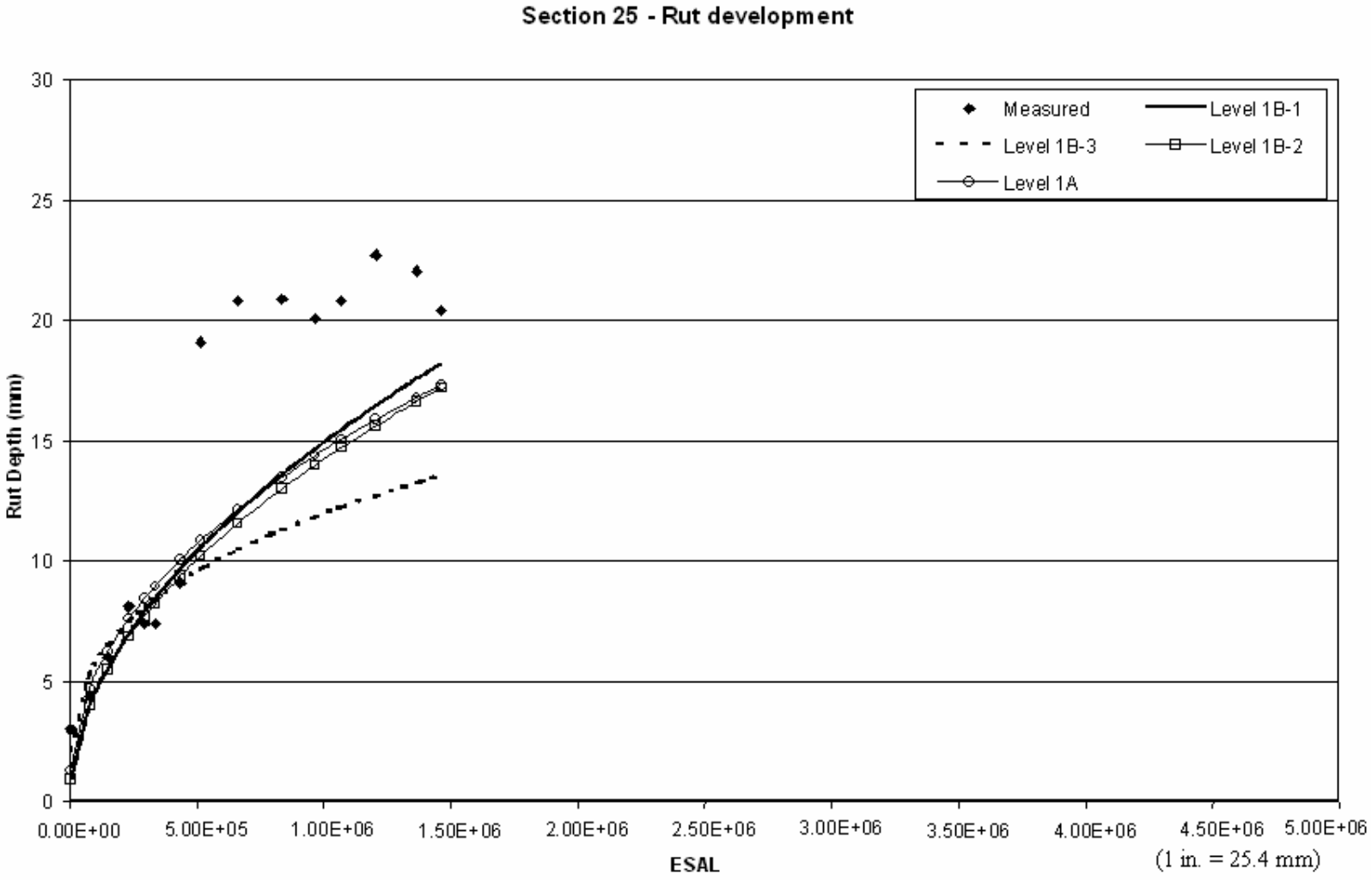

Section 20 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

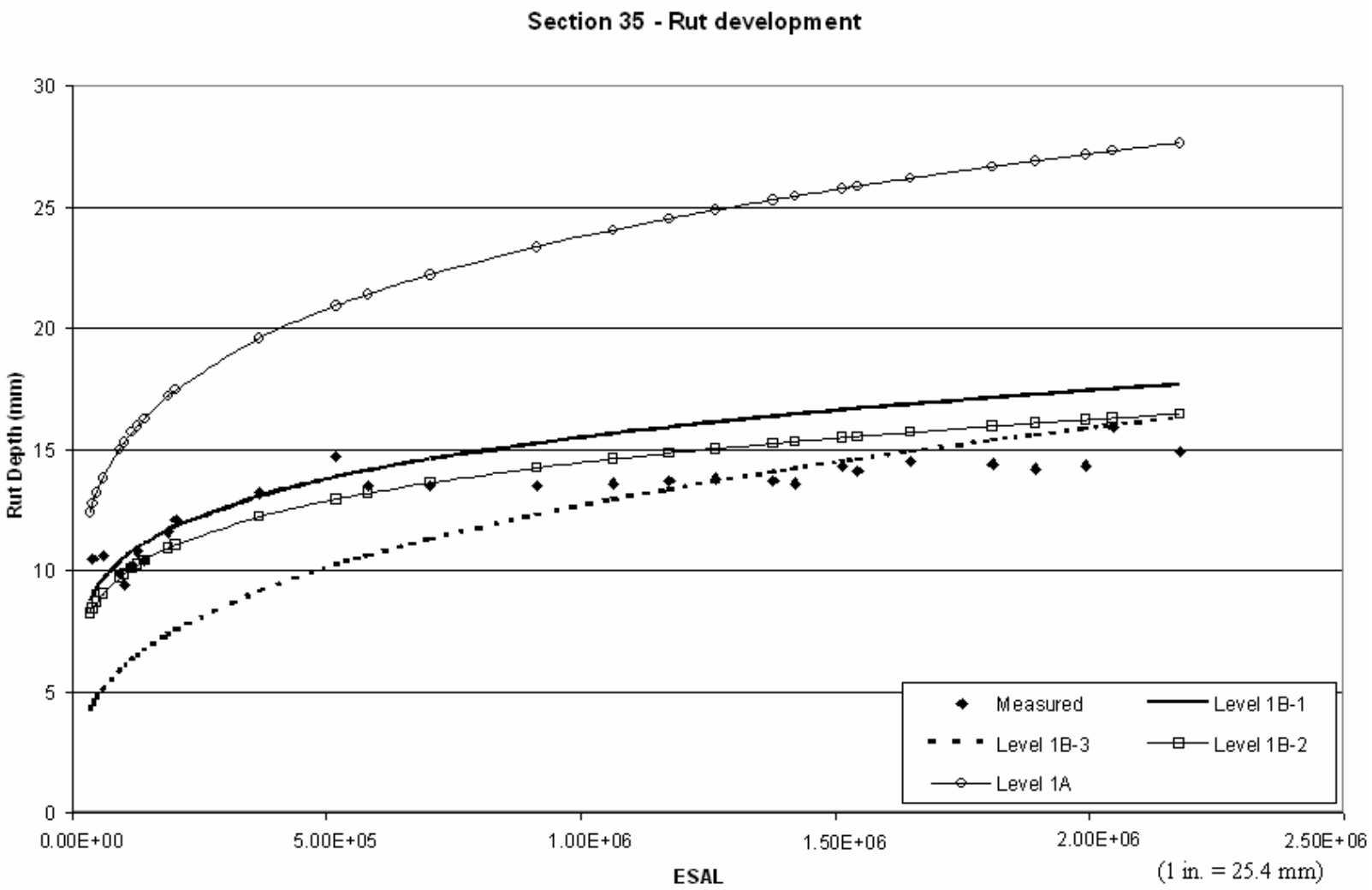

Section 21 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

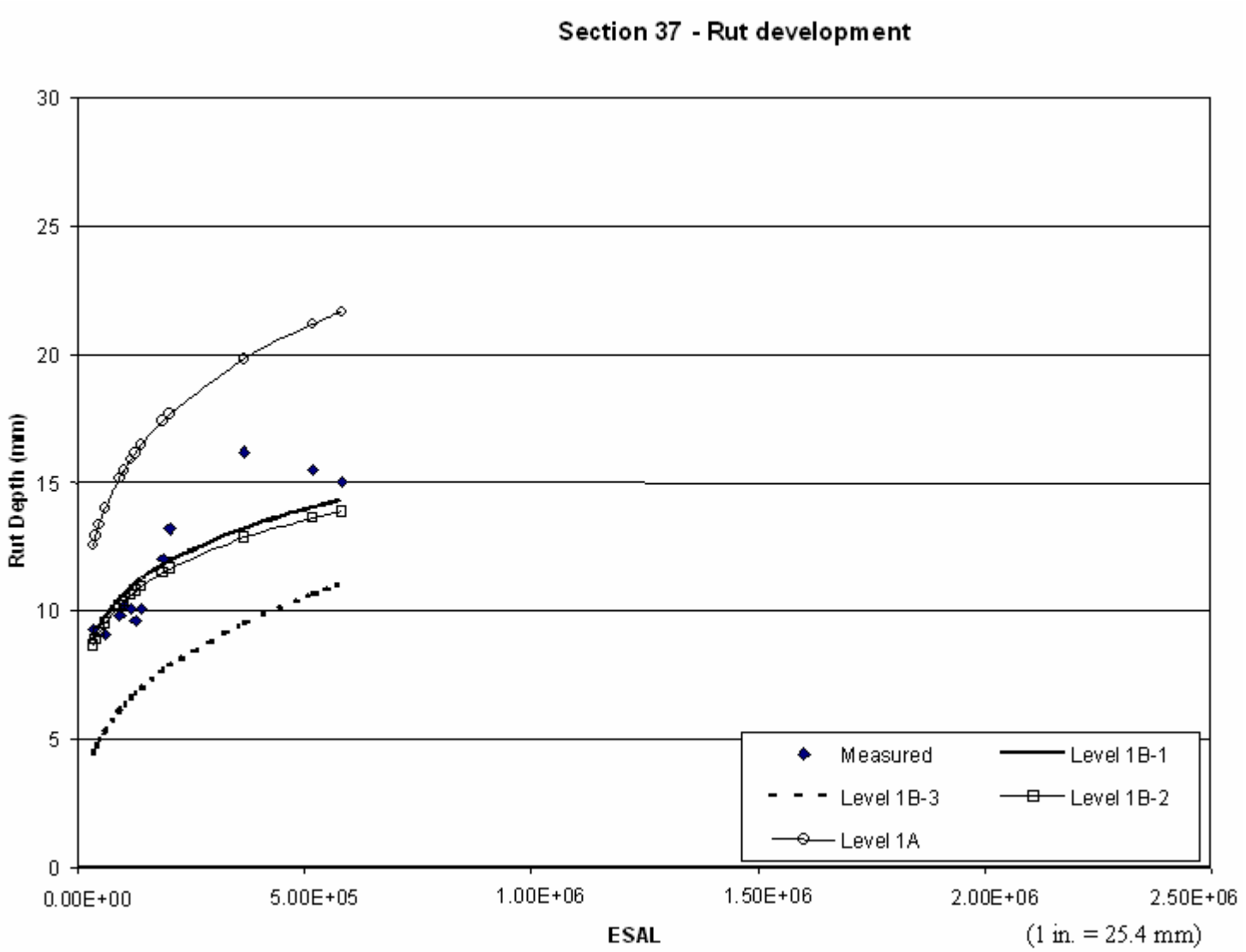

Section 22 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

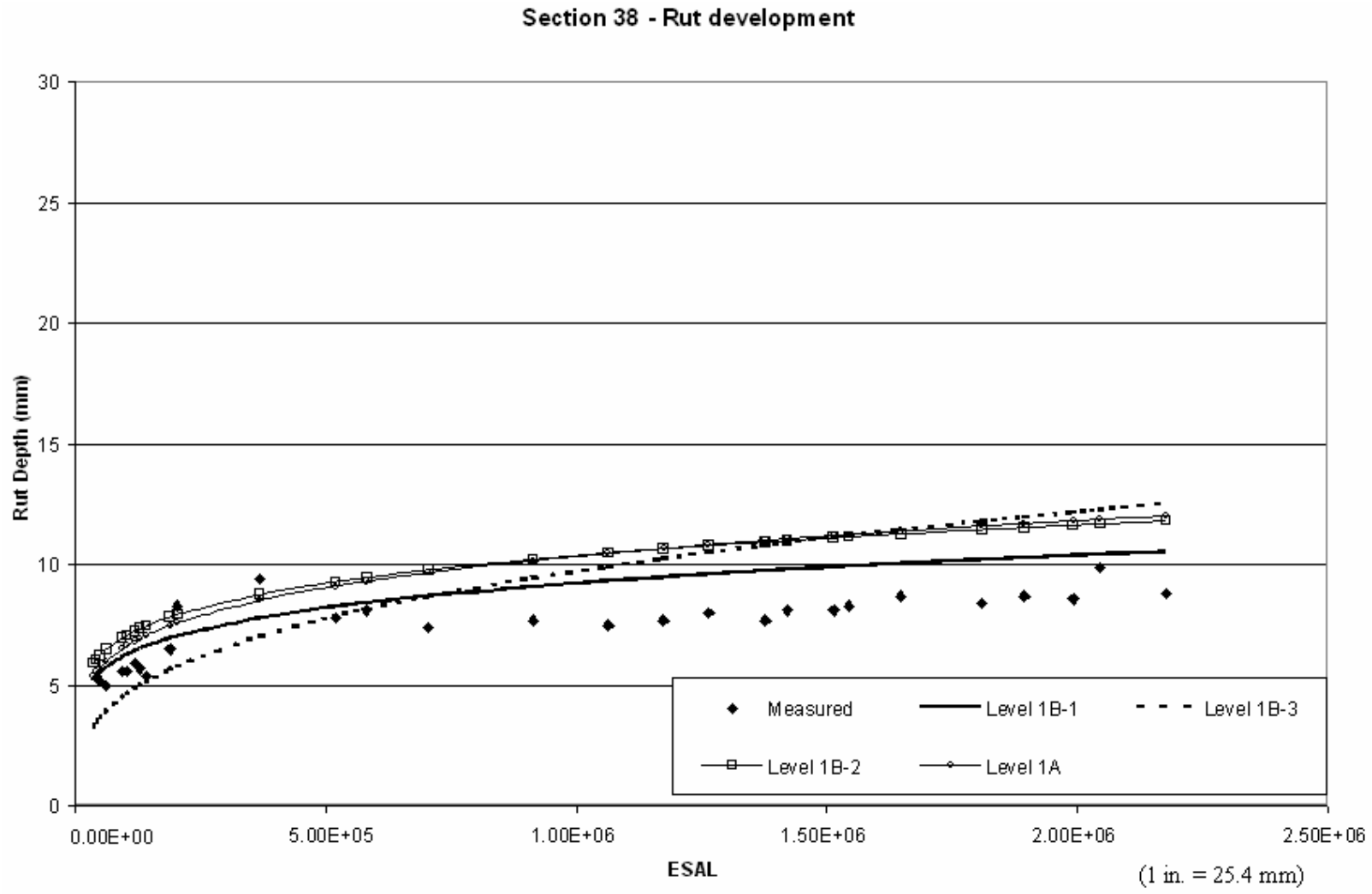

Section 23 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

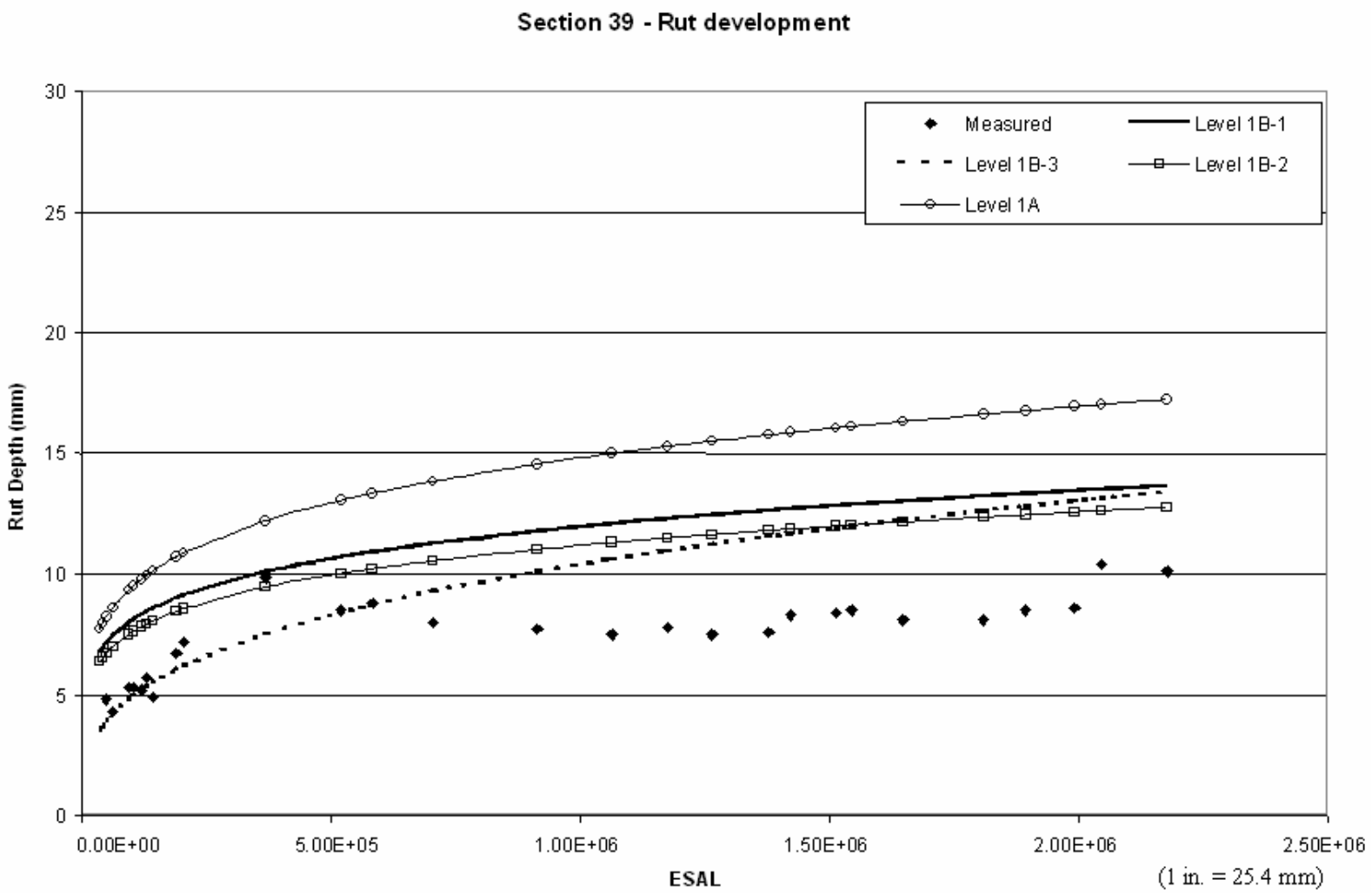

Section 24 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

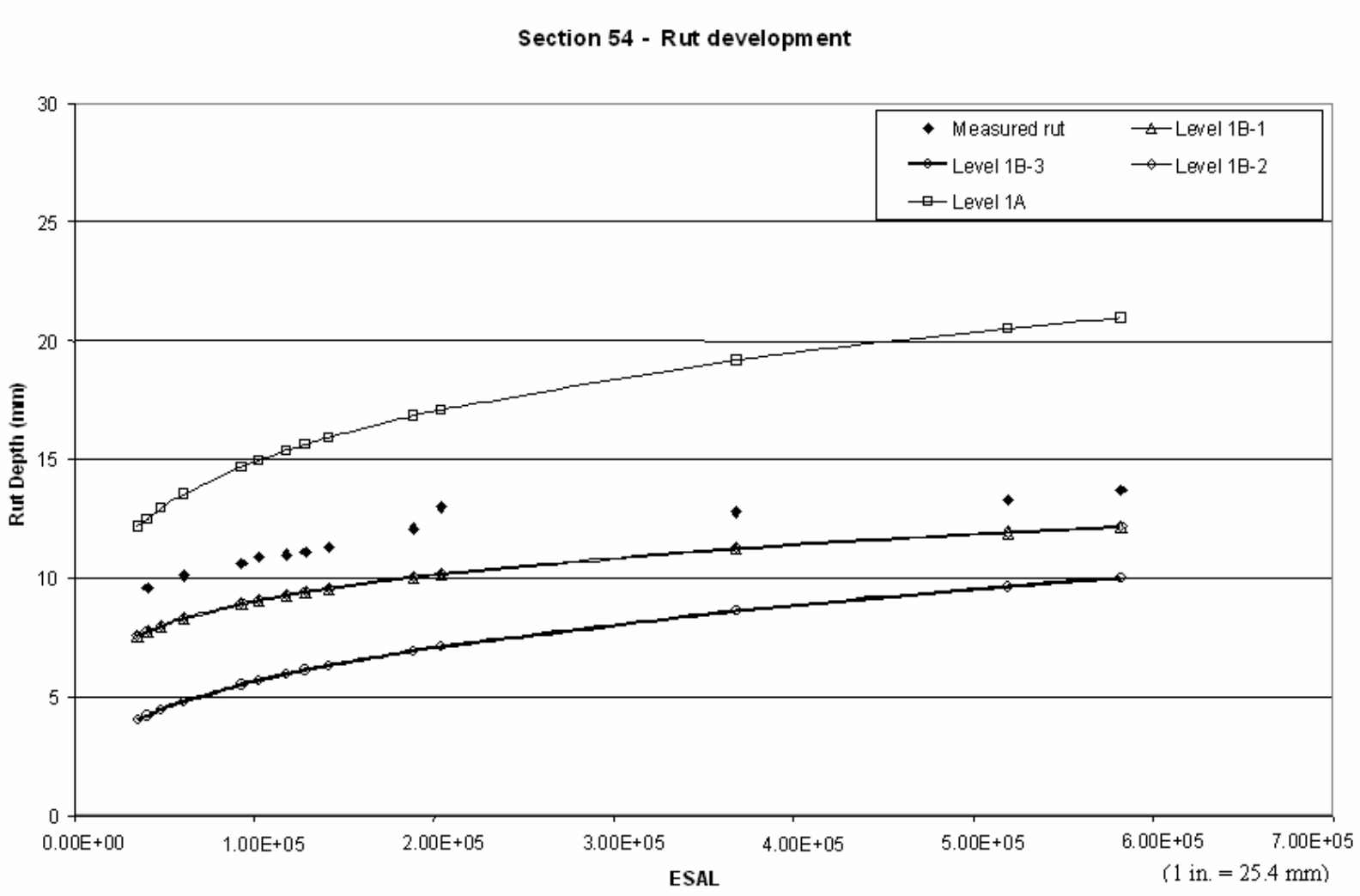

Section 25 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
4.00E+06
4.50E+06
5.00E+06
ESAL
(1 in. = 25.4 mm)

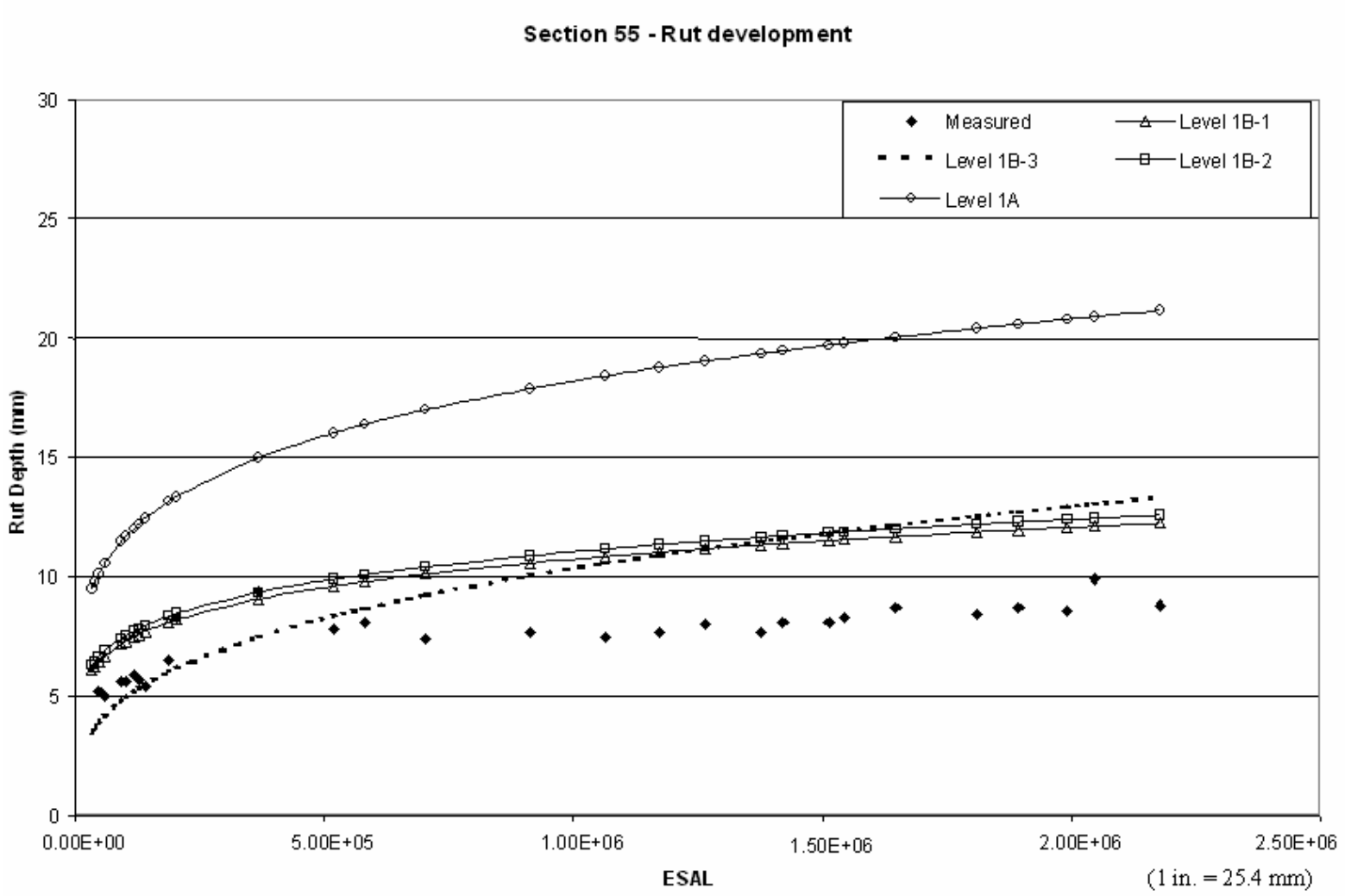

Section 35 - Rut development
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
ESAL
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
(1 in. = 25.4 mm)


Section 37 - Rut development
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
ESAL
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
(1 in. = 25.4 mm)


Section 38 - Rut development
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
ESAL
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
(1 in. = 25.4 mm)


Section 39 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
ESAL
(1 in. = 25.4 mm)

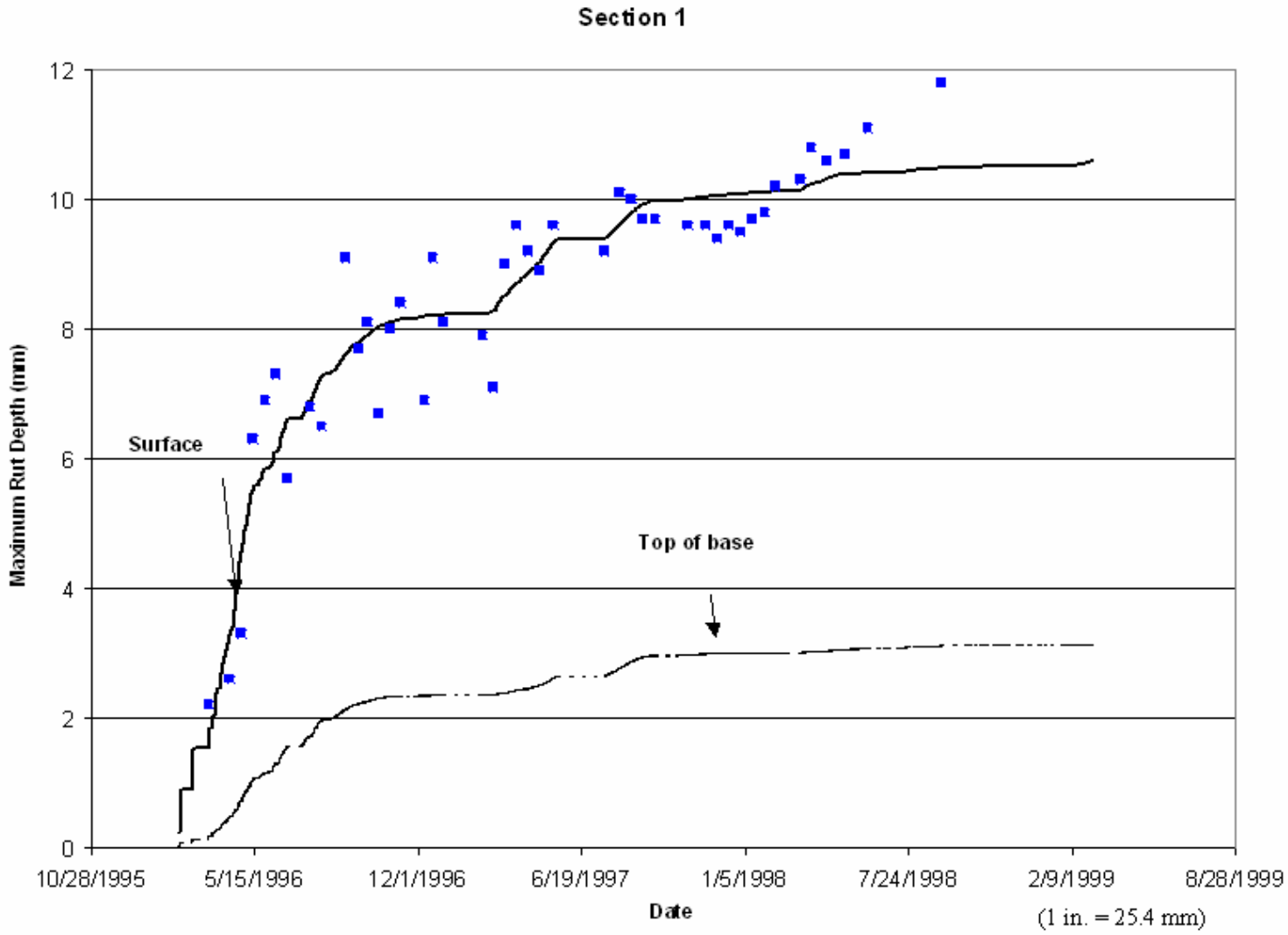

Section 54 - Rut development
Measured rut
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
1.00E+05
2.00E+05
3.00E+05
4.00E+05
5.00E+05
6.00E+05
7.00E+05
ESAL
(1 in. = 25.4 mm)

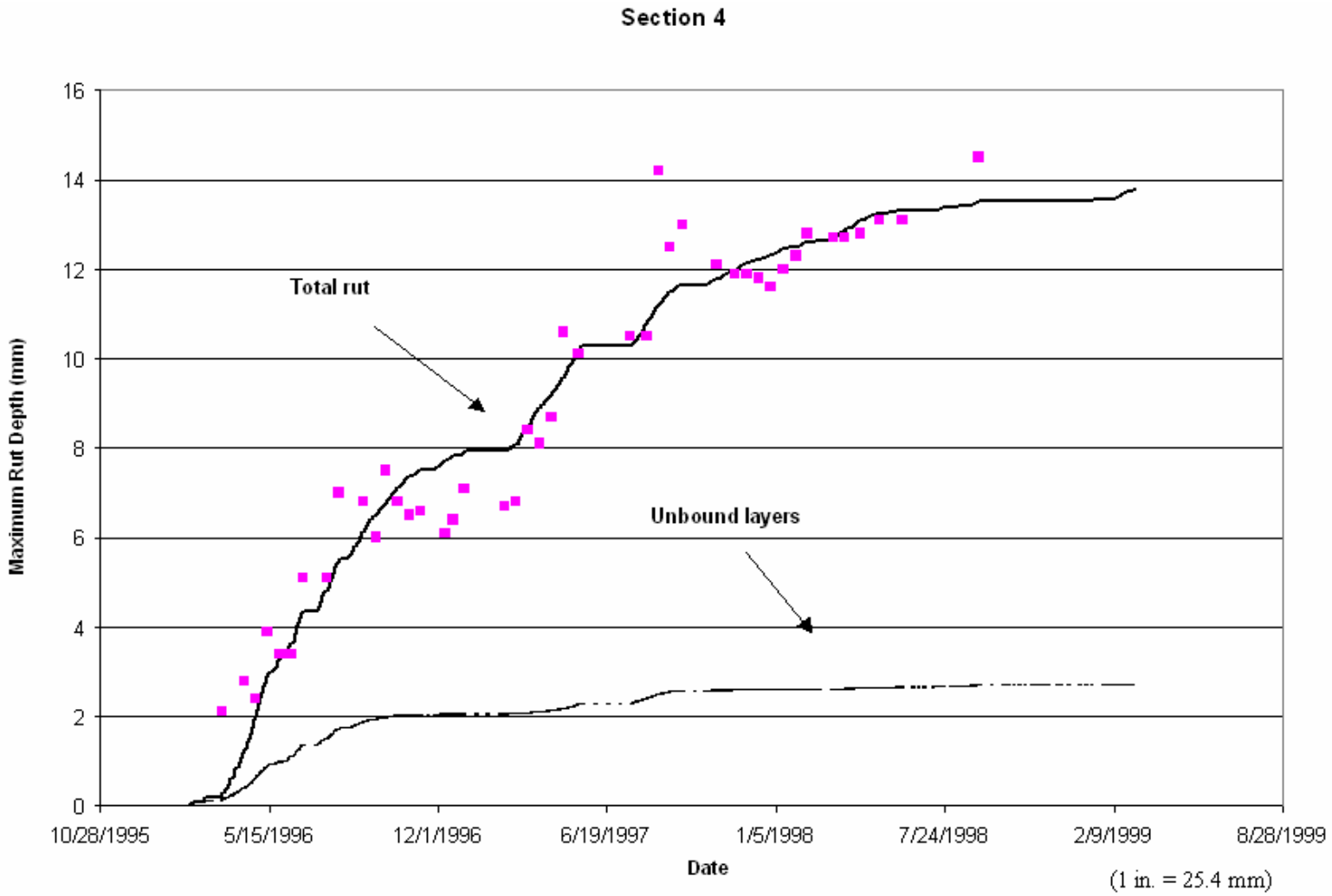

Section 55 - Rut development
Measured
Level 1B-1
Level 1B-3
Level 1B-2
Level 1A
Rut Depth (mm)
30
25
20
15
10
5
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
ESAL
(1 in. = 25.4 mm)

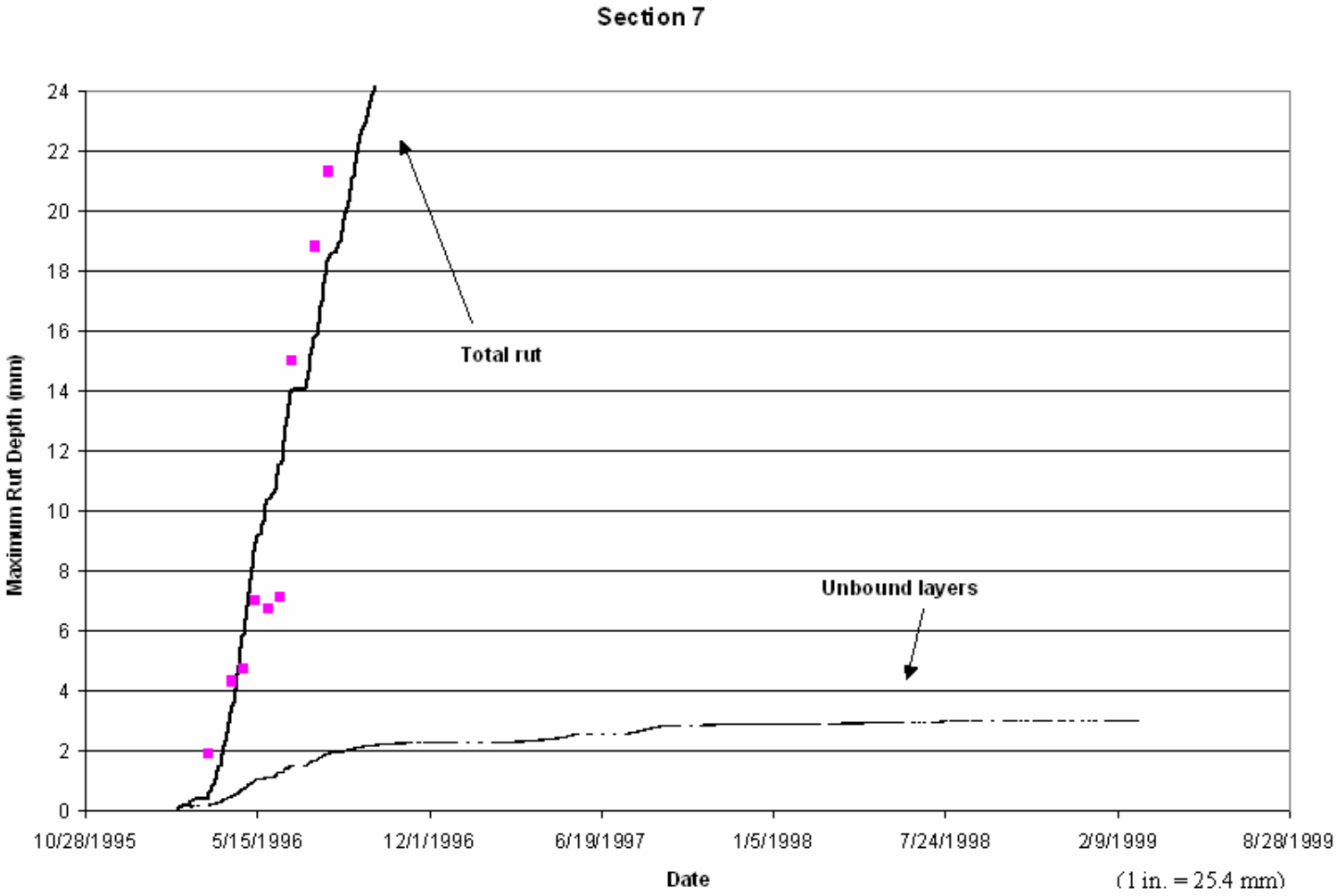
APPENDIX F

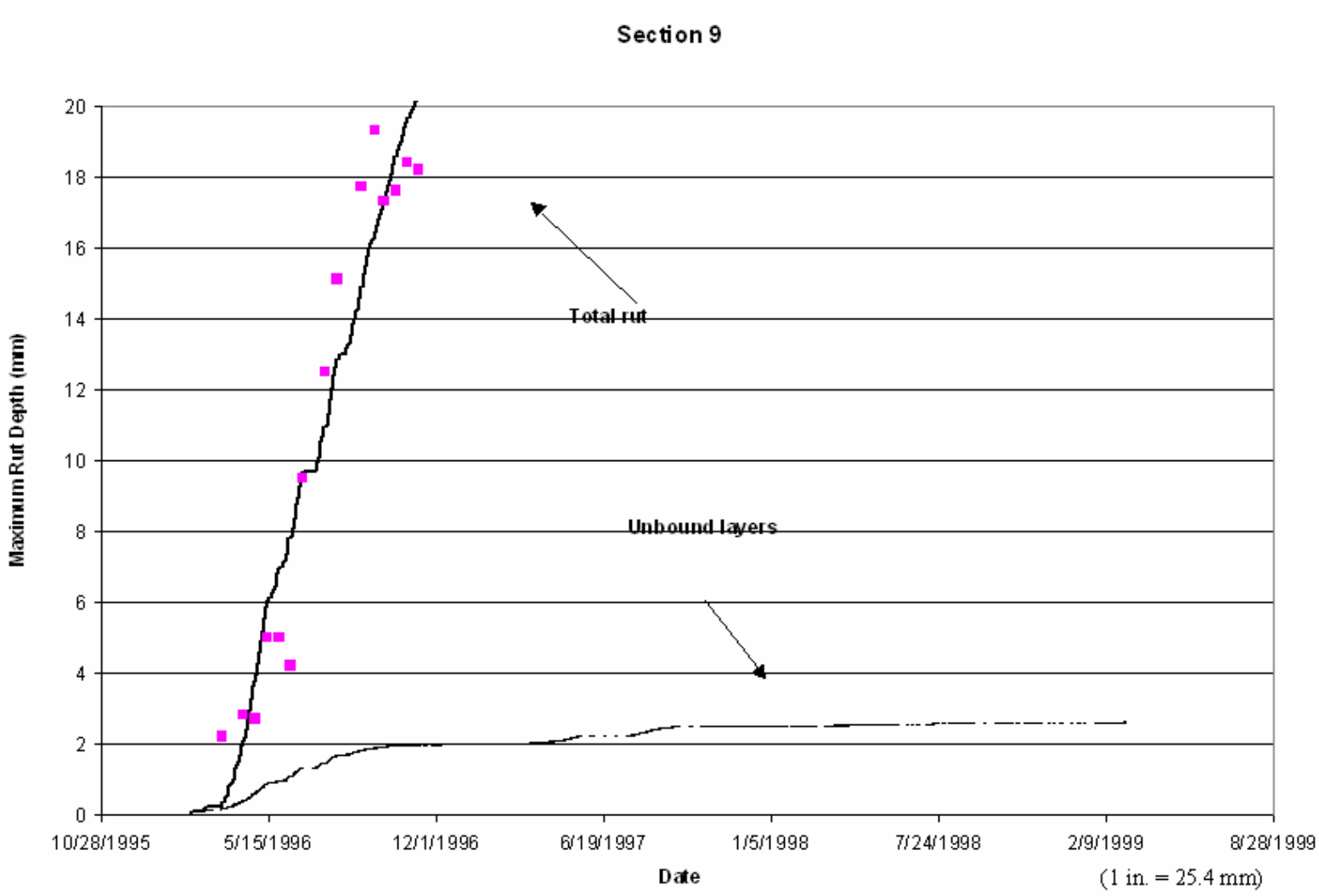
Rut Depth versus ESALs; Mechanistic Analyses and Least Squares Fitting

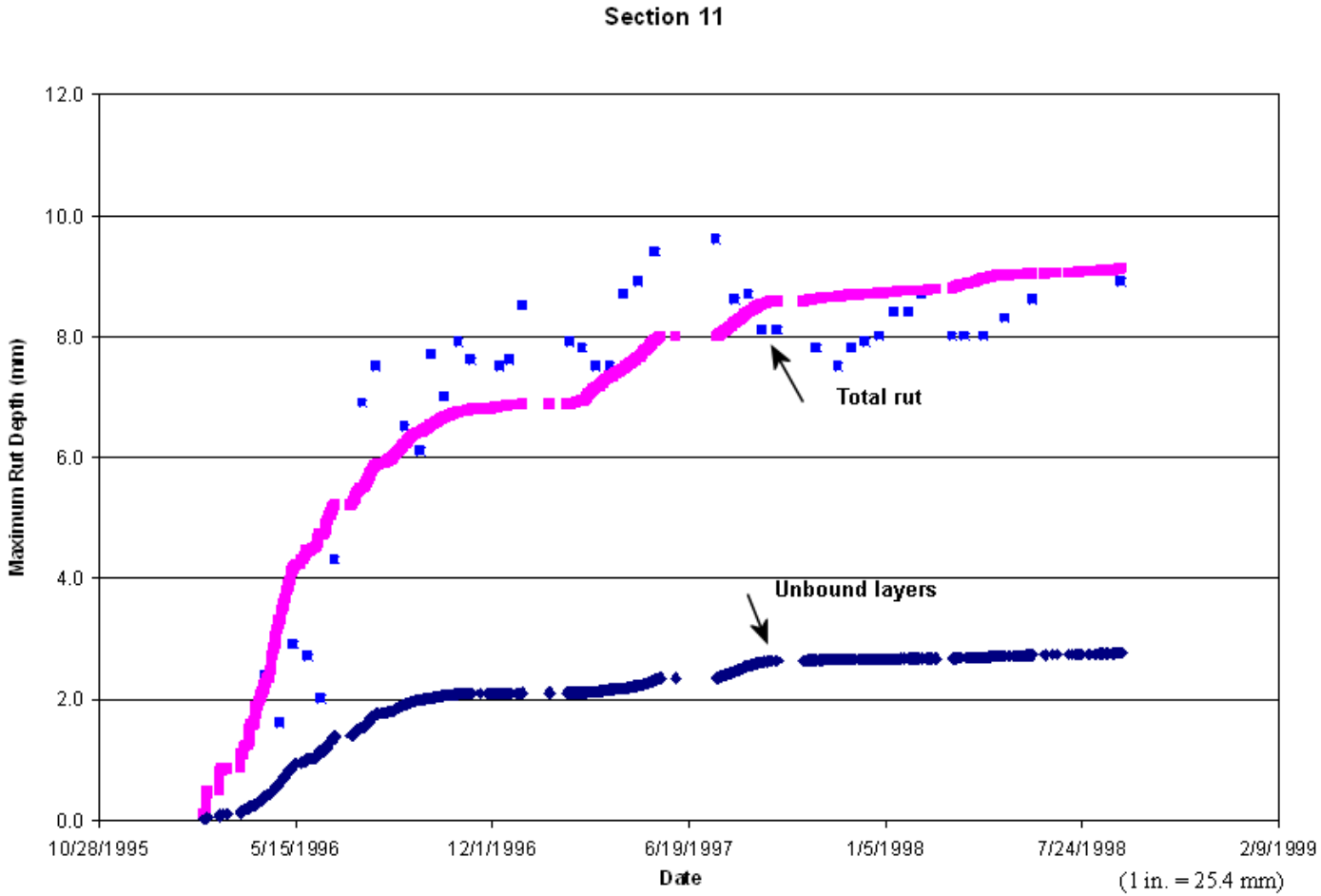
Sections 1, 4, 7, 9, 11-15, 19-25, 35, 37-39, 54, and 55

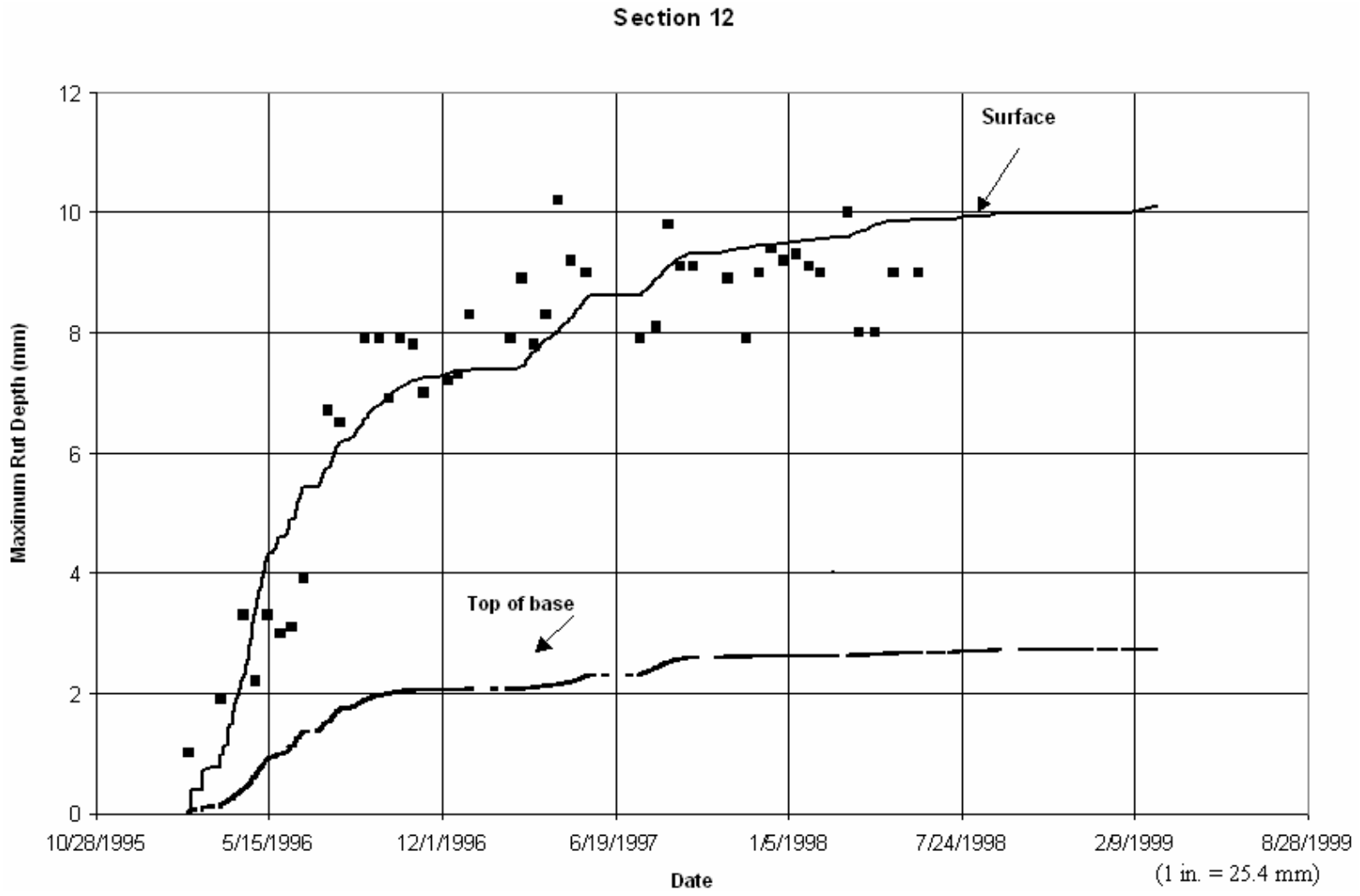

Section 1
Maximum Rut Depth (mm)
12
10
8
6
4
2
0
Surface
Top of base
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

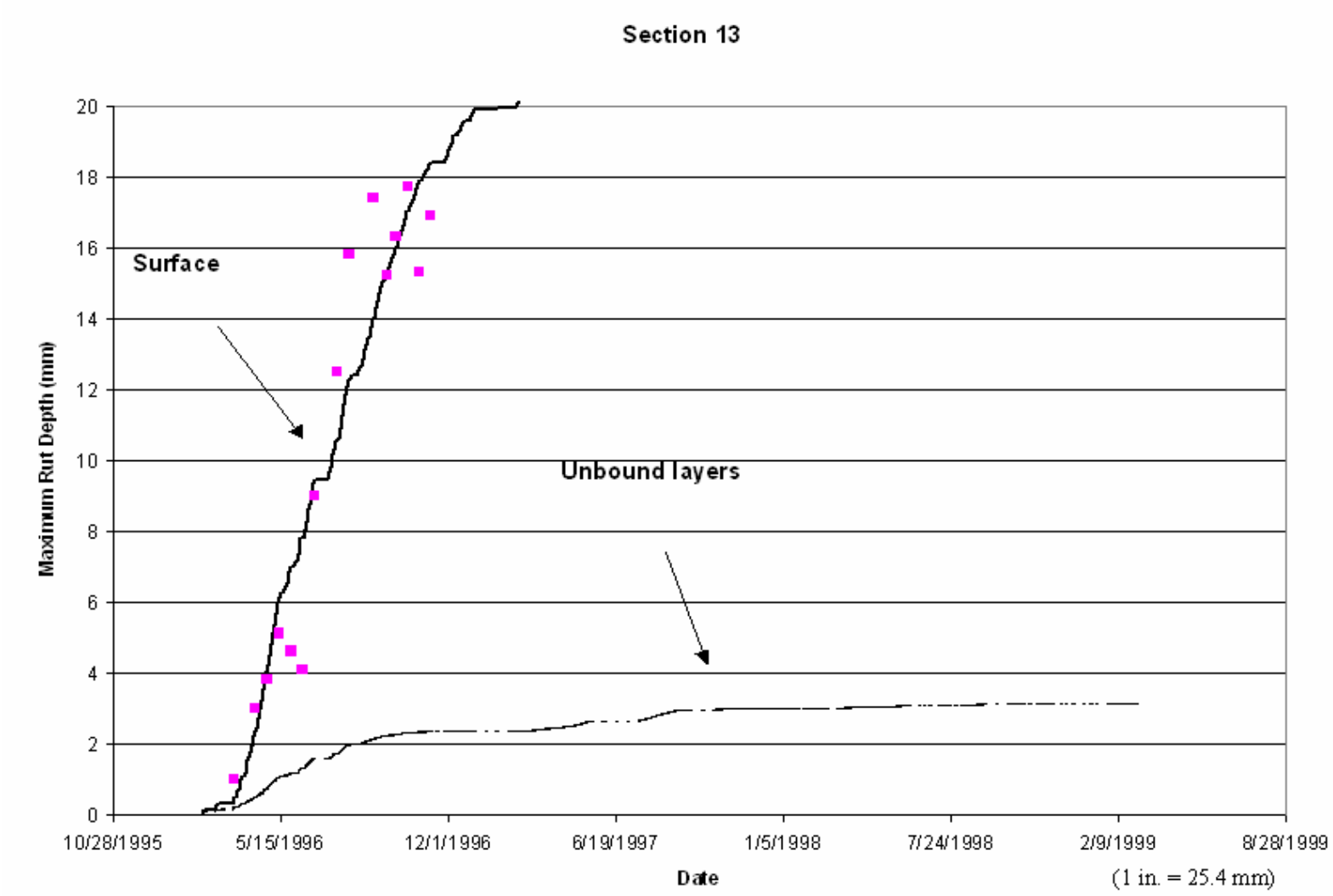

Section 4
Maximum Rut Depth (mm)
16
14
12
10
8
6
4
2
0
Total rut
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

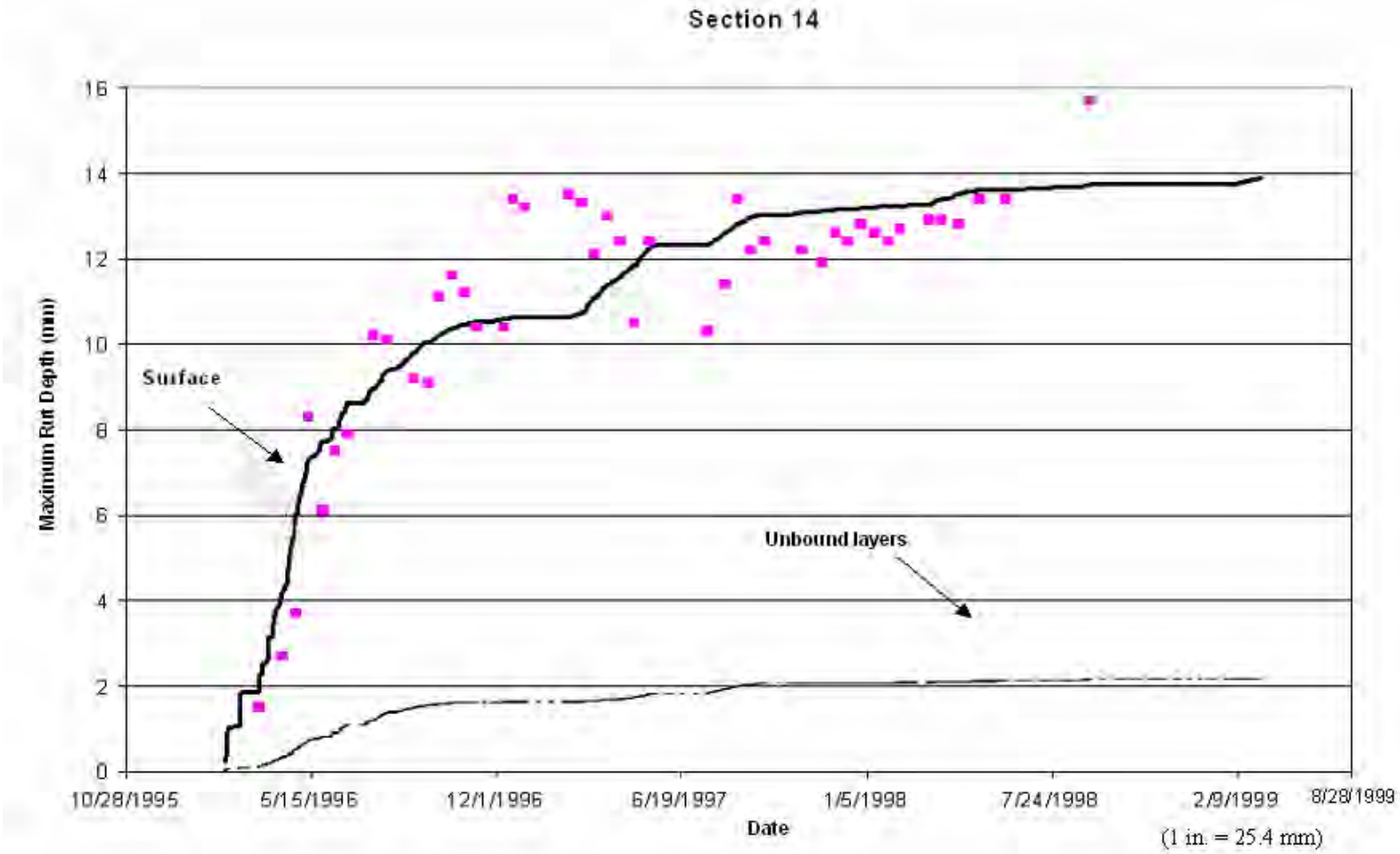

Section 7
Maximum Rut Depth (mm)
24
22
20
18
16
14
12
10
8
6
4
2
0
Total rut
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

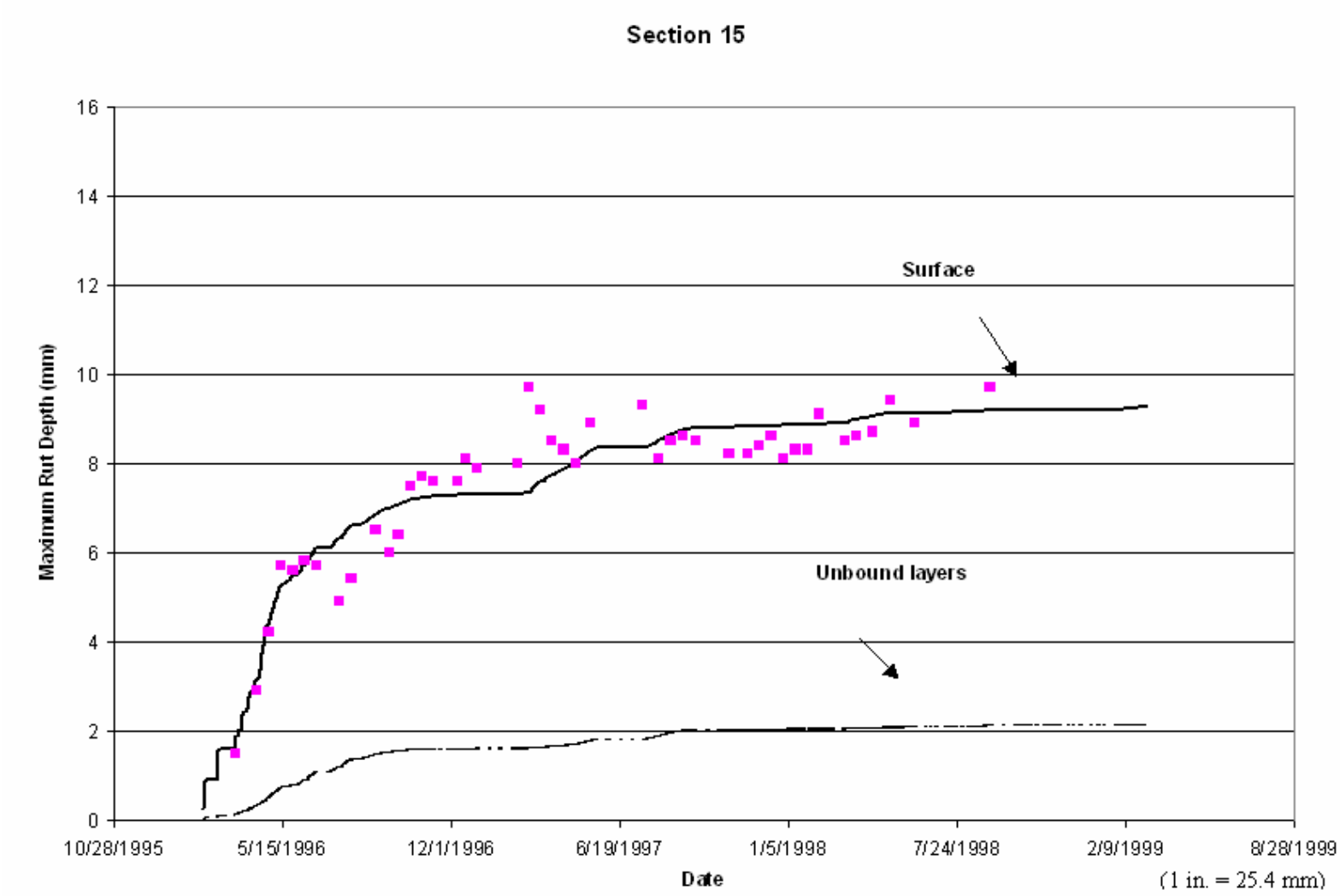

Section 9
Maximum Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
Total rut
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

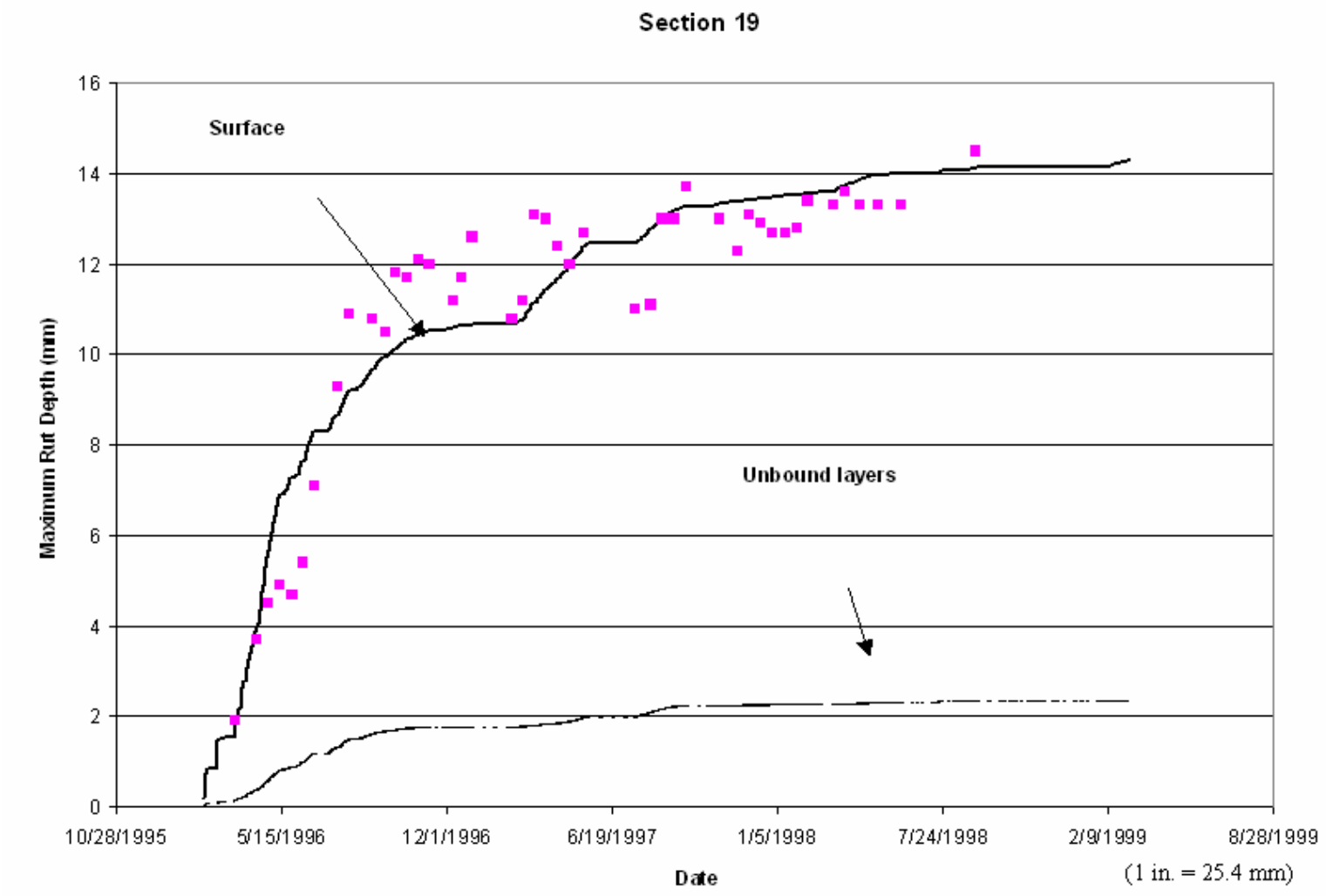

Section 11
Maximum Rut Depth (mm)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Total rut
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
Date
(1 in. = 25.4 mm)

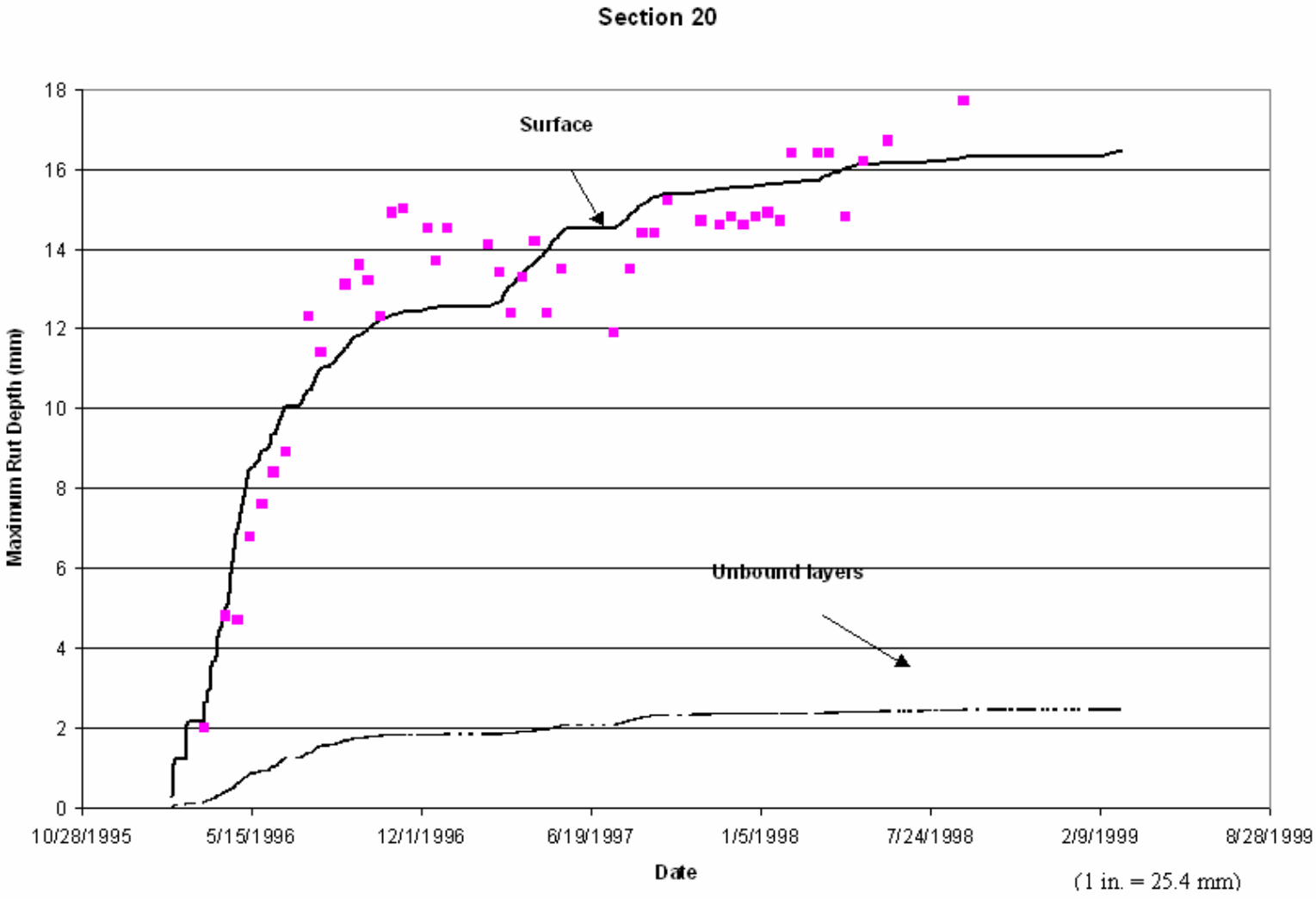

Section 12
Maximum Rut Depth (mm)
12
10
8
6
4
2
0
Surface
Top of base
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

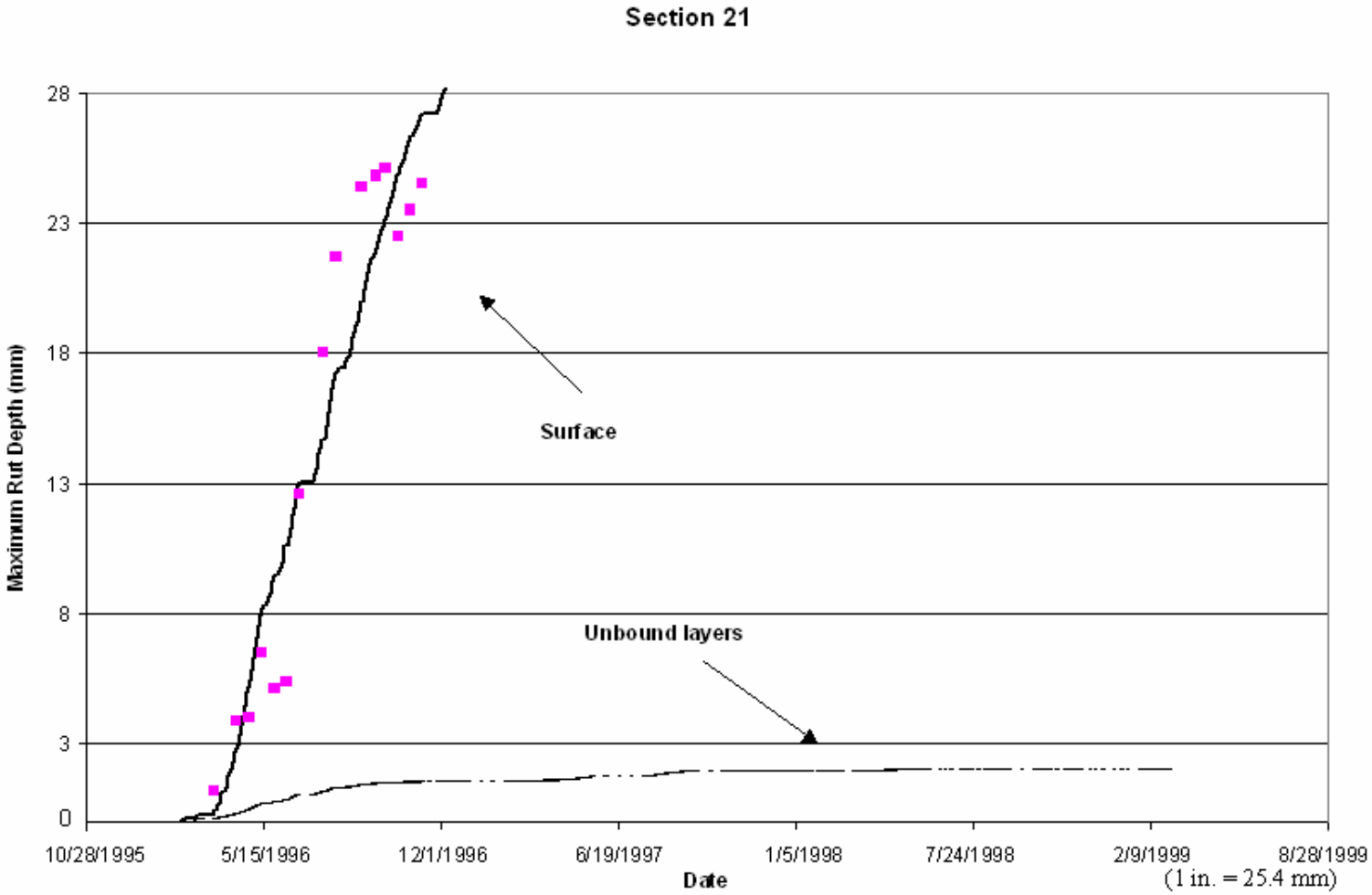

Section 13
Maximum Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
Surface
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

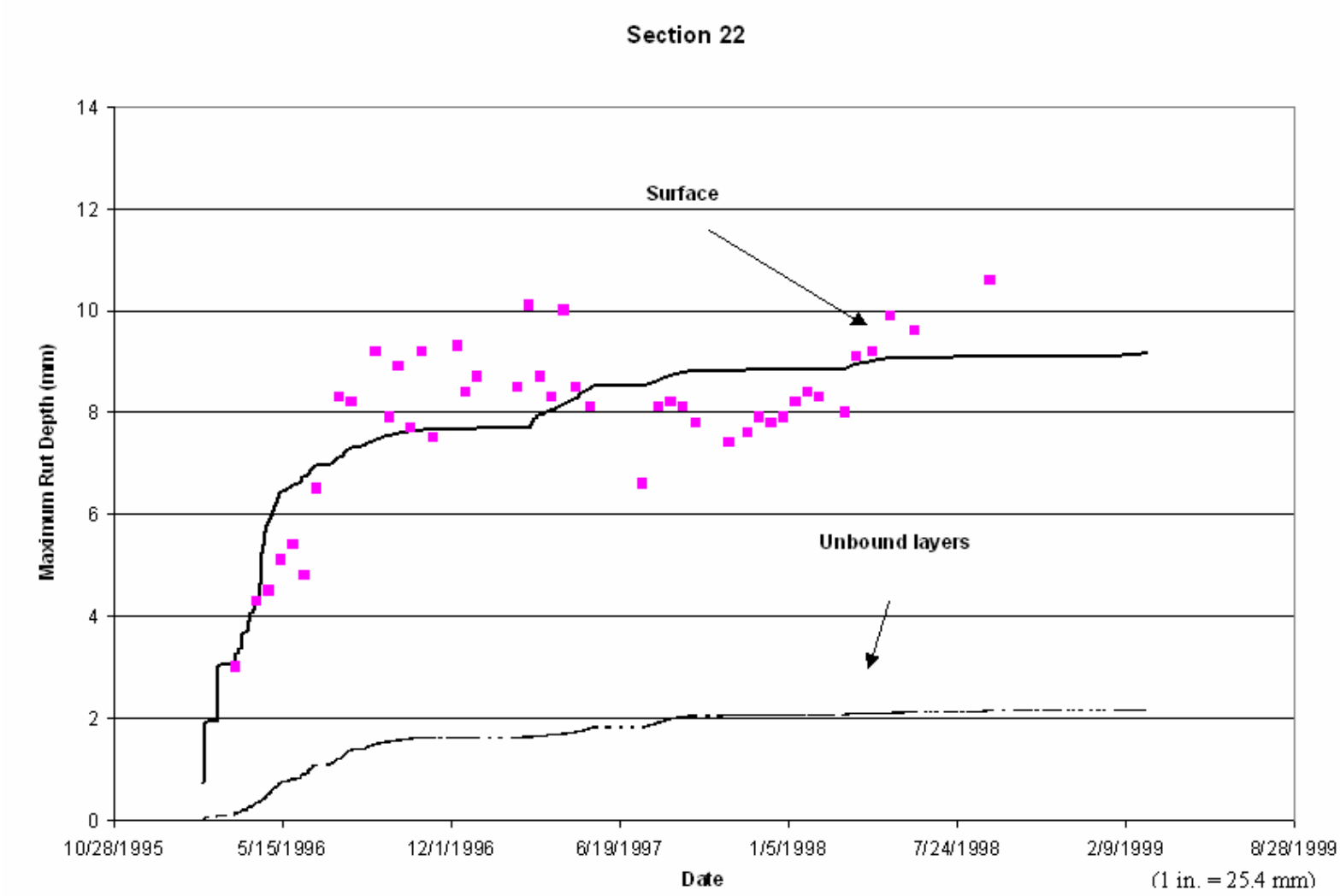

Section 14
Maximum Rut Depth (mm)
16
14
12
10
8
6
4
2
0
Surface
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

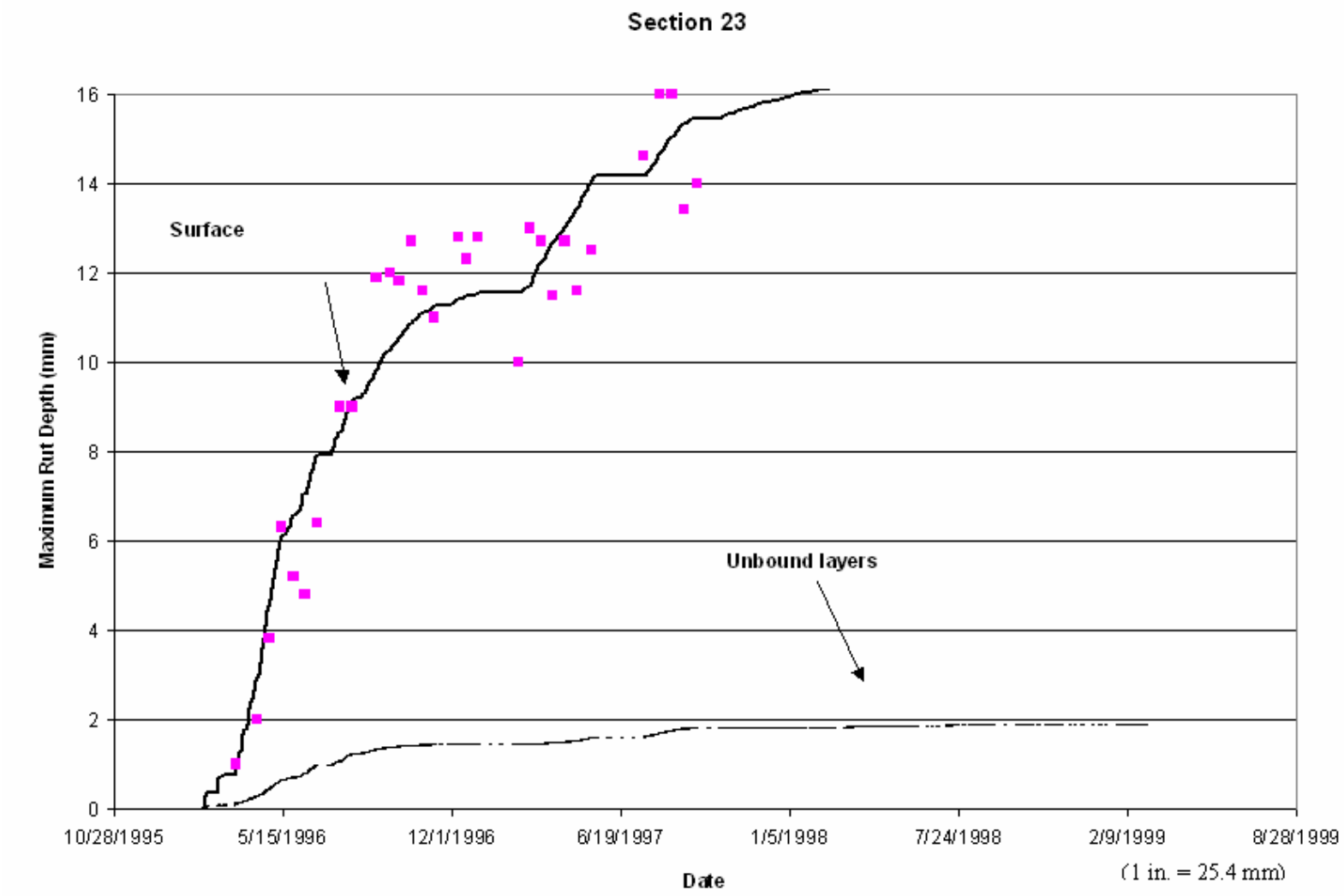

Section 15
Maximum Rut Depth (mm)
16
14
12
10
8
6
4
2
0
Surface
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

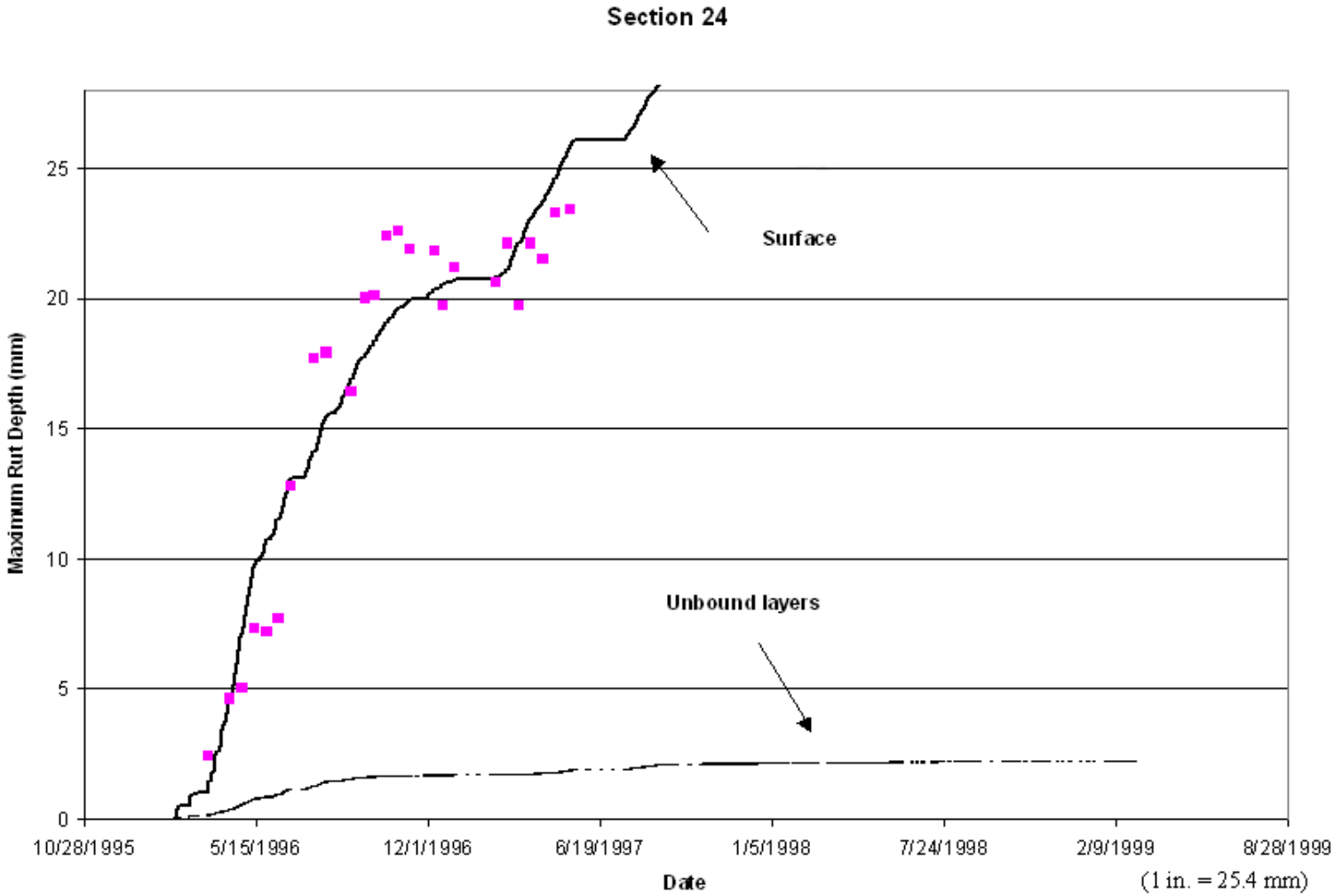

Section 19
Surface
Unbound layers
Maximum Rut Depth (mm)
16
14
12
10
8
6
4
2
0
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

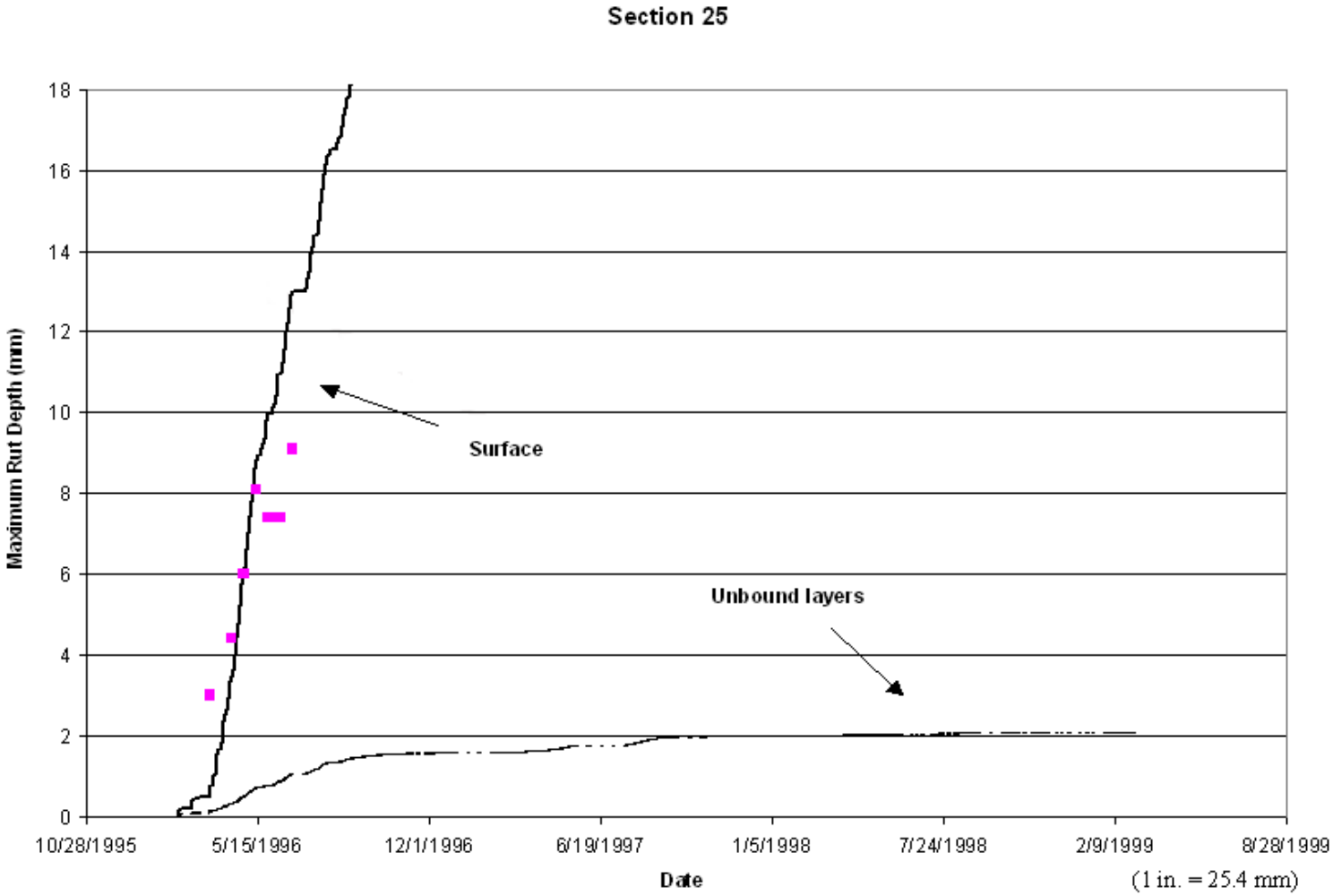

Section 20
Surface
Unbound layers
Maximum Rut Depth (mm)
0
2
4
6
8
10
12
14
16
18
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

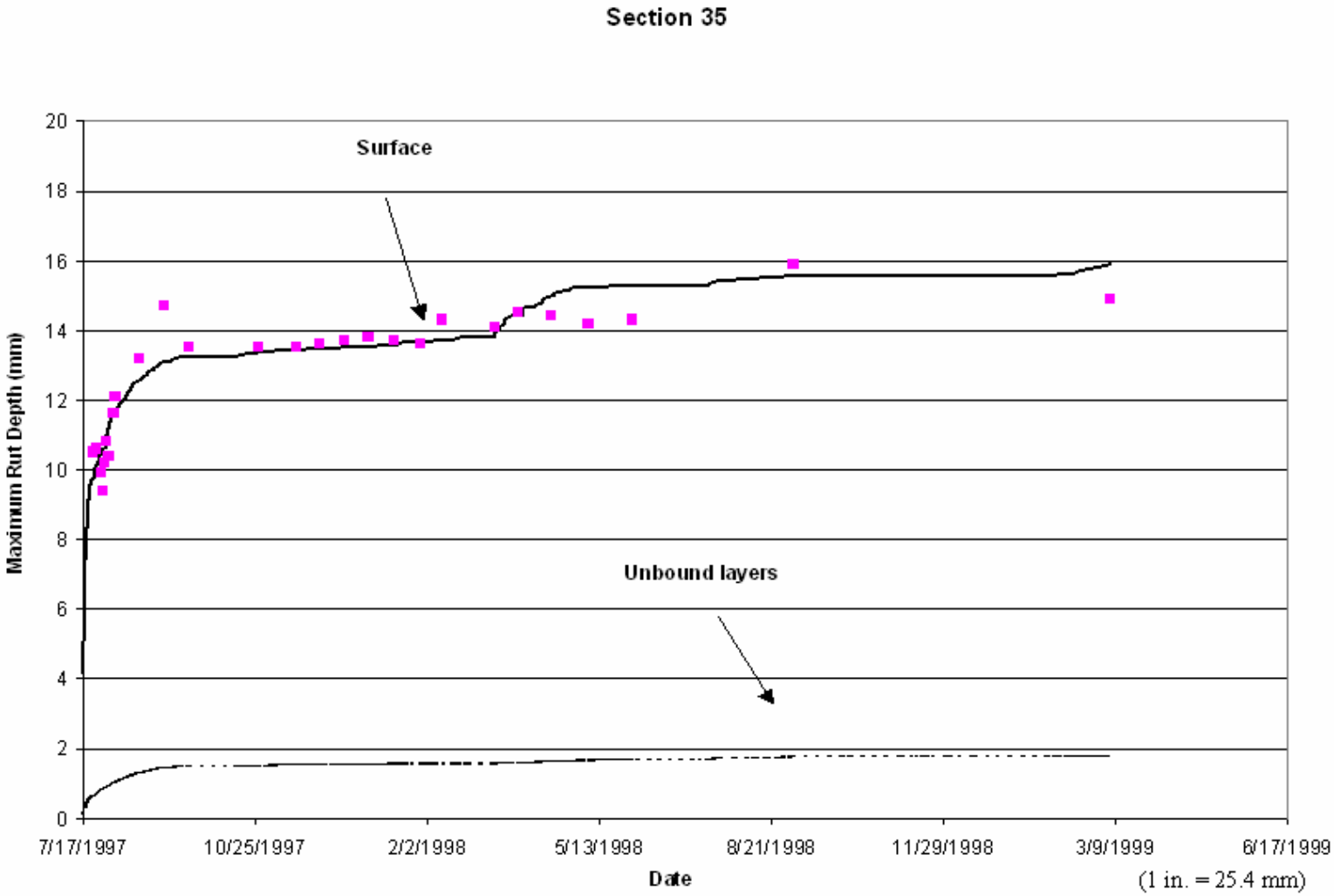

Section 21
Maximum Rut Depth (mm)
28
23
18
13
8
3
0
Surface
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

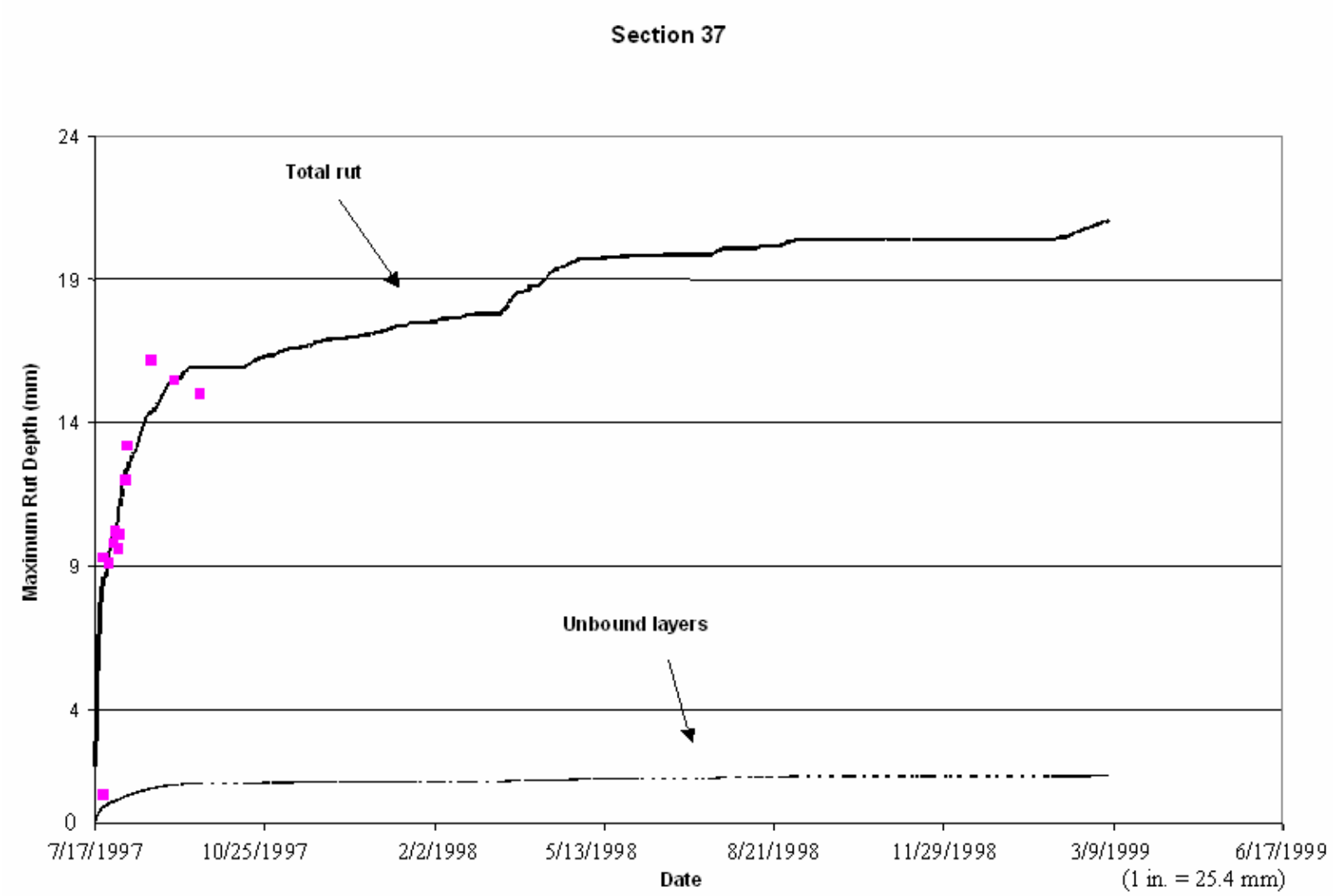

Section 22
Maximum Rut Depth (mm)
14
12
10
8
6
4
2
0
Surface
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

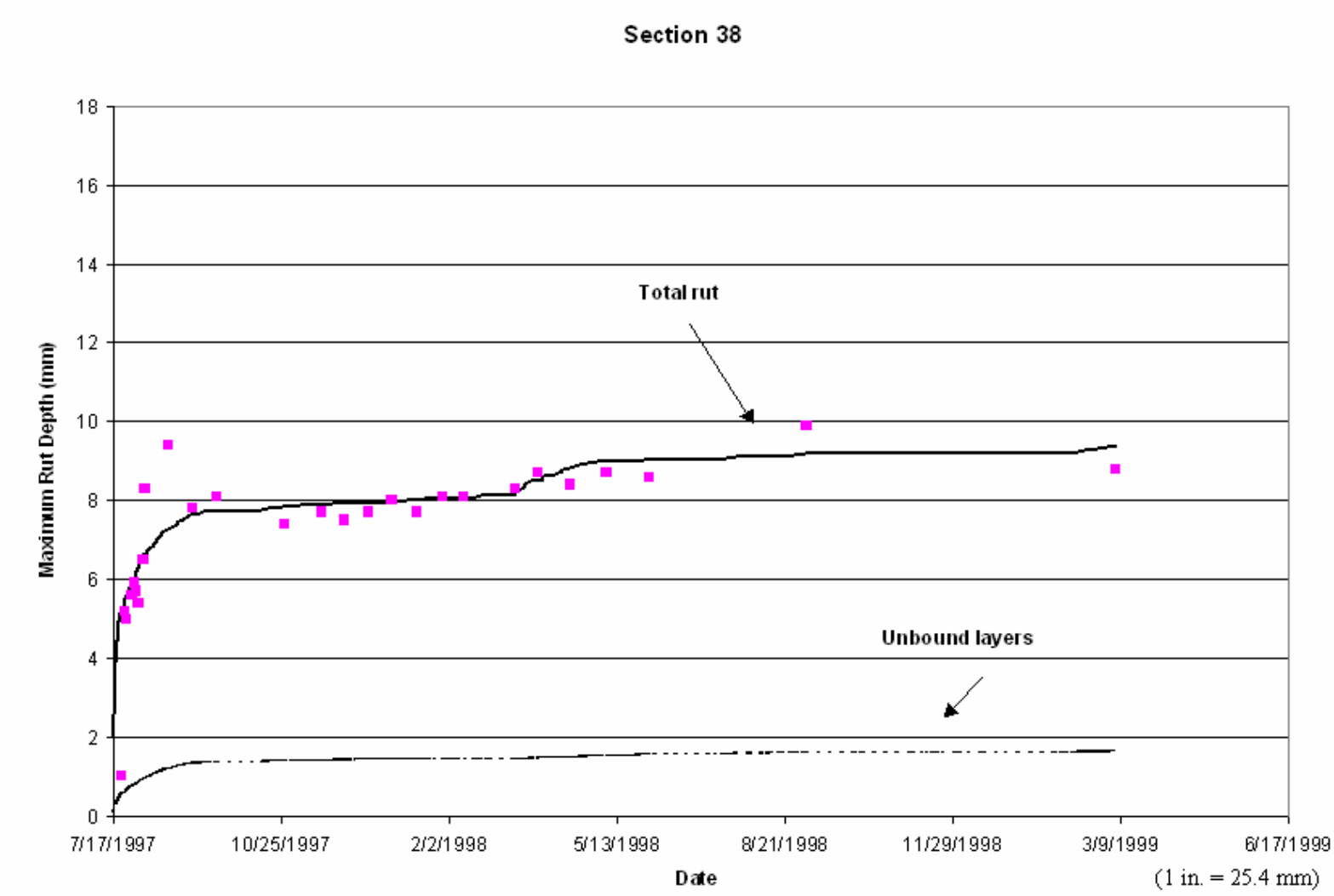

Section 23
Maximum Rut Depth (mm)
16
14
12
10
8
6
4
2
0
Surface
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

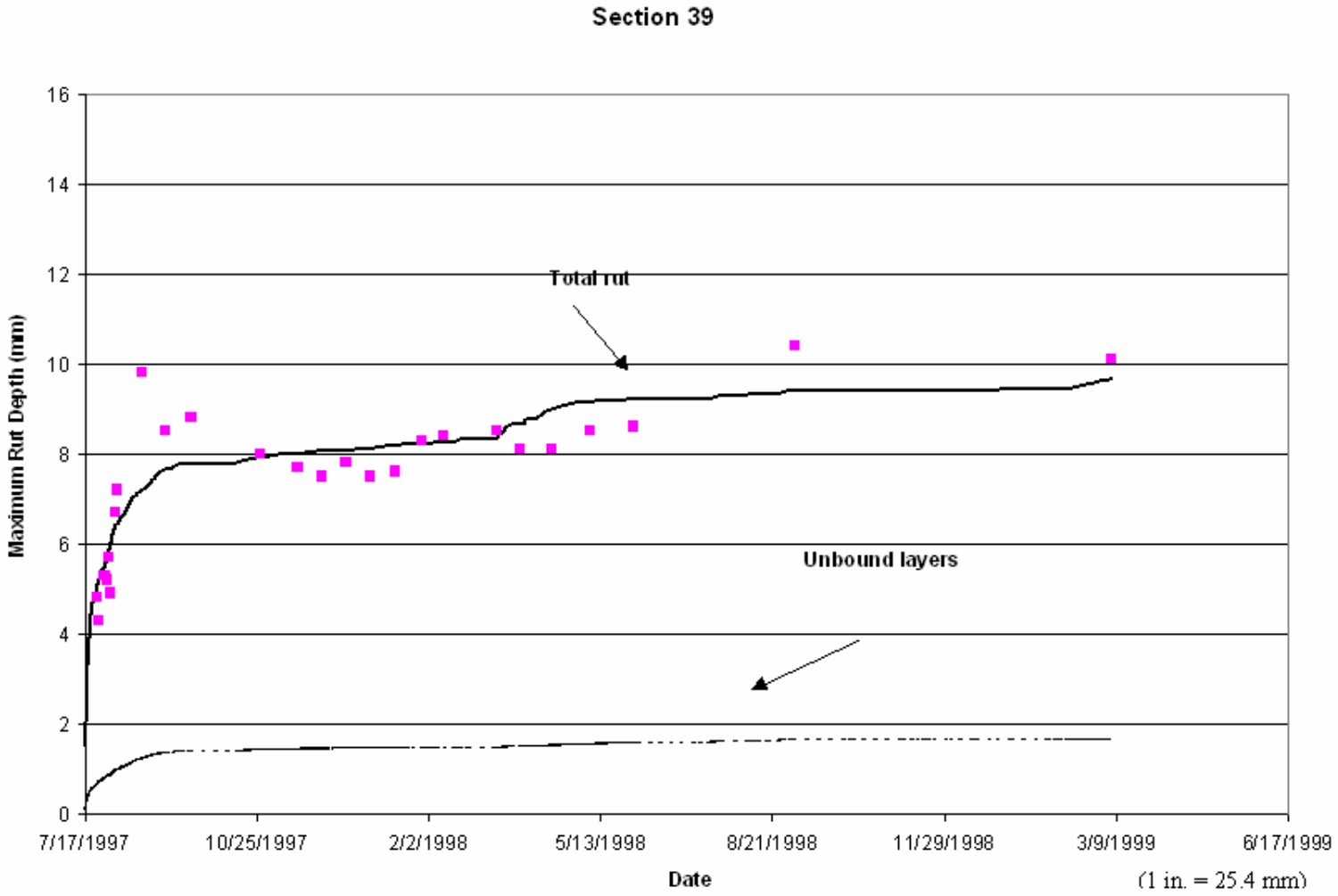

Section 24
Maximum Rut Depth (mm)
0
5
10
15
20
25
Surface
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

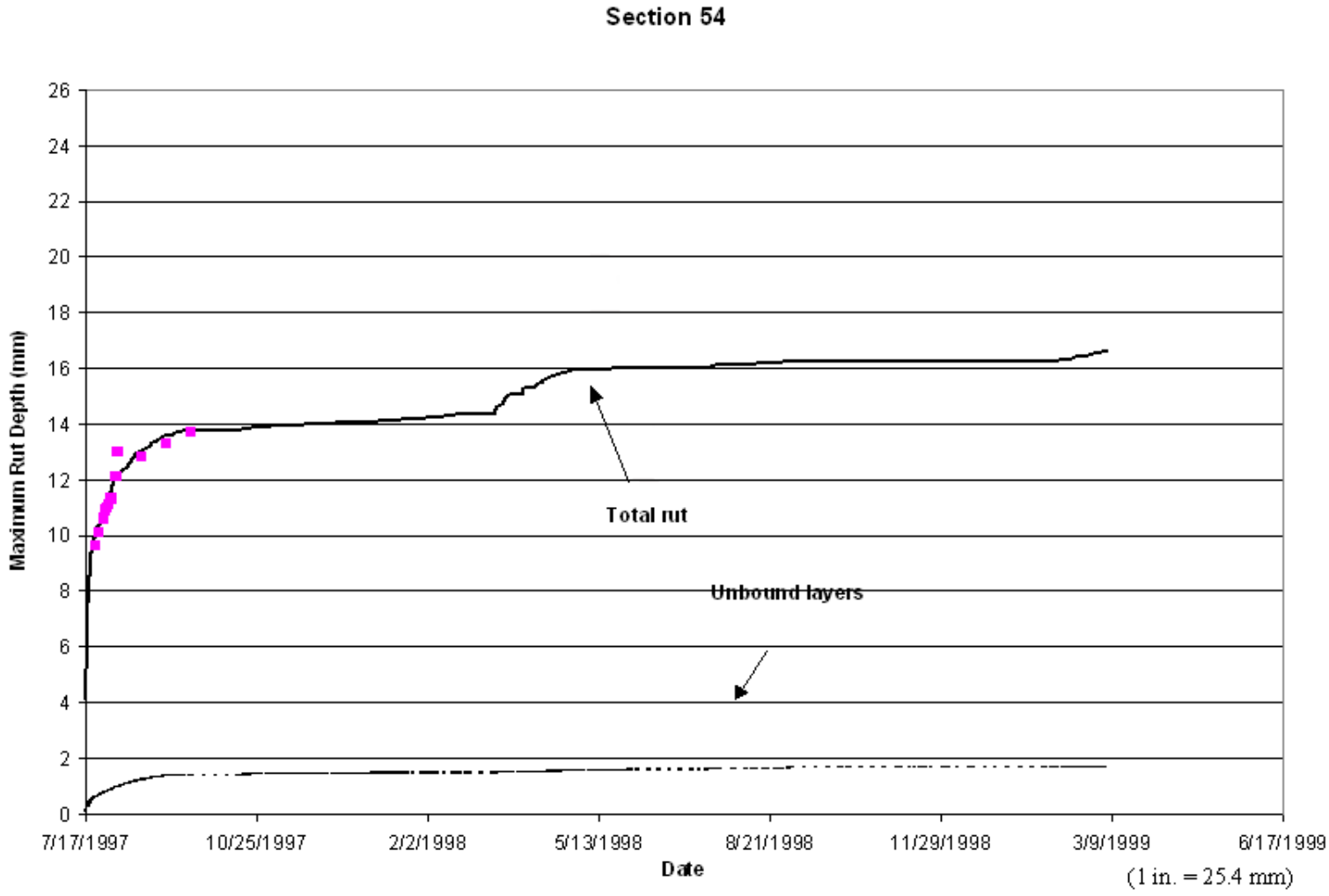

Section 25
Maximum Rut Depth (mm)
18
16
14
12
10
8
6
4
2
0
Surface
Unbound layers
10/28/1995
5/15/1996
12/1/1996
6/19/1997
1/5/1998
7/24/1998
2/9/1999
8/28/1999
Date
(1 in. = 25.4 mm)

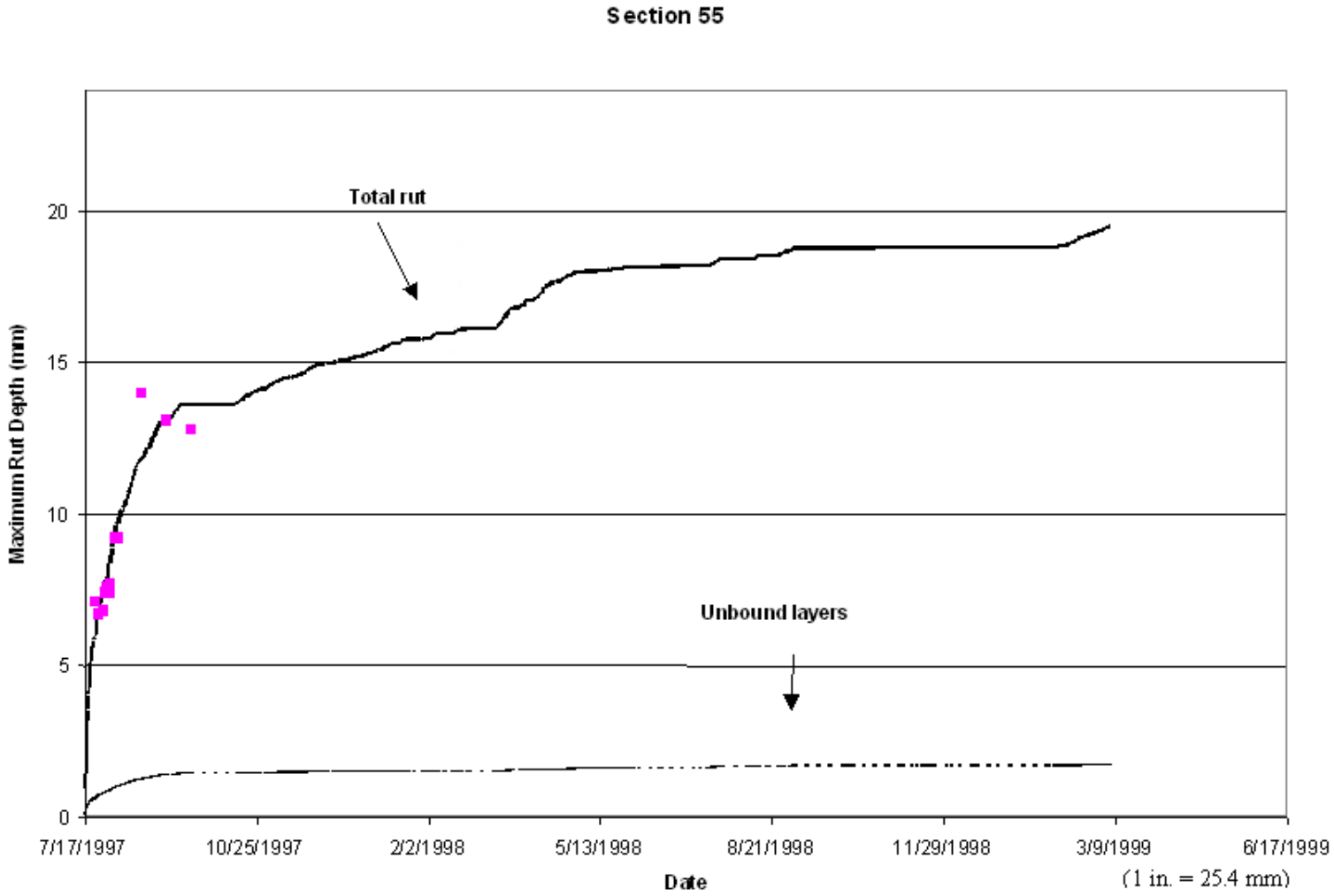

Section 35
Surface
Unbound layers
Maximum Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
7/17/1997
10/25/1997
2/2/1998
5/13/1998
8/21/1998
11/29/1998
3/9/1999
6/17/1999
Date
(1 in. = 25.4 mm)


Section 37
Total rut
Unbound layers
Maximum Rut Depth (mm)
24
19
14
9
4
0
7/17/1997
10/25/1997
2/2/1998
5/13/1998
8/21/1998
11/29/1998
3/9/1999
6/17/1999
Date
(1 in. = 25.4 mm)


Section 38
Maximum Rut Depth (mm)
18
16
14
12
10
8
6
4
2
0
Total rut
Unbound layers
7/17/1997
10/25/1997
2/2/1998
5/13/1998
8/21/1998
11/29/1998
3/9/1999
6/17/1999
Date
(1 in. = 25.4 mm)

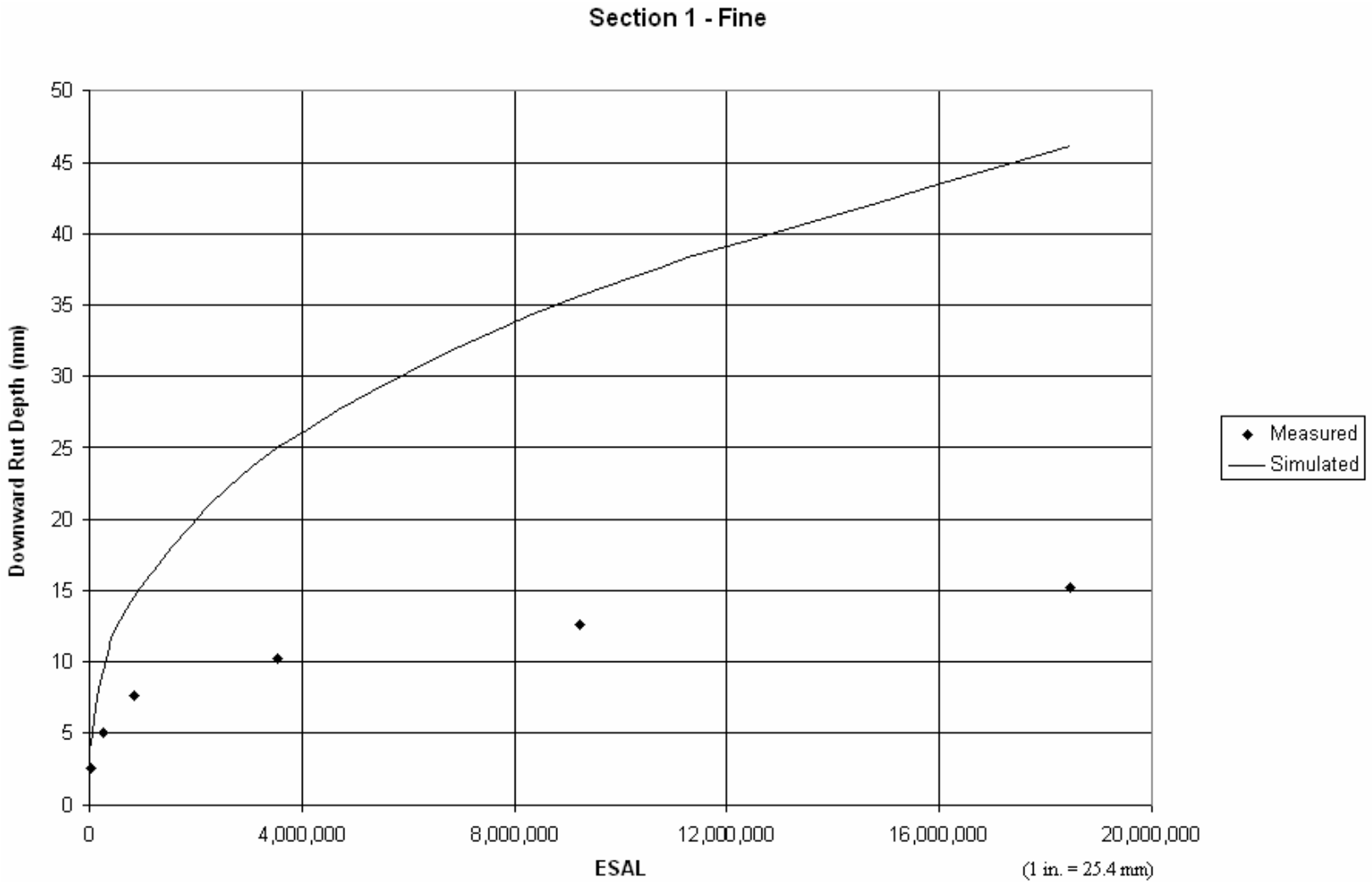

Section 39
Maximum Rut Depth (mm)
16
14
12
10
8
6
4
2
0
Total rut
Unbound layers
7/17/1997
10/25/1997
2/2/1998
5/13/1998
8/21/1998
11/29/1998
3/9/1999
6/17/1999
Date
(1 in. = 25.4 mm)

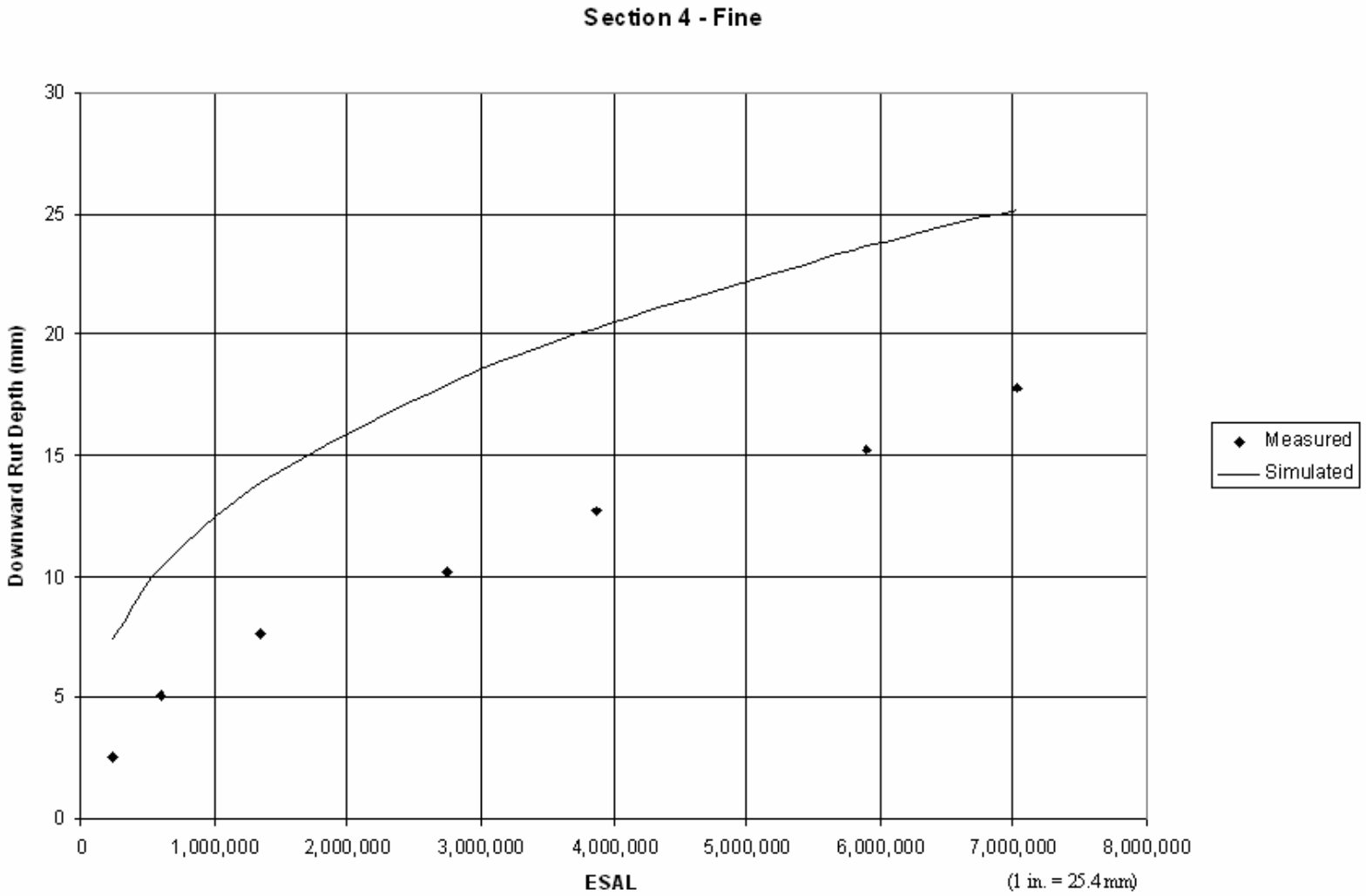

Section 54
Maximum Rut Depth (mm)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Total rut
Unbound layers
7/17/1997
10/25/1997
2/2/1998
5/13/1998
8/21/1998
11/29/1998
3/9/1999
6/17/1999
Date
(1 in. = 25.4 mm)

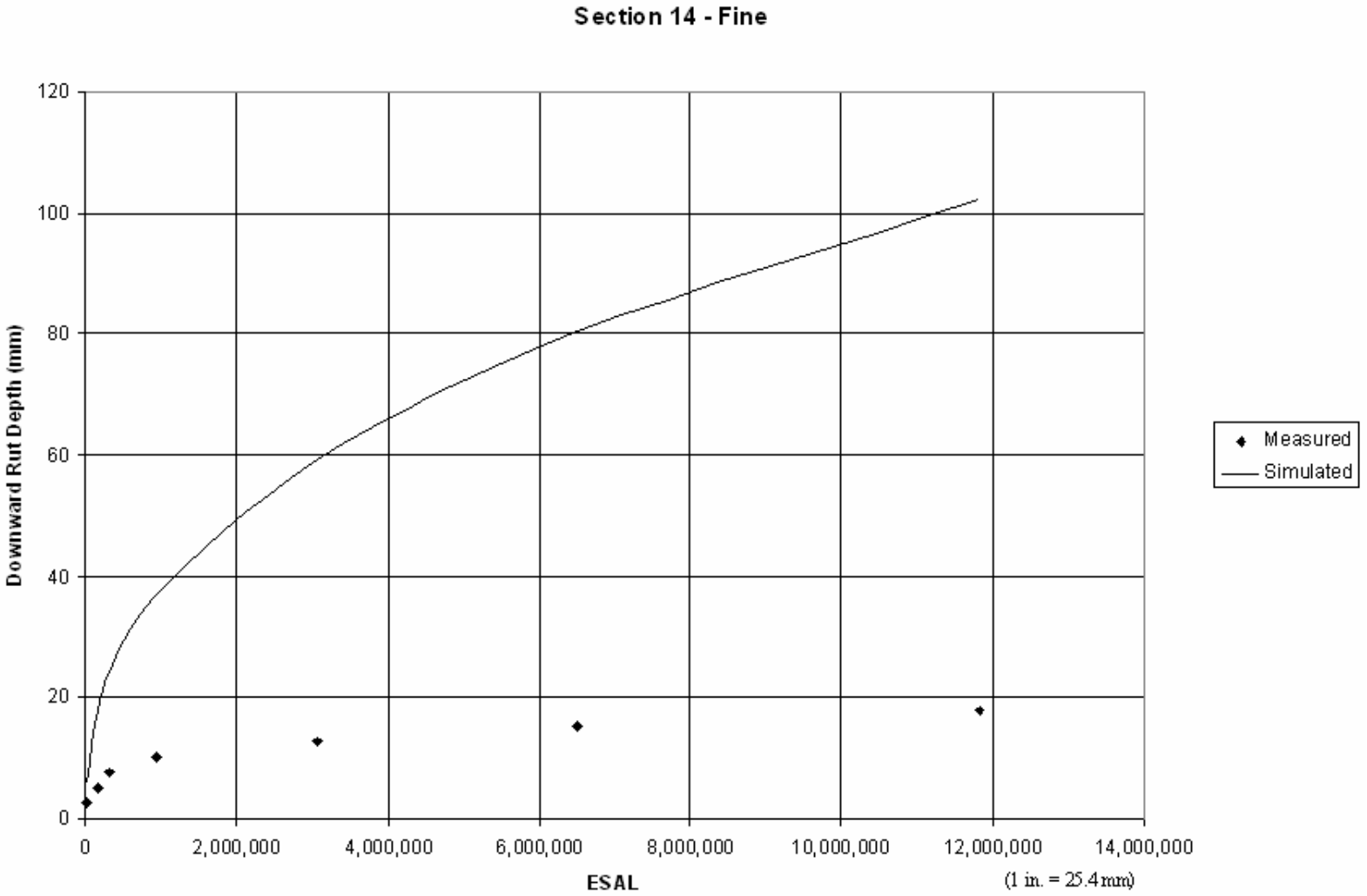

Section 55
Total rut
Unbound layers
Maximum Rut Depth (mm)
20
15
10
5
0
7/17/1997
10/25/1997
2/2/1998
5/13/1998
8/21/1998
11/29/1998
3/9/1999
6/17/1999
Date
(1 in. = 25.4 mm)

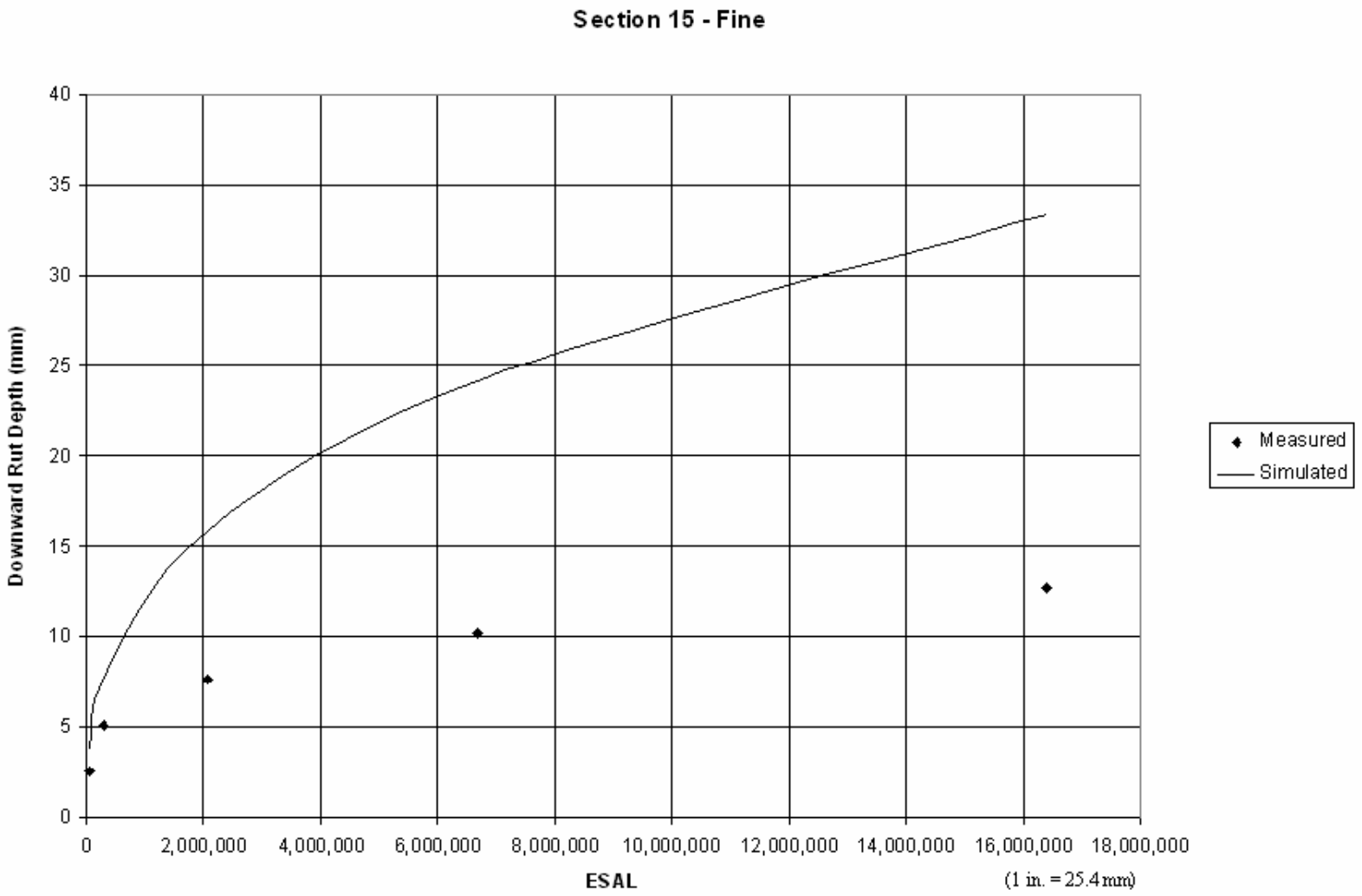
APPENDIX G

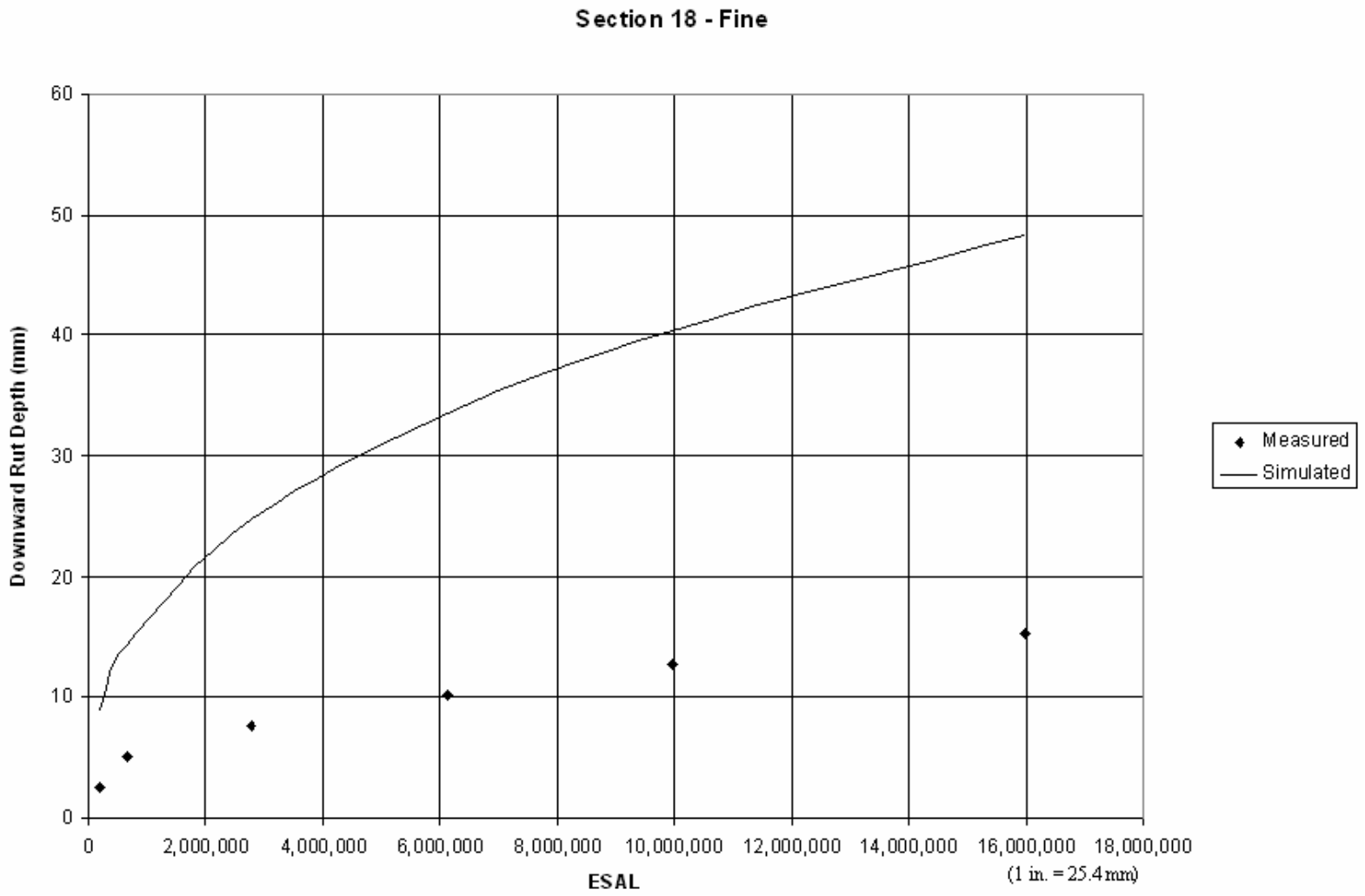
Comparisons of Simulations based on Regression Equations in Table 3.13 and Measured Rut Depths for 23 Sections Used to Develop the Mechanistic-Empirical Performance Relationships.

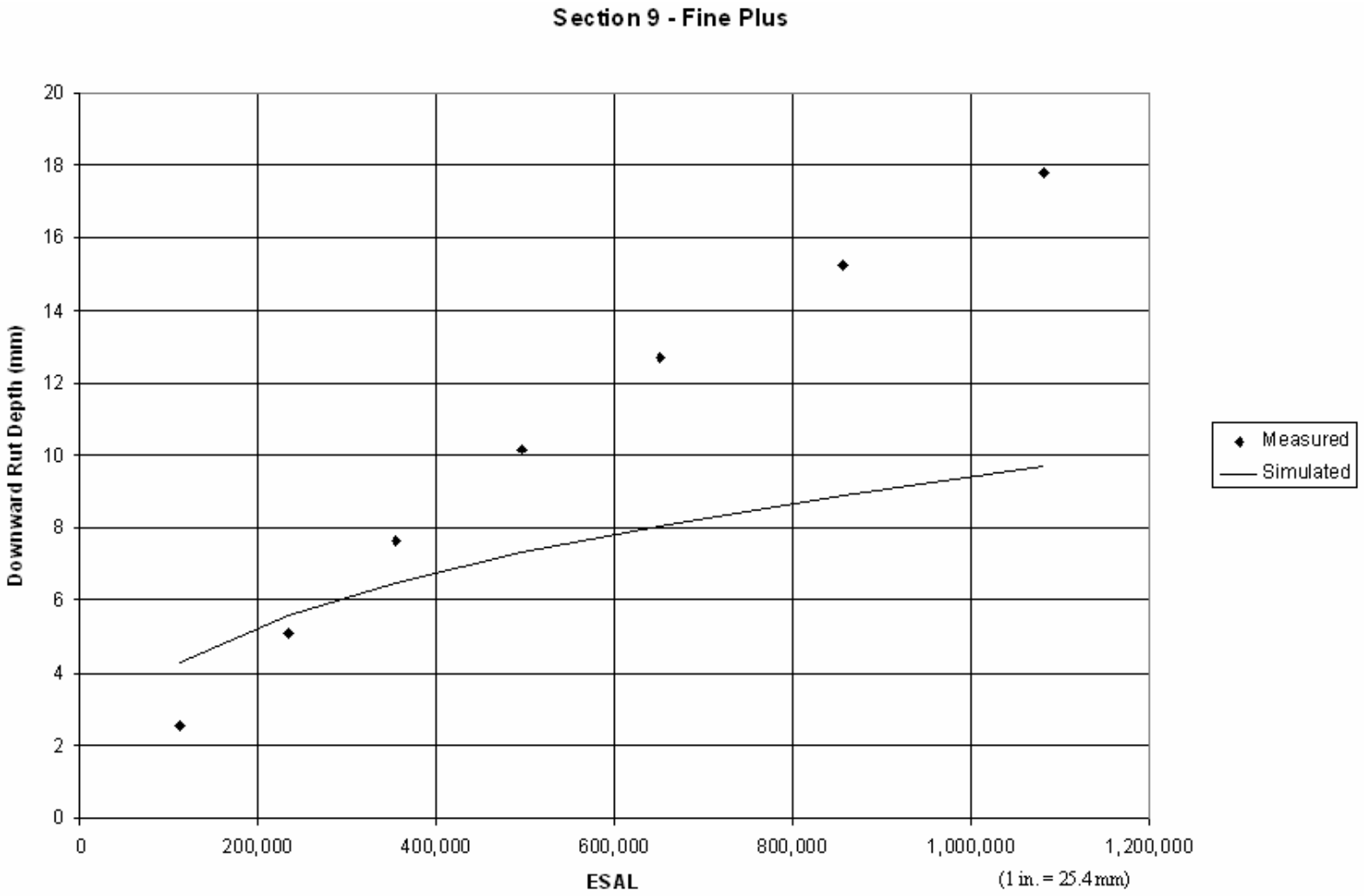

Section 1 - Fine
Downward Rut Depth (mm)
50
45
40
35
30
25
20
15
10
5
0
0
4,000,000
8,000,000
12,000,000
16,000,000
20,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

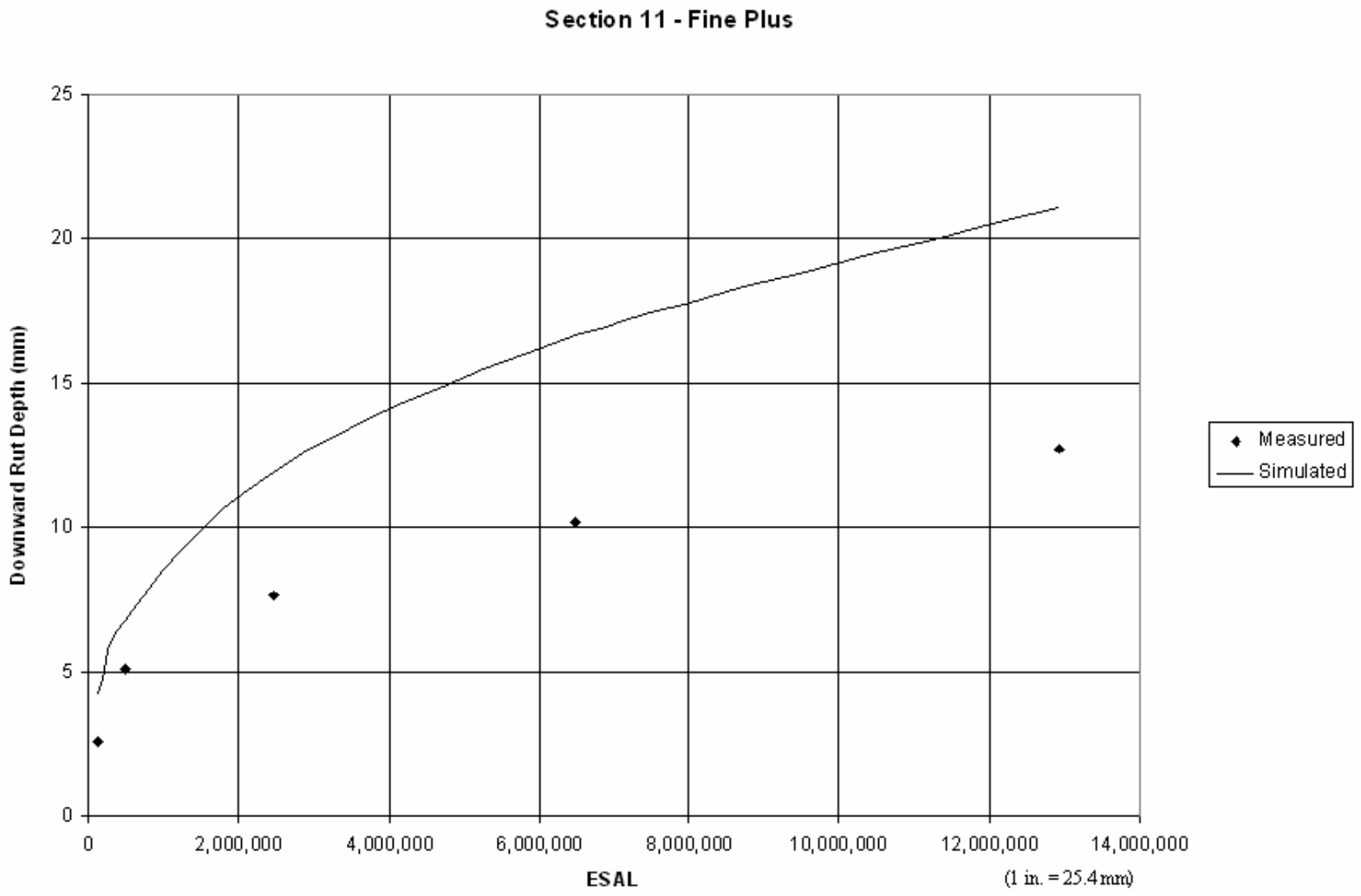

Section 4 - Fine
Downward Rut Depth (mm)
30
25
20
15
10
5
0
0
1,000,000
2,000,000
3,000,000
4,000,000
5,000,000
6,000,000
7,000,000
8,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

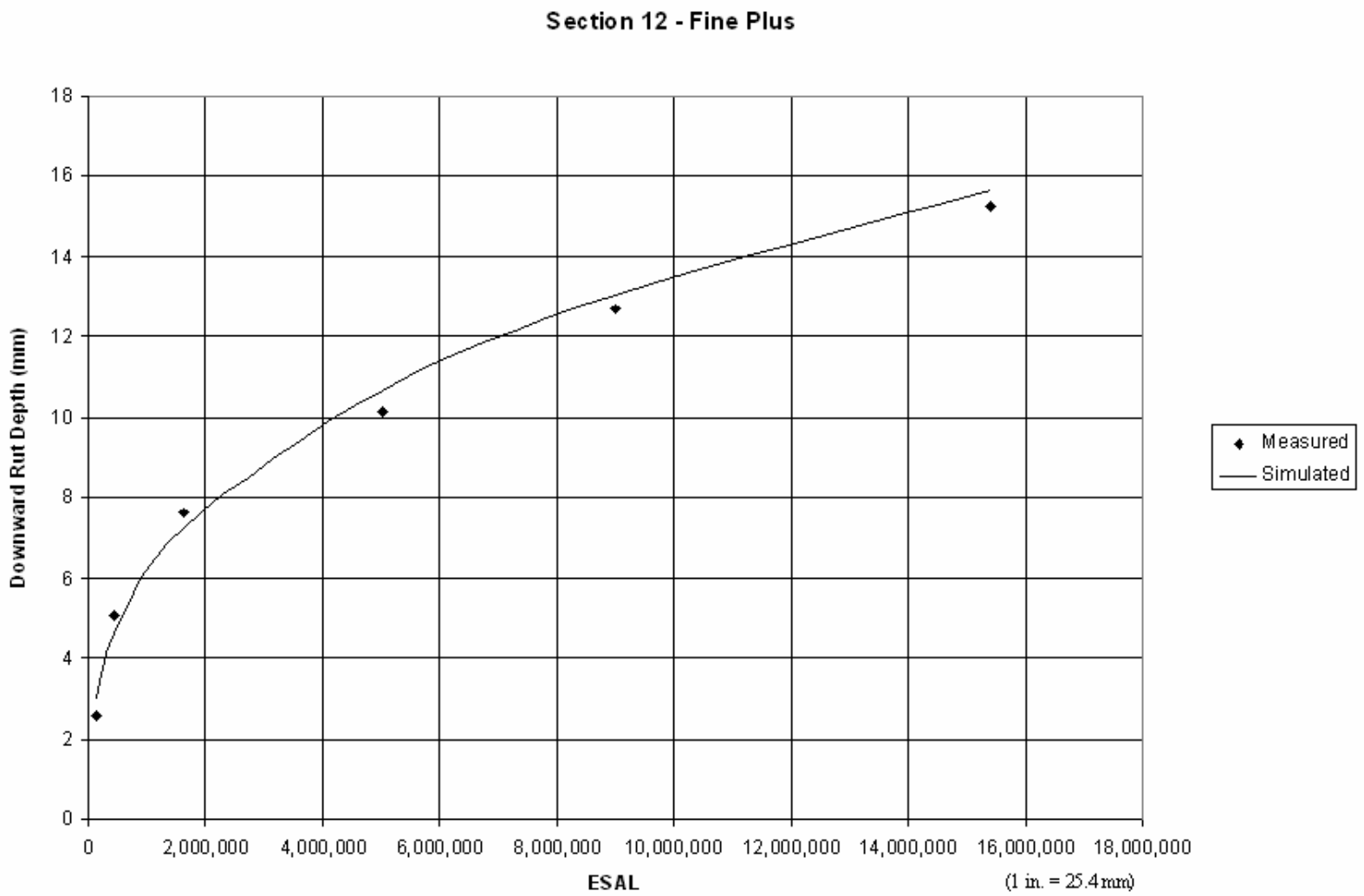

Section 14 - Fine
Downward Rut Depth (mm)
120
100
80
60
40
20
0
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
14,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

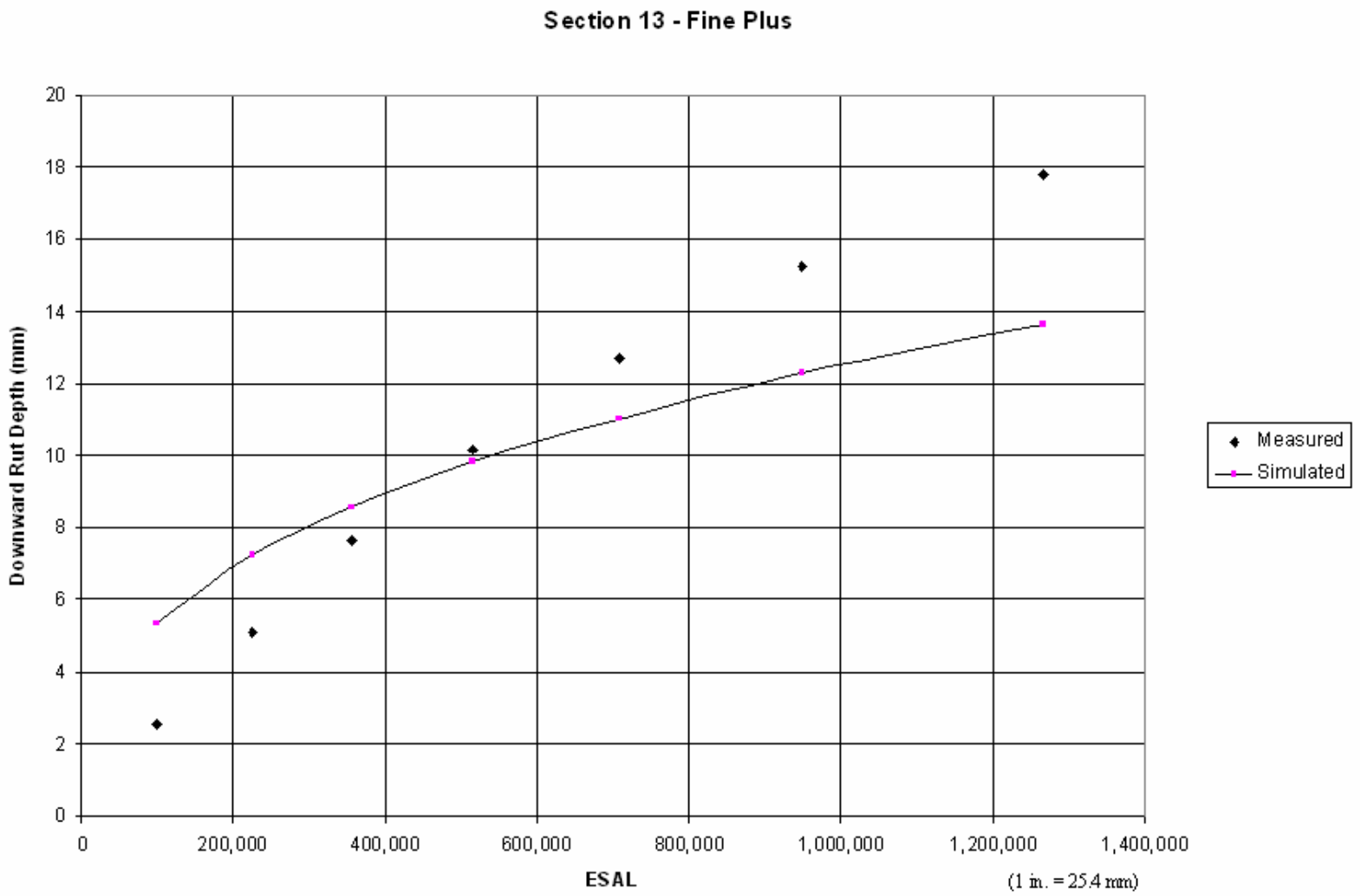

Section 15 - Fine
Downward Rut Depth (mm)
40
35
30
25
20
15
10
5
0
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
14,000,000
16,000,000
18,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

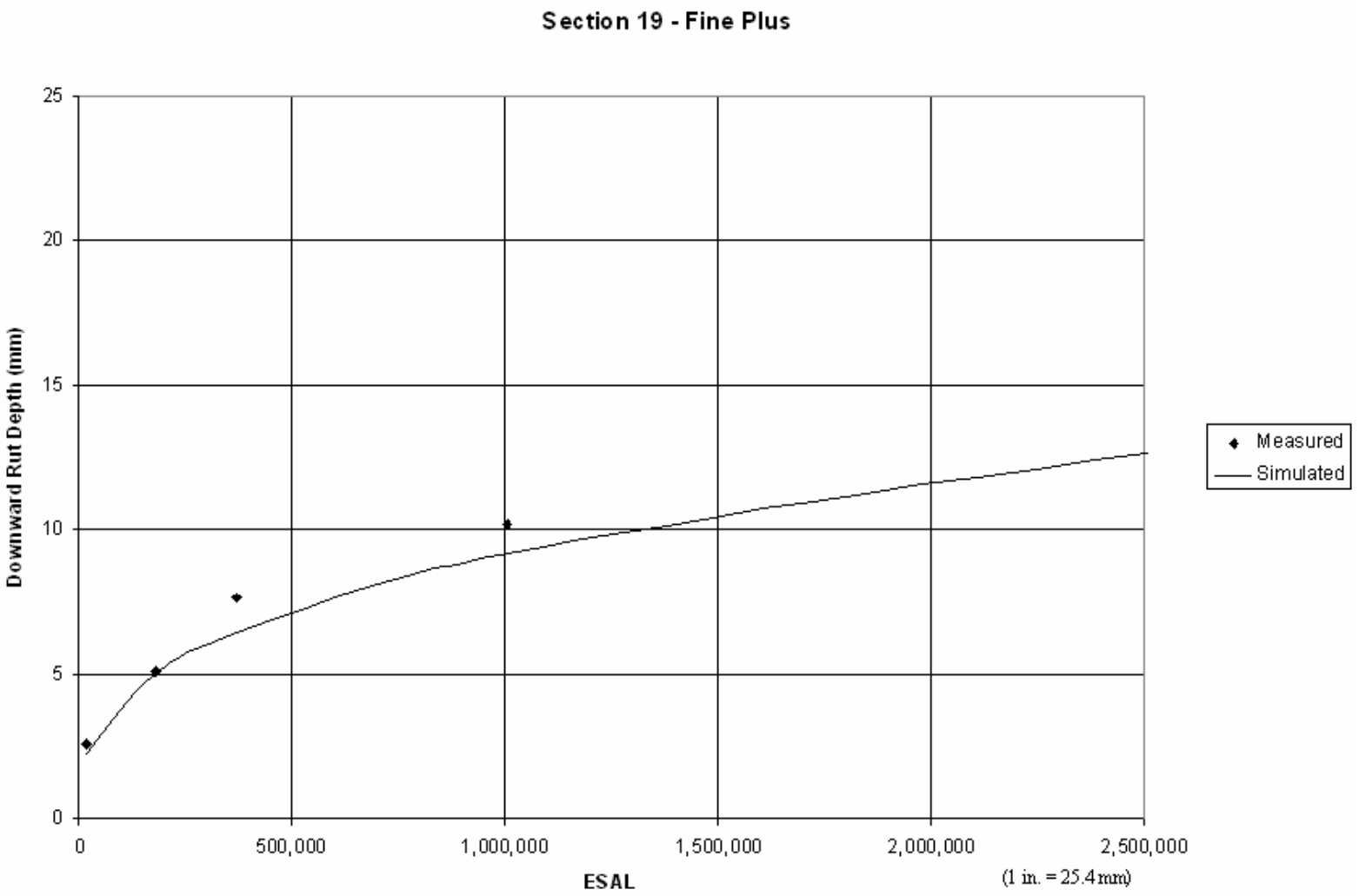

Section 18 - Fine
Downward Rut Depth (mm)
60
50
40
30
20
10
0
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
14,000,000
16,000,000
18,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

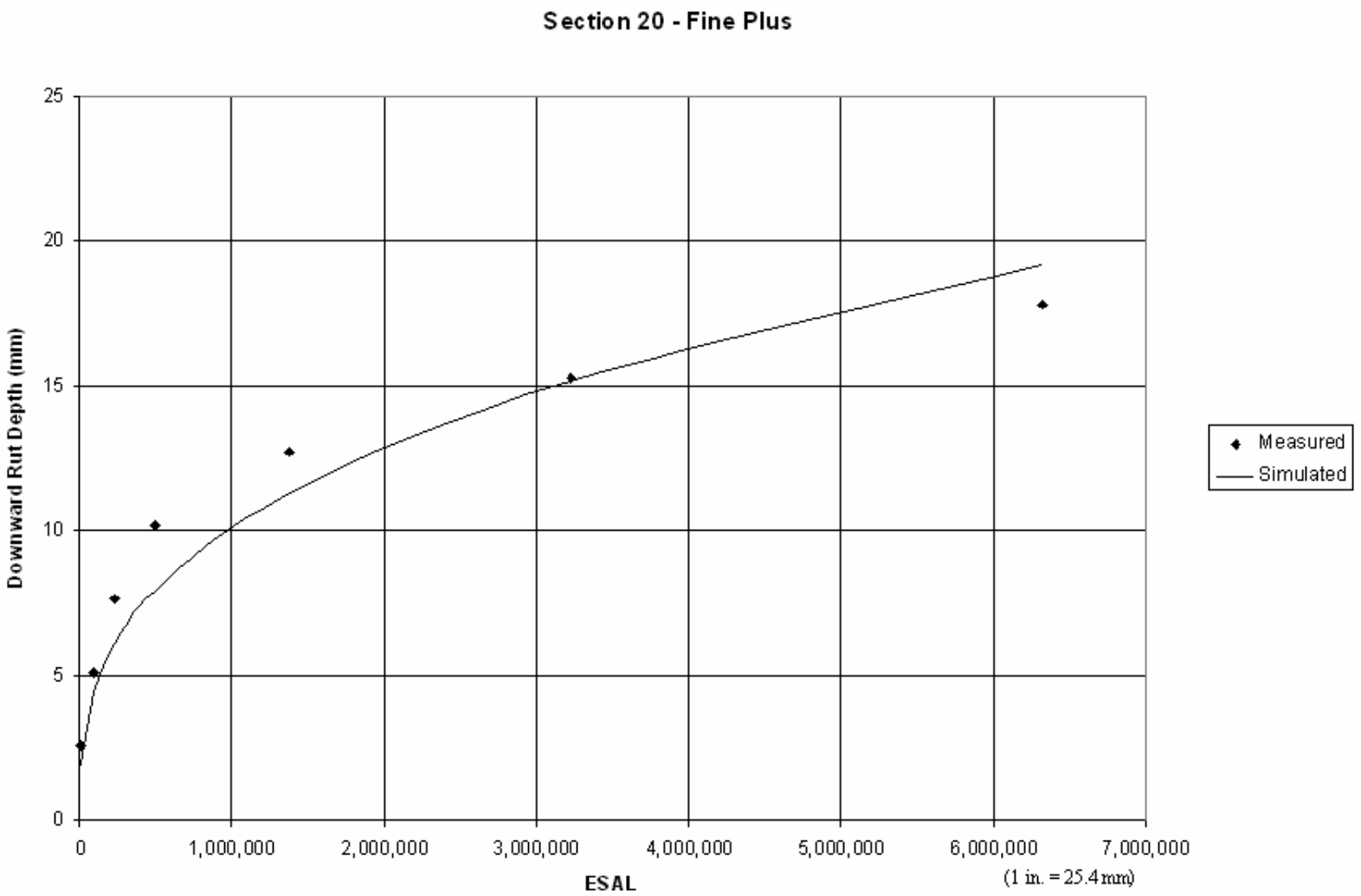

Section 9 - Fine Plus
Downward Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
0
200,000
400,000
600,000
800,000
1,000,000
1,200,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

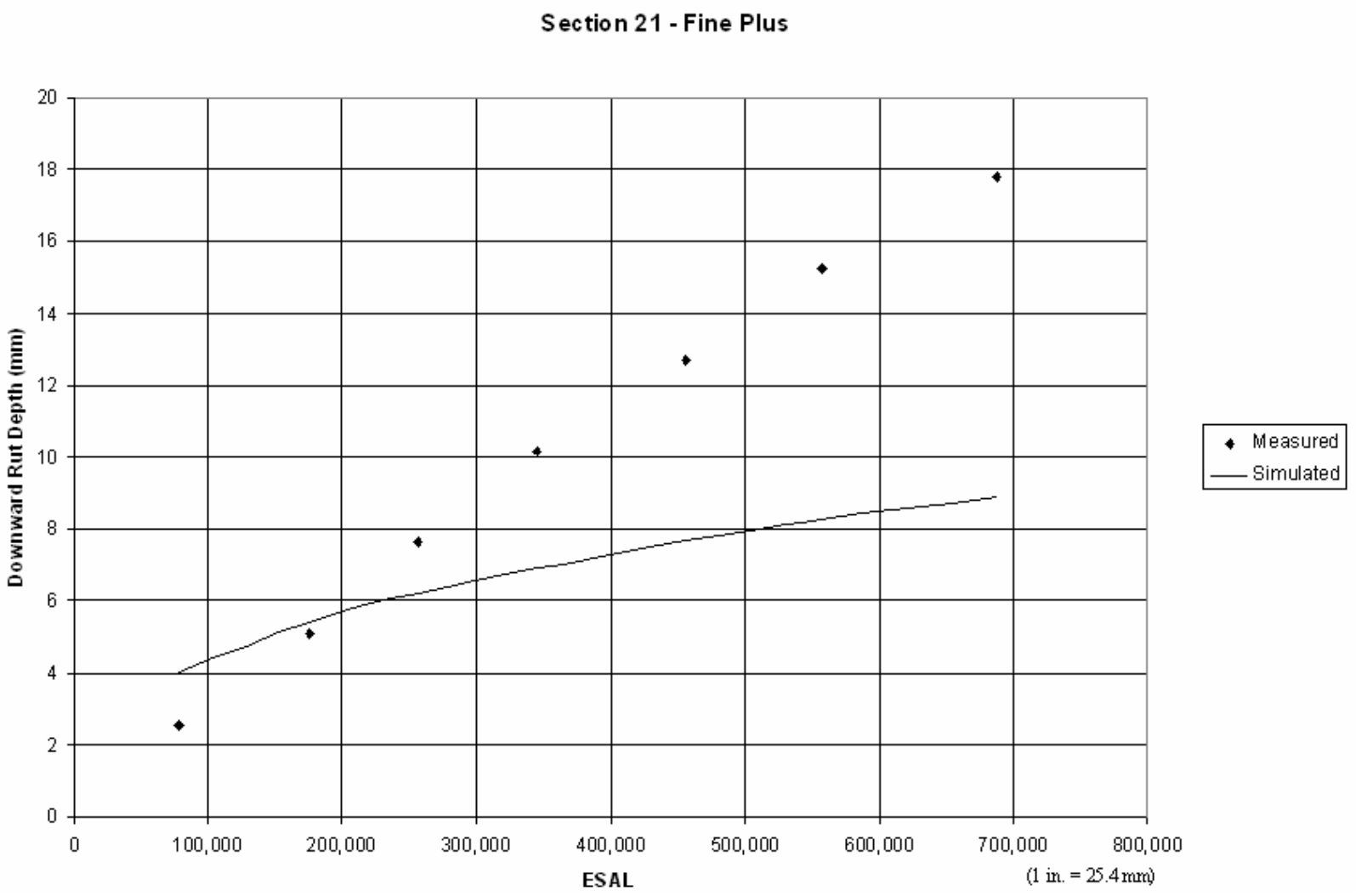

Section 11 - Fine Plus
Downward Rut Depth (mm)
25
20
15
10
5
0
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
14,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

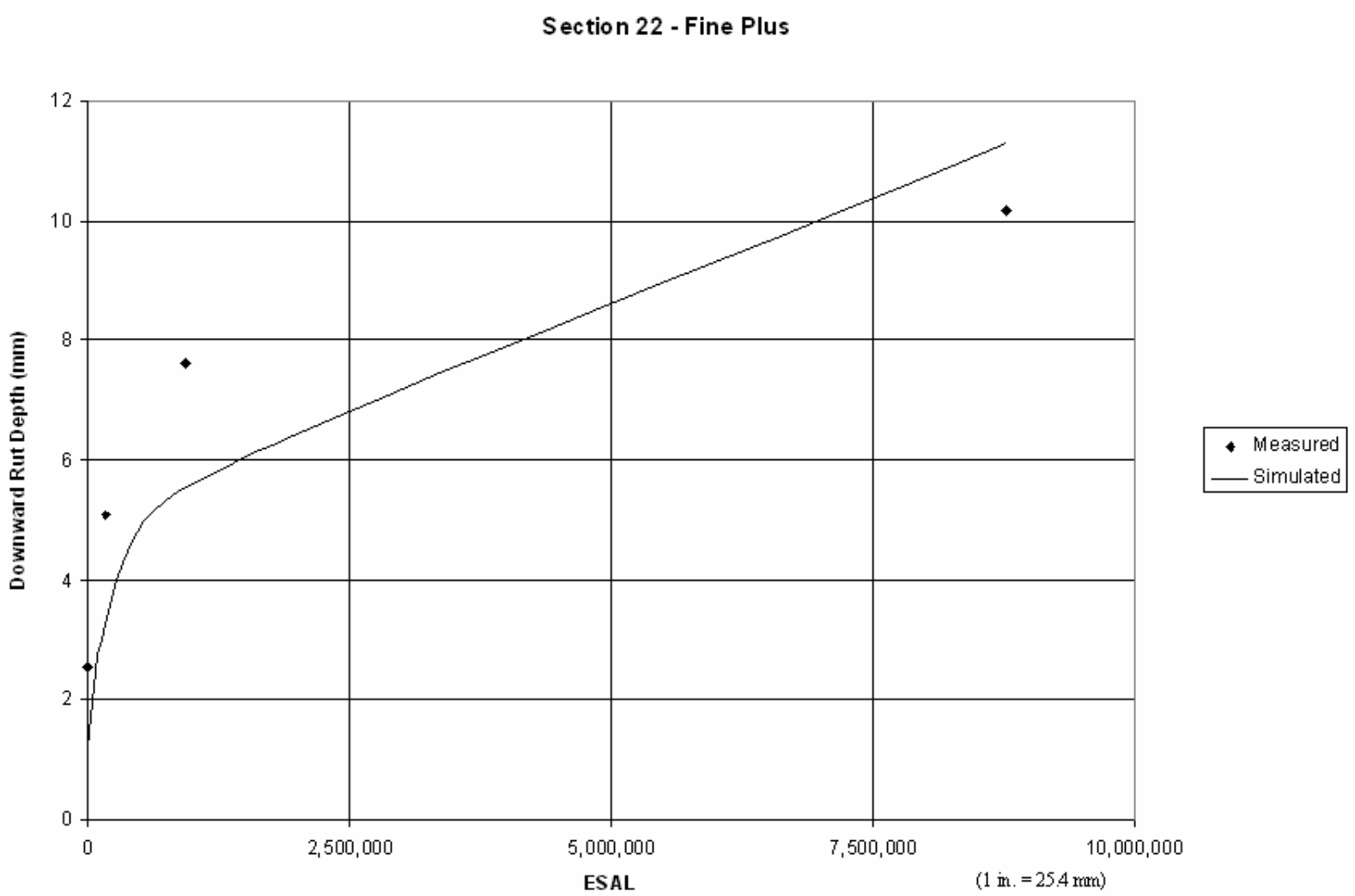

Section 12 - Fine Plus
Downward Rut Depth (mm)
18
16
14
12
10
8
6
4
2
0
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
14,000,000
16,000,000
18,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

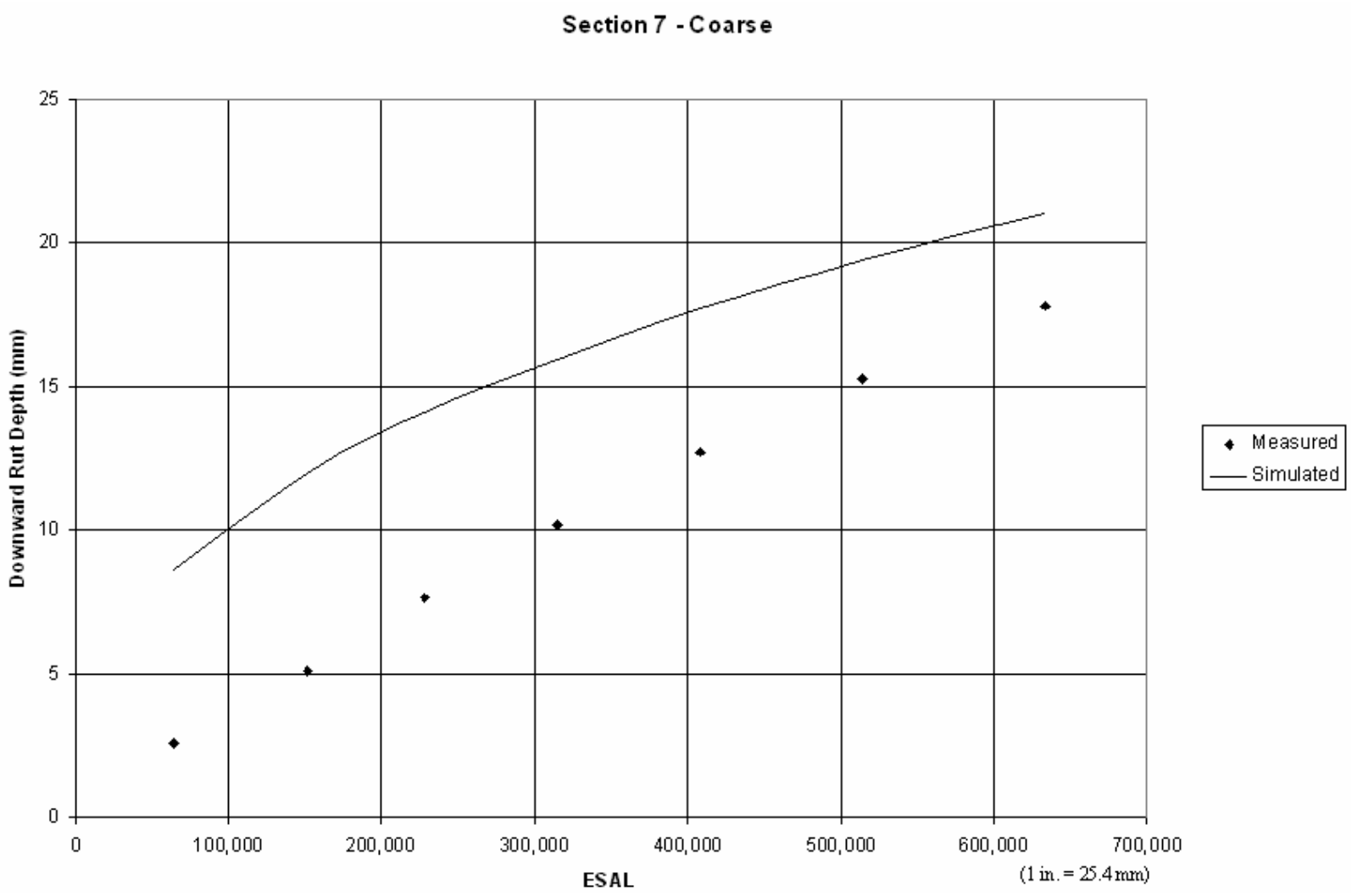

Section 13 - Fine Plus
Downward Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
0
200,000
400,000
600,000
800,000
1,000,000
1,200,000
1,400,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

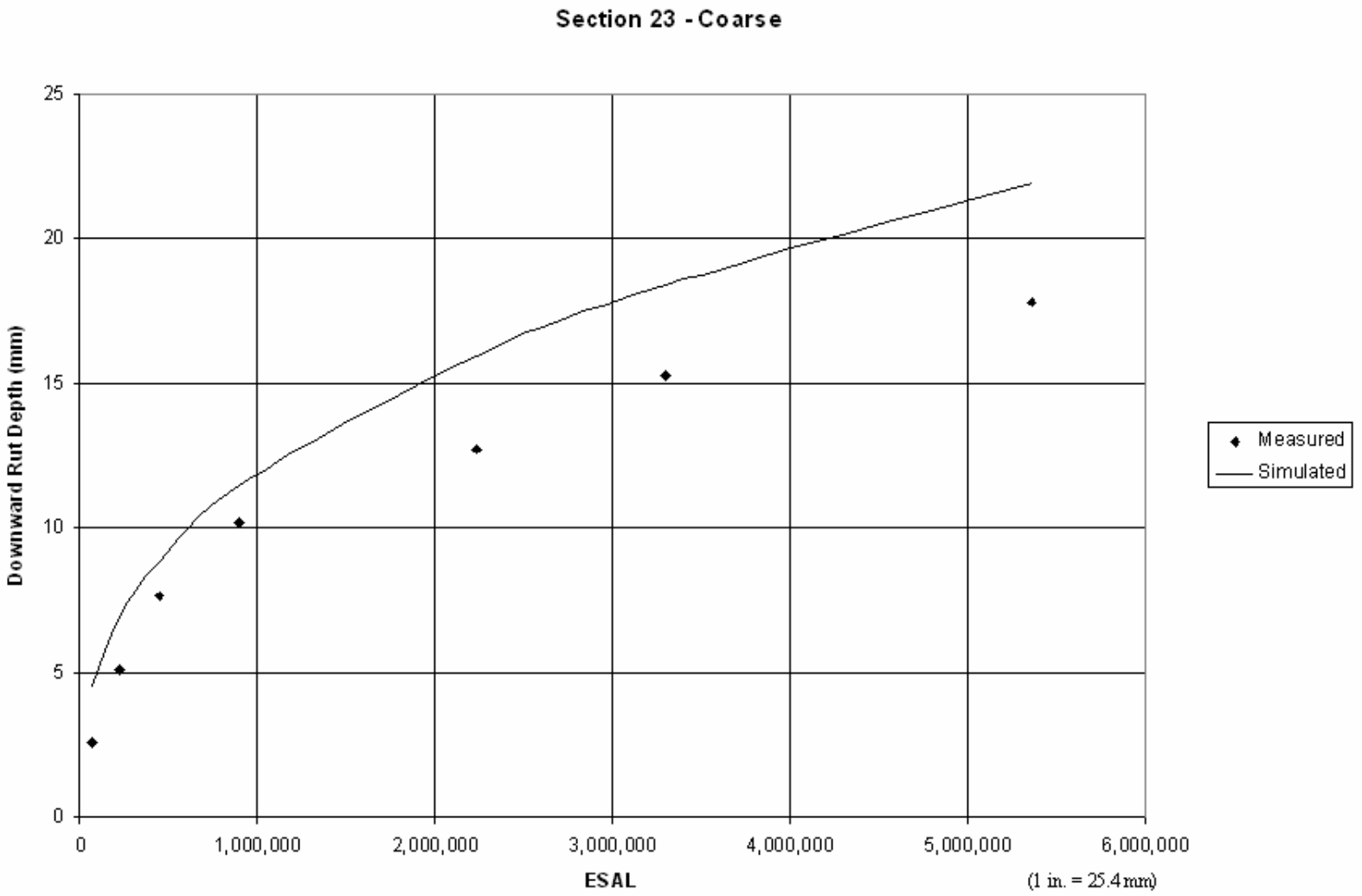

Section 19 - Fine Plus
Downward Rut Depth (mm)
25
20
15
10
5
0
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

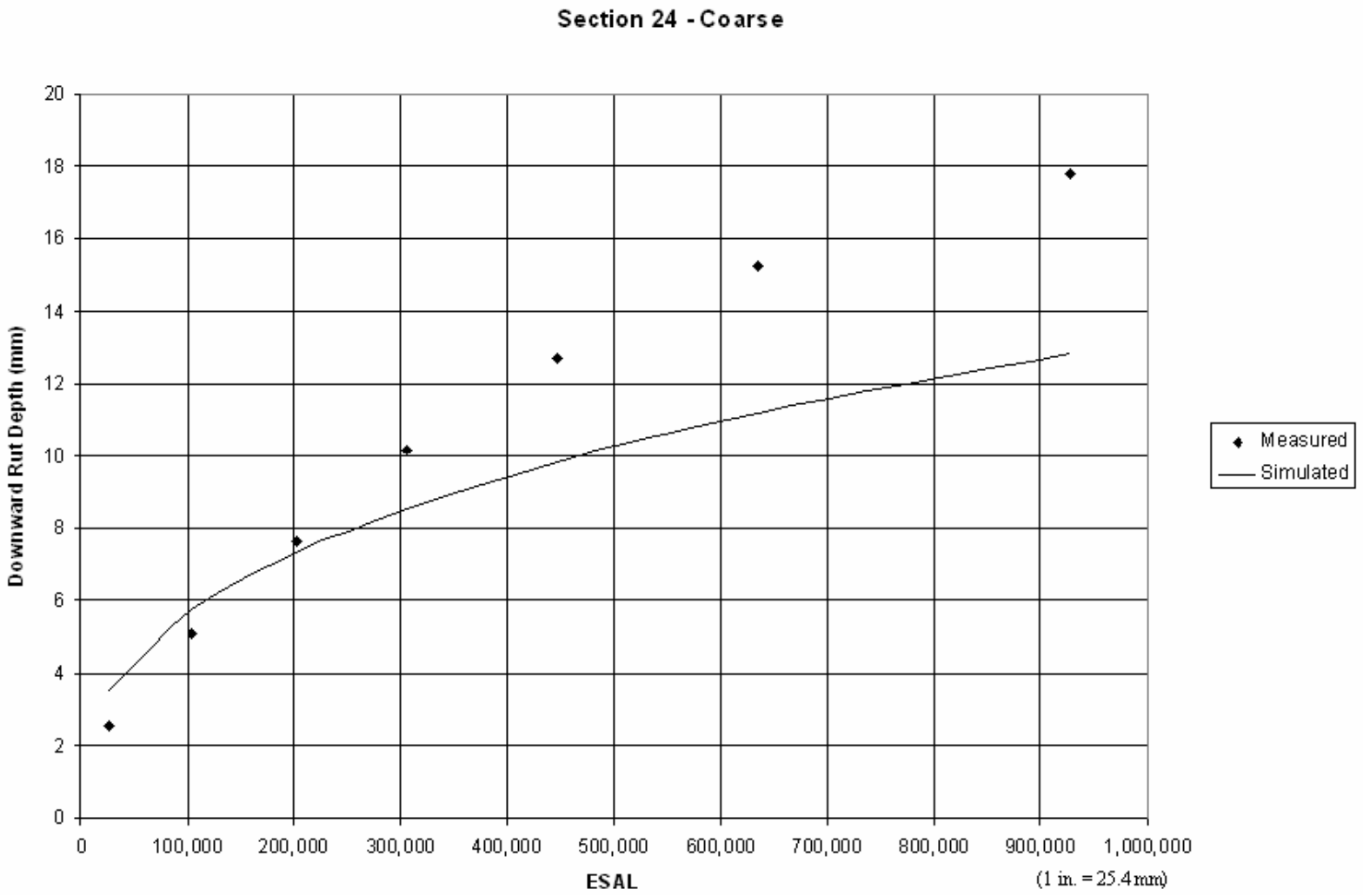

Section 20 - Fine Plus
Downward Rut Depth (mm)
25
20
15
10
5
0
0
1,000,000
2,000,000
3,000,000
4,000,000
5,000,000
6,000,000
7,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

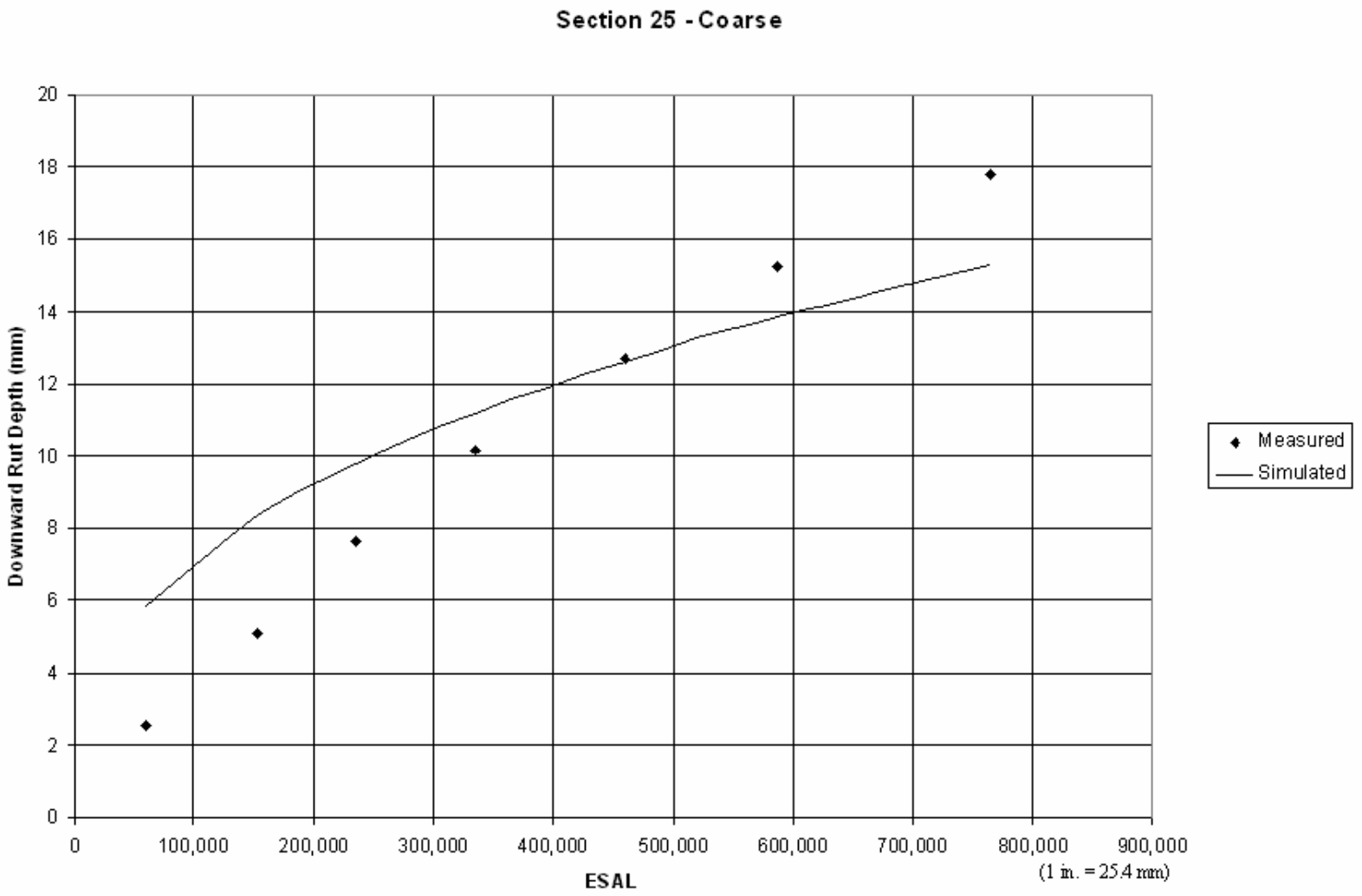

Section 21 - Fine Plus
Downward Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

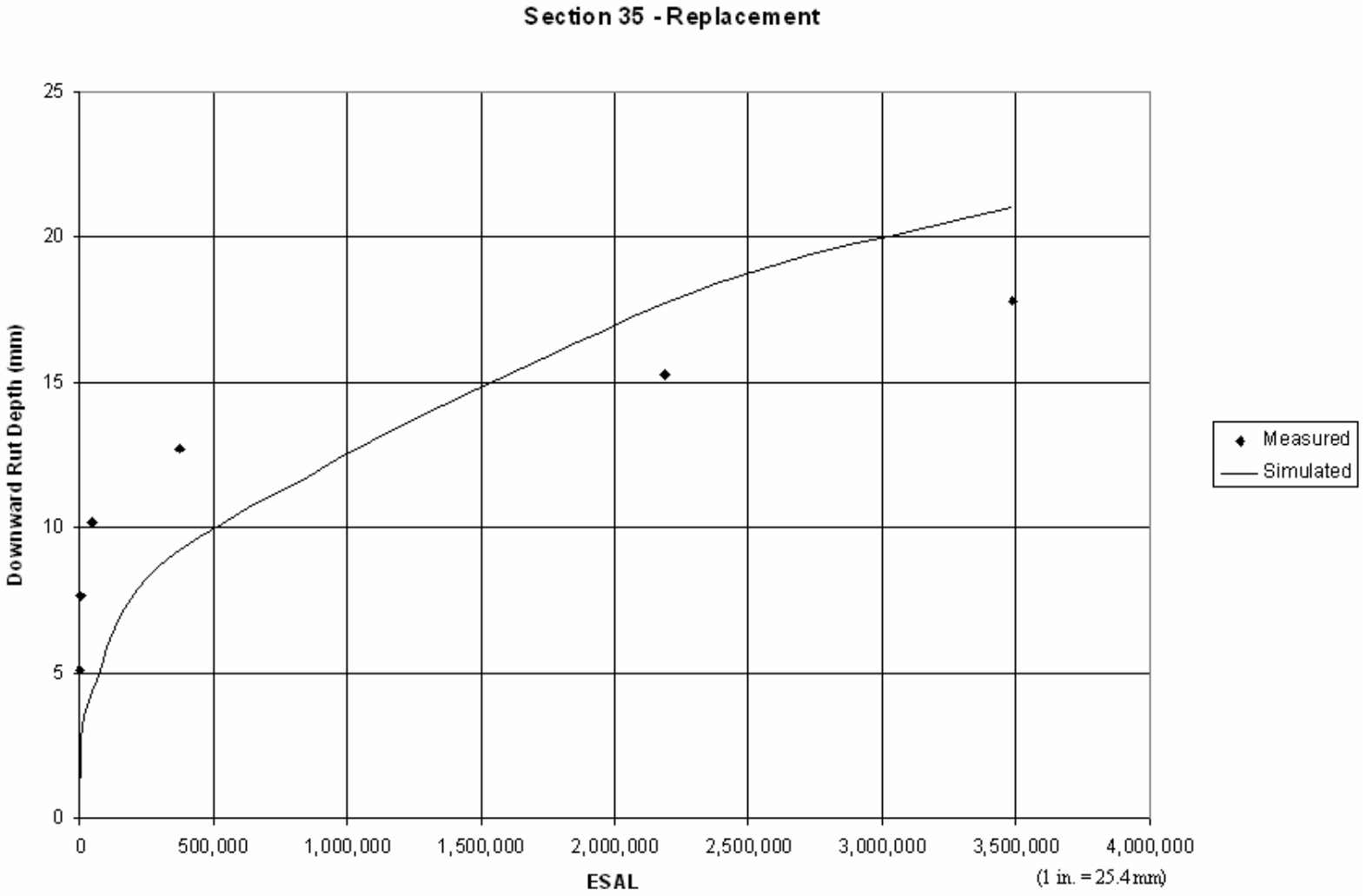

Section 22 - Fine Plus
Downward Rut Depth (mm)
12
10
8
6
4
2
0
0
2,500,000
5,000,000
7,500,000
10,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

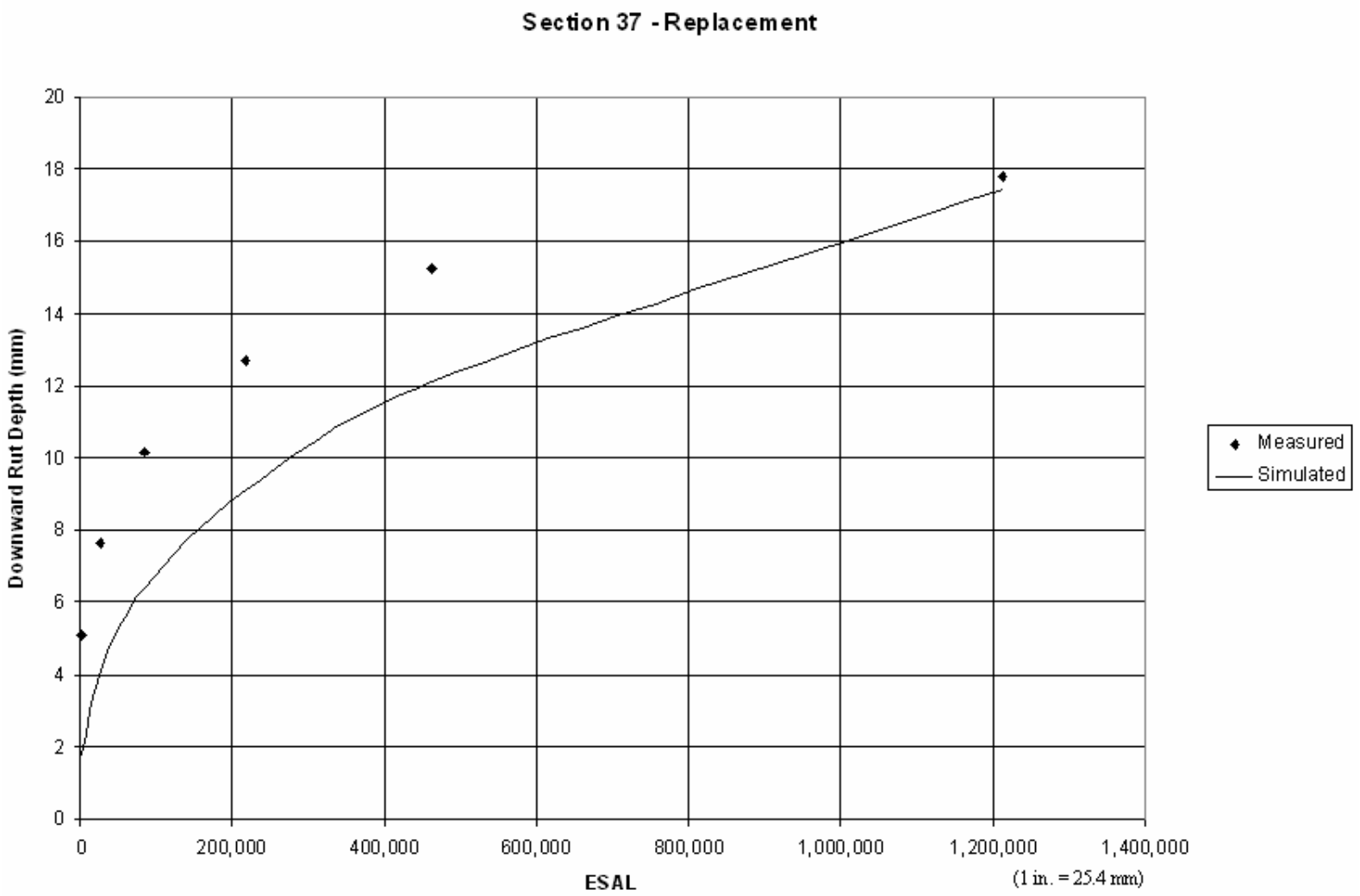

Section 7 - Coarse
Downward Rut Depth (mm)
25
20
15
10
5
0
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

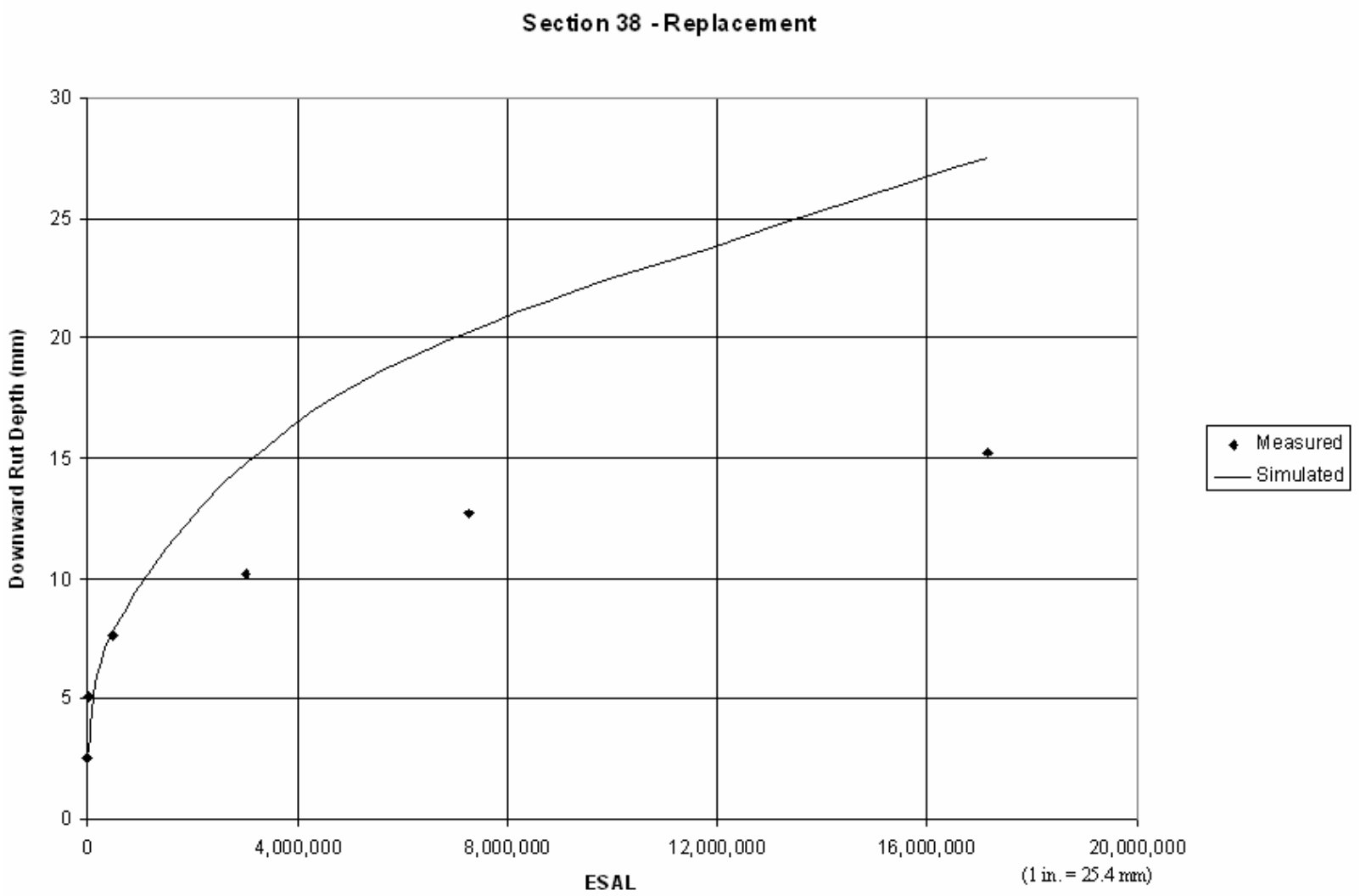

Section 23 - Coarse
Downward Rut Depth (mm)
25
20
15
10
5
0
0
1,000,000
2,000,000
3,000,000
4,000,000
5,000,000
6,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

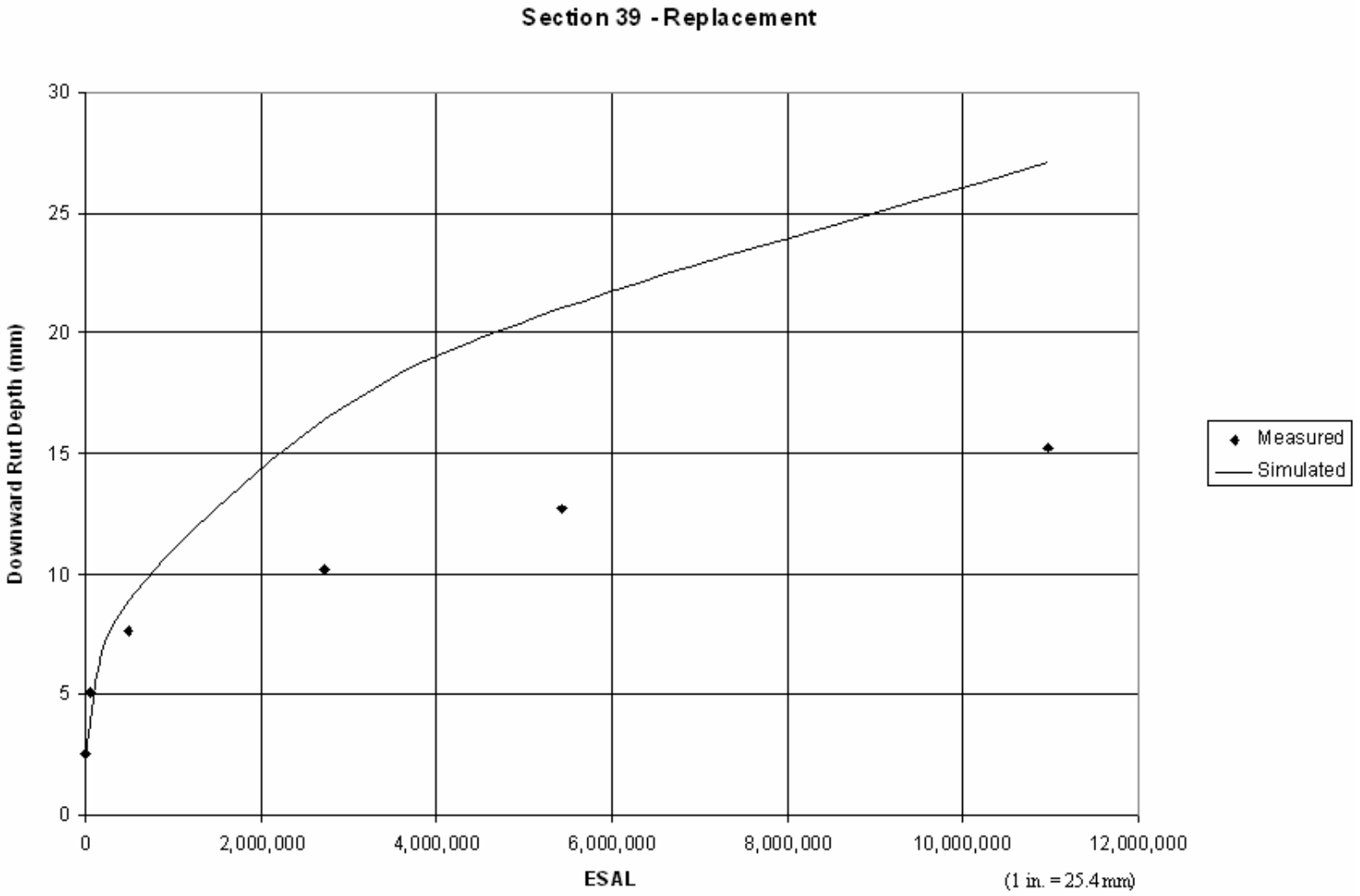

Section 24 - Coarse
Downward Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
900,000
1,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

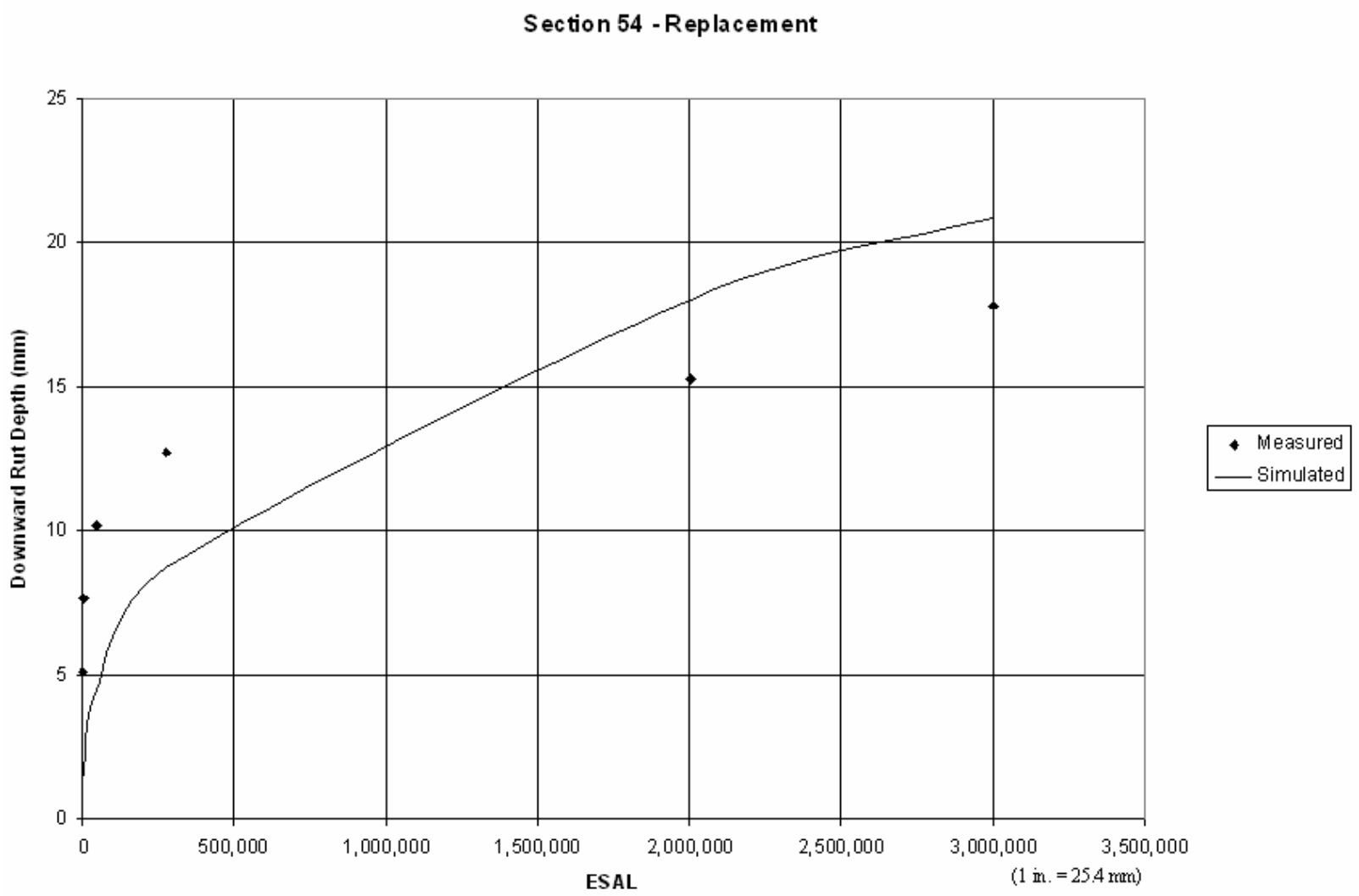

Section 25 - Coarse
Downward Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
900,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

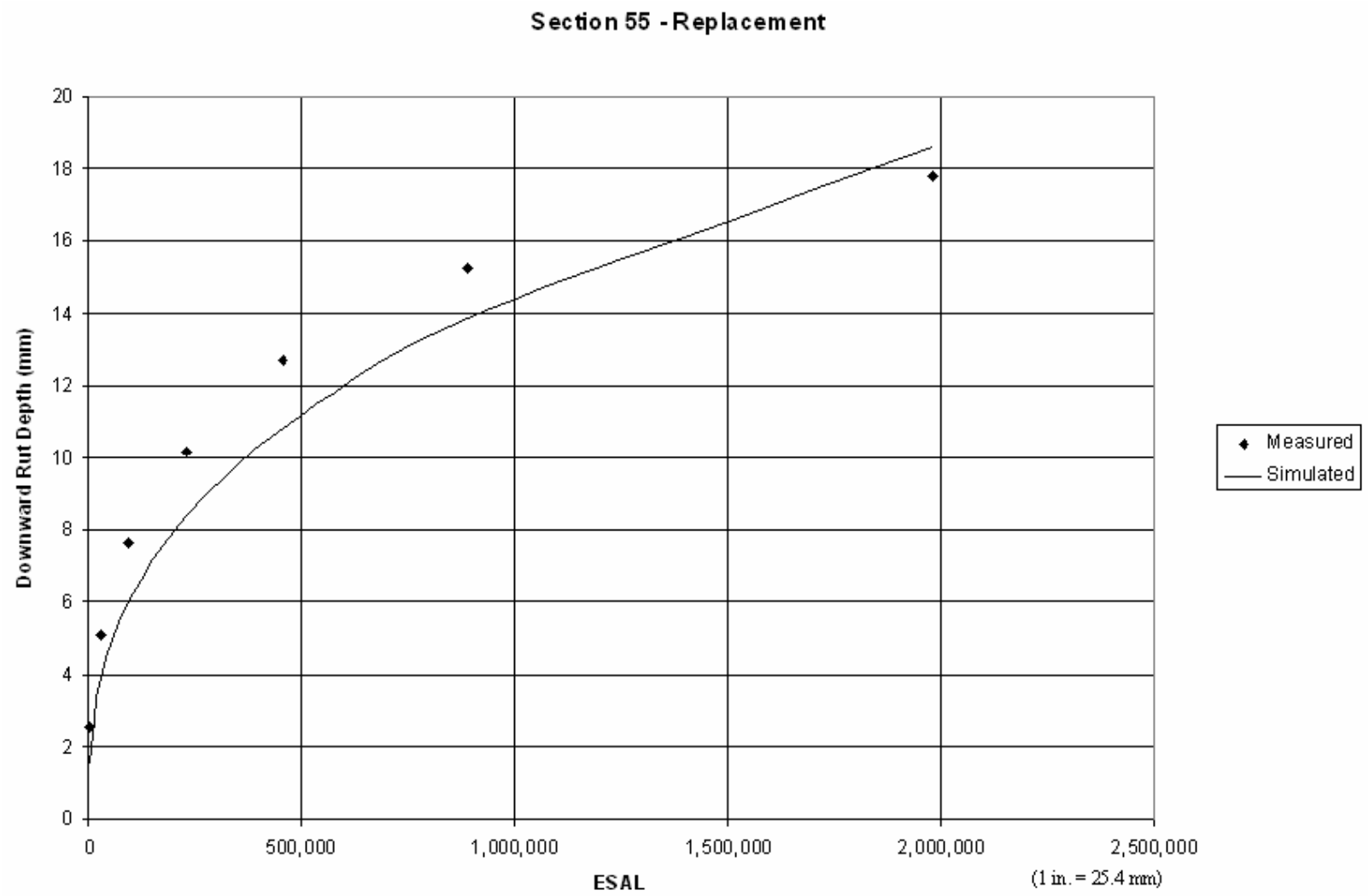

Section 35 - Replacement
Downward Rut Depth (mm)
25
20
15
10
5
0
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
3,000,000
3,500,000
4,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated


Section 37 - Replacement
Downward Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
0
200,000
400,000
600,000
800,000
1,000,000
1,200,000
1,400,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated


Section 38 - Replacement
Downward Rut Depth (mm)
30
25
20
15
10
5
0
0
4,000,000
8,000,000
12,000,000
16,000,000
20,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated


Section 39 - Replacement
Downward Rut Depth (mm)
30
25
20
15
10
5
0
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated


Section 54 - Replacement
Downward Rut Depth (mm)
25
20
15
10
5
0
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
3,000,000
3,500,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated


Section 55 - Replacement
Downward Rut Depth (mm)
20
18
16
14
12
10
8
6
4
2
0
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
ESAL
(1 in. = 25.4 mm)
Measured
Simulated

APPENDIX H

Laboratory Fatigue Test Data; FMFC Specimens

Table H.1.–Fatigue beam testing for WesTrack: bottom lift.

Table H.2.–Original sections temperature study.

Table H.3.–Frequency effects study.

Table H.4.–Replacement sections, FMFC.

Table H.5.–LMLC specimens.

Table H.1. Fatigue beam testing for WesTrack: bottom lift.

Specimen	Section	Mix	Gradation	Target AC	Target AV	UCB AV	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT01-FB	1	1	Fine	5.4	8.0	8.9	1.97E-04	1693277	30.8	3085			
WT01-AB	1	1	Fine	5.4	8.0	8.8	1.98E-04	1361835	28.6	3259			
WT01-BB	1	1	Fine	5.4	8.0	9.0	3.98E-04	82500	32.0	2892			
WT01-CB	1	1	Fine	5.4	8.0	8.8	4.02E-04	63379	30.8	3290			
WT01-EB	1	1	Fine	5.4	8.0	8.6	4.01E-04	56018	30.5	3444	Slope	Intercept	R^2
				average		*8.8*			*30.5*	*3194*	-4.4328	5.77E-11	0.9930
WT02-KB	2	2	Fine	4.7	8.0	8.9	2.00E-04	1984922	20.1	5866			
WT02-NB	2	2	Fine	4.7	8.0	9.8	2.01E-04	1814493	19.2	5979			
WT02-LB	2	2	Fine	4.7	8.0	10.4	1.98E-04	1066325	18.7	6071			
WT02-GB	2	2	Fine	4.7	8.0	9.3	3.99E-04	167149	22.1	4986			
WT02-IB	2	2	Fine	4.7	8.0	10.3	4.01E-04	58979	21.6	5246			
WT02-HB	2	2	Fine	4.7	8.0	11.4	3.97E-04	11370	20.0	5012	Slope	Intercept	R^2
				average		*9.7*			*20.3*	*5527*	-5.013	4.44E-13	0.8181
WT03-FB	3	3	Fine	4.7	12.0	12.0	1.98E-04	649225	28.7	3052			
WT03-CB	3	3	Fine	4.7	12.0	11.4	1.98E-04	531729	27.0	3745			
WT03-EB	3	3	Fine	4.7	12.0	12.5	1.97E-04	219257	24.6	3640			
WT03-DB	3	3	Fine	4.7	12.0	12.4	4.00E-04	25395	31.4	2931			
WT03-BB	3	3	Fine	4.7	12.0	11.9	3.98E-04	19395	30.1	3309			
WT03-AB	3	3	Fine	4.7	12.0	11.8	3.98E-04	12507	30.5	3182	Slope	Intercept	R^2
				average		*12.0*			28.7	*3310*	-4.4672	1.2E-11	0.9383
WT04-AT	4	4	Fine	5.4	4.0	6.5	1.99E-04	1628332	20.7	5600			
WT04-DB	4	4	Fine	5.4	4.0	5.7	1.85E-04	1100000	19.8	5728			
WT04-AB	4	4	Fine	5.4	4.0	5.8	1.84E-04	783333	19.5	5865			
WT04-EB	4	4	Fine	5.4	4.0	5.8	3.71E-04	20337	22.9	5144			
WT04-CB	4	4	Fine	5.4	4.0	6.7	3.69E-04	20000	22.0	4710	Slope	Intercept	R^2
				average		*6.1*			*21.0*	*5409*	-5.8888	1.3E-16	0.9620

Table H.1., continued.

Specimen	Section	Mix	Gradation	Target AC	Target AV	UCB AV	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT05-EB	5	19	Coarse	5.7	8.0	9.2	1.97E-04	2074970	27.3	4534			
WT05-AT	5	19	Coarse	5.7	8.0	8.9	1.86E-04	1730000	23.8	6344			
WT05-DT	5	19	Coarse	5.7	8.0	8.8	1.85E-04	1560000	21.3	5403			
WT05-AB	5	19	Coarse	5.7	8.0	9.5	1.97E-04	1383439	25.3	4159			
WT05-CB	5	19	Coarse	5.7	8.0	8.9	3.98E-04	99996	26.6	4120			
WT05-FB	5	19	Coarse	5.7	8.0	9.5	3.98E-04	69060	27.8	4222			
WT05-BB	5	19	Coarse	5.7	8.0	9.5	4.05E-04	59514	28.6	3505	Slope	Intercept	R^2
				average		*9.2*			*25.8*	*4612*	-4.1941	4.21E-10	0.9831
WT06-ET	6	20	Coarse	5.7	12.0	14.1	1.85E-04	9464858	22.7	3566			
WT06-CT	6	20	Coarse	5.7	12.0	14.6	1.85E-04	3028267	20.7	3674			
WT06-BT	6	20	Coarse	5.7	12.0	14.7	1.85E-04	2750000	20.8	3890			
WT06-CB	6	20	Coarse	5.7	12.0	13.8	1.97E-04	1668256	22.0	3960			
WT06-DB	6	20	Coarse	5.7	12.0	13.4	4.02E-04	81026	27.4	3159			
WT06-BB	6	20	Coarse	5.7	12.0	12.8	4.00E-04	80888	25.6	3468	Slope	Intercept	R^2
				average		*13.9*			*23.2*	*3620*	-4.9668	1.07E-12	0.9382
WT07-FT	7	21	Coarse	6.4	8.0	7.9	2.00E-04	6175457	22.7	4776			
WT07-DB	7	21	Coarse	6.4	8.0	8.0	1.87E-04	3828442	23.3	4708			
WT07-CB	7	21	Coarse	6.4	8.0	8.4	1.84E-04	2474999	19.8	5268			
WT07-EB	7	21	Coarse	6.4	8.0	8.3	3.99E-04	101026	23.3	4859			
WT07-BB	7	21	Coarse	6.4	8.0	8.2	4.04E-04	99364	26.5	4064			
WT07-AB	7	21	Coarse	6.4	8.0	7.9	4.00E-04	63293	23.9	4821	Slope	Intercept	R^2
				average		*8.1*			*23.3*	*4749*	-5.0387	6.76E-13	0.9526
WT08-EB	8	22	Coarse	5.0	8.0	7.2	1.85E-04	6603786	18.5	6538			
WT08-BB	8	22	Coarse	5.0	8.0	8.8	1.85E-04	2020000	17.1	6268			
WT08-FB	8	22	Coarse	5.0	8.0	9.4	1.86E-04	1774999	19.3	5538			
WT08-DB	8	22	Coarse	5.0	8.0	8.6	3.63E-04	126786	19.5	6197			
WT08-AB	8	22	Coarse	5.0	8.0	7.3	3.63E-04	94166	18.3	7188			
WT08-CB	8	22	Coarse	5.0	8.0	9.3	3.76E-04	29582	22.2	6013	Slope	Intercept	R^2
				average		*8.4*			*19.2*	*6290*	-5.4578	1.25E-14	0.9166
WT09-BT	9	14	Fine-Plus	6.1	4.0	3.1	1.99E-04	5201449	23.5	6356			
WT09-CT	9	14	Fine-Plus	6.1	4.0	3.5	1.98E-04	3547924	22.6	6269			
WT09-FB	9	14	Fine-Plus	6.1	4.0	2.1	1.99E-04	3402782	25.4	6135			
WT09-BB	9	14	Fine-Plus	6.1	4.0	1.9	4.01E-04	146187	27.6	5789			
WT09-CB	9	14	Fine-Plus	6.1	4.0	2.4	3.98E-04	141553	24.4	6380			
WT09-EB	9	14	Fine-Plus	6.1	4.0	2.0	4.01E-04	120557	24.1	6640	Slope	Intercept	R^2
				average		*2.4*			*24.6*	*6262*	-4.8259	5.42E-12	0.9922

Table H.1., continued.

Specimen	Section	Mix	Gradation	Target AC	Target AV	UCB AV	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT10-KB	10	15	Fine-Plus	4.7	12.0	12.4	1.99E-04	479152	17.9	4638			
WT10-JB	10	15	Fine-Plus	4.7	12.0	13.7	1.99E-04	160543	18.1	4474			
WT10-GB	10	15	Fine-Plus	4.7	12.0	12.9	2.01E-04	134182	16.8	4226			
WT10-HB	10	15	Fine-Plus	4.7	12.0	11.5	4.00E-04	14367	19.3	4523			
WT10-LB	10	15	Fine-Plus	4.7	12.0	13.1	4.00E-04	6737	19.9	4218	Slope	Intercept	R^2
				average		*12.7*			*18.4*	*4416*	-4.4623	6.76E-12	0.9061
WT11-AB	11	16	Fine-Plus	5.4	8.0	6.9	2.00E-04	1510343	22.3	5460			
WT11-CB	11	16	Fine-Plus	5.4	8.0	6.5	1.99E-04	728637	21.7	5935			
WT11-EB	11	16	Fine-Plus	5.4	8.0	7.3	1.98E-04	456612	23.4	5381			
WT11-BB	11	16	Fine-Plus	5.4	8.0	6.7	4.00E-04	71561	23.9	5560			
WT11-DB	11	16	Fine-Plus	5.4	8.0	7.2	3.99E-04	33086	24.1	5513			
WT11-FB	11	16	Fine-Plus	5.4	8.0	6.6	4.00E-04	31497	23.6	5644	Slope	Intercept	R^2
				average		*6.9*			*23.2*	*5582*	-4.2045	2.17E-10	0.9144
WT12-CB	12	17	Fine-Plus	5.4	4.0	5.5	1.99E-04	1954591	21.3	6603			
WT12-BB	12	17	Fine-Plus	5.4	4.0	5.8	1.97E-04	1950901	21.7	6452			
WT12-FB	12	17	Fine-Plus	5.4	4.0	4.9	2.01E-04	749999	21.2	6472			
WT12-DB	12	17	Fine-Plus	5.4	4.0	5.1	3.99E-04	57875	21.8	6378			
WT12-AB	12	17	Fine-Plus	5.4	4.0	5.3	4.00E-04	44854	23.0	5922			
WT12-EB	12	17	Fine-Plus	5.4	4.0	5.6	4.01E-04	37368	22.4	6068	Slope	Intercept	R^2
				average		*5.4*			*21.9*	*6316*	-4.9219	8.63E-13	0.9662
WT13-CB	13	18	Fine-Plus	6.1	8.0	6.8	1.99E-04	2212757	27.3	4682			
WT13-BB	13	18	Fine-Plus	6.1	8.0	6.2	1.98E-04	1771490	27.4	4264			
WT13-AB	13	18	Fine-Plus	6.1	8.0	6.5	2.03E-04	974825	25.5	4790			
WT13-FB	13	18	Fine-Plus	6.1	8.0	6.2	3.82E-04	144416	28.2	4044			
WT13-EB	13	18	Fine-Plus	6.1	8.0	6.5	3.93E-04	112069	27.9	4079			
WT13-DB	13	18	Fine-Plus	6.1	8.0	6.8	3.96E-04	99999	26.8	4426	Slope	Intercept	R^2
				average		*6.5*			*27.2*	*4381*	-3.8842	6.73E-09	0.9697
WT14-DB	14	5	Fine	6.1	8.0	7.0	2.00E-04	2746741	26.1	4197			
WT14-CB	14	5	Fine	6.1	8.0	6.6	1.98E-04	2205142	26.1	4419			
WT14-BB	14	5	Fine	6.1	8.0	6.3	1.98E-04	1729116	25.4	4494			
WT14-EB	14	5	Fine	6.1	8.0	6.9	4.00E-04	107267	26.8	3898			
WT14-FB	14	5	Fine	6.1	8.0	6.6	4.04E-04	89011	27.0	4150	Slope	Intercept	R^2
				average		*6.7*			*26.3*	*4232*	-4.4077	1.06E-10	0.9879

Table H.1., continued.

Specimen	Section	Mix	Gradation	Target AC	Target AV	UCB AV	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT15-AB	15	6	Fine	5.4	8.0	7.4	1.48E-04	10745213	27.4	4081			
WT15-DB	15	6	Fine	5.4	8.0	7.6	1.96E-04	1329105	27.2	4117			
WT15-EB	15	6	Fine	5.4	8.0	7.7	1.98E-04	1180799	25.9	4648			
WT15-BB	15	6	Fine	5.4	8.0	7.4	2.98E-04	257485	28.6	4068			
WT15-FB	15	6	Fine	5.4	8.0	7.6	4.00E-04	65556	29.8	3772			
WT15-CB	15	6	Fine	5.4	8.0	7.5	4.52E-04	53330	29.6	3851	Slope	Intercept	R^2
				average		*7.5*			*28.1*	*4090*	-4.5258	2.97E-11	0.9721
WT16-FB	16	7	Fine	4.7	12.0	11.6	1.99E-04	1079316	25.3	3773			
WT16-AB	16	7	Fine	4.7	12.0	11.2	2.00E-04	694716	27.3	3505			
WT16-BB	16	7	Fine	4.7	12.0	11.5	1.98E-04	504443	26.2	3632			
WT16-DB	16	7	Fine	4.7	12.0	11.6	4.01E-04	34185	28.2	3129			
WT16-EB	16	7	Fine	4.7	12.0	11.4	4.01E-04	32552	25.9	3431	Slope	Intercept	R^2
				average		*11.5*			*26.6*	*3494*	-4.3867	4.2E-11	0.9734
WT17-AB	17	8	Fine	5.4	12.0	10.5	1.97E-04	1999999	24.9	3802			
WT17-BB	17	8	Fine	5.4	12.0	10.3	2.01E-04	1305955	25.0	3963			
WT17-DB	17	8	Fine	5.4	12.0	10.8	2.01E-04	1017455	25.3	3912			
WT17-EB	17	8	Fine	5.4	12.0	10.4	3.98E-04	55658	24.9	3794			
WT17-CB	17	8	Fine	5.4	12.0	10.6	4.02E-04	49949	26.5	3745			
WT17-FB	17	8	Fine	5.4	12.0	10.4	4.01E-04	45164	26.0	3641	Slope	Intercept	R^2
				average		*10.5*			*25.4*	*3810*	-4.7911	2.63E-12	0.9892
WT18-BB	18	9	Fine	6.1	4.0	3.7	1.99E-04	2845417	22.3	6530			
WT18-EB	18	9	Fine	6.1	4.0	4.3	2.02E-04	2739498	24.4	5756			
WT18-DB	18	9	Fine	6.1	4.0	4.1	2.02E-04	2315129	23.8	5977			
WT18-AB	18	9	Fine	6.1	4.0	4.0	4.04E-04	189168	25.4	5558			
WT18-FB	18	9	Fine	6.1	4.0	4.1	4.00E-04	133412	24.2	5760			
WT18-CB	18	9	Fine	6.1	4.0	4.1	3.97E-04	115835	24.4	5766	Slope	Intercept	R^2
				average		*4.0*			*24.1*	*5891*	-4.2186	6.65E-10	0.9857
WT19-FB	19	10	Fine-Plus	5.4	8.0	7.0	1.97E-04	2312885	26.5	4144			
WT19-CB	19	10	Fine-Plus	5.4	8.0	6.7	1.97E-04	2296949	25.8	4410			
WT19-AT	19	10	Fine-Plus	5.4	8.0	7.1	2.00E-04	2242245	22.5	4902			
WT19-EB	19	10	Fine-Plus	5.4	8.0	7.5	4.02E-04	89074	28.1	3987			
WT19-AB	19	10	Fine-Plus	5.4	8.0	7.2	4.04E-04	63069	27.0	4416			
WT19-BT	19	10	Fine-Plus	5.4	8.0	7.6	4.00E-04	34103	24.5	4308	Slope	Intercept	R^2
				average		*7.2*			*25.7*	*4361*	-5.1901	1.37E-13	0.9756

Table H.1., continued.

Specimen	Section	Mix	Gradation	Target AC	Target AV	UCB AV	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT20-FB	20	11	Fine-Plus	5.4	12.0	8.1	1.99E-04	3312789	25.0	4397			
WT20-BB	20	11	Fine-Plus	5.4	12.0	9.4	1.98E-04	2356508	24.3	4020			
WT20-AB	20	11	Fine-Plus	5.4	12.0	9.0	2.01E-04	1340813	25.0	3872			
WT20-CB	20	11	Fine-Plus	5.4	12.0	8.8	4.03E-04	57544	26.0	3883			
WT20-DB	20	11	Fine-Plus	5.4	12.0	8.6	3.97E-04	37528	24.5	3970			
WT20-EB	20	11	Fine-Plus	5.4	12.0	9.0	4.00E-04	35055	26.3	3627	Slope	Intercept	R^2
				average		*8.8*			*25.2*	*3962*	-5.6637	2.41E-15	0.9773
WT21-ET	21	12	Fine-Plus	6.1	4.0	4.1	1.99E-04	4869664	24.0	5776			
WT21-EB	21	12	Fine-Plus	6.1	4.0	3.0	1.99E-04	2958772	26.4	5932			
WT21-FT	21	12	Fine-Plus	6.1	4.0	3.1	2.00E-04	2257739	22.9	6599			
WT21-AB	21	12	Fine-Plus	6.1	4.0	3.3	3.98E-04	288812	28.8	5389			
WT21-BB	21	12	Fine-Plus	6.1	4.0	2.9	3.98E-04	170432	28.6	5510			
WT21-CB	21	12	Fine-Plus	6.1	4.0	2.8	3.99E-04	149443	28.7	5468	Slope	Intercept	R^2
				average		*6.2*			*25.8*	*4800*	-4.0449	3.44E-09	0.9570
WT22-BB	22	13	Fine-Plus	4.7	8.0	8.1	1.99E-04	1261168	22.3	5421			
WT22-CB	22	13	Fine-Plus	4.7	8.0	8.4	1.99E-04	1150030	22.6	5337			
WT22-EB	22	13	Fine-Plus	4.7	8.0	7.9	1.99E-04	649999	21.8	5480			
WT22-FB	22	13	Fine-Plus	4.7	8.0	8.2	4.00E-04	34778	24.2	4750			
WT22-AB	22	13	Fine-Plus	4.7	8.0	8.0	4.00E-04	27130	23.7	5148			
WT22-DB	22	13	Fine-Plus	4.7	8.0	8.1	3.99E-04	23273	23.9	5099	Slope	Intercept	R^2
				average		*8.1*			*23.1*	*5206*	-5.0918	1.4E-13	0.9822
WT23-FB	23	23	Coarse	5.7	4.0	7.0	1.99E-04	3495733	21.2	6673			
WT23-DB	23	23	Coarse	5.7	4.0	6.2	1.99E-04	2939924	21.6	6873			
WT23-CB	23	23	Coarse	5.7	4.0	7.1	1.99E-04	1804173	20.3	6703			
WT23-EB	23	23	Coarse	5.7	4.0	6.2	3.97E-04	143012	22.3	6543			
WT23-AB	23	23	Coarse	5.7	4.0	6.6	3.98E-04	121915	22.3	6792			
WT23-BB	23	23	Coarse	5.7	4.0	6.7	3.98E-04	105560	22.6	6351	Slope	Intercept	R^2
				average		*6.6*			*21.7*	*6656*	-4.4387	9.88E-11	0.9807
WT24-BB	24	24	Coarse	5.7	8.0	9.1	1.99E-04	5312952	18.9	5570			
WT24-CB	24	24	Coarse	5.7	8.0	8.9	1.99E-04	3295240	22.5	4798			
WT24-FB	24	24	Coarse	5.7	8.0	8.9	2.03E-04	2807182	22.5	4791			
WT24-EB	24	24	Coarse	5.7	8.0	9.5	4.00E-04	83453	22.5	4928			
WT24-DB	24	24	Coarse	5.7	8.0	9.1	3.99E-04	62036	21.6	5112			
WT24-AB	24	24	Coarse	5.7	8.0	9.9	3.99E-04	60607	23.3	4673	Slope	Intercept	R^2
				average		*9.2*			*21.9*	*4979*	-5.778	1.56E-15	0.9900

Table H.1., continued.

Specimen	Section	Mix	Gradation	Target AC	Target AV	UCB AV	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT25-FB	25	25	Coarse	6.4	4.0	4.5	2.00E-04	5474962	26.2	5298			
WT25-EB	25	25	Coarse	6.4	4.0	4.1	2.00E-04	5078448	25.6	5424			
WT25-BB	25	25	Coarse	6.4	4.0	5.0	1.99E-04	5002759	22.7	6091			
WT25-DB	25	25	Coarse	6.4	4.0	5.0	3.97E-04	172232	21.8	5125			
WT25-AB	25	25	Coarse	6.4	4.0	4.5	3.98E-04	154517	23.7	6085	Slope	Intercept	R^2
				average		*4.6*			*24.0*	*5605*	-5.0238	1.34E-12	0.9991
WT26-BB	26	26	Coarse	5.0	12.0	13.0	1.86E-04	2452992	20.1	4301			
WT26-AB	26	26	Coarse	5.0	12.0	12.4	1.81E-04	1381976	19.0	4577			
WT26-FB	26	26	Coarse	5.0	12.0	13.3	1.85E-04	1050000	19.0	4323			
WT26-DB	26	26	Coarse	5.0	12.0	12.6	3.64E-04	52500	21.5	4231			
WT26-CB	26	26	Coarse	5.0	12.0	13.1	3.68E-04	48999	19.7	4570			
WT26-EB	26	26	Coarse	5.0	12.0	13.0	3.65E-04	26071	19.6	4385	Slope	Intercept	R^2
				average		*12.9*			*19.8*	*4398*	-5.2786	2.93E-14	0.9638

(1 psi = 6.9 kPa)

Table H.2. Original sections temperature study.

UC-Berkeley Pavement Research Program
WesTrack Temperature Susceptibility
Beams taken from top lift
November-18-1997
Italicized specimen denotes beams from bottom lift tested at standard 20C

Specimen	Mix-Type	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT23-BT	Coarse	6.0	3.6	5.1	0.000197	1409614	8.8	12312			
WT23-CT	Coarse	5.5	3.5	5.2	0.000297	645455	9.2	11868			
WT24-BT	Coarse	7.6	5.0	5.2	0.000397	176290	8.5	9171	*Slope*	*Intercept*	*R^2*
Average		*6.4*	*4.0*	*5.2*			*8.8*	*11117*	*-2.9009*	*2.8359E-05*	*0.9446*
Specimen	Mix-Type	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT24-FT	Coarse	6.6	5.0	19.6	0.000198	3047948	20.7	5693			
WT23-DT	Coarse	7.1	3.6	20.1	0.000199	2166426	20.1	6686			
WT05-CT	Coarse	7.5	5.2	20.0	0.000399	195440	22.7	5336			
WT23-AT	Coarse	5.5	3.4	20.0	0.000397	151923	21.8	6902			
WT23-FB	*Coarse*	*7.0*	*4.8*	*20.0*	*0.000199*	*3495733*	*21.2*	*6673*			
WT23-DB	*Coarse*	*6.2*	*4.6*	*20.0*	*0.000199*	*2939924*	*21.6*	*6873*			
WT23-CB	*Coarse*	*7.1*	*5.0*	*20.0*	*0.000199*	*1804173*	*20.3*	*6703*			
WT23-EB	*Coarse*	*6.2*	*4.6*	*20.0*	*0.000397*	*143012*	*22.3*	*6543*			
WT23-AB	*Coarse*	*6.6*	*4.8*	*20.0*	*0.000398*	*121915*	*22.3*	*6792*			
WT23-BB	*Coarse*	*6.7*	*5.1*	*20.0*	*0.000398*	*105560*	*22.6*	*6351*	*Slope*	*Intercept*	*R^2*
Average		*6.7*	*4.6*	*20.0*			*21.6*	*6455*	*-4.2118*	*6.6970E-10*	*0.9766*
Specimen	Mix-Type	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT23-FT	Coarse	6.0	3.6	30.2	0.000400	182077	38.5	2970			
WT23-ET	Coarse	7.2	3.8	29.8	0.000400	154032	40.3	2286			
WT05-BT	Coarse	7.0	4.5	30.0	0.000806	17608	44.1	2185			
WT05-FT	Coarse	7.5	4.6	29.9	0.000797	14160	42.8	2079	*Slope*	*Intercept*	*R^2*
Average		*6.9*	*4.1*	*30.0*			*41.4*	*2380*	*-3.3935*	*4.9228E-07*	*0.9916*

Table H.2., continued.

UC-Berkeley Pavement Research Program
WesTrack Temperature Susceptibility
Beams taken from top lift
November-18-1997
Italicized specimen denotes beams from bottom lift tested at standard 20C

Specimen	Mix-Type	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT01-CT	Fine	11.8	8.9	5.1	0.000178	7495425	9.2	7609			
WT01-ET	Fine	11.0	9.0	5.1	0.000198	738687	9.3	9100			
WT15-BT	Fine	11.1	8.5	5.1	0.000299	41122	10.0	6806			
WT15-FT	Fine	10.6	8.3	5.2	0.000397	8784	10.4	7252	*Slope*	*Intercept*	*R^2*
Average		*11.1*	*8.7*	*5.1*			*9.7*	*7692*	*-7.8904*	*9.1802E-24*	*0.9493*

Specimen	Mix-Type	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT17-FT	Fine	12.7	11.4	19.7	0.000179	1846222	23.6	3500			
WT15-DT	Fine	10.5	8.0	21.6	0.000199	204774	22.9	4125			
WT17-ET	Fine	12.8	11.6	20.1	0.000400	66914	24.4	3515			
WT15-AT	Fine	10.9	8.0	21.0	0.000300	27555	24.1	3505			
WT15-AB	*Fine*	*7.4*	*6.2*	*20.0*	*0.000148*	*10745213*	*27.4*	*4081*			
WT15-DB	*Fine*	*7.6*	*6.3*	*20.0*	*0.000196*	*1329105*	*27.2*	*4117*			
WT15-EB	*Fine*	*7.7*	*6.6*	*20.0*	*0.000198*	*1180799*	*25.9*	*4648*			
WT15-BB	*Fine*	*7.4*	*6.3*	*20.0*	*0.000298*	*257485*	*28.6*	*4068*			
WT15-FB	*Fine*	*7.6*	*6.4*	*20.0*	*0.000400*	*65556*	*29.8*	*3772*			
WT15-CB	*Fine*	*7.5*	*6.6*	*20.0*	*0.000452*	*53330*	*29.6*	*3851*			
WT01-FB	*Fine*	*8.9*	*7.0*	*20.0*	*0.000197*	*1693277*	*30.8*	*3085*			
WT01-AB	*Fine*	*8.8*	*6.9*	*20.0*	*0.000198*	*1361835*	*28.6*	*3259*			
WT01-BB	*Fine*	*9.0*	*7.2*	*20.0*	*0.000398*	*82500*	*32.0*	*2892*			
WT01-CB	*Fine*	*8.8*	*7.5*	*20.0*	*0.000402*	*63379*	*30.8*	*3290*			
WT01-EB	*Fine*	*8.6*	*6.9*	*20.0*	*0.000401*	*56018*	*30.5*	*3444*	*Slope*	*Intercept*	*R^2*
Average		*9.1*		*20.2*			*27.7*	*3677*	*-4.2414*	*2.1613E-10*	*0.8180*

Specimen	Mix-Type	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT17-CT	Fine	12.5	11.3	30.1	0.000178	5212204	38.8	1536			
WT15-CT	Fine	11.7	7.6	30.0	0.000201	376450	38.7	1530			
WT01-DT	Fine	11.1	8.3	30.0	0.000397	91839	40.8	1855			
WT15-ET	Fine	10.8	8.1	30.1	0.000299	82025	38.5	1866	*Slope*	*Intercept*	*R^2*
Average		*11.5*	*8.8*	*30.1*			*39.2*	*1697*	*-4.4543*	*3.4586E-11*	*0.7245*

Table H.2., continued.

UC-Berkeley Pavement Research Program
WesTrack Temperature Susceptibility
Beams taken from top lift
November-18-1997
Italicized specimen denotes beams from bottom lift tested at standard 20C

Specimen	Mix-Type	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT12-ET	Fine-Plus	5.0	3.2	5.1	0.000196	3872422	7.9	13766			
WT19-ET	Fine-Plus	8.4	6.2	5.1	0.000178	923182	8.9	9232			
WT19-FT	Fine-Plus	9.3	7.0	5.1	0.000296	144082	9.0	9633			
WT21-AT	Fine-Plus	8.1	4.0	5.1	0.000400	25615	11.2	5551	*Slope*	*Intercept*	*R^2*
Average		*7.7*	*5.1*	*5.1*			*9.3*	*9546*	*-5.4069*	*1.2219E-14*	*0.8639*
Specimen	Mix-Type	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT12-FT	Fine-Plus	4.5	2.9	19.8	0.000198	3308278	19.9	7769			
WT11-ET	Fine-Plus	8.8	7.0	19.7	0.000178	1191716	22.2	5245			
WT12-DT	Fine-Plus	5.3	3.3	20.2	0.000298	194603	20.7	6511			
WT21-BT	Fine-Plus	6.5	3.5	19.5	0.000401	25559	24.4	4424			
WT11-AB	*Fine-Plus*	*6.9*	*5.3*	*20.0*	*0.000200*	*1510343*	*22.3*	*5460*			
WT11-CB	*Fine-Plus*	*6.5*	*5.0*	*20.0*	*0.000199*	*728637*	*21.7*	*5935*			
WT11-EB	*Fine-Plus*	*7.3*	*5.3*	*20.0*	*0.000198*	*456612*	*23.4*	*5381*			
WT11-BB	*Fine-Plus*	*6.7*	*4.7*	*20.0*	*0.000400*	*71561*	*23.9*	*5560*			
WT11-DB	*Fine-Plus*	*7.2*	*4.9*	*20.0*	*0.000399*	*33086*	*24.1*	*5513*			
WT11-FB	*Fine-Plus*	*6.6*	*5*	*20.0*	*0.0004*	*31497*	*23.6*	*5644*	*Slope*	*Intercept*	*R^2*
Average		*6.6*	*4.7*	*19.9*			*22.6*	*5744*	*-4.6976*	*4.2470E-12*	*0.8931*
Specimen	Mix-Type	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT12-AT	Fine-Plus	7.5	3.9	30.1	0.000199	925205	37.2	2410			
WT19-CT	Fine-Plus	9.4	6.3	30.2	0.000181	820324	37.5	1874			
WT12-CT	Fine-Plus	7.6	4.1	30.1	0.000300	174999	40.5	2037			
WT12-BT	Fine-Plus	8.9	4.0	30.1	0.000404	49999	40.4	1741	*Slope*	*Intercept*	*R^2*
Average		*8.4*	*4.6*	*30.1*			*38.9*	*2016*	*-3.6903*	*1.6096E-08*	*0.9789*

(°F = 1.8 °C + 32; 1 psi = 6.9 kPa)

Table H.3. Frequency effects study.

University of California, Berkeley
WesTrack Beams Top Lift
3/5/99

WT04-CT: Fine Mix

Frequency	Ampl._strain	Complex Modulus Mpa	Phase Angle
15.15	0.000404	4383.2	22.2
10.00	0.000397	3963.4	23.4
5.00	0.000400	3323.3	26.0
2.00	0.000396	2556.9	29.6
1.00	0.000399	2027.9	32.8
0.50	0.000397	1617.3	35.5
0.20	0.000397	1169.9	38.9
0.10	0.000398	902.7	41.4
0.05	0.000397	685.0	43.3
0.01	0.000396	343.5	46.7

WT21CT: Fine Plus Mix

15.15	0.000391	5688.0	22.8
10.00	0.000393	5130.4	24.5
5.00	0.000403	4257.0	27.6
2.00	0.000391	3196.3	32.2
1.00	0.000399	2482.9	36.2
0.50	0.000397	1902.6	39.6
0.20	0.000396	1299.8	43.7
0.10	0.000396	952.8	45.9
0.05	0.000396	678.4	48.3
0.01	0.000396	296.0	51.1

WT25AT: Coarse Mix

15.15	0.000393	5670.3	22.3
10.00	0.000392	5172.0	24.0
5.00	0.000403	4276.9	27.4
2.00	0.000392	3229.5	32.0
1.00	0.000400	2490.4	36.3
0.50	0.000397	1903.8	39.8
0.20	0.000397	1286.6	44.2
0.10	0.000397	938.2	46.9
0.05	0.000397	656.7	49.7
0.01	0.000397	281.6	52.6

(1 psi = 6.9 kPa)

Table H.4. Replacement sections, FMFC.

UC-Berkeley Pavement Research Program
WesTrack Fatigue Beam Test
Replacement time zero Beams
13-Jul-99

Test Temperature=20 C

	Specimen	AVwp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
	WT35GB	9.5	20	2.01E-04	14029151	25.7	3597			
	WT35CB	8.3	20	1.98E-04	9313747	25.5	3699			
	WT35EB	8.8	20	2.00E-04	8805723	25.3	3658			
	WT35FB	8.4	20	4.03E-04	430458	26.4	3692			
	WT35DB	9.4	20	4.06E-04	319481	27.3	3359			
	WT35AB	8.8	20	4.03E-04	233236	26.5	3684	Slope	Intercept	R^2
35	*Average*	***8.9***				***26.1***	***3615***	***-4.952400354***	***4.97351E-12***	***0.9814967***

	Specimen	AVwp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
	WT36CB	12.0	20	2.00E-04	6453237	24.7	3031			
	WT36BB	13.5	20	2.01E-04	5370190	24.4	3179			
	WT36GB	14.3	20	2.01E-04	4565347	24.7	2807			
	WT36AB	13.3	20	3.97E-04	379425	26.0	2706			
	WT36DB	12.9	20	4.00E-04	314099	26.0	2855			
	WT36EB	13.8	20	3.98E-04	276801	26.2	2346	***Slope***	***Intercept***	***R^2***
36	*Average*	***13.3***				***25.3***	***2821***	***-4.122218299***	***3.09976E-09***	***0.9917639***

	Specimen	AVwp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
	WT37BB	7.4	20	1.96E-04	32147488	25.3	4433			
	WT37DB	8.5	20	1.96E-04	12135678	24.9	4643			
	WT37GB	10.1	20	1.99E-04	7184540	24.7	3868			
	WT37AB	8.8	20	4.02E-04	508000	26.3	3490			
	WT37EB	8.1	20	3.95E-04	349328	26.3	4184			
	WT37CB	8.2	20	4.00E-04	319603	24.6	3911	***Slope***	***Intercept***	***R^2***
37	*Average*	***8.5***				***25.4***	***4088***	***-5.112808711***	***1.60213E-12***	***0.941801***

	Specimen	AVwp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
	WT38GB	11.2	20	1.99E-04	14150633	22.4	3803			
	WT38AB	9.3	20	1.99E-04	8842100	22.5	4369			
	WT38BB	10.5	20	1.97E-04	5878182	21.3	4865			
	WT38EB	9.6	20	3.95E-04	199964	22.4	4478			
	WT38FB	10.6	20	4.01E-04	193580	22.8	4115			
	WT38DB	10.7	20	4.01E-04	127130	22.4	3855	***Slope***	***Intercept***	***R^2***
38	*Average*	***10.3***				***22.3***	***4248***	***-5.677540058***	***8.57358E-15***	***0.977547***

	Specimen	AVwp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
	WT39EB	4.6	20	1.98E-04	13623527	26.1	4503			
	WT39CB	6.3	20	1.97E-04	9359641	26.4	4236			
	WT39AB	6.6	20	1.98E-04	9280584	26.8	3855			
	WT39GB	5.8	20	4.01E-04	286848	26.2	3946			
	WT39BB	6.3	20	4.04E-04	249032	27.0	3974			
	WT39DB	5.1	20	4.03E-04	236589	26.3	4277	***Slope***	***Intercept***	***R^2***
39	*Average*	***5.8***				***26.4***	***4132***	***-5.226280589***	***4.63266E-13***	***0.9943827***

Table H.4., continued.

Specimen	AVwp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT54AB	7.5	20	1.99E-04	7647832	25.2	3951			
WT54CB	9.8	20	2.00E-04	7596758	25.5	4124			
WT54DB	8.7	20	1.99E-04	7144247	25.3	3960			
WT54BB	7.5	20	3.94E-04	276280	26.7	4283			
WT54FB	9.1	20	4.03E-04	257033	24.9	3937			
WT54GB	9.4	20	3.99E-04	232813	24.4	4294	***Slope***	***Intercept***	***R^2***
54 *Average*	***8.7***				***25.3***	***4092***	***-4.871519356***	***7.01346E-12***	***0.999074***

Specimen	AVwp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT55AB	4.7	20	1.99E-04	16026392	27.7	4289			
WT55GB	2.8	20	1.99E-04	10652512	30.4	3848			
WT55CB	4.2	20	1.98E-04	7925942	28.4	4123			
WT55DB	2.9	20	3.99E-04	599722	29.1	3736			
WT55FB	3.8	20	3.98E-04	577790	30.4	3931			
WT55BB	4.5	20	3.99E-04	539843	30.2	3529	***Slope***	***Intercept***	***R^2***
55 *Average*	***3.8***				***29.4***	***3909***	***-4.250532427***	***2.03457E-09***	***0.9798675***

Specimen	AVwp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WT56GB	15.5	20	1.99E-04	14869092	22.1	2767			
WT56FB	15.6	20	1.96E-04	13812013	20.3	3409			
WT56BB	14.0	20	1.99E-04	11640007	20.3	3176			
WT56DB	14.2	20	3.96E-04	174999	22.3	2719			
WT56EB	15.0	20	4.03E-04	172063	21.0	2788			
WT56CB	14.5	20	3.99E-04	164675	21.3	2962	***Slope***	***Intercept***	***R^2***
56 *Average*	***14.8***				***21.2***	***2970***	***-6.216022481***	***1.27588E-16***	***0.9986703***

(°F = 1.8 °C + 32; 1 psi = 6.9 kPa)

Table H.5. LMLC specimens.

UC-Berkeley Pavement Research Program
WesTrack Lab Mix/ Lab Compacted Fatigue Beam Test
Coarse medium and Fine medium Beams
3-Feb-00

Coarse Medium Temperature Susceptibility Test

Test Temperature = 5 °C

Specimen	AVwp	Avnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTCM57-3AA	8.7	6.2	5	1.99E-04	4199446	8.9	13018			
WTCM57-8CA	7.9	6.0	5	1.99E-04	3630781	8.9	12567			
WTCM57-12CA	8.2	6.1	5	3.99E-04	63473	9.4	12076			
WTCM57-2CB	7.7	5.7	5	3.99E-04	51908	8.7	12767	***Slope***	***Intercept***	***R^2***
Average	***8.1***	***6.0***				***9.0***	***12607***	***-6.071339223***	***1.32042E-16***	***0.9983501***

Test Temperature = 20 °C

Specimen	AVwp	Avnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTCM57-12CB	7.9	5.9	20	1.98E-04	4996639	23.2	5202			
WTCM57-20CA	8.5	6.1	20	1.98E-04	4102125	22.5	5771			
WTCM57-14CB	7.8	5.6	20	3.96E-04	123075	24.4	5517			
WTCM57-22CB	8.1	5.9	20	3.99E-04	122160	25.5	5221	***Slope***	***Intercept***	***R^2***
Average	***8.1***	***5.9***				***23.9***	***5428***	***-5.178001122***	***3.0195E-13***	***0.99847***

Test Temperature = 30 °C

Specimen	AVwp	Avnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTCM57-25AA	8.8	6.7	30	2.00E-04	14467692	39.9	2746			
WTCM57-10CB	7.9	5.6	30	2.02E-04	8852903	38.4	2905			
WTCM57-16CA	8.3	5.9	30	3.97E-04	524424	40.4	2590			
WTCM57-22CA	7.6	5.4	30	3.98E-04	444880	42.7	2444	***Slope***	***Intercept***	***R^2***
Average	***8.1***	***5.9***				***40.3***	***2671***	***-4.630527028***	***8.63641E-11***	***0.9890152***

Fine Medium Temperature Susceptibility Test

Test Temperature = 5 °C

Specimen	AVwp	Avnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTFM54-4AB	8.3	5.8	5	1.99E-04	1758811	8.2	11939			
WTFM54-1CA	8.7	6.4	5	1.99E-04	813040	17.0	9184			
WTFM54-6AA	8.0	6.2	5	3.99E-04	46541	12.0	10220			
WTFM54-3CB	7.7	6.2	5	3.99E-04	41750	11.1	11332	***Slope***	***Intercept***	***R^2***
Average	***8.2***	***6.2***				***12.1***	***10669***	***-4.744539604***	***3.29175E-12***	***0.972887***

Test Temperature = 20 °C

Specimen	AVwp	Avnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTFM54-5CB	7.8	6.0	20	2.01E-04	1005114	22.3	5342			
WTFM54-1CB	8.7	6.4	20	1.99E-04	699999	22.6	4905			
WTFM54-4AA	7.5	5.7	20	4.01E-04	92708	26.1	4744			
WTFM54-2AB	9.1	6.8	20	4.02E-04	65837	27.0	4004	***Slope***	***Intercept***	***R^2***
Average	***8.3***	***6.2***				***24.5***	***4749***	***-3.402782992***	***2.16949E-07***	***0.9767209***

Test Temperature = 30 °C

Specimen	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTFM54-3CA	8.0	5.8	30	2.00E-04	3399999	36.6	2745			
WTFM54-2AA	9.6	6.7	30	2.00E-04	2514857	38.4	2333			
WTFM57-4CB	8.2	6.3	30	4.00E-04	347105	40.3	2580			
WTFM54-5CA	7.7	6.0	30	3.96E-04	184006	37.7	2872	***Slope***	***Intercept***	***R^2***
Average	***8.4***	***6.2***				***38.2***	***2633***	***-3.551052803***	***2.13646E-07***	***0.9567149***

Table H.5., continued.

Coarse High
Test Temperature = 20 °C

Specimen	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTCH57-1CA	10.8	6.3	20	3.05E-04	632624	31.1	3105			
WTCH57-1CB	9.6	5.8	20	3.01E-04	218936	25.8	4547			
WTCH57-2AA	9.3	5.6	20	5.08E-04	84999	30.8	3730			
WTCH57-2AB	10.3	5.8	20	5.00E-04	52601	27.2	4163	***Slope***	***Intercept***	***R^2***
Average	***10.0***	***5.9***				***28.7***	***3886***	***-3.329173423***	***7.11042E-07***	***0.7922775***

Coarse Low
Test Temperature = 20 °C

Specimen	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTCL57-2AA	7.7	5.5	20	2.98E-04	931499	25.1	5295			
WTCL57-1CB	7.7	5.8	20	3.00E-04	712167	22.6	5925			
WTCL57-1CA	8.0	5.8	20	4.97E-04	109928	27.8	4703			
WTCL57-2AB	7.3	5.7	20	4.97E-04	84038	26.4	5051	***Slope***	***Intercept***	***R^2***
Average	***7.7***	***5.7***				***25.5***	***5244***	***-4.208559699***	***1.19913E-09***	***0.9860002***

Fine High
Test Temperature = 20 °C

Specimen	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTFH54-2AB	8.5	6.5	20	2.99E-04	91724	19.3	6370			
WTFH54-2AA	9.3	6.4	20	2.97E-04	58298	22.8	5338			
WTFH54-1CB	9.4	6.4	20	5.02E-04	19696	25.7	4537			
WTFH54-1CA	8.5	7.0	20	5.00E-04	8131	21.7	5678	***Slope***	***Intercept***	***R^2***
Average	***8.9***	***6.6***				***22.4***	***5481***	***-3.363902664***	***1.00519E-07***	***0.8553422***

Fine Low
Test Temperature = 20 °C

Specimen	AVwp	AVnp	Test Temp, °C	Mean Strain	Nf	Phase Angle	Stiffness (MPa)			
WTFL54-2AA	6.4	4.7	20	2.98E-04	719748	25.9	5152			
WTFL54-1CA	6.5	5.3	20	3.03E-04	487122	27.3	4855			
WTFL54-2AB	6.8	4.8	20	4.99E-04	49999	27.2	5152			
WTFL54-1CB	7.5	5.2	20	5.01E-04	35444	27.3	4796	***Slope***	***Intercept***	***R^2***
Average	***6.8***	***5.0***				***26.9***	***4989***	***-5.204240515***	***2.77677E-13***	***0.9861857***

APPENDIX I

ESTIMATES OF VARIABILITY IN FATIGUE USING WESTRACK DATA (*LEVEL 1A MODEL*) AND THICKNESS EFFECTS FROM CALTRANS DATA [AS DESCRIBED IN REFERENCE (*1*)]

Prepared by Charles Shin, Graduate Student Researcher

INTRODUCTION

In the WesTrack experiment, regression equations were established relating traffic repetitions (ESALs) to a specific level of cracking with air-void content (V_{air}) and asphalt content (P_{Wasp}) as discussed in Chapter 4. Thickness was not included as a variable since a uniform thickness of 150 mm (6 in.) was used for the AC layer of the structural pavement section. To include the effects of thickness in the *Level 1A* model, an analysis was performed in which data reported in Reference (*1*) for California experience were combined with the WesTrack data.

This Appendix describes the methodology used to combine the two sets of data to incorporate the effects of thickness variance on performance in a *Level 1A* type model.

PERFORMANCE MODEL

As discussed in Chapter 4, discrete choice analysis is an appropriate approach for performance modeling of crack initiation with the initiation mechanism represented by a Probit model. This model assumes a normal distribution of the variables and two such models were obtained for WesTrack, one for the *fine* gradation and the other for the *coarse*. So that a joint estimation technique (the combination of two Probit models) could be used, it was necessary to express the CAL/APT results (*1*) in this form.

THEORETICAL BACKGROUND

Cracking initiation is modeled as a discrete event:

$$y = \begin{cases} 1 \text{ if the pavement has cracked} \\ 0 \text{ if the pavement has not cracked} \end{cases}$$

Cracking is considered to be the result of a latent (unobserved) process. When the unobserved variable exceeds a threshold, cracking starts.

The two models to be combined are the WesTrack and CAL/APT models.

WesTrack Model (Field Model)

$$u_i^F = \beta' x_i^F + \alpha' w_i^F + \varepsilon_i$$

$$y_i^F = \begin{cases} 1 \text{ if } u_i^F \geq 0 \\ 0 \text{ if } u_i^F < 0 \end{cases} \quad i = 1, \ldots, N^F$$

where:

u_i = latent variable of facility *i*

ε_i = random component of the field latent variable for facility *i*

y_i = indicator variable for facility *i*

x_i, w_i = vectors of explanatory variables for facility *i* and

α, β = vectors of unknown parameters

For the WesTrack specific model, x_i are P_{Wasp} and V_{air}, and w_i could be an aggregate grading index, but it was not used in this analysis.

CAL/APT Model (Experimental Model)

$$u_i^E = \beta' x_i^E + \gamma' z_i^E + \nu_i$$

$$y_i^E = \begin{cases} 1 \text{ if } u_i^E \geq 0 \\ 0 \text{ if } u_i^E < 0 \end{cases} \quad i = 1, \ldots, N^E$$

where:

u_i = latent variable of facility i

ν_i= random component of the experimental latent variable for facility i

y_i = indicator variable for facility i

x_i, z_i = vectors of explanatory variables for facility i and

α , γ = vectors of unknown parameters

For the CAL/APT model, x_i are P_{Wasp} and V_{air}, and z_i is the thickness variable (t_{AC}).

For the estimation, ε and ν are assumed to be independent and distributed normally with zero means for different facilities and with variances σ_ε and σ_ν, respectively.

It is expected that the variance of ε is greater than the variance of ν. Thus:

$$\text{Var}(\varepsilon) = \mu\ \text{Var}(\nu) \qquad \text{where } \mu \geq 1$$

Therefore,

$$P\left(y_i^F = 1\right) = P\left(u_i^F > 0\right) = P\left(\varepsilon_i > -\left(\beta' x_i^F + \alpha' w_i^F\right)\right) = \Phi\left(\beta' x_i^F + \alpha' w_i^F\right)$$

Note that if σ_ε is set equal to 1, then $1 = \mu\sigma_\nu$. Thus, $\sigma_\nu = 1/\mu$.

Therefore,

$$\begin{aligned} P\left(y_i^E = 1\right) &= P\left(u_i^E > 0\right) = P\left(\nu_i > -\left(\beta' x_i^E + \gamma' z_i^E\right)\right) \\ &= P\left(\frac{\nu}{(1/\mu)} > \frac{\left(\beta' x_i^E + \gamma' z_i^E\right)}{(1/\mu)}\right) \\ &= \Phi\left(\mu\left(\beta' x_i^E + \gamma' z_i^E\right)\right) \end{aligned}$$

Limitation

For this type of study, the best estimate is obtained from one reliable source with complete data including a range of P_{Wasp}, V_{air}, and t_{AC}. Since this was not the case here, it is necessary to use the technique described. With this method, when two sources have similar environments other than explanatory variables, better results are expected because the effects of environmental factors can not be captured in the estimation process. WesTrack and the

CAL/APT data sources have different environments, and that is a limitation of this study. Moreover, if one source is synthetic, then error levels increase, resulting in a significant decrease in precision. Nonetheless, this approach is the best way to work with these limited data sources.

Estimation Procedures

The unknown parameters are β, α, γ,and μ. The unknown parameters could be jointly estimated using both data sources by maximizing the joint log-likelihood function, but this is a very complex process. A sequential estimation procedure, consistent but less efficient, was used to establish the parameters. The steps are as follows:

Step 1

Estimate the WesTrack Probit model. This yields $\hat{\beta}$ and $\hat{\alpha}$. Define $y_i = \beta' x_i^E$ and calculate the fitted value $\hat{y}_i^E = \hat{\beta}' x_i^E$ for the CAL/APT observations.

Step 2

Estimate the following CAL/APT model with the fitted value $\hat{y}_i^E$ included as a variable to obtain $\hat{\lambda}$ and $\hat{\mu\gamma}$:

$$\hat{\mu}_i^E = \lambda \hat{y}_i^E + \mu\gamma' z_i^E + \nu_i = \lambda\hat{\beta}' x_i^E + \mu\gamma' z_i^E + \nu_i$$

Thus λ = μ. Calculate $\hat{\mu} = \hat{\lambda}$ and $\hat{\gamma} = \frac{\hat{\mu\gamma}}{\hat{\lambda}}$.

Step 3

Multiply x^E and z^E by $\hat{\mu}$ to obtain a modified CAL/APT data set. Pool the WesTrack data and the modified CAL/APT data and then estimate the two models jointly to obtain best estimates, $\hat{\hat{\alpha}}$, $\hat{\hat{\beta}}$, and $\hat{\hat{\gamma}}$. Note: 150 mm (6 in.) was used as the WesTrack asphalt thickness and 5.5% for the P_{200} in the mixes.

Estimation Results

The dependent variable is an indicator variable, INDCR; if there is no crack, then the value of INDCR is zero; if a crack is observed then the value of INDCR is one. Φ represents the cumulative density function of normal distribution.

Three variables, P_{Wasp}, V_{air}, and t_{AC}, were considered. Gradation was discarded since its effect on performance was statistically unclear without further research.

Ten percent of crack probability is considered best, but 5% and 2% are also shown.

Three different estimation methods were tried:

1. **Use of a linear relation for each variable.** From a physical point of view, it may not be representative; nevertheless, it does provide expected trends. Mechanistically, ln(ESALs) is more natural. This was also tried, but was not satisfactory.

   - 10% criteria (μ=0.0012)

   Prob (INDCR=1) = Φ[-0.220+0.16E-5*ESALs-2.74*P_{Wasp}+1.03*V_{air}-0.697*t_{AC}]
   (0.043)[29] (0.000) (0.000) (0.017) (0.093)

[29] The items in parentheses below the equations are p-values. When the value is less than 0.05, it is considered significant.

- 5% criteria (μ=0.0015)

Prob (INDCR=1) = Φ[-0.422+0.35E-5*ESALs-0.439*P_{Wasp} +0.513*V_{air} -0.770*t_{AC}]
(0.043) (0.000) (0.050) (0.000) (0.003)

- 2% criteria (μ=0.0022)

Prob (INDCR=1) = Φ[-0.221+0.92E-6*ESALs-0.622*P_{Wasp} +0.478*V_{air} -0.810* t_{AC}]
(0.040) (0.000) (0.002) (0.000) (0.000)

The signs and p-values show that these specifications are statistically significant and it is the author's opinion that this model captures trends well. However, in addition to the problems referred to above, it will be observed that the μ values are very low (i.e., the μ values were expected to be greater than 1). Because the CAL/APT data are synthetic, the values could be small. Generally, these models predict crack initiation probability well using average values for the parameters. Accordingly, these models are recommended at this stage.

2. **Use of linear relations to P_{Wasp}, V_{air}, and t_{AC}, each divided by ln(ESALs).** In this instance, the model for the *coarse* mix was not significant.[30]

- 10% criteria (μ=0.202)

Prob (INDCR=1) = Φ[0.897 - 12.5*P_{Wasp}/ln(ESALs) + 6.22*V_{air}/ln(ESALs) -
(0.000) (0.000) (0.000)

5.70*t_{AC}/ln(ESALs)]
(0.017)

- 5% criteria (μ=0.0015)

[30] Likely reasons are that the CAL/APT gradations were comparable to the WesTrack *fine* mixes, and that the less accurate synthetic CAL/APT data played a more dominant role.

$$\text{Prob (INDCR=1)} = \Phi[1.27 - \underset{(0.000)}{9.45}*P_{Wasp}/\ln(\text{ESALs}) + \underset{(0.000)}{5.49}*V_{air}/\ln(\text{ESALs}) - \underset{(0.000)}{7.02}*t_{AC}/\ln(\text{ESALs})]$$

- 2% criteria (μ=0.0022)

$$\text{Prob (INDCR=1)} = \Phi[1.12 - \underset{(0.000)}{6.36}*P_{Wasp}/\ln(\text{ESALs}) + \underset{(0.000)}{3.82}*V_{air}/\ln(\text{ESALs}) - \underset{(0.017)}{5.58}*t_{AC}/\ln(\text{ESALs})]$$

The signs and p-values show that these specifications are statistically significant. However, predictions using average values were poor.

3. **Use of linear relation to ESALs divided by the variables.** Model for *coarse* mix was not significant.

- 10% criteria (μ=0.03)

$$\text{Prob (INDCR=1)} = \Phi[-1.24 + \underset{(0.000)}{0.0090}*\ln(\text{ESALs})/P_{Wasp} - \underset{(0.145)}{0.0024}*\ln(\text{ESALs})/V_{air} + \underset{(0.006)}{0.013}*\ln(\text{ESALs})/t_{AC}]$$

- 2% criteria (μ=0.23)

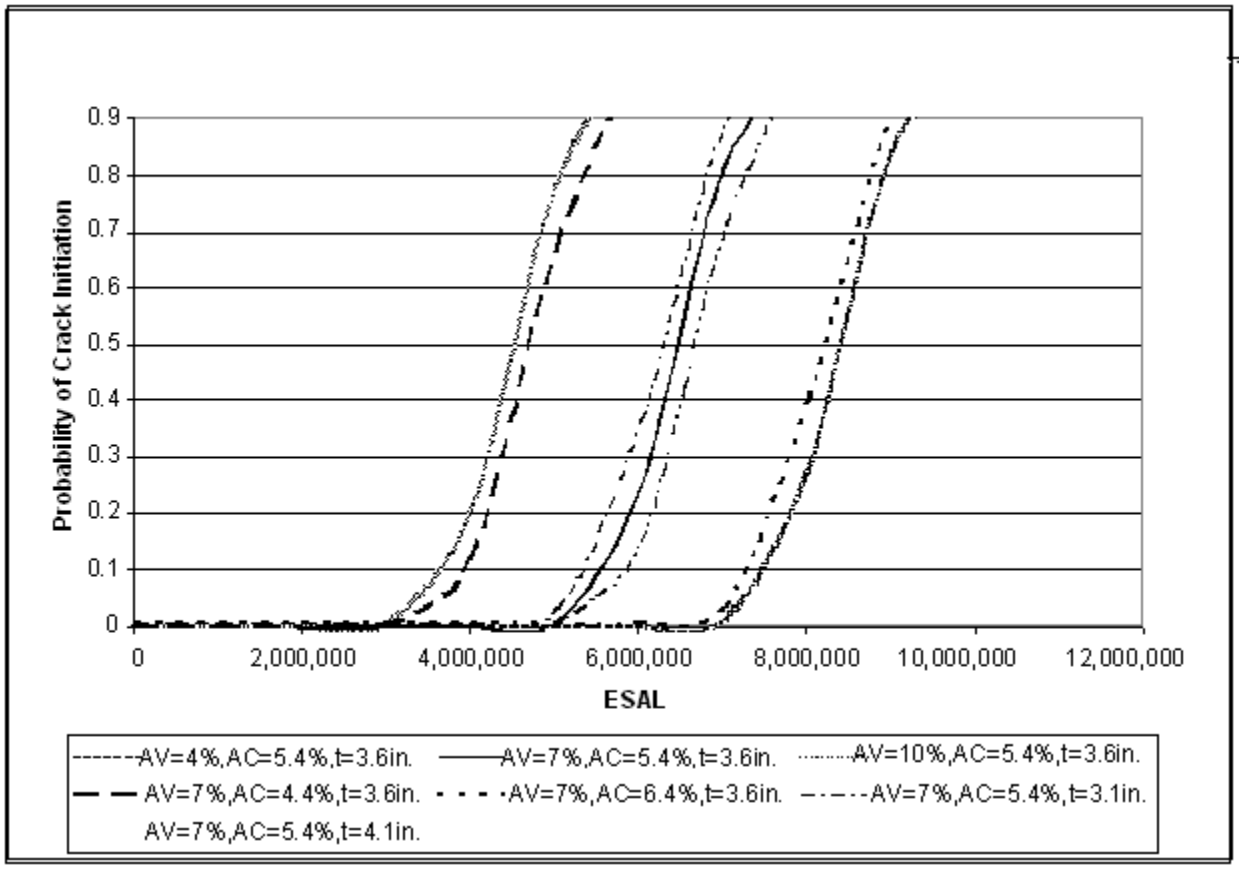
$$\text{Prob (INDCR=1)} = \Phi[-1.40 + \underset{(0.000)}{0.091}*\ln(\text{ESALs})/P_{Wasp} - \underset{(0.001)}{0.033}*\ln(\text{ESALs})/V_{air} + \underset{(0.007)}{0.079}*\ln(\text{ESALs})/t_{AC}]$$

The 5% model has not been included. However, as can be seen, the model for the 2% criterion has correct signs and significant p-values.

Recommended Model

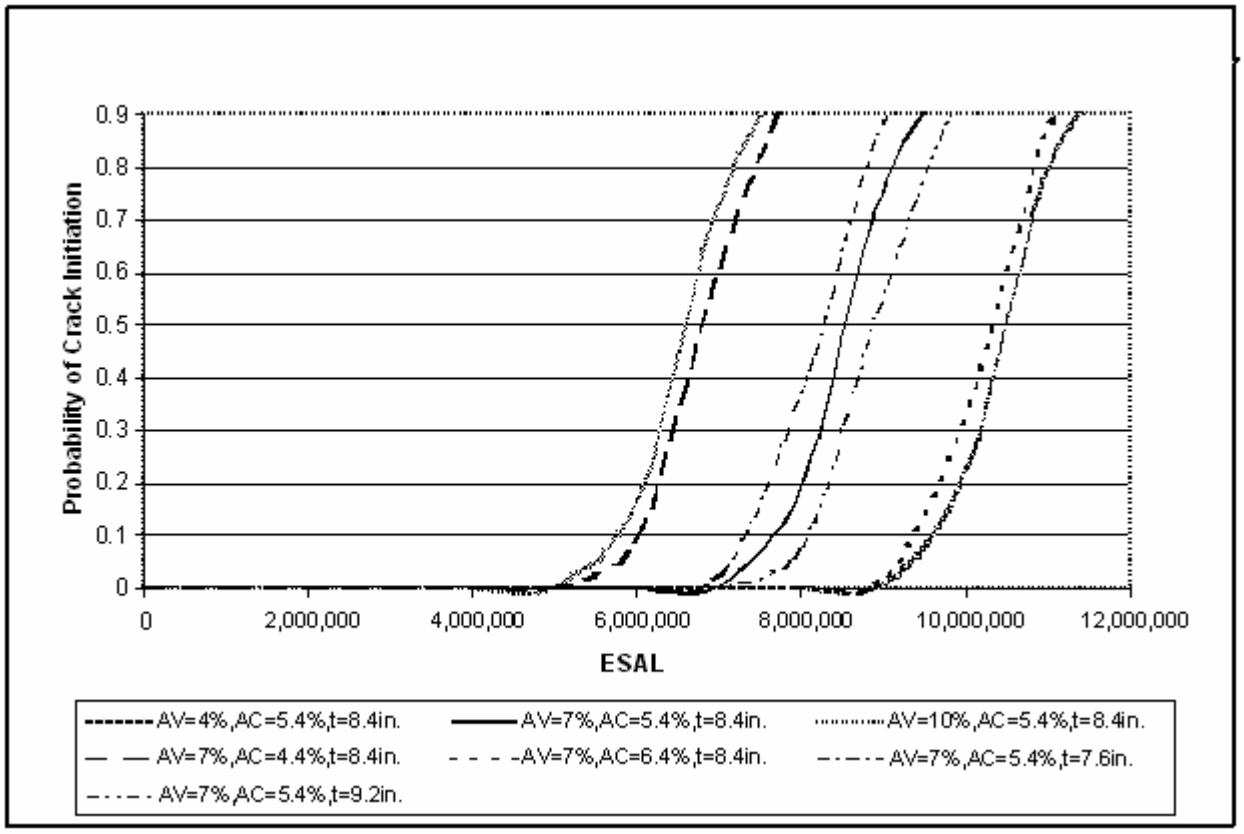
The model using the linear relation (Model No. 1) is recommended at this stage. It appears to capture the trends reasonably well; see Figures I.1, I.2, and I.3 for a probability of 10% cracking. The signs and p-values indicate that the expressions are statistically significant. Note: As shown in Figures I.1, I.2, and I.3, TI represents the Traffic Index in the California pavement design procedure and is related to ESALs according to the following relation:

$$ESALs = 1.2895 \cdot 10^{-2} (TI)^{8.2919}$$



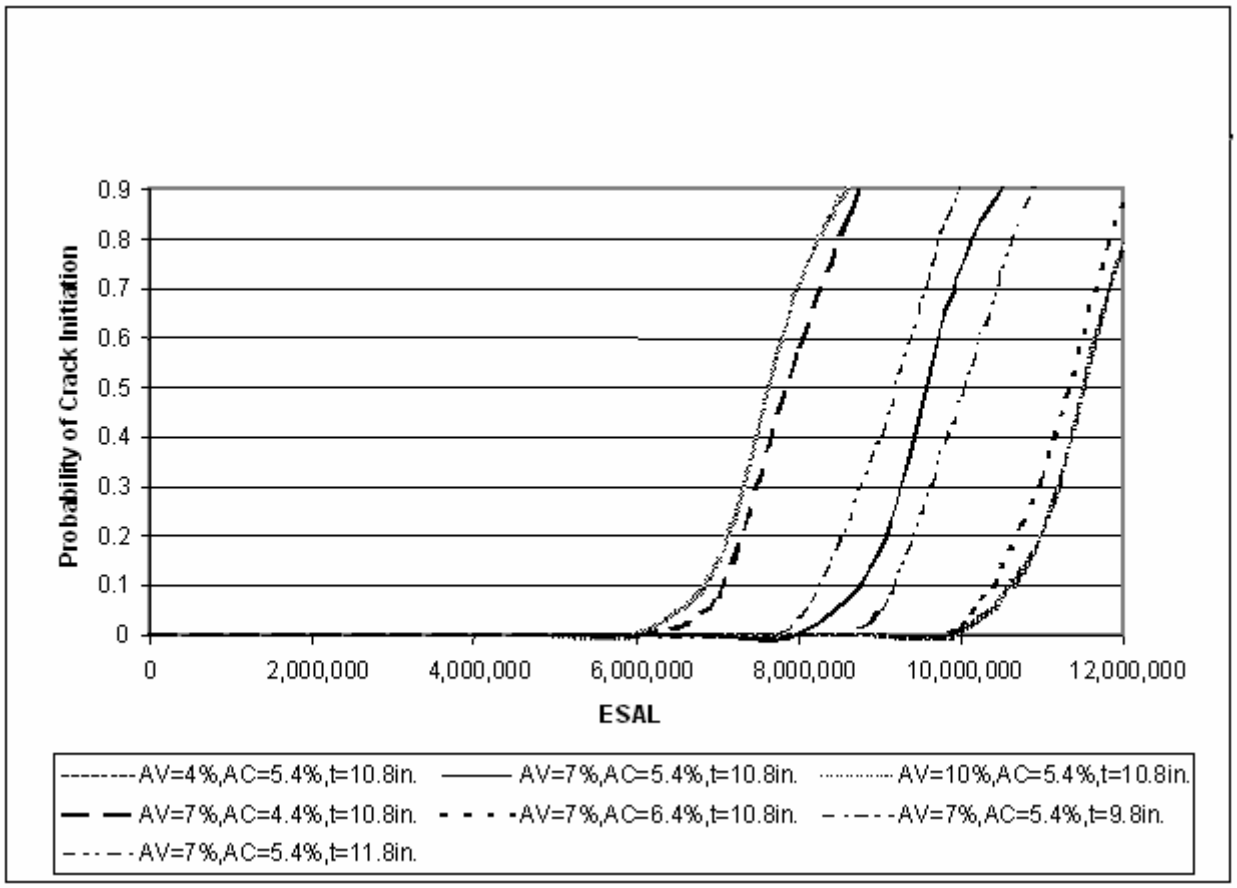
(1 in. = 25.4 mm)

Figure I.1. Crack initiation for fine gradation (10%); TI=7.



(1 in. = 25.4 mm)

Figure I.2. Crack initiation for fine gradation (10%); TI=11.



(1 in. = 25.4 mm)

Figure I.3. Crack initiation for fine gradation (10%); TI=15.

APPENDIX J

Procedures for Estimating the Stiffness Moduli of Asphalt Concrete

Mix stiffnesses can be estimated from parameters such as the properties of the binders as they exist in the mix in the field and the volumetric proportions of the components. Two such examples include: (1) the estimation procedures developed by the Shell Investigators and incorporated in the Shell design procedure (*10*); and (2) the procedure developed by Witczak [and recently updated (*72*)] and used in the Asphalt Institute design procedure (*12*).

The Shell method requires a measure of the stiffness of the binder and the volumetric properties of the aggregate, binder, and air in the compacted mix. Stiffness of the binder is usually determined from tests on the material recovered from the mix or estimated; these tests include the penetration at 25°C (77°F) and the temperature at which the penetration is 800 dmm. In both instances, the load on the needle in the penetration test is 100 g and the time of loading is 5 seconds. Mix stiffness can then be determined from the binder stiffness and the volumetric proportions of the mix components using an equation with the following parameters:

$$S_{mix} = f\left(S_{asp}, V_{aggr}, V_{asp}, V_{air}\right) \quad \textbf{(J.1)}$$

The procedure developed by Witczak is described in Reference (*12*) and was based on the analysis of tests on 60 different mixes containing well-graded aggregates (dense-graded mixes). While the original procedure is still a part of the Asphalt Institute method, Witczak has updated the procedure to consider the effects of aging. The resulting equation is based on 1,429 data points (*16*) and is as follows:

$$\log E = -0.261 + 0.008225\,p_{200} - 0.00000101\left(p_{200}\right)^2 + 0.00196\,p_4 - 0.03157V_a - 0.415\frac{V_{beff}}{\left(V_{beff} + V_a\right)} + \frac{1.87 + 0.002808\,p_4 + 0.0000404\,p_{3/8} - 0.0001786\left(p_{3/8}\right)^2 + 0.0164\,p_{3/4}}{1 + e^{\left(-0.716\log f - 0.7425\log \eta\right)}} \quad \textbf{(J.2)}$$

where the variables represent:

E = Asphalt mix dynamic modulus, in 10^5 psi

η = Bitumen viscosity in 10^6 poise (at any temperature, degree of aging)

f = Load frequency, in Hz

V_a = % air voids in the mix, by volume

V_{beff} = % effective bitumen content, by volume

$p_{3/4}$ = % retained on the 19-mm (3/4-in.) sieve, by total aggregate weight (cumulative)

$p_{3/8}$ = % retained on the 9.5-mm (3/8-in.) sieve, by total aggregate weight (cumulative)

p_4 = % retained on the 4.75-mm (No. 4) sieve, by total aggregate weight (cumulative)

p_{200} = % retained on the 0.074-mm (No. 200) sieve, by total aggregate weight (cumulative)

APPENDIX K

Development of an RSST-CH Inelastic Strain Model Based on LMLC Test Specimens of WesTrack Mix

As a first step in the development of a procedure to simulate the progression of rutting in WesTrack pavements, a typical WesTrack mix was tested in the RSST-CH device over a range of temperatures and shear stresses. This Appendix briefly describes the testing and the preliminary analysis of test results.

Mix and Testing Descriptions

Testing was limited to one mix, the coarse mix incorporating the medium asphalt content (5.7% of total weight or 6.0% by weight of aggregate) and the medium air-void content (8.0%). This mix was designated as Mix 19 in WesTrack Test Section 5 and Mix 24 in WesTrack Test Section 24. Specimens were prepared to within a ±1% tolerance in air-void content.

Testing was conducted at three temperatures (40, 50, and 60°C [104, 122, and 140°F]) and at three levels of shearing stress (4, 8, and 12 psi [27.6, 55.1, 82.7 kPa]). A total of 27 specimens were tested, three at each combination of temperature and shearing stress. Results of the two tests that were considered to be outliers (WT 22-1 at 40°C and 4 psi and WT 18-1 at 50°C and 4 psi) were not used in the analysis of test results. Table K.1 contains a summary of the test data obtained in the RSST-CH.

The RSST-CH test applies a repetitive shearing stress to the test specimen while maintaining a constant specimen height. For this testing, the cyclic loading consisted of a 0.1-sec load pulse followed by a 0.6-sec rest period.

Stiffness

The resilient shear stiffness is readily calculated from test measurements as follows:

$$G = \frac{\tau}{\gamma^e}$$

Table K.1. Summary of test data obtained in the RSST-CH.

SPECIMEN	AV	TEST PARAMETERS		TEST RESULTS: RSST Reps to Shear Strain							
		Temp, C	Stress, kPa (psi)	1.0% Strain	2.0% Strain	3.0% Strain	4.0% Strain	5.0% Strain	G*, MPa	a	b
WTNMM5-3	7.34	60	84 (12)	15	68	214	495	**927**	41.9	4.62E-03	0.349
WTNMM6-3	8.83	60	84 (12)	12	48	124	246	**423**	42.7	4.05E-03	0.416
WTNMM7-1	8.18	60	84 (12)	13	66	191	478	1020	43.0	5.85E-03	0.311
WTNMM4-1	7.71	60	56 (8)	22	122	451	1084	2161	31.2	4.30E-03	0.319
WTNMM4-3	8.92	60	56 (8)	18	86	248	540	986	34.4	3.87E-03	0.371
WTNMM5-2	7.60	60	56 (8)	100	641	1554	2960	4731	48.2	1.28E-03	0.431
WTNMM3-1	8.22	60	28 (4)	63	291	796	1548	2624	22.4	1.78E-03	0.424
WTNMM3-2	7.79	60	28 (4)	41	196	709	1657	**3128**	22.1	3.18E-03	0.343
WTNMM6-1	7.62	60	28 (4)	105	635	2208	5744	10599	16.4	2.23E-03	0.336
WTNMM8-1	8.58	50	84 (12)	67	321	811	1578	2870	53.9	1.70E-03	0.427
WTNMM8-3	8.83	50	84 (12)	32	153	466	988	1779	66.3	2.99E-03	0.376
WTNMM9-1	7.84	50	84 (12)	78	532	1739	3913	7735	68.3	2.33E-03	0.343
WTNMM9-2	8.71	50	56 (8)	158	1112	4351	10078	**19632**	51.0	1.93E-03	0.329
WTNMM10-3	7.71	50	56 (8)	281	1585	4435	9138	**15888**	60.9	1.12E-03	0.392
WTNMM12-1	8.47	50	56 (8)	1236	9192	30685	**78001**	**156559**	53.1	1.08E-03	0.320
WTNMM18-1	8.94	50	28 (4)	15619	**73697**	**159374**	**275473**	**421138**	36.8	5.52E-05	0.526
WTNMM13-2	7.88	50	28 (4)	5066	**46042**	**155606**	**369202**	**721641**	52.0	5.60E-04	0.333
WTNMM13-3	7.46	50	28 (4)	9182	**66625**	**176725**	**353094**	**604015**	54.8	1.98E-04	0.416
WTNMM19-1	8.69	40	84 (12)	597	7216	28956	**76154**	**164165**	166.8	1.53E-03	0.291
WTNMM20-1	8.60	40	84 (12)	514	3408	10111	21267	**38475**	177.3	8.77E-04	0.383
WTNMM15-3	7.80	40	84 (12)	953	6219	29453	**53328**	**101505**	163.2	9.19E-04	0.347
WTNMM21-1	8.86	40	56 (8)	604	6140	25792	**63321**	**132051**	185.5	1.39E-03	0.304
WTNMM21-2	8.55	40	56 (8)	2102	20965	**67236**	**161840**	**319883**	186.4	7.87E-04	0.328
WTNMM21-3	7.57	40	56 (8)	2201	27322	**82129**	**206150**	**420925**	162.0	8.73E-04	0.313
WTNMM22-1	7.61	40	28 (4)	**20499**	**166774**	**568435**	**1356851**	**2664506**	134.9	3.75E-04	0.331
WTNMM22-2	9.03	40	28 (4)	**11856**	**86040**	**274290**	**624388**	**1181830**	199.3	3.76E-04	0.350
WTNMM22-3	7.18	40	28 (4)	44497	**185413**	**646358**	**1567708**	**3116972**	98.9	3.90E-04	0.325

(°F = 1.8 °C + 32; 1 psi = 6.9 kPa)

in which G = resilient shear stiffness, τ = shear stress, and γ^e = elastic or resilient shear strain. The resilient axial stiffness can also be estimated as follows:

$$E = G \cdot 2(1+\nu)$$

in which E = resilient axial stiffness and ν = Poisson's ratio.

Measurements of resilient shear strain commonly vary as the cyclic loading accumulates during each test, and stiffness estimates are usually computed from measurements taken in an "undamaged" state, that is, before the specimens are permanently deformed. Figures K.1 through K.7 show the representation curves of the variation in resilient shear stress in the region of greatest interest, the first 200 load cycles. These figures suggest that, following a period of initial instability, the measurements tend to stabilize at about 100 load cycles. Accordingly, all computations of resilient stiffness were based on measurements of resilient shear strain at 100 cycles of loading. Average resilient axial stiffnesses, computed using a Poisson's ratio of 0.35, are summarized in Table K.2.

Table K.2. Average resilient axial stiffness (psi).

Temperature (°C)	**Shear Stress, τ (psi)**			**Average**
	4	**8**	**12**	
40	54,300	68,300	65,200	62,600
50	20,500	21,400	25,200	22,400
60	7,500	14,600	16,600	12,900
Average	27,400	34,800	35,700	32,600

(°F = 1.8 °C + 32; 1 psi = 6.9 kPa)

As shown in Table K.2, the resilient stiffness shows both a temperature dependence and a stress dependence. The stress dependence, which seems to increase in significance as the temperature increases, likely reflects an effect of differences in the axial stress necessary to maintain the constant-height condition. Such differences are shown in Tables K.3 and K.4.

Table K.3. Average axial stress (psi).

Temperature (°C)	Shear Stress, τ (psi)			Average
	4	8	12	
40	0.3	0.6	2.0	1.0
50	0.5	5.6	7.0	4.4
60	3.3	7.2	9.3	6.6
Average	1.4	4.5	6.1	4.0

(°F = 1.8 °C + 32; 1 psi = 6.9 kPa)

Table K.4. Average ratio of axial stress to shear stress (psi).

Temperature (°C)	Shear Stress, τ (psi)			Average
	4	8	12	
40	0.07	0.08	0.18	0.11
50	0.12	0.70	0.59	0.47
60	0.82	0.89	0.78	0.83
Average	0.34	0.56	0.51	0.47

(°F = 1.8 °C + 32; 1 psi = 6.9 kPa)

By means of regression analysis, the resilient axial stiffness, *E* (in psi), is related to the temperature, *T* (in °C), and shearing stress, τ **(**in psi), as follows:

$$E = \exp\left(14.15246 - 0.08931 \cdot T + 0.001127 \cdot T \cdot \tau\right)$$

The adjusted R^2 for this calibration is 0.902, and all terms are statistically significant at a probability level of 5% or less. The fit between calibration and measurement is shown in Figures K.4 through K.6.

Because the RSST-CH load duration of 0.1 second considerably exceeds the load duration experienced in the pavement under moving traffic loads and because the test does not mimic the confinement anticipated in situ, the resilient stiffnesses reported above can not be accurately used in multi-layer elastic analysis. Assuming, however, that the temperature sensitivity of the mix stiffness in situ is similar to its temperature sensitivity in the RSST-CH, a useful approximation can be developed rather easily. In this case, utilization is made of a flexural test at 20 °C (68 °F) and 10 Hz, a frequency compatible with moving traffic loads; this test yielded a stiffness of 725,000 psi (5,000 MPa). Figure K.7 shows this stiffness, together

with a best fit line through the average results, obtained from the RSST-CH and reported above. Applying a multiplicative factor of 2.58 to the best fit line yields a new line passing through 725,000 psi at 20°C.

Other considerations suggest that this new line may also understate the resilient stiffness slightly. A multiplicative factor of 3.56, which yields an estimate of approximately 90,000 psi (620 MPa) at 50°C (122°F) seems more appropriate. The recommended estimate of the resilient stiffness for use in multi-layer elastic analysis is therefore:

$$E = \exp\left(15.42222 - 0.08931 \cdot T + 0.00127 \cdot T \cdot \tau\right)$$

or, for an average shear stress during testing at 8 psi (55.1 kPa),

$$E = \exp\left(15.42222 - 0.08029 \cdot T\right)$$

Inelastic Shear Strain

The primary purpose of the RSST-CH testing is to measure, and eventually to model, the accumulation of permanent (inelastic) shear strains with repetitive loading. Preliminary examination of the inelastic strain, γ^i, versus number of load applications, *n*, plots revealed an apparently excessive measurement of strain at the first load application (Figures K.8 through K.10) and a nonlinear relationship in the $\ln \gamma^i$ versus $\ln n$ plots (Figures K.11 through K.13*).

Set-up slack in the instrumentation seems to have been the most likely cause of the excessive initial strain. In an attempt to eliminate any adverse effects of slack, all inelastic strain measurements were reduced by an amount equaling the constant term of the best-fit polynomials of Figures K.8 through K.10. The nonlinearity, combined with the proposed use of the time-

* Numbers on these figures represent the coefficients of best-fit polynomials. The best fit equation for Figure K.11, for example, is: $\ln \gamma^i = -8.897 + 0.564(\ln n) + 0.00164(\ln n)^2 - 0.00144(\ln n)^3$

hardening approach to strain accumulation, precipitated a search for non-traditional models of inelastic strain accumulation.

The first model was of the following form:

$$\ln\left(\frac{\Delta\gamma^i}{\Delta n}\right) = a\exp\left(b\gamma^{i^c}\right)$$

in which $\Delta\gamma^i/\Delta n$ = change in inelastic strain per load application, γ^i = prior cumulative inelastic strain, and *a*, *b*, and *c* = constants. Nonlinear search techniques embedded within Microsoft Excel were used to calibrate this equation. Two approaches were used: the first evaluated $\Delta\gamma^i/\Delta n$ after first fitting third-degree polynomials to the ln γ^i versus ln *n* data, and the second evaluated the following cumulative damage equation:

$$\gamma_j^i = \gamma_{j-1}^i + \Delta\gamma^i = \gamma_j^i = \exp\left(a\exp\left(b\gamma_{j-1}^{i^c}\right)\right)\Delta n$$

in which γ_j^i = cumulative inelastic strain after *j* loading blocks, γ_{j-1}^i = cumulative inelastic strain after *j*-1 loading blocks, and Δn = number of load applications in *j*th loading block.

Although this equation produced an excellent fit to the data, it proved difficult to calibrate because of local minima, it required an initial seed value to which the modeling was quite sensitive, and, most importantly, it proved difficult to relate the constants (*a*, *b*, and *c*) to the two test parameters, temperature and shear stress. Additional work looked at another non-traditional equation defined as follows:

$$\left(\frac{\Delta\gamma^i}{\Delta n}\right)^a = b + c\gamma^{i^d}$$

This equation adequately fit the data (but possibly not as well as the former) but, unfortunately, also appeared to be impractical for routine use.

As a result, attention turned to the traditional models defined as follows:

$$\gamma^i = a\, n^b$$

In order to assure an adequate fit in the region of greatest importance, that of greatest inelastic shear strain, calibrations ignored the first 100 load applications. Best-fit relationships are shown graphically in Figures K.14 through K.16*.

In order to be useful, the constants, *a* and *b*, must be related to the two test parameters, temperature and shear stress. Initial investigation showed that *b* was apparently unaffected by variations in temperature and shear stress (Table K.5). At the least, the specimen-to-specimen variation in *b* was so large that it masked any general effects of temperature and shear stress. Therefore, for the purposes of this investigation, *b* was assumed to be constant, and its value was fixed at the average of 0.36.

Table K.5. Average value of b.

Temperature (°C)	**Shear Stress, τ (psi)**			**Average**
	4	**8**	**12**	
40	0.33	0.32	0.34	0.33
50	0.45	0.35	0.38	0.39
60	0.37	0.37	0.36	0.37
Average	0.39	0.35	0.36	0.36

(°F = 1.8 °C + 32; 1 psi = 6.9 kPa)

The next task was to recalibrate the basic model for each test specimen, assuming a constant value of 0.36 for *b*. Results are depicted in Figures K.17 through K.19. The assumption of a constant exponent did not appear to significantly degrade the fit of the equation to the data in any of the tests.

Analysis next focused on the constant *a*. Most interestingly, *a* was found to be closely related to the elastic shear strain, generally confirming the hypothesis that the inelastic shear

* Numbers shown on these of these figures represent the coefficients of best-fit equations and the elastic shear strain at the 100th load application. For Figure K.14, for example, the best fit equation is: $\gamma^i = 0.0003678 n^{0.3519}$, and the elastic strain is 0.000144.

strain might be proportional to the elastic shear strain (Figure K.20). Further analysis indicated that temperature apparently did not have a residual effect (Figure K.21) but that shear stress apparently did have an effect (Figure K.22). The effect of shear stress on the coefficients of the Figure K.22 best-fit lines is shown in Figure K.23. Thus, it appears that a suitable expression for *a* is:

$$a = 1.262\exp(0.0487\tau)\gamma^{e}$$

and one for inelastic shear strain is:

$$\gamma^{i} = 1.262\exp(0.0487\tau)\gamma^{e}n^{0.36}$$

Figures K.24 through K.26 illustrate the fit of this model to the test measurements.

In order to use this information to simulate the development of rutting in WesTrack test sections and, ultimately, to design rut-resistant pavements, further analysis will be necessary to evaluate the variability associated with the RSST-CH method.

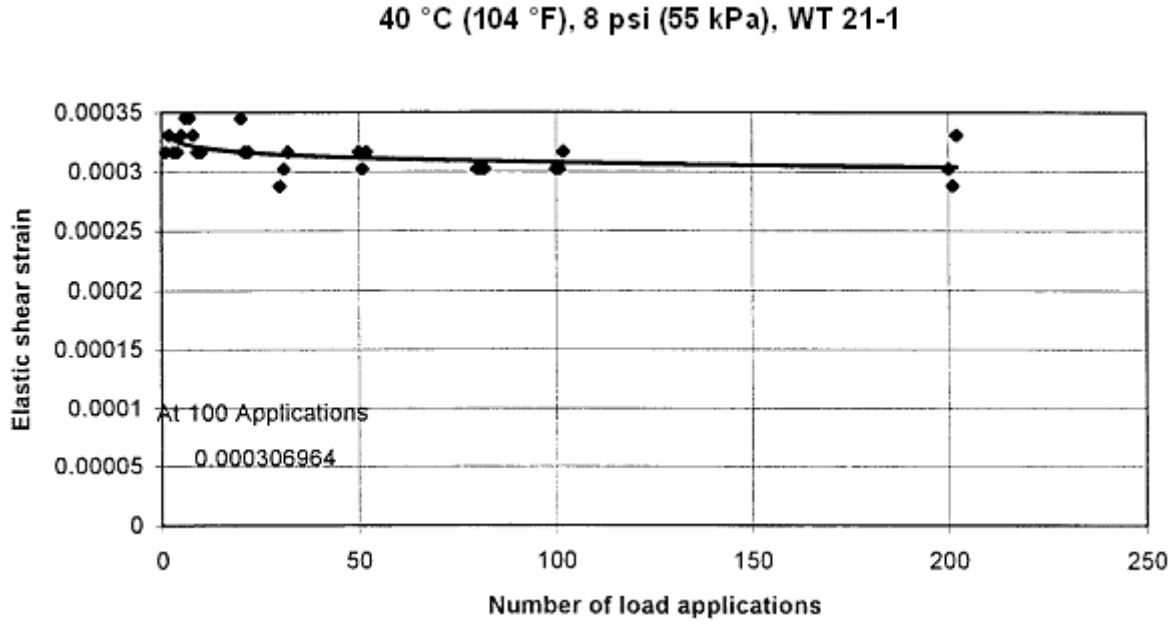
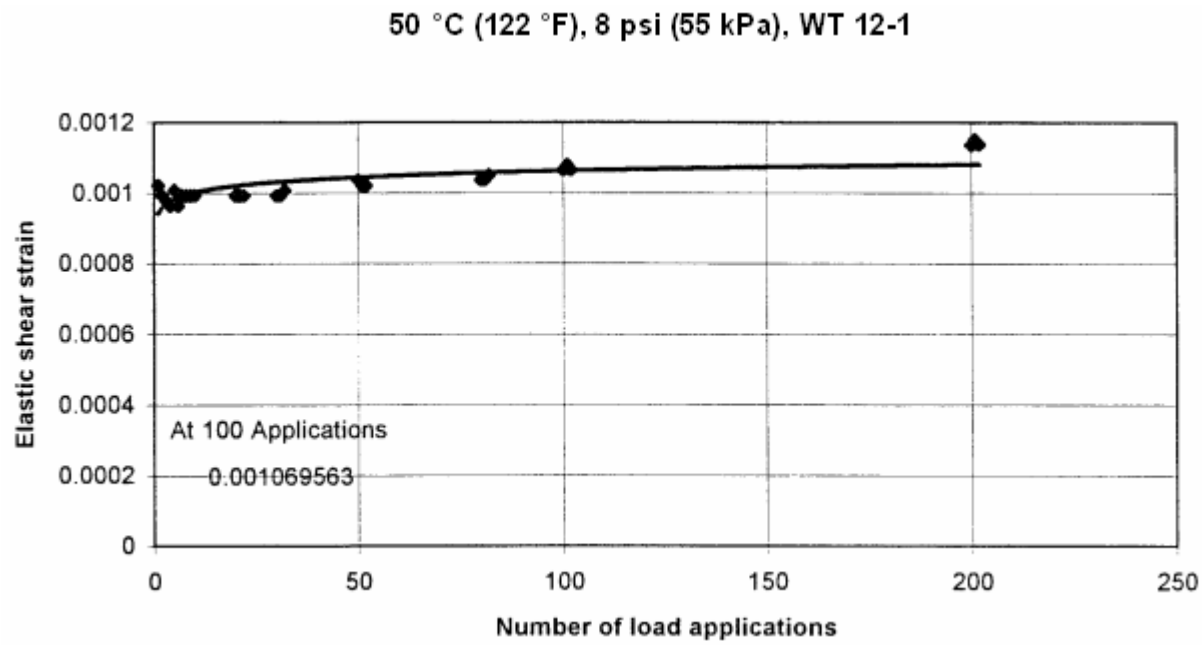


Figure K.1.



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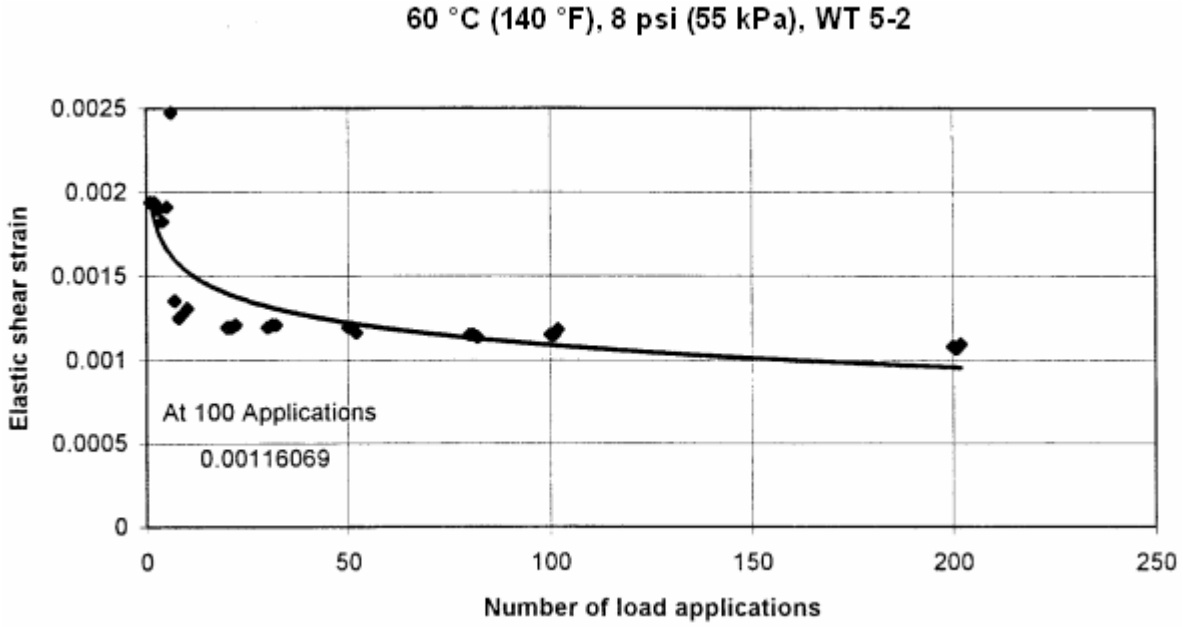

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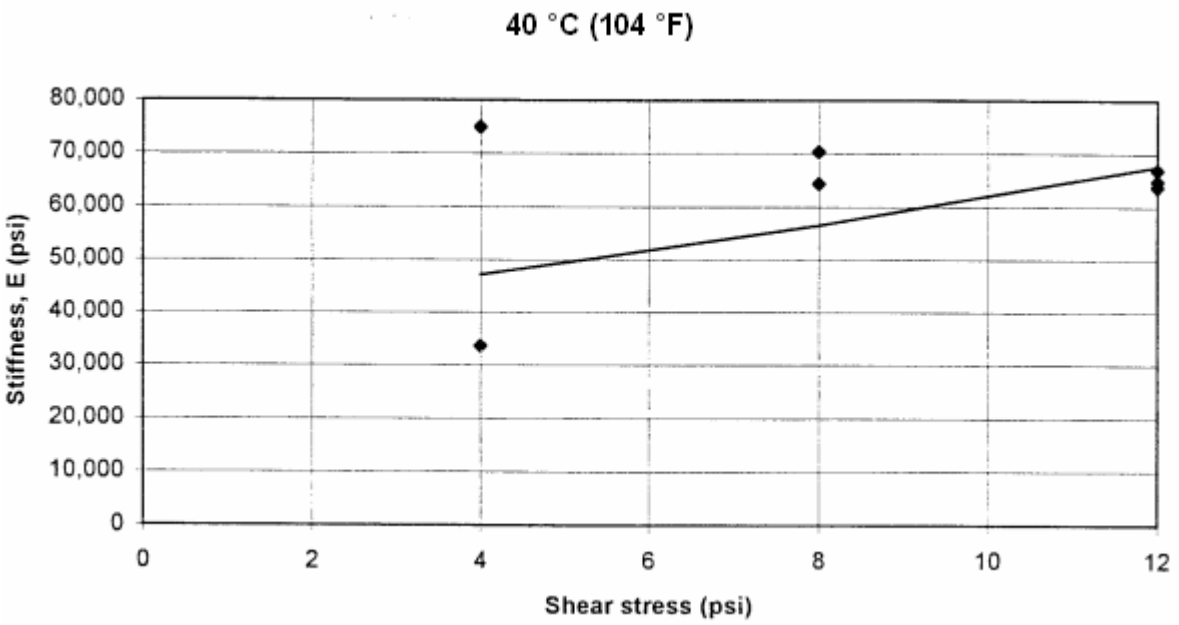
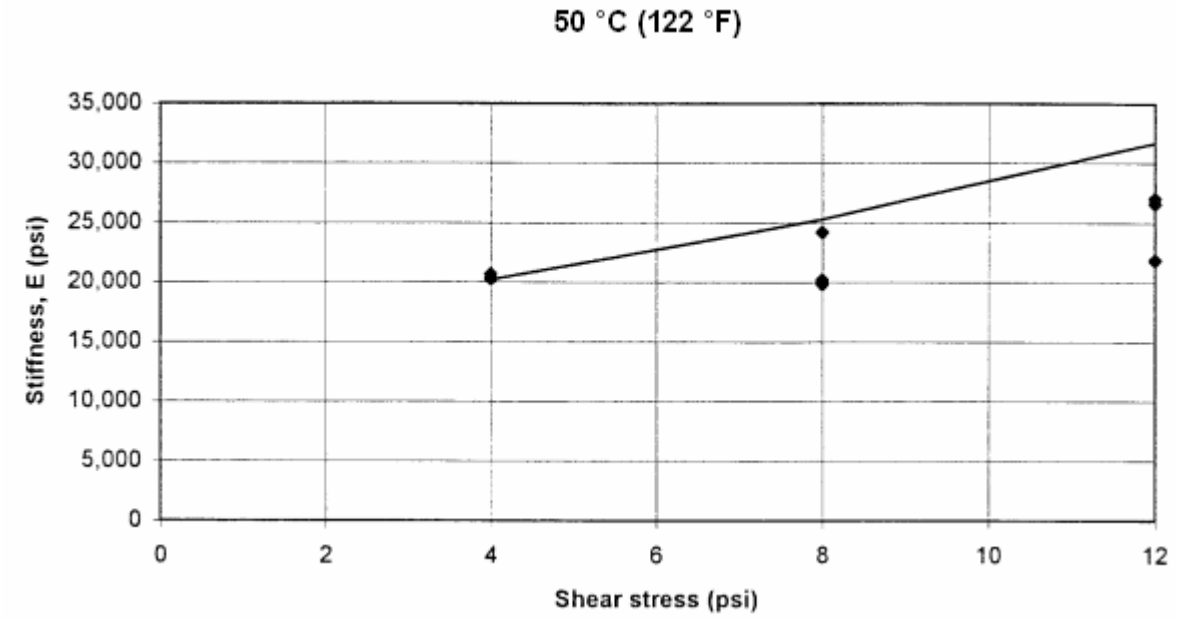


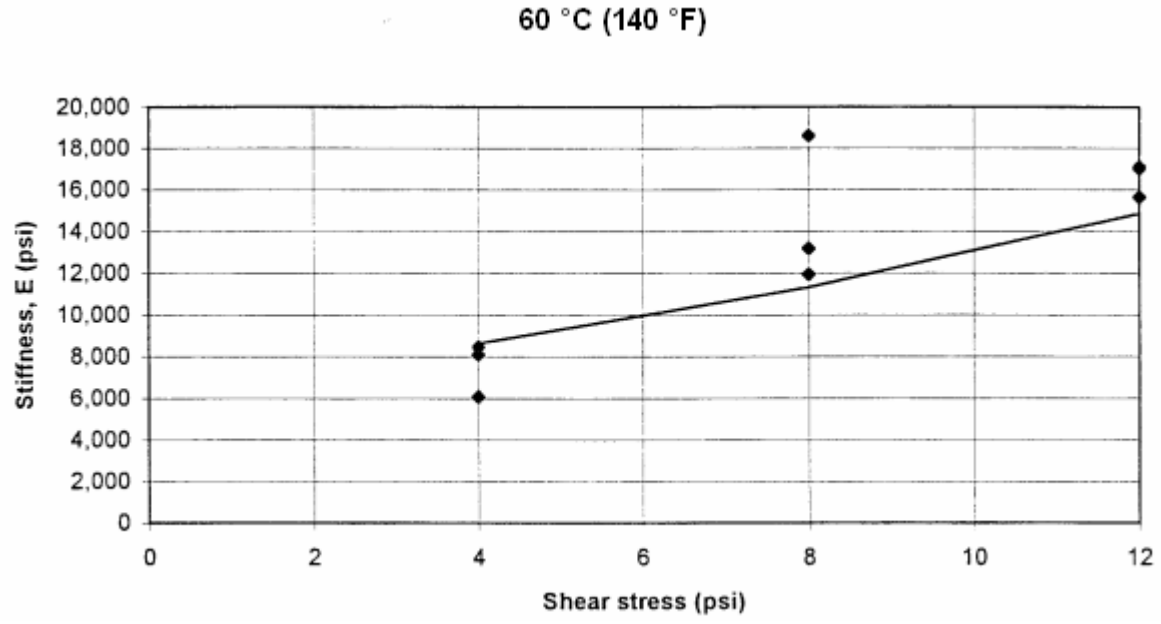
(1 psi = 6.9 kPa)

Figure K.4.



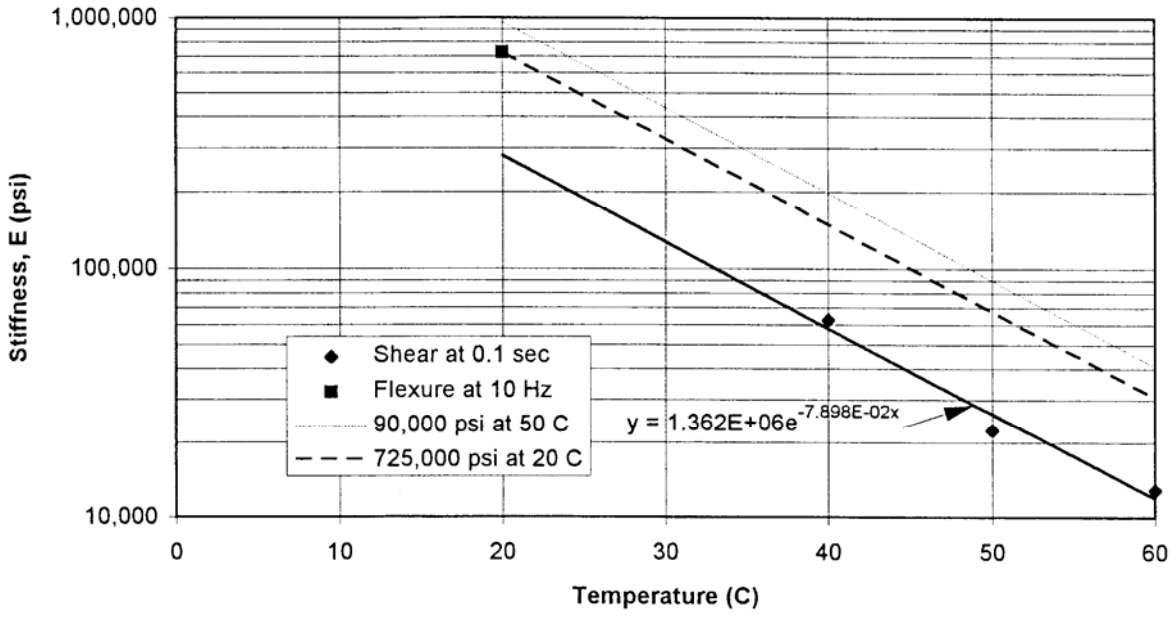
(1 psi = 6.9 kPa)

Figure K.5.



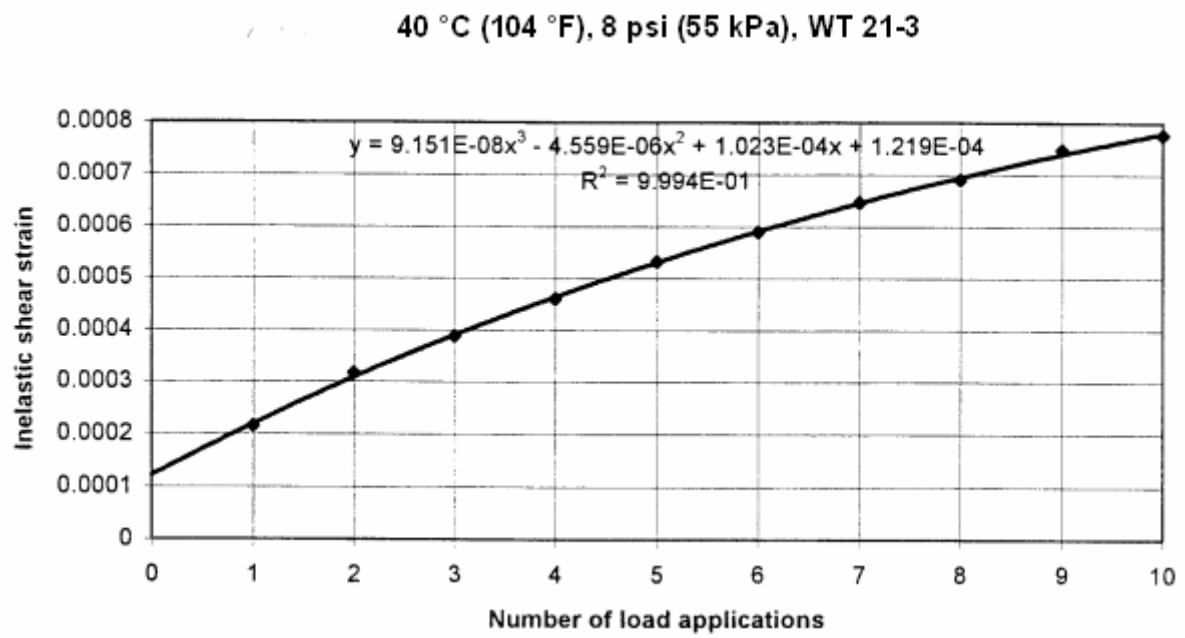
(1 psi = 6.9 kPa)

Figure K.6.



(°F = 1.8 °C + 32)
(1 psi = 6.9 kPa)

Figure K.7.



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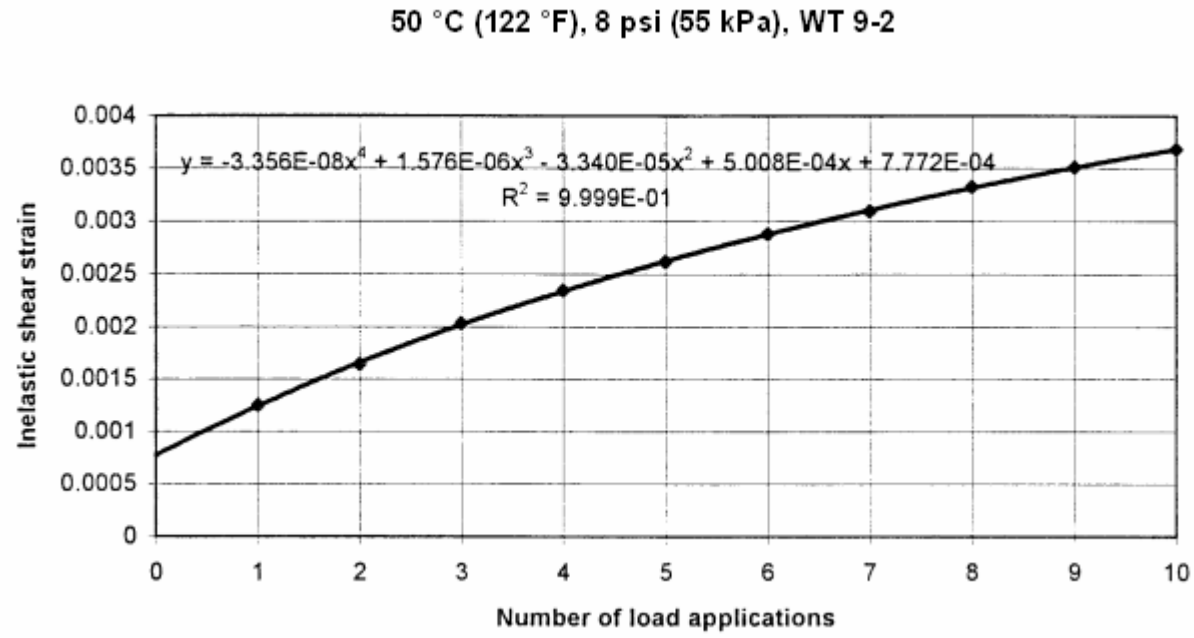

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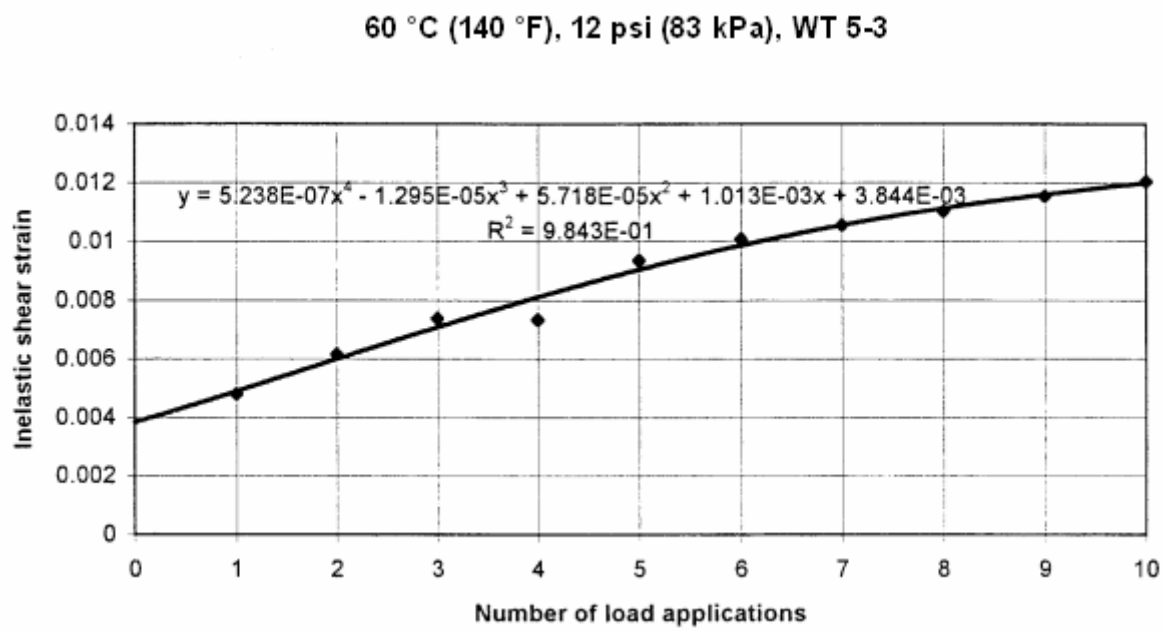

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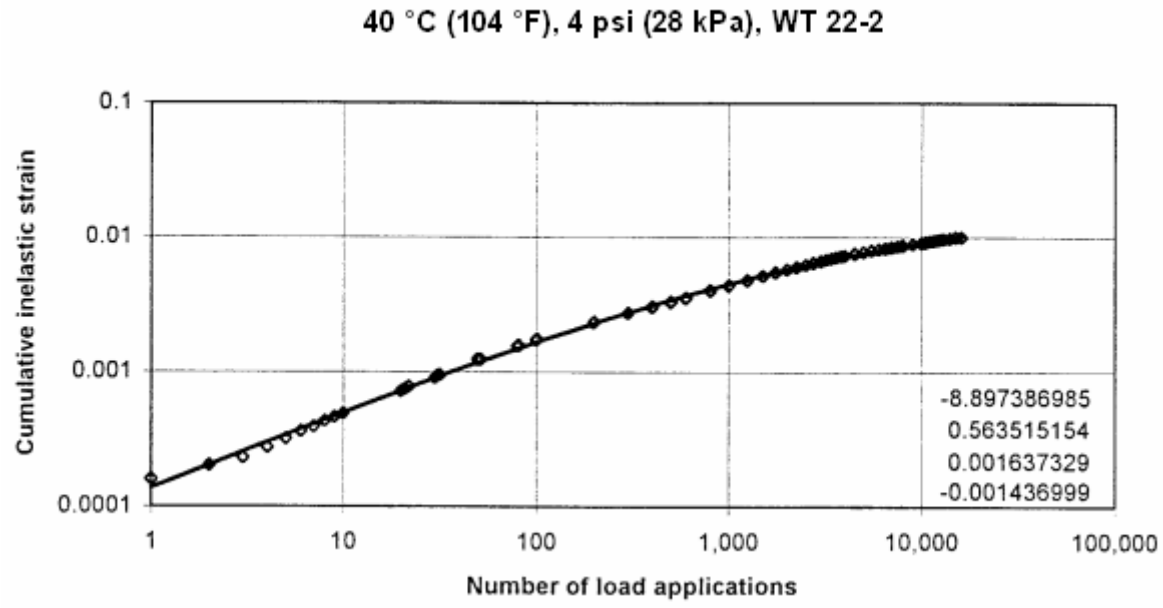

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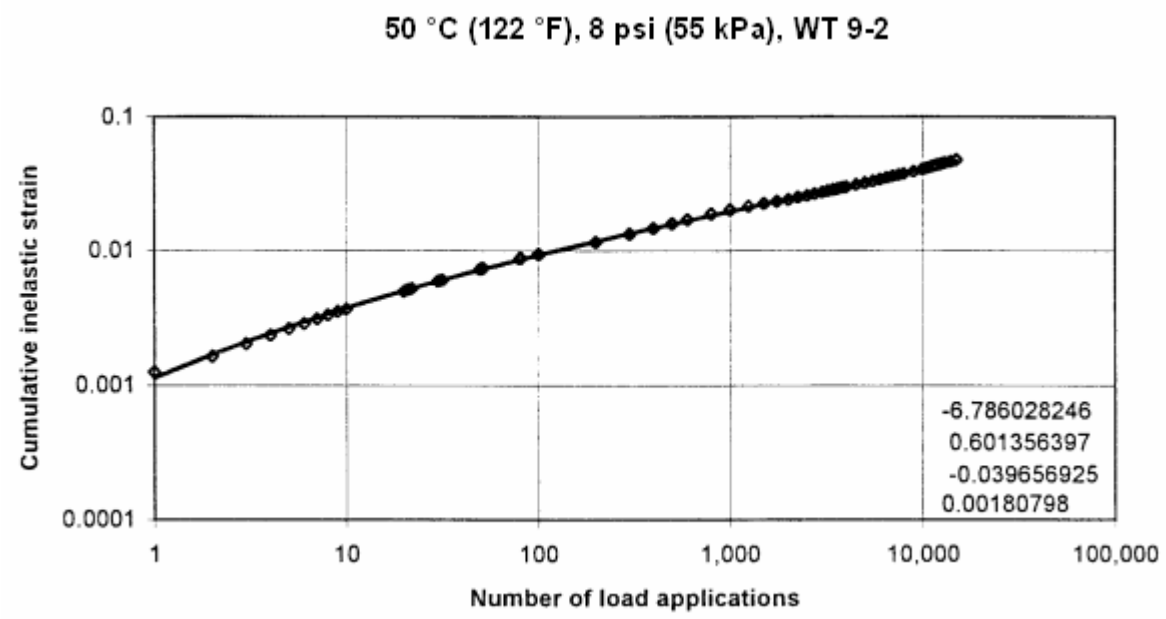

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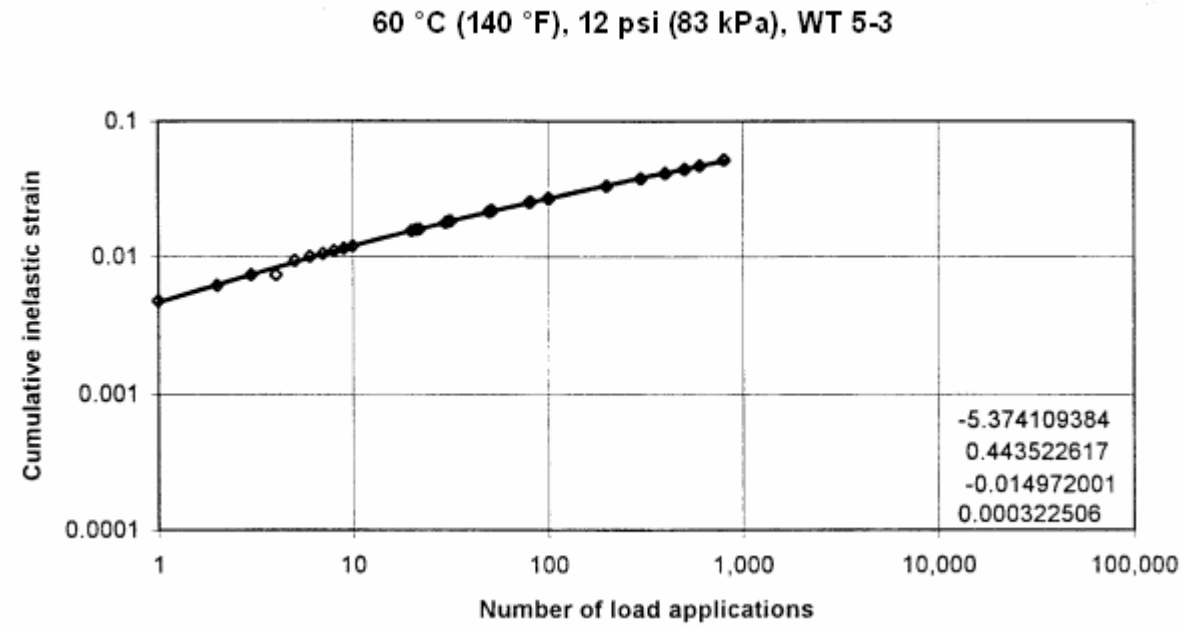

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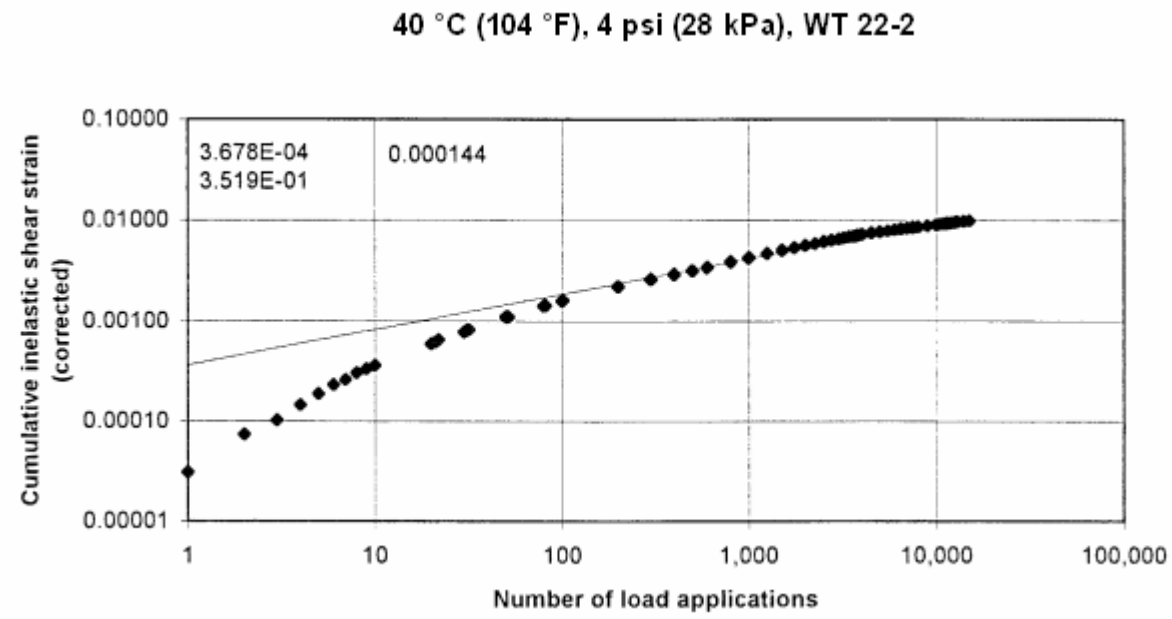

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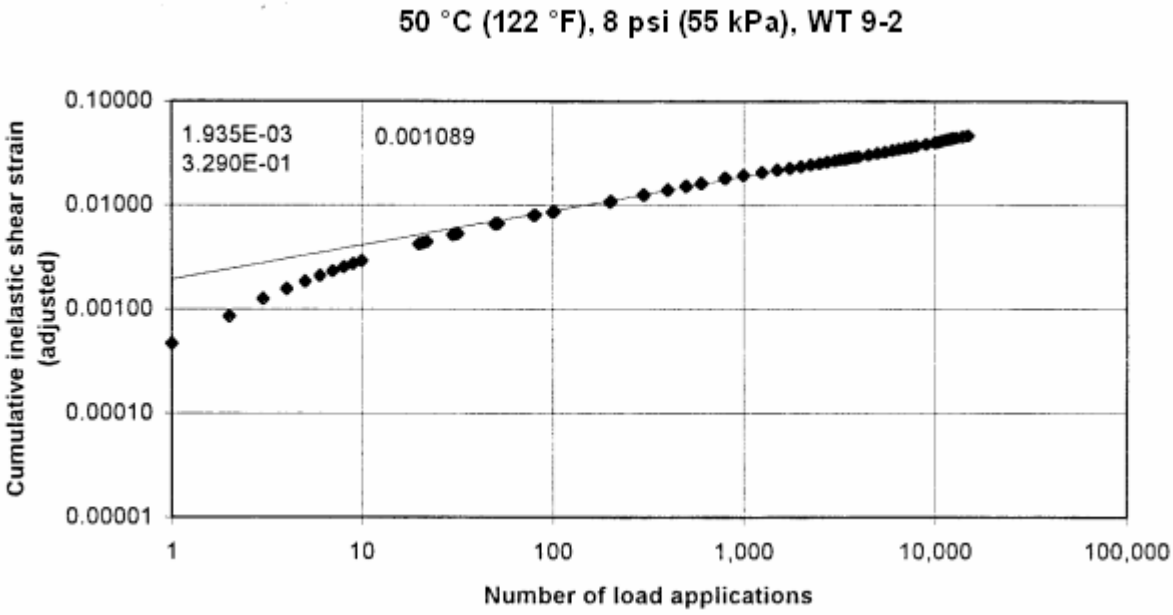

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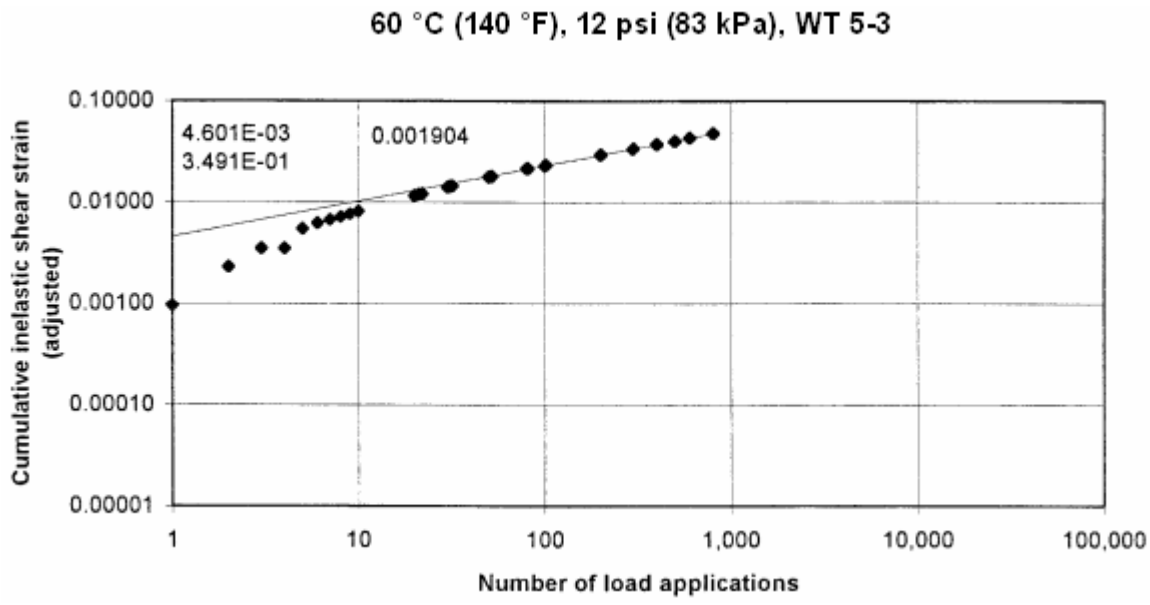

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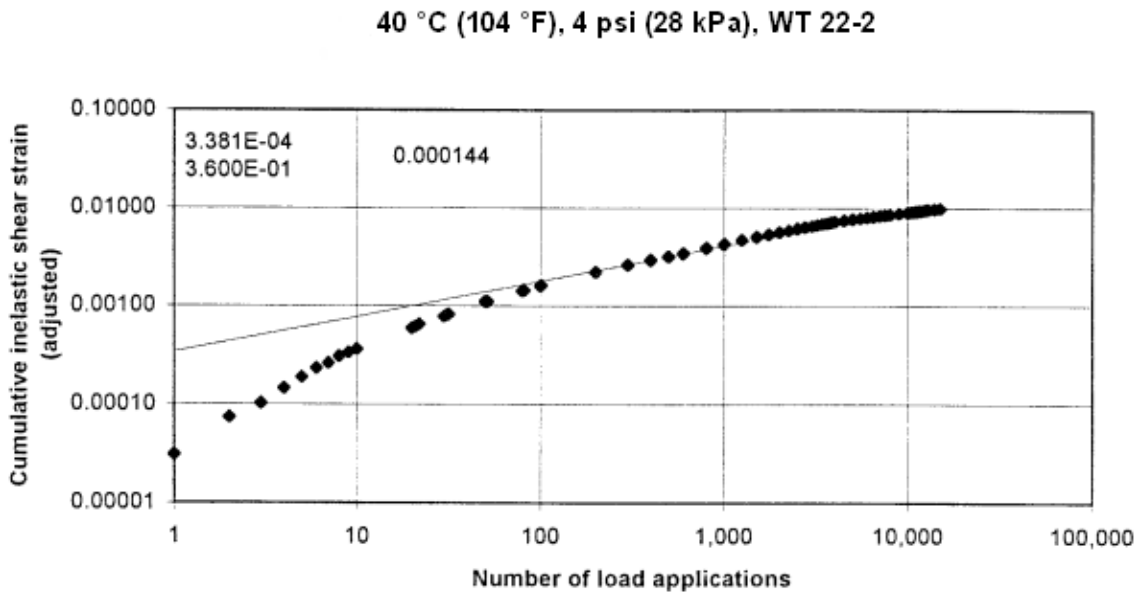

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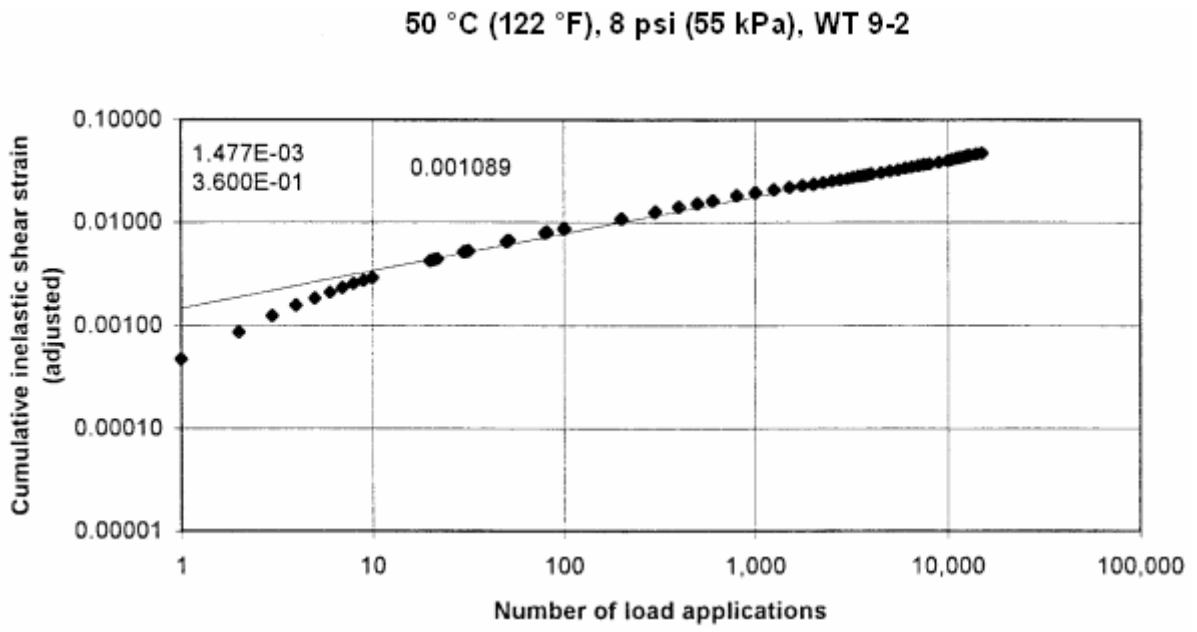

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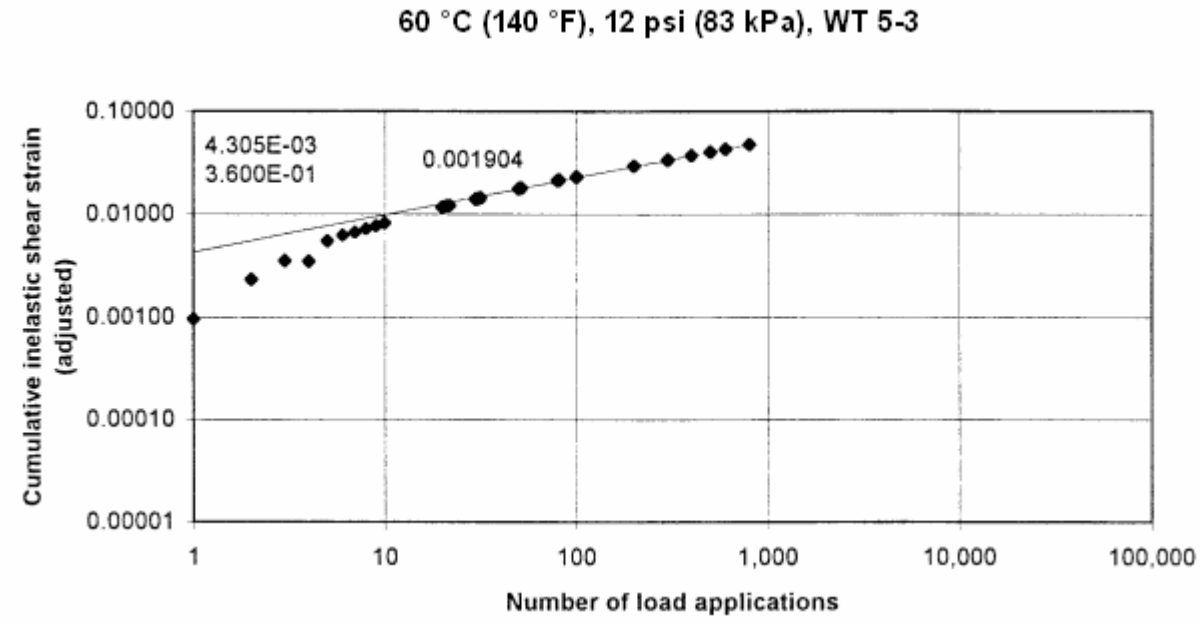

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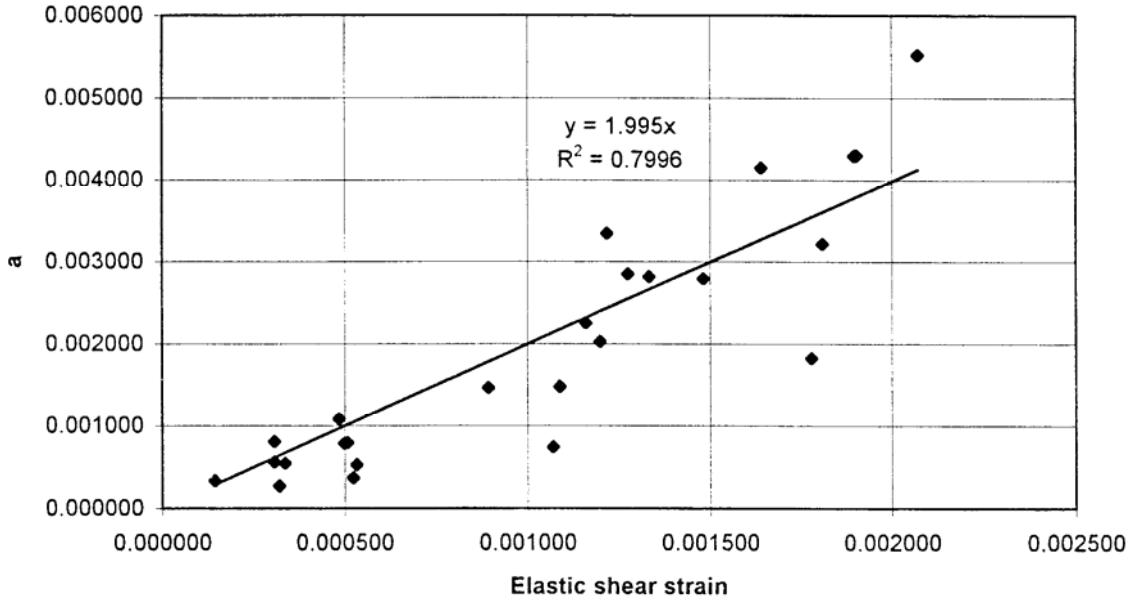

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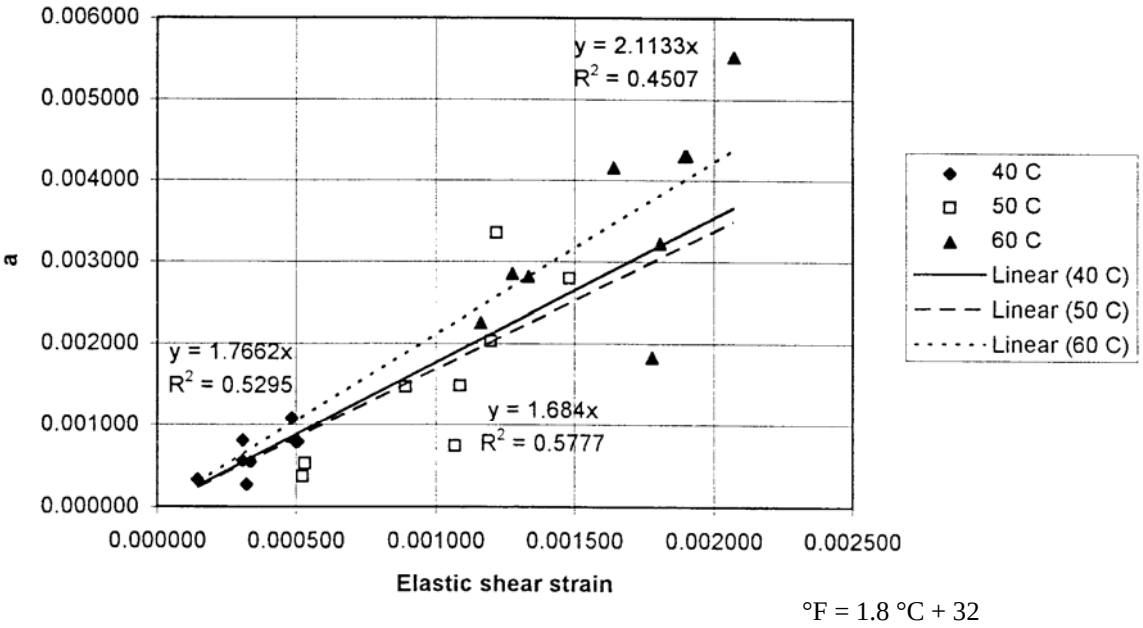
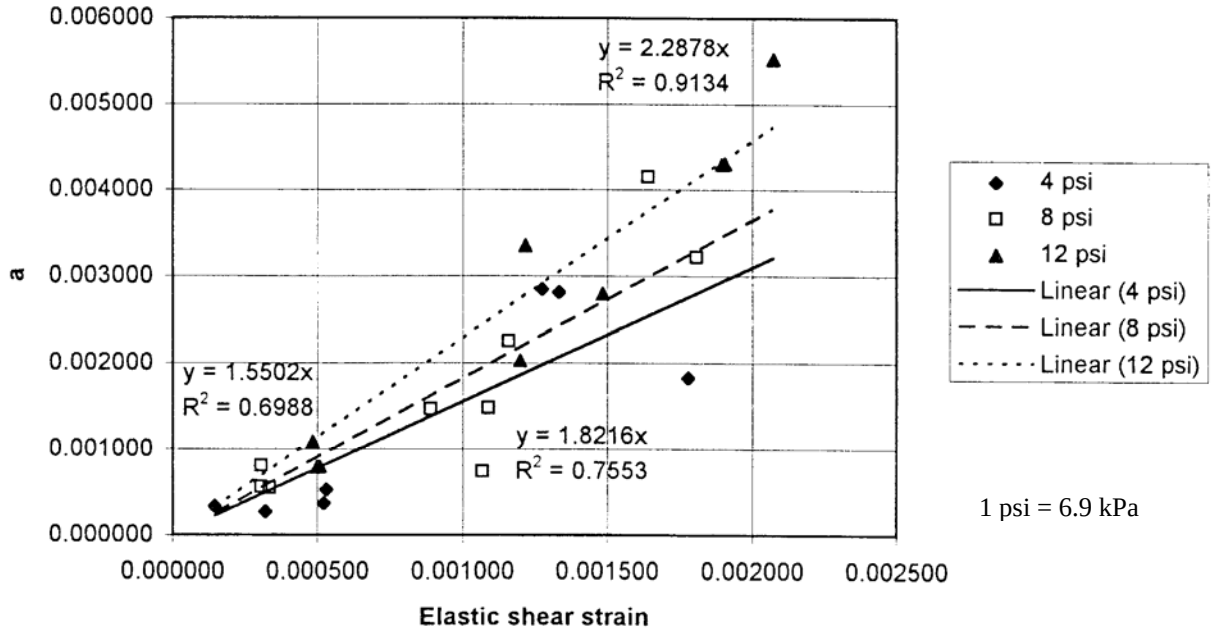


°F = 1.8 °C + 32

Figure K.21.



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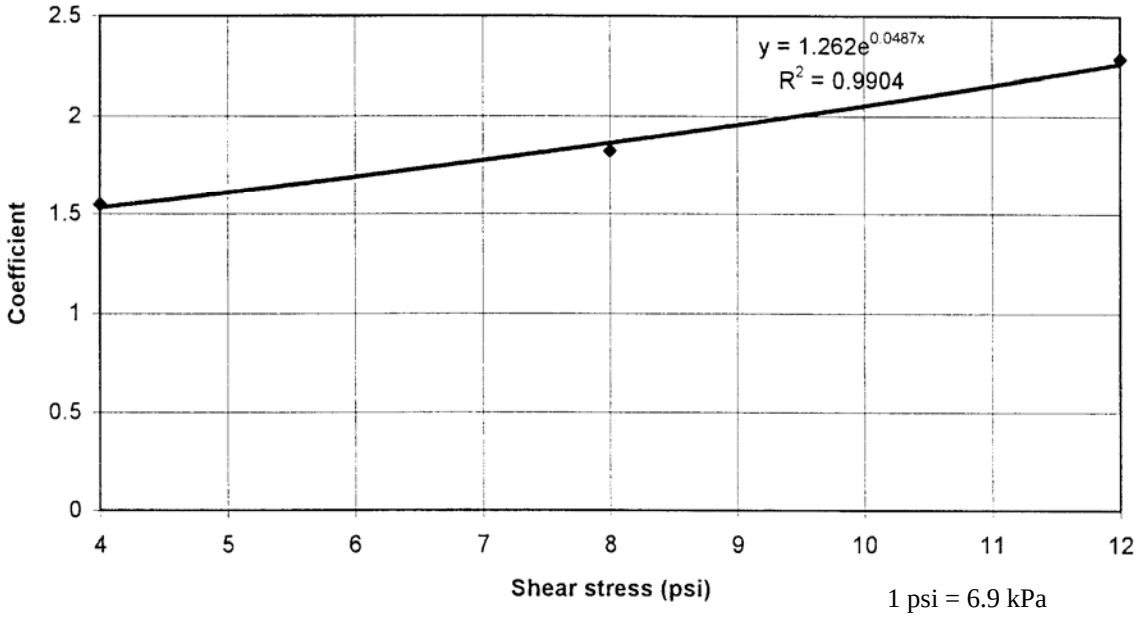

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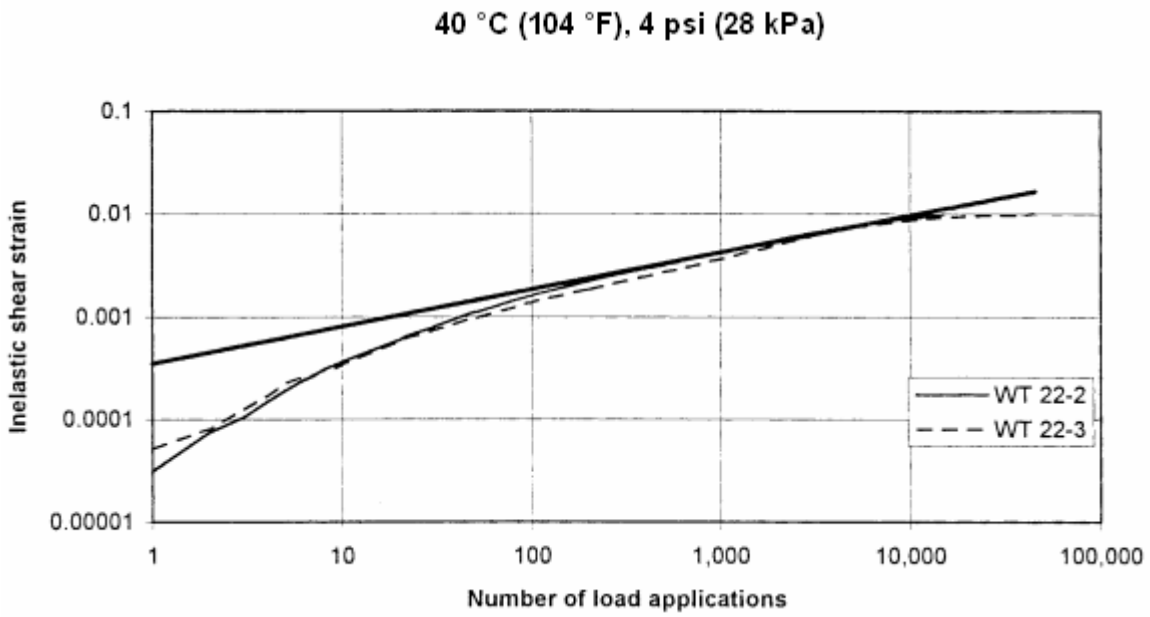

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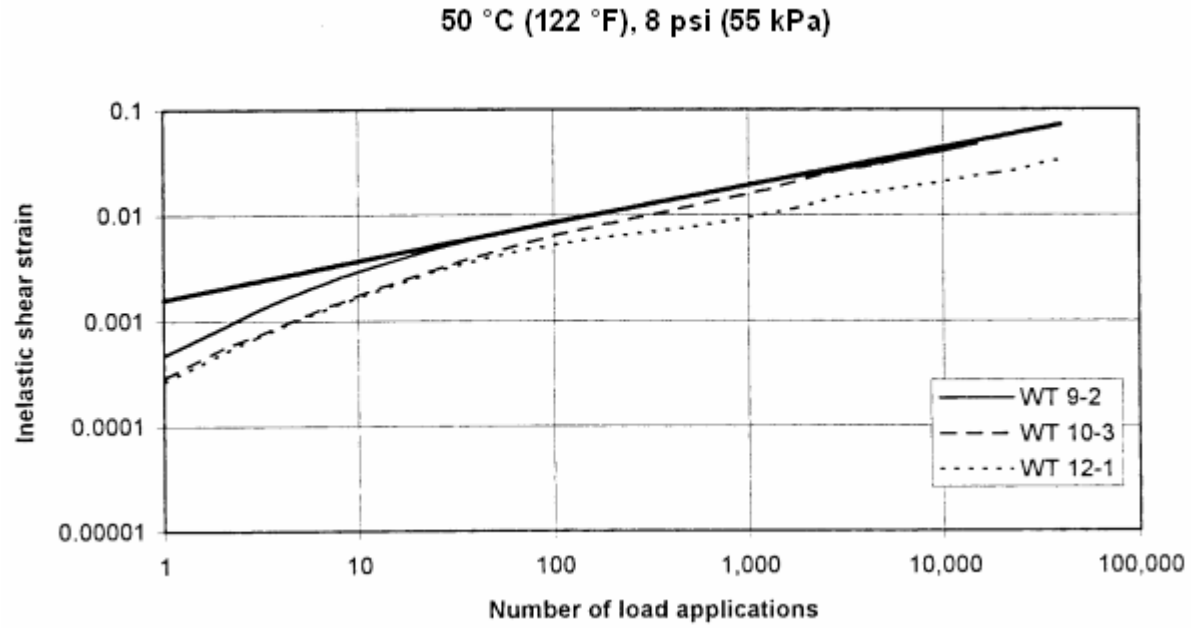

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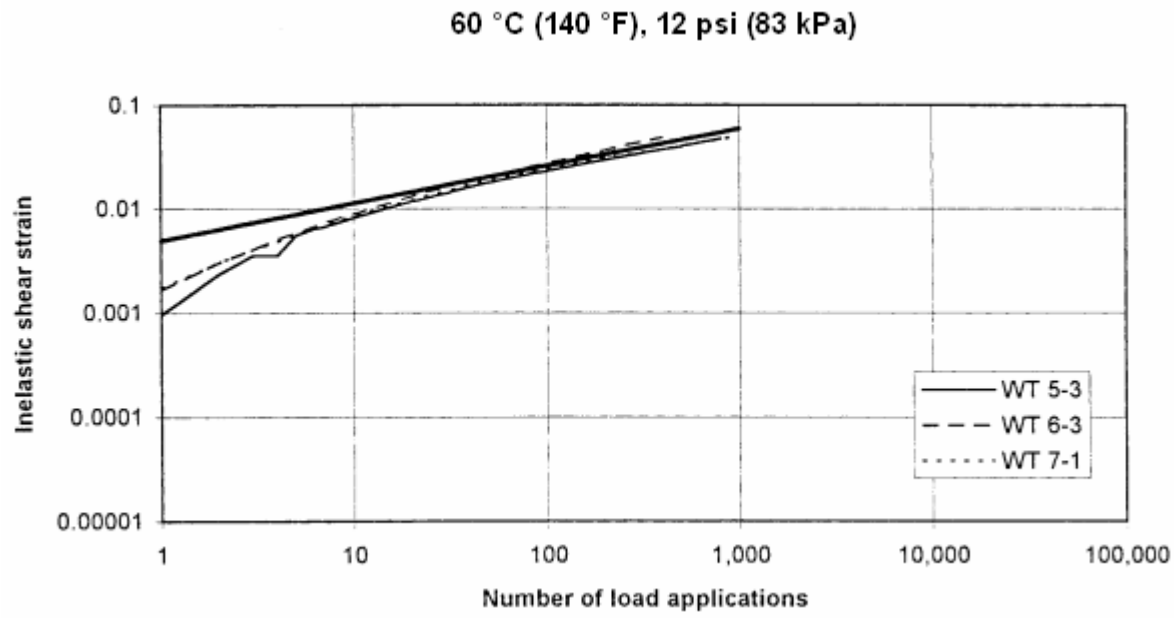
60 °C (140 °F), 12 psi (83 kPa)
Inelastic shear strain
0.1
0.01
0.001
0.0001
0.00001
1
10
100
1,000
10,000
100,000
Number of load applications
WT 5-3
WT 6-3
WT 7-1

Figure K.26.

Asphalt Binder Properties— Original Construction

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-1
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million, 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on the properties of the asphalt binder used during "original construction" of the HMA during the period of September to October 1995. The report describes the asphalt binder grade selection process, the selection of the binder source, and the properties of the asphalt binder used for construction. Asphalt binder properties were determined using both the Superpave binder test equipment and conventional viscosity testing equipment. Variability of properties of samples obtained during construction were determined and are contained in the report.

This report provides only information on asphalt binder samples obtained during construction (original binders) and does not contain aging information on the asphalt binder during the hot-mix process and in service during the life of the facility. Original construction asphalt binder aging information is provided in a separate WesTrack technical report. Likewise, properties of the asphalt binder used in the ten "replacement sections" are contained in a separate report.

BACKGROUND

BINDER GRADE SELECTION

The WesTrack team held several discussions on the selection of the asphalt binder for the project. Due to the limited number of test sections (26) available at the WesTrack accelerated test facility, a decision was made to use a single asphalt binder that would meet the Superpave specification requirements for the track location. Since the Superpave binder specification was developed primarily on research conducted on "neat" or non-modified asphalt binders, and since some issues were being raised relative to the suitability of the SHRP-developed asphalt binder test methods for use with modified asphalt binders, the research team elected to use a non-modified asphalt binder.

The SHRP-developed "SHRPBIND" software was used to select the asphalt binder grade for WesTrack.[4] Nine weather stations in the northwest portion of Nevada with similar elevations were selected and SHRPBIND was used to determine the performance-graded (PG) binder for use at each location. Table 1 contains a summary of the output from SHRPBIND. Reliability for selected grades are shown for each weather station and the PG grade for 50 percent and 98 percent reliability are given.

The weather stations at Fernley, Lahontan Dam, Wellington, and Yerrington are in the same general area (within 50 km [30 mi]) and at approximately the same elevation (1,300 m [4,100 ft]). The Lahontan Dam weather station site is approximately 12 km (7 mi) from the site and about the same elevation. The 50 percentile asphalt binder grade for Lahontan Dam is a PG 58-16, while the 98 percentile asphalt binder grade is a PG 64-28.

For the Lahontan weather station, table 1 indicates that a high-temperature designation of 58 would provide a 68 percent reliability and a 64 designation would provide a 98 percent reliability. Table 1 also indicates that the low-temperature designation of -16 would provide a 58 percent reliability, the -22 designation a 94 percent reliability, and the -28 designation a 98 percent reliability for the Lahontan Dam site. A PG 64-22 was selected for the project. Based on the information presented above, the high-temperature designation of 64 should provide for a 98 percent reliability throughout the general geographic area of the test track. The low-temperature designation of -22 should provide for 60 to 90 percentile reliability in the general area.

Superpave binder selection criteria available in late 1994[5] indicated that the asphalt binder grade selected by climate assumes that a binder will be used in an HMA mixture subjected to traffic moving at speeds of approximately 90 km/h (55 mi/h). For traffic moving at slower speeds, an increase in the high-temperature designation of the binder should be considered. An increase of one or two grades, depending on traffic speed, was suggested in existing publications.[5] The geometrics of the track and the driverless vehicle control systems were designed for a 65 km/h (40 mi/h) truck traffic speed. An increase in Superpave asphalt binder grade, based on speed, could not be justified based on available information.

Superpave binder selection criteria available in late 1994[6] also indicated that the asphalt binder grade selected by climate assumes that the design traffic level is less than 10 million ESALs. When the design traffic level exceeds 10 million ESALs, the designer is encouraged to "consider" increasing the high-temperature designation by one grade. When the design traffic level exceeds 30 million ESALs, the designer is required to increase the high-temperature designation by one grade. These guidelines were considered by the WesTrack team. Since the expected total traffic on the facility was to be 10 million ESALs and since the basis for this high-temperature designation increase was "considered" to be based on little published engineering information, the WesTrack team elected not to increase the asphalt binder high-temperature designation. It should be recognized that WesTrack was an accelerated test track experiment and hence the traffic level (average daily truck traffic) was relatively high and was imposed at a rate equivalent to 20 to 30 million ESALs over a 20-year period.

ASPHALT BINDER SOURCE

Based on the above-described binder selection process, a PG 64-28 neat asphalt cement was the desired binder as both the high and low temperature reliability were above 98 percent. Data were collected from refineries and departments of transportation in several western states in an attempt to locate a PG 64-28 neat asphalt cement. None of the refineries indicated that they could reliably produce a PG 64-28 neat asphalt cement. Two sources of PG 64-22 were located. A PG 64-22 could reliably be produced from western Canadian crude and was available from either United States or Canadian refineries. A second source of PG 64-22 was available from a San Francisco Bay area refinery and was a blend of a domestic and foreign crude. A decision was made to work with the San Francisco Bay area refinery due to its proximity, the willingness of the refinery to produce a "tank" of the asphalt binder and hold the tank until construction, and a price for the asphalt binder about $50 per ton less than from alternate sources.

The selection of the PG 64-22 grade, rather than a PG 64-28 grade was based on both the Superpave-designated grade, and the availability of the PG 64-22. Only modified PG 64-28 grades of asphalt binders were reliably available in the western states in late 1994 and early 1995. As indicated above, the high-temperature designation of 64 provided a 98 percent reliability and the -22 low-temperature designation provided a 60 to 94 percent reliability, depending on the weather station selected, as shown in table 1. The Lahontan Dam weather station, only about 12 km (7 mi) from the test track, indicated a 94 percentile low-temperature reliability as shown in table 1.

The final selection of the -22 low-temperature grade was, therefore, based on the following criteria:

- Availability of -22 low-temperature neat asphalt binder at reasonable cost.
- Relatively high reliability of 90 percent plus for -22 grade.
- Low probability of thermal cracking in only 3 years of operation of the test track.
- Low probability of thermal cracking due to the short length of the test sections.

Properties of the asphalt binder used for mixture design and construction on WesTrack are provided below. The sampling plan and the test methods used for property determination, as well as an analysis of the data collected on these asphalt binders, are also described.

SAMPLING

SAMPLING PLAN

The Task G Interim Report for the project provided detailed sampling and testing plans for the construction of WesTrack.[3] Samples of the asphalt binder were obtained prior to the start of construction for verification of the asphalt binder properties and to provide asphalt binder for mixture design purposes. During construction of the HMA, two samples of asphalt binder were obtained during placement of the "trial sections," samples were obtained from each transport load of asphalt binder used for placement of the "test sections," and samples were obtained at the end of the paving operation. Additional samples were obtained during placement of the curves and a relatively large amount of asphalt binder was obtained for storage at the FHWA's Materials Reference Library in Reno, Nevada. Trial sections were utilized to finalize mixture design and to establish roller patterns prior to placement of the test sections on which the traffic was placed.

SAMPLING LOCATION

The samples were obtained by Granite Construction personnel from the asphalt binder storage tanks at the HMA production facility. The sampling date, sampling time, and number of samples taken at each sampling period are shown in table 2.

The sampling date represents the asphalt binder used for production of the HMA the following day. The binder was typically supplied to the contractor by the refiner one day prior to paving. Table 3 provides information to allow for the asphalt binder sampling date to match with the HMA production and paving dates, and hence the lift and section number. As noted, multiple samples were taken on some paving days and, in some cases, split samples were obtained at the same sampling time on the same day. Data obtained on these samples are reported below.

TEST METHODS AND TEST SEQUENCE

Two separate testing programs were conducted on the asphalt binder samples obtained from the WesTrack project. Superpave binder tests were performed according to American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM) procedures, in order to determine the binder PG. In addition, conventional viscosity binder testing was performed according to AASHTO and ASTM procedures to determine if the asphalt binder satisfied the viscosity grading designations as described in table 2 of AASHTO M 226 and ASTM D 3381. Test methods and the test sequence for each of these programs are described below.

SUPERPAVE BINDER TESTING

Test Methods

Two forms of Superpave binder testing were used in the WesTrack project. Classification testing to determine the asphalt binder PG was performed during the initial phases of the project, and to a limited, degree during the conduct of the project. Conformance testing was performed during the construction of the project to verify that the asphalt binder met the requirements for PG 64-22. Conformance testing involves performing binder tests only at the temperatures required for the verification of the desired grade. Classification testing requires testing over a range of temperatures to determine the grade of the asphalt binder. Table 4 identifies the Superpave binder tests used in this project.

Test Sequence

The test sequence used for grading the asphalt binder samples (with respect to the Superpave specification) is shown in figure 1. The dynamic shear modulus (stiffness measurement) for original and aged asphalt binder samples was determined at four temperatures; 52°C, 58°C, 64°C, and 70°C. Testing over this range of temperatures allowed for the high-temperature specification designation to be defined as well as to maintain the accuracy of the data set. Four intermediate temperatures were also selected (16°C, 19°C, 22°C, and 25°C) to determine the stiffness of the binder at temperatures associated with fatigue of asphalt-bound pavements.

Two temperatures were selected to determine the low-temperature properties of the binder. Bending beam rheometer (BBR) tests were performed at -12°C and -18°C. The low-temperature designation of the asphalt binder was determined from these data.

The loading rate of 10 radians per second was used to perform the classification testing described above. Additional tests were performed at different loading rates. The loading rate was increased from 1 to 10 radians per second at constant temperatures of 52°C, 58°C, and 64°C to provide a wide range of stiffness values. The test was performed three times for each temperature and loading rate. Samples obtained on October 2 and 4, 1995, were selected for this testing.

VISCOSITY BINDER TESTING

Test Methods

The test methods shown in table 5 were used to determine the asphalt binder properties and classify the binder according to the AASHTO and ASTM viscosity grading system. The penetration of the asphalt cement was also determined at 4°C. The penetration test is normally not performed at this temperature to determine compliance with specifications used in the United States. The penetration at 4°C can be used to determine an index for asphalt binder temperature sensitivity and, therefore, was included in the test sequence.

Test Sequence

The test sequence used for classification of the asphalt binder according to the viscosity grading system is shown in figure 2. Viscosity was determined at 60°C and 135°C and penetration at 4°C and 25°C. The asphalt binder was aged by use of the rolling thin film oven test (RTFOT) and tested for viscosity at 60°C, penetration at 25°C, and ductility at 25°C. The rolling thin film oven test was used rather than the thin film oven test (TFOT), as the RTFOT is used to classify asphalt according to the Superpave grading system.

TEST RESULTS

Asphalt binder test results were obtained on samples obtained prior to construction and used for mixture design purposes, during placement of "trial lane" sections, and during placement of the "test lane" sections. Information obtained prior to the start of HMA placement will be discussed below in the Preconstruction section. During construction, a limited number of tests was conducted on samples obtained from the contractor's storage tank. These test results will be discussed in the Quality Control section. After construction, samples of the asphalt binder that were taken during the placement of the test lanes were extensively tested. Results obtained on binder samples tested after construction will be discussed in the Quality Assurance section.

PRECONSTRUCTION

Construction of the HMA started on September 9, 1995. The plant calibration (asphalt binder and aggregate) was performed on September 8, 1995. Test results from samples of asphalt binders tested by the University of Nevada Pavement and Materials Laboratory, prior to the start of production, are shown in table 6. These samples are identified as sample numbers 1 through 4.

Samples designated as numbers 1 and 2 were used to verify the grade and for use in mixture designs prior to June 24, 1995. This asphalt meets the PG 64-22 grade designation criteria. On June 10, 1995, the refinery notified the WesTrack team that the binder represented as samples number 1 and 2 would not be available for the project as the source of the foreign crude, used to blend with the domestic crude, would not be available to produce the desired asphalt. Sample numbers 3 and 4 were supplied by the refinery for use in mixture design and to verify the grade.

One of the two preconstruction samples tested by the University of Nevada (sample 3) did not meet the desired PG designation. The asphalt binder did not meet the intermediate temperature (fatigue) properties for a PG 64-22 and was classified as a PG 64-16. Samples were tested by the refinery and the University during the period prior to construction. The refinery and the University exchanged samples of binders and compared test results on split samples to assure that the asphalt binder did meet the desired PG grade. Test results of all of these split samples and the refinery test results are not contained in this report, but are available in the project

files. A blend of domestic crudes was used to produce the asphalt binder represented by samples 3 through 8 in table 5 and this represents the asphalt binder used during the construction of WesTrack.

QUALITY CONTROL

Placement of the HMA at WesTrack started on September 9, 1995, and was completed on October 7, 1995. The test lanes were placed during the period of September 21 to October 4, 1995. As described above, numerous samples of the asphalt binder were obtained during construction. Some of the asphalt binders were tested during construction (quality control tests) and some of the samples were tested after construction (quality assurance tests). Quality control asphalt binder test results, shown in table 6 and appendix A, are identified as samples 5 through 8. As noted, replicate samples were tested by the University of Nevada during this period as several of the samples failed to meet the PG 64-22 criteria. In some cases, the original binder dynamic shear rheometer (DSR) test results were below the acceptance criteria. The fatigue or intermediate temperature DSR value was out of the specification limits on one sample and the bending bean rheometer (BBR) stiffness and "m" value were out of the specification range in other cases. Based on these data, the asphalt binder was considered to be marginal in its ability to meet the desired PG 64-22 specification criteria. In order to complete construction of the test facility prior to the winter of 1995-1996, a decision was made to proceed with the existing asphalt binder to complete the project. Quality assurance testing was to be used to define the properties of the binder that was used during placement of the test lanes.

QUALITY ASSURANCE

Post construction asphalt binder samples were tested from samples obtained on September 14, 18, 19, 20, 28, and 29 and October 1, 2, and 4, 1999. Table 3 indicates that samples obtained on September 19 represent the bottom lift of the fine graded mixture test lane, samples obtained on September 20 represent the bottom lift of the fine plus graded mixture test lane, samples obtained on September 29 represent the bottom lift of the coarse graded mixture test lane, samples obtained on October 1 represent the top lift of the fine graded mixture test lane, samples obtained on October 2 represent the top lift of the fine plus graded mixture test lane, and samples obtained on October 4 represent the top lift of the coarse graded mixture test lane. Replicate samples on some dates were available or additional split samples were tested to investigate variability over a 1-day sampling period.

Superpave Grading System

Quality assurance Superpave test results are shown in tables 7 and 8 and appendix B. Table 7 shows the rheologic properties of the binders at the test temperature associated with a PG 64-22 or PG 64-16 grade classification. For example, the original and RTFOT DSR values are reported at 64°C. The DSR values after the pressure aging vessel (PAV) are reported at a temperature of 25°C for the PG 64-22 grade and at 28°C for the PG 64-16 grade. The BBR test results are reported for a temperature of -12°C.

Twenty samples were tested in the quality assurance testing program. Seventeen of the 20 samples met the DSR and BBR requirements for a PG 64-22 Superpave binder. All three of the

samples that failed to meet the PG 64-22 requirements were in excess of the limits on the intermediate temperature DSR as shown in table 8.

Viscosity Grading System

Table 9 contains results of tests that allow the asphalt binder to be graded according to the viscosity grading system. Viscosity determinations at 60°C indicated that the binder is graded as an AC-20 asphalt cement. The viscosity of the asphalt binders tested indicated that all exceeded the required minimum viscosity requirement of 300 centistokes at 135°C.

As described in table 2 of the specification for AC-20, the minimum requirement for penetration at 25°C is 60. Most of the samples tested indicated a penetration value of less than 60. The average reported value was 56. The reported flash points and solubility values met the specification requirements.

Properties of the binder after aging by the RTFOT indicate that binder viscosity and ductility are within acceptable limits as shown in table 9.

DATA ANALYSIS

VARIABILITY

Tables 7 through 9 contain information from 20 samples obtained on nine sample dates. Three sample dates and times contained replicate samples to investigate test variability on split field samples. Tables 10 through 12 contain test results summarized from 13 samples obtained from different dates or times of day. Replicate samples are not present in this data set. One of the three replicate samples was randomly selected from those dates with replicate samples in tables 7 through 9 to create the 13 samples whose results are presented in tables 10 through 12.

The average, standard deviation, and coefficient of variation were determined for each parameter tested as shown in tables 10 through 12. All tests were performed by a single operator in a single laboratory. The statistics, therefore, represent variability of an asphalt binder supplied over a 20-day period as determined by a single operator in a single laboratory.

Figures 3 through 6 show control type charts for Superpave binder tests with specification limits. Figures 3 and 4 describe the temperatures at which the specification limits are met. Figures 5 and 6 describe the test parameter values at the Superpave binder specification temperature for the PG 64-22 binder (64°C, 25°C, and -12°C).

Comparisons of the variability of WesTrack quality assurance testing with a National and regional round-robin testing program have been performed and are reported in reference 7.

Tables 13 through 15 show within laboratory variability for samples with replicates obtained on September 20 and October 2 and 4, 1995. Variability is shown for both Superpave tests and conventional binder tests. Comparison of WesTrack within-laboratory variability with within-laboratory variability from other studies[8] is shown in table 16. Table 17 shows between-laboratory variability tests from the AASHTO Materials Reference Laboratory proficiency sample programs compared to WesTrack results.

WesTrack quality assurance testing has low variability as compared to the variability reported for both the within- and between-laboratory variability studies. The WesTrack quality assurance testing program contained both within-laboratory variability as well as variability associated with the production of the asphalt binder over a 20-day period.

FREQUENCY SWEEP

The stiffness of the WesTrack binder was obtained over a range of temperatures and at different test frequencies that ranged from 1 to 10 radians per second. Test results from samples obtained on October 2 and 4, 1995, are shown in figures 7 and 8, respectively, and in appendix C. These data can be used to determine time-temperature shift factors, etc.

TEMPERATURE SUSCEPTIBILITY

Temperature susceptibility parameters determined from conventional penetration and viscosity tests have been determined for the WesTrack binder.[7] These parameters are based on a summary of the literature and typical results presented for binders in reference 9. Table 18 contains a listing of penetration/viscosity numbers and penetration ratio values for the WesTrack binders.

Figures 9 through 11 show the relationship among the WesTrack binder and historically typical asphalts as utilized in the United States.[9,10] The WesTrack asphalt is similar to most AC-20 asphalt cements that have been used in the United States as shown in figures 9 through 11.

SUMMARY

Tables 19 and 20 have been developed to summarize the asphalt binder test property information contained in this report. The average Superpave and viscosity graded binder properties determined from the 13 samples obtained during the placement of the HMA at WesTrack and presented in tables 10 and 12 were used to develop tables 14 and 15.

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9. Epps, J., Button, J.W., and Gallaway, B.M., "Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance," Transportation Research Board, Record 268, December 1983.

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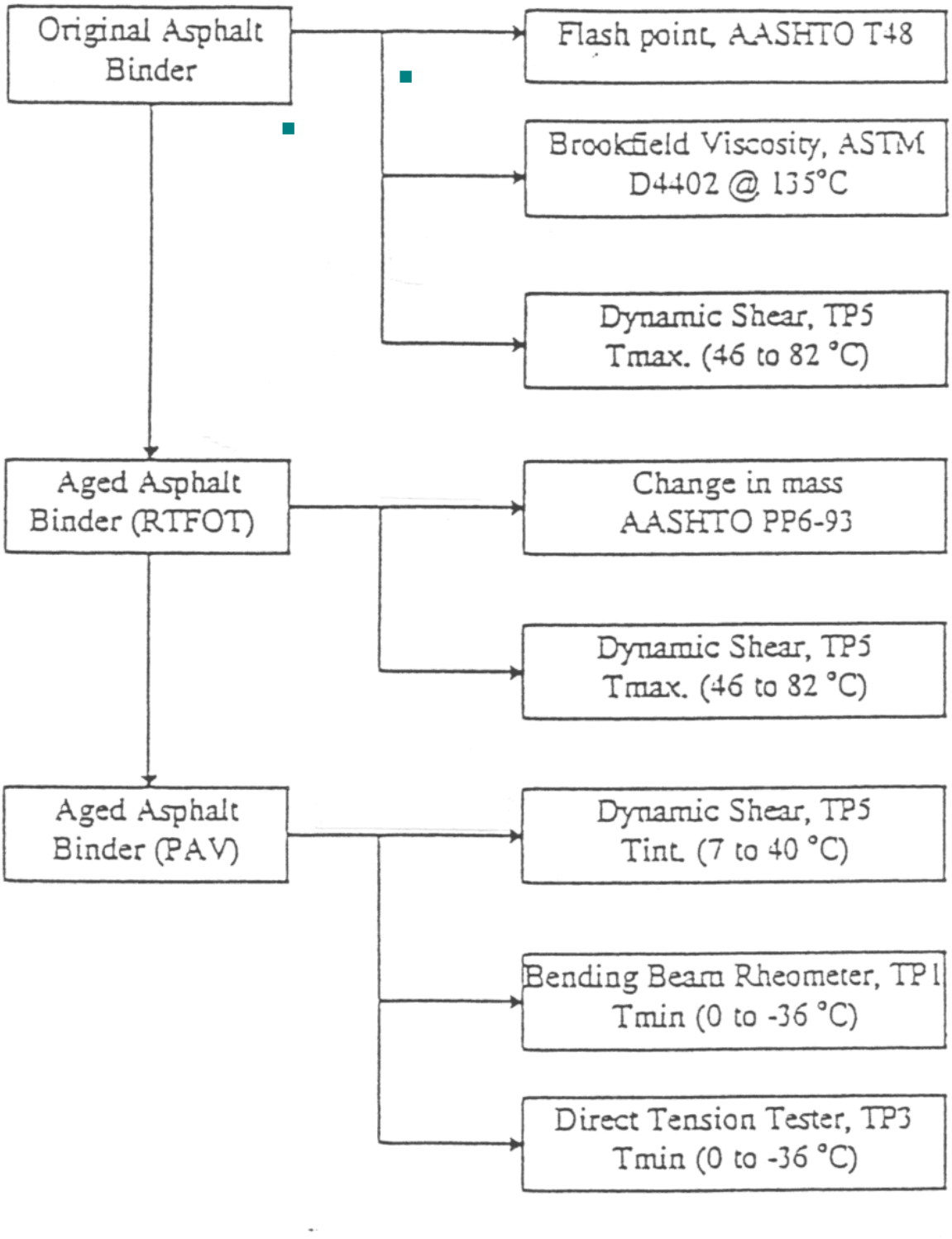


Figure 1. Test sequence for Superpave asphalt binder grade classification.

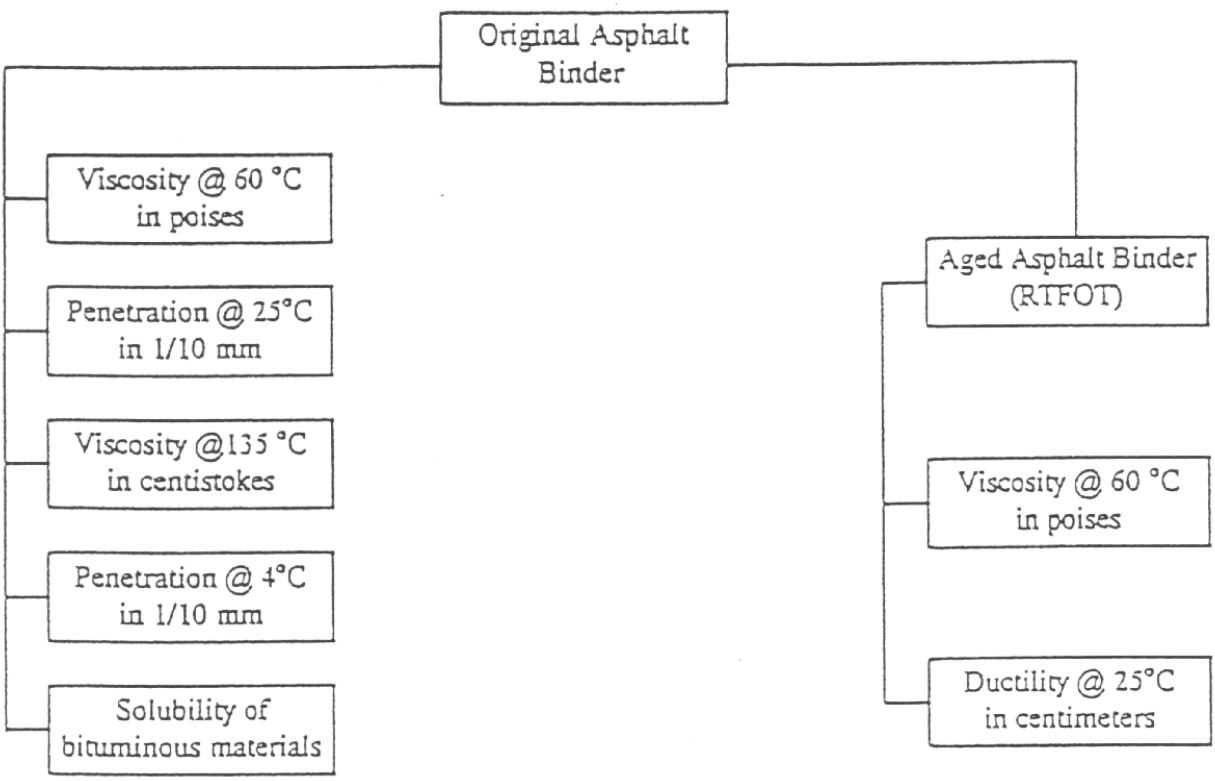


Figure 2. Test sequence for viscosity grade classification.

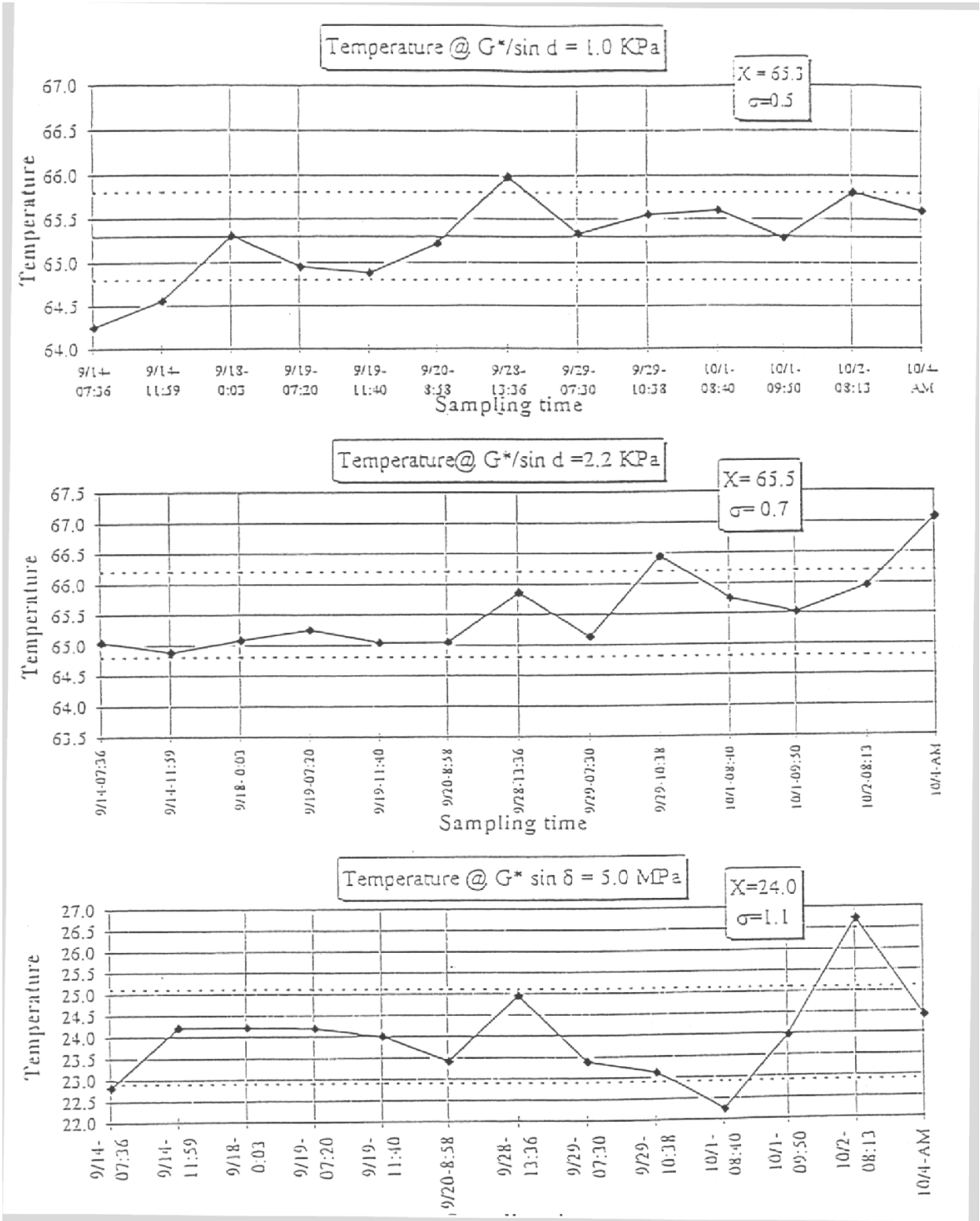


Figure 3. Superpave binder test results.

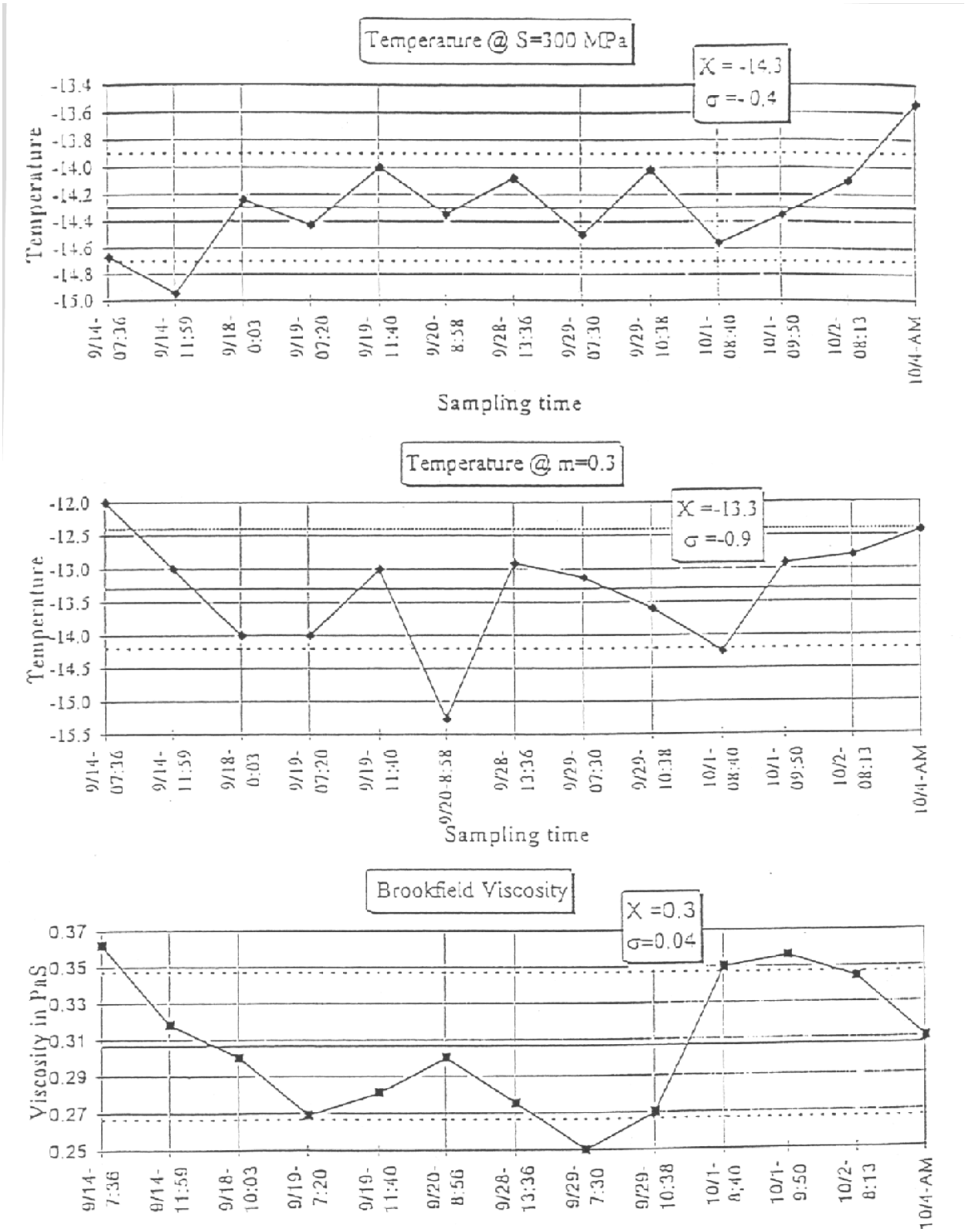


Figure 4. Superpave binder test results.

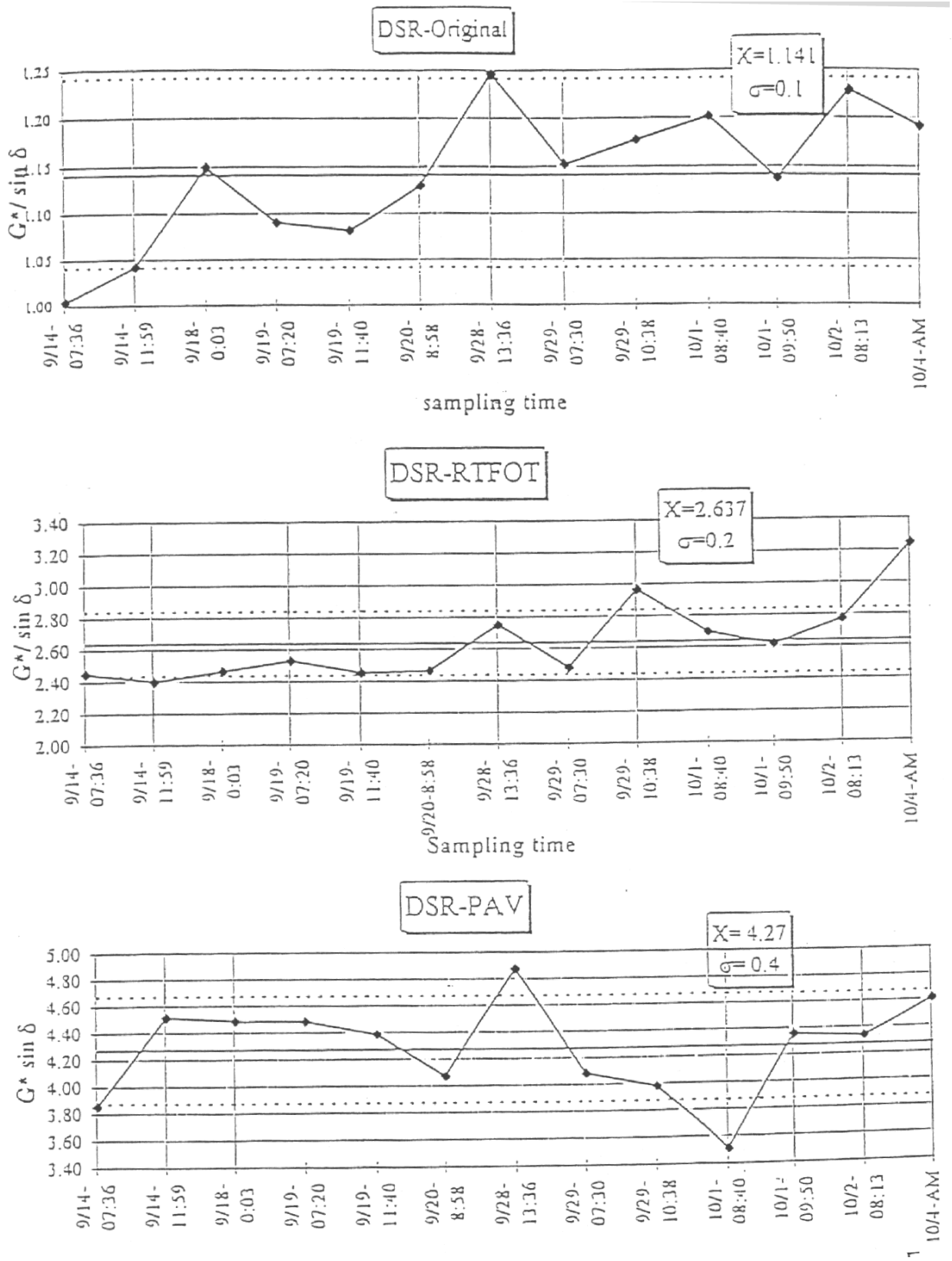


Figure 5. Superpave binder test results.

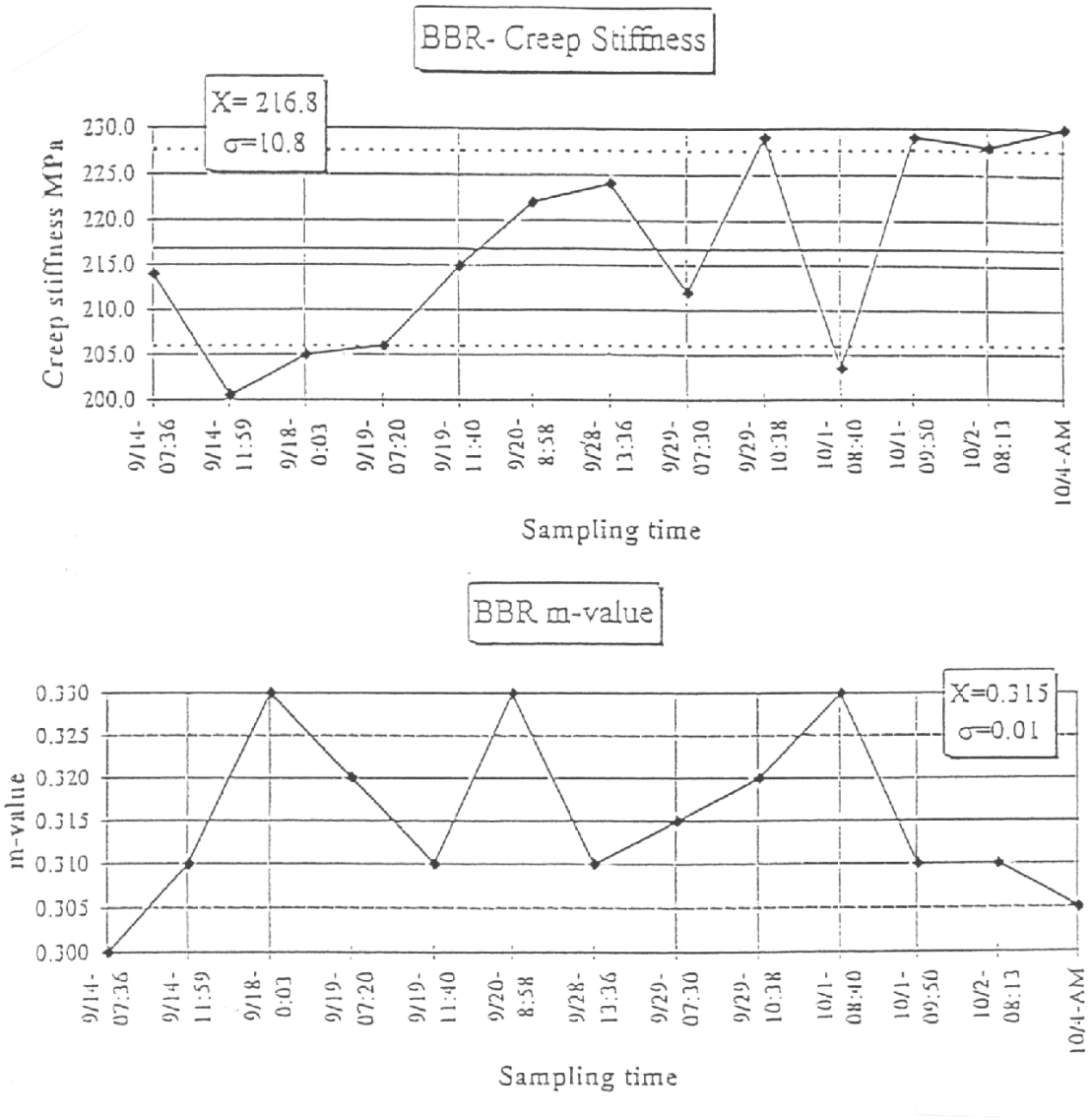
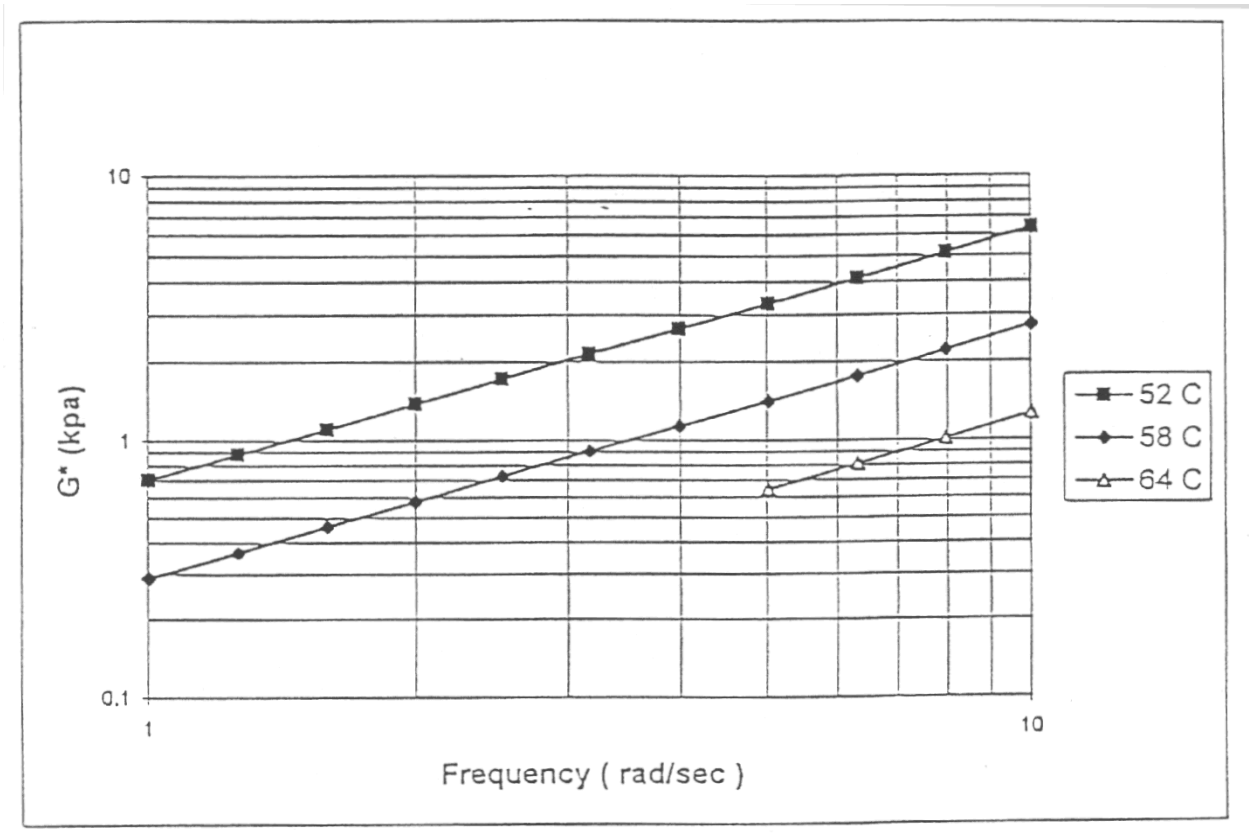
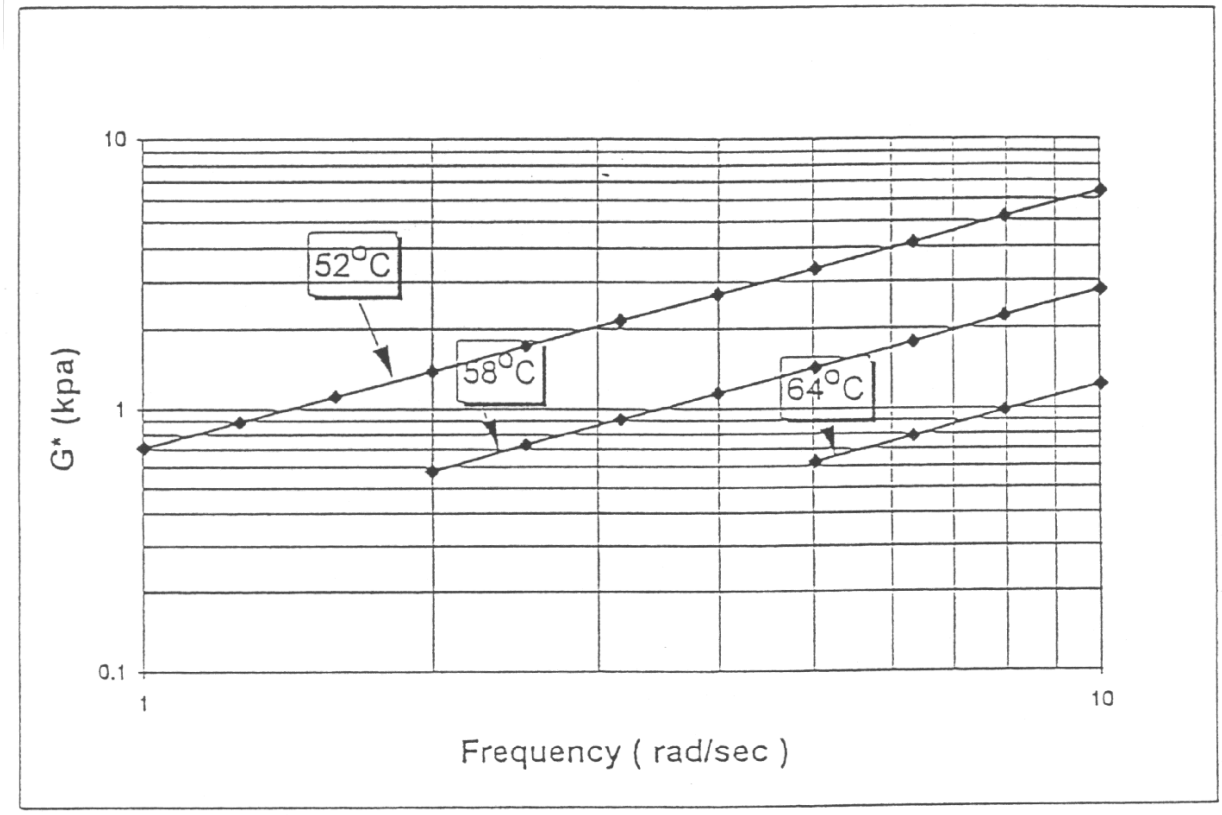


Figure 6. Superpave binder test results.



*Sampled date: 10/2 - sampled time: 8:13 a.m.

Figure 7. Superpave binder test results — frequency sweep test.



*Sampled date: 10/4

Figure 8. Superpave binder test results –
frequency sweep test.

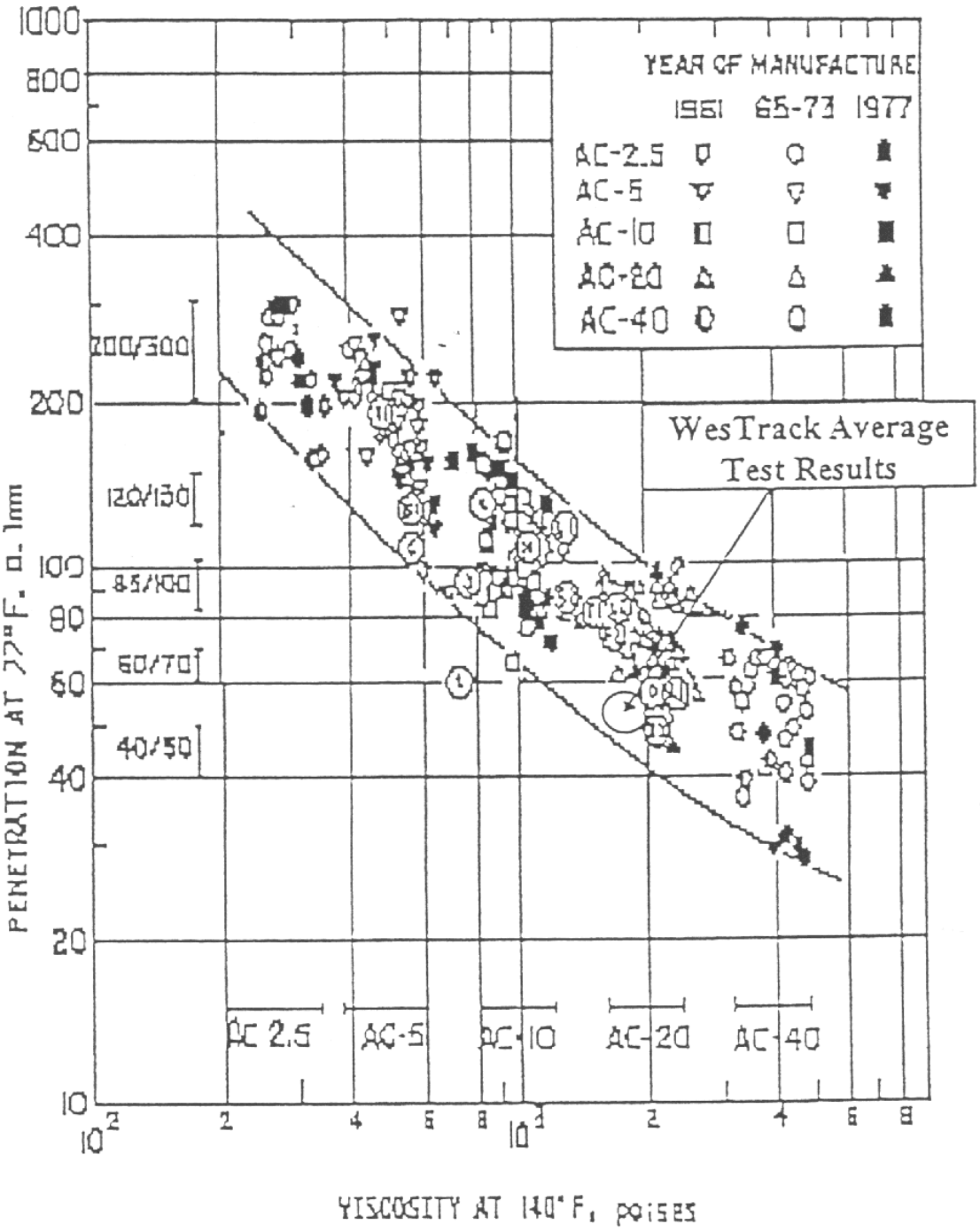


Figure 9. Relationship between viscosity at 60ºC (140ºF) and penetration at 25ºC (77ºF) for asphalt cements.

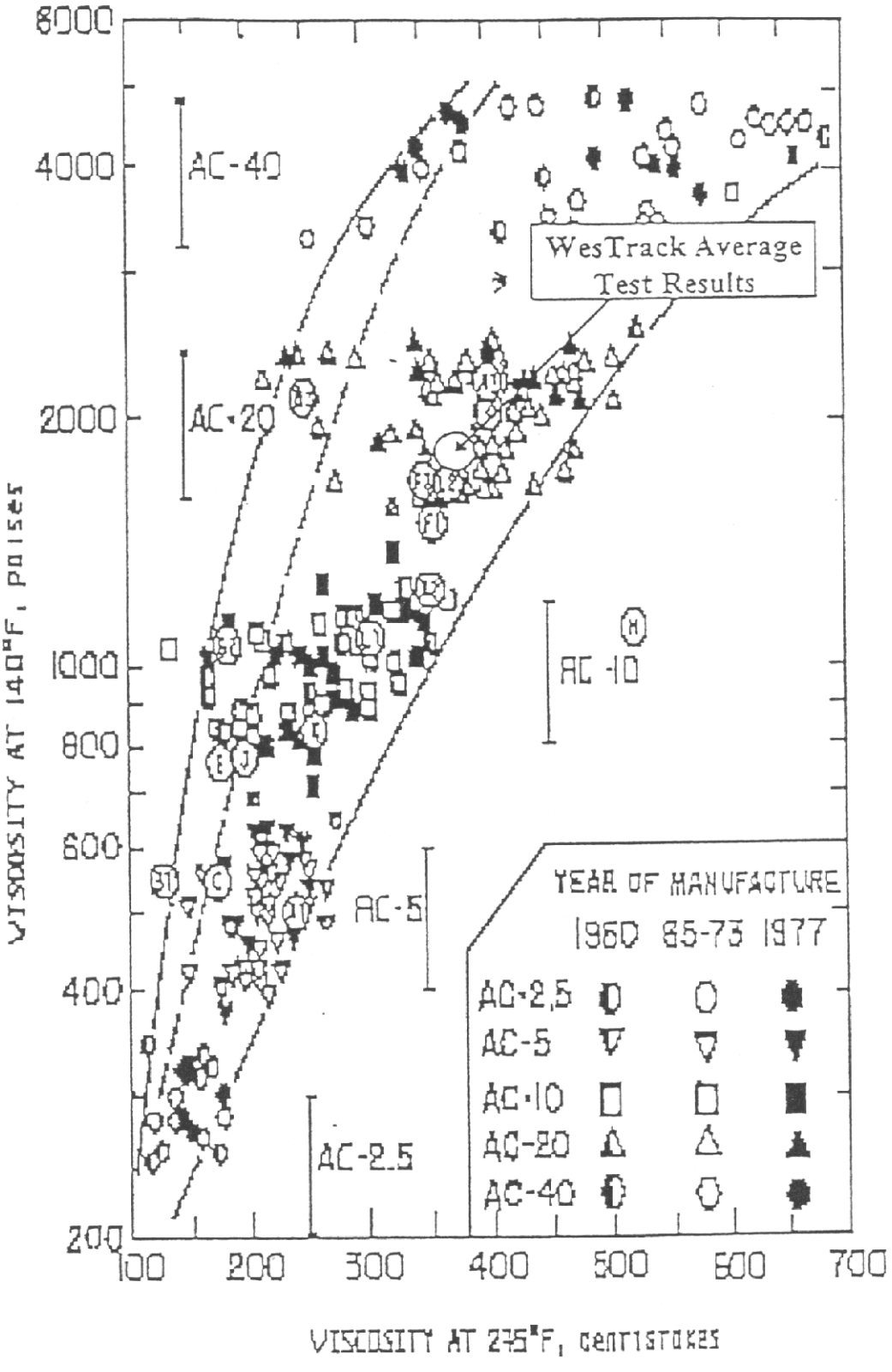


Figure 10. Relationship between viscosity at 60ºC (140ºF) and 135ºC (275ºF) for asphalt cements.

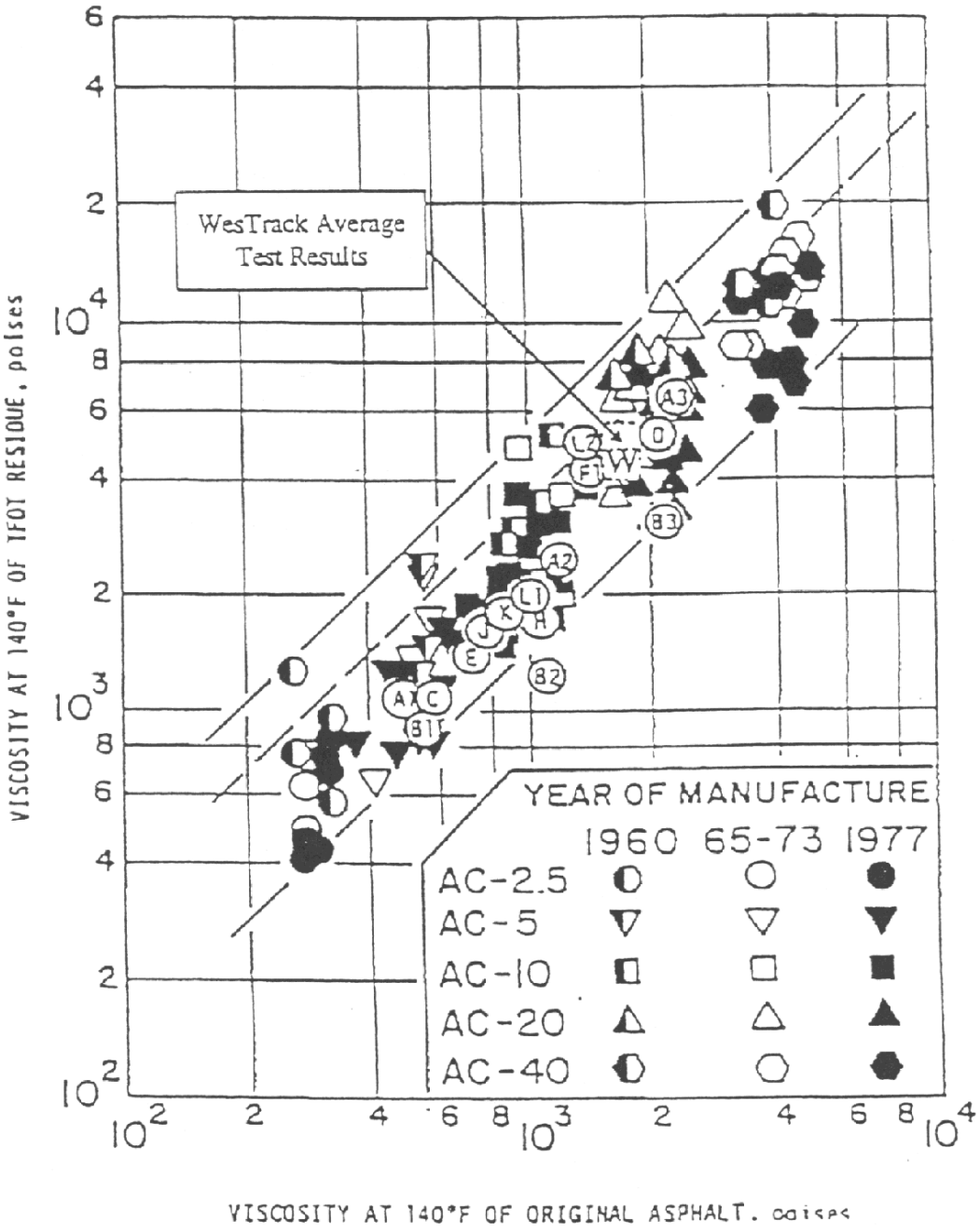


Figure 11. Relationship between viscosities at 60°C for original and aged asphalts.

Table 1. Asphalt binder grade selection reliability.

Weather Station	Reliability for Indicated PG Grade							Grade for Indicated Reliability	
	58-16	58-22	58-28	58-34	64-22	64-28	64-34	Minimum 50%	Minimum 98%
Fallon Exp Stn		85-72*	85-96			98-96	98-98	58-22	64-34
Fernley		68-77			98-77	98-98		58-22	64-28
Gerlach		77-70	77-94			98-94	98-98	58-22	64-34
Lahontan Dam	68-58	68-94			98-94	98-98		58-16	64-28
Reno WSFO AP		95-81	95-98			98-98		58-22	64-28
Sand Pass		72-84			98-84	98-98		58-22	64-28
Virginia City	98-72	98-98						58-16	58-22
Yerrington R5		98-60	98-96	98-98				58-22	58-34
Yerrington		93-65	93-94			98-94	98-98	58-22	64-34

*High and low temperature reliability.

Table 2. Asphalt binder sampling times and dates.

No. of Samples	Sampling Date	Sampling Time
2	9/14	07:36
2	9/14	11:59
2	9/15	07:15
1	9/18	10:03
2	9/19	07:20
2	9/19	11:40
1	9/19	05:51
2	9/20	08:58
2	9/21	12:10
1	9/21	06:00
2	9/22	12:23
2	9/22	09:27
2	9/23	07:02
2	9/23	11:02
3	9/28	10:08
2	9/28	13:36
1	9/28	N/A
1	9/29	10:38
1	9/29	07:30
8	9/30	09:47
1	9/30	08:55
7	9/30	08:35
11	10/1	08:40
9	10/1	09:52
19	10/2	08:13
39	10/4	N/A
4	N/A	N/A

Table 3. Asphalt binder samples and representative test lane sections.

No. of Samples	Date of Sampling	Time of Sampling	Represents			Mixture Designa-tion
			Lane-Lift	Mix No.	Section No.	
1	9/19	07:20	Test-Bottom	1-9	1-2-3-4-14-15-16-17-18	Fine
1	9/19	11:40				
1	9/20	08:58	Test-Bottom	10-18	19-20-21-22-9-10-11-12-13	Fine plus
1	9/20	08:58				
1	9/29	07:30	Test-Bottom	19-26	5-6-7-8-23-24-25-26	Coarse
1	9/29	10:38				
1	10/1	08:40	Test-Top	1-9	1-2-3-4-14-15-16-17-18	Fine
1	10/1	09:50				
1	10/2	08:13	Test-Top	10-18	19-20-21-22-9-10-11-12-13	Fine plus
1	10/2	08:13				
1	10/4	A.M.	Test-Top	19-26	5-6-7-8-23-24-25-26	Coarse
1	10/4	A.M.				
1	9/14	07:36	Beginning of project			Fine plus
1	9/14	11:59				
1	10/4	A.M.	End of project			Coarse
1	10/4	A.M.				
1	9/18	10:03	Curves			Coarse
1	9/28	13:36	Curves			Coarse

Table 4. Superpave asphalt binder tests.

Description	Designation	
	ASTM	AASHTO
Flash point	D 92	T 48
Brookfield viscometer	D 4402	
Dynamic shear rheometer		TP 5
Mass loss		PP 6-93
Bending beam rheometer		TP 1
Direct tension tester		TP 3
Rolling thin film oven test	D 2872	T 240
Pressure aging vessel		PP 1

Table 5. Viscosity asphalt binder tests.

Description	Designation	
	ASTM	AASHTO
Flash point	D 92	T 48
Solubility of bituminous materials	D 2042	T 44
Ductility of bituminous materials	D 113	T 51
Penetration of bituminous materials @ 25°C	D 5	T 49
Kinematic viscosity of asphalt @ 135°C	D 2970	T 201
Absolute viscosity of asphalt @ 60°C	D 2171	T 202
Thin film oven test	D 1754	

Table 6. WesTrack preconstruction and quality control – SHRP binder test results.

No.	Binder I.D.	Date	Test Method					PG
			DSR-Original Temp @ 1.0 kPa	DSR-RTFOT Temp @ 2.2 kPa	DSR-PAV Temp @ 5.0 MPa	BBR		
						Temp @ 300 MPa	Temp @ m=0.3	
1	Huntway VZ-49		80.2	64.6	22	-15.1	-16.3	64-22
2	Huntway VZ-50		66.3	66.9	22.1	-16	-16	64-22
3	Huntway PBA-5	6/22/95	66.06	>64	25.43	-12.39	-13.54	64-16
4	Huntway 1512	6/29/95	>64	>64	21.55	-14.21	-12.75	64-22
5	Huntway truck Sample 2-Rep. 1 Huntway truck Sample 2-Rep. 2 Huntway truck Sample 2-Rep.3	9/08/95	63.5 64.25 64.51	63.23		-12.89 -14.14 -12.43	-13.84 -14.19 -14.44	58-22 64-22 64-22
6	Huntway 215 Rep. 1 Huntway 215 Rep. 2 Huntway 215 Rep. 3	9/11/95	61.69 61.92 64.32	64.31 64.46 63.97	24.12 23.34	-13.84 -13.63 -12.32	-14.06 -14.08 -13.16	58-16 58-16 64-22
7	Huntway truck Sample 3-Rep. 1 Huntway truck Sample 3-Rep. 2 Huntway truck Sample 3-Rep. 3 Huntway truck Sample 3-Rep. 4	9/18/95 4:30 A.M.	65.2 64.65 64.95 65.02	64.5 65.06	16.05 20.26	-18.39 -11.29 -11.29	-10.81 -12.99 -12.01	64-16 64-16 64-16
8	Huntway 471-1(Ref. sample) Huntway 471-1(Ref. sample)	9/20/95	65.2 64.9	64.3 64.1	25.6 24.	-14.6 -13.8	-10.8 -12.3	64-16 64-22

Table 7. Superpave quality assurance binder test results.

Sampled Date	Sampled Time	DSR-Original			DSR-RTFOT			DSR-PAV			BBR		PG-Grade
		G*(kPa)	δ	G*/sinδ	G*(kPa)	δ	G*/sinδ	G*(kPa)	δ	G*/sinδ	S (t)	m	
9/14	07:36	1.003	87.2	1.004	2.439	84.3	2.451	5.374	45.8	3.853	214.0	0.300	64-22
	11:59	1.041	87.0	1.042	2.389	84.2	2.401	6.346	45.3	4.511	200.5	0.310	64-22
9/18	10:03	1.148	87.2	1.149	2.454	84.5	2.465	6.045	47.9	4.483	205.0	0.330	64-22
9/19	07:20	1.089	87.3	1.090	2.518	84.3	2.531	6.115	47.1	4.479	206.0	0.320	64-22
	11:40	1.081	87.2	1.082	2.443	84.7	2.453	5.941	47.5	4.381	215.0	0.310	64-22
9/20	8:58 No. 1	1.244	84.7	1.249	2.395	84.5	2.406	4.454	48.0	3.308	215.5	0.335	64-22
	8:58 No. 2	1.127	87.2	1.128	2.577	84.4	2.589	5.751	48.6	4.313	215.0	0.335	64-22
	8:58 No. 3	1.129	87.1	1.130	2.455	84.5	2.466	5.450	48.3	4.071	222.0	0.330	64-22
9/28	13:36	1.245	87.0	1.246	2.735	84.3	2.748	6.660	47.1	4.874	224.0	0.310	64-22
9/29	07:30	1.151	87.4	1.152	2.469	84.6	2.480	5.533	47.5	4.080	212.0	0.315	64-22
	10:38	1.176	87.3	1.177	2.951	84.4	2.965	5.411	47.3	3.978	229.0	0.320	64-22
10/1	08:40	1.199	86.9	1.201	2.687	84.1	2.692	4.526	50.8	3.505	203.5	0.330	64-22
	09:50	1.136	87.2	1.137	2.604	84.2	2.617	5.879	47.8	4.353	229.0	0.310	64-22
10/2	8:13 No. 1	1.227	87.3	1.228	2.754	84.3	2.768	5.524	51.6	4.332	228.0	0.310	64-16
	8:13 No. 2	1.236	87.3	1.237	2.763	84.4	2.776	5.092	50.8	3.948	230.5	0.315	64-16
	8:13 No. 3	1.195	87.0	1.196	2.613	84.2	2.626	6.076	49.9	4.649	216.0	0.320	64-22
10/4	A.M. No. 1	1.232	87.5	1.233	2.324	84.9	2.333	6.562	47.7	4.855	233.0	0.305	64-22
	A.M. No. 2	1.240	86.8	1.242	2.800	82.9	2.822	5.061	51.5	3.960	246.0	0.310	64-16
	A.M. No. 3	1.117	86.9	1.119	2.710	84.1	2.724	4.859	47.2	3.564	224.5	0.310	64-22
	A.M. No. 4	1.189	86.4	1.191	3.224	83.6	3.244	6.360	46.4	4.607	230.0	0.305	64-22
$\bar{x}$		1.160	87.0	1.162	2.615	84.3	2.628	5.651	48.2	4.205	219.9	0.317	------
σ		0.071	0.6	0.071	0.220	0.4	0.222	0.638	1.8	0.435	11.7	0.011	------
C.O.V		6.1	0.7	6.1	8.4	0.5	8.4	11.3	3.8	10.3	5.3	3.3	---
Number of samples		20											

Table 8. Superpave quality assurance binder test results.

Identification		Superpave								
Sampled Date	Sampled Time	Flash Point	Brook-Field	DSR-Orig. Temp @ 1.0 kPa	Mass-Loss	DSR-RTFOT Temp @ 2.2 kPa	DSR-PAV Temp @ 5.0 KPa	BBR		PG-Grade
								Temp @ 300 MPa	Temp @ m=0.3	
		°C	PaS							
9/14	07:36	285	0.362	64.3	0.23	65.1	22.8	-14.7	-12.0	64-22
	11:59	279	0.318	64.6	0.27	64.9	24.2	-15.0	-13.0	64-22
9/18	10:03	282.2	0.300	65.3	0.25	65.1	24.2	-14.2	-14.0	64-22
9/19	07:20	271	0.269	65.0	0.28	65.3	24.2	-14.4	-14.0	64-22
	11:40	268	0.281	64.9	0.25	65.0	24.0	-14.0	-13.0	64-22
9/20	8:58 No. 1	268	0.306	66.0	0.25	64.9	21.6	-14.6	-15.0	64-22
	8:58 No. 2	279	0.256	65.2	0.25	65.5	23.9	-14.6	-15.2	64-22
	8:58 No. 3	277	0.300	65.2	0.26	65.1	23.4	-14.4	-15.3	64-22
9/28	13:36	274	0.275	66.0	0.24	65.9	24.9	-14.1	-12.9	64-22
9/29	07:30	279	0.250	65.3	0.25	65.1	23.4	-14.5	-13.1	64-22
	10:38	279	0.270	65.6	0.26	66.4	23.1	-14.0	-13.6	64-22
10/1	08:40	274	0.350	65.6	0.23	65.8	22.2	-14.6	-14.3	64-22
	09:50	263	0.356	65.3	0.25	65.5	24.0	-14.4	-12.9	64-22
10/2	8:13 No. 1	282	0.344	65.8	0.24	66.0	26.7	-14.1	-12.8	64-16
	8:13 No. 2	279	0.344	65.9	0.24	66.0	25.9	-13.8	-13.3	64-16
	8:13 No. 3	277	0.362	65.7	0.24	65.6	24.3	-14.2	-13.7	64-22
10/4	A.M No. 1	274	0.300	65.8	0.21	64.7	24.9	-13.9	-12.4	64-22
	A.M No. 2	279	0.320	66.0	0.25	66.3	25.9	-13.4	-12.9	64-16
	A.M No. 3	271	0.360	65.2	0.25	65.8	22.1	-13.8	-12.9	64-22
	A.M No. 4	273	0.310	65.6	0.29	67.1	24.4	-13.5	-12.4	64-22
		275.8	0.312	65.4	0.25	65.5	24.0	-14.2	-13.4	------
$\bar{x}$		5.6	0.309	0.5	0.02	0.6	1.3	0.4	0.9	------
σ		2.0	00.4	0.7	7.1	0.9	5.4	2.8	7.0	------
C.O.V		20								
Number of samples										

Table 9. Conventional quality assurance binder test results.

Sample Identification		ASTM 3381 (Table 2) Specifications for Asphalt Cement Viscosity Graded at 60°C							
		Original						RTFOT	
Sampled Date	Sampled Time	Vis@60°C in Poises	Vis@135°C in cSt.	Pen@25°C in 1/10 mm	Pen@4°C in 1/10 mm	Flash Point in °C	Solubility %	Vis@60°C in Poises	Duct.@25°C in cm
		2000±400	min. 300	min. 60	------ ------	min. 232	min. 99.0	max. 10000	min. 50
Measured Values									
9/14	07:36	1619.2	337.4	61	25	285		4377.8	>50
	11:59	1659.2	346.2	62	25	279		4837.6	>50
9/18	10:03	1928.7	364.7	50	18	282		4514.7	>50
9/19	07:20	1903.7	364.7	49	19	271		4611.2	>50
	11:40	1834.5	360.7	51	19	268		4508.6	>50
9/20	8:58 No.1	1876.8	363.8	54	18	268		4583.5	>50
	8:58 No.2	1934.5	363.9	56	17	279		4731.4	>50
	8:58 No.3	1905.6	365.0	56	18	277	99.9	4708.4	>50
9/28	13:36	1969.0	371.5	58	20	274		4489.5	>50
9/29	07:30	1904.8	362.9	58	20	279		4587.3	>50
	10:38	1999.0	372.4	56	19	279		5474.1	>50
10/1	08:40	2001.7	373.2	53	17	274		4349.5	>50
	09:50	1988.2	373.8	57	17	263		4134.9	>50
10/2	8:13 No.1	1979.0	372.4	56	26	282	99.9	5000.8	>50
	8:13 No.2	2039.0	354.9	56	21	279		5067.0	>50
	8:13 No.3	2075.1	378.7	46	18	277		5138.7	>50
10/4	A.M No.1	2019.0	352.0	59	21	274		4145.4	>50
	A.M No.2	1959.0	346.2	57	23	279	99.9	5000.8	>50
	A.M No.3	1999.0	343.3	57	20	271		4869.2	>50
	A.M No.4	1979.0	363.6	58	21	273		5790.4	>50
$\bar{x}$		1928.7	361.6	55.5	20.1	275.8	------	4746.0	------
σ		114.7	11.4	4.0	2.8	5.6	------	417.1	------
C.O.V		5.9	3.2	7.2	13.7	2.0	------	8.8	------
Number of samples		20							

Table 10. Superpave quality assurance binder test results.

Sampled Date	Sampled Time	DSR-Original			DSR-RTFOT			DSR-PAV			BBR		PG
		G*(kPa)	δ	G*/sinδ	G*(kPa)	δ	G*/sinδ	G*(kPa)	δ	G*/sinδ	S (t)	m	
9/14	07:36	1.003	87.2	1.004	2.439	84.3	2.451	5.374	45.8	3.853	214.0	0.300	64-22
	11:59	1.041	87.0	1.042	2.389	84.2	2.401	6.346	45.3	4.511	200.5	0.310	64-22
9/18	10:03	1.148	87.2	1.149	2.454	84.5	2.465	6.045	47.9	4.483	205.0	0.330	64-22
9/19	07:20	1.089	87.3	1.090	2.518	84.3	2.531	6.115	47.1	4.479	206.0	0.320	64-22
	11:40	1.081	87.2	1.082	2.443	84.7	2.453	5.941	47.5	4.381	215.0	0.310	64-22
9/20	08:58	1.129	87.1	1.130	2.455	84.5	2.466	5.450	48.3	4.071	222.0	0.330	64-22
9/28	13:36	1.245	87.0	1.246	2.735	84.3	2.748	6.660	47.1	4.874	224.0	0.310	64-22
9/29	07:30	1.151	87.4	1.152	2.469	84.6	2.480	5.533	47.5	4.080	212.0	0.315	64-22
	10:38	1.176	87.3	1.177	2.951	84.4	2.965	5.411	47.3	3.978	229.0	0.320	64-22
10/1	08:40	1.199	86.9	1.201	2.687	84.1	2.692	4.526	50.8	3.505	203.5	0.330	64-22
	09:50	1.136	87.2	1.137	2.604	84.2	2.617	5.879	47.8	4.353	229.0	0.310	64-22
10/2	08:13	1.227	87.3	1.228	2.754	84.3	2.768	5.524	51.6	4.332	228.0	0.310	64-16
10/4	A.M	1.189	86.4	1.191	3.224	83.6	3.244	6.360	46.4	4.607	230.0	0.305	64-22
$\bar{x}$		1.140	87.12	1.141	2.625	84.30	2.637	5.782	47.73	4.270	216.8	0.315	------
σ		0.1	0.3	0.1	0.2	0.3	0.2	0.6	1.8	0.4	10.8	0.01	------
C.O.V		6.2	0.3	6.2	9.3	0.3	9.3	9.7	3.7	8.5	5.0	3.1	---
Number of samples		13											

Table 11. Superpave quality assurance binder test results.

Identification		Superpave								
Sampled Date	Sampled Time	Flash Point	Brook-field	DSR-Orig. Temp @ 1.0 kPa	Mass-Loss	DSR-RTFOT Temp @ 2.2 kPa	DSR-PAV Temp @ 5.0 kPa	BBR		PG
								Temp @ 300 MPa	Temp @ m=0.30	
		°C	PaS							
9/14	07:36	285	0.36	64.3	0.230	65.1	22.8	-14.7	-12.0	64-22
	11:59	279	0.32	64.6	0.270	64.9	24.2	-15.0	-13.0	64-22
9/18	10:03	282.2	0.30	65.3	0.250	65.1	24.2	-14.2	-14.0	64-22
9/19	07:20	271	0.27	65.0	0.275	65.3	24.2	-14.4	-14.0	64-22
	11:40	268	0.28	64.9	0.247	65.0	24.0	-14.0	-13.0	64-22
9/20	8:58	277	0.30	65.2	0.261	65.1	23.4	-14.4	-15.3	64-22
9/28	13:36	274	0.28	66.0	0.235	65.9	24.9	-14.1	-12.9	64-22
9/29	07:30	279	0.25	65.3	0.250	65.1	23.4	-14.5	-13.1	64-22
	10:38	279	0.27	65.6	0.260	66.4	23.1	-14.0	-13.6	64-22
10/1	08:40	274	0.35	65.6	0.230	65.8	22.2	-14.6	-14.3	64-22
	09:50	263	0.36	65.3	0.250	65.5	24.0	-14.4	-12.9	64-22
10/2	08:13	282	0.34	65.8	0.235	66.0	26.7	-14.1	-12.8	64-16
10/4	A.M No.1	273	0.31	65.6	0.290	67.1	24.4	-13.5	-12.4	64-22
$\bar{x}$		276	0.31	65.3	0.253	65.5	24.0	-14.3	-13.3	------
σ		6.278	0.037	0.5	0.018	0.7	1.1	0.4	0.9	------
C.O.V		2.275	12.145	0.8	7.2	1.0	4.6	-2.5	-6.5	------
Number of samples		13								

Table 12. Conventional quality assurance binder test results.

Sample Identification		ASTM 3381 (Table 2) Specifications for Asphalt Cement Viscosity Graded at 60°C							
		Original						RTFOT	
Sampled Date	Sampled Time	Vis@60°C in Poises	Vis@135°C in cSt.	Pen@25°C in 1/10 mm	Pen@4°C in 1/10 mm	Flash Point in °C	Solubility %	Vis@60°C in Poises	Duct.@25°C in cm
		2000±400	min. 300	min. 60	------ ------	min. 232	min. 99.0	max. 10000	min. 50
Measured Values									
9/14	07:36	1619.2	337.4	61	25	285		4377.8	>50
	11:59	1659.2	346.2	62	25	279		4837.6	>50
9/18	10:03	1928.7	364.7	50	18	282		4514.7	>50
9/19	07:20	1903.7	364.7	49	19	271		4611.2	>50
	11:40	1834.5	360.7	51	19	268		4508.6	>50
9/20	08:58	1876.8	363.8	54	18	268		4583.5	>50
9/28	13:36	1969.0	371.5	58	20	274		4489.5	>50
9/29	07:30	1904.8	362.9	58	20	279		4587.3	>50
	10:38	1999.0	372.4	56	19	279		5474.1	>50
10/1	08:40	2001.7	373.2	53	17	274		4349.5	>50
	09:50	1988.2	373.8	57	17	263		4134.9	>50
10/2	8:13	1979.0	372.4	56	26	282	99.9	5000.8	>50
10/4	A.M.	1999.0	343.3	57	20	271		4869.2	>50
$\bar{x}$		1897.1	362.1	55.5	20.2	275.1	99.9	4641.4	
σ		126.2	12.2	4.0	3.1	6.7		340.1	
C.O.V		6.7	3.4	7.2	15.3	2.4		7.3	
Number of samples		13							

Table 13. Superpave data analysis for replicated samples.

Sampled Date	Sampled Time	DSR-Original			DSR-RTFOT			DSR-PAV			BBR		PG
		G*(kPa)	δ	G*/sinδ	G*(kPa)	δ	G*/sinδ	G*(MPa)	δ	G*/sinδ	S (t)	m	
9/20	8:58 No. 1	1.244	84.7	1.249	2.395	84.5	2.406	4.454	48.0	3.308	215.5	0.335	64-22
	8:58 No. 2	1.127	87.2	1.128	2.577	84.4	2.589	5.751	48.6	4.313	215.0	0.335	64-22
	8:58 No. 3	1.129	87.1	1.130	2.455	84.5	2.466	5.450	48.3	4.071	222.0	0.330	64-22
$\bar{x}$		1.167	86.4	1.169	2.476	84.5	2.487	5.218	48.3	3.897	217.5	0.333	------
S		0.067	1.4	0.069	0.093	0.1	0.093	0.679	0.3	0.525	3.905	0.003	------
C.O.V.		5.7	1.6	5.9	3.7	0.1	3.8	13.0	0.6	13.5	1.8	0.9	------
Number of samples		3											
10/2	8:13 No. 1	1.227	87.3	1.228	2.754	84.3	2.768	5.524	51.6	4.332	228.0	0.310	64-16
	8:13 No. 2	1.236	87.3	1.237	2.763	84.4	2.776	5.092	50.8	3.948	230.5	0.315	64-16
	8:13 No. 3	1.195	87.0	1.196	2.613	84.2	2.626	6.076	49.9	4.649	216.0	0.320	64-22
$\bar{x}$		1.219	87.2	1.220	2.710	84.3	2.723	5.564	50.8	4.310	224.8	0.315	------
S		0.022	0.2	0.022	0.084	0.1	0.084	0.493	0.9	0.351	7.751	0.005	------
C.O.V.		1.8	0.2	1.8	3.1	0.1	3.1	8.9	1.7	8.1	3.4	1.6	-----
Number of samples		3											
10/4	A.M. No. 1	1.232	87.5	1.233	2.324	84.9	2.333	6.562	47.7	4.855	233.0	0.305	64-22
	A.M. No. 2	1.240	86.8	1.242	2.800	82.9	2.822	5.061	51.5	3.960	246.0	0.310	64-16
	A.M. No. 3	1.117	86.9	1.119	2.710	84.1	2.724	4.859	47.2	3.564	224.5	0.310	64-22
	A.M. No. 4	1.189	86.4	1.191	3.224	83.6	3.244	6.360	46.4	4.607	230.0	0.305	64-22
$\bar{x}$		1.195	86.9	1.196	2.765	83.9	2.781	5.711	48.2	4.247	233.4	0.308	------
S		0.056	0.5	0.056	0.369	0.9	0.374	0.874	2.3	0.591	9.123	0.003	------
C.O.V		4.7	0.5	4.7	13.4	1.0	13.5	15.3	4.7	13.9	3.9	0.9	---
Number of samples		4											

Table 14. Data analysis of the replicated samples for Superpave testing.

Identification		Superpave								
Sampled Date	Sampled Time	Flash Point	Brook-field	DSR-Orig. Temp @ 1.0 kPa	Mass-Loss	DSR-RTFOT Temp @ 2.2 kPa	DSR-PAV Temp @ 5.0 kPa	BBR		PG
								Temp @ 300 MPa	Temp @ m=0.30	
Measured Values										
9/20	8:58 No. 1	268	0.3	66.0	0.2	64.9	21.6	-14.6	-15.0	64-22
	8:58 No. 2	279	0.3	65.2	0.2	65.5	23.9	-14.6	-15.2	64-22
	8:58 No. 3	277	0.3	65.2	0.3	65.1	23.4	-14.4	-15.3	64-22
$\bar{x}$		275	0.3	65.5	0.25	65.1	23.0	-14.5	-15.2	------
σ		5.8	0.03	0.47	0.01	0.33	1.19	0.14	0.15	------
C.O.V.		2.1	9.5	0.7	3.2	0.5	5.2	1.0	1.0	------
n		3								
10/2	8:13 No. 1	282	0.3	65.8	0.2	66.0	26.7	-14.1	-12.8	64-16
	8:13 No. 2	279	0.3	65.9	0.2	66.0	25.9	-13.8	-13.3	64-16
	8:13 No. 3	277	0.4	65.7	0.2	65.6	24.3	-14.2	-13.7	64-22
$\bar{x}$		279	0.4	65.8	0.2	65.8	25.6	-14.0	-13.3	------
σ		2.8	0.0	0.1	0.0	0.2	1.2	0.2	0.5	------
C.O.V.		1.0	3.0	0.2	1.2	0.3	4.7	1.6	3.4	------
n		3								
10/4	A.M. No. 1	274	0.3	65.8	0.2	64.7	24.9	-13.9	-12.4	64-22
	A.M. No. 2	279	0.3	66.0	0.3	66.3	25.9	-13.4	-12.9	64-16
	A.M. No. 3	271	0.4	65.2	0.3	65.8	22.1	-13.8	-12.9	64-22
	A.M. No. 4	273	0.3	65.6	0.3	67.1	24.4	-13.5	-12.4	64-22
$\bar{x}$		274	0.3	65.6	0.3	66.0	24.3	-13.6	-12.6	------
σ		3.6	0.03	0.3	0.03	1.0	1.6	0.3	0.3	------
C.O.V		1.3	8.2	0.5	13.1	1.5	6.7	1.8	2.1	------

Table 15. Conventional binder data analysis for replicated samples.

Sample Identification		ASTM 3381 (Table 2) Specifications for Asphalt Cement Viscosity Graded at 60°C							
		Original						RTFOT	
Sampled Date	Sampled Time	Vis@60°C in Poises	Vis@135°C in cSt.	Pen@25°C in 1/10 mm	Pen@4°C in 1/10 mm	Flash Point in °C	Solubility %	Vis@60°C in Poises	Duct.@25°C in cm
		2000±400	min. 300	min. 60	------ ------	min. 232	min. 99.0	max. 10000	min. 50
Measured Values									
9/20	8:58 No.1	1876.8	363.8	54	18	268		4583.5	>50
	8:58 No.2	1934.5	363.9	56	17	279		4731.4	>50
	8:58 No.3	1905.6	365.0	56	18	277	99.9	4708.4	>50
$\bar{x}_i$		1905.6	364.2	55.3	17.7	274.8		4674.4	
S		28.8	0.7	1.2	0.6	5.8		79.6	
C.O.V.		1.5	0.2	2.1	3.3	2.1		1.7	
n		3							
10/2	8:13 No.1	1979.0	372.4	56	26	282	99.9	5000.8	>50
	8:13 No.2	2039.0	354.9	56	21	279		5067.0	>50
	8:13 No.3	2075.1	378.7	46	18	277		5138.7	>50
$\bar{x}_i$		2031.0	368.6	52.7	21.7	279.4		5068.8	
S		48.5	12.3	5.8	4.0	2.8		69.0	
C.O.V.		2.4	3.3	11.0	18.7	1.0		1.4	
n		3							
10/4	A.M No.1	2019.0	352.0	59	21	274		4145.4	>50
	A.M No.2	1959.0	346.2	57	23	279	99.9	5000.8	>50
	A.M No.3	1999.0	343.3	57	20	271		4869.2	>50
	A.M No.4	1979.0	363.6	58	21	273		5790.4	>50
$\bar{x}_i$		1989.0	351.3	57.8	21.3	274.4		4951.5	
S		25.8	9.0	1.0	1.3	3.6		674.0	
C.O.V		1.3	2.6	1.7	5.9	1.3		13.6	

Table 16. Comparison of within-laboratory coefficient of variation for different kinds of binders.

A - For Complex Modulus and Phase Angle

Asphalt Source	Test Temp (°C)		G* (kPa)	Phase Angle (δ)	G* (kPa)	Phase Angle (δ)
	Plate		Using 25-mm Plate	Using 25-mm Plate	Using 8-mm Plate	Using 8-mm Plate
	25 mm	8 mm	Within-Lab CV	Within-Lab CV	Within-Lab CV	Within-Lab CV
California Valley (thin film residue)	45	20	12.5	0.3	8.4	0.9
West Texas Intermediate (thin film residue)	70	35	7.7	0.9	10.5	0.9
West Texas Intermediate	60	15	7.8	0.2	10.2	2.1
California Valley	55	10	9.2	1.1	9.1	3
WesTrack	64	25	6.2	0.3	9.7	3.7

B - For Creep Stiffness S(t) and m-value

Asphalt Source	Test Temp (°C)	Creep Stiffness S(60) Within-Lab CV	m-Value m(60) Within-Lab CV
West Texas Intermediate	-18	7.7	3.7
Boscan	-12	9.1	3.6
Redwater	-24	6.7	2.8
WesTrack	-12	5.0	3.1

Table 17. Statistical comparison of WesTrack binder test results and AMRL binder test results (proficiency sample program - May 1996 report).

Parameters	No. of Labs	Sample #1			Sample #2			WesTrack		
		Average	Stand. Dev.	C.O.V.	Average	Stand. Dev.	C.O.V.	Average	Stand. Dev.	C.O.V.
Brookfield Viscosity, PaS	72	0.22	0.03	15.4	0.22	0.03	15.3	0.3	0.04	12.1
Mass Loss, %	65	0.02	0.01	61.8	0.02	0.01	68.8	0.3	0.02	7.2
DSR-original G*, kPa	68	1.35	0.15	10.9	1.37	0.16	12	1.1	0.1	6.2
Phase Angle δ	63	85.48	0.87	1.02	85.38	1.10	1.28	87.1	0.3	0.3
G*/sin δ, kPa	67	1.35	0.14	10.2	1.36	0.14	10	1.1	0.1	6.2
DSR-RTFOT G*, kPa	66	3.24	0.44	13.6	3.27	0.39	11.8	2.6	0.2	9.3
Phase Angle δ	64	80.59	1.07	1.33	80.53	0.98	1.22	84.3	0.3	0.3
G*/sin δ, kPa	68	3.30	0.46	13.9	3.34	0.41	12.3	2.6	0.2	9.3
DSR-PAV G*	62	2.91	0.89	30.5	2.88	0.88	30.5	5.8	0.6	9.7
Phase Angle δ	60	47.55	2.00	4.22	47.62	1.80	3.69	47.7	1.8	3.7
G*sin δ, kPa	60	2.25	0.50	22.4	2.240	0.48	21.3	4.3	0.4	8.5
Creep Stiffness, MPa	55	182.80	20.70	11.3	182.70	19.80	10.8	216.8	10.8	5.0
Slope, m	59	0.34	0.02	5.27	0.34	0.02	5.08	0.3	0.0	3.1

Binder used for AMRL binder testing is PG 52-34.

Binder used for WesTrack binder testing is PG 64-22.

Table 18. Calculated parameters for asphalt cement temperature susceptibility.

Identification		Original Asphalt Cement							
Sampled Date	Sampled Time	Vis@60°C in Poises	Vis@135°C in cSt.	Pen@25°C in 1/10 mm	Pen@4°C in 1/10 mm	Penetration Ratio	Penetration Index	Penetration Viscosity No.	Penetration Viscosity No.
		2000±400	min. 300	min. 60	------ ------		Range -2 to +2	temp. range 25-135°C	temp. range 25-60°C
Measured Values									
9/14	07:36	1619.2	337.4	61	25	41.0	-1.0	-1.0	-1.0
	11:59	1659.2	346.2	62	25	40.3	-1.0	-0.9	-1.0
9/18	10:03	1928.7	364.7	50	18	36.0	-1.2	-1.1	-1.1
9/19	07:20	1903.7	364.7	49	19	38.8	-1.0	-1.1	-1.2
	11:40	1834.5	360.7	51	19	37.3	-1.2	-1.1	-1.1
9/20	8:58	1876.8	363.8	54	18	33.3	-1.2	-1.0	-1.0
9/28	13:36	1969.0	371.5	58	20	34.5	-1.0	-0.9	-0.9
9/29	07:30	1904.8	362.9	58	20	34.5	-0.5	-0.9	-0.9
	10:38	1999.0	372.4	56	19	33.9	-1.0	-0.9	-0.9
10/1	08:40	2001.7	373.2	53	17	32.1	-1.0	-1.0	-1.0
	09:50	1988.2	373.8	57	17	29.8	-1.0	-0.9	-0.9
10/2	8:13	1979.0	372.4	56	26	46.4	-1.0	-0.9	-0.9
10/4	A.M.	1999.0	343.3	57	20	35.1	-1.0	-1.0	-0.9
$\bar{x}$		1897.1	362.1	55.5	20.2	36.4	-1.0	-1.0	-1.0
σ		126.2	12.2	4.0	3.1	4.4	0.2	0.1	0.1
C.O.V		6.7	3.4	7.2	15.3	12.0	-17.4	6.3	9.6
Number of samples		13							

Penetration/Viscosity Number (Temperature Range: 25 - 135°C):

$$PVN = \frac{(4.258 - 0.7967 \log(Pen@25^\circ C) - \log(Vis.@135^\circ C)\ x\ (-1.5)}{0.7951 - 0.1858 \log(Pen.@25^\circ C)}$$

Penetration/Viscosity Number (Temperature Range: 25 - 60°C):

$$PVN = \frac{6.489 - 1.590 * \log(Pen.@25^\circ C) - \log(Vis.@60^\circ C)\ x\ (-1.5)}{1.050 - 0.2234 \log(Pen.@25^\circ C)}$$

Penetration Ratio (PR):

$$PR = \frac{Pen@4^\circ C, 200 gm, 60 \text{ sec.}\ x\ 100}{Pen@25^\circ C, 100\ gm, 5 \text{ sec.}}$$

Table 19. WesTrack asphalt binder properties as determined by Superpave binder tests.*

Aging	Test Method	Temperature of Test, °C	Test Parameter	Value	Specification (AASHTO MPI)*
Original	DSR (AASHTO TP5)	64	G*/sinδ	1.141 kPa	Min. 1.0 kPa
	Flash point (AASHTO T48)			276°C	Min. 230°C
	Viscosity (ASTM D 4402)	135	Viscosity	0.37 Pa.s	Max. 3.0 Pa.s
RTFOT	DSR (AASHTO TP5)	64	G*/sinδ	2.637 kPa	Min. 2.2 kPa
	Mass loss (AASHTO T240)		Mass loss	0.253 percent	Max. 1.0%
RTFOT Plus PAV	DSR (AASHTO TP5)	25	G*sinδ	4270 kPa	Max. 5000 kPa
	BBR (AASHTO TP1)	-12	Stiffness	216.8 MPa	Max. 300 MPa
		-12	"m" Value	0.315	Min. 0.30

*Classified as PG 64-22.

Table 20. WesTrack asphalt binder properties as determined by viscosity and penetration tests.*

Aging	Test Method	Temperature of Test, °C	Value	Specification AASHTO M 226 ASTM D 3381*
Original	Viscosity	60	1897 poise	1600-2400 poise
	(D 2171) (D 2170)	135	362 poise	Min. 300 poise
	Penetration (D 5)	25	55.5 dmm	Min. 60 dmm
		4	20.2 dmm	
	Flash point		275°C	Min. 232°C
	Solubility		99.9 percent	Min. 99.0 percent
RTFOT	Viscosity	60	4641 poises	Max. 10,000 poises
	Ductility	25	>50 cm	Min. 50 cm

*AC-20 asphalt cement, table 2.

APPENDIX A

ASPHALT BINDER QUALITY CONTROL TEST RESULTS AT SELECTED TEMPERATURES - ORIGINAL CONSTRUCTION

Contract #	Westrack	Superpave Performance Grade
Sample ID	VZ-49	
Supplier	Huntway	
Asphalt Type	AC-20	
Mass Loss, %	0.1754	
Brookfield Vis., Pa*s	0.354	
Flash Pt., C	>230	PG 64-22
Limiting Temp. for Tmax, C	64.6	
Limiting Temp. for Tint, C	22.0	
Limiting Temp. for Tmin, C	-15.1	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.0	1.80	86.9	1.81	70	25	10.0	1.12	87.3	1.12
64	"	"	3.16	85.9	3.17	64	"	"	2.31	85.6	2.31
58	"	"	4.98	85.2	5.00	58	"	"	5.05	83.6	5.08
52	"	"	5.92	85.1	5.94	52	"	"	12.34	81.4	12.48

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	3.98	55.2	3.27	-10.2	156	0.40			
22	"	"	6.40	51.7	5.02	-19.9	557	0.24			
19	"	"	10.20	48.0	7.58						
16	"	"	16.87	43.9	11.70						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa 80.2°C

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa 64.6°C

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa 22.0°C

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa -15.1°C
   Temperature at which m = 0.30 -16.3°C

Contract #	Westrack	Superpave Performance Grade
Sample ID	VZ-50	
Supplier	Huntway	
Asphalt Type	AC-20	
Mass Loss, %	0.4023	
Brookfield Vis., Pa*s	0.317	
Flash Pt., C	>230	PG 64-22
Limiting Temp. for Tmax, C	66.3	
Limiting Temp. for Tint, C	22.1	
Limiting Temp. for Tmin, C	-16.0	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.0	0.65	87.5	0.65	70	25	10.0	1.49	84.3	1.50
64	"	"	1.26	86.6	1.27	64	"	"	3.10	82.2	3.13
58	"	"	2.81	84.2	2.83	58	"	"	6.41	79.8	6.51
52	"	"	5.95	82.4	6.00	52	"	"	14.71	77.2	15.09

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	4.74	48.1	3.53	-10.2	124	0.36			
22	"	"	7.14	45.3	5.08	-19.9	421	0.26			
19	"	"	10.66	42.7	7.23						
16	"	"	15.26	39.7	9.75						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa 66.3°C

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa 66.9°C

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa 22.1°C

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa -16.0°C
   Temperature at which m = 0.30 -16.0°C

Contract #	Huntway
Sample ID.	1512
Asphalt Type	AC-20
Mass Loss, %	0.03
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	21.6
Limiting Temp. for Tmin, C	

DSR-Original

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			
64	"	"			1.441 [illegible]
58	"	"			
52	"	"			

DSR-RTFOT

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			
64	"	"			3.353 [illegible]
58	"	"			
52	"	"			

DSR-PAV

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1	4.623	46.75	3.367
22	"	"	6.899	43.96	4.792
19	"	"	9.929	41.193	6.539
16	"	"			

BBR-PAV

Temp, C	S(t), MPa	m
-12	214	0.31
-18		

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	1S2#2
Sample ID.	
Asphalt Type	
Mass Loss, %	
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

DSR-Original

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			0.522
64	"	"			1.088
58	"	"			2.41
52	"	"			5.62

DSR-RTFOT

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			
64	"	"			
58	"	"			
52	"	"			

DSR-PAV

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1			5.23
22	"	"			7.632
19	"	"			10.047
16	"	"			14.634

BBR-PAV

Temp, C	S(t), MPa	m
-17.9	484	0.25
-6.6	107	0.38

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 KPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRC	Truck Sample 2
Sample ID	Rep #1	
Asphalt Type		
Mass Loss, %		
Brookfield Vis., cp		
Flash Pt., C		
Limiting Temp. for Tmax, C		
Limiting Temp. for Tint, C		
Limiting Temp. for Tmin, C		

10 DSR-Original 9/11/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.436	86.75	0.437
64	"	"	0.914	86.73	0.915
58	"	"	1.995	84.94	2.003
52	"	"	4.634	83.21	4.667

10 DSR-RTFOT 9/12/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.893	84.85	0.896
64	"	"	1.909	83.15	1.923
58	"	"	4.388	80.95	4.444
52	"	"	10.335	77.59	10.58

DSR-PAV

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1			
22	"	"			
19	"	"			
16	"	"			

BBR-PAV

Temp, C	S(t), MPa	m
-0.04	36	0.46
-18.1	407	0.25

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRC
Sample ID.	Rep #2
Asphalt Type	
Mass Loss, %	
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

Truck Sample 2

10 DSR-Original 9/11/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.483	87.42	0.483
64	"	"	1.002	86.99	1.003
58	"	"	2.203	85.21	2.211
52	"	"	5.045	83.49	5.078

DSR-RTFOT

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			
64	"	"			
58	"	"			
52	"	"			

DSR-PAV

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1			
22	"	"			
19	"	"			
16	"	"			

BBR-PAV

Temp, C	S(t), MPa	m
-0.04	33	0.45
-18.0	373	0.26

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRL
Sample ID.	Rep. #3
Asphalt Type	
Mass Loss, %	
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

Truck Sample 2

10 DSR-Original 9/12/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.506	86.11	0.507
64	"	"	1.022	84.48	1.027
58	"	"	2.218	83.87	2.230
52	"	"	5.101	82.49	5.145

DSR-RTFOT

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			
64	"	"			
58	"	"			
52	"	"			

DSR-PAV

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1			
22	"	"			
19	"	"			
16	"	"			

BBR-PAV

Temp, C	S(t), MPa	m
-0.03	35	0.46
-18.0	419	0.26

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRC
Sample ID.	Rep. #1
Asphalt Type	
Mass Loss, %	0.25%
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

PG 70 DSR-Original 9/12/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.347	88.89	0.347
64	"	"	0.720	87.55	0.721
58	"	"	1.590	86.08	1.593
52	"	"	3.608	84.48	3.625

9/14/95 DSR-RTFOT PG 70

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	1.025	85.54	1.028
64	"	"	2.205	84.65	2.214
58	"	"	5.045	82.21	5.092
52	"	"	11.997	79.42	12.20

9/14/95 DSR-PAV PG 70

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1	4.281	45.21	4.457
22	"	"	9.545	42.39	6.435
19	"	"	13.205	40.46	8.569
16	"	"	18.622	37.92	11.443

9/11/95 BBR-PAV PG 70

Temp, C	S(t), MPa	m
-0.092	39	0.45
-17.9	376	0.26

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmin
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmin
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint max
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRC
Sample ID.	Rep #2
Asphalt Type	
Mass Loss, %	0.25%
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

AO DSR-Original 7/12/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.359	88.34	0.359
64	"	"	0.742	87.23	0.743
58	"	"	1.620	86.30	1.623
52	"	"	3.708	84.34	3.726

AO DSR-RTFOT 9/14/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	1.059	85.72	1.062
64	"	"	2.248	84.08	2.261
58	"	"	5.271	81.96	5.323
52	"	"	12.417	79.36	12.63

AO DSR-PAV 9/15/95

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1	5.638	46.21	4.070
22	"	"	8.622	43.45	5.929
19	"	"	12.534	40.57	8.152
16	"	"	17.852	37.86	10.956

9/14/95 BBR-PAV AO

Temp, C	S(t), MPa	m
-0.077	40	0.45
-17.8	379	0.26

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRL
Sample ID.	Rep #3
Asphalt Type	
Mass Loss, %	0.25%
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

PG DSR-Original 9/14/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.491	87.17	0.492
64	"	"	1.005	89.20	1.006
58	"	"	2.210	85.67	2.217
52	"	"	5.190	84.27	5.216

PG DSR-RTFOT 9/15/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	1.000	85.56	1.003
64	"	"	2.116	84.12	2.127
58	"	"	4.834	82.01	4.881
52	"	"	11.449	79.36	11.650

DSR-PAV

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1			
22	"	"			
19	"	"			
16	"	"			

BBR-PAV

Temp, C	S(t), MPa	m
0.05	38	0.44
-17.8	416	0.25

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRC
Sample ID.	#1 Rep
Asphalt Type	
Mass Loss, %	0.24 %
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

4 9/18/95 DSR-Original 10

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.539	86.98	0.539
64	"	"	1.128	87.10	1.130
58	"	"	2.513	86.38	2.518
52	"	"	5.861	84.74	5.886

9/23/95 DSR-RTFOT 10

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	1.011	86.32	1.013
64	"	"	2.183	84.54	2.193
58	"	"	5.036	82.39	5.081
52	"	"	12.03	79.87	12.22

10 DSR-PAV 9/20/95

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1	1.042	69.01	0.973
22	"	"	1.871	65.79	1.707
19	"	"	3.276	62.54	2.907
16	"	"	5.935	58.24	5.047

BBR-PAV

Temp, C	S(t), MPa	m
-0.08	45	0.44
-18.1	296	0.2

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: ~~Tmax~~ Tmin
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: ~~Tmax~~ Tmin
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint max
   Temperature at which G*(sinδ) = 5.0 MPa

4. BER PAV: Tmin
   Temperature at which S(t) max = 300 MPa
   Temperature at which m min = 0.30

Contract #	HRL
Sample ID	Rep #2
Asphalt Type	
Mass Loss, %	
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

9/18/95 DSR-Original 1.0

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.503	86.45	0.504
64	"	"	1.086	86.75	1.087
58	"	"	2.352	85.92	2.358
52	"	"	5.483	84.22	5.512

9/23/95 DSR-RTFOT 1.0

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70.3	25	6	1.135	86.41	1.137
64.2	"	"	2.469	84.58	2.480
58	"	"	5.662	82.15	5.716
~~52~~	"	"	13.54	79.44	13.77

9/29/95 DSR-PAV 1.0

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
~~25~~	8	1	3.855	47.34	2.835
~~22~~	"	"	5.975	44.04	4.154
~~19~~	"	"	8.920	40.94	5.845
~~16~~	"	"	13.23	37.81	8.110

BBR-PAV

Temp, C	S(t), MPa	m
-0.12	45	0.43
-18.0	453	0.25

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRL
Sample ID.	Rep. #3
Asphalt Type	
Mass Loss, %	
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

9/19/95 DSR-Original 10

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.536	87.65	0.537
64	"	"	1.070	87.23	1.091
58	"	"	2.404	86.06	2.410
52	"	"	5.633	84.30	5.661

DSR-RTFOT

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			
64	"	"			
58	"	"			
52	"	"			

DSR-PAV

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	"	1			
22	"	"			
19	"	"			
16	"	"			

BBR-PAV

Temp, C	S(t), MPa	m
-0.13	44	0.42
-17.9	434	0.24

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBF-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRC
Sample ID.	Rep. #4
Asphalt Type	
Mass Loss, %	
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

9/19/95 DSR-Original 1.0

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6	0.535	88.42	0.535
64	"	"	1.121	87.46	1.122
58	"	"	2.458	86.19	2.464
52	"	"	5.699	84.39	5.726

DSR-RTFOT

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			
64	"	"			
58	"	"			
52	"	"			

DSR-PAV

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1			
22	"	"			
19	"	"			
16	"	"			

BBR-PAV

Temp, C	S(t), MPa	m

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRL
Sample ID.	Rep. #1
Asphalt Type	
Mass Loss, %	0.27
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

PG DSR-Original 9/21/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
~~70~~	25	6	0.543	88.09	0.543
~~64~~	"	"	1.116	87.24	1.117
58	"	"	2.491	85.96	2.497
~~52~~	"	"	5.898	84.03	5.930

PG DSR-RTFOT 9/21/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
~~70~~ 70.3	25	6	1.023	85.65	1.026
~~64~~ 64.2	"	"	2.200	84.54	2.210
58	"	"	5.055	82.32	5.100
~~52~~ 51.9	"	"	12.06	79.75	12.26

PG DSR-PAV 10/3/95

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1	7.212	47.24	5.295
22	"	"	11.05	43.95	7.668
19	"	"	16.47	40.73	10.75
~~16~~	"	"	24.39	37.44	14.83

BBR-PAV

Temp, C	S(t), MPa	m
-0.03	43	0.42
-18.2	465	0.24

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRC
Sample ID.	Rep #1
Asphalt Type	
Mass Loss, %	
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

DSR-Original

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			
64	"	"	1.131	87.34	1.1323
58	"	"			
52	"	"			

DSR-RTFOT

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	6			
64	"	"			
58	"	"			
52	"	"			

DSR-PAV

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1			#3
22	"	"			
19	"	"			#4
16	"	"			

BBR-PAV

Temp, C	S(t), MPa	m
-0.06	38	0.42
-17.9	666	0.22
-0.02	43	0.41
-18.1	486	0.23

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
1.5798		-0.3768
2.825		-.0570
1.6335		-.3872
2.6866		-.6383

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	HRL
Sample ID.	Rep # 2
Asphalt Type	
Mass Loss, %	0.22
Brookfield Vis., cp	
Flash Pt., C	
Limiting Temp. for Tmax, C	
Limiting Temp. for Tint, C	
Limiting Temp. for Tmin, C	

10 DSR-Original 9/20/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
~~70~~	25	6	0.523	88.08	0.523
~~64~~	"	"	1.091	87.36	1.092
58	"	"	2.430	86.23	2.435
~~52~~	"	"	5.654	84.44	5.681

10 DSR-RTFOT 9/22/95

Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70.3	25	6	1.004	86.04	1.006
~~64~~	"	"	2.154	84.52	2.164
58	"	"	4.991	82.29	5.036
~~52~~	"	"	11.88	79.81	12.07

10 DSR-PAV 10/3/95

Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa
~~25~~	8	1	6.198	46.98	4.532
~~22~~	"	"	9.509	43.77	6.578
~~19~~	"	"	14.18	40.57	9.226
~~16~~	"	"	21.07	37.30	12.77

BBR-PAV

Temp, C	S(t), MPa	m
-0.04	145	0.43
-18.2	536	0.26

DT-PAV

Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
1.653	~~.366~~ .365	
2.729	-.595	

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway VZ-49

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	1.81	1.0 KPa min.	80.2
	64	3.17		
	58	5.00		
	52	5.94		
DSR-RTFOT	70	1.12	2.2KPa min.	64.6
	64	2.31		
	58	5.08		
	52	12.48		
DSR-PAV	25	3.27	5.0 MPa max.	22.0
	22	5.02		
	19	7.58		
	16	11.70		
BBR- S(t)	-10.2	156	300 MPa max.	-15.1
	-19.9	557	0.3 min.	-16.3
BBR-m	-10.2	0.40		
	-19.9	0.24		

The binder meets the PG 64-22 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway VZ-50

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.65	1.0 KPa min.	66.3
	64	1.27		
	58	2.83		
	52	6.00		
DSR-RTFOT	70	1.50	2.2KPa min.	66.9
	64	3.13		
	58	6.51		
	52	15.09		
DSR-PAV	25	3.53	5.0 MPa max.	22.1
	22	5.08		
	19	7.23		
	16	9.75		
BBR- S(t)	-10.2	124	300 MPa max.	-16.0
	-19.9	421	0.3 min.	-16.0
BBR-m	-10.2	0.36		
	-19.9	0.26		

The binder meets the PG 64-22 specs.

SHRP BINDER TESTING

Project : WesTrack
Date : 6/22/95
Binder ID : Huntway PBA-5

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.58	1.0 KPa min.	66.06
	64	1.22		
	58			
	52			
DSR-RTFOT	70		2.2KPa min.	>64
	64	2.55		
	58			
	52			
DSR-PAV	28	3.46	5.0 MPa max.	25.43
	25	5.07		
	22	7.31		
BBR- S(t)	-6	115	300 MPa max.	-12.39
	-12	268	0.3 min.	-13.54
	-18	481		
BBR-m	-6	0.38		
	-12	0.32		
	-18	0.25		

The binder meets the PG 64-16 specs.

SHRP BINDER TESTING

Project : WesTrack
Date : 6/29/95
Binder ID : Huntway 1512

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70		1.0 KPa min.	> 64
	64	1.34		
	58			
	52			
DSR-RTFOT	70		2.2KPa min.	
	64	3.35		> 64
	58			
	52			
DSR-PAV	25	3.37	5.0 MPa max.	21.55
	22	4.79		
	19			
	16			
BBR- S(t)	-18	447	300 MPa max.	-14.21
	-12	214	0.3 min.	-12.75
BBR-m	-18	0.23		
	-12	0.31		

The binder meets the PG 64-22 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway Truck sample 2- Rep. 1
ID# 9/8/95

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.44	1.0 KPa min.	63.5
	64	0.92		
	58	2.00		
	52	4.67		
DSR-RTFOT	70	0.90	2.2KPa min.	63.23
	64	1.92		
	58	4.44		
	52	10.58		
DSR-PAV	25		5.0 MPa max.	
	22			
	19			
	16			
BBR- S(t)	-18	407	300 MPa max.	-12.89
	0	36	0.3 min.	-13.84
BBR-m	-18	0.25		
	0	0.46		

The binder meets the PG 58-22 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway Truck sample 2- Rep. 2
ID# 9/8/95

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.48	1.0 KPa min.	64.25
	64	1.00		
	58	2.21		
	52	5.08		
DSR-RTFOT	70		2.2KPa min.	
	64			
	58			
	52			
DSR-PAV	25		5.0 MPa max.	
	22			
	19			
	16			
BBR- S(t)	-18	373	300 MPa max.	-14.14
	0	33	0.3 min.	-14.19
BBR-m	-18	0.26		
	0	0.45		

The binder meets the PG 64-22 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway Truck sample 2- Rep. 3
ID# 9/8/95

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.51	1.0 KPa min.	64.51
	64	1.02		
	58	2.22		
	52	5.10		
DSR-RTFOT	70		2.2KPa min.	
	64			
	58			
	52			
DSR-PAV	25		5.0 MPa max.	
	22			
	19			
	16			
BBR- S(t)	-18	419	300 MPa max.	-12.43
	0	35	0.3 min.	-14.44
BBR-m	-18	0.26		
	0	0.46		

The binder meets the PG 64-22 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway 215 Replicate No. 1
ID# 9/11/95

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.35	1.0 KPa min.	61.69
	64	0.72		
	58	1.59		
	52	3.63		
DSR-RTFOT	70	1.03	2.2KPa min.	64.31
	64	2.21		
	58	5.09		
	52	12.20		
DSR-PAV	25	4.46	5.0 MPa max.	24.12
	22	6.44		
	19	8.57		
	16	11.44		
BBR- S(t)	-18	376	300 MPa max.	-13.84
	0	39	0.3 min.	-14.06
BBR-m	-18	0.26		
	0	0.45		

The binder meets the PG 58-16 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway 215 Replicate No. 2
ID# 9/11/95

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.36	1.0 KPa min.	61.92
	64	0.74		
	58	1.62		
	52	3.73		
DSR-RTFOT	70	1.06	2.2KPa min.	64.46
	64	2.26		
	58	5.32		
	52	12.63		
DSR-PAV	25	4.07	5.0 MPa max.	23.34
	22	5.93		
	19	8.15		
	16	10.96		
BBR- S(t)	-18	379	300 MPa max.	-13.63
	0	40	0.3 min.	-14.08
BBR-m	-18	0.26		
	0	0.45		

The binder meets the PG 58-16 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway 215 Replicate No. 3
ID# 9/11/95

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.49	1.0 KPa min.	64.32
	64	1.01		
	58	2.22		
	52	5.22		
DSR-RTFOT	70	1.00	2.2KPa min.	63.97
	64	2.13		
	58	4.88		
	52	11.65		
DSR-PAV	25		5.0 MPa max.	
	22			
	19			
	16			
BBR- S(t)	-18	416	300 MPa max.	-12.32
	0	38	0.3 min.	-13.16
BBR-m	-18	0.25		
	0	0.44		

The binder meets the PG 64-22 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway Truck sample 3- Rep. 1
ID# 9/18/95- 4:30 A.M.

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.54	1.0 KPa min.	65.2
	64	1.13		
	58	2.52		
	52	5.89		
DSR-RTFOT	70	1.01	2.2KPa min.	64.5
	64	2.19		
	58	5.08		
	52	12.22		
DSR-PAV	25	0.97	5.0 MPa max.	16.05
	22	1.71		
	19	2.91		
	16	5.05		
BBR- S(t)	-18	296	300 MPa max.	-18.39
	0	45	0.3 min.	-10.81
BBR-m	-18	0.20		
	0	0.44		

The binder meets the PG 64-16 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway Truck sample 3- Rep. 2
ID# 9/18/95- 4:30 A.M.

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.50	1.0 KPa min.	64.65
	64	1.09		
	58	2.36		
	52	5.51		
DSR-RTFOT	70	1.14	2.2KPa min.	65.06
	64	2.48		
	58	5.72		
	52	13.77		
DSR-PAV	25	2.84	5.0 MPa max.	20.26
	22	4.15		
	19	5.85		
	16	8.11		
BBR- S(t)	-18	453	300 MPa max.	-11.29
	0	45	0.3 min.	-12.99
BBR-m	-18	0.25		
	0	0.43		

The binder meets the PG 64-16 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway Truck sample 3- Rep. 3
ID# 9/18/95- 4:30 A.M.

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.54	1.0 KPa min.	64.95
	64	1.09		
	58	2.41		
	52	5.66		
DSR-RTFOT	70		2.2KPa min.	
	64			
	58			
	52			
DSR-PAV	25		5.0 MPa max.	
	22			
	19			
	16			
BBR- S(t)	-18	434	300 MPa max.	-11.29
	0	44	0.3 min.	-12.01
BBR-m	-18	0.24		
	0	0.42		

The binder meets the PG 64-16 specs.

SHRP BINDER TESTING

Project : WesTrack
Date :
Binder ID : Huntway Truck sample 3- Rep. 4
ID# 9/18/95- 4:30 A.M.

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70	0.54	1.0 KPa min.	65.02
	64	1.12		
	58	2.46		
	52	5.73		
DSR-RTFOT	70		2.2KPa min.	
	64			
	58			
	52			
DSR-PAV	25		5.0 MPa max.	
	22			
	19			
	16			
BBR- S(t)	-18	434	300 MPa max.	
	0	44	0.3 min.	
BBR-m	-18	0.24		
	0	0.42		

SHRP BINDER TESTING

Project : WesTrack
Date : 9/20/95
Binder ID : Huntway 471-1 (Refinery Sample)

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70		1.0 KPa min.	65.2
	64			
	58			
	52			
DSR-RTFOT	70		2.2KPa min.	64.3
	64			
	58			
	52			
DSR-PAV	25		5.0 MPa max.	25.6
	22			
	19			
	16			
BBR- S(t)	-18		300 MPa max.	-14.6
	-12		0.3 min.	-10.8
BBR-m	-18			
	-12			

The binder meets the PG 64-16 specs.

SHRP BINDER TESTING

Project : WesTrack
Date : 9/20/95
Binder ID : Huntway 471-2 (Refinery Sample)

Test	Temp (C)	Result	Specification	Temp @ specification
DSR-Original	70		1.0 KPa min.	64.9
	64			
	58			
	52			
DSR-RTFOT	70		2.2KPa min.	64.1
	64			
	58			
	52			
DSR-PAV	25		5.0 MPa max.	24.3
	22			
	19			
	16			
BBR- S(t)	-18		300 MPa max.	-13.8
	-12		0.3 min.	-12.3
BBR-m	-18			
	-12			

The binder meets the PG 64-22 specs.

APPENDIX B

ASPHALT BINDER QUALITY ASSURANCE TEST RESULTS AT SELECTED TEMPERATURES - ORIGINAL CONSTRUCTION

Contract #	Westrack	GRADE
Sample ID.	9/14-7:36	
Asphalt Type	AC20	
Mass Loss, %	0.23%	
Brookfield Vis., cp	0.362 Pas	
Flash Pt., C	285°C	64-22
Limiting Temp. for Tmax, C	64.25	
Limiting Temp. for Tint, C	22.82	
Limiting Temp. for Tmin, C		

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.4997	88.05	0.499	70	25	10.0	1.171	85.56	1.1745
64	"	"	1.003	87.24	1.004	64	"	"	2.459	84.27	2.461
58	"	"	2.135	86.06	2.14	58	"	"	5.447	81.72	5.501
52	"	"	4.712	84.86	4.731	52	"	"	12.34	79.49	12.55

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	5.374	45.82	3.853	-12	214	0.3			
22	"	"	8.16	43.26	5.592	-18	407	0.24			
19	"	"	12.08	40.04	7.771						
16	"	"	17.2	37.37	10.439						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	Westrack	GRADE
Sample ID.	9/14 - 11:59	
Asphalt Type	AC-20	
Mass Loss, %	0.27%	
Brookfield Vis., cp	0.318 Pas	
Flash Pt., C	535°F/279.4	64-22
Limiting Temp. for Tmax, C	64.56	
Limiting Temp. for Tint, C	24.21	
Limiting Temp. for Tmin, C	-14.95C	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.591	88.2	0.591	70	25	10.0	1.142	85.73	1.145
64	"	"	1.041	87.03	1.042	64	"	"	2.389	84.16	2.401
58	"	"	2.225	85.78	2.231	58	"	"	5.339	82.01	5.381
52	"	"	4.734	84.17	4.749	52	"	"	12.21	79.51	12.417

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	6.346	45.31	4.511	-12	200.5	0.31			
22	"	"	9.529	42.52	6.44	-18	262.5	0.25			
19	"	"	13.90	39.62	8.864						
16	"	"	19.41	37.17	11.727						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	WESTRACK	SHRP PG Grade
Sample ID,	9/18 - 10:03	
Asphalt Type	AC-20	
Mass Loss, %	0.25	
Brookfield Vis ,PaS @135°C	0.300	64-
Brookfield Vis ,PaS @150°C	0.100	
Flash Pt., C	282.22	
Limiting Temp. for Tmax, C	55.08	
Limiting Temp. for Tint, C	24.22	
Limiting Temp. for Tmin, C	-14.24	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	illegible	27.92	0.553	70	25	10.0	1.170	85.87	1.173
64	"	"	1.148	97.2?	1.141	64	"	"	2.454	84.43	2.465
58	"	"	illegible	35.17	illegible	58	"	"	5.499	82.50	5.540
52	"	"	5.618	84.42	5.644	52	"	"	12.76	80.1?	12.95

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Stram, %	Avg. Failure Stress, Pa
25	8	1	6.045	47.87	4.483	-12	205	0.33			
22	"	"	9.346	illegible	6.586	-15	457	0.24			
19	"	"	14.00	41.73	9.318						
16	"	"	20.17	38.80	12.638						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	Westrack	SHRP PG Grade
Sample ID.	9/19 - 7:20	64-22
Asphalt Type	AC-20	
Mass Loss, %	0.275	
Brookfield Vis., PaS	0.269	
Flash Pt., C	271 °C	
Limiting Temp. for Tmax, C	64.95	
Limiting Temp. for Tint, C	24.19	
Limiting Temp. for Tmin, C	-14.43	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.542	88.04	0.542	70	25	10.0	1.193	85.35	1.196
64	"	"	1.089	87.27	1.090	64	"	"	2.518	84.30	2.531
58	"	"	2.355	85.96	2.361	58	"	"	5.639	82.16	5.692
52	"	"	5.291	84.46	5.316	52	"	"	12.97	79.38	13.175

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	6.115	47.10	4.477	-12	206	0.32			
22	"	"	9.345	44.02	6.528	-18	438	0.26			
19	"	"	13.95	40.74	9.141						
16	"	"	19.73	35.05	11.333						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	Westrack	SHRP PG Grade
Sample ID.	9/19 - 11:40	64-22
Asphalt Type	AC-20	
Mass Loss, %	0.247	
Brookfield Vis., PaS	0.281	
Flash Pt., C	515°F/268.3°C	
Limiting Temp. for Tmax, C	64.88	
Limiting Temp. for Tint, C	24.0	
Limiting Temp. for Tmin, C	-14.0	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.537	87.84	0.537	70	25	10.0	1.167	[illegible]	1.17
64	"	"	1.081	87.22	1.082	64	"	"	[illegible]	[illegible]	2.453
58	"	"	2.336	86.13	2.341	58	"	"	[illegible]	82.43	5.495
52	"	"	5.279	84.57	5.303	52	"	"	[illegible]	80.47	12.57

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	5.741	47.52	4.381	-12	215	[illegible]			
22	"	"	9.097	44.52	6.378	-18	471	0.25			
19	"	"	13.43	41.57	8.914						
16	"	"	19.23	38.34	12.06						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	WESTRACK	SHRP PG Grade
Sample ID.	9/20-8:58 I	64-22
Asphalt Type	AC-20	
Mass Loss, %	0.247%	
Brookfield Vis., PaS	0.306, Pas.	
Flash Pt., C	515°F/268.3°C	
Limiting Temp. for Tmax, C	64.88	
Limiting Temp. for Tint, C	21.63	
Limiting Temp. for Tmin, C	-15	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.632	84.69	0.633	70	25	10.0	1.136	86.05	1.133
64	"	"	1.244	86.73	1.249	64	"	"	2.375	84.51	2.406
58	"	"	2.561	84.63	2.572	58	"	"	5.389	82.57	5.434
52	"	"	5.166	83.4	5.771	52	"	"	12.39	80.29	12.57

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	4.454	47.78	3.308	-12	215.5	0.335			
22	"	"	6.89	45.11	4.874	-18	414.5	0.265			
19	"	"	10.34	42.16	6.91						
16	"	"	14.87	39.57	9.432						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	Westrack	SHRP PG Grade
Sample ID.	9/20-8.58 II	
Asphalt Type		
Mass Loss, %	0.247%	
Brookfield Vis., PaS	0.256 Pas.	
Flash Pt., C	535/279.4°C	
Limiting Temp. for Tmax, C	65.22	
Limiting Temp. for Tint, C	23.9	
Limiting Temp. for Tmin, C	-15.23	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.555	82.20	0.560	70	25	10.0	1.228	85.13	1.232
64	"	"	1.127	87.23	1.128	64	"	"	2.577	89.38	2.589
58	"	"	2.451	86.07	2.457	58	"	"	5.804	92.31	5.86
52	"	"	5.585	84.52	5.61	52	"	"	13.391	88.14	13.59

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	5.751	48.59	4.313	-12	215	0.335			
22	"	"	8.906	45.56	6.358	-15	409.5	0.27			
19	"	"	13.44	42.44	9.043						
16	"	"	19.29	39.55	12.453						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	Westrack	SHRP PG Grade
Sample ID	9/20-8:58 III	
Asphalt Type		
Mass Loss, %	0.261 %	
Brookfield Vis., PaS	C.3, Pas.	
Flash Pt., C	530°F/276.6C	
Limiting Temp. for Tmax, C		
Limiting Temp. for Tint, C		
Limiting Temp. for Tmin, C		

DSR-Original					
Temp, C	Plate Diam., mm	Strain %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.560	88.21	0.560
64	"	"	1.129	87.11	1.130
58	"	"	2.453	85.85	2.459
52	"	"	5.563	84.50	5.588

DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	10.0	1.153	86.23	1.160
64	"	"	2.455	84.54	2.466
58	"	"	5.497	82.57	5.543
52	"	"	12.66	80.27	12.84

DSR-PAV					
Temp, C	Plate Diam., mm	Strain %	G*, MPa	Phase angle δ	G*sinδ MPa
25	8	1	5.45	48.33	4.071
22	"	"	8.1451	45.25	6.014
19	"	"	12.74	42.15	8.549
16	"	"	18.21	37.45	11.571

BBR-PAV		
Temp, C	S(t), MPa	m
-12	222	0.332
-18	471	0.275

DT-PAV		
Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	WESTRACK	SHRP PG Grade
Sample ID.	9/28 -13:36	64- 22
Asphalt Type	AC-20	
Mass Loss, %	0.235	
Brookfield Vis., PaS	0.275	
Flash Pt., C	525/273.8	
Limiting Temp. for Tmax, C	65.86	
Limiting Temp. for Tint, C	24.94	
Limiting Temp. for Tmin, C	-14.08	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.615	88.09	0.615	70	25	10.0	1.291	86.02	1.294
64	"	"	1.245	87.01	1.246	64	"	"	2.735	84.29	2.748
58	"	"	2.725	85.70	2.733	58	"	"	6.157	82.20	6.214
52	"	"	6.289	83.99	6.323	52	"	"	14.19	79.76	14.42

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	6.66	47.05	4.874	-12	224	0.31			
22	"	"	10.19	43.96	7.0734	-18	443	0.245			
19	"	"	15.27	40.79	9.976						
16	"	"	21.63	38.01	13.32						

Original: Tmax
Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
Temperature at which S(t) = 300MPa

Temperature at which m = 0.30

Contract #	WESTRACK	SHRP PG Grade
Sample ID.	9/29-7:30	64- 22
Asphalt Type	AC-20	
Mass Loss, %	0.245	
Brookfield Vis., PaS	0.25 Pas.	
Flash Pt., C	535 / 279.45°C	
Limiting Temp. for Tmax, C	65.13	
Limiting Temp. for Tint, C	23.38	
Limiting Temp. for Tmin, C	-14.3	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.563	88.71	0.563	70	25	10.0	1.178	86.27	1.18
64	"	"	1.151	87.36	1.152	64	"	"	2.469	84.60	2.48
58	"	"	2.509	86.03	2.515	58	"	"	5.574	82.52	5.62
52	"	"	5.725	84.85	5.751	52	"	"	12.78	80.11	12.97

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	5.533	47.51	4.080	-12	212	0.315			
22	"	"	8.498	44.68	5.975	-18	440.5	0.235			
19	"	"	12.56	41.64	8.345						
16	"	"	17.97	39.26	11.305						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	Westrack	GRADE
Sample ID.	9/29-10:38	
Asphalt Type	AC-20	
Mass Loss, %	0.26%	
Brookfield Vis., cp	0.269	
Flash Pt., C	535°F/279.4°C	
Limiting Temp. for Tmax, C	65.55	64-22
Limiting Temp. for Tint, C	23.12	
Limiting Temp. for Tmin, C	-14.02	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.5842	88.33	0.5844	70	25	10.0	1.4	85.69	1.404
64	"	"	1.176	87.30	1.177	64	"	"	2.751	86.25	2.705
58	"	"	2.559	85.92	2.565	58	"	"	6.558	81.71	6.627
52	"	"	5.776	84.32	5.804	52	"	"	15.21	79.11	15.48

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	5.411	47.33	3.978	-12	229	0.32			
22	"	"	8.24	44.37	5.762	-18	440	0.245			
19	"	"	12.28	41.32	8.108						
16	"	"	17.37	38.56	10.827						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0 KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2 KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0 MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300 MPa
   Temperature at which m = 0.30

Contract #	WESTRACK	SHRP PG Grade
Sample ID:	10/1 - 8:40	
Asphalt Type	AC-20	
Mass Loss, %	0.23	
Brookfield Vis., PaS	0.35 Pas	
Flash Pt., C	525°F/274°C	64- 22
Limiting Temp. for Tmax, C	65.6	
Limiting Temp. for Tint, C	22.33	
Limiting Temp. for Tmin, C	-16.5	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.584	87.91	0.584	70	25	10.0	1.275	85.71	1.278
64	"	"	1.199	86.87	1.201	64	"	"	2.678	84.07	2.692
58	"	"	2.585	85.66	2.593	58	"	"	5.066	82.05	6.125
52	"	"	5.820	84.60	5.846	52	"	"	11.02	79.70	14.24

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G* MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	4.526	50.76	3.505	-12	203.5	0.33			
22	"	"	7.097	47.44	5.220	-18	170	0.25			
19	"	"	10.52	44.43	7.374						
16	"	"	15.82	41.37	10.454						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	WESTRACK	SHRP PG Grade
Sample ID.	10/1-9:50	64-22
Asphalt Type	AC-20	
Mass Loss, %	0.25 %	
Brookfield Vis., PaS	0.356	
Flash Pt., C	505F/262.7C	
Limiting Temp. for Tmax, C	65.29	
Limiting Temp. for Tint, C	23.97	
Limiting Temp. for Tmin, C	-14.35	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.567	87.69	0.567	70	25	10.0	1.245	85.87	1.248
64	"	"	1.136	87.14	1.137	64	"	"	2.604	86.24	2.617
58	"	"	2.456	85.99	2.462	58	"	"	5.795	82.25	5.848
52	"	"	5.593	84.39	5.620	52	"	"	13.30	79.42	13.406

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G* MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	5.879	47.77	4.353	-12	229	0.31			
22	"	"	9.082	44.53	6.403	-18	410	0.245			
19	"	"	13.49	41.52	8.912						
16	"	"	19.36	38.71	12.107						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	Westrack	SHRP PG Grade
Sample ID.	10/2-8:13 No.1	64-16
Asphalt Type	AC20	
Mass Loss, %	0.235	
Brookfield Vis., PaS	0.344	
Flash Pt., C	282.2	
Limiting Temp. for Tmax, C	65.89	
Limiting Temp. for Tint, C	26.73	
Limiting Temp. for Tmin, C	-14.08	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.608	88.23	0.609	70	25	10.0	1.314	86.15	1.317
64	"	"	1.227	87.28	1.228	64	"	"	2.754	84.27	2.767
58	"	"	2.694	85.92	2.700	58	"	"	6.193	82.18	6.251
52	"	"	6.103	84.25	6.134	52	"	"	14.400	79.90	14.63

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	8.121	47.32	5.970	-12	228	0.31			
22	"	"	12.480	44.07	8.680	-18	435	0.24			
19	"	"	18.78	40.80	12.271						
16	"	"	26.970	37.68	16.485						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa 65.89

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa 65.95

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa 26.73

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa -14.08

   Temperature at which m = 0.30 -12.86

Contract #	Westrack	SHRP PG Grade
Sample ID.	10/2-8:13 No.2	64-16
Asphalt Type	AC20	
Mass Loss, %	0.24	
Brookfield Vis., PaS	0.344	
Flash Pt., C	279.45	
Limiting Temp. for Tmax, C	65.93	
Limiting Temp. for Tint, C	25.88	
Limiting Temp. for Tmin, C	-13.8	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.614	88.98	0.614	70	25	10.0	1.323	85.95	1.326
64	"	"	1.236	87.32	1.237	64	"	"	2.763	84.63	2.776
58	"	"	2.679	85.83	2.686	58	"	"	6.169	82.26	6.225
52	"	"	6.050	84.34	6.079	52	"	"	14.250	79.8	14.470

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	7.434	46.74	5.410	-12	230.5	0.315			
22	"	"	11.430	43.54	7.870	-18	462	0.245			
19	"	"	17.10	40.37	11.076						
16	"	"	24.360	37.36	14.782						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa 65.93

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa 65.98

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa 25.88

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa -13.8

   Temperature at which m = 0.30 -13.29

Contract #	WESTRACK	SHRP PG Grade
Sample ID.	10/2-8:13 III	64-22
Asphalt Type	AC-20	
Mass Loss, %	0.24%	
Brookfield Vis.,PaS @135°C	0.362	
Brookfield Vis.,PaS @150°C	0.112	
Flash Pt., C	276.67 °C	
Limiting Temp. for Tmax, C	65.57	
Limiting Temp. for Tint, C	24.33	
Limiting Temp. for Tmin, C	-14.24	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.513	84.03	0.515	70	25	10.0	1.243	85.77	1.246
64	"	"	1.195	86.94	1.196	64	"	"	2.613	84.20	2.626
58	"	"	2.602	85.14	2.609	58	"	"	5.930	82.14	5.976
52	"	"	5.957	84.06	5.939	52	"	"	13.80	79.74	14.02

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	6.076	49.92	4.649	-12	216	0.33			
22	"	"	9.177	43.33	6.370	-18	441	0.25			
19	"	"	13.66	40.93	8.949						
16	"	"	19.39	38.03	11.98						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa

   Temperature at which m = 0.30

Contract #	Westrack	SHRP PG Grade
Sample ID.	10/4 AM No.1	64-22
Asphalt Type	AC20	
Mass Loss, %	0.21	
Brookfield Vis., PaS	0.300	
Flash Pt., C	273.8	
Limiting Temp. for Tmax, C	64.68	
Limiting Temp. for Tint, C	24.94	
Limiting Temp. for Tmin, C	-13.9	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.600	88.7	0.601	70	25	10.0	1.114	86.61	1.116
64	"	"	1.232	87.54	1.233	64	"	"	2.324	84.91	2.333
58	"	"	2.664	86.1	2.670	58	"	"	5.213	82.84	5.254
52	"	"	6.112	84.26	6.143	52	"	"	11.93	80.73	12.087

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	6.562	47.72	4.855	-12	233	0.305			
22	"	"	10.13	44.69	7.124	-18	438	0.235			
19	"	"	15.21	41.42	10.063						
16	"	"	21.71	38.24	13.437						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa 65.8

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa 64.68

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa 24.94

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa -13.9

   Temperature at which m = 0.30 -12.4

Contract #	Westrack	SHRP PG Grade
Sample ID.	10/4 AM No.2	64-16
Asphalt Type	AC20	
Mass Loss, %	0.25	
Brookfield Vis., PaS	0.318	
Flash Pt., C	279.4	
Limiting Temp. for Tmax, C	65.95	
Limiting Temp. for Tint, C	25.91	
Limiting Temp. for Tmin, C	-13.35	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.615	87.85	0.615	70	25	10.0	1.395	84.28	1.410
64	"	"	1.24	86.77	1.242	64	"	"	2.800	82.86	2.822
58	"	"	2.687	85.62	2.694	58	"	"	6.400	81.07	6.478
52	"	"	6.104	84.21	6.135	52	"	"	14.650	78.43	14.954

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	7.397	47.06	5.415	-12	246	0.31			
22	"	"	11.390	44.04	7.918	-18	485	0.24			
19	"	"	16.970	40.84	11.097						
16	"	"	24.330	37.53	14.821						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa 65.95

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa 66.28

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa 25.91

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa -13.35

   Temperature at which m = 0.30 -12.86

Contract #	Westrack	SHRP PG Grade
Sample ID.	10/4 AM No.3	64-22
Asphalt Type	AC20	
Mass Loss, %	0.25	
Brookfield Vis., PaS	0.356	
Flash Pt., C	271.2	
Limiting Temp. for Tmax, C	65.15	
Limiting Temp. for Tint, C	22.07	
Limiting Temp. for Tmin, C	-13.8	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.558	87.84	0.558	70	25	10.0	1.284	85.42	1.288
64	"	"	1.117	86.91	1.118	64	"	"	2.710	84.11	2.724
58	"	"	2.405	85.73	2.412	58	"	"	6.110	82.08	6.168
52	"	"	5.367	84.26	5.394	52	"	"	14.22	79.79	14.448

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	4.859	47.18	3.564	-12	224.5	0.31			
22	"	"	7.304	44.40	5.110	-18	465.5	0.245			
19	"	"	10.870	41.21	7.161						
16	"	"	15.470	38.30	9.587						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa 65.15

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa 65.81

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa 22.07

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa -13.8

   Temperature at which m = 0.30 -12.9

Contract #	Westrack	SHRP PG Grade
Sample ID.	10/4 AM No.4	64-22
Asphalt Type	AC20	
Mass Loss, %	0.29	
Brookfield Vis., PaS	0.306	
Flash Pt., C	273	
Limiting Temp. for Tmax, C	65.6	
Limiting Temp. for Tint, C	24.41	
Limiting Temp. for Tmin, C	-13.54	

DSR-Original						DSR-RTFOT					
Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa	Temp, C	Plate Diam., mm	Strain, %	G*, kPa	Phase angle δ	G*/sinδ kPa
70	25	12.5	0.585	88.02	0.585	70	25	10.0	1.515	85.18	1.52
64	"	"	1.189	86.40	1.191	64	"	"	3.224	83.63	3.244
58	"	"	2.581	85.95	2.587	58	"	"	7.282	81.60	7.361
52	"	"	5.845	84.28	5.874	52	"	"	16.82	78.75	17.149

DSR-PAV						BBR-PAV			DT-PAV		
Temp, C	Plate Diam., mm	Strain, %	G*, MPa	Phase angle δ	G*sinδ MPa	Temp, C	S(t), MPa	m	Temp, C	Avg. Failure Strain, %	Avg. Failure Stress, Pa
25	8	1	6.360	46.42	4.607	-12	230	0.305			
22	"	"	9.606	43.17	6.570	-18	502	0.235			
19	"	"	14.050	40.27	9.081						
16	"	"	19.670	37.35	11.933						

1. Original: Tmax
   Temperature at which G*/sinδ = 1.0KPa 65.6

2. RTFOT: Tmax
   Temperature at which G*/sinδ = 2.2KPa 67.08

3. DSR-PAV: Tint
   Temperature at which G*(sinδ) = 5.0MPa 24.41

4. BBR-PAV: Tmin
   Temperature at which S(t) = 300MPa -13.54

   Temperature at which m = 0.30 -12.43

APPENDIX C

BENDING BEAM RHEOMETER LOAD-TIME DATA

Table C1. BBR stiffness – time of loading.

Sample Date	Sample Time	Replicate	Temp, °C	Creep Stiffness, MPa @ load times, sec.					
				8	15	30	60	120	24
9-14-95	7:36	1	-12.0	348	291	239	195	137	124
		2	-12.0	414	346	285	233	186	147
		1	-18.1	626	547	478	405	338	280
		2	-18.1	643	550	433	409	344	284
	11:59	1	-11.9	363	303	249	202	181	126
		2	-11.9	351	296	245	199	159	125
		1	-18.0	640	553	472	402	335	276
		2	-17.9	643	558	476	403	336	275
9-18-95	10:03	1	-11.9	389	323	264	213	168	131
		2	-12.0	379	311	250	197	153	119
		1	-18.1	709	623	534	457	382	315
		2	-18.0	731	628	541	462	385	315
9-19-95	7:20	1	-12.0	392	325	269	218	174	135
		2	-12.0	374	304	245	194	151	116
		1	-18.3	721	629	541	458	382	313
		2	-17.9	670	587	500	418	341	274
	11:40	1	-12.0	388	323	264	215	173	135
		1	-18.3	755	655	570	482	402	330
		2	-18.1	746	648	552	460	378	303
9-28-95	13:36	1	-12.2	399	333	276	226	181	143
		2	-12.2	405	338	275	222	174	135
		1	-18.0	720	625	536	456	382	314
		2	-18.0	682	593	510	430	351	287

Table C1. BBR stiffness – time of loading (continued).

Sample Date	Sample Time	Replicate	Temp, °C	Creep Stiffness, MPa @ load times, sec.					
				8	15	30	60	120	24
9-29-95	7:30	1	-12.2	393	329	271	222	177	137
		2	-12.1	375	308	252	202	160	124
		1	-18.0	702	608	525	445	374	305
		2	-18.0	667	585	509	436	363	300
	10:38	1	-12.0	421	346	286	233	187	147
		2	-11.9	418	347	281	224	175	134
		1	-18.0	679	606	521	446	373	306
		2	-17.9	693	597	511	434	358	289
10-1-95	8:40	1	-12.0	371	307	252	203	161	126
		2	-12.0	390	320	258	204	158	119
		1	-17.9	677	595	508	430	356	291
	9:50	1	-12.1	435	362	297	242	194	153
		2	-12.1	394	324	263	215	172	136
10-295	8:13(I)	1	-11.9	407	339	280	227	180	140
		2	-11.9	406	341	279	228	182	143
		1	-18.1	654	573	493	416	348	286
		2	-18.1	706	618	535	453	379	315
	8:13(II)	1	-11.9	404	335	276	224	180	141
		2	-11.9	413	322	296	237	188	146
		1	-18.1	742	652	563	473	396	324
		2	-18.1	705	617	533	451	379	310
	8:13(III)	1	-12.2	412	335	271	216	169	131
		1	-18.1	709	624	538	461	386	318
		2	-17.9	695	602	506	421	345	279

Table C1. BBR stiffness - time of loading (continued).

Sample Date	Sample Time	Replicate	Temp, °C	Creep Stiffness, MPa @ load times, sec.					
				8	15	30	60	120	24
10-4-95	AM(I)	1	-12.1	421	352	292	238	190	149
		2	-12.1	406	340	282	228	183	144
		1	-17.9	786	672	583	492	409	336
		2	-17.8	749	654	562	478	400	330
	AM(II)	1	-11.9	453	374	309	250	198	154
		2	-11.9	435	361	300	242	193	151
		1	-18.0	685	590	511	434	362	299
		2	-18.0	686	605	520	441	373	309
	AM(III)	1	-12.0	391	327	269	217	173	136
		2	-12.0	422	348	287	232	185	145
		1	-18.2	718	644	557	473	398	328
		2	-18.2	726	631	544	458	382	314
	AM(IV)	1	-12.1	393	333	276	224	180	142
		2	-12.0	416	350	289	235	188	149
		1	-18.0	787	682	587	502	423	349
		2	-17.9	779	680	591	502	425	350

Asphalt Binder Properties—Replacement Sections

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-2
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million, 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on the properties of the asphalt binder used during the replacement of the 10 sections of HMA during May and June 1997. The report describes the asphalt binder grade selection process, selection of the binder source, and properties of the asphalt binder used for construction. Asphalt binder properties were determined using both the Superpave binder test equipment and conventional viscosity testing equipment. Variability of properties of samples obtained during construction were determined and are contained in the report.

BACKGROUND

BINDER GRADE SELECTION

The major objective of the experiment associated with the replacement sections was to determine the performance of a Superpave coarse graded mixture prepared from a 100 percent crushed aggregate. The placement and testing of the replacement coarse-graded mixture was compared with the coarse-graded mixture placed during original construction, which was prepared from a partially crushed gravel aggregate.

In order to reduce the number of variables associated with this comparison of two different aggregate types, it was desirable to use the same asphalt binder grade from the same refinery for

the replacement sections as was used on the sections placed during original construction. Since a PG 64-22 "neat" asphalt cement was selected for original construction, the same grade of asphalt was used for the replacement sections. Background information on the selection process for the PG 64-22 for original construction is contained in reference 4. The SHRP-developed "SHRPBIND" software was used for the selection of the asphalt binder grade.[5]

ASPHALT BINDER SOURCE

As stated above, it was desirable to use the same binder grade and source for both the replacement and original sections placed at WesTrack. Initial mixture design work was, therefore, performed with samples of the asphalt binder obtained during original construction of the track. On May 12, 1997, Huntway (supplier of asphalt binder used for original construction) notified the WesTrack Team that they would not be able to supply the same PG 64-22 asphalt binder that was used in the HMA placed during original construction. Alternative sources of a neat PG 64-22 were immediately investigated via telephone calls to suppliers of asphalt binders.

Samples of PG 64-22 asphalt binders were obtained from Idaho Asphalt Supply, Inc, Nampa, Idaho, and Albina Asphalt in Oregon. Properties of these asphalt binders, as tested by the University of Nevada laboratory, are shown in tables 1 and 2 and appendix A. Appendix A contains information obtained on samples over a range of temperatures, while table 1 is a summary of asphalt binder properties at the specification temperature.

Appendix B shows a comparison of asphalt binder properties obtained on the asphalt binder used for original construction (Huntway) and candidate asphalt binders being considered for use on the replacement sections. Asphalt binder test data are shown on an asphalt binder from Idaho Asphalt Supply as tested by the refinery and as tested by the University of Nevada, an asphalt binder from Husky that represents a binder that was to be supplied by Albina (tested by University of Nevada), and the asphalt binder used for the original construction of WesTrack (Huntway). Property comparisons were made for high, intermediate, and low specification temperatures as shown in figures 3 to 7 and appendix B. Based on these comparisons (appendix B) and the availability of the asphalt binder for mixture design and construction, the researchers elected to use the PG 64-22 binder from Idaho Asphalt Supply, Inc. Samples of the Idaho Asphalt Supply, PG 64-22 neat asphalt binder were received in the University of Nevada laboratory on May 18, 1997, and were used to complete the mixture design work for the replacement sections. Trial section paving was initiated with the Idaho asphalt binder on May 23, 1997.

SAMPLING

SAMPLING PLAN

The asphalt binder sampling plan used during construction of the replacement sections was not as extensive as that used for the construction of the original sections. Due to the short time available to place the test lanes during construction of the replacement sections, no quality control samples were taken or tested. Construction would have been complete prior to receiving

test information on any asphalt binder samples taken for quality control purposes. Therefore, a preconstruction and post-construction (i.e., quality assurance) sampling and test program was utilized.

Details of the sampling plan used for the construction of the replacement sections is available in another WesTrack technical report.[6] The sampling plan required samples prior to construction (preconstruction) to verify the refinery-supplied information on the grade of asphalt binder supplied for mixture design purposes and on the binder that was to be supplied for construction purposes.

SAMPLE LOCATION

The preconstruction samples were supplied by Idaho Asphalt Supply. Samples taken during placement of the test lanes were obtained by Granite Construction from the asphalt binder storage tank located at the company's Patrick, Nevada, facility.

Asphalt binder samples were taken during construction on June 23 and 28, 1997. On June 23, 1997, the bottom lift of the test lane was placed at the track. On June 28, 1997, the top lift of the test lane was place at the track. Table 3 shows the relationship between sample date and placement of the sections by lift.

TEST METHODS AND TEST SEQUENCE

Two separate testing programs were performed on the asphalt binder samples obtained from the WesTrack Project. Superpave binder tests were performed according to American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM) procedures to determine the binder performance grade (PG). In addition, conventional viscosity binder testing was performed according to AASHTO and ASTM procedures to determine if the asphalt binder satisfied the viscosity grading designations as described in table 2 of AASHTO M 226 and ASTM D 3381. Test methods and the test sequence for each of these testing programs are described below.

SUPERPAVE BINDER TESTING

Test Methods

Superpave asphalt binder testing was performed according to the test methods identified in table 4.

Test Sequence

The test sequence used for grading the asphalt binder samples with respect to the Superpave specification is shown in figure 1. The dynamic shear modulus for original and aged asphalt binder samples was determined at four temperatures: 52°C, 58°C, 64°C, and 70°C. Testing over this temperature range allowed the high-temperature specification designation to be defined, and for maintaining the accuracy of the data set. Four intermediate temperatures were also selected (16°C, 19°C, 22°C, and 25°C) to determine the stiffness of the binder at temperatures associated with fatigue of asphalt-bound pavements. Two temperatures were selected to determine the low temperature properties of the asphalt binder. Bending beam rheometer (BBR) tests were performed at -12°C and -18°C. The low-temperature designation of the asphalt binder was determined from these data.

VISCOSITY BINDER TESTING

Test Methods

The test methods shown in table 5 were used to determine the asphalt binder properties and to classify the binder according to the AASHTO and ASTM viscosity grading system. The Utah Department of Transportation performed the viscosity asphalt binder testing. The toughness and tenacity test was performed according to Utah Department of Transportation testing procedures.

Test Sequence

The test sequence used for classifying the asphalt binder according to the viscosity grading system is shown in figure 2. Viscosity was determined at 60°C and 135°C and penetration at 25°C. The asphalt binder was aged by use of the rolling thin film oven test (RTFOT).

TEST RESULTS

Asphalt binder test results were obtained on samples obtained prior to construction, during placement of the trial sections, and during placement of the test lane sections. As stated previously, samples obtained during construction were not tested during construction (as quality control samples), but were retained and served as quality assurance samples after the completion of the placement of the test lanes.

PRECONSTRUCTION

Construction of the HMA asphalt for the replacement sections started on May 23, 1997, with the placement of the bottom lift of a trial section on the off-ramp at the track. The top lift of the trial section was placed on the off-ramp on May 30, 1997. The final trial section was placed on the access road to WesTrack on June 20, 1997. Test lane paving was performed on June 23 and 28, 1997, for the bottom and top lifts, respectively.

Test results obtained on samples of asphalt binders supplied by Idaho Asphalt Supply on May 18, 1997, and used for binder selection and mixture design purposes, are shown in tables 1 and 2 and appendix A. Test results for samples of asphalt binder obtained from Albina in the middle of May 1997 also are shown in these tables and appendix A.

These data indicate that the materials supplied met the requirements for a PG 64-22 binder and were suitable for use on WesTrack.

QUALITY ASSURANCE

As stated previously, asphalt binder samples were obtained on June 23 and 28, 1997, for quality assurance testing. Test results are shown in tables 6 through 8 and appendix C.

Superpave Grading System

Quality assurance Superpave test results performed by the University of Nevada are shown in tables 6 and 7. Table 6 shows the rheologic properties of the binders at the test temperatures associated with the PG 64-22 classification. For example, the original and RTFOT-aged dynamic shear rheometer (DSR) values are reported at 64°C. The DSR values after aging in the pressure aging vessel (PAV) are reported at a temperature of 25°C. The bending beam rheometer (BBR) test results are reported at a temperature of -12°C.

Table 7 shows the test temperatures at which the acceptance criteria are met for the Superpave asphalt binder specification. For example, table 7 indicates the 1.0 kPa requirement for the original asphalt binder DSR value is met at a temperature of 67.3°C for the first replicate sample obtained on June 23, 1997.

Appendix A contains Superpave binder test properties over a range of temperatures for various aging and test conditions. These data can be used to define the temperature susceptibility of the asphalt binder used on WesTrack.

Superpave asphalt binder test properties also were obtained by the Utah Department of Transportation and by Idaho Asphalt Supply. Typically these tests were performed at a single temperature for each aging condition. Test results are shown in table 8. These test results indicate that the asphalt binder supplied met the requirements for a PG 64-22 binder.

Viscosity Grading System

Table 9 contains results of tests that allow the asphalt binder to be graded according to the viscosity grading system. These tests were performed by the Utah Department of Transportation. Viscosity determinations at 60°C indicate that the binder exceeds the upper limit for viscosity. The reported viscosity is 2520 poise and the upper limit is 2400 poise for an AC-20 asphalt cement. All other reported test results are within the limits for an AC-20 asphalt cement.

DATA ANALYSIS

Table 10 shows representative properties of the asphalt binder used for the replacement sections at WesTrack. The values shown are the average values obtained from the four quality assurance samples as reported in detail in tables 6 and 7. Table 10 shows the asphalt binder meets the requirements of the Superpave PG 64-22 specification.

Since only a limited amount of binder testing was performed, control charts and detailed variability studies were not performed on the data. Statistical information presented in tables 6 and 7 indicate that variability was low on the samples tested as compared to national studies reported in references 4 and 7.

SUMMARY

Properties of the asphalt binder used for Westrack replacement sections were determined. Table 10 contains representative values for the PG 64-22 asphalt binder used in the HMA mixture for the replacement sections at WesTrack. Tables 11 and 12 compare the asphalt binders used for construction of the original and replacement sections at WesTrack. These data represent the average values from the quality assurance test samples reported by the University of Nevada.[(4)] The asphalt binder used for the replacement sections has a higher stiffness at the design rutting temperature (64°C), lower stiffness at the intermediate fatigue temperature (25°C), and lower stiffness at the thermal cracking temperature (-12°C).

Tables 13 and 14 compare properties of the asphalt binders used on original and replacement sections at various temperatures and aging conditions. These data also are shown in figures 3 through 7. The DSR and BBR data for unaged or original asphalts, and for RTFOT-aged and PAV-aged asphalts also are shown in these tables and figures. The data used to develop tables 13 and 14 and figures 3 through 7 are from two representative samples of original and replacement section quality assurance testing performed by the University of Nevada. Representative samples were used rather than average values for all samples tested.

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6. Hand, A. and Epps, J., "WesTrack Replacement Hot-Mix Asphalt — Preconstruction, Construction, and Postconstruction Material Sampling and Testing Plan," WesTrack Technical Report UNR-19, February 2000.

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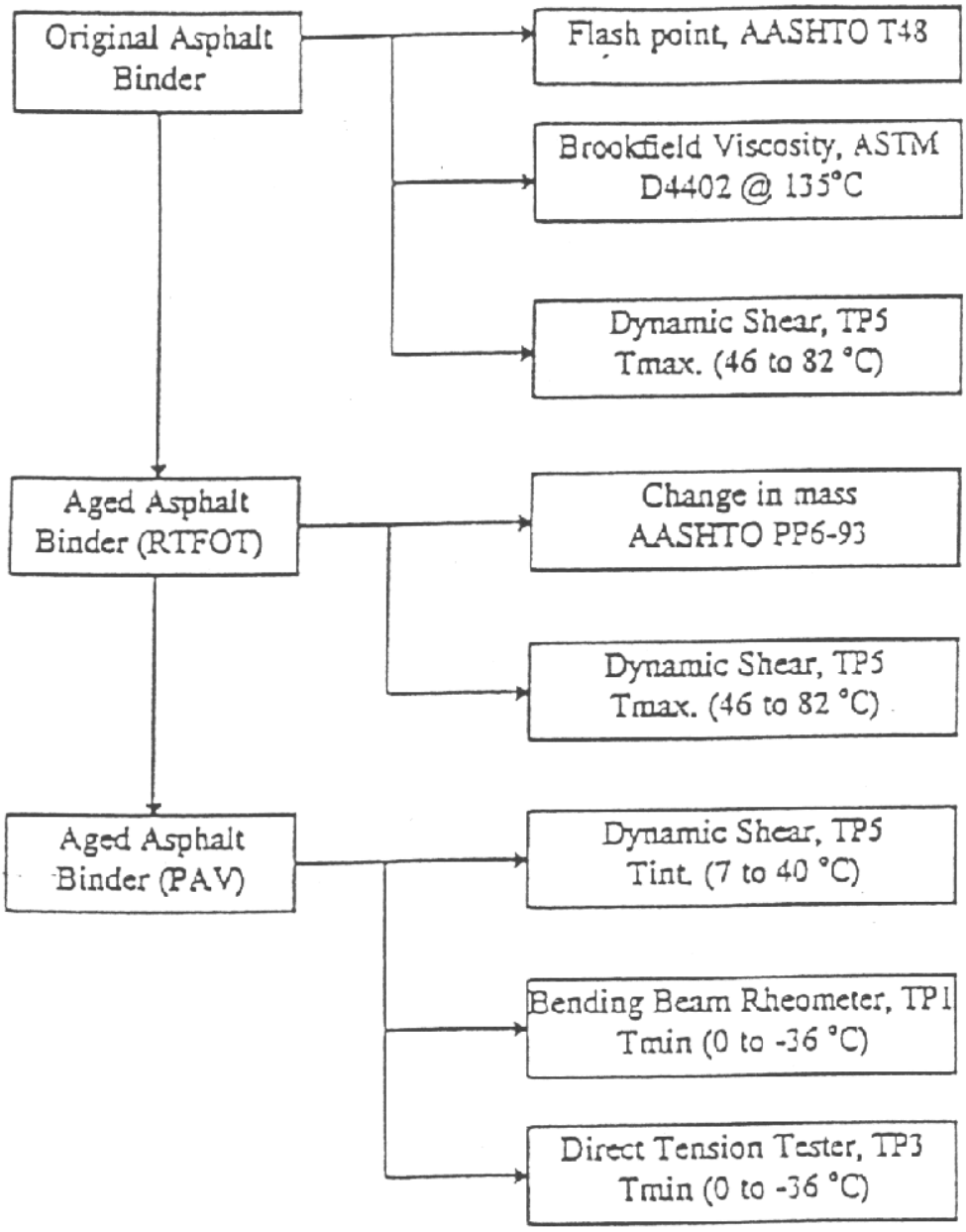

Figure 1. Test sequence for Superpave asphalt binder grade classification.

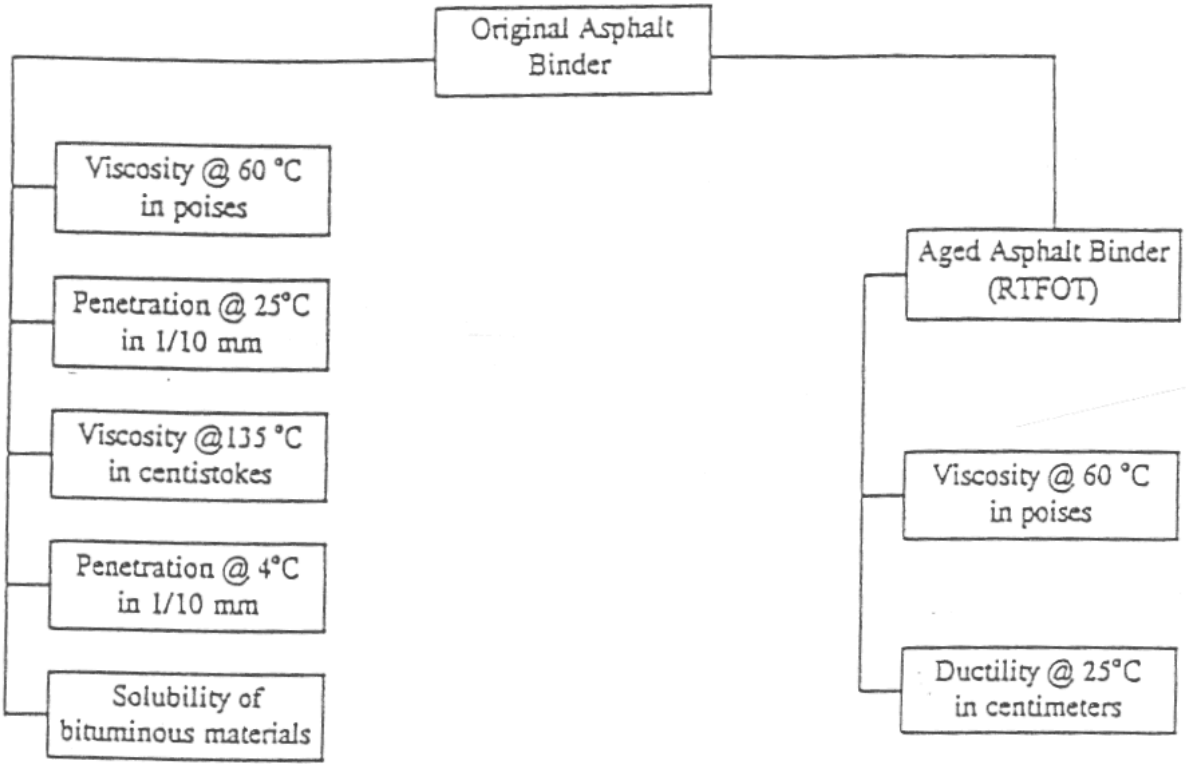

Figure 2. Test sequence for viscosity grade classification.

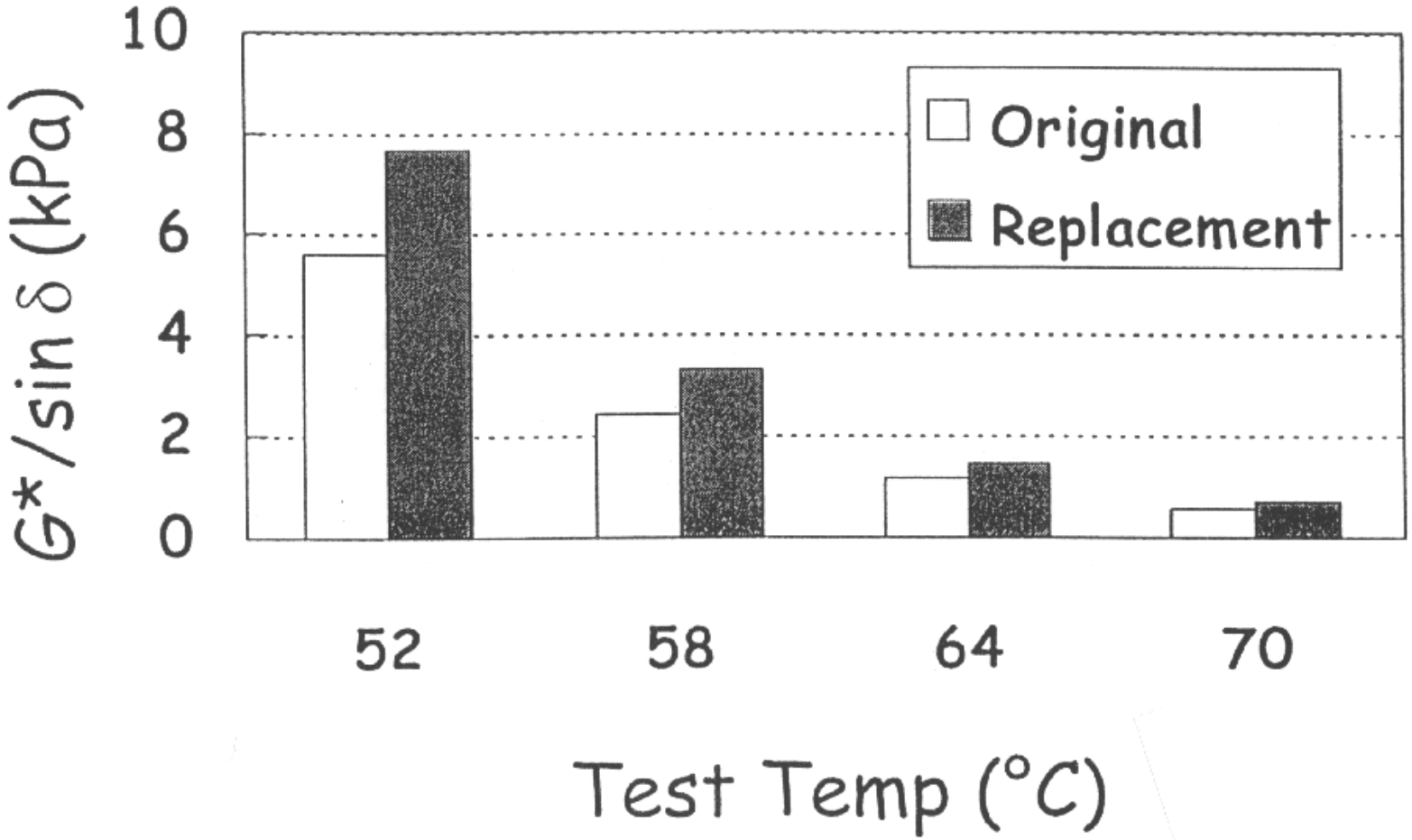

Figure 3. DSR binder data – unaged.

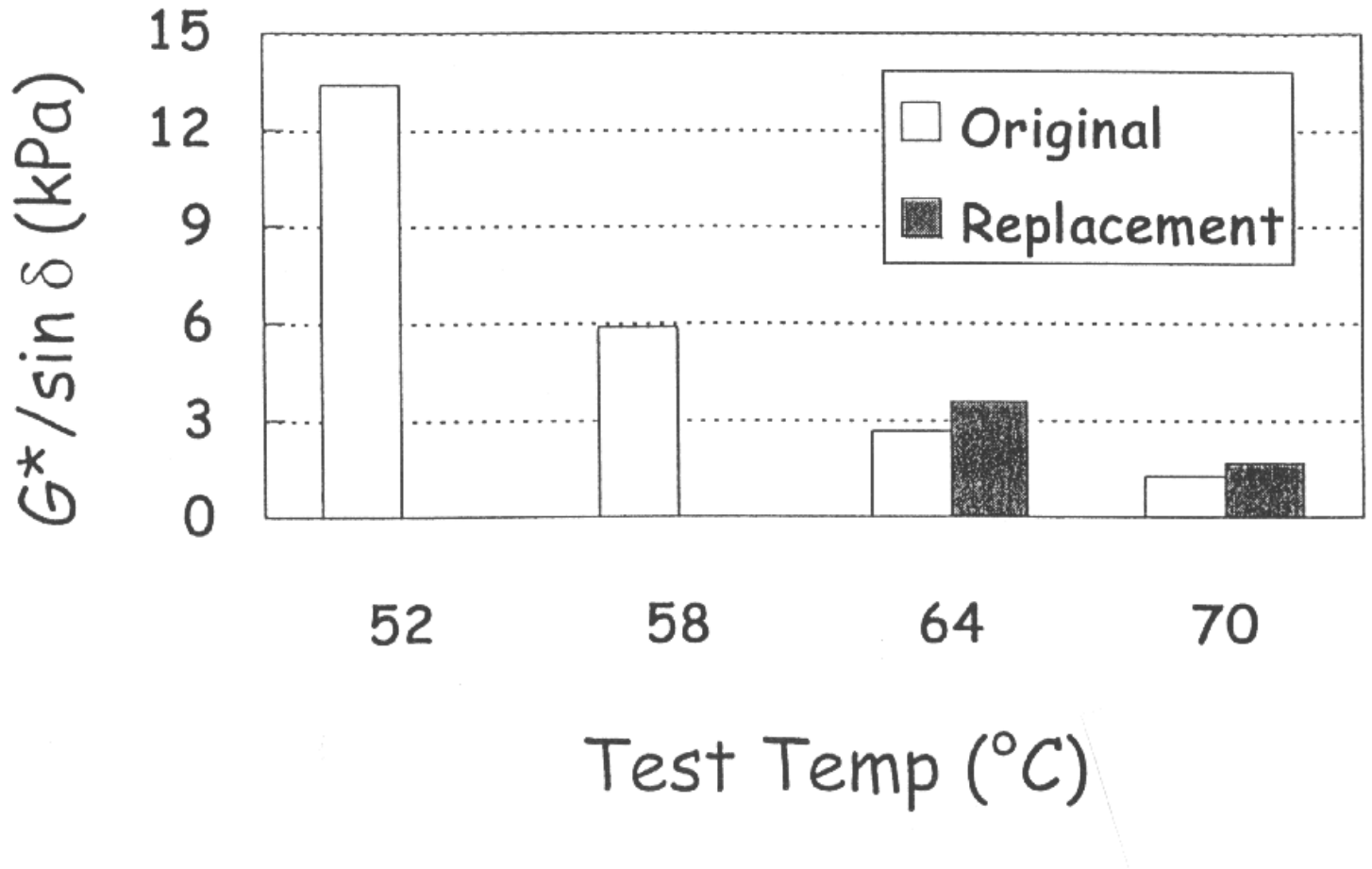

Figure 4. DSR binder data – RTFOT.

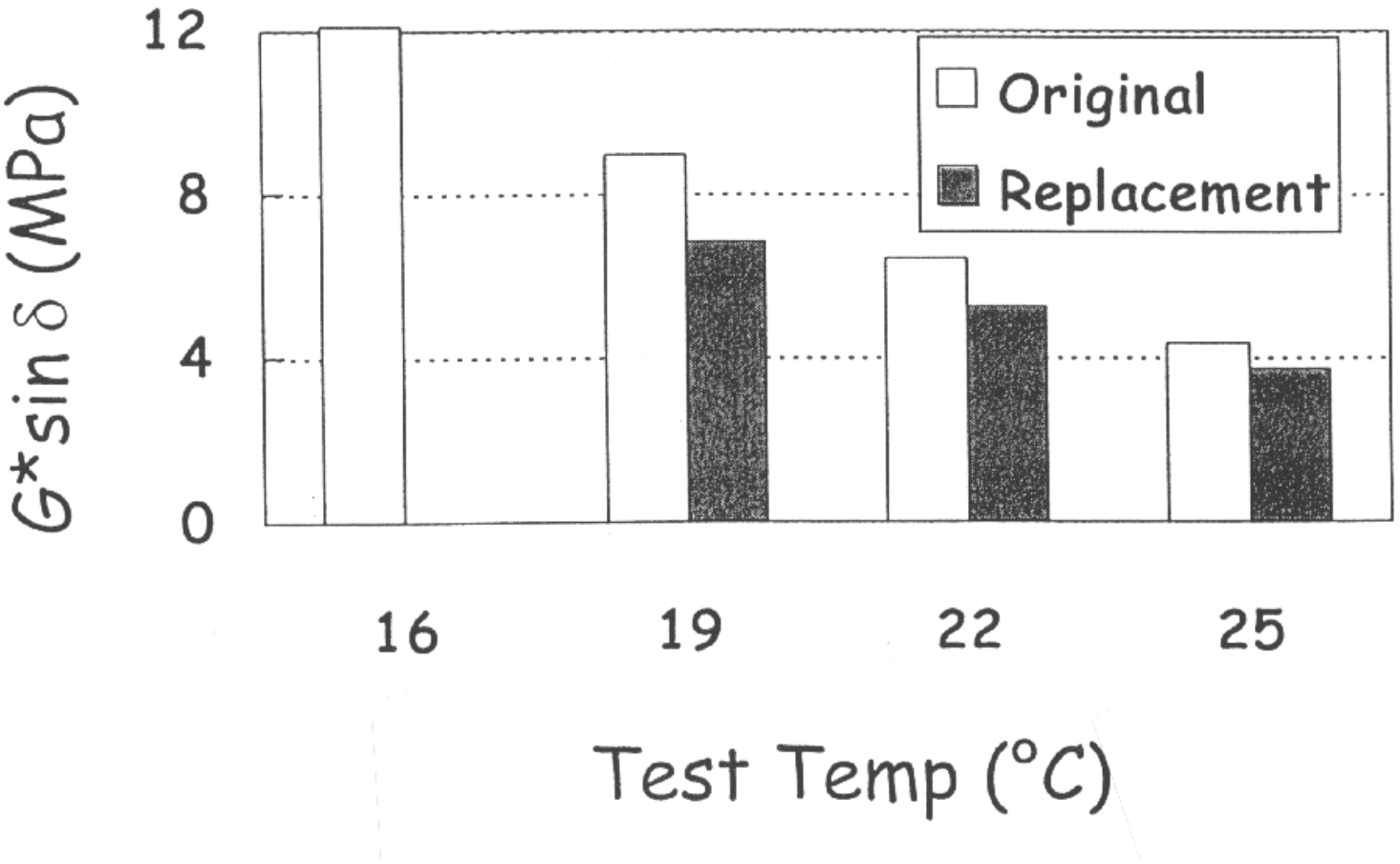

Figure 5. DSR binder data — PAV.

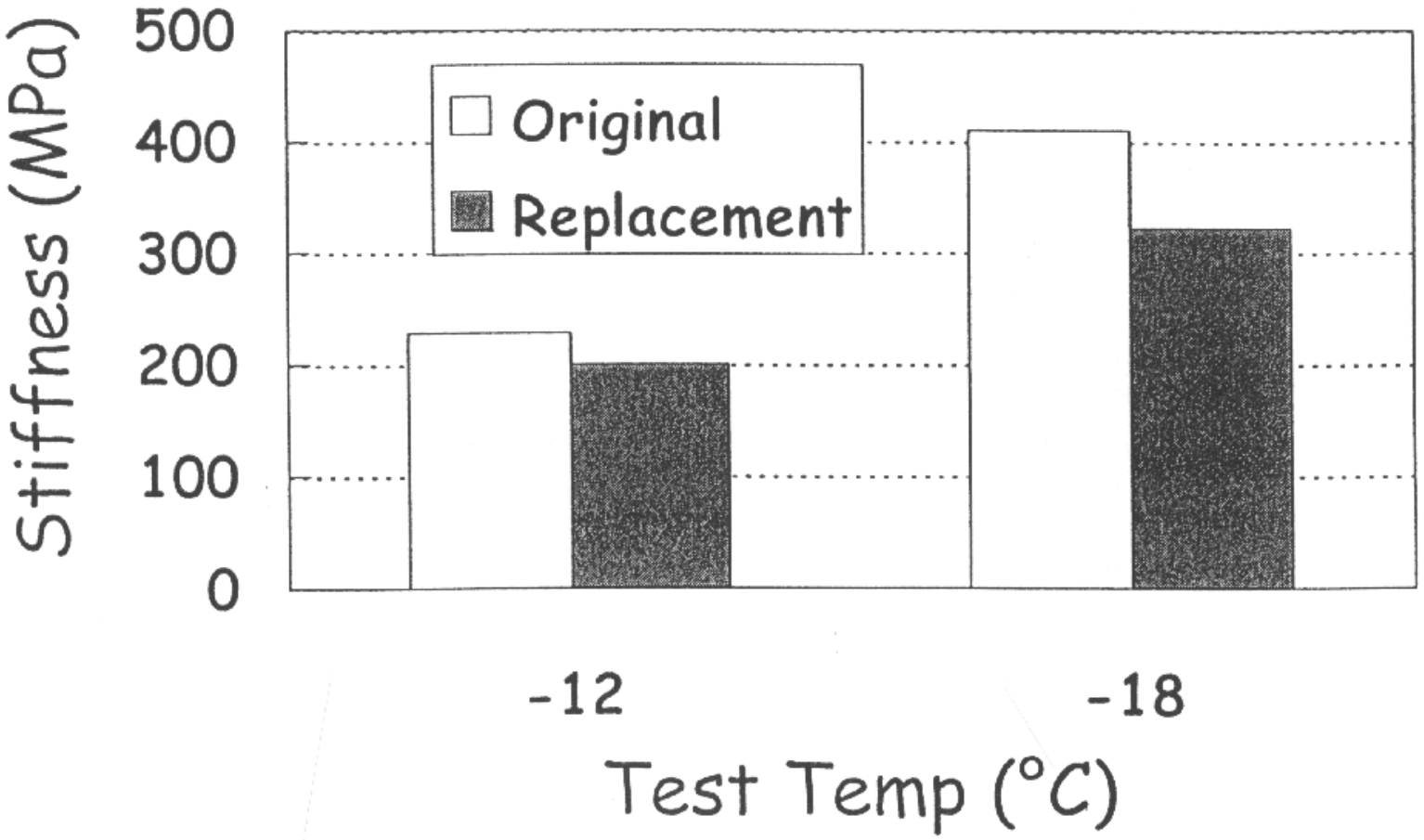

Figure 6. BBR binder data — PAV.

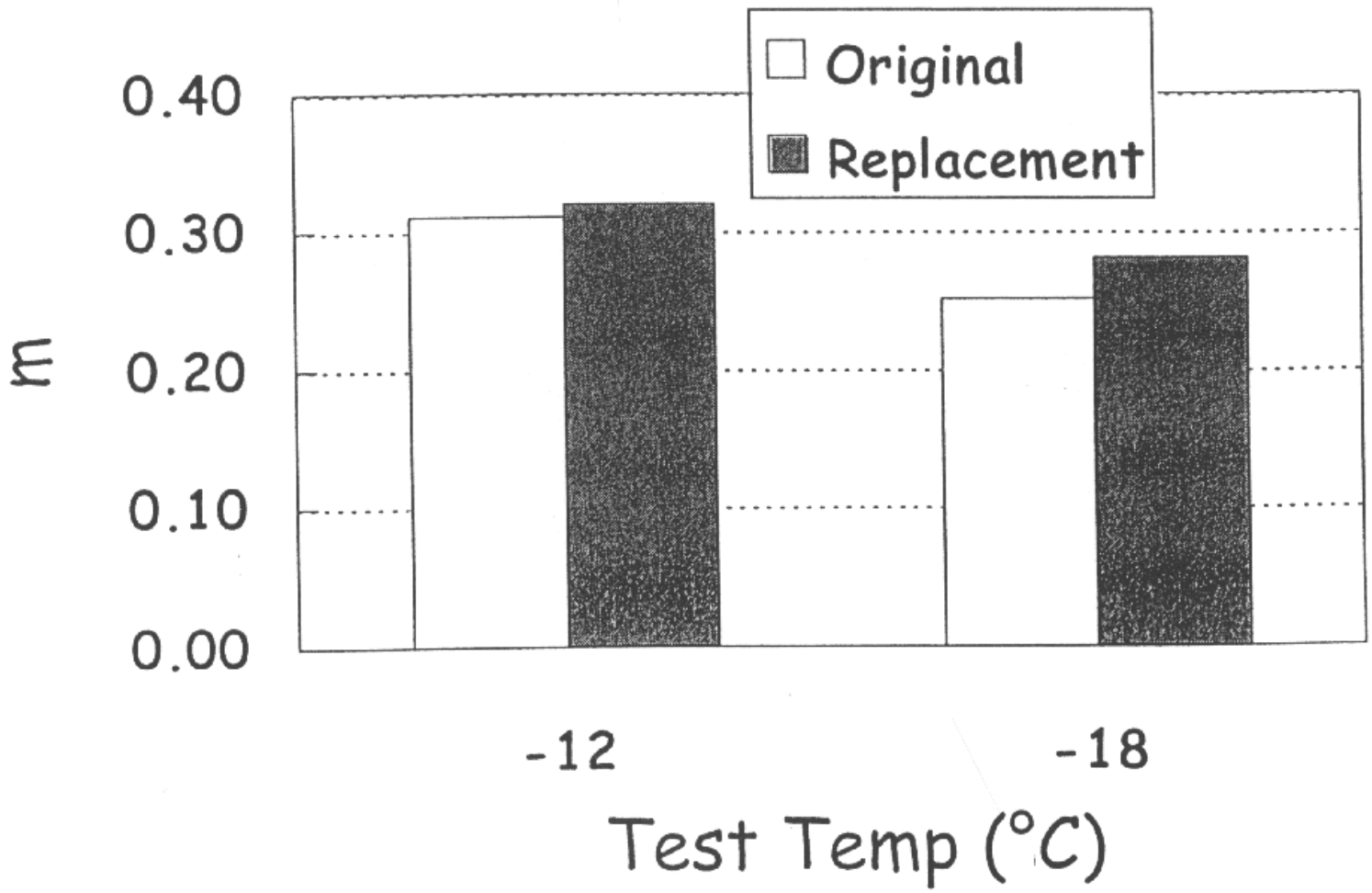

Figure 7. BBR binder data — PAV.

Table 1. Superpave binder test results – preconstruction samples.

Sample Identification	DSR-Original @ 64°C			DSR-RTFOT @ 64°C			DSR-PAV @ 25°C			BBR @-12°C		PG
	G*, kPa	δ	G*/sin δ, kPa	G*, kPa	δ	G*/sin δ, kPa	G*, MPa	δ	G*/sin δ, MPa	S(t), MPa	m	
Idaho asphalt TR-048-1	1.289	87.5	1.290	3.112	84.5	3.126	5.824	45.5	4.081	178	0.326	64-22
Idaho asphalt TR-048-2	1.278	87.5	1.279	3.041	84.4	3.056	6.039	45.1	4.276	165	0.330	64-22
Albina 1	1.443	86.6	1.446	2.941	83.4	2.961	3.084	51.1	2.400	130	0.375	64-22
Albina 2	1.420	86.2	1.423	3.001	83.2	3.022	3.495	50.3	2.688	130	0.375	64-22

Table 2. Superpave binder test results – preconstruction samples.

Sample Identification	Flash Point, °C	Viscosity @ 135°C, Pa.s	DSR Original Temp @ 1.0 kPa	DSR RTFOT Temp @ 2.2 kPa	Mass Loss, Percent	DSR PAV Temp @ 5.0 MPa	BBR		PG
							Temp @ 300 MPa	Temp @ m=0.30	
Idaho asphalt TR-048-1	30.4	0.35	66.2	66.8	0.275	23.2	-17.0	-14.4	64-22
Idaho asphalt TR-048-2	302	0.35	65.8	66.7	0.260	23.7	-17.0	-15.1	64-22
Albina 1	274	0.40	67.1	66.5	0.250	19.0	-17.7	-18.0	64-22
Albina 2	274	0.40	67.1	66.7	0.250	20.1	-17.7	-18.0	64-22

Table 3. Asphalt binder samples and test lane sections.

Asphalt Binder Sampling Date	Lane – Lift Paved	Section Number	Mixture Designation
6-23-97	Test lane bottom lift	35, 36, 37, 38, 39, 54, 55, 56	Coarse replacement
6-28-97	Test lane top lift	35, 36, 37, 38, 39, 54, 55, 56	Coarse replacement

Table 4. Superpave asphalt binder tests.

Description	Designation	
	ASTM	AASHTO
Flash point	D 92	T 48
Brookfield	D 4402	
Dynamic shear rheometer		TP 5
Mass loss		PP 6-93
Bending beam rheometer		TP 1
Direct tension tester		TP 3
Rolling thin film oven	D 2872	T 240
Pressure aging vessel		PP 1

Table 5. Viscosity asphalt binder tests.

Description	Designation	
	ASTM	AASHTO
Flash point	D 92	T 48
Solubility of bituminous materials	D 2042	T 44
Ductility of bituminous materials	D 113	T 51
Penetration of bituminous materials @ 25°C	D 5	T 49
Kinematic viscosity of asphalt @ 135°C	D 2970	T 201
Absolute viscosity of asphalt @ 60°C	D 2171	T 202
Thin film oven test	D 1754	

Table 6. Superpave binder test result — construction samples.

Sample Identification	DSR-Original @ 64°C			DSR-RTFOT @ 64°C			DSR-PAV @ 25°C			BBR @-12°C		PG
	G*, kPa	δ	G*/sin δ, kPa	G*, kPa	δ	G*/sin δ, kPa	G*, MPa	δ	G*/sin δ, MPa	S(t), MPa	m	
6-23-97 REP 1	1.522	86.9	1.524	3.970	83.5	3.995	5.832	43.1	3.988	196	0.314	64-22
6-23-97 REP 2	1.492	87.4	1.494	3.445	84.1	3.463	6.080	44.5	4.261	200	0.320	64-22
6-28-97 REP 1	1.450	86.8	1.452	3.511	84.2	3.529	5.381	43.9	3.735	201	0.317	64-22
6-28-97 REP 2	1.499	86.8	1.501	3.404	83.8	3.424	5.491	43.9	3.804	194	0.314	64-22
Mean	1.491	87.0	1.493	3.583	83.9	3.603	5.696	43.9	3.946	198	0.316	64-22
Standard deviation	0.030	0.271	0.030	0.262	0.316	0.265	0.320	0.574	0.237	3.3	0.003	
Coef. of variation, percent	2.0	0.3	2.0	7.3	0.4	7.4	5.6	1.3	6.0	1.7	0.9	

Table 7. Superpave binder test results — construction samples.

Sample Identification	Flash Point, °C	Viscosity @ 135°C, Pa.s	DSR Original Temp @ 1.0 kPa	DSR RTFOT Temp @ 2.2 kPa	Mass Loss, Percent	DSR PAV Temp @ 5.0 MPa	BBR		PG
							Temp @ 300 MPa	Temp @ m=0.30	
6-23-97 REP 1	304	0.36	67.3	68.6	0.230	22.8	-14.6	-16.6	64-22
6-23-97 REP 2	268	0.36	67.4	67.6	0.272	23.6	-16.4	-14.2	64-22
6-28-97 REP 1	316	0.35	67.1	67.7	0.250	22.2	-17.1	-14.7	64-22
6-28-97 REP 2	264	0.36	67.4	67.5	0.293	22.4	-17.0	-14.9	64-22
Mean	280	0.358	67.3	67.9	0.261	22.8	-16.3	-15.1	
Standard deviation	25.9	0.005	0.19	0.51	0.27	0.62	1.16	1.04	
Coef. of variation, percent	9.0	1.4	0.3	0.7	10.4	2.7	7.1	6.9	

Table 8. Superpave binder test results performed by UDOT and Idaho Asphalt Supply.

Sample Identification	DSR-Original @ 64°C			DSR-RTFOT @ 64°C			DSR-PAV @ 25°C			BBR @-12°C		PG
	G*, kPa	δ	G*/sin δ, kPa	G*, kPa	δ	G*/sin δ, kPa	G*, MPa	δ	G*/sin δ, MPa	S(t), MPa	M	
UDOT* 6-9-97			1.53			3.53			4.201	188	0.322	64-22
Idaho Asphalt** Orig. Cert. Test Report			1.44			3.29			2.326	116	0.390	64-22
Idaho Asphalt WN 15549 not shipped			1.35			3.03			-----	144	0.338	64-22
Idaho Asphalt 15591 shipped			1.50			3.49			3.732	143	0.336	64-22
Idaho Asphalt 15650 shipped			1.44			3.21			3.892	144	0.350	64-22

*Tested by Utah Department of Transportation — direct tension value of 2.1 mm @ -12°C.
**Tested by Idaho Asphalt Supply.

Table 9. WesTrack asphalt binder properties as determined by viscosity and penetration tests.*

Aging	Test Method	Temperature of Test, °C	Value	Specification AASHTO M 226 ASTM D 3381
Original	Viscosity, P (AASHTO T202)	60	2521	16-2400
	Viscosity, cSt (AASHTO T201)	135	440	Min. 300
	Penetration, dmm (AASHTO T49)	25	65	Min. 60
	Ductility, cm (AASHTO T51)	4	9	Min. 5 (UDOT)
	Toughness, in.- lb		57	
	Tenacity, in.- lb		0	
RTFOT	Viscosity, P (AASHTO T202)	60	6250	Max. 10,000
	Viscosity, cSt (AASHTO T 201)	135	639	
	Penetration, dmm (AASHTO T49)	25	19	
	Ductility, cm (AASHTO T 51)	4	0	
	Mass loss, % (AASHTO T240)		0.28	Max. 1.0

*Tests performed by Utah Department of Transportation and reported December 1, 1997, on sample obtained on June 9, 1997.

Table 10. WesTrack asphalt binder properties as determined by Superpave binder tests.*

Aging	Test Method	Temperature of Test, °C	Test Parameter	Value	Specification (AASHTO MP 1)*
Original	DSR (AASHTO TPS)	64	G*/sinδ	1.493 kPa	Min. 1.0 kPa
	Flash Point (AASHTO T48)			288°C	Min. 230°C
	Viscosity (ASTM D 4402)	135	Viscosity	0.358 Pa.s	Max. 3.0 Pa.s
RTFOT	DSR (AASHTO TP5)	64	G*/sinδ	3.603 kPa	Min. 2.0 kPa
	Mass Loss (AASHTO T240)		Mass Loss	0.261 percent	Max. 1.0%
RTFOT plus PAV	DSR (AASHTO TP5)	25	G*/sinδ	3946 kPa	Max. 5000 kPa
	BBR (AASHTO TP1)	-12	Stiffness	198 MPa	Max. 300 MPa
		-12	"m" Value	0.316	Min. 0.30

*Classified as PG 64-22.

Table 11. Comparison of asphalt binders used for original and replacement sections at WesTrack.

Sample Identification	DSR-Original @ 64°C			DSR-RTFOT @ 64°C			DSR-PAV @ 25°C			BBR @-12°C		PG
	G*, kPa	δ	G*/sin δ, kPa	G*, kPa	δ	G*/sin δ, kPa	G*, MPa	δ	G*/sin δ, MPa	S(t), MPa	m	
Original sections*	1.140	87.1	1.141	2.625	84.3	2.637	5.782	47.7	4.270	217	0.315	64-22
Replacement sections*	1.491	87.0	1.493	3.583	83.9	3.603	5.696	43.9	3.946	198	0.316	64-22

*Average values.

Table 12. Comparison of asphalt binders used for original and replacement sections at WesTrack.

Sample Identification	Flash Point, °C	Viscosity @ 135°C, Pa.s	DSR Original Temp @ 1.0 kPa	DSR RTFOT Temp @ 2.2 kPa	Mass Loss, Percent	DSR PAV Temp @ 5.0 MPa	BBR		PG
							Temp @ 300 MPa	Temp @ m=0.30	
Original sections	276*	0.31	65.3	65.5	0.25	24.0	-14.3	-13.3	64-22
Replacement sections	288*	0.36	67.3	67.9	0.26	22.8	-16.3	-15.1	64-22

*Average values.

Table 13. Comparison of original and replacement sections at WesTrack — DSR rheologic properties over a range of temperatures.

Sample Identification	DSR-Original (G*/sin δ) @ Temp °C, kPa				DSR-RTFOT (G*/sin δ) @ Temp °C, kPa				DSR-PAV (G*sin δ) @ Temp °C, MPa			
	52	58	64	70	52	58	64	70	16	19	22	25
Original sections 10-1-95 9:50 a.m.	5.62	2.46	1.14	0.57	13.41	5.85	2.62	1.25	12.11	8.94	6.40	4.35
Replacement sections 6-28-97 REP 1	7.69	3.29	1.45	0.69			3.53	1.64		6.79	5.25	3.73

Table 14. Comparison of original and replacement sections at WesTrack – BBR rheologic low-temperature properties.

Sample Identification	BBR			
	Stiffness @ Temp °C MPa		m Value @ Temp °C	
	-12	-18	-12	-18
Original sections 10-1-95 9:50 a.m.	229	410	0.31	0.25
Replacement sections 6-28-97 REP 1	201	322	0.32	0.28

APPENDIX A

SUPERPAVE BINDER TEST PROPERTIES
PRECONSTRUCTION SAMPLES

Contract Number	WESTRACK	SUPERPAVE PG GRADE
AC Sample Number	TR -048-1	
Source of Sample	IDAHO	PG 64-22
Asphalt Type		
Mass of Loss	0.275	
Brookfield Vis., PaS	0.35	
Flash Point	304	Remarks
Limiting Temp. for T_{max}	66.2	
Limiting Temp. for T_{int}	23.1	
Limiting Temp. for T_{min}	-14.4	

DSR-ORIGINAL

Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	12.0	6.270	84.15	6.3028
58	"	"	2.813	86.10	2.8195
64	"	"	1.289	87.51	1.2902
70	"	"	0.6363	88.53	0.6365

DSR-RTFOT

Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	10	16.430	78.97	16.740
58	"	"	7.098	81.39	7.170
64	"	"	3.112	84.54	3.126
70	"	"	1.444	86.67	1.446

DSR-PAV

Temp., C	Plate Dia., mm	Strain %	G*, MPa	Phase angle δ	G* Sin δ kPa
16	8	1	16.38	37.42	10.257
19	"	"	12.16	39.97	7.8114
22	"	"	8.466	42.66	5.7369
25	"	"	5.824	45.43	4.0812

BBR-PAV

Temp., C	S(t), MPa	m
-12	177	0.324
	179	0.327
-24	615	0.219
	619	0.212

DT-PAV

Temp., C	Avg. Fail Strain, %	Avg. Fail Stress, Pa

1. DSR-Original: T_{max}
   Temperature at which G*/sinδ = 1.0kPa 66.2

2. DSR-RTFOT: T_{max}
   Temperature at which G*/sinδ = 2.2kPa 66.8

3. DSR-PAV: T_{int}
   Temperature at which G*(sinδ) = 5.0MPa 23.2

4. BBR-PAV: T_{min}
   Temperature at which S(t) = 300MPa -17.0

   Temperature at which m = 0.30 -14.4

Contract Number	WESTRACK	SUPERPAVE PG GRADE
AC Sample Number	TR-048-2	
Source of Sample	IDAHO	PG 64-22
Asphalt Type		
Mass of Loss	0.26	
Brookfield Vis., PaS	0.35	
Flash Point	302	Remarks
Limiting Temp. for T_{max}	65.8	
Limiting Temp. for T_{int}	23.7	
Limiting Temp for T_{min}	-15.1	

DSR-ORIGINAL

Temp., C	Plate Dia., mm	Strain, %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	12.0	6.054	83.94	6.0880
58	"	"	2.662	85.94	2.6687
64	"	"	1.218	87.53	1.2191
70	"	"	0.598	88.30	0.5986

DSR-RTFOT

Temp., C	Plate Dia., mm	Strain, %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	10	16.120	79.16	16.4129
58	"	"	6.946	81.98	7.0146
64	"	"	3.041	84.38	3.0557
70	"	"	1.445	86.09	1.4434

DSR-PAV

Temp., C	Plate Dia., mm	Strain, %	G*, MPa	Phase angle δ	G* Sin δ kPa
16	8	1	18.210	37.21	11.0123
19	"	"	13.010	39.66	8.3034
22	"	"	9.023	42.33	6.0761
25	"	"	6.039	45.08	4.2762

BBR-PAV

Temp., C	S(t), MPa	m
-12	177	0.33
	154	0.33
-18	344	0.26
	330	0.29

DT-PAV

Temp., C	Avg. Fail Strain, %	Avg. Fail Stress, Pa

1. DSR-Original: T_{max}
   Temperature at which G*/sinδ = 1.0kPa — 65.8

2. DSR-RTFOT: T_{max}
   Temperature at which G*/sinδ = 2.2kPa — 66.7

3. DSR-PAV: T_{int}
   Temperature at which G*(sinδ) = 5.0MPa — 23.7

4. BBR-PAV: T_{min}
   Temperature at which S(t) = 300MPa — -17.0
   Temperature at which m = 0.30 — -15.1

Contract Number	WESTRACK	SUPERPAVE PG GRADE
AC Sample Number	1	
Source of Sample	ALBINA	PG 64-22
Asphalt Type		
Mass of Loss	0.25	
Brookfield Vis., PaS	0.4	
Flash Point	274	Remarks
Limiting Temp. for T_{max}	66.5	
Limiting Temp. for T_{int}	19.0	
Limiting Temp for T_{min}	-17.7	

DSR-ORIGINAL					
Temp, C	Plate Dia, mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	12.0	6.919	82.39	6.9805
58	"	"	3.080	84.59	3.0938
64	"	"	1.443	86.55	1.4456
70	"	"	0.714	87.64	0.7150

DSR-RTFOT					
Temp, C	Plate Dia, mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	10	14.680	78.01	15.0074
58	"	"	6.450	80.84	6.5333
64	"	"	2.941	83.40	2.9606
70	"	"	1.419	85.19	1.4240

DSR-PAV					
Temp, C	Plate Dia, mm	Strain %	G*, MPa	Phase angle δ	G* Sin δ kPa
16	8	1	10.470	43.17	7.1632
19	"	"	7.115	45.70	5.0921
22	"	"	4.699	48.42	3.5150
25	"	"	3.084	51.11	2.4004

BBR-PAV		
Temp, C	S(t), MPa	m
-12	123	0.37
	136	0.38
-18	315	0.3

DT-PAV		
Temp, C	Avg. Fail Strain, %	Avg. Fail Stress, Pa

1. DSR-Original: T_{max}
   Temperature at which G*/sinδ = 1.0kPa 67.1

2. DSR-RTFOT: T_{max}
   Temperature at which G*/sinδ = 2.2kPa 66.5

3. DSR-PAV: T_{int}
   Temperature at which G*(sinδ) = 5.0MPa 19.0

4. BBR-PAV: T_{min}
   Temperature at which S(t) = 300MPa -17.7
   Temperature at which m = 0.30 -18.0

Contract Number	WESTRACK	SUPERPAVE PG GRADE
AC Sample Number	2	
Source of Sample	ALBINA	PG 64-22
Asphalt Type		
Mass of Loss	0.25	
Brookfield Vis., PaS	0.4	
Flash Point	274	Remarks
Limiting Temp. for T_{max}	66.7	
Limiting Temp. for T_{int}	20.1	
Limiting Temp for T_{min}	-17.7	

DSR-ORIGINAL

Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	12.0	6.724	82.41	6.7834
58	"	"	3.029	84.67	3.0422
64	"	"	1.420	86.22	1.4231
70	"	"	0.718	87.44	0.7189

DSR-RTEOT

Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	10	15.000	78.01	15.3345
58	"	"	6.562	80.96	6.6445
64	"	"	3.001	83.22	3.0221
70	"	"	1.472	85.03	1.4776

DSR-PAV

Temp., C	Plate Dia., mm	Strain %	G*, MPa	Phase angle δ	G* Sin δ kPa
16	8	4	12.16	42.75	8.2542
19	"	"	8.118	45.11	5.7513
22	"	"	5.349	47.73	3.9580
25	"	"	3.495	50.27	2.6378

BBR-PAV

Temp C	S(t), MPa	m
-12	123	0.37
	136	0.38
-18	315	0.3

DT-PAV

Temp., C	Avg. Fail Strain, %	Avg. Fail Stress, Pa

1. DSR-Original: T_{max}
   Temperature at which G*/sinδ = 1.0kPa — 67.1

2. DSR-RTFOT: T_{max}
   Temperature at which G*/sinδ = 2.2kPa — 66.7

3. DSR-PAV: T_{int}
   Temperature at which G*(sinδ) = 5.0MPa — 20.1

4. BBR-PAV: T_{min}
   Temperature at which S(t) = 300MPa — -17.7
   Temperature at which m = 0.30 — -18.0

APPENDIX B

COMPARISON OF ASPHALT BINDER USED DURING ORIGINAL CONSTRUCTION WITH CANDIDATE ASPHALT BINDERS FOR REPLACEMENT SECTIONS

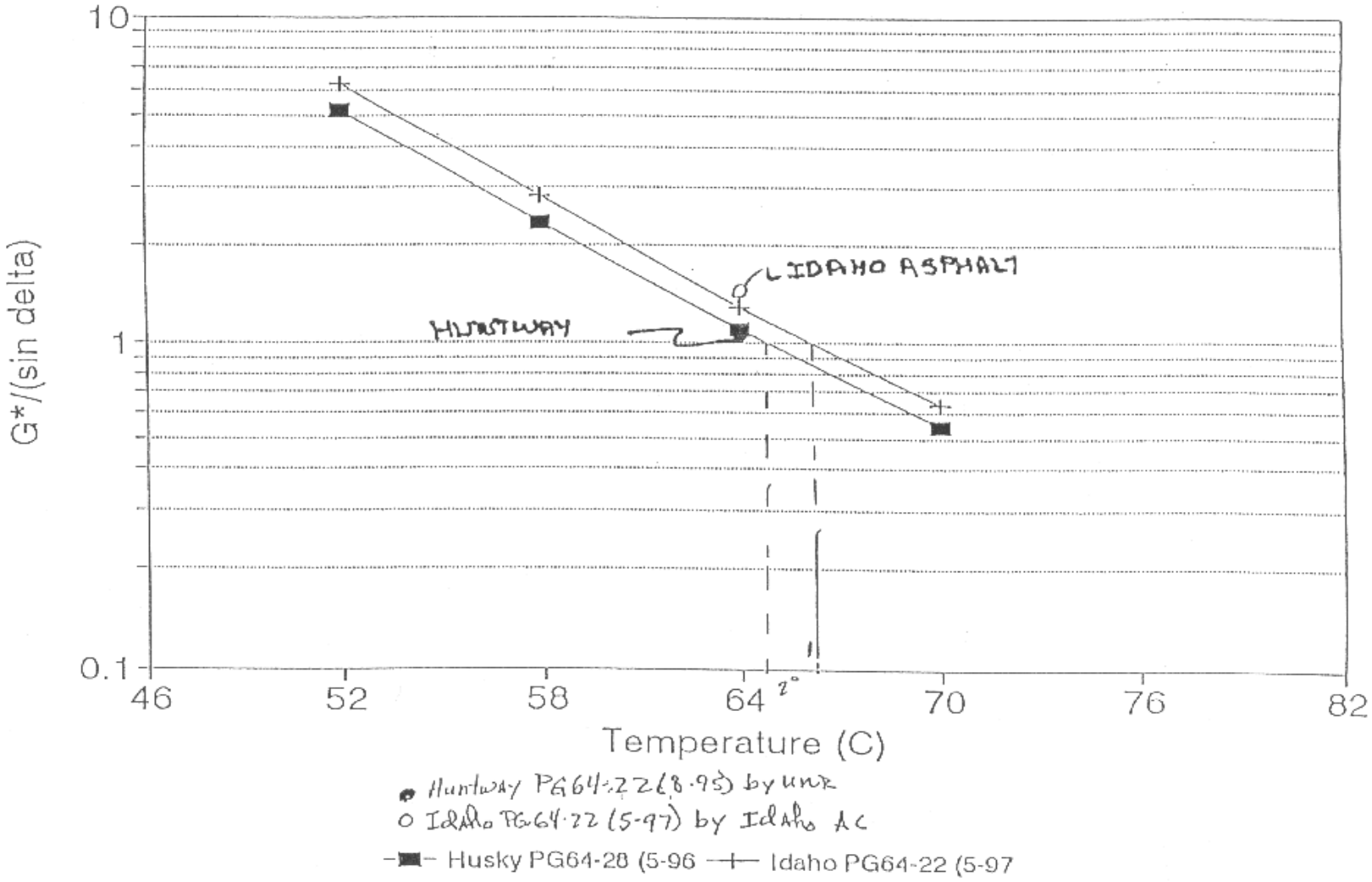

Figure B1. DSR original asphalt binder properties.

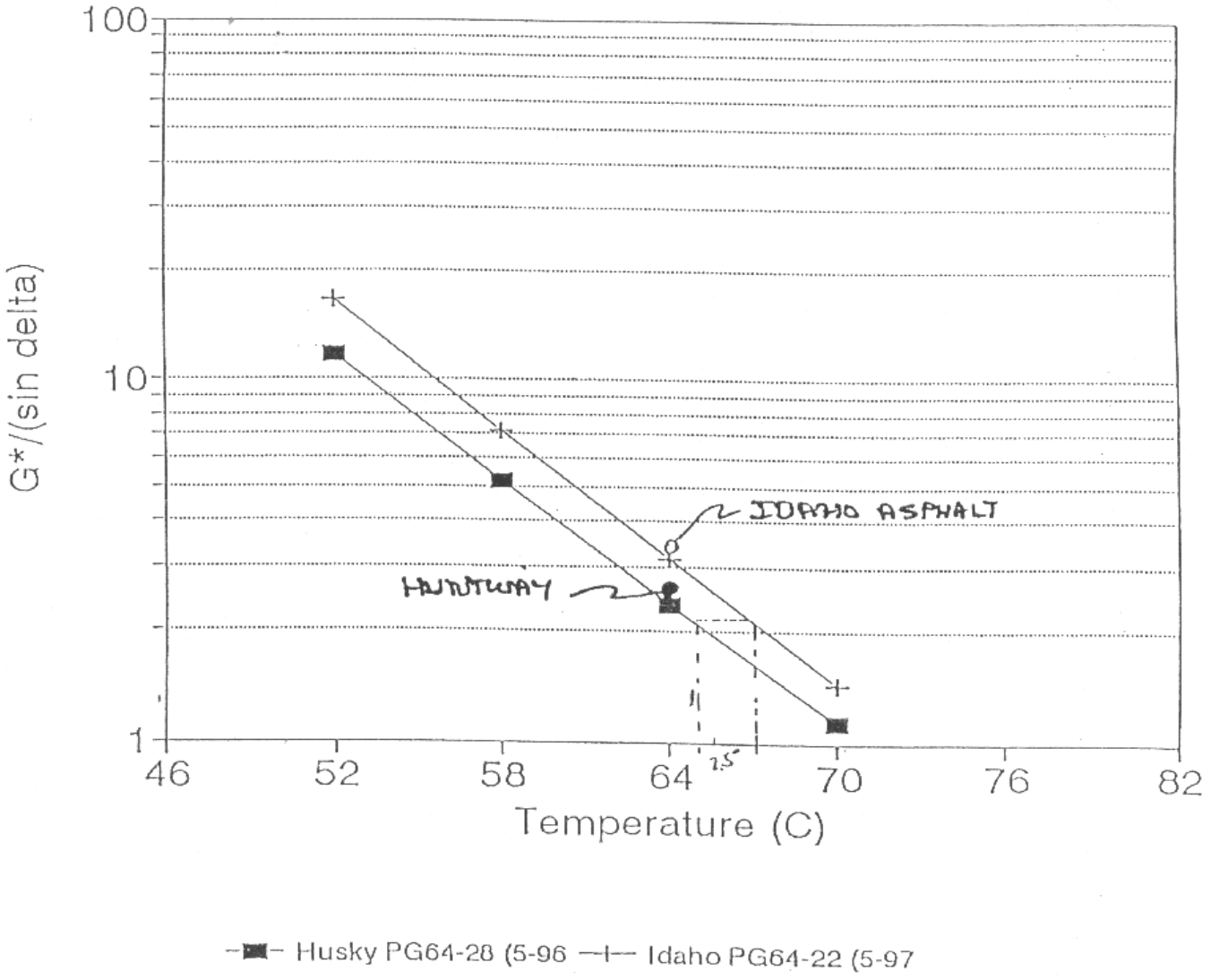

Figure B2. DSR RTFOT asphalt binder properties.

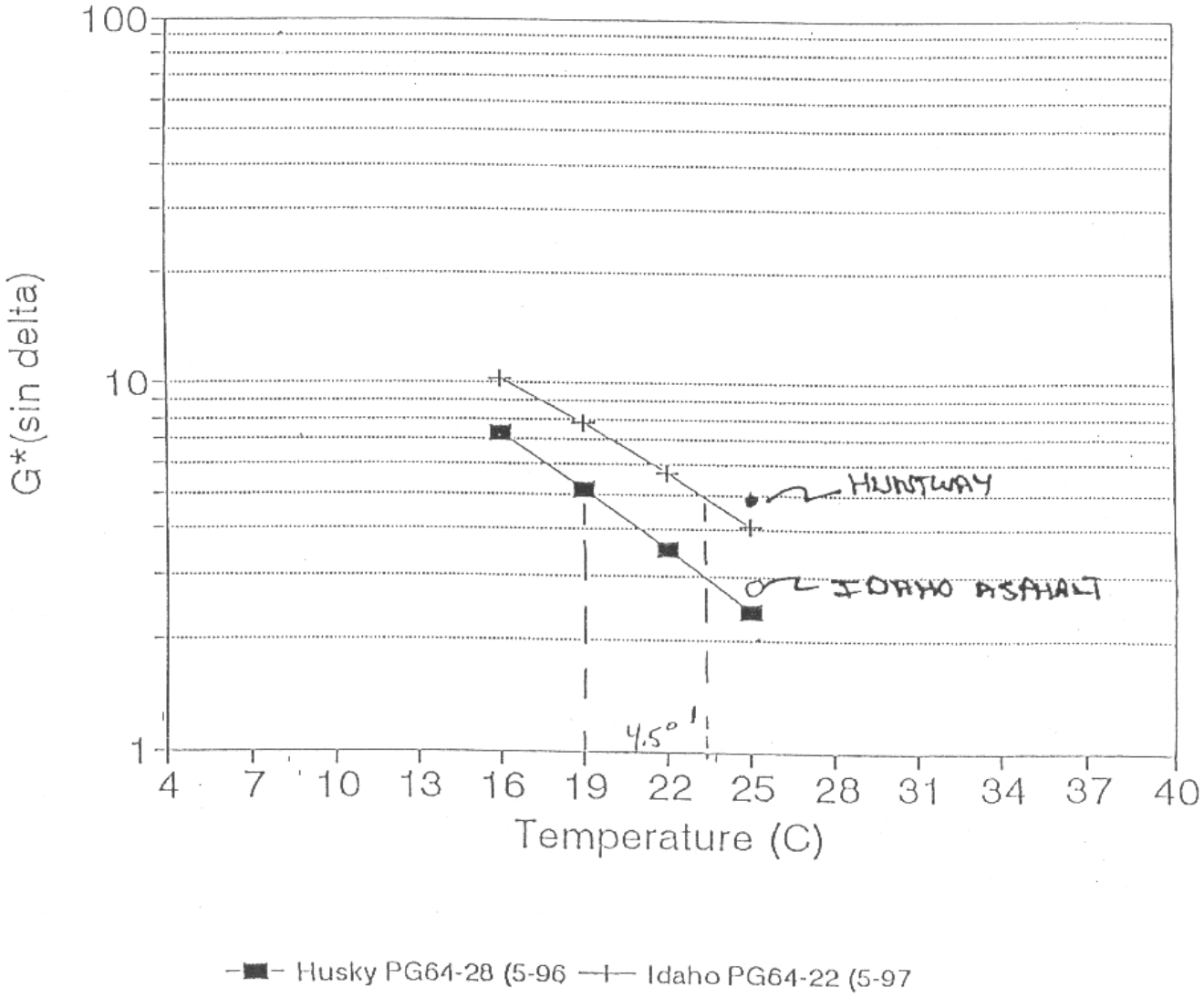

Figure B3. DSR PAV asphalt binder properties.

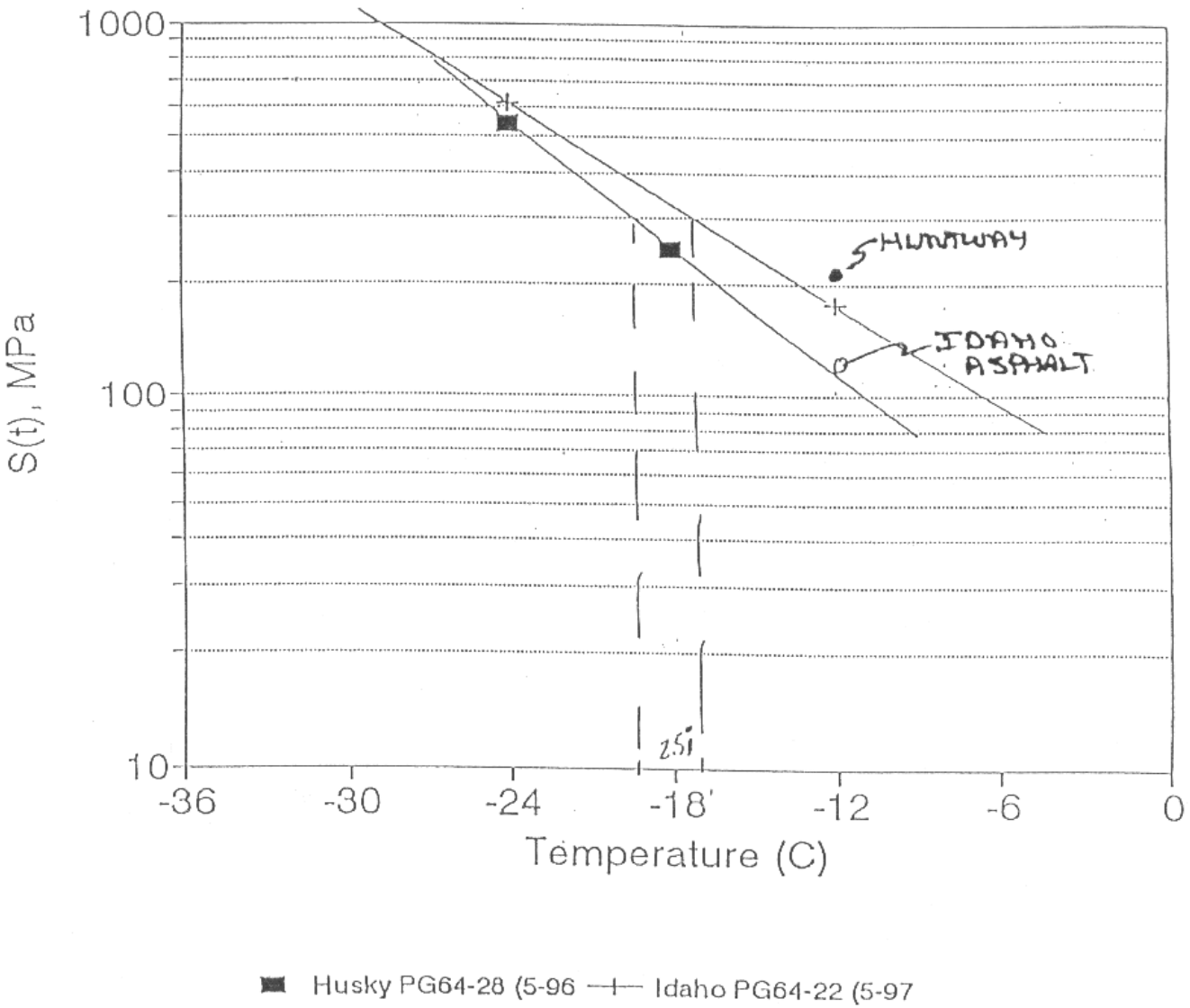

Figure B4. BBR creep stiffness asphalt binder properties.

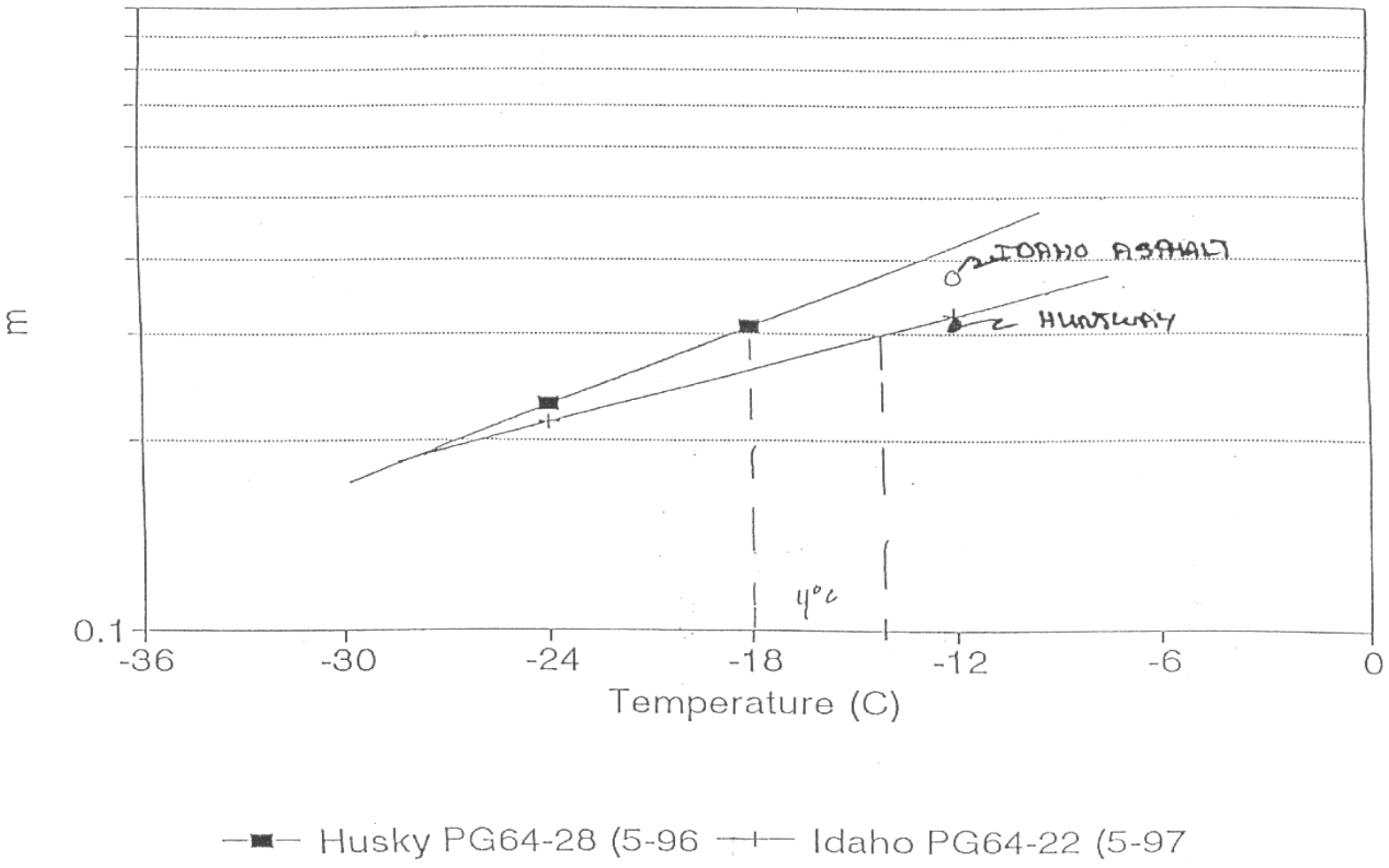

Figure B5. BBR slope asphalt binder properties.

APPENDIX C

SUPERPAVE BINDER TEST PROPERTIES – CONSTRUCTION SAMPLES

Project	WESTRACK	SUPERPAVE PG GRADE
AC Sample I.D.	06/23/97 Rep #1	
Source of Sample	Idaho Asphalt	PG 64-22
Specified Asphalt Type	PG 64-22	
Mass of Loss	0.23	
Brookfield Vis., PaS	0.36	
Flash Point	304	Remarks
Limiting Temp. for T_{max}	67.3	Field Sampled
Limiting Temp. for T_{int}	22.8	
Limiting Temp for T_{min}	-14.6	

DSR-ORIGINAL						DSR-RTFOT					
Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa	Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	12.0	8.064	83.22	8.1208	52	25	10			
58	"	"	3.454	85.48	3.4648	58	"	"			
64	"	"	1.522	86.96	1.5241	64	"	"	3.970	83.54	3.9954
70	"	"	0.714	88.23	0.7143	70	"	"	1.845	85.31	1.8512

DSR-PAV						BBR-PAV			DT-PAV		
Temp., C	Plate Dia., mm	Strain %	G*, MPa	Phase angle δ	G* Sin δ kPa	Temp., C	S(t), MPa	m	Temp., C	Avg. Fail Strain, %	Avg. Fail Stress, Pa
16	8	1	16.06	35.85	9.4058	-12	196	0.314			
19	"	"	11.82	38.17	7.3047						
22	"	"	8.463	40.50	5.4963	-18	342	0.283			
25	"	"	5.832	43.14	3.9878						

1. DSR-Original: T_{max}
   Temperature at which G*/sinδ = 1.0kPa ___67.3___

2. DSR-RTFOT: T_{max}
   Temperature at which G*/sinδ = 2.2kPa ___68.6___

3. DSR-PAV: T_{int}
   Temperature at which G*(sinδ) = 5.0MPa ___22.8___

4. BBR-PAV: T_{min}
   Temperature at which S(t) = 300MPa ___-14.6___
   Temperature at which m = 0.30 ___-16.6___

Project	WESTRACK	SUPERPAVE PG GRADE
AC Sample I. D.	6/23/97 Rep #2	
Source of Sample	Idaho Asphalt	PG 64-22
Specified Asphalt Type	PG 64-22	
Mass of Loss	0.272	
Brookfield Vis., PaS	0.358	
Flash Point	268	Remarks
Limiting Temp. for T_{max}	67.4	Field Sampled
Limiting Temp. for T_{int}	23.6	
Limiting Temp for T_{min}	-14.2	

DSR-ORIGINAL					
Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	12.0			
58	"	"			
64	"	"	1.492	87.39	1.494
70	"	"	0.7287	88.18	0.729

DSR-RTFOT					
Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	10			
58	"	"			
64	"	"	3.445	84.11	3.463
70	"	"	1.615	85.87	1.619

DSR-PAV					
Temp., C	Plate Dia., mm	Strain %	G*, MPa	Phase angle δ	G* Sin δ kPa
16	8	1			
19	"	"	12.76	39.06	8.04
22	"	"	8.976	41.65	5.965
25	"	"	6.080	44.49	4.261

BBR-PAV		
Temp., C	S(t), MPa	m
-18	348.9	0.269
-12	200.2	0.320

DT-PAV		
Temp., C	Avg. Fail Strain, %	Avg. Fail Stress, Pa

1. DSR-Original: T_{max}
   Temperature at which G*/sinδ = 1.0kPa — 67.4 °C

2. DSR-RTFOT: T_{max}
   Temperature at which G*/sinδ = 2.2kPa — 67.6 °C

3. DSR-PAV: T_{int}
   Temperature at which G*(sinδ) = 5.0MPa — 23.6 °C

4. BBR-PAV: T_{min}
   Temperature at which S(t) = 300MPa — -16.4 °C
   Temperature at which m = 0.30 — -14.2 °C

Project	WESTRACK	SUPERPAVE PG GRADE
AC Sample I.D.	06/28/97 Rep #1	
Source of Sample	Idaho Asphalt	PG 64-22
Specified Asphalt Type	PG 64-22	
Mass of Loss	0.25	
Brookfield Vis., PaS	0.35	
Flash Point	316	Remarks
Limiting Temp. for T_{max}	67.1	Field Sampled
Limiting Temp. for T_{int}	22.2	
Limiting Temp for T_{min}	-14.7	

DSR-ORIGINAL					
Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	12.0	7.637	83.21	7.6909
58	"	"	3.282	85.19	3.2936
64	"	"	1.450	86.83	1.4522
70	"	"	0.694	87.89	0.6945

DSR-RTFOT					
Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	10			
58	"	"			
64	"	"	3.511	84.19	3.5291
70	"	"	1.638	85.78	1.6425

DSR-PAV					
Temp., C	Plate Dia., mm	Strain %	G*, MPa	Phase angle δ	G* Sin δ kPa
16	8	1			
19	"	"	10.75	39.20	6.7943
22	"	"	7.928	41.51	5.2543
25	"	"	5.381	43.95	3.7346

BBR-PAV		
Temp., C	S(t), MPa	m
-12	201	0.317
-18	322	0.280

DT-PAV		
Temp., C	Avg. Fail Strain, %	Avg. Fail Stress, Pa

1. DSR-Original: T_{max}
   Temperature at which G*/sinδ = 1.0kPa 67.1

2. DSR-RTFOT: T_{max}
   Temperature at which G*/sinδ = 2.2kPa 67.7

3. DSR-PAV: T_{int}
   Temperature at which G*(sinδ) = 5.0MPa 22.2

4. BBR-PAV: T_{min}
   Temperature at which S(t) = 300MPa -17.1
   Temperature at which m = 0.30 -14.7

Project	WESTRACK	SUPERPAVE PG GRADE
AC Sample I. D.	6/28/97 Rep #2	
Source of Sample	Idaho Asphalt	PG 64-22
Specified Asphalt Type	PG 64-22	
Mass of Loss	0.293	
Brookfield Vis., PaS	0.358	
Flash Point	264	Remarks
Limiting Temp. for T_{max}	67.4	Field Sampled
Limiting Temp. for T_{int}	22.4	
Limiting Temp for T_{min}	-14.9	

DSR-ORIGINAL

Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	12.0			
58	"	"			
64	"	"	1.499	86.75	1.501
70	"	"	0.7249	87.46	0.7256

DSR-RTFOT

Temp., C	Plate Dia., mm	Strain %	G*, kPa	Phase angle δ	G*/Sin δ kPa
52	25	10			
58	"	"			
64	"	"	3.404	83.81	3.424
70	"	"	1.586	86.02	1.590

DSR-PAV

Temp., C	Plate Dia., mm	Strain %	G*, MPa	Phase angle δ	G* Sin δ kPa
16	8	1			
19	"	"	10.69	39.10	6.742
22	"	"	7.852	41.39	5.192
25	"	"	5.491	43.85	3.804

BBR-PAV

Temp., C	S(t), MPa	m
-18	327.7	0.286
-12	193.9	0.314

DT-PAV

Temp., C	Avg. Fail Strain, %	Avg. Fail Stress, Pa

1. DSR-Original: T_{max}
   Temperature at which G*/sinδ = 1.0kPa ____67.4 °C____

2. DSR-RTFOT: T_{max}
   Temperature at which G*/sinδ = 2.2kPa ____67.5 °C____

3. DSR-PAV: T_{int}
   Temperature at which G*(sinδ) = 5.0MPa ____22.4 °C____

4. BBR-PAV: T_{min}
   Temperature at which S(t) = 300MPa ____-17.0 °C____
   Temperature at which m = 0.30 ____-14.9 °C____

Hydrated Lime Properties— Original Construction

U.S. Department of Transportation
Federal Highway Administration

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on the physical-chemical properties of the hydrated lime utilized in the HMA for the original construction of the test track facility during September and October 1995. The report describes the background information associated with the decision to use lime for this project, as well as the physical-chemical properties of the hydrated lime.

BACKGROUND

USE OF LIME

The main objective of the WesTrack experiment was to determine the performance of HMA mixtures placed with different aggregates, aggregate gradations, asphalt binder contents, and in-place air void contents. The types of distress of interest were rutting or permanent deformation and fatigue. The selection of the asphalt binder was based on minimizing or eliminating the occurrence of transverse cracks associated with thermal cracking.[4,5] The design of the structural section was based on producing fatigue cracking in typical HMA mixtures at about 3.0 to 3.5 million ESALs. Hydrated lime was used in the HMA to minimize or eliminate water sensitivity of the mixture as a contributor to rutting or fatigue distress on the test track.

Two aggregate sources were initially considered for use on WesTrack: Granite Construction's Dayton, Nevada, aggregate, and Graniterock's Watsonville, California, granite aggregate. Field performance information on HMA mixtures constructed with the Dayton aggregate indicated moderate water sensitivity. Historically, Watsonville granite does not exhibit water sensitivity problems when used in relatively mild, but somewhat wet, climates such as that of the central California coast. However, laboratory tests performed on HMA mixtures prepared with Watsonville aggregate indicated moderate water sensitivity. In addition, many granite aggregates used in the southeast use an anti-strip agent.

Since the mid 1980s, the Nevada Department of Transportation has required that all HMA placed in northern Nevada use lime as an anti-strip agent. The severe climate (numerous freeze-thaw cycles in the presence of moisture) in northern Nevada, the general mineralogy of the aggregate supplies, and the historic field performance of pavements were the basis for this policy. Since lime is considered to be the most universal anti-strip agent currently available, hydrated lime was selected for use on the WesTrack project.

HYDRATED LIME SOURCE

The hydrated lime was supplied to Granite Construction by the Chemical Lime Company. The production facility for the hydrated lime was Chemical Lime Company's Apex, Nevada, plant. The hydrated lime was manufactured to meet the requirements of the ASTM D 1097-90 specification. This hydrated lime source was typically used by Granite Construction at the time of the construction of WesTrack.

SAMPLING

SAMPLING PLAN

The sampling plan for the construction of the original sections on WesTrack is contained in WesTrack Technical Report UNR-19[6]. Samples of lime were obtained during placement of the trial lanes and test lanes for each lift. Additional sampling was performed as time allowed. Samples used for determination of physical-chemical properties were selected from the numerous samples obtained during construction.

SAMPLE LOCATION

The hydrated lime samples were taken from the feed lines that ran from the lime storage silo to the pug mill mixing chamber. Dry hydrated lime was added to the moistened aggregate and mixed in a pug mill. The lime-treated aggregate was not stockpiled, but was introduced directly into the continuous drum mixer plant used for production of the HMA.

TEST RESULTS

PHYSICAL-CHEMICAL PROPERTIES

Physical-chemical properties of the hydrated lime were obtained on selected samples by Chemical Lime Company. Table 1 shows the samples selected for testing and their relationship to the lane, lift, and test sections paved. Table 2 shows the physical-chemical test properties of the hydrated lime used for construction of WesTrack as represented by the samples taken on the dates given. The hydrated lime met the specifications of ASTM C 1097-90, except for the sample taken on September 18, 1995 at 12:23. This sample exceeded the maximum amount of material allowed to be retained on the No. 30 sieve. This reported value appears to be very large as compared to the values reported for the other samples of lime.

LIME IN BAGHOUSE FINES

To determine the percent of hydrated lime contained in the plant-produced HMA, it was necessary to determine the percentage of hydrated lime in the baghouse fines since some of this material was being "wasted" and not returned to the HMA plant. Chemical Lime Company determined the percent quick lime (CaO) in the baghouse-sampled fines.[7] Since the aggregate supply did not contain carbonate material, this determination provided a reliable measure of the percentage of lime contained in the baghouse fines.

Table 3 shows the lime content determinations in the baghouse fines. The amount of quick lime or calcium oxide present in the baghouse fines averaged 6.4 percent by weight of the baghouse fines. The equivalent amount of hydrated lime in the baghouse fines was 8.4 percent by weight of the baghouse fines.

During construction, it was necessary to calibrate the baghouse return system, as the amount of baghouse fines returned to the HMA was adjusted to meet the target gradations. Table 4 shows the amount of aggregate fines that were being diverted to the baghouse by the air quality control system on the plant and the amount of baghouse fines returned to the HMA during production of the various mixtures. Several measurements indicated that 4.3 percent by weight of the total aggregate was being diverted to the baghouse. Depending on the mixture, a portion of these fines was being returned to the HMA mixture. The fine plus mixture required the return of a large portion of the baghouse fines.

PERCENTAGE OF LIME IN HOT-MIX ASPHALT

Table 4 indicates that about 4.3 percent by weight of the total aggregate was diverted to the baghouse. Table 3 indicates that about 8.4 percent by weight of these baghouse fines contained hydrated lime. Thus, the amount of hydrated lime by total weight of aggregate in the baghouse was approximately 0.36 percent (0.084 x 4.3). Since 1.5 percent hydrated lime was being placed on the aggregate, the percent of the hydrated lime that was added to the aggregate that was captured by the baghouse was approximately 25 percent (0.36/1.5).

Table 4 indicates that 30 to100 percent of the baghouse fines were being returned to the HMA. Thus, the amount of hydrated lime contained in the produced HMA ranged from approximately 1.25 percent to 1.5 percent, depending on the mixture. The fine and coarse mixtures probably contained about 1.3 percent hydrated lime by weight of total aggregate. The fine plus mixtures contained about 1.4 to 1.5 percent hydrated lime by weight of total aggregate.

SUMMARY

The physical-chemical properties used on WesTrack (table 2) met the specifications of ASTM C 1097-90. About 25 percent of the lime placed on the damp aggregate was diverted to the baghouse during production of the HMA. The amount of hydrated lime in the mixtures placed at WesTrack ranged from 1.3 to 1.5 percent by dry weight of total aggregate.

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Table 1. Hydrated lime samples for physical-chemical properties testing — original condition.

Sampling Date	Lane-Lift Paved	Section Number	Mixture Designation
9-14-95 14:17	Trial lane Bottom lift	1, 2, 3, 4, 14, 15, 16, 17, 18	Fine
9-18-95 12:23	Trial lane Bottom lift	5, 6, 7, 8, 23, 24, 25, 26	Coarse
9-20-95 14:08	Test lane Bottom lift	1, 2, 3, 4, 14, 15, 16, 17, 18	Fine
9-22-95 14:05	Trial lane Top lift	1, 2, 3, 4, 14, 15, 16, 17, 18	Fine
9-27-95 7:55	Trial lane Top lift	9, 10, 11, 12, 19, 20, 21, 22	Fine Plus
9-28-95	East curve		Coarse
10-3-95 16:02	Test lane Top lift	5, 6, 7, 8, 23, 24, 25, 26	Coarse

Table 2. Physical-chemical properties of hydrated lime used during construction of original sections.

Property	Sample Date and Time							Specification Limits*
	9/14/95 14:17	9/18/95 12:23	9/20/95 14:08	9/22/95 14:05	9/27/95 7:55	9/28/95	10/3/95 16:02	
Ca and Mg Hydroxides (%)	93.2	93.1	93.9	93.1	93.4	91.3	93.4	Min. 90.0
Carbon Dioxide (%)	1.1	1.0	0.7	1.2	1.2	1.6	1.1	Max. 5.0
Unhydrated Ca and Mg Oxides (%)	0.0	0.2	0.6	0.1	0.0	0.4	0.1	Max. 8.0
Free Moisture (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Max. 3.0
Retained %, No. 30 sieve	0.4	3.9	0.0	0.7	0.5	0.7	0.7	Max. 3.0
Retained %, No. 200 sieve	13	5	4	9	7	8	10	Max. 30

*Specifications per ASTM C 1097-90, standard specification for hydrated lime for use in asphalt-concrete mixtures.

Note: Tests performed by Chemical Lime Company's Henderson, Nevada, Laboratory.[7]

Table 3. Lime content of baghouse fines.

Sampling Date	Lane-Lift Paved	Section Number	Mixture Designation	Lime in Baghouse Dust, Percent	
				Calcium Oxide	Equivalent Calcium Hydroxide
9-20-95	Test lane Bottom lift	1, 2, 3, 4, 14, 15, 16, 17, 18	Fine	7.9	10.4
9-21-95 8:19	Test lane Bottom lift	9, 10, 11, 12, 19, 20, 21, 22	Fine plus	7.1	9.4
9-23-95	West curve Parking area		Coarse	8.8	11.6
9-23-95 8:05	West curve Parking area		Coarse	6.2	8.2
9-28-95	East curve		Coarse	4.1	5.4
9-28-95	East curve		Coarse	4.2	5.5
Mean				6.4	8.4
Standard deviation				1.93	2.56
Coefficient of variation				30.3	30.3

Table 4. Baghouse fines calibration information.

Calibration Date	Lane-Lift Paved	Section Number	Mixture Designation	Fines to Baghouse, Percent of Total Aggregate	Baghouse Fines to Mixture, Percent of Total Aggregate
9-15-95	Trial lane Bottom lift	9, 10, 11, 12, 13, 19, 20, 21, 22	Fine plus		2.7
9-19-95	Curves		Coarse		3.2
9-20-95	Test lane Bottom lift	1, 2, 3, 4, 14, 15, 16, 17, 18	Fine		3.1
9-30-95	Test lane Bottom lift	1, 2, 3, 4, 14, 15, 16, 17, 19	Fine	4.3	1.4
				4.3	1.3
10-1-95	Trial lane Top lift	5, 6, 7, 8, 23, 24, 25, 26	Coarse	4.3	2.3
10-2-95	Test lane Top lift	1, 2, 3, 4, 14, 15, 16, 17, 19	Fine		1.7
10-3-95	Test lane Top lift	9, 10, 11, 12, 13, 19, 20, 21, 22	Fine plus	4.3	3.3 Mix 10 3.7 Mix 11 4.3 Mix 12-13

Aggregate Properties— Original Construction

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INTRODUCTION

WesTrack[1, 2, 3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on the physical properties of the aggregates used to produce HMA mixtures during the original construction of the WesTrack facility. Information on the aggregates used for construction of the replacement sections is contained in WesTrack Technical Report UNR-5.[4] This report also describes the background information associated with the selection of the aggregates used in the study.

BACKGROUND

AGGREGATE SELECTION

The WesTrack team held several discussions on the selection of the aggregate to be used for the project. Since one of the objectives was to obtain information on the performance of Superpave mixtures, it was decided to select an aggregate whose physical properties would meet the Superpave volumetric mixture design criteria.[5] Superpave aggregate requirements are shown in table 1, as defined in reference 5. The consensus properties of coarse aggregate angularity, fine aggregate angularity, flat and elongated particles, and clay content (sand equivalent) were defined for the aggregate under consideration for use on WesTrack. Source properties as defined by Superpave (toughness, soundness, and deleterious materials) also were defined for aggregates under consideration for use at WesTrack.

Aggregate selection was primarily based on: 1) meeting the Superpave volumetric design aggregate and mixture criteria, 2) producing HMA mixtures whose mechanical properties were either sensitive or not sensitive to changes in asphalt binder content and/or aggregate gradation, and 3) minimizing the cost of the aggregate. Rounded gravels, partially crushed gravels, crushed limestones, and crushed igneous aggregates were initially considered by the WesTrack Team.

AGGREGATE SOURCE

Major sources of crushed limestones are over 600 km (400 mi) from the WesTrack site. A crushed granite aggregate was available from a quarry near Watsonville, California, operated by Graniterock. The granite aggregate source was about 360 km (225 mi) from the WesTrack site and rail delivery was possible. In addition, the granite aggregate had been used in HMA in the San Francisco and Monterey Bay areas for over 75 years. The Watsonville granite aggregate was selected for preliminary testing and mixture design purposes.

Partially crushed gravel aggregate was available from several sources near the WesTrack site. Two of the larger aggregate sources were operated by Granite Construction and are located near Dayton, Nevada, and Patrick, Nevada. The partially crushed gravel located near Dayton, Nevada, was selected for preliminary testing and mixture design purposes because of its proximity to the WesTrack site. Rounded or uncrushed aggregates were not considered for use as their surface texture would not meet the Superpave requirements for coarse aggregate angularity and fine aggregate angularity.

Aggregate property information indicated that the Dayton partially crushed gravel and the Watsonville granite both met the Superpave requirements as shown in table 1. Initial mixture designs were directed toward producing a sensitive mixture (rapid change in properties with increase in asphalt binder content) with a Superpave fine gradation from the Dayton aggregate, a nonsensitive mixture with a Superpave coarse gradation from the Dayton aggregate, and a nonsensitive mixture with a coarse gradation from the Watsonville aggregate. Initially, the sensitive mixture was referred to as the "critical" mixture and the nonsensitive mixtures as the "noncritical" mixtures.

A satisfactory Superpave volumetric mixture design could not be made with the Watsonville granite aggregate. Satisfactory Superpave volumetric coarse and fine mixture designs were made with the Dayton aggregate. A third mixture was developed by adding additional minus No. 200 sieve material to the Dayton aggregate fine-graded mixture. This mixture was designed to be more sensitive to asphalt binder content than the other mixtures designed for WesTrack. The three Dayton aggregate mixtures were designated as fine, fine plus, and coarse mixtures. The fine and fine plus mixtures utilized a natural sand from Wadsworth, Nevada, to satisfy the Superpave fine gradations.

A geologic description of the aggregate supplies used for the original construction of WesTrack is shown in table 2. This information was supplied by the School of Mines at the University of Nevada. The Dayton aggregate is an unweathered to slightly weathered, fine-grained andesite with some granite and rhyolite. The Wadsworth sand is a decomposed granite.

SAMPLING

Detailed sampling and testing plans for the original construction are available in WesTrack Technical Report UNR-18.[6] Samples of the aggregate were obtained from aggregate stockpiles prior to construction. These samples are designated as preconstruction samples.

The aggregate stockpiles were established in early 1995 from aggregate produced during the 1994 construction season. Dedicated aggregate stockpiles were created to supply a constant source of aggregate for both mixture design and construction. The use of dedicated stockpiles for WesTrack was necessary not only for uniformity of the HMA mixtures placed on the track, but also because the crushing operation for the Dayton pit was being changed during the winter of 1994-95 and samples of the new production would not be available until late in the following spring.

During construction of the HMA, both "cold-feed" and aggregate stockpile samples were obtained. A chute sampling device was utilized to sample the cold feed. Aggregate stockpiles were sampled with the aid of a front-end loader. The front-end loader would expose a portion of the stockpile and create a level sampling area. Samples of aggregate obtained during construction were used for both quality control testing and quality assurance testing. The cold-feed samples were used to determine gradations during construction and thus were used for quality control purposes. The cold feed samples also were used to determine aggregate properties other than gradation for quality assurance purposes.

Stockpile samples were retained for future use by the universities involved in WesTrack, as well as for storage at the FHWA's Materials Reference Library in Reno. The stockpiled aggregate samples have been used by several research organizations in the United States and overseas.

TEST METHODS

The test methods used to obtain samples, establish gradations, and determine the physical properties of the aggregates are shown in table 3. Results of these tests are provided below for the preconstruction and quality assurance samples. The gradations established during the quality control testing on the cold-feed samples are presented in WesTrack Technical Report UNR-21.[7]

TEST RESULTS

PRECONSTRUCTION

Samples of aggregates obtained prior to construction (preconstruction) were tested to determine the gradation of the stockpiles, the physical properties of the aggregate for use in mixture design, and the aggregate properties for comparison to Superpave requirements.

Stockpile Gradations

As stated previously, dedicated stockpiles of aggregate were established for this project. Stockpiles of the Dayton aggregate 3/4-in., 1/2-in., 3/8-in., rock dust, and sand, and of the Wadsworth sand, were established. Five samples were obtained from each of the stockpiles at each of five locations. Individual sample gradations and statistics are shown in appendix A. The average gradation for the stockpiles, as determined from the five samples, is shown in table 4.

During the placement of the top lift of the coarse aggregate test sections at WesTrack, aggregate from the 1995 production was utilized. Insufficient aggregate from the 1994 production was available to complete the track construction. Gradations of the stockpiles of aggregate from the 1995 production are shown in table 5. This table also provides a comparison of stockpiles produced in 1994 and 1995. The gradations from the 1995 production were obtained from Granite Construction records. Individual sample gradations and statistics are shown in appendix A for both the 1994 and 1995 production years.

Specific Gravity

The bulk (dry) specific gravity of the aggregate was used to calculate volumetric parameters for mixture design purposes and for field quality control and quality assurance purposes. Voids in the mineral aggregate (VMA) and percent voids filled with asphalt (VFA) were calculated from the bulk (dry) specific gravity (Gsb) of the aggregate in the HMA.

Determination of the bulk specific gravity of the aggregate was performed according to AASHTO T 85 (ASTM C 127) for coarse aggregate and AASHTO T 84 (ASTM C 128) for fine aggregate. These test methods allow for determination of apparent, bulk (dry), and bulk (saturated, surface-dried [SSD]) specific gravities, as well as the absorption capacity of the coarse and fine aggregate.

The aggregate specific gravities for the WesTrack Project were determined prior to construction (preconstruction) and, after construction was completed, on samples of aggregate obtained during construction. The preconstruction test results are presented in this section of the report. These values were used for calculation of the HMA volumetrics associated with mixture design.

Table 6 contains a list of aggregate specific gravity values for the coarse and fine aggregate portions of the various aggregate stockpile samples obtained prior to construction (preconstruction). These values were determined by the FHWA's mobile laboratory (trailer) and by the University of Nevada as shown table 6. The University of Nevada determined specific gravities on replicate samples. These data are shown in table 7.

Aggregates were produced in both 1994 and 1995 from Granite Construction's Dayton, Nevada, pit. Specific gravity values for both production years were determined. All mixture design work was performed on the aggregate produced in 1994. The top lift of the coarse graded mixture sections contained some of the 1995-produced aggregate. All other mixtures and lifts contained only 1994-produced aggregate.

Table 8 contains a list of specific gravities for coarse and fine fractions of the aggregates used for mixture design purposes. Combined coarse and fine aggregate specific gravities for the WesTrack aggregates are shown in table 9. The combined specific gravities are based on the stockpile blends shown in table 10. Calculated values and specific gravities obtained from tests performed on blended samples are shown in table 9. The combined bulk (dry) specific gravities used for laboratory mixture design were 2.529 for the fine and fine plus gradation, and 2.504 for the coarse gradation.

Coarse Aggregate Angularity

Coarse aggregate angularity is a "consensus aggregate" property requirement in the Superpave volumetric mixture design method.[4] The FHWA determined the coarse aggregate angularity according to Pennsylvania Department of Transportation Test Method 621 on preconstruction aggregate stockpile samples. Results are shown in table 11 for aggregates produced in 1994 and in table 12 for aggregates produced in 1995. According to the data reported in these tables, the one and two crushed face count exceeded 95 percent and met the requirements for the Superpave volumetric mixture design (table 1) for 30 million ESALs. WesTrack Technical Report UNR-20[8] contains information on coarse aggregate angularity as determined by 10 participating laboratories.

Fine Aggregate Angularity

Fine aggregate angularity is a consensus aggregate property requirement in the Superpave volumetric mixture design method.[4] The FHWA determined the fine aggregate angularity according to the AASHTO TP 33 test method on preconstruction aggregate stockpile samples. Results are shown in table 11 for aggregates produced in 1994 and in table 12 for aggregates produced in 1995. According to the data reported in these tables, the Dayton rock dust had a fine aggregate angularity of 47.6 for the 1994 production and 47.9 for the 1995 production. The Dayton sand and Wadsworth sand fine aggregate angularity values were 44.5 and 44.0, respectively. The blended fine aggregate angularities were 44.9 for the fine and fine plus graded mixtures and 45.0 for the coarse graded mixture (table 11). The Superpave fine aggregate angularity requirements for the top 100 mm of HMA are a minimum of 45. For HMA placed below the top 100 mm, a minimum value of 40 is desired (table 1).

Flat and Elongated Particles

The flat and elongated particle count for coarse aggregates is a consensus aggregate property requirement in the Superpave volumetric mixture design method.[4] The FHWA determined the flat and elongated particle count according to the ASTM D 4791 test method on preconstruction aggregate stockpile samples. Results are shown in table 11 for aggregates produced in 1994 and in table 12 for aggregates produced in 1995. According to the data reported in these tables, the Dayton coarse aggregates had flat and elongated particle counts below 2 percent for the individual and combined aggregates. The Superpave volumetric mixture design method requires the flat and elongated particle counts (5 to 1 ratio) to be below 10 percent.

Sand Equivalent

The sand equivalent (clay content) is a consensus aggregate property requirement in the Superpave volumetric mixture design method.[4] The FHWA determined the sand-equivalent value according to AASHTO T 176 on preconstruction aggregate stockpile samples. Results are shown in table 11 for aggregates produced in 1994 and in table 12 for aggregates produced in 1995. According to the data reported in these tables, the combined Dayton aggregates for the fine, fine plus, and coarse mixtures had values of 65 and above. The reported sand-equivalent values for the Dayton rock dust were 49 for the 1994 production year samples and 66 for the 1995 production year samples. The Dayton natural sand had a sand- equivalent value of 31 (this material was not used in the production of the WestTrack mixtures) and the Wadsworth sand had a reported value of 74. Table 1 indicates that the Superpave criterion for sand equivalent is a minimum of 45.

Los Angeles Abrasion

The Los Angeles Abrasion Test is used to measure "toughness" of the aggregate and is a source aggregate property as defined by the Superpave volumetric mixture design method.[4] The University of Nevada determined the Los Angeles abrasion value according to AASHTO T 96 on preconstruction aggregate stockpile samples. Results are shown in table 11 and appendix B for aggregates produced in 1994. According to the data reported in this table, the Los Angeles abrasion values for individual or combined aggregates were less than 21. Typical maximum allowable values used by public agencies range from 35 to 45.

Soundness

Soundness as measured by the sodium or magnesium sulfate soundness test is a source aggregate property as defined by the Superpave volumetric mixture design method.[4] Soundness values were available on the Dayton aggregate from Nevada Department of Transportation records and were used to establish that the Dayton aggregate met the Superpave soundness requirement. Maximum acceptance values of 10 to 15, depending on the use of either sodium or magnesium sulfate, are typical of those used by public agencies in the United States.

Deleterious Materials

Deleterious materials are defined as the weight percentage of contaminants such as clay lumps, friable particles, shale, wood, mica, and coal in the blended aggregate. Deleterious materials is a source aggregate property as defined by the Superpave volumetric mixture design method.[4] The amount of deleterious materials was determined according to AASHTO T 112 (Clay Lumps and Friable Particles in Aggregates). Deleterious materials values from 0.21 to 0.46 were reported for individual aggregate stockpile samples obtained in 1994 (table 11 and appendix B). Combined aggregate values for the fine, fine plus, and coarse mixtures ranged from 0.21 to 0.34 (table 11). A wide range in percentage of clay lumps, friable particles, and other contaminants is permissible, depending on the public agency and material present. Maximum values ranging from 0.l2 to 10.00 percent are found in acceptance criteria currently.

QUALITY ASSURANCE

Samples of aggregate obtained during construction were tested after construction was completed to determine gradation, physical properties of the aggregate for use in calculation of mixture volumetrics, and the aggregate properties for comparison to Superpave requirements. The aggregate physical property data reported in this section of the report were obtained during production of the HMA from cold-feed samples. Since the testing was performed after completion of construction and since the results were not used to control the process of the plant during construction, this group of data has been identified as "quality assurance" (postconstruction) test results. Cold-feed gradation information is presented in WesTrack Technical Report UNR-21.[7]

Table 13 contains a list of dates of construction for the various lifts of HMA placed on the test lane at WesTrack. This table allows for the paving day, mixture designation, lift, and section number to be correlated.

Specific Gravity

Specific gravity measurements were made on cold-feed aggregate samples obtained during construction. These values were to be used to determine the mixture volumetrics based on the quality assurance testing of the HMA materials placed at WesTrack. These tests were performed by Harding Lawson and Associates (HLA).

Table 14 contains a summary of the coarse and fine aggregate fraction specific gravities for the fine, fine plus, and coarse mixtures placed at WesTrack. These fine and coarse aggregate specific gravities were used to calculate combined specific gravities for the WesTrack aggregates (table 15). These calculated combined specific gravities were determined from: 1) stockpile percentages used for mixture design and used by the FHWA to calculate volumetrics during construction (quality control volumetrics), 2) stockpile percentages used during construction (table 16), and 3) from the cold-feed specific gravities combined with the percent coarse and fine aggregate measured from the core samples obtained during the construction operation.

Table 16, as stated above, contains the stockpile or cold-feed bin percentages used during construction. Note that the top lift of the coarse-graded aggregate sections contained some 1995 production aggregate. This was the last lift placed on the test track and insufficient 1994 production 1/2-in. (12.7-mm) Dayton aggregate material was available to complete construction. A blend of Dayton 1/2-in. and Dayton 3/8-in. (9.5-mm)1995 production material was used as a substitute for the 1994 production Dayton 1/2-in. material.

Based on a review of the specific gravity information obtained during preconstruction and quality assurance testing, the combined specific gravities shown in table 17 were selected for use to calculate volumetrics during mixture design and quality control testing, and for quality assurance purposes.

Coarse Aggregate Angularity

Coarse aggregate angularity consensus property values were determined by HLA on cold-feed samples obtained during construction. Table 18 contains a summary of the information by mixture and lift for the test sections. Appendix C contains individual test results. The reported values are for two fractured face counts. The data indicate that the Superpave volumetric design criteria were met.

Fine Aggregate Angularity

Fine aggregate angularity consensus property values were determined by HLA on cold-feed samples obtained during construction. Table 18 contains a summary of the information by mixture and lift for the test sections. Appendix C contains individual test results. The reported values ranged from 41.5 to 47.4. As expected, the fine and fine plus mixtures had lower values than the coarse mixtures as the fine and fine plus mixtures contained a natural sand with a fine aggregate angularity value of 44.0. Based on the preconstruction data obtained on the aggregates (table 11), fine aggregate angularity values should have been close to 45. The Superpave volumetric mixture design criterion is a minimum of 45.

Flat and Elongated Particles

Flat and elongated particle count consensus property values were determined by HLA on cold-feed samples obtained during construction. Table18 contains a summary of the information by mixture and lift for the test sections. Appendix C contains individual test results. The reported values ranged from 0.0 to 0.37 for the 3/4- by 1/2-in. (19- by 12.5-mm) and the 1/2- by 3/8-in. (12.5- by 9.5-mm) aggregate size fractions. The Superpave volumetric mixture design method (table 1) requires the flat and elongated particle counts (5 to 1 ratio) to be below 10 percent.

Sand Equivalent

Sand equivalent consensus property values were determined by HLA on cold-feed samples obtained during construction. Table 18 contains a summary of the information by mixture and lift for the test sections. Appendix C contains individual test results. The reported values ranged from 53 to 70 for the mixtures prepared with the 1994-produced aggregates (appendix C). The single mixture that contained some 1995-produced aggregate had reported sand-equivalent values in the range from 41 to 50 (appendix C). Average values for the individual lifts are shown in table 18. All of the reported average values exceeded the minimum requirement of 45 for the Superpave volumetric mixture design method (table 1).

Los Angeles Abrasion

The Los Angeles abrasion source property values were determined by HLA on cold-feed samples obtained during construction. Table 18 contains a summary of the information by mixture and lift for the test sections. Appendix C contains individual test results. The reported values ranged from 20 to 23. These reported values are below the values of 35 to 45 typically required.

Soundness

The sodium sulfate soundness source property test results were obtained by HLA on cold-feed samples. Table 18 contains a summary of the information by mixture and lift for the test sections. Appendix C contains individual test results. Soundness values were obtained on both the coarse and fine aggregate fractions. These reported values are below the maximum values of 10 to 15 typically required for sodium sulfate soundness.

Deleterious Materials

Clay content is a source property that was determined by HLA on cold-feed samples obtained during construction. Appendix C contains individual test results of the clay content on various sizes of material. A summary of information for material on the No. 4 (4.75-mm) sieve is shown in table 18 by mixture and lift for the test sections.

Plastic Index

The Atterberg Limit tests were performed according to AASHTO T 84 and T 85 by HLA on cold-feed samples obtained during construction. All samples tested indicated that the aggregate was nonplastic (table 18).

SPECIAL TEST

The University of Nevada School of Mines determined fractal dimension of the aggregates used on WesTrack. "Fractal" is a term used in geometry to describe an object, the shape of which is an intermediate between topological ideals. The fractal dimension describes the deviation that a line, surface, or volume has from a topological ideal. In general, a large fractal dimension for an aggregate indicates that the aggregate has a large surface texture.[9]

Table 19 contains information that describes fractal dimensions that are typical for selected shapes.[9] Fractal dimensions for the Dayton aggregate produced in 1994 are shown in table 20. Information is provided for the 3/4-in. (19-mm), 1/2-in. (12.5-mm), and 3/8-in. (9.75-mm) Dayton aggregate stockpiles. These data indicate that the Dayton aggregate has a relatively rough surface texture.

SUMMARY

Physical properties of the aggregates used for construction of WesTrack were determined on both preconstruction and construction samples. Tables 4 and 5 contain the gradation of the aggregate stockpiles used for construction of WesTrack. Table 17 contains the bulk (dry) specific gravity values used for all volumetric calculations (mixture design, quality control, and quality assurance) associated with the original construction of WesTrack.

Tables 11, 12, and 18 contain physical property data on the WesTrack aggregates used for original construction. Physical properties include both the Superpave "consensus" and "source" properties. The consensus aggregate properties measured on the original construction aggregates met the traffic requirement for less than 30 million ESALs. The estimated WesTrack 20-year ESAL is on the order of 20 to 30 million.

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Table 1. Superpave aggregate requirements.

Aggregate Property		Test Method	Superpave Requirements			
Type	Description		3-10 Million ESALs		10-30 Million ESALs	
			<100 mm*	>100 mm	<100 mm	>100 mm
Consensus	Coarse aggregate angularity	PENN DOT 621 ASTM D 5821	85/80**	60/-	95/90	80/75
	Fine aggregate angularity	AASHTO TP33	45	40	45	40
	Flat and elongated particles	ASTM D4791	10		10	
	Clay content (sand equivalent)	AASHTO T176	45		45	
Source	Toughness (LA abrasion)	AASHTO T96				
	Soundness	AASHTO T104				
	Deleterious materials (clay lumps and friable particles)	AASHTO T112				

* Depth of HMA layer.
**One and two fractured face requirements.

Table 2. Geologic description of aggregate — original construction.

Aggregate	Geologic Description
Dayton 3/4-in to rock dust	Unweathered to slightly weathered, fine-grained andesite (volcanic), with a few (10%) pieces of granite (quartz monzonite), and a few (10%) pieces of rhyolite (volcanic).
Dayton sand	Weathered fragments of andesite, rhyolite, and granite (in sizes up to 6 mm [0.25 in.]) mixed with a smaller sized fraction consisting of decomposed granite (mica, feldspar, and quartz); sizeable component of fines.
Wadsworth sand	Decomposed granite composed of weathered fragments of mica and feldspar, with rounded quartz grains; clean, few fines.

Table 3. WesTrack aggregate test procedures.

Designation	Description
AASHTO T2	Sampling aggregates
AASHTO T11	Amount of material finer than the No. 200 sieve
AASHTO T27	Sieve analysis of fine and coarse aggregate
AASHTO T30	Mechanical analysis of extracted aggregate
AASHTO T37	Sieve analysis of mineral filler for road and paving materials
AASHTO T84	Specific gravity and absorption of fine aggregate
AASHTO T85	Specific gravity and absorption of coarse aggregate
AASHTO T89	Determination of liquid limit
AASHTO T90	Determination of plastic limit and plastic index of soils
AASHTO T96	Resistance to degradation by L.A. machine
AASHTO T104	Soundness of aggregate by use of sodium sulfate or magnesium sulfate
AASHTO T176	Plastic fines in graded aggregates and soils by the sand-equivalent test
AASHTO T248	Reducing field samples of aggregate to testing size
AASHTO TP33	Uncompacted void content of fine aggregate
AASHTO D4791	Flat or elongated particles in coarse aggregates
Penn DOT 621	Determination of percent crushed faces (CA angularity)

Table 4. Stockpile gradations — 1994 production.*

Sieve Size		Aggregate Source					
mm	U.S.	Dayton 3/4-in.	Dayton 1/2-in.	Dayton 3/8-in.	Dayton Rock Dust	Dayton Sand	Wadsworth Sand
25.0	1-in.	100	100	100	100	100	100
19.0	3/4-in.	99.8	100	100	100	100	100
12.5	1/2-in.	63.5	99.9	100	100	100	100
9.5	3/8-in.	33.7	82.6	97.5	100	100	100
4.75	No. 4	10.8	19.5	27.5	99.1	96.5	99.7
2.36	No. 8	5.0	4.3	5.1	76.6	78.9	99.0
1.18	No. 16	4.3	3.2	4.2	54.1	62.1	96.0
0.60	No. 30	4.0	2.9	3.8	39.2	45.0	79.9
0.30	No. 50	3.7	2.6	3.5	28.7	28.9	40.1
0.15	No. 100	3.4	2.4	3.1	20.3	17.9	11.0
0.075	No. 200	3.0	2.0	2.5	13.9	11.5	3.3

*Represents the average of five samples — see appendix A for individual sieve analysis and statistics.

Table 5. Comparison of 1994 and 1995 Dayton aggregate stockpile gradations.

Sieve Size (U.S.)	Sieve Size (mm)	3/4-in.		1/2-in.		3/8-in. Before Z-Screen		3/8-in. After Z-Screen		Rock Dust	
		1994	1995	1994	1995	1994	1995	1994	1995	1994	1995
		Cumulative % Passing (5-Sample Average)	Cumulative % Passing (16-Sample Average)	Cumulative % Passing (5-Sample Average)	Cumulative % Passing (33-Sample Average)	Cumulative % Passing (5-Sample Average)	Cumulative % Passing (30-Sample Average)	Cumulative % Passing (5-Sample Average)	Cumulative % Passing (8-Sample Average)	Cumulative % Passing (5-Sample Average)	Cumulative % Passing (30-Sample Average)
3/4"	19	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1/2"	12/5	63.5	73.2	99.9	98.8	100.0	100.0	100.0	100.0	100.0	100.0
3/8"	9.5	33.7	49.1	82.6	43.8	97.7	100.0	97.7	100.0	100.0	100.0
#4	4.75	10.8	10.8	19.5	1.7	29.8	29.0	29.8	26.0	99.1	99.8
#8	2.36	5.0	2.6	4.3	1.6	6.4	3.4	6.4	3.5	76.6	76.3
#16	1.18	4.3	2.1	3.2	1.5	5.0	2.5	5.0	2.6	54.1	53.3
#30	0.60	4.0	1.9	2.9	1.4	4.4	2.4	4.4	2.5	39.2	38.3
#50	0.30	3.7	1.8	2.6	1.4	3.9	2.1	3.9	2.4	28.7	26.3
#100	0.15	3.4	1.6	2.4	1.4	3.4	2.0	3.4	2.1	20.3	17.6
#200	0.075	3.0	1.3	2.0	1.1	2.8	1.8	2.8	1.9	13.9	11.3

Z - screen – A different aggregate screening technique was used to produce these aggregates. The Z - screen has a "Z" shape opening as compared to a square or slot typical of other production screens.

Table 6. Preconstruction aggregate stockpile specific gravities (continued).

Stockpile	Source of Data	Coarse Aggregate				Fine Aggregate			
		Apparent Sp. Gr.	Bulk Sp. Gr.	Bulk (SSD) Sp. Gr.	Absorption Capacity, Percent	Apparent Sp. Gr.	Bulk Sp. Gr.	Bulk (SSD) Sp. Gr.	Absorption Capacity, Percent
Dayton 3/4-in. 1994 Production	FHWA Mix Design Original	2.701	2.539		2.37				
	FHWA Mix Design Rerun	2.713	2.566		2.11				
Dayton 3/4-in. 1995 Production	FHWA Mix Design Original	2.686	2.515		2.53				
Dayton 1/2-in. 1994 Production	FHWA Mix Design Original	2.679	2.553		1.84				
	FHWA Mix Design Rerun	2.712	2.560		2.19				
Dayton 1/2-in. 1995 Production	FHWA Mix Design Original	2.708	2.573		1.95				
Dayton 3/8-in. 1994 Production	FHWA Mix Design Original	2.643	2.519		1.87				
	FHWA Mix Design Rerun	2.682	2.508		2.59				
Dayton 3/8-in. 1995 Production	FHWA Mix Design Original	2.712	2.559		2.19				

Table 6. Preconstruction aggregate stockpile specific gravities. (continued)

Stockpile	Source of Data	Coarse Aggregate				Fine Aggregate			
		Apparent Sp. Gr.	Bulk Sp. Gr.	Bulk (SSD) Sp. Gr.	Absorption Capacity, Percent	Apparent Sp. Gr.	Bulk Sp. Gr.	Bulk (SSD) Sp. Gr.	Absorption Capacity, Percent
Dayton Rock Dust 1994 Production	FHWA Mix Design Original					2.711	2.438		4.12
	FHWA Mix Design Rerun					2.714	2.419		4.49
	UNR - Average of Three Test Results					2.726	2.470		3.86
Dayton Rock Dust 1994 Production	FHWA Mix Design Original					2.710	2.552		2.29
Dayton Sand 1994 Production	FHWA Mix Design Original					2.671	2.472		3.02
	FHWA Mix Design Rerun					2.704	2.467		3.56
Wadsworth Sand 1994 Production	FHWA Mix Design Original					2.727	2.569		2.25
	FHWA Mix Design Rerun					2.721	2.552		2.44
	UNR - Average of Four Test Results					2.707	2.552		2.23

Table 7. Preconstruction aggregate stockpile specific gravities for fine aggregates (tested at University of Nevada).

Stockpile	Replicate Number/Statistics	Apparent Sp. Gr.	Bulk Sp. Gr.	Bulk (SSD) Sp. Gr.	Absorption Capacity, Percent
Dayton Rock Dust* 1994 Production	2	2.724	2.479		3.80
	4	2.735	2.467		3.98
	5	2.719	2.464		3.81
	Mean	2.726	2.470		3.86
	Standard Deviation	0.008	0.008		0.101
	COV, Percent	0.300	0.321		2.62
	Range	0.016	0.015		0.18
	Number of Tests	3	3		3
Wadsworth Sand 1994 Production	1	2.694	2.537		2.3
	2	2.702	2.549		2.2
	3	2.717	2.568		2.1
	4	2.713	2.553		2.3
	Mean	2.707	2.552		2.23
	Standard Deviation	0.010	0.013		0.096
	COV, Percent	0.386	0.501		4.30
	Range	0.023	0.031		0.20
	Number of Tests	4	4		4

*Fine aggregate

Table 8. Aggregate specific gravities used for mix design volumetrics.*

Stockpile	Coarse Aggregate			Fine Aggregate		
	Apparent Sp. Gr.	Bulk Sp. Gr.	Absorption Capacity, Percent	Apparent Sp. Gr.	Bulk Sp. Gr.	Absorption Capacity, Percent
Dayton 3/4-in.	2.701	2.539	2.37			
Dayton 1/2-in.	2.679	2.553	1.84			
Dayton 3/8-in.	2.643	2.519	1.87			
Dayton Rock Dust				2.711	2.438	4.12
Dayton Sand				2.671	2.472	3.02
Wadsworth Sand				2.727	2.569	2.25
Lime					2.297	

*1994 production aggregates.
Test performed by FHWA on stockpile samples.

Table 9. Combined aggregate specific gravities for mix design purposes.

Mixture Designation	Source of Data	Coarse Aggregate		Fine Aggregate		Combined Aggregate*	
		Apparent Sp. Gr.	Bulk Sp. Gr.	Apparent Sp. Gr.	Bulk Sp. Gr.	Apparent Sp. Gr.	Bulk Sp. Gr.
Fine and Fine Plus	Calculated from stockpile percentages FHWA and UNR		2.540 (60%)**		2.522 (38.5%)	2.692	2.529
	Stockpiles blended June 1995						
	Stockpiles blended July 8, 1995		2.521 (50.3%)		2.595 (48.2%)		2.552
Coarse	Calculated from stockpile percentages FHWA and UNR		2.543 (66%)		2.438 (32.5%)	2.693	2.504
	Stockpiles blended June 1995		2.548 (57.9%)		2.410 (40.6%)		2.486
	Stockpiles blended July 8, 1995		2.526 (57.9%)		2.442 (40.6%)		2.488

* With lime.
**Percent coarse or fine aggregate.

Table 10. Aggregate stockpile percentages for mixture design.*

Stockpile	Mixture Designation		
	Fine	Fine Plus	Coarse
Dayton 3/4-in.	31.0	31.0	47.0
Dayton 1/2-in.	19.0	19.0	19.0
Dayton 3/8-in.	10.0	10.0	0.0
Dayton Rock Dust	13.5	13.5	32.5
Dayton Sand	0.0	0.0	0.0
Wadsworth Sand	25.0	25.0	0.0
Lime	1.5	1.5	1.5

*All stockpiles from 1994 production.

Table 11. Preconstruction aggregate properties — 1994 production.

Stockpile/ Mixture Designation	Coarse Aggregate Angularity*		Fine Aggregate Angularity*	Flat or Elongated,* Percent	Sand Equivalent*, Percent	LA Abrasion,*	Soundness**	Deleterious Materials**
	1 Face	2 Face						
Dayton 3/4-in.	98.9	95.4		0.2		18.9		0.46
Dayton 1/2-in.	99.7	98.9		2.0		20.2		0.42
Dayton 3/8-in.	98.2	96.4				21.3		0.30
Dayton Rock Dust			47.6		49.0			0.46
Dayton Sand			44.5		31.0			
Wadsworth Sand			44.0		74.0			0.15
Fine	98.1	96.5	44.9***	0.6	65.0	20.3		0.21
Fine Plus	98.1	96.5	44.9***	0.6	65.0	20.3		0.21
Coarse	98.8	96.7	45.0	1.3	70.0	20.8		0.34

* Performed by Federal Highway Administration.
** Performed by University of Nevada.
***Based on FA Gsb of 2.595 from field blend of July 8, 1995.

Table 12. Preconstruction aggregate properties — 1995 production.

	Coarse Aggregate Angularity		Fine Aggregate Angularity	Flat or Elongated Percent	Sand Equivalent, Percent
	1 Face	2 Face			
Dayton 3/4-in.	99.7	99.0		0.9	
Dayton 1/2-in.	99.7	99.2		0.0	
Dayton 3/8-in.	99.7	99.6			
Dayton Rock Dust			47.9		66.0
Dayton Sand			44.5		

Table 13. Construction schedule for test lane — original construction.

Date	Mixture Designation	Lift	Section Numbers	Paving Day
9-20-95	Fine	Bottom	1, 2, 3, 4, 14, 15, 16, 17, 18	5
9-21-95	Fine plus	Bottom	9, 10, 11, 12, 13, 19, 20, 21, 22	6
9-30-95	Coarse	Bottom	5, 6, 7, 8, 23, 24, 25, 26	7
10-2-95	Fine	Top	1, 2, 3, 4, 14, 15, 16, 17, 18	13
10-3-95	Fine plus	Top	9, 10, 11, 12, 13, 19, 20, 21, 22	14
10-4-95	Coarse	Top	5, 6, 7, 8, 23, 24, 25, 26	15

Table 14. Aggregate specific gravities – cold-feed sample.*

					Coarse Aggregate				Fine Aggregate			
Paving Day	Date	Section	Mix Type	Date Tested	Apparent Sp. Gr.	Bulk Sp. Gr	SSD Sp. Gr.	Percent Absorption	Apparent Sp. Gr.	Bulk Sp. Gr.	SSD Sp. Gr.	Percent Absorption
	Sampled											
5	9/20/95	1	fine	7/17/96	2.732	2.524	2.6	3.01				
5	9/20/95	1	fine	7/18/96					2.713	2.453	2.549	3.91
5	9/20/95	4	fine	7/19/96	2.712	2.53	2.597	2.65				
5	9/20/95	4	fine	7/19/96					2.703	2.457	2.548	3.7
5	9/20/95	16	fine		2.708	2.543	2.604	2.39				
5	9/20/95	16	fine						2.709	2.464	2.554	3.67
				mean	2.717	2.532	2.600	2.68	2.708	2.458	2.550	3.76
				std dev	0.013	0.010	0.004	0.311	0.005	0.006	0.003	0.131
				COV	0.473	0.384	0.135	11.603	0.186	0.227	0.126	3.478
				n	3	3	3	3	3	3	3	3
				range	0.024	0.019	0.007	0.62	0.01	0.011	0.006	0.24
6	9/21/95	20	fine+		2.712	2.544	2.606	2.44				
6	9/21/95	20	fine+	9/11/96					2.695	2.465	2.551	3.48
6	9/21/95	9	fine+		2.716	2.542	2.606	2.52				
6	9/21/95	9	fine+	9/11/96					2.696	2.486	2.564	3.13
6	9/21/95	12	fine+		2.716	2.545	2.608	2.48				
6	9/21/95	12	fine+	9/11/96					2.701	2.48	2.562	3.29
				mean	2.715	2.544	2.607	2.48	2.697	2.477	2.559	3.30
				std dev	0.002	0.002	0.001	0.040	0.003	0.011	0.007	0.175
				COV	0.085	0.060	0.044	1.613	0.119	0.437	0.274	5.310
				n	3	3	3	3	3	3	3	3
				range	0.004	0.003	0.002	0.08	0.006	0.021	0.013	0.35

Table 14. Aggregate specific gravities – cold feed sample* (continued).

					Coarse Aggregate				Fine Aggregate			
Paving Day	Date	Section	Mix Type	Date Tested	Apparent Sp. Gr.	Bulk Sp. Gr.	SSD Sp. Gr.	Percent Absorption	Apparent Sp. Gr.	Bulk Sp. Gr.	SSD Sp. Gr.	Percent Absorption
	Sampled											
7	9/30/95	5	coarse		2.728	2.542	2.61	2.68				
7	9/30/95	5	coarse	8/27/96					2.707	2.365	2.491	5.35
7	9/30/95	7	coarse		2.725	2.546	2.612	2.58				
7	9/30/95	7	coarse	8/27/96					2.708	2.341	2.477	5.79
7	10/2/95	25	coarse		2.727	2.539	2.608	2.72				
7	10/2/95	25	coarse						2.716	2.357	2.489	5.61
				mean	2.727	2.542	2.610	2.66	2.710	2.354	2.486	5.58
				std dev	0.002	0.004	0.002	0.072	0.005	0.012	0.008	0.221
				COV	0.056	0.138	0.077	2.711	0.182	0.519	0.305	3.962
				n	3	3	3	3	3	3	3	3
				range	0.003	0.007	0.004	0.14	0.009	0.024	0.014	0.44
13	10/2/95	2	fine		2.722	2.546	2.61	2.55				
13	10/2/95	2	fine						2.691	2.489	2.564	3.01
13	10/2/95	14	fine		2.712	2.544	2.606	2.44				
13	10/2/95	14	fine						2.691	2.5	2.571	2.84
13	10/2/95	17	fine		2.722	2.549	2.613	2.5				
13	10/2/95	17	fine						2.689	2.497	2.568	2.86
				mean	2.719	2.546	2.610	2.50	2.690	2.495	2.568	2.90
				std dev	0.006	0.003	0.004	0.055	0.001	0.006	0.004	0.093
				COV	0.212	0.099	0.135	2.206	0.043	0.228	0.137	3.200
				n	3	3	3	3	3	3	3	3
				range	0.01	0.005	0.007	0.11	0.002	0.011	0.007	0.17

Table 14. Aggregate specific gravities – cold-feed sample* (continued).

					Coarse Aggregate				Fine Aggregate			
Paving Day	Date	Section	Mix Type	Date Tested	Apparent Sp. Gr.	Bulk Sp. Gr.	SSD Sp. Gr.	Percent Absorption	Apparent Sp. Gr.	Bulk Sp. Gr.	SSD Sp. Gr.	Percent Absorption
	Sampled											
14	10/3/95	21	fine+		2.713	2.536	2.602	2.58				
14	10/3/95	21	fine+	7/29/96					2.691	2.466	2.55	3.39
14	10/3/95	21	fine+		2.715	2.53	2.598	2.69				
14	10/3/95	21	fine+	7/31/96					2.696	2.469	2.553	3.42
14	10/3/95	10	fine+		2.708	2.541	2.603	2.44				
14	10/3/95	10	fine+	7/31/96					2.708	2.456	2.549	3.8
				mean	2.712	2.536	2.601	2.57	2.698333	2.463667	2.55067	3.53666667
				std dev	0.004	0.006	0.003	0.125	0.009	0.007	0.002	0.229
				COV	0.133	0.217	0.102	4.875	0.324			
				n	3	3	3	3	3	3	3	3
				range	0.007	0.011	0.005	0.25	0.017	0.013	0.004	0.41
15	10/4/95	7	coarse		2.706	2.542	2.603	2.38				
15	10/4/95	7	coarse						2.702	2.421	2.525	4.29
15	10/4/95	8	coarse		2.709	2.547	2.607	2.35				
15	10/4/95	8	coarse						2.703	2.427	2.529	4.21
15	10/4/95	24	coarse		2.715	2.56	2.617	2.22				
15	10/4/95	24	coarse						2.703	2.41	2.518	4.49
				mean	2.710	2.550	2.609	2.32	2.703	2.419	2.524	4.33
				std dev	0.005	0.009	0.007	0.085	0.001	0.009	0.006	0.144
				COV	0.169	0.364	0.276	3.671	0.021	0.356	0.221	3.331
				n	3	3	3	3	3	3	3	3
				range	0.009	0.018	0.014	0.16	0.001	0.017	0.011	0.28

*Cold feed samples tested by HLA.

Table 15. Combined aggregate specific gravities for field-constructed mixtures.

Mixture Designation	Source of Data		Coarse Aggregate		Fine Aggregate		Combined Aggregate*	
			Apparent Sp. Gr.	Bulk Sp. Gr.	Apparent Sp. Gr.	Bulk Sp. Gr.	Apparent Sp. Gr.	Bulk Sp. Gr.
Fine	Used by FHWA to calculate volumetrics during construction							2.529
	Calculated from stockpile percentages used during construction						2.690	2.530
	Cold-feed samples, calculated from average CA and FA percentages****	Top	2.719	2.546	2.690	2.495		2.517
		Bottom	2.717	2.532	2.708	2.458		2.493
Fine Plus	Used by FHWA to calculate volumetrics during construction							2.529
	Calculated from stockpile percentages used during construction						2.690	2.530
	Cold-feed samples, calculated from average CA and FA percentages	Top	2.712	2.536	2.698	2.464		2.507
		Bottom	2.715	2.544	2.697	2.477		2.496
Coarse	Used by FHWA to calculate volumetrics during construction							2.504
	Calculated from stockpile percentages used during construction						2.689 2.691	2.502** 2.505***
	Cold-feed samples, calculated from average CA and FA percentages	Top	2.710	2.550	2.703	2.419		2.492
		Bottom	2.727	2.542	2.710	2.354		2.457

* With lime.
** Top lift.
*** Bottom lift.
**** Core gradations.

Table 16. Aggregate stockpile percentages during construction.

Stockpile	Mixture Designation			
	Fine*	Fine Plus*	Coarse	
			Bottom	Top
Dayton 3/4-in. 1994 Production	25.0	25.0	39.0	39.0
Dayton 1/2-in. 1994 Production	25.0	25.0	27.0	
Dayton 1/2-in. 1995 Production				12.2
Dayton 3/8-in. 1994 Production	10.0	10.0		14.8
Dayton Rock Dust 1994 Production	13.5	13.5	32.5	32.5
Dayton Sand 1994 Production				
Wadsworth Sand 1994 Production	25.0	25.0		
Lime	1.5	1.5	1.5	1.5

* Top and bottom lifts.

Table 17. Dry bulk specific gravity used for volumetric calculations.

Mixture Designation	Lift	Dry Bulk Specific Gravity for Combined Aggregate
Fine	Top	2.529
	Bottom	2.529
Fine Plus	Top	2.529
	Bottom	2.529
Coarse	Top	2.504
	Bottom	2.504

Table 18. Properties of aggregate samples from cold feeds.*

Mix Designation	Lift	Coarse Aggregate Angularity	Fine Aggregate Angularity	Flat or Elongated		Sand Equivalent	LA Abrasion	Soundness		Deleterious Materials, No. 4 Sieve	Plastic Index
				3/4 x 1/2	1/2 x 3/8			CA	FA		
Fine	Top	93.6	44.9	0.0	0.05	64.3	21.1	6.8	7.2	0.25	NP
	Bottom	97.1	42.1	0.23	0.33	63.7	22.5	4.0	6.8	0.16	NP
Fine Plus	Top	97.7	44.2	0.37	0.20	66.3	20.7	1.9	5.8	0.99	NP
	Bottom	94.5	44.8	0.0	0.03	65.7	20.9	6.4	8.3	0.42	NP
Coarse	Top	90.5	47.0	0.0	0.03	45.7	20.1	4.7	9.0	0.73	NP
	Bottom	94.9	46.1	0.0	0.11	58.3	21.9	6.0	9.0	0.20	NP

*Tests performed by HLA.

Table 19. Average fractal dimension for typical aggregate shapes.

Description of Aggregate	Number of Samples Evaluated	Average Fractal Dimension*
Rounded	10	1.052
Rectangular	12	1.120
Square	2	1.068
Triangular	5	1.110
Elongated	1	1.00

*Relates to texture of aggregate surface. Larger fractal dimension implies greater surface texture.

Table 20. Fractal dimensions – original construction.

Aggregate	Fractal Dimension*	
	Average	Range
Dayton 3/4-in. 1994 production	1.13	1.023-1.235
Dayton 1/2-in. 1994 production	1.13	1.100-1.145
Dayton 3/8-in. 1994 production	1.21	1.050-1.300

*Relates to texture of aggregate surface. Larger fractal dimension implies greater surface texture.

APPENDIX A

PRECONSTRUCTION AGGREGATE STOCKPILE GRADATIONS

Statistical Analysis of
Sieve Analysis of Coarse & Fine Aggregate
(ASTM C117 & C136)

Project: Testrack
Aggregate Source: Granite Dayton 3/4" (Second Sampling)
Other: 5 Samples
Date: 3-4-95 Technician: DR / AH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
3/4"	99.2	100.0	99.8	100.0	100.0	99.8	0.3	0.3
1/2"	54.8	58.1	64.0	74.1	66.8	63.5	6.8	10.7
3/8"	23.9	25.0	36.4	46.2	36.8	33.7	8.3	24.6
#4	9.2	6.8	11.5	15.6	11.0	10.8	2.9	26.8
#8	5.2	3.2	4.9	7.2	4.7	5.0	1.3	25.4
#16	4.3	2.9	4.1	6.0	4.0	4.3	1.0	23.3
#30	3.9	2.8	3.9	5.5	3.7	4.0	0.9	21.9
#50	3.6	2.7	3.7	5.1	3.5	3.7	0.8	20.8
#100	3.3	2.6	3.4	4.6	3.2	3.4	0.7	19.5
#200	2.9	2.3	2.9	4.0	2.9	3.0	0.5	18.0
Pan								

Statistical Analysis of
Sieve Analysis of Coarse & Fine Aggregate
(ASTM C117 & C136)

Project: Testrack
Aggregate Source: Granite Dayton 1/2"
Other: 5 Samples
Date: 2-16-95 Technician: DR / AH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	99.5	100.0	100.0	100.0	99.9	99.9	0.2	0.2
3/8"	83.0	82.3	83.6	82.8	81.4	82.6	0.8	0.9
#4	18.1	20.7	20.3	21.6	16.8	19.5	1.8	9.2
#8	3.7	4.2	3.5	5.7	4.2	4.3	0.8	17.9
#16	2.9	3.2	2.6	4.1	3.4	3.2	0.5	15.2
#30	2.6	2.8	2.4	3.5	3.1	2.9	0.4	13.1
#50	2.4	2.6	2.2	3.2	2.8	2.6	0.3	12.0
#100	2.2	2.3	2.1	2.8	2.5	2.4	0.3	10.9
#200	1.9	2.0	1.8	2.3	2.1	2.0	0.2	9.3
Pan								

Statistical Analysis of
Sieve Analysis of Coarse & Fine Aggregate
(ASTM C117 & C136)

Project: Testrack
Aggregate Source: Granite Dayton 3/8"
Other: 5 Samples
Date: 2-17-95 Technician: DR / AH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
3/8"	98.4	97.4	97.5	97.3	97.9	97.7	0.4	0.4
#4	30.0	28.2	27.5	26.8	36.6	29.8	3.5	11.9
#8	5.2	5.8	5.1	5.5	10.4	6.4	2.0	31.6
#16	4.1	4.7	4.2	4.5	7.6	5.0	1.3	26.5
#30	3.7	4.2	3.8	3.9	6.4	4.4	1.0	23.3
#50	3.4	3.8	3.5	3.5	5.6	3.9	0.8	21.5
#100	3.0	3.3	3.1	3.0	4.8	3.4	0.7	20.2
#200	2.6	2.6	2.5	2.5	3.9	2.8	0.5	18.7
Pan								

Statistical Analysis of
Sieve Analysis of Coarse & Fine Aggregate
(ASTM C117 & C136)

Project: Testrack
Aggregate Source: Granite Dayton Rock Dust
Other: 5 Samples
Date: 2-16-95 Technician: DR / AH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation
1"	100.0	100.0	100.0	100.0	100.0	100.0	0	0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0	0
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	0	0
3/8"	100.0	100.0	100.0	100.0	100.0	100.0	0	0
#4	99.7	99.6	98.2	99.3	98.6	99.1	0.6	0.6
#8	76.4	80.1	73.7	78.5	74.5	76.6	2.4	3.1
#16	53.3	57.6	51.8	56.3	51.5	54.1	2.4	4.5
#30	38.4	41.3	38.0	41.2	37.2	39.2	1.7	4.3
#50	27.9	29.8	28.0	30.6	27.2	28.7	1.3	4.5
#100	19.6	20.6	19.8	21.9	19.6	20.3	0.9	4.3
#200	13.4	14.0	13.4	15.0	13.4	13.9	0.6	4.3
Pan								

Statistical Analysis of
Sieve Analysis of Coarse & Fine Aggregate
(ASTM C117 & C136)

Project: Testrack
Aggregate Source: Granite Dayton Sand
Other: 5 Samples
Date: 2-14-95 Technician: DR / AH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation
1"	100	100	100	100	100	100	0	0
3/4"	100	100	100	100	100	100	0	0
1/2"	100	100	100	100	100	100	0	0
3/8"	100	100	100	100	100	100	0	0
#4	97.9	96.9	95.7	95.9	96.1	96.5	0.8	0.8
#8	82.0	79.0	76.5	78.1	79.1	78.9	1.8	2.3
#16	65.4	60.9	59.5	61.1	63.7	62.1	2.2	3.5
#30	47.0	42.7	42.8	44.0	48.5	45.0	2.3	5.2
#50	28.9	26.7	27.6	28.3	33.2	28.9	2.2	7.8
#100	17.1	16.7	17.2	17.2	21.2	17.9	1.7	9.2
#200	11.1	11.1	11.0	10.9	13.4	11.5	1.0	8.3
Pan								

Statistical Analysis of
Sieve Analysis of Coarse & Fine Aggregate
(ASTM C117 & C136)

Project: Testrack
Aggregate Source: Wadsworth Sand
Other: 5 Samples
Date: 2-15-95 Technician: DR / AH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation
1"	100	100	100	100	100	100	0	0
3/4"	100	100	100	100	100	100	0	0
1/2"	100	100	100	100	100	100	0	0
3/8"	100	100	100	100	100	100	0	0
#4	99.8	99.3	99.9	99.8	99.8	99.7	0.2	0.2
#8	99.0	98.4	99.2	99.0	99.5	99.0	0.4	0.4
#16	95.7	95.6	96.5	96.0	96.3	96.0	0.4	0.4
#30	78.4	80.6	81.9	79.5	79.1	79.9	1.3	1.6
#50	37.9	45.0	39.9	37.3	40.3	40.1	2.7	6.7
#100	11.0	12.6	9.1	10.4	12.0	11.0	1.2	10.9
#200	3.2	3.7	2.2	4.0	3.5	3.3	0.6	19.1
Pan								

Table . . 1995 Dayton 3/4" stockpile production gradations.

	Dates																MIN	MAX	AVG	STD	COV
Sieve Size	4/25	4/25	4/26	4/27	5/1	5/2	5/3		5/8	5/16	5/17	5/18	5/23	5/24	5/26	6/2					
3/4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
1/2	71.0	79.0	79.0	68.0	74.0	83.0	74.0	79.0	69.0	56.0	81.0	69.0	71.0	76.0	75.0	67.0	56.0	83.0	73.2	6.5	8.9
3/8	47.0	57.0	57.0	41.0	52.0	56.0	49.0	51.0	50.0	32.0	62.0	46.0	48.0	49.0	49.0	39.0	32.0	62.0	49.1	7.2	14.7
#4	8.0	13.0	15.0	6.0	16.0	12.0	8.0	12.0	11.0	8.0	17.0	13.0	9.0	10.0	8.0	7.0	6.0	17.0	10.8	3.2	30.0
#8	1.0	2.0	3.0	1.0	3.0	2.0	1.0	1.0	2.0	3.0	3.0	4.0	3.0	5.0	5.0	3.0	1.0	5.0	2.6	1.3	48.3
#16	1.0	2.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	4.0	3.0	3.0	3.0	3.0	1.0	4.0	2.1	0.9	40.3
#30	1.0	2.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	3.0	2.0	3.0	3.0	2.0	1.0	3.0	1.9	0.7	34.0
#50	1.0	2.0	2.0	1.0	1.0	2.0	1.0	1.0	2.0	2.0	2.0	3.0	2.0	2.0	3.0	2.0	1.0	3.0	1.8	0.6	35.0
#100	1.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	1.6	0.5	31.7
#200	1.2	1.1	1.3	0.8	1.1	0.9	1.2	0.7	1.6	1.4	1.2	1.9	1.6	1.9	2.1	1.3	0.7	2.1	1.3	0.4	29.2

c:\testrack\blends\1995\34avgjim.wq2

Table . 1995 Dayton 1/2" stockpile production gradations.

	Dates																		
Sieve Size	2/27	2/29	3/2	3/3	3/6	3/7	3/8	3/17	3/20	3/23	3/29			4/5	4/7	4/10	4/19	4/24	4/25
3/4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1/2	100	100	100	100	98.0	99.0	99.0	100	98.0	97.0	99.0	99.0	98.0	98.0	99.0	97.0	99.0	98.0	98.0
3/8	45.0	44.0	38.0	35.0	39.0	49.0	39.0	44.0	43.0	39.0	46.0	43.0	48.0	40.0	46.0	47.0	46.0	39.0	38.0
#4	1.0	1.0	1.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0
#8	1.0	1.0	1.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0
#16	1.0	1.0	1.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0
#30	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0
#50	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0
#100	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0
#200	0.5	0.3	0.7	0.8	1.2	1.3	1.5	0.5	1.5	1.1	0.4	0.9	1.8	1.0	1.6	1.9	0.6	1.1	1.2

	Dates														MIN	MAX	AVG	STD	COV
Sieve Size	4/26	4/26	5/1	5/2	5/3	5/4	5/8	5/16	5/17	5/18	5/24	5/25	5/30	6/2					
3/4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
1/2	99.0	97.0	95.0	98.0	99.0	98.0	99.0	100	100	100	100	100	100	100	95.0	100	98.8	1.2	1.2
3/8	33.0	29.0	33.0	35.0	34.0	41.0	46.0	49.0	51.0	59.0	53.0	60.0	56.0	58.0	29.0	60.0	43.8	7.7	17.6
#4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	3.0	3.0	4.0	2.0	3.0	2.0	1.0	4.0	1.7	0.8	45.9
#8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	2.0	2.0	2.0	1.0	4.0	1.6	0.7	44.3
#16	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	3.0	2.0	2.0	1.0	1.0	3.0	1.5	0.6	41.0
#30	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	2.0	2.0	2.0	1.0	1.0	3.0	1.4	0.6	38.8
#50	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0	1.4	0.5	35.3
#100	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0	1.4	0.5	35.3
#200	1.0	1.0	0.9	0.8	0.7	1.0	1.2	1.3	1.1	1.5	1.8	1.3	1.6	1.0	0.3	1.9	1.1	0.4	37.2

c:\testrack\blends\1995\12jimavg.w

Table . 1995 Dayton 3/8" stockpile production gradations before adding Z-Screens.

Sieve Size	2/27	2/28	3/2	3/3	3/6	3/7	3/8	3/17	3/20	3/21	3/22	3/23	3/24	3/27	3/28	3/29	3/31	4/3
3/4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1/2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3/8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
#4	21.0	19.0	24.0	28.0	22.0	35.0	34.0	29.0	33.0	34.0	44.0	33.0	48.0	30.0	31.0	33.0	45.0	32.0
#8	2.0	2.0	2.0	4.0	2.0	7.0	6.0	3.0	3.0	3.0	9.0	2.0	12.0	3.0	3.0	4.0	9.0	2.0
#16	2.0	2.0	1.0	2.0	2.0	4.0	4.0	2.0	2.0	2.0	5.0	2.0	6.0	3.0	2.0	3.0	6.0	2.0
#30	2.0	2.0	1.0	2.0	2.0	4.0	4.0	2.0	2.0	2.0	4.0	2.0	5.0	3.0	2.0	3.0	5.0	2.0
#50	1.0	2.0	1.0	2.0	2.0	3.0	3.0	2.0	2.0	2.0	3.0	2.0	3.0	2.0	2.0	3.0	4.0	2.0
#100	1.0	2.0	1.0	2.0	2.0	2.0	3.0	1.0	2.0	2.0	3.0	2.0	4.0	2.0	2.0	3.0	4.0	2.0
#200	1.1	1.6	0.7	1.3	1.9	2.2	2.5	1.3	1.8	1.9	2.7	1.8	3.1	1.9	2.1	2.8	3.1	2.4

	Dates												MIN	MAX	AVG	STD	COV
Sieve Size	4/5	4/7	4/10	4/24	4/25	4/26	4/27	5/1	5/2	5/3	5/4	5/8					
3/4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
1/2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
3/8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
#4	32.0	30.0	26.0	26.0	21.0	23.0	23.0	27.0	21.0	23.0	22.0	20.0	19.0	48.0	29.0	7.4	25.4
#8	3.0	3.0	3.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	12.0	3.4	2.6	75.8
#16	2.0	3.0	3.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	6.0	2.5	1.3	51.4
#30	2.0	3.0	3.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	5.0	2.4	1.1	43.8
#50	2.0	3.0	3.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	4.0	2.1	0.7	33.7
#100	2.0	3.0	3.0	2.0	1.0	1.0	1.0	2.0	1.0	2.0	1.0	1.0	1.0	4.0	2.0	0.9	42.8
#200	1.8	2.4	2.6	1.5	0.9	1.1	1.3	1.6	1.3	1.3	1.1	1.1	0.7	3.1	1.8	0.7	36.0

c:\testrack\blends\1995\38bavg.wq2

Table . 1995 Dayton 3/8" stockpile production gradations after adding Z-Screens.

	Dates								MIN	MAX	AVG	STD	COV
Sieve Size	5/16	5/17	5/18				5/26						
3/4	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
1/2	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
3/8	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
#4	35.0	29.0	37.0	18.7	15.7	15.6	32.0	25.0	15.6	37.0	26.0	8.0	30.9
#8	6.0	3.0	4.0	1.0	3.0	2.0	6.0	3.0	1.0	6.0	3.5	1.7	47.4
#16	4.0	2.0	3.0	1.0	2.0	2.0	4.0	3.0	1.0	4.0	2.6	1.0	37.8
#30	4.0	2.0	3.0	1.0	2.0	2.0	3.0	3.0	1.0	4.0	2.5	0.9	34.6
#50	4.0	2.0	3.0	1.0	2.0	2.0	3.0	2.0	1.0	4.0	2.4	0.9	36.1
#100	3.0	2.0	2.0	1.0	2.0	2.0	3.0	2.0	1.0	3.0	2.1	0.6	28.2
#200	2.5	1.8	2.0	1.1	1.5	1.6	2.3	2.0	1.1	2.5	1.9	0.4	22.8

c:\testrack\blends\1995\38aavg.wq

Table . 1995 Dayton rock dust stockpile production gradations.

	Dates																		
Sieve Size	2/27	2/28		3/3	3/6	3/7	3/8	3/17	3/20	3/21		3/23	3/24	3/25	3/28	3/29	4/3	4/5	4/7
3/4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1/2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3/8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
#4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
#8	75.0	74.0	76.0	79.0	74.0	79.0	80.0	78.0	87.0	84.0	84.0	77.0	82.0	78.0	79.0	77.0	79.0	76.0	73.0
#16	50.0	49.0	50.0	54.0	50.0	55.0	56.0	51.0	59.0	60.0	59.0	54.0	59.0	54.0	54.0	52.0	55.0	52.0	46.0
#30	37.0	35.0	36.0	38.0	36.0	39.0	41.0	36.0	40.0	43.0	41.0	38.0	42.0	39.0	38.0	38.0	40.0	38.0	31.0
#50	25.0	27.0	24.0	25.0	25.0	28.0	28.0	25.0	26.0	30.0	27.0	26.0	29.0	27.0	26.0	26.0	24.0	27.0	21.0
#100	16.0	16.0	17.0	17.0	17.0	18.0	19.0	16.0	18.0	20.0	16.0	17.0	19.0	18.0	18.0	18.0	18.0	19.0	14.0
#200	10.5	10.2	10.5	11.8	11.4	12.1	13.0	10.5	12.1	12.7	9.4	10.2	12.3	11.9	11.4	11.5	11.0	12.9	9.4

	Dates													MIN	MAX	AVG	STD	COV
Sieve Size	4/10	5/3	5/4	5/8	5/10	5/16	5/17	5/19	5/24	5/26		5/31	6/2					
3/4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
1/2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
3/8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.0	0.0
#4	100	100	100	100	100	100	100	100	99.0	99.0	98.0	98.0	99.0	98.0	100	99.8	0.5	0.5
#8	75.0	80.0	76.0	72.0	74.0	81.0	77.0	79.0	70.0	71.0	67.0	65.0	78.0	65.0	87.0	76.8	4.6	6.0
#16	52.0	57.0	53.0	49.0	50.0	58.0	55.0	58.0	47.0	50.0	53.0	45.0	59.0	45.0	60.0	53.3	4.0	7.5
#30	37.0	42.0	39.0	35.0	38.0	42.0	40.0	41.0	35.0	37.0	39.0	32.0	44.0	31.0	44.0	38.3	2.9	7.6
#50	26.0	28.0	27.0	25.0	25.0	28.0	28.0	29.0	27.0	26.0	24.0	22.0	30.0	21.0	30.0	26.3	2.0	7.7
#100	17.0	20.0	18.0	18.0	17.0	18.0	19.0	18.0	18.0	17.0	17.0	15.0	19.0	14.0	20.0	17.6	1.3	7.5
#200	11.0	12.9	12.2	12.0	11.5	11.2	12.1	11.1	10.4	10.3	10.1	9.7	11.2	9.4	13.0	11.3	1.0	8.9

c:\testrack\blends\1995\rdjimavg.wq2

APPENDIX B

PRECONSTRUCTION
AGGREGATE PHYSICAL PROPERTIES

Preconstruction Aggregate Testing - L.A. Abrasion, by UNR.

Sample ID	% Loss	Average	STD	COV
SPD16 blend - 1	21.5	20.3	1.4	6.8
SPD16 blend - 2	20.7			
SPD16 blend - 3	18.8			
SPD18 blend - 1	20.3	20.8	1.0	4.6
SPD18 blend - 2	21.9			
SPD18 blend - 3	20.2			
3/4" Stockpile - 1	18.9	18.9	2.0	10.5
3/4" Stockpile - 2	21.0			
3/4" Stockpile - 3	17.0			
1/2" Stockpile - 1	19.6	20.2	0.81	4.0
1/2" Stockpile - 2	21.1			
1/2" Stockpile - 3	19.8			
3/8" Stockpile - 1	19.6	21.3	1.8	8.4
3/8" Stockpile - 2	21.3			
3/8" Stockpile - 3	23.2			
Rock Dust	n/a	n/a	n/a	n/a
Wadsworth Sand	n/a	n/a	n/a	n/a

Preconstruction Aggregate Testing - Deleterious Materials, by UNR.

Sample ID	% Clay	Average	STD	COV
SPD16 blend - 1	0.05	0.21	0.24	115.9
SPD16 blend - 2	0.09			
SPD16 blend - 3	0.49			
SPD18 blend - 1	0.03	0.34	0.38	112.6
SPD18 blend - 2	0.23			
SPD18 blend - 3	0.77			
3/4" Stockpile - 1	0.52	0.46	0.36	79.1
3/4" Stockpile - 2	0.79			
3/4" Stockpile - 3	0.07			
1/2" Stockpile - 1	0.84	0.42	0.38	92.2
1/2" Stockpile - 2	0.09			
1/2" Stockpile - 3	0.32			
3/8" Stockpile - 1	0.32	0.30	0.23	76.7
3/8" Stockpile - 2	0.06			
3/8" Stockpile - 3	0.52			
Rock Dust - 1	0.07	0.46	0.55	119.6
Rock Dust - 2	0.85			
Rock Dust - 3				
Wadsworth Sand - 1	0.14	0.145	0.007	4.9
Wadsworth Sand - 2	0.15			
Wadsworth Sand - 3				

APPENDIX C

CONSTRUCTION
AGGREGATE PHYSICAL PROPERTIES

C.A.A. (PennDOT 621)

Paving Day	Section	Mix	% Fractured Faces	$\bar{X}$	S	CV, %	R	n
5	1	1	97.8					
5	4	4	97	97.1	0.61	0.6		3
5	16	7	96.6					
6	20	11	92.3					
6	9	14	94.5	94.5	2.2	2.3		3
6	12	17	96.6					
7	5	19	95.4					
7	7	21	95.2	94.9	0.64	0.7		3
7	25	25	94.2					
13	2	2	93					
13	14	5	93.8	93.6	0.53	0.6		3
13	17	8	94					
14	21	10	95.3					
14	21	12	98.86	97.7	2.1	2.1		3
14	10	15	98.96					
15	7	21	91.53					
15	8	22	88.54	90.5	1.7	1.9		3
15	24	24	91.34					

F.A.A. (AASHTO TP33)

			Uncompacted Void Content (%)			$\bar{X}$	S	CV,%	R	n
Paving Day	Section	Mix	trial 1	trial 2	Average of two trials					
5	1	1	42.3	42.6	42.5	42.1	0.5	1.3		3
5	4	4	41.6	41.3	41.5					
5	16	7	42.5	42.2	42.4					
6	20	11	44.6	44.6	44.6	44.8	0.2	0.5		3
6	9	14	45	45	45					
6	12	17	44.7	44.7	44.7					
7	5	19	46.06	45.81	45.94	46.1	0.2	0.4		3
7	7	21	46.04	45.96	46					
7	25	25	46.18	46.42	46.3					
13	2	2	45.01	45.24	45.13	44.9	0.2	0.5		3
13	14	5	44.84	44.61	44.73					
13	17	8	44.78	44.86	44.82					
14	21	10	44.07	44.15	44.1	44.2	0.1	0.2		3
14	21	12	44.14	44.34	44.2					
14	10	15	44.09	44.41	44.3					
15	7	21	47.34	47.5	47.4	47.0	0.3	0.7		3
15	8	22	46.79	46.95	46.9					
15	24	24	46.87	46.72	46.8					

FLAT OR ENLONGATED (ASTM D4791)

			-1/2" X 3/8"			-3/4" X 1/2"		
Paving Day	Section	Mix	% Flat Particles	% Elongated particles	% neither Flat nor elongated particles	% Flat Particles	% Elongated particles	% neither Flat nor elongated particles
5	1	1	0	0	100 X 5	0.3	0	99.7
5	4	4	0.4	0	99.6	0.1	0	99.9
5	16	7	0.6	0	99.4 0.33, 0.21	0.3	0	99.7 0.03
6	20	11	0	0	100	0	0	100
6	9	14	0	0	100	0	0	100
6	12	17	0	0	99.91 0.03 0.05	0	0	100 0
7	5	19	0.18	0	99.82	0	0	100
7	7	21	0	0	100	0	0	100
7	25	25	0.14	0	99.86 0.11	0	0	100 0
13	2	2	0	0	100	0	0	100
13	14	5	0	0	100	0	0	100
13	17	8	0.14	0	99.86 .097	0	0	100 0
14	21	10	0.33	0	99.67	0	0	100
14	21	12	0	0	100	0.54	0	99.46
14	10	15	0.26	0	99.74 0.197	0.57	0	99.43 0.37
15	7	21	0.1	0	99.9	0	0	100
15	8	22	0	0	100	0	0	100
15	24	24	0	0	100 0.63	0	0	100 0

SAND EQUIVALENT

			SAND EQUIVALENT				$\bar{X}$	S	Cv%	R	
Paving Day	Section	Mix	test 1	test 2	test 3	Average					
5	1	1	62	61	64	62					
5	4	4	64	63	63	64	63.7				
5	16	7	64	64	65	65					
6	20	11	65	64	66	65					
6	9	14	68	64	65	66	65.7				
6	12	17	66	65	66	66					
7	5	19	56	56	59	57					
7	7	21	62	65	62	63	58.3				
7	25	25	56	56	53	55					
13	2	2	68	65	67	67					
13	14	5	59	60	59	60	64.3				
13	17	8	67	65	65	66					
14	21	10	68	66	70	68					
14	21	12	67	67	65	67	66.3				
14	10	15	62	66	64	64					
15	7	21	44	48	46	46					
15	8	22	42	41	43	42	45.7				
15	24	24	50	46	50	49					

ABRASION
LA ~~ABBRATION~~

Paving Day	Section	Mix	Percent Loss after 500 Revolutions	$\bar{x}$	S	Cv, %	R	n
5	1	1	23.1	22.5				
5	4	4	21.7					
5	16	7	22.7					
6	20	11	20.8	20.9				
6	9	14	21.6					
6	12	17	20.3					
7	5	19	21.8	21.9				
7	7	21	21.8					
7	25	25	22.1					
13	2	2	21.11	21.1				
13	14	5	20.32					
13	17	8	21.81					
14	21	10	20.7	20.7				
14	21	12	20.9					
14	10	15	20.4					
15	7	21	19.97	20.1				
15	8	22	19.98					
15	24	24	20.26					

SOUNDNESS

Paving Day	Section	Mix	Weighted % Loss Course Agg	Weighted % Loss Fine Agg	$\bar{x}$
15	24	24	4.2	8.8	
15	7	21	4.8	8.2	
15	8	22	5.2	10.1	9.0
			4.7		
14	10	15	2.0	4.6	
14	21	12	1.6	6.8	
14	19	10	2.1	5.9	5.5
			1.9		
13	14	5	7.2	7.4	
13	17	8	5.9	7.0	7.2
13	2	2	7.3	7.3	
			6.0		
7	5	19	6.3	10.3	
7	7	21	5.4	8.5	
7	25	25	6.2	8.2	9.0
			6.0		
6	12	17	5.6	8.2	
6	20	11	6.9	8.1	
6	9	14	6.6	8.6	8.3
			6.7		
5	16	7	3.2	5.3	
5	4	4	4.7	8.0	6.8
5	1	1	4.0	7.2	
			4.0		

DELETERIOUS MAT(AASHTO T112-91)

			% Clay Lumps			No. 4 SIEVE			
Paving Day	Section	Mix	#16 Screen	#4 Screen	3/8" Screen	$\bar{X}$	S	CV	n
5	1	1	0.85	0.09	0.01				
5	4	4	0.3	0.1	0.1	0.16	0.12	72.5	3
5	16	7	0.6	0.3	0.4				
6	20	11	0.48	0.39	0.37				
6	9	14	0.29	0.55	0.25	0.42	0.12	29.3	3
6	12	17	0.2	0.31	0.1				
7	5	19	0.19	0.25	0.13				
7	7	21	0.48	0.36	0.09	0.20	0.18	90.7	3
7	25	25	0.2	0	0				
13	2	2	0.32	0.09	0.16				
13	14	5	0.42	0.3	0.12	0.25	0.14	55.9	3
13	17	8	0.18	0.35	0.23				
14	21	10	0.42	0.87	0.71				
14	21	12	0.18	1.07	1.11	0.99	0.10	10.5	3
14	10	15	0.63	1.02	0.61				
15	7	21	0.5	0.8	0.7				
15	8	22	0.6	0.7	0.6	0.73	0.06	7.8	3
15	24	24	0.8	0.7	0.7				

Aggregate Properties—Replacement Sections

U.S. Department of Transportation
Federal Highway Administration

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WesTrack Report UNR-5
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research project was awarded in September of 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June of 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on the physical properties of the aggregates used to produce the HMA mixtures in the replacement sections. This report also describes the background information associated with the selection of the aggregates used for the replacement sections. Information on the aggregates used for construction of the original pavement sections at WesTrack is contained in WesTrack Technical Report UNR-4.[4]

BACKGROUND

AGGREGATE SELECTION

The WesTrack team preferred using a quarried aggregate, with nearly 100 percent of the coarse aggregate having at least two fractured faces, for the HMA in the replacement sections. Since the majority of the aggregate sources used in the western United States are partially crushed fluvial deposits, locating a source near the WesTrack site was difficult. The Watsonville granite produced by Graniterock was again considered for use. The difficulty in obtaining a mixture design during the original construction phase of WesTrack eliminated this material from further consideration.

Crushed limestone deposits in the Las Vegas and Salt Lake City areas also were briefly considered. Because of the long hauls and the associated costs, these sources were not used. Granite Construction was opening a new aggregate source near Reno, Nevada, in 1995 and 1996 (Lockwood Quarry). This aggregate was an unweathered to slightly weathered, fine-grained

andesite (table 1). Since this aggregate was located relatively close to the WesTrack site, and since the aggregate was produced from a quarry operation with nearly 100 percent crushed faces, it was selected for use.

SCHEDULE OF ACTIVITIES

Tables 2, 3, and 4 present a time schedule of activities associated with materials selection, mixture design, and construction of the replacement sections at WesTrack. The FHWA mobile asphalt binder and mixture laboratory was set up at the University of Nevada in March 1997. An HMA mixture design was developed by FHWA and presented to the WesTrack Technical Advisory Committee on April 4, 1997. This mixture design is identified as the mixture design dated March 28, 1997, in WesTrack Technical Reports (table 3).

A series of changes in asphalt binder availability, aggregate crushing operations, and importing/blending operations occurred between the time the initial mix design work was completed and the final mix design and construction were completed. Tables 2 and 3 summarize these activities.

The FHWA initial mixture design was performed with aggregates sampled on March 14, 1997. The aggregates were most likely produced at the end of the 1996 construction season and produced with a cone and vertical shaft impact crusher at the lower plant crushing area. At the beginning of the 1997 construction season, Granite Construction removed the cone crusher and installed a second vertical shaft impact crusher in the lower plant area. In addition, the mining area in the pit was moved during this time, resulting in a change in the pit raw material feed.

The 1997 production aggregate was sampled at the Lockwood quarry site on April 14, 1997, and a new mixture design was developed by the University of Nevada. An effort was made to use a blend of aggregates as close as possible to that of the FHWA mixture design. The change in the raw material feed to the crushing operation and the use of a second vertical shaft impact crusher changed the rock dust stockpile material. Since the rock dust stockpile controlled the gradation of the mixture on the 2.36 mm (No. 8 sieve) and the 0.075 mm (No. 200 sieve), a new mixture design was developed and designated as "TBE." The sensitivity of this mixture to the amount of material passing the 0.075 mm (No. 200 sieve) was established on May 6, 1997.

On May 12, 1997, Huntway Refining notified the WesTrack team that they would be unable to supply an asphalt binder with nearly the same properties as that used for the original construction of WesTrack. A new asphalt binder was obtained from Idaho Asphalt on May 18, 1997, and used for subsequent mixture designs. On May 20, 1997, the new "TBE" Superpave mixture design was verified with the Idaho asphalt.

As indicated above, the aggregate was produced at Granite Construction's Lockwood facility. The HMA was produced at Granite’s facility at Patrick, which is located a few miles from the Lockwood quarry. The aggregate was transported from the Lockwood facility to the hot-mix production site at Patrick during the period from May 19 through 22, 1997. The stockpiled materials were sampled and gradations were performed by Granite Construction during this period. The sieve analysis indicated that the gradation of some of the stockpiles was different than the material sampled on April 14, 1997, and used for the "TBE" mixture design with the Idaho Asphalt binder. Granite Construction indicated that the material transported to the Patrick

site was obtained when portland cement concrete and HMA aggregates were being produced simultaneously at the plant. Production of portland cement concrete aggregate can vary the gradations of other products and, thus, is the likely reason for the difference in stockpile gradations from the April 14 through May 19, 1997, sampling dates.

Trial section paving was scheduled for May 23, 1997. Since it was not possible to perform a new mixture design prior to the placement of the first trial sections, a paper blend was performed to determine the stockpile percentages for matching the design gradation (as closely as possible).

After placement of the bottom lift of the trial sections on May 23, 1997, five samples of the hot-mix were taken per stockpile and sieve analyses were performed (May 23, 1997, sampling date) (table 3). The sieve analysis data were used to develop a new mixture design, designated "P7" and completed on May 28, 1997. The sieve analysis test results indicated non-uniformity in the coarse aggregate stockpiles, so the stockpiles were blended with a front-end loader prior to paving of trial sections on May 30, 1997. The "P7" mixture design was used for paving on May 30, 1997.

After paving the top lift of the trial sections on May 30, 1997, five samples were taken per stockpile and sieve analyses were performed. The test results indicated some non-uniformity of the coarse stockpiles and a visual inspection suggested that quantities of materials in the stockpiles were not adequate to complete the project. Additional material was imported to the hot-mix production facility area at Patrick.

A mixture design designated as "T1" was completed on June 6, 1997, based on the average gradation of the mixture (determined by ignition oven) placed on May 30, 1997. The mix design resulted in a high percentage of voids in the mineral aggregate (VMA). Drain down of this mixture was also noted in the field during the May 30, 1997, production and placement.

On June 7, 1997, additional material was imported and each stockpile was thoroughly blended. When the blending operation was completed, ten samples were taken from each stockpile and sieve analyses were performed. Granite Construction and the University of Nevada performed five sieve analyses per stockpile. Independent samples were taken by each laboratory.

The mixture design completed on June 12, 1997, was based on the aggregate stockpiles and their gradations obtained on June 7, 1997. The new mixture design was designated as "F" and was used for construction of the test lane sections on the track.

Based on the sieve analyses conducted on the material sampled on June 7, 1997, additional blending of the stockpiles was performed by a front-end loader. This blending was performed prior to placement of the third set of trial sections on June 17, 1997. No additional material or blending was performed on the stockpiles after June 17, 1997. The test lane sections were placed on the track on June 23 and 28, 1997, as shown in table 4. The stockpile blends for the various mixture designs are shown in table 5.

TEST METHODS

The test methods used to obtain samples, perform gradations, and determine the physical properties of the aggregates are shown in table 6.[5] Results of these tests are provided below for the preconstruction samples. The gradations performed during the quality control testing on the cold-feed samples are presented in WesTrack Technical Report UNR-23.[6]

TEST RESULTS

As indicated above, the aggregate stockpiles were sampled prior to construction for mixture design purposes. These samples also were used to determine physical properties as required by the Superpave volumetric mixture design method. Samples also were taken during construction at the "cold-feed" and from the aggregate stockpiles. The cold-feed samples were used to determine gradations for quality control purposes. Portions of both the cold-feed samples and the aggregate stockpile samples obtained during construction have been stored at FHWA's Materials Reference Library in Reno.

Aggregate physical property measurements obtained on preconstruction stockpile samples are presented below. The sampling date and the stockpile designations are identified for all properties.

STOCKPILE GRADATIONS

Gradations of the Lockwood aggregate 3/4-in., 1/2-in., 3/8-in., and rock dust stockpiles are shown in appendix A for each sampling date. Variability information is included in these gradation summary sheets. Table 7 shows the combined gradations of the stockpiles used for mixture design purposes. Stockpile blend percentages are shown in table 5.

SPECIFIC GRAVITY

The bulk (dry) specific gravity of the aggregate was used to calculate volumetric parameters for mixture design purposes and for field quality control and quality assurance purposes. VMA and percent voids filled with asphalt (VFA) were calculated from the bulk (dry) specific gravity (Gsb) of the aggregate in the HMA.

Determination of the bulk specific gravity of the aggregate was performed according to AASHTO T 85 (ASTM C 127) for coarse aggregate and AASHTO T 84 (ASTM C 128) for fine aggregate. These test methods allow for determination of apparent, bulk (dry) and bulk (saturated, surface-dried) specific gravities, as well as the absorption capacity of the coarse and fine aggregate.

The specific gravity and absorption capacity test data are shown in tables 8 through 12 and in appendix B. Table 8 contains bulk (dry) specific gravity information for each stockpile as sampled on three dates prior to construction of the test lane sections at WesTrack. Tables 9 and 10 contain the apparent specific gravity and the absorption capacity information for the stockpile samples from these same sample dates.

Table 11 shows the bulk (dry) specific gravity for the coarse and fine fraction of the various aggregate blends used for the three primary mixture designs developed for the replacement sections. The combined bulk (dry) specific gravity, apparent specific gravity, and water absorption capacity for the aggregates used with the mixture designs are shown in table 12.

COARSE AGGREGATE ANGULARITY

Coarse aggregate angularity is a "consensus aggregate" property requirement in the Superpave volumetric mixture design method.[5] The coarse aggregate angularity was determined by the University of Nevada, according to the Pennsylvania Department of Transportation Test Method 621, on preconstruction samples. Results are shown in table 13 for the various aggregate stockpiles sampled on the dates shown. Variability data for the three replicate samples are shown in appendix C. According to the data reported in these tables, the counts of one and two fractured faces exceeded 95 percent and met the requirements for the Superpave volumetric mixture design (table 14) for 30 million ESALs.

Table 16 shows the calculated coarse aggregate angularity values for the aggregate blends that were used for the three primary mixture designs for the replacement sections at WesTrack. The calculations are shown in appendix C.

FINE AGGREGATE ANGULARITY

Fine aggregate angularity is a "consensus aggregate" property requirement in the Superpave volumetric mixture design method.[5] The fine aggregate angularity was determined by the University of Nevada, according to AASHTO Test Method TP 33, on preconstruction samples. Results are shown in table 13 for the various aggregate stockpiles sampled on the dates shown. Variability data for the three replicate samples are shown in appendix C. According to the data reported, the Lockwood rock dust has a fine aggregate angularity value that exceeds the minimum value of 45 (table 14) that is required by the Superpave volumetric mixture design method.

Table 16 shows the calculated fine aggregate angularity values for the aggregate blends that were used for the three primary mixture designs for the replacement sections at WesTrack. The calculations are shown in Appendix C.

FLAT AND ELONGATED PARTICLES

Flat and elongated particle count for coarse aggregates is a "consensus aggregate" property requirement in the Superpave volumetric mixture design method.[5] The flat and elongated particle count was determined by the University of Nevada, according to the ASTM D 4791 Test Method, on preconstruction samples. Results are shown in table 15 for the various aggregate stockpiles sampled during the dates shown. Variability data for the three replicate samples are shown in appendix C. According to the data reported, the flat and elongated particle count does not exceed the Superpave volumetric design procedure maximums (table 14).

Table 16 shows the calculated flat and elongated particle count values for the aggregate blends that were used for the three primary mixture designs for the replacement sections at WesTrack. The calculations are shown in appendix C.

SAND EQUIVALENT

The sand equivalent value (clay content) is a "consensus aggregate" property requirement in the Superpave volumetric mixture design method.[5] The sand equivalent value was determined by the University of Nevada, according to AASHTO T 176, on preconstruction samples. Results are shown in table 15 for the various aggregate stockpiles sampled during the dates shown. Variability data for the three replicate samples are shown in appendix C. According to the data reported, the sand equivalent value does not exceed the Superpave volumetric design procedure limits (table 14).

Table 16 shows the calculated sand equivalent value for the aggregate blends that were used for the three primary mixture designs for the replacement sections at WesTrack. The calculations are shown in appendix C.

SPECIAL TEST

The University of Nevada School of Mines determined the fractal dimension of the aggregates used on WesTrack. "Fractal" is a term used in geometry to describe an object the shape of which is intermediate between topological ideals. The fractal dimension describes the deviation that a line, surface, or volume has from a topological ideal. In general, a large fractal dimension for an aggregate indicates that the aggregate has a larger surface texture.[7]

Table 17 contains information that describes fractal dimensions that are typical for selected shapes.[5] Fractal dimensions for the Lockwood aggregate are shown in table 18. Information is provided for the 3/4-in., 1/2-in., 3/8-in., and rock dust stockpiles. These data indicate that the Lockwood aggregate has a fairly rough surface texture. The fractal data indicate that the Dayton aggregate has a rougher surface texture.

SUMMARY

Physical properties of the aggregates used in the HMA for the replacement sections at WesTrack were determined on preconstruction samples. Information contained in appendix A shows the gradation of the aggregate stockpiles used for construction. Table 12 contains the bulk (dry) specific gravity for the combined aggregate used for volumetric calculations (mixture design, quality control, and quality assurance testing) associated with the replacement sections at WesTrack. Table 16 contains physical property data on the Lockwood aggregates used for the replacement sections. The consensus aggregate properties measured on the replacement section aggregates meet the traffic requirements for less than 30 million ESALs. The estimated WesTrack 20-year ESAL equivalent is on the order of 20 to 30 million.

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Table 1. Geologic description of aggregate – replacement sections.

Aggregate	Geologic Description
Lockwood 3/4-in. to Rock Dust	Unweathered, to slightly weathered, fine-grained andesite (volcanic).
Patrick Sand	Decomposed granite composed of weathered fragments of mica and feldspar, with rounded quartz grains; clean, few fines.

Table 2. WesTrack rehabilitation schedule.
May 1997

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
4	5	6	7	8	9 UNR TBE mix designs completed.	10
11	12 Huntway cannot supply binder hot plant visit.	13	14	15	16	17
18 Idaho asphalt concrete (AC) arrives.	19	20 Hot plant visit.	21 Stop trafficking. Postmortem monitoring and sampling begins.	22 Postmortem monitoring and sampling.	23 Trial lane paving - bottom lift.	24
25	26	27 Postmortem monitoring and sampling.	28 Postmortem monitoring and sampling.	29 Data review meeting (May 23, 1997 results).	30 Trial lane paving - top lift.	31

Table 2. WesTrack rehabilitation schedule (continued).

June 1997

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3 Data review meeting (May 28, 1997 results).	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20 Trial mix paving (day 3).	21
22 Data review meeting (June 20, 1997 data).	23 Test lane bottom lift paving.	24	25	26	27 Data review meeting (June 23, 1997 data).	28 Test lane top lift paving.
29	30					

Table 3. Summary of HMA gyratory mix designs – Lockwood aggregates.

Mix Design Designation	Date of Mix Design	Asphalt Cement Source	Aggregate Sampling Date	Comments
FHWA	03-28-97	Huntway	03-14-97	• Stockpiles sampled at Lockwood. • Cone crusher, not vertical shaft impact crusher.
UNR - TBE	04-29-97 05-06-97 05-09-97	Huntway Huntway Huntway	04-14-97 04-14-97 04-14-97	• Stockpiles sampled at Lockwood. • Vertical impact crusher in place. • Selected blend gradation. • Determined influence of minus #200 material.
UNR - TBE	05-20-97	Idaho AC	04-14-97	• Stockpiles sampled at Lockwood.
UNR - P7	05-28-97	Idaho AC	05-23-97	• Stockpiles sampled at Patrick.
UNR - T1	06-06-97	Idaho AC	05-30-97	• Stockpiles sampled at Patrick. • Used 05-30-97 core ignition gradation.
UNR - F	06-12-97	Idaho AC	06-07-97	• Stockpiles sampled at Patrick. • Selected blend gradation. • Determined influence of minus #200 material.

Table 4. Aggregate samples and test lane sections.

Asphalt Binder Sampling Date	Lane-Lift Paved	Section Number	Mixture Designation
06-23-97	Test lane bottom lift	35, 36, 37, 38, 39, 54, 55, 56	Coarse replacement
06-28-97	Test lane top lift	35, 36, 37, 38, 39, 54, 55, 56	Coarse replacement

Table 5. Stockpile blends for mixture designs.*

Stock Designations	Mix Design Designation		
	TBE	**P7**	**F**
3/4-in.	28.0	25.0	24.0
1/2-in.	10.0	13.5	15.5
3/8-in.	31.5	30.5	27.5
Rock Dust	29.0	29.5	31.5
Hydrated Lime	1.5	1.5	1.5

*Mix design "F" was the final mixture design selected for the replacement sections.

Table 6. WesTrack aggregate test procedures.

Designations	Description
AASHTO T2	Sampling aggregates.
AASHTO T11	Amount of material finer than the No. 200 sieve.
AASHTO T27	Sieve analysis of fine and coarse aggregate.
AASHTO T30	Mechanical analysis of extracted aggregate.
AASHTO T37	Sieve analysis of mineral filler for road and paving materials.
AASHTO T84	Specific gravity and absorption of fine aggregate.
AASHTO T85	Specific gravity and absorption of coarse aggregate.
AASHTO T89	Determination of liquid limit.
AASHTO T90	Determination of plastic limit and plastic index of soils.
AASHTO T96	Resistance to degradation by L.A. machine.
AASHTO T104	Soundness of aggregate by use of sodium sulfate or magnesium sulfate.
AASHTO T176	Plastic fines in graded aggregates and soils by the sand equivalent test.
AASHTO T248	Reducing field samples of aggregate to testing size.
AASHTO TP33	Uncompacted void content of fine aggregate.
ASTM D4791	Flat or elongated particles in coarse aggregates.
Penn DOT 621	Determination of percent crushed faces (CA angularity).

Table 7. HMA blends in chronological order.

Sieve Size (US)	Sieve Size (mm)	Blend ID (Cumulative Percent Passing)				
		FHWA (04-03-97)	TBE (04-29-97)	P7 (05-23-97)	T1 (06-06-97)	F (06-12-97)
1-in.	25	100.0	100.0	100.0	100.0	100.0
3/4-in.	19	100.0	100.0	99.5	99.9	99.2
1/2-in.	12.5	83.0	83.2	83.3	86.7	82.8
3/8-in.	9.5	67.4	66.8	68.1	71.7	69.5
No. 4	4.75	42.5	37.6	38.4	39.6	41.4
No. 8	2.36	26.7	24.4	24.1	23.9	25.6
No. 16	1.18	17.2	16.6	16.4	15.9	16.8
No. 30	0.60	11.6	11.9	11.8	11.5	12.1
No. 50	0.30	8.8	9.0	8.9	8.7	9.1
No. 100	0.15	7.0	7.1	7.2	6.8	7.2
No. 200	0.075	4.7	5.8	5.8	5.4	5.8

Table 8. Chronological summary of HMA stockpile aggregate bulk specific gravity determinations.

Property	Sampling Location	Sampling Date	Tech	Stockpile	Average Measured Value	STD	COV	Range	Number of Observations
Bulk Specific Gravity	Lockwood	04-14-97	TO	3/4-in.	2.644	0.001	0.0	0.002	3
				1/2-in.	2.633	0.002	0.1	0.003	3
				3/8-in.	2.628	0.004	0.2	0.010	3
			TO	RD	2.538	0.008	0.3	0.013	3
	Patrick	05-23-97	BH	3/4-in.	2.623	0.003	0.1	0.007	3
				1/2-in.	2.606	0.002	0.1	0.003	3
				3/8-in.	2.602	0.008	0.3	0.020	3
			TO	RD	2.498	0.008	0.3	0.018	3
	Patrick	06-07-97	WC	3/4-in.	2.624	0.012	0.4	0.029	5
				1/2-in.	2.635	0.021	0.8	0.055	5
				3/8-in.	2.544	0.142	5.6	0.343	5
			TO	RD	2.485	0.025	1.0	0.070	5

Table 9. Chronological summary of HMA stockpile aggregate – apparent specific gravity determinations.

Property	Sampling Location	Sampling Date	Tech	Stockpile	Average Measured Value	STD	COV	Range	Number of Observations
Apparent Specific Gravity	Lockwood	04-14-97	TO	3/4-in.	2.783	0.002	0.1	0.004	3
				1/2-in.	2.784	0.002	0.1	0.004	3
				3/8-in.	2.788	0.005	0.2	0.007	3
			TO	RD	2.783	0.013	0.5	0.031	3
	Patrick	05-23-97	BH	3/4-in.	2.770	0.000	0.0	0.001	3
				1/2-in.	2.769	0.004	0.1	0.010	3
				3/8-in.	2.777	0.004	0.1	0.008	3
			TO	RD	2.498	0.004	0.1	0.009	3
	Patrick	06-07-97	WC	3/4-in.	2.778	0.002	0.1	0.006	5
				1/2-in.	2.760	0.006	0.2	0.011	5
				3/8-in.	2.767	0.010	0.4	0.025	5
			TO	RD	2.775	0.011	0.4	0.035	5

Table 10. Chronological summary of HMA stockpile aggregate – water absorption determinations.

Property	Sampling Location	Sampling Date	Tech	Stockpile	Average Measured Value	STD	COV	Range	Number of Observations
Water Absorption	Lockwood	04-14-97	TO	3/4-in.	1.89	0.01	0.7	0.02	3
				1/2-in.	2.07	0.02	0.8	0.04	3
				3/8-in.	2.17	0.10	4.4	0.22	3
			TO	RD	3.48	0.05	1.4	0.11	3
	Patrick	05-23-97	BH	3/4-in.	2.02	0.05	2.4	0.84	3
				1/2-in.	2.25	0.06	2.5	0.13	3
				3/8-in.	2.41	0.14	5.9	0.32	3
			TO	RD	4.09	0.13	3.2	0.30	3
	Patrick	06-07-97	WC	3/4-in.	2.11	0.19	8.8	0.50	5
				1/2-in.	1.73	0.34	19.6	0.97	5
				3/8-in.	2.09	0.24	11.6	0.64	5
			TO	RD	4.25	0.38	9.0	1.07	5

Table 11. Chronological summary of HMA blend aggregate – specific gravity and absorption determinations.

Property	Sampling Location	Sampling Date	Blend	Tech	Fraction	Average Measured Value	STD	COV	Range	Number of Observations
Bulk Specific Gravity	Lockwood	04-14-97	TBE	TO	+#4	2.636	0.002	0.1	0.005	3
				TO	-#4	2.511	0.007	0.3	0.017	3
	Patrick	05-23-97	P7	BH	+#4	2.640	0.002	0.1	0.004	3
				TO	-#4	2.511	0.008	0.3	0.019	3
	Patrick	06-07-97	F	WC	+#4	2.625	0.002	0.1	0.005	3
				TO	-#4	2.527	0.007	0.3	0.016	3
Apparent Specific Gravity	Lockwood	04-14-97	TBE	TO	+#4	2.791	0.001	0.0	0.003	3
				TO	-#4	2.808	0.005	0.2	0.013	3
	Patrick	05-23-97	P7	BH	+#4	2.781	0.001	0.0	0.003	3
				TO	-#4	2.778	0.003	0.1	0.007	3
	Patrick	06-07-97	F	WC	+#4	2.777	0.004	0.2	0.010	3
				TO	-#4	2.784	0.007	0.3	0.017	3
Water Absorption	Lockwood	04-14-97	TBE	TO	+#4	2.11	0.02	0.8	0.04	3
				TO	-#4	4.20	0.06	1.4	0.13	3
	Patrick	05-23-97	P7	BH	+#4	1.92	0.04	1.9	0.09	3
				TO	-#4	3.82	0.11	2.9	0.26	3
	Patrick	06-07-97	F	WC	+#4	2.09	0.03	1.2	0.06	3
				TO	-#4	3.65	0.17	4.8	0.30	3

Table 12. Combined specific gravities of Lockwood aggregate.

Property	Sample Location	Sample Date	Blend	Combined Specific Gravity
Bulk Specific Gravity	Lockwood	04-14-97	TBE	2.600
	Patrick	05-23-97	P7	2.571
	Patrick	06-07-97	F	2.553*
Apparent Specific Gravity	Lockwood	04-14-97	TBE	2.776
	Patrick	05-23-97	P7	2.767
	Patrick	06-07-97	F	2.763
Water Absorption	Lockwood	04-14-97	TBE	2.32
	Patrick	05-23-97	P7	2.57
	Patrick	06-07-97	F	2.41

*Mixture design "F" utilized a combined bulk specific gravity of 2.599.

Table 13. Chronological summary of HMA stockpile aggregate – coarse and fine aggregate angularity determinations.

Property	Sampling Location	Sampling Date	Tech	Stockpile	Average Measured Value	STD	COV	Range	Number of Observations
Coarse Aggregate Angularity	Lockwood	04-14-97	TO	3/4-in.	100 / 100	0.06 / 0.06	0.06 / 0.06	0.1 / 0.1	3
				1/2-in.	100 / 99.8	0.00 / 0.32	0.00 / 0.32	0.0 / 0.6	3
				3/8-in.	100 / 99.8	0.00 / 0.29	0.00 / 0.29	0.0 / 0.5	3
	Patrick	05-23-97	WC	3/4-in.	93.4 / 92.0	1.84 / 3.08	1.97 / 3.35	4.4 / 5.9	3
				1/2-in.	94.8 / 93.8	1.05 / 1.48	1.11 / 1.58	2.1 / 3.7	3
				3/8-in.	96.2 / 95.0	1.01 / 0.86	1.05 / 0.91	2.0 / 1.7	3
	Patrick	06-07-97	WC	3/4-in.	92.9 / 90.9	3.69 / 1.76	3.97 / 1.94	6.9 / 3.4	3
				1/2-in.	94.5 / 92.9	1.45 / 1.42	1.53 / 1.53	2.9 / 2.8	3
				3/8-in.	99.1 / 98.8	0.41 / 0.41	0.41 / 0.42	0.7 / 0.8	3
Fine Aggregate Angularity	Lockwood	04-14-97	TO	RD	46.9	0.1	0.3	0.3	3
	Patrick	05-23-97	WC	RD	45.6	0.4	0.8	0.9	3
	Patrick	06-07-97	WC	RD	45.5	0.6	1.3	1.3	3

Table 14. Superpave aggregate requirements.

Aggregate Property		Test Method	Superpave Requirements			
			3-10 Million ESAL		10-30 Million ESAL	
Type	**Description**		**<100 mm***	**>100 mm**	**<100 mm**	**>100 mm**
Consensus	Coarse aggregate angularity	Penn DOT 621 ASTM D 5821	85/80**	60/-	95/90	80/75
	Fine aggregate angularity	AASHTO TP33	45	40	45	40
	Flat and elongated particles	ASTM D 4791	10		10	
	Clay content (sand equivalent)	AASHTO T176	45		45	
Source	Toughness (L.A. abrasion)	AASHTO T96				
	Soundness	AASHTO T104				
	Deleterious materials (clay lumps and friable particles)	AASHTO T112				

* Depth of hot-mix asphalt layer.
**One and two fractured face requirements.

Table 15. Chronological summary of HMA stockpile aggregate – flat and elongated particles and sand-equivalent determinations.

Property	Sampling Location	Sampling Date	Tech	Stockpile	Average Measured Value	STD	COV	Range	Number of Observations
Flat and Elongated Particles	Lockwood	04-14-97	TO	3/4-in.	0.02	0.01	74.8	0.03	3
				1/2-in.	0.03	0.01	27.2	0.02	3
				3/8-in.	0.01	0.02	141.4	0.04	3
	Patrick	05-23-97	WC	3/4-in.	0.41	0.24	59.0	0.56	3
				1/2-in.	0.20	0.28	141.4	0.60	3
				3/8-in.	0.00	0.00	0.0	0.00	3
	Patrick	06-07-97	WC	3/4-in.	0.00	0.00	0.00	0.00	3
				1/2-in.	0.24	0.17	70.9	0.37	3
				3/8-in.	0.00	0.00	0.00	0.00	3
Sand Equivalent	Lockwood	04-14-97	TO	RD	64.0	0.8	1.3	2.0	3
	Patrick	05-23-97	WC	RD	61.0	4.5	7.5	11.0	3
	Patrick	06-07-97	WC	RD	66.3	1.9	2.8	4.0	3

Table 16. Chronological summary of HMA blend – coarse and fine aggregate angularity, flat and elongated particles, and sand-equivalent determinations.

Property	Sampling Location	Sampling Date	Blend	Tech	Fraction	Average Measured Value	STD	COV	Range	Number of Observations
Coarse Aggregate Angularity	Lockwood	04-14-97	TBE	TO	+#4	99.9 / 99.9	0.10 / 0.10	0.1 / 0.1	0.2 / 0.2	3
	Patrick	05-23-97	P7	WC	+#4	85.7 / 84.5	7.1 / 7/6	8.3 / 9.0	13.3 / 14.6	3
	Patrick	06-07-97	F	WC	+#4	81.3 / 78.8	3.6 / 4.5	4.4 / 5.7	11.9 / 10.3	3
Fine Aggregate Angularity	Lockwood	04-14-97	TBE	TO	-#8	46.1	0.2	0.4	0.4	3
	Patrick	05-23-97	P7	TO	-#8	46.3	0.2	0.5	0.5	3
	Patrick	06-07-97	F	WC	-#8	46.2	0.2	0.4	0.5	3
Flat and Elongated Particles	Lockwood	04-14-97	TBE	TO	+#4	0.0	0.0	0.0	0.0	3
	Patrick	05-23-97	P7	WC	+#4	0.0	0.0	0.0	0.0	3
	Patrick	06-07-97	F	TO	+#4	0.1	0.2	141.4	0.43	3
Sand Equivalent	Lockwood	04-14-97	TBE	TO	-#4	67.0	0.47	0.7	1.0	3
	Patrick	05-23-97	P7	WC	-#4	73.0	0.56	0.8	1.0	3
	Patrick	06-07-97	F	TO	-#4	73.0	1.93	2.6	5.0	3

Table 17. Average fractal dimensions for typical aggregate shapes.

Description of Aggregate	No. of Sample Evaluated	Average Fractal Dimension*
Rounded	10	1.052
Rectangular	12	1.120
Square	2	1.068
Triangular	5	1.110
Elongated	1	1.00

*Relates to texture of aggregate surface; larger fractal dimension implies greater surface texture.

Table 18. Fractal dimensions – replacement sections.

Aggregate	Fractal Dimension*	
	Average	Range
Lockwood 3/4-in.	1.14	1.073-1.231
Lockwood 1/2-in.	1.11	1.040-1.140
Lockwood 3/8-in.	1.07	1.040-1.140
Lockwood Rock Dust	1.10	1.030-1.233

*Relates to texture of aggregate surface; larger fractal dimension implies greater surface texture.

APPENDIX A

AGGREGATE GRADATION

Table 1x: 3/4" HMA aggregate stockpile gradations, April 14, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: Lockwood 3/4" - Sampled @ Lockwood (4-14-97) - New VSI's
Other: 5 Samples
Date: 4-16-97 Technician: DR / AH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	42.4	38.7	45.5	38.0	37.9	40.5	3.0	7.4	7.6
3/8"	5.3	3.9	7.7	4.3	4.5	5.2	1.4	26.7	3.8
#4	0.6	0.5	0.6	0.9	0.8	0.7	0.2	22.0	0.4
#8	0.4	0.4	0.3	0.7	0.7	0.5	0.1	27.8	0.4
#16	0.4	0.4	0.3	0.5	0.7	0.4	0.1	32.1	0.4
#30	0.3	0.3	0.2	0.4	0.6	0.4	0.1	35.0	0.4
#50	0.3	0.3	0.2	0.4	0.6	0.4	0.1	36.3	0.4
#100	0.3	0.3	0.2	0.4	0.6	0.3	0.1	39.2	0.4
#200	0.3	0.3	0.1	0.3	0.5	0.3	0.1	44.0	0.4

Table x2: 1/2" HMA aggregate stockpile gradations, April 14, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: Lockwood 1/2" - Sampled @ Lockwood (4-14-97) - New VSI's
Other: 5 Samples
Date: 4-16-97 Technician: DR / AH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Sample 6 Percent Passing	Sample 7 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	98.5	98.6	98.7	99.4	99.1	99.0	98.5	98.8	0.3	0.3	0.8
3/8"	38.7	39.2	33.5	35.2	30.8	40.6	38.8	36.7	3.3	9.0	9.8
#4	0.8	0.8	0.9	0.7	0.4	0.8	0.9	0.8	0.2	20.1	0.5
#8	0.7	0.6	0.8	0.5	0.3	0.7	0.7	0.6	0.1	24.0	0.5
#16	0.6	0.5	0.7	0.4	0.3	0.6	0.7	0.5	0.1	26.2	0.5
#30	0.6	0.4	0.7	0.4	0.2	0.6	0.6	0.5	0.1	27.3	0.4
#50	0.5	0.4	0.6	0.4	0.2	0.6	0.6	0.5	0.1	28.6	0.4
#100	0.5	0.3	0.6	0.3	0.2	0.6	0.5	0.4	0.1	30.5	0.4
#200	0.5	0.3	0.6	0.3	0.2	0.5	0.5	0.4	0.1	33.2	0.4

Table x3: 3/8" HMA aggregate stockpile gradations, April 14, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: Lockwood 3/8" - Sampled @ Lockwood (4-14-97) - New VSI's
Other: 5 Samples
Date: 4-16-97 Technician: DR / AH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0		100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0		100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	100.0		100.0	100.0	99.8	99.9	0.1	0.1	0.2
3/8"	99.2		98.9	99.4	99.1	99.1	0.2	0.2	0.5
#4	26.6		20.8	20.7	22.1	22.6	2.4	10.6	5.9
#8	1.6		1.5	1.0	1.4	1.4	0.2	14.8	0.5
#16	0.6		1.0	0.4	0.6	0.6	0.2	31.6	0.6
#30	0.5		0.9	0.3	0.5	0.5	0.2	37.7	0.6
#50	0.4		0.8	0.2	0.5	0.5	0.2	43.3	0.6
#100	0.4		0.8	0.2	0.4	0.4	0.2	47.6	0.6
#200	0.3		0.7	0.1	0.4	0.4	0.2	54.0	0.6

Table 4x: Rockdust HMA aggregate stockpile gradations, April 14, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: Lockwood Rock Dust - Sampled @ Lockwood (4-14-97) - New VSI's
Other: 5 Samples
Date: 4-16-97 Technician: AH/DV

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/8"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
#4	99.0	99.0	98.9	98.8	99.1	99.0	0.1	0.1	0.3
#8	76.5	78.1	77.9	75.9	75.0	76.7	1.2	1.6	3.2
#16	50.3	51.9	53.1	50.5	47.9	50.7	1.7	3.4	5.2
#30	34.6	35.9	36.5	34.6	32.7	34.8	1.3	3.7	3.8
#50	24.8	25.7	25.6	24.4	23.4	24.8	0.8	3.4	2.3
#100	18.9	19.6	19.9	19.0	17.9	19.1	0.7	3.7	2.1
#200	14.9	15.3	15.8	14.9	14.2	15.0	0.5	3.5	1.6

Table 5x: 3/4" HMA aggregate stockpile gradations, May 23, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: Lockwood 3/4" - Sampled @ Patrick (5-23-97)
Other: 5 Samples
Date: 5-26-97 Technician: ZE / BH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	99.6	98.4	98.2	98.4	98.5	98.6	0.5	0.5	1.4
1/2"	35.1	34.8	33.3	35.7	34.0	34.6	0.8	2.4	2.4
3/8"	5.9	5.1	5.0	5.9	5.2	5.4	0.4	7.5	0.9
#4	1.5	2.0	1.2	1.4	1.5	1.5	0.3	17.7	0.8
#8	1.1	1.8	1.0	1.3	1.1	1.3	0.3	21.5	0.8
#16	1.0	1.6	0.8	1.1	1.0	1.1	0.3	24.6	0.8
#30	0.9	1.6	0.8	1.0	0.9	1.0	0.3	26.7	0.8
#50	0.8	1.5	0.7	1.0	0.8	1.0	0.3	28.2	0.8
#100	0.8	1.4	0.7	0.9	0.8	0.9	0.3	29.4	0.8
#200	0.7	1.4	0.6	0.9	0.7	0.9	0.3	32.2	0.8

Table 6x: 1/2" HMA aggregate stockpile gradations, May 23, 1997 sampling.

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood 1/2" - Sampled @ Patrick (5-23-97)**
Other: **5 Samples**
Date: **5-26-97** Technician: **ZE / BH**

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	99.1	99.4	99.2	99.7	100.0	99.5	0.3	0.3	0.9
3/8"	43.6	46.0	41.9	59.2	54.9	49.1	6.7	13.7	17.3
#4	1.9	1.8	1.6	1.8	1.9	1.8	0.1	6.6	0.4
#8	1.5	1.4	1.3	1.3	1.4	1.4	0.1	5.2	0.2
#16	1.3	1.2	1.2	1.1	1.2	1.2	0.1	5.5	0.2
#30	1.2	1.1	1.1	1.0	1.1	1.1	0.1	5.7	0.2
#50	1.1	1.1	1.0	0.9	1.0	1.0	0.1	5.5	0.2
#100	1.0	1.0	1.0	0.9	1.0	1.0	0.0	4.3	0.1
#200	0.9	1.0	0.9	0.9	0.9	0.9	0.0	3.2	0.1

Table 7x: 3/8" HMA aggregate stockpile gradations, May 23, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: Lockwood 3/8" - Sampled @ Patrick (5-23-97)
Other: 5 Samples
Date: 5-26-97 Technician: ZE / BH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/8"	97.4	96.7	95.6	97.2	97.6	96.9	0.7	0.7	1.9
#4	28.2	31.7	23.8	24.2	20.7	25.7	3.8	14.8	11.0
#8	4.0	7.0	4.0	2.6	2.6	4.1	1.6	40.1	4.5
#16	2.5	3.2	1.9	2.0	1.9	2.3	0.5	21.8	1.3
#30	2.1	2.1	1.4	1.8	1.8	1.9	0.3	13.7	0.7
#50	1.9	1.7	1.3	1.7	1.7	1.7	0.2	12.4	0.6
#100	1.8	1.4	1.2	1.6	1.7	1.5	0.2	13.7	0.6
#200	1.6	1.1	1.1	1.5	1.6	1.4	0.2	16.4	0.5

Table 8x: Rockdust HMA aggregate stockpile gradations, May 23, 1997 sampling.

Project: WesTrack Rebabilitation
Aggregate Source: Lockwood Rock Dust - Sampled @ Patrick (5-23-97)
Other: 5 Samples
Date: 5-26-97 Technician: ZE / BH

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/8"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
#4	98.9	98.8	99.5	99.0	98.8	99.0	0.3	0.3	0.7
#8	71.8	73.8	76.3	73.6	72.0	73.5	1.6	2.2	4.6
#16	47.7	50.6	53.7	47.8	49.0	49.8	2.2	4.5	6.0
#30	33.2	35.7	38.6	33.5	34.6	35.1	2.0	5.6	5.4
#50	24.1	26.1	28.4	24.6	25.2	25.7	1.5	5.9	4.3
#100	19.3	20.9	22.5	19.2	20.0	20.4	1.2	6.0	3.3
#200	16.0	17.1	18.0	15.9	16.2	16.6	0.8	4.9	2.1

Table 9x: 3/4" HMA aggregate stockpile gradations, May 30, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: 3/4" Lockwood - Sampled @ Patrick (5-30-97)
Other: 5 Samples
Date: 5-31-97 Technician: ZE

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	98.4	99.1	97.0	98.1	97.9	98.1	0.7	0.7	2.0
1/2"	29.9	39.6	31.9	33.8	30.0	33.0	3.6	10.8	9.7
3/8"	7.8	6.8	4.0	5.1	4.9	5.7	1.4	24.6	3.9
#4	3.2	1.6	1.3	1.3	1.4	1.8	0.7	40.5	1.9
#8	2.2	1.1	1.1	1.0	1.2	1.3	0.4	32.7	1.2
#16	1.9	1.0	1.0	0.9	1.2	1.2	0.4	30.1	1.0
#30	1.7	0.9	1.0	0.8	1.1	1.1	0.3	29.4	0.9
#50	1.7	0.8	0.9	0.8	1.1	1.1	0.3	29.5	0.8
#100	1.6	0.8	0.9	0.8	1.0	1.0	0.3	30.0	0.8
#200	1.5	0.7	0.8	0.7	0.9	0.9	0.3	31.4	0.8

Table 10x: 1/2" HMA aggregate stockpile gradations, May 30, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: 1/2" Lockwood - Sampled @ Patrick (5-30-97)
Other: 5 Samples
Date: 5-31-97 Technician: ZE

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	98.7	98.6	95.7	99.4	99.8	98.4	1.4	1.5	4.1
3/8"	36.1	30.2	33.4	30.0	29.9	31.9	2.5	7.7	6.2
#4	1.8	2.2	2.2	2.2	1.8	2.0	0.2	9.7	0.5
#8	1.4	1.7	1.8	1.9	1.7	1.7	0.2	9.7	0.5
#16	1.3	1.5	1.7	1.7	1.6	1.6	0.2	10.5	0.5
#30	1.2	1.4	1.6	1.6	1.5	1.5	0.2	11.5	0.4
#50	1.1	1.3	1.6	1.6	1.5	1.4	0.2	12.6	0.4
#100	1.0	1.2	1.5	1.5	1.5	1.3	0.2	13.7	0.5
#200	0.9	1.1	1.4	1.4	1.4	1.2	0.2	15.0	0.5

Table 11x: 3/8" HMA aggregate stockpile gradations, May 30, 1997 sampling.

Project: **WesTrack Rehabilitation**
Aggregate Source: **3/8" Lockwood - Sampled @ Patrick (5-30-97)**
Other: **5 Samples**
Date: **5-30-97 Sampling** Technician: **ZE**

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/8"	97.7	97.5	97.1	96.6	95.2	96.8	0.9	0.9	2.5
#4	30.5	26.2	28.3	25.1	26.3	27.3	1.9	7.0	5.4
#8	6.2	6.0	4.9	3.3	4.2	4.9	1.1	22.5	3.0
#16	2.7	3.3	2.8	1.7	2.6	2.6	0.5	19.2	1.6
#30	2.0	2.6	2.3	1.5	2.2	2.1	0.4	17.5	1.1
#50	1.7	2.2	2.0	1.4	2.0	1.9	0.3	15.6	0.8
#100	1.6	1.9	1.8	1.3	1.9	1.7	0.2	14.3	0.6
#200	1.4	1.6	1.6	1.1	1.7	1.5	0.2	13.8	0.6

Table 12x: Rockdust HMA aggregate stockpile gradations, May 30, 1997 sampling.

Project: **WesTrack Rehabilitation**
Aggregate Source: **Rockdust - Lockwood Sampled @ Patrick (5-30-97)**
Other: **5 Samples**
Date: **5-31-97** Technician: **ZE**

Sieve Size	Sample 1 Percent Passing	Sample 2 Percent Passing	Sample 3 Percent Passing	Sample 4 Percent Passing	Sample 5 Percent Passing	Average of All 5 Samples	Standard Deviation	Coefficient of Variation	Range
1"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/8"	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
#4	99.1	98.5	98.6	98.9	98.9	98.8	0.2	0.2	0.6
#8	72.5	72.8	73.6	74.0	76.1	73.8	1.3	1.7	3.6
#16	46.5	48.2	49.3	49.6	51.0	48.9	1.5	3.1	4.5
#30	32.1	33.8	35.1	35.2	36.1	34.5	1.4	4.0	4.0
#50	23.4	24.6	26.1	25.9	26.6	25.3	1.2	4.6	3.2
#100	18.2	18.9	20.4	20.1	20.7	19.7	1.0	4.9	2.5
#200	14.9	15.2	16.8	16.4	16.9	16.0	0.8	5.1	1.9

Table 13x: 3/4" HMA aggregate stockpile gradations, June 7, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: 3/4" Lockwood - Sampled @ Patrick (6-7-97)
Other: 10 Samples Lab: Granite and UNR
Date: 6-9-97 Technician:

Sieve Size	Sample ID					Sample ID					Average of All 10	Standard Deviation	Coefficient of Variation	Range
	1	3	5	7	9	2	4	6	8	10				
	Cumulative Percent Passing					Cumulative Percent Passing								
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	89.3	98.1	100.0	97.3	97.1	95.9	96.7	97.1	98.1	98.1	96.8	2.7	2.8	10.7
1/2"	30.8	28.7	38.3	27.3	27.0	26.0	27.7	28.2	29.2	30.8	29.4	3.3	11.3	12.3
3/8"	6.9	6.3	11.4	6.9	6.3	5.4	6.6	8.9	8.5	6.7	7.4	1.7	22.4	6.0
#4	3.4	2.8	4.5	3.5	2.1	1.8	2.7	3.2	4.2	2.3	3.0	0.8	27.4	2.7
#8	2.5	2.1	2.4	2.4	1.4	1.0	1.7	1.8	2.8	1.8	2.0	0.5	26.6	1.8
#16	2.0	1.8	1.9	1.9	1.2	0.9	1.3	1.5	2.3	1.5	1.6	0.4	25.2	1.4
#30	1.7	1.7	1.7	1.7	1.1	0.8	1.2	1.3	2.0	1.4	1.5	0.3	23.9	1.2
#50	1.5	1.5	1.6	1.5	1.0	0.7	1.0	1.2	1.8	1.3	1.3	0.3	24.3	1.1
#100	1.3	1.4	1.4	1.3	0.9	0.6	0.9	1.1	1.6	1.2	1.2	0.3	24.2	1.0
#200	1.1	1.2	1.3	1.1	0.8	0.5	0.8	1.0	1.5	1.1	1.0	0.3	25.8	1.0

Statistical Analysis of
Sieve Analysis of Coarse & Fine Aggregate
(ASTM C117 & C136)

Table 14x: 1/2" HMA aggregate stockpile gradations, June 7, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: 1/2" Lockwood - Sampled @ Patrick (6-7-97)
Other: 10 Samples Lab: Granite and UNR
Date: 6-9-97 Technician:

Sieve Size	Sample ID					Sample ID					Average of All 10	Standard Deviation	Coefficient of Variation	Range
	1	3	5	7	9	2	4	6	8	10				
	Cumulative Percent Passing					Cumulative Percent Passing								
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	99.8	100.0	99.9	99.6	99.6	99.1	99.5	99.0	99.6	99.3	99.5	0.3	0.3	0.9
3/8"	48.7	49.6	48.8	54.2	49.1	43.3	51.6	48.8	50.9	51.7	49.7	2.7	5.5	10.9
#4	0.9	1.6	1.9	2.4	1.7	1.1	1.5	2.6	1.7	2.8	1.8	0.6	32.3	1.9
#8	0.6	1.2	1.2	1.6	1.3	0.8	1.0	2.1	1.1	2.0	1.3	0.5	34.9	1.5
#16	0.6	1.0	1.1	1.3	1.1	0.7	0.8	1.8	1.0	1.7	1.1	0.4	33.8	1.2
#30	0.6	0.9	1.0	1.1	1.1	0.7	0.7	1.6	0.9	1.6	1.0	0.3	32.9	1.0
#50	0.5	0.8	0.9	0.9	1.0	0.7	0.5	1.5	0.8	1.5	0.9	0.3	35.6	1.0
#100	0.5	0.7	0.8	0.8	0.9	0.6	0.5	1.4	0.7	1.3	0.8	0.3	35.5	0.9
#200	0.4	0.6	0.7	0.6	0.8	0.5	0.4	1.3	0.6	1.2	0.7	0.3	40.3	0.9

Table 15x: 3/8" HMA aggregate stockpile gradations, June 7, 1997 sampling.

Project: WesTrack Rehabilitation
Aggregate Source: 3/8" Lockwood - Sampled @ Patrick (6-7-97)
Other: 10 Samples Lab: Granite and UNR
Date: 6-9-97 Technician:

Sieve Size	Sample ID					Sample ID					Average of All 10	Standard Deviation	Coefficient of Variation	Range
	1	3	5	7	9	2	4	6	8	10				
	Cumulative Percent Passing					Cumulative Percent Passing								
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/8"	99.7	99.7	100.0	98.6	99.6	99.9	99.4	99.3	99.1	99.7	99.5	0.4	0.4	1.4
#4	27.8	21.2	36.4	31.7	36.4	35.1	24.5	34.2	35.1	30.8	31.3	5.0	15.9	15.2
#8	3.6	2.4	6.5	5.7	5.2	4.7	2.4	6.2	6.0	4.1	4.7	1.4	30.6	4.1
#16	2.0	1.6	2.9	3.3	2.4	2.4	1.6	2.9	3.1	2.2	2.4	0.6	23.1	1.7
#30	1.6	1.4	2.2	2.5	1.9	2.0	1.5	2.3	2.5	1.8	2.0	0.4	19.8	1.2
#50	1.5	1.2	1.9	2.2	1.7	1.9	1.4	2.1	2.2	1.6	1.8	0.3	18.8	1.0
#100	1.4	1.1	1.7	2.0	1.6	1.8	1.4	1.9	1.9	1.4	1.6	0.3	17.4	0.9
#200	1.3	1.0	1.5	1.8	1.4	1.7	1.3	1.7	1.7	1.3	1.5	0.2	16.5	0.4

Table 16x: Rockdust HMA aggregate stockpile gradations, June 7, 1997 sampling.

Project: WesTrack Rehab
Aggregate Source: Rockdust Lockwood @ Patrick
Other: 10 Samples
Lab: Granite and UNR
Date: 6-7-97 Sampling
Technician:

Sieve Size	Sample ID					Sample ID					Average of All 10	Standard Deviation	Coefficient of Variation	Range
	1	3	5	7	9	2	4	6	8	10				
	Cumulative Percent Passing					Cumulative Percent Passing								
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
3/8"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
#4	97.6	98.1	98.7	99.1	99.0	98.3	98.0	98.9	99.0	98.8	98.5	0.5	0.5	1.5
#8	66.7	74.2	73.1	75.9	75.5	71.7	70.3	74.5	75.1	72.8	73.0	2.7	3.6	9.1
#16	41.7	50.3	47.6	51.4	51.4	46.6	45.2	49.0	48.9	47.0	47.9	2.8	5.9	9.7
#30	29.0	35.9	33.3	36.8	37.1	32.5	31.4	34.3	33.6	32.5	33.6	2.4	7.1	8.1
#50	21.5	26.6	24.6	27.3	27.8	24.0	22.8	25.1	24.5	23.8	24.8	1.9	7.6	6.3
#100	16.9	20.7	19.4	21.2	21.8	18.9	17.6	19.8	19.2	18.8	19.4	1.4	7.5	4.9
#200	13.7	16.5	15.8	17.0	17.6	15.2	13.6	16.2	15.6	15.1	15.6	1.2	7.9	2.6

Table 22: Trial Blend E (TBE), Blending Spreadsheet.

Project: WesTrack - 19mm NOMINAL SUPERPAVE GRADATION
Date: 4-19-97
Tech: AH/TO
Blend ID: Blend (TBE) (Based on 4-14-97 sampling)

SIEVE ANALYSIS DATA FOR BINS CONSIDERED

		Sieve Size in millimeters (mm)										
Bin No.		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
3/4"		100	100	40.5	5.2	0.7	0.5	0.4	0.4	0.4	0.3	0.3
1/2"		100	100	98.8	36.7	0.8	0.6	0.5	0.5	0.5	0.4	0.4
3/8"		100	100	99.9	99.1	22.6	1.4	0.6	0.5	0.5	0.4	0.4
RD		100	100	100	100	99.0	76.7	50.7	34.8	24.8	19.1	15.0
HL		100	100	100	100	100	100	100	99.8	97.2	90.2	81.3

BLENDING CALCULATIONS

		Sieve Size in millimeters (mm)										
Bin No.	% USE	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
3/4"	28.0	28.0	28.0	11.3	1.5	0.2	0.1	0.1	0.1	0.1	0.1	0.1
1/2"	10.0	10.0	10.0	9.9	3.7	0.1	0.1	0.1	0.1	0.1	0.0	0.0
3/8"	31.5	31.5	31.5	31.5	31.2	7.1	0.4	0.2	0.2	0.2	0.1	0.1
RD	29.0	29.0	29.0	29.0	29.0	28.7	22.2	14.7	10.1	7.2	5.5	4.4
HL	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.2
BLEND	100	100.0	100.0	83.2	66.8	37.6	24.4	16.6	11.9	9.0	7.1	5.8
SPEC - H		100.0	100.0	90.0			34.6	28.3	20.7	13.7		8.0
SPEC - L			90.0	49.0			34.6	22.3	16.7	13.7		2.0
OK ?		IN	IN	IN			OUT	OUT	OUT	OUT		IN
							23, 49	Restricted Zone				

Table 23: Trial blend P7, blending spreadsheet.

Project: WesTrack Rehab - 19mm nom. (Lockwood Material @ Patrick)
Date: 5-26-97
Tech: AH/JAE
Blend ID: P7 (Based on 5-23-97 sampling)

SIEVE ANALYSIS DATA FOR BINS CONSIDERED

		Sieve Size in millimeters (mm)										
Bin No.		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
3/4"		100	98.6	34.6	5.4	1.5	1.3	1.1	1.0	1.0	0.9	0.9
1/2"		100	100	99.5	49.1	1.8	1.4	1.2	1.1	1.0	1.0	0.9
3/8"		100	100	100	96.9	25.7	4.1	2.3	1.9	1.7	1.5	1.4
RD		100	100	100	100	99.0	73.5	49.8	35.1	25.7	20.4	16.6
HL		100	100	100	100	100	100	100	99.8	97.2	90.2	81.3

BLENDING CALCULATIONS

		Sieve Size in millimeters (mm)										
Bin No.	% USE	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
3/4"	25.0	25.0	24.7	8.7	1.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2
1/2"	13.5	13.5	13.5	13.4	6.6	0.2	0.2	0.2	0.1	0.1	0.1	0.1
3/8"	30.5	30.5	30.5	30.5	29.6	7.8	1.3	0.7	0.6	0.5	0.5	0.4
RD	29.5	29.5	29.5	29.5	29.5	29.2	21.7	14.7	10.4	7.6	6.0	4.9
HL	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.2
BLEND	100	100.0	99.7	83.6	68.5	39.2	24.9	17.3	12.8	9.9	8.2	6.9
SPEC - H		100.0	100.0	90.0			34.6	28.3	20.7	13.7		8.0
SPEC - L			90.0	49.0			34.6	22.3	16.7	13.7		2.0
OK ?		IN	IN	IN			OUT	OUT	OUT	OUT		IN
							23,49	Restricted Zone				

Target	100.0	100.0	83.2	66.8	37.6	24.4	16.6	11.9	9.0	7.1	5.8
Adjusted (-1.1%)	99.9	99.5	83.3	68.1	38.4	24.1	16.4	11.8	8.9	7.2	5.8
Delta	0.1	0.5	-0.1	-1.3	-0.8	0.3	0.2	0.1	0.1	-0.1	-0.0

Table 24: Trial Blend T1, blending spreadsheet.

Project: WesTrack - 19mm NOMINAL SUPERPAVE GRADATION
Date: 6-3-97 Stockpile Gradations from 5/stockpile samples taken 5/30/97 (Lockwood @ Patrick)
Tech: AH/TO
Blend ID: T1 Blend (Based on 5-30-97 sampling)*

SIEVE ANALYSIS DATA FOR BINS CONSIDERED

		Sieve Size in millimeters (mm)										
Bin No.		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
3/4"		100	98.1	33	5.7	1.8	1.3	1.2	1.1	1.1	1	0.9
1/2"		100	100	98.4	31.9	2	1.7	1.6	1.5	1.4	1.3	1.2
3/8"		100	100	100	96.8	27.3	4.9	2.6	2.1	1.9	1.7	1.5
RD		100	100	100	100	98.8	73.8	48.9	34.5	25.3	19.7	16.0
HL		100	100	100	100	100	100	100	99.8	97.2	90.2	81.3

BLENDING CALCULATIONS

		Sieve Size in millimeters (mm)										
Bin No.	% USE	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
3/4"	25.0	25.0	24.5	8.3	1.4	0.5	0.3	0.3	0.3	0.3	0.3	0.2
1/2"	13.5	13.5	13.5	13.3	4.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
3/8"	30.5	30.5	30.5	30.5	29.5	8.3	1.5	0.8	0.6	0.6	0.5	0.5
RD	29.5	29.5	29.5	29.5	29.5	29.1	21.8	14.4	10.2	7.5	5.8	4.7
HL	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.2
BLEND	100	100.0	99.5	83.0	66.3	39.7	25.3	17.2	12.8	10.0	8.1	6.8
SPEC - H		100.0	100.0	90.0			34.6	28.3	20.7	13.7		8.0
SPEC - L			90.0	49.0			34.6	22.3	16.7	13.7		2.0
OK ?		IN	IN	IN			OUT	OUT	OUT	OUT		IN
							23,49	Restricted Zone				

Target (TBE)	100	100.0	83.2	66.8	37.6	24.4	16.6	11.9	9.0	7.1	5.8
Target (P7 -1.1 lab)	100	100.0	83.3	68.1	38.4	24.1	16.4	11.8	8.9	7.2	5.8
Adjusted (0)	100	99.5	83.0	66.3	39.7	25.3	17.2	12.8	10.0	8.1	6.8
Adjusted (-1.0)	100	99.5	82.9	65.9	39.1	24.6	16.4	11.9	9.1	7.2	5.8
Adjusted (-1.1)	100	99.5	82.8	65.9	39.0	24.5	16.3	11.8	9.0	7.1	5.7
Adjusted (-1.2)	100	99.5	82.8	65.8	39.0	24.4	16.2	11.7	8.9	7.0	5.7
Adjusted (-1.3)	100	99.5	82.8	65.8	38.9	24.3	16.1	11.6	8.8	6.9	5.6
Adjusted (-1.4)	100	99.5	82.8	65.8	38.8	24.3	16.1	11.6	8.7	6.8	5.5
Adjusted (-1.5)	100	99.5	82.8	65.7	38.8	24.2	16.0	11.5	8.6	6.7	5.4
5-30-97 Core Ign.	100	99.9	86.7	71.7	39.6	23.9	15.9	11.5	8.7	6.8	5.4

* The T1 blend was adjusted in the laboratory to match the 5-30-97 core ingnition gradation average.

Table 25: Trail Blend F Blending Spreadsheet.

Project: WesTrack - 19mm NOMINAL SUPERPAVE GRADATION
Date: 6-7-97 Stockpile Gradations from 10/stockpile samples taken 6/73/97 (Lockwood @ Patrick)
Tech: AH/JAE
Blend ID: F Blend (Based on 6-7-97 sampling)

SIEVE ANALYSIS DATA FOR BINS CONSIDERED

		Sieve Size in millimeters (mm)										
Bin No.		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
3/4"		100	96.8	29.4	7.4	3	2	1.6	1.5	1.3	1.2	1
1/2"		100	100	99.5	49.7	1.8	1.3	1.1	1	0.9	0.8	0.7
3/8"		100	100	100	99.5	31.3	4.7	2.4	2	1.8	1.6	1.5
RD		100	100	100	100	98.5	73.0	47.9	33.6	24.8	19.4	15.6
HL		100	100	100	100	100	100	100	99.8	97.2	90.2	81.3

BLENDING CALCULATIONS

		Sieve Size in millimeters (mm)										
Bin No.	% USE	25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
3/4"	24.0	24.0	23.2	7.1	1:8	0.7	0.5	0.4	0.4	0.3	0.3	0.2
1/2"	15.5	15.5	15.5	15.4	7.7	0.3	0.2	0.2	0.2	0.1	0.1	0.1
3/8"	27.5	27.5	27.5	27.5	27.4	8.6	1.3	0.7	0.6	0.5	0.4	0.4
RD	31.5	31.5	31.5	31.5	31.5	31.0	23.0	15.1	10.6	7.8	6.1	4.9
HL	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.2
BLEND	100	100.0	99.2	83.0	69.8	42.1	26.5	17.8	13.1	10.2	8.3	6.9
SPEC - H		100.0	100.0	90.0			34.6	28.3	20.7	13.7		8.0
SPEC - L			90.0	49.0			34.6	22.3	16.7	13.7		2.0
OK ?		IN	IN	IN			OUT	OUT	OUT	OUT		IN
							23,49	Restricted Zone				

Target (TBE)	100	100.0	83.2	66.8	37.6	24.4	16.6	11.9	9.0	7.1	5.8
Adjusted (0)	100	99.2	83.0	69.8	42.1	26.5	17.8	13.1	10.2	8.3	6.9
Adjusted (-0.6)	100	99.2	82.9	69.7	41.8	26.0	17.3	12.6	9.7	7.8	6.3
Adjusted (-0.8)	100	99.2	82.8	69.6	41.7	25.9	17.1	12.4	9.5	7.6	6.1
Adjusted (-1.0)	100	99.2	82.8	69.5	41.5	25.7	17.0	12.3	9.3	7.4	6.0
Adjusted (-1.1)	100	99.2	82.8	69.5	41.5	25.7	16.9	12.2	9.2	7.3	5.9
Adjusted (-1.2)	100	99.2	82.8	69.5	41.4	25.6	16.8	12.1	9.1	7.2	5.8
Adjusted (-1.3)	100	99.2	82.8	69.4	41.4	25.5	16.7	12.0	9.0	7.1	5.7
Adjusted (-1.5)	100	99.2	82.7	69.4	41.3	25.3	16.6	11.8	8.8	6.9	5.5

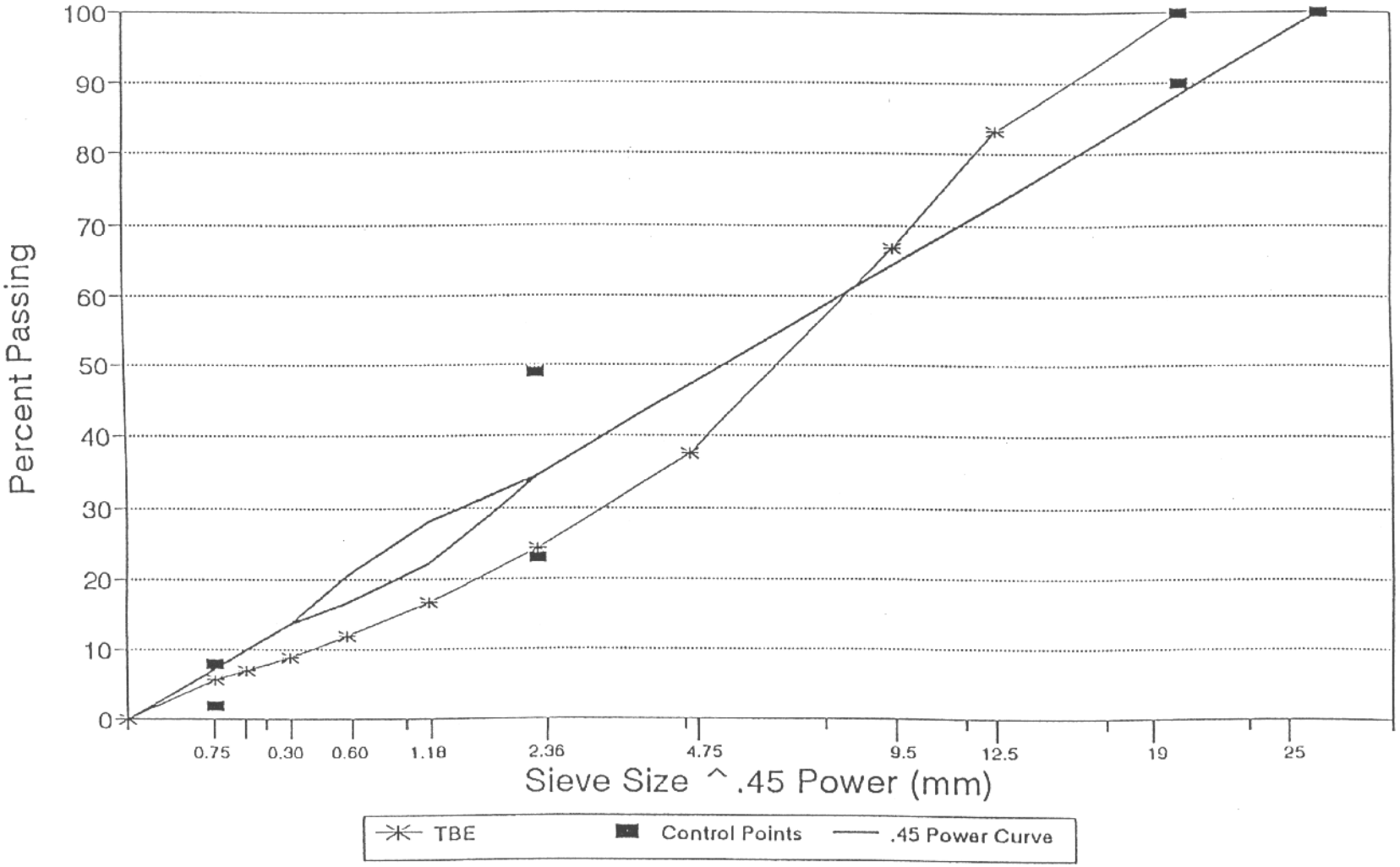

Figure 1: Blend TBE (based on 4-14-97 sampling).

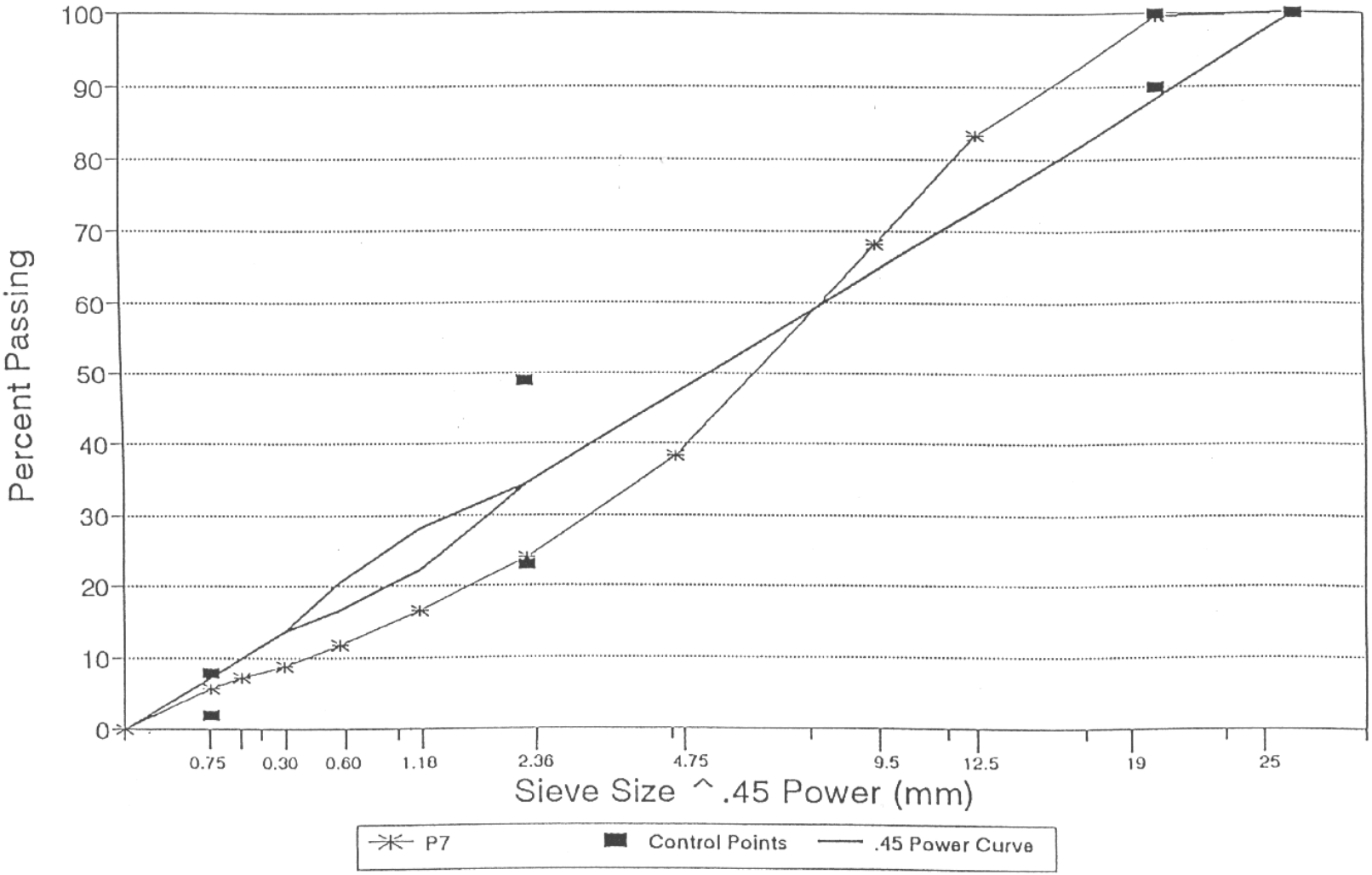

Figure 2: Blend P7 (based on 5-23-97 sampling

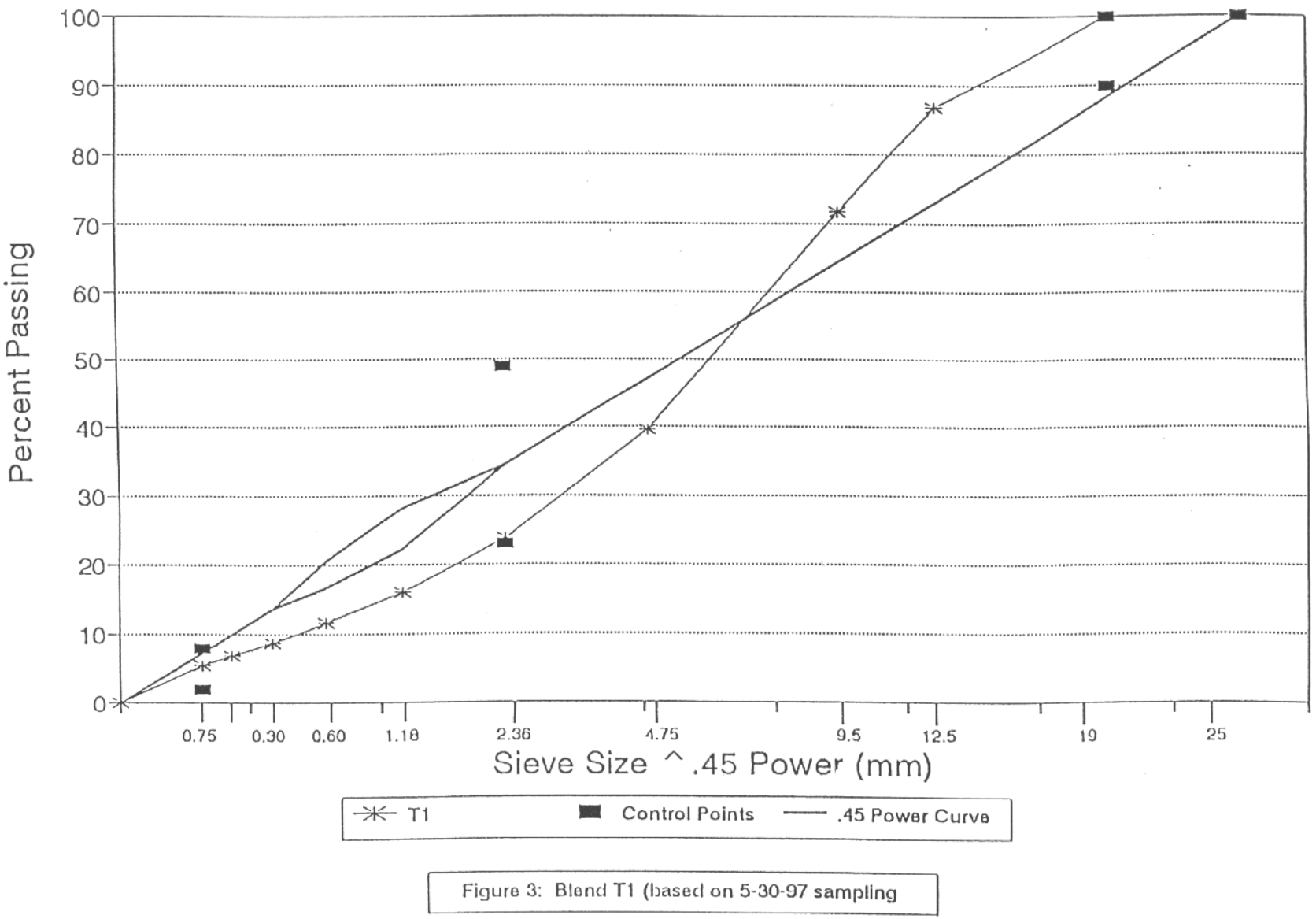

Figure 3: Blend T1 (based on 5-30-97 sampling

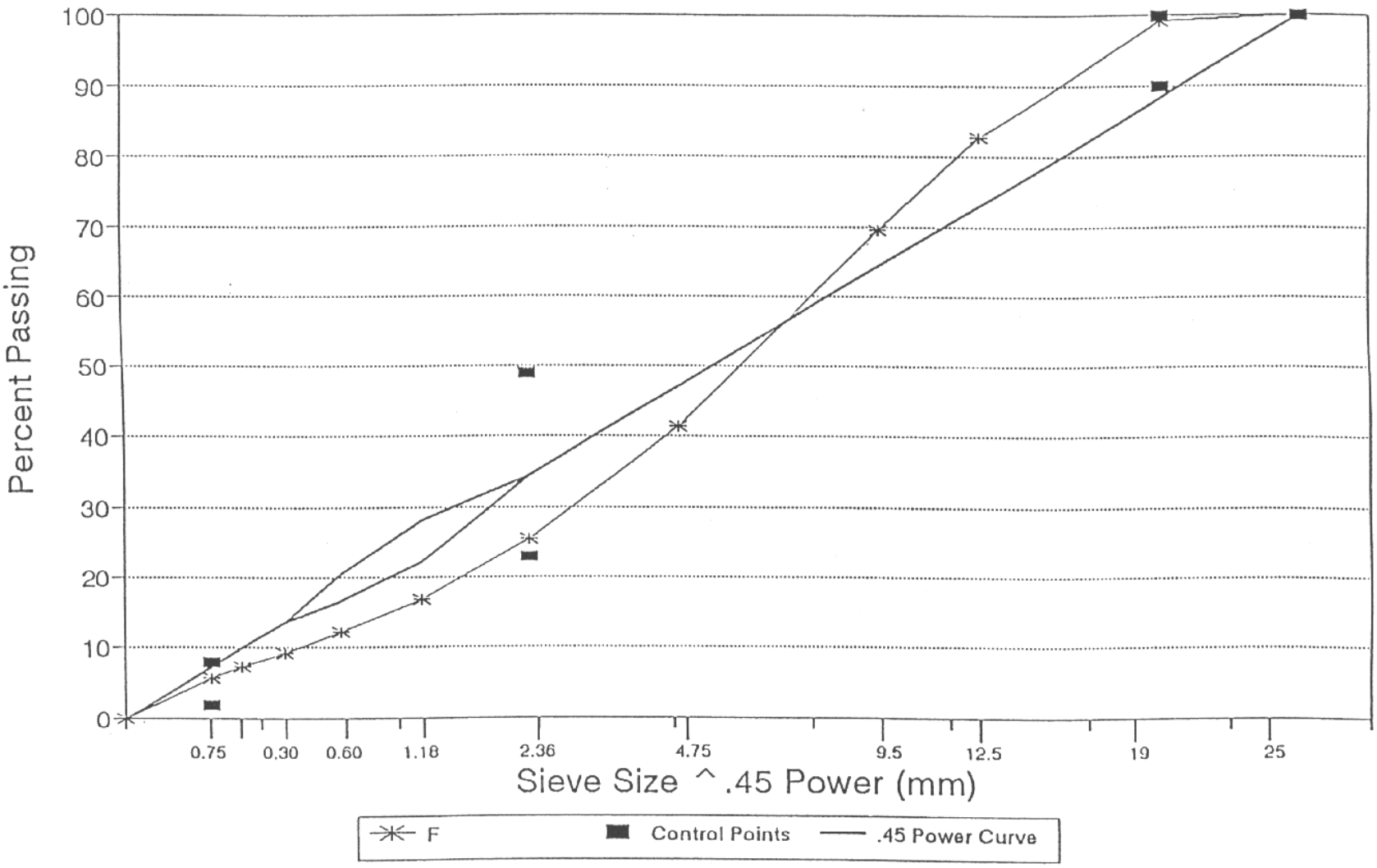

Figure 4: Blend F (based on 6-7-97 sampling)

APPENDIX B

AGGREGATE SPECIFIC GRAVITY

Statistical Analysis of Blend
Coarse and Fine Aggregate Specific Gravities
(AASHTO T84 & T85)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Blend TBE**
Date: **5-14-97**
Technician: **TO**

Stockpile	Percentage in Blend	Bulk Specific Gravity (Gsb)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	62.4	2.633	2.637	2.638	2.636	0.002	0.1
-#4	36.5	2.521	2.509	2.504	2.511	0.007	0.3
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Bulk Specific Gravity					2.584		
Stockpile	Percentage in Blend	Apparent Specific Gravity (Gsa)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	62.4	2.789	2.791	2.792	2.791	0.001	0.0
-#4	36.5	2.814	2.809	2.801	2.808	0.005	0.2
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Apparent Specific Gravity					2.788		
Stockpile	Percentage in Blend	Absorption Capacity					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	62.4	2.130	2.100	2.090	2.107	0.017	0.8
-#4	36.5	4.122	4.255	4.231	4.203	0.058	1.4
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Absorption					2.577		

Statistical Analysis of Blend
Coarse and Fine Aggregate Specific Gravities
(AASHTO T84 & T85)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (5-23-97)**
Other: **Blend P7**
Date: **5-29-97**
Technician: **BH**

Stockpile	Percentage in Blend	Bulk Specific Gravity (Gsb)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	61.6	2.639	2.639	2.643	2.640	0.002	0.1
-#4	36.9	2.511	2.502	2.521	2.511	0.008	0.3
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Bulk Specific Gravity					2.586		
Stockpile	Percentage in Blend	Apparent Specific Gravity (Gsa)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	61.6	2.783	2.781	2.780	2.781	0.001	0.0
-#4	36.9	2.774	2.778	2.781	2.778	0.003	0.1
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Apparent Specific Gravity					2.771		
Stockpile	Percentage in Blend	Absorption Capacity					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	61.6	1.960	1.930	1.870	1.920	0.037	1.9
-#4	36.9	3.778	3.974	3.712	3.821	0.111	2.9
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Absorption					2.359		

Statistical Analysis of Blend
Coarse and Fine Aggregate Specific Gravities
(AASHTO T84 & T85)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (6-7-97)**
Other: **Blend F**
Date: **6-16-97**
Technician: **WC**

Stockpile	Percentage in Blend	Bulk Specific Gravity (Gsb)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	58.6	2.627	2.622	2.626	2.625	0.002	0.1
-#4	39.9	2.529	2.518	2.534	2.527	0.007	0.3
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Bulk Specific Gravity					2.580		
Stockpile	Percentage in	Apparent Specific Gravity (Gsa)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	58.6	2.781	2.771	2.779	2.777	0.004	0.2
-#4	39.9	2.791	2.786	2.774	2.784	0.007	0.3
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Apparent Specific Gravity					2.771		
Stockpile	Percentage in Blend	Absorption Capacity					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	58.6	2.107	2.102	2.050	2.086	0.026	1.2
-#4	39.9	3.712	3.821	3.411	3.648	0.173	4.8
HL	1.5						
Calculated Blend Absorption					2.524		

Statistical Analysis of Stockpile
Coarse and Fine Aggregate Specific Gravities
(AASHTO T84 & T85)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Stockpile Samples - TBE BLEND**
Date: **4-18-97**
Technician: **TO**

Stockpile	Percentage in Blend	Bulk Specific Gravity (Gsb) Sample ID 1	2	3	Average All Samples	Standard Deviation	Coefficient of Variation
3/4"	28.0	2.644	2.643	2.645	2.644	0.001	0.0
1/2"	10.0	2.635	2.631	2.632	2.633	0.002	0.1
3/8"	31.5	2.632	2.630	2.622	2.628	0.004	0.2
RD	29.0	2.527	2.546	2.540	2.538	0.008	0.3
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Bulk Specific Gravity					2.600		

Stockpile	Percentage in Blend	Apparent Specific Gravity (Gsa) Sample ID 1	2	3	Average All Samples	Standard Deviation	Coefficient of Variation
3/4"	28.0	2.781	2.782	2.785	2.783	0.002	0.1
1/2"	10.0	2.786	2.784	2.782	2.784	0.002	0.1
3/8"	31.5	2.782	2.794	2.787	2.788	0.005	0.2
RD	29.0	2.765	2.796	2.788	2.783	0.013	0.5
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Apparent Specific Gravity					2.776		

Stockpile	Percentage in Blend	Absorption Capacity Sample ID 1	2	3	Average All Samples	Standard Deviation	Coefficient of Variation
3/4"	28.0	1.87	1.89	1.90	1.89	0.01	0.7
1/2"	10.0	2.06	2.09	2.05	2.07	0.02	0.8
3/8"	31.5	2.04	2.22	2.26	2.17	0.10	4.4
RD	29.0	3.41	3.52	3.51	3.48	0.05	1.4
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend Absorption					2.317		

Statistical Analysis of Stockpile
Coarse and Fine Aggregate Specific Gravities
(AASHTO T84 & T85)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (5-23-97)**
Other: **Stockpile Samples – 97 BLEND**
Date: **5-26-97**
Technician: **BH**

Stockpile	Percentage in Blend	Bulk Specific Gravity (Gsb) Sample ID 1	2	3	Average All Samples	Standard Deviation	Coefficient of Variation
3/4"	25.0	2.624	2.626	2.619	2.623	0.003	0.1
1/2"	13.5	2.604	2.608	2.607	2.606	0.002	0.1
3/8"	30.5	2.599	2.594	2.614	2.602	0.008	0.3
RD	29.5	2.492	2.510	2.492	2.498	0.008	0.3
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Bulk Specific Gravity					2.571		

Stockpile	Percentage in Blend	Apparent Specific Gravity (Gsa) Sample ID 1	2	3	Average All Samples	Standard Deviation	Coefficient of Variation
3/4"	25.0	2.770	2.769	2.770	2.770	0.000	0.0
1/2"	13.5	2.768	2.764	2.774	2.769	0.004	0.1
3/8"	30.5	2.782	2.774	2.774	2.777	0.004	0.1
RD	29.5	2.779	2.783	2.788	2.783	0.004	0.1
HL	1.5	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Apparent Specific Gravity					2.767		

Stockpile	Percentage in Blend	Absorption Capacity Sample ID 1	2	3	Average All Samples	Standard Deviation	Coefficient of Variation
3/4"	25.0	2.01	1.96	2.08	2.02	0.05	2.4
1/2"	13.5	2.27	2.17	2.30	2.25	0.06	2.5
3/8"	30.5	2.53	2.49	2.21	2.41	0.14	5.9
RD	29.5	4.14	3.91	4.21	4.09	0.13	3.2
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend Absorption					2.573		

Statistical Analysis of Stockpile
Coarse and Fine Aggregate Specific Gravities
(AASHTO T84 & T85)

Project: WesTrack Rehabilitation
Aggregate Source: Lockwood sampled @ Patrick (6-7-97)
Other: Stockpile Samples - F BLEND
Date: 6-8-97
Technician: WC/TO

Stockpile	Percentage in Blend	Bulk Specific Gravity (Gsb)							
		Sample ID					Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
3/4"	24.0	2.623	2.647	2.616	2.618	2.618	2.624	0.012	0.4
1/2"	15.5	2.619	2.674	2.638	2.621	2.623	2.635	0.021	0.8
3/8"	27.5	2.606	2.604	2.261	2.621	2.626	2.544	0.142	5.6
RD	31.5	2.466	2.447	2.517	2.495	2.502	2.485	0.025	1.0
HL	1.5	2.297	2.297	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Bulk Specific Gravity							2.553		
Stockpile	Percentage in Blend	Apparent Specific Gravity (Gsa)							
		Sample ID					Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
3/4"	24.0	2.777	2.776	2.780	2.782	2.777	2.778	0.002	0.1
1/2"	15.5	2.753	2.755	2.760	2.770	2.764	2.760	0.006	0.2
3/8"	27.5	2.775	2.772	2.777	2.761	2.750	2.767	0.010	0.4
RD	31.5	2.779	2.755	2.777	2.773	2.790	2.775	0.011	0.4
HL	1.5	2.297	2.297	2.297	2.297	2.297	2.297	0.000	0.0
Calculated Blend Apparent Specific Gravity							2.763		
Stockpile	Percentage in Blend	Absorption Capacity							
		Sample ID					Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
3/4"	24.0	2.12	1.75	2.25	2.25	2.19	2.11	0.19	8.8
1/2"	15.5	1.86	1.10	1.67	2.07	1.94	1.73	0.34	19.6
3/8"	27.5	2.35	2.33	2.15	1.94	1.71	2.09	0.24	11.6
RD	31.5	4.56	4.78	3.71	4.01	4.19	4.25	0.38	9.0
HL	1.5	n/a			n/a	n/a	n/a	n/a	n/a
Calculated Blend Absorption							2.409		

APPENDIX C

SUPERPAVE CONSENSUS AGGREGATE PROPERTIES

Statistical Analysis of Stockpile Coarse Aggregate Angularity (ASTM D5821)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Stockpile Samples**
Date: **4-21-97**
Technician: **TO**

Stockpile	Percentage in Blend	Coarse Aggregate Angularity (CAA)											
		Sample ID						Average		Standard Deviation		Coefficient of Variation	
		1		2		3							
		One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces
3/4"	28.0	99.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	0.06	0.06	0.06	0.06
1/2"	10.0	100.0	99.4	100.0	100.0	100.0	99.9	100.0	99.8	0.00	0.32	0.00	0.32
3/8"	31.5	100.0	99.5	100.0	100.0	100.0	100.0	100.0	99.8	0.00	0.29	0.00	0.29
RD	29.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend Coarse Aggregate Angularity (CAA)								100.0	99.9				

Statistical Analysis of Stockpile
Fine Aggregate Angularity (FAA)
(ASTM C1252)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Stockpile Samples**
Date: **4-18-97**
Technician: **TO**

Stockpile	Percentage in Blend	Fine Aggregate Angularity (FAA)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
3/4"	28.0	n/a	n/a	n/a	n/a	n/a	n/a
1/2"	10.0	n/a	n/a	n/a	n/a	n/a	n/a
3/8"	31.5	n/a	n/a	n/a	n/a	n/a	n/a
RD	29.0	46.9	46.8	47.1	46.9	0.1	0.3
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a

Statistical Analysis of Stockpile
Flat and Elongated Particles
(ASTM D4791)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Stockpiles Samples**
Date: **4-21-97**
Technician: **TO**

Stockpile	Percentage in Blend	Flat and Elongated Particles (FEP)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
3/4"	1.0	0.00	0.02	0.03	0.02	0.01	74.8
1/2"	10.0	0.04	0.02	0.03	0.03	0.01	27.2
3/8"	31.5	0.00	0.04	0.00	0.01	0.02	141.4
RD	29.0	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend FEP					0.02		

Statistical Analysis of Stockpile
Sand Equivalent
(AASHTO T176)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Stockpile Samples**
Date: **4-21-97**
Technician: **TO**

Stockpile	Percentage in Blend	Sand Equivalent (SE)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
3/4"	28.0	n/a	n/a	n/a	n/a	n/a	n/a
1/2"	10.0	n/a	n/a	n/a	n/a	n/a	n/a
3/8"	31.5	n/a	n/a	n/a	n/a	n/a	n/a
RD	29.0	65	63	64	64.0	0.8	1.3
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend SE					64.0		

Statistical Analysis of Stockpile Coarse Aggregate Angularity (ASTM D5821)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (5-23-97)**
Other: **Stockpile Samples**
Date: **5-27-97**
Technician: **WC**

Stockpile	Percentage in Blend	Coarse Aggregate Angularity (CAA)											
		Sample ID						Average		Standard Deviation		Coefficient of Variation	
		1		2		3							
		One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces
3/4"	25.0	95.5	95.5	92.6	91.0	92.1	89.6	93.4	92.0	1.84	3.08	1.97	3.35
1/2"	13.5	93.8	92.2	95.9	95.1	94.8	94.2	94.8	93.8	1.05	1.48	1.11	1.58
3/8"	30.5	97.1	95.9	95.1	94.2	96.3	94.8	96.2	95.0	1.01	0.86	1.05	0.91
RD	29.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend Coarse Aggregate Angularity (CAA)								94.9	93.7				

Statistical Analysis of Stockpile
Fine Aggregate Angularity (FAA)
(ASTM C1252)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (5-23-97)**
Other: **Stockpile Samples**
Date: **5-28-97**
Technician: **TO**

Stockpile	Percentage in Blend	Fine Aggregate Angularity (FAA)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
3/4"	25.0	n/a	n/a	n/a	n/a	n/a	n/a
1/2"	13.5	n/a	n/a	n/a	n/a	n/a	n/a
3/8"	30.5	n/a	n/a	n/a	n/a	n/a	n/a
RD	29.5	45.6	46.1	45.2	45.6	0.4	0.8
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a

Statistical Analysis of Stockpile
Flat and Elongated Particles
(ASTM D4791)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (5-23-97)**
Other: **Stockpiles Samples**
Date: **5-29-97**
Technician: **WC**

Stockpile	Percentage in Blend	Flat and Elongated Particles (FEP)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
3/4"	25.0	0.46	0.09	0.67	0.41	0.24	59.0
1/2"	13.5	0.00	0.60	0.00	0.20	0.28	141.4
3/8"	30.5	0.00	0.00	0.00	0.00	0.00	0.0
RD	29.5	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend FEP					0.30		

Statistical Analysis of Stockpile
Sand Equivalent
(AASHTO T176)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (5-23-97)**
Other: **Stockpile Samples**
Date: **5-28-97**
Technician: **WC**

Stockpile	Percentage in Blend	Sand Equivalent (SE)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
3/4"	25.0	n/a	n/a	n/a	n/a	n/a	n/a
1/2"	13.5	n/a	n/a	n/a	n/a	n/a	n/a
3/8"	30.5	n/a	n/a	n/a	n/a	n/a	n/a
RD	29.5	60	56	67	61.0	4.5	7.5
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend SE					61.0		

Statistical Analysis of Stockpile Coarse Aggregate Angularity (ASTM D5821)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (6-7-97)**
Other: **Stockpile Samples**
Date: **6-12-97**
Technician: **WC**

Stockpile	Percentage in Blend	Coarse Aggregate Angularity (CAA)											
		Sample ID						Average		Standard Deviation		Coefficient of Variation	
		1		2		3							
		One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces
3/4"	24.0	97.1	92.3	90.2	88.9	91.4	91.4	92.9	90.9	3.69	1.76	3.97	1.94
1/2"	15.5	95.9	94.4	93.0	91.6	94.6	92.6	94.5	92.9	1.45	1.42	1.53	1.53
3/8"	27.5	98.9	98.7	99.6	99.2	98.9	98.4	99.1	98.8	0.41	0.41	0.41	0.42
RD	31.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend Coarse Aggregate Angularity (CAA)								95.7	94.4				

Statistical Analysis of Stockpile
Fine Aggregate Angularity (FAA)
(ASTM C1252)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (6-7-97)**
Other: **Stockpile Samples**
Date: **6-12-97**
Technician: **WC**

Stockpile	Percentage in Blend	Fine Aggregate Angularity (FAA)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
3/4"	24.0	n/a	n/a	n/a	n/a	n/a	n/a
1/2"	15.5	n/a	n/a	n/a	n/a	n/a	n/a
3/8"	27.5	n/a	n/a	n/a	n/a	n/a	n/a
RD	31.5	45.0	45.2	46.3	45.5	0.6	1.3
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a

Statistical Analysis of Stockpile
Flat and Elongated Particles
(ASTM D4791)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (6-7-97)**
Other: **Stockpiles Samples**
Date: **6-12-97**
Technician: **WC**

Stockpile	Percentage in Blend	Flat and Elongated Particles (FEP)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
3/4"	24.0	0.00	0.00	0.00	0.00	0.00	0.0
1/2"	15.5	0.37	0.34	0.00	0.24	0.17	70.9
3/8"	27.5	0.00	0.00	0.00	0.00	0.00	0.0
RD	31.5	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend FEP					0.05		

Statistical Analysis of Stockpile
Sand Equivalent
(AASHTO T176)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (6-7-97)**
Other: **Stockpile Samples**
Date: **6-10-97**
Technician: **TO**

Stockpile	Percentage in Blend	Sand Equivalent (SE)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
3/4"	24.0	n/a	n/a	n/a	n/a	n/a	n/a
1/2"	15.5	n/a	n/a	n/a	n/a	n/a	n/a
3/8"	27.5	n/a	n/a	n/a	n/a	n/a	n/a
RD	31.5	65	65	69	66.3	1.9	2.8
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend SE					66.3		

Statistical Analysis of Blend
Coarse Aggregate Angularity
(ASTM D5821)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Blend TBE**
Date: **5-15-97**
Technician: **TO**

Stockpile	Percentage in Blend	Coarse Aggregate Angularity (CAA)											
		Sample ID						Average		Standard Deviation		Coefficient of Variation	
		1		2		3							
		One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces
+#4	62.4	100.0	100.0	99.9	99.9	99.8	99.8	99.9	99.9	0.10	0.10	0.10	0.10
-#4	36.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend Coarse Aggregate Angularity (CAA)								99.9	99.9				

Statistical Analysis of Blend
Fine Aggregate Angularity (FAA)
(ASTM C1252)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Blend TBE**
Date: **5-15-97**
Technician: **TO**

Stockpile	Percentage in Blend	Fine Aggregate Angularity (FAA)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	62.4	n/a	n/a	n/a	n/a	n/a	n/a
-#4	36.5	45.8	46.2	46.2	46.1	0.2	0.41
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a

Statistical Analysis of Blend
Flat and Elongated Particles
(ASTM D4791)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Blend TBE**
Date: **5-15-97**
Technician: **TO**

Stockpile	Percentage in Blend	Flat and Elongated Particles (FEP)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	62.4	0.00	0.00	0.00	0.00	0.00	0.0
-#4	36.5	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend FEP					0.00		

Statistical Analysis of Blend
Sand Equivalent
(AASHTO T176)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Lockwood (4-14-97) - New VSI's**
Other: **Blend TBE**
Date: **5-15-97**
Technician: **TO**

Stockpile	Percentage in Blend	Sand Equivalent (SE)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	62.4	n/a	n/a	n/a	n/a	n/a	n/a
-#4	36.5	68	67	67	67	0.47	0.700
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend SE					67.0		

Statistical Analysis of Blend
Coarse Aggregate Angularity
(ASTM D5821)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (5-23-97)**
Other: **Blend P7**
Date: **5-29-97**
Technician: **WC**

Stockpile	Percentage in Blend	Coarse Aggregate Angularity (CAA)											
		Sample ID						Average		Standard Deviation		Coefficient of Variation	
		1		2		3							
		One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces
+#4	61.6	88.5	87.1	91.0	90.5	77.7	75.9	85.7	84.5	7.07	7.64	8.25	9.04
-#4	36.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend Coarse Aggregate Angularity (CAA)								85.7	84.5				

Statistical Analysis of Blend
Fine Aggregate Angularity (FAA)
(ASTM C1252)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (5-23-97)**
Other: **Blend P7**
Date: **5-29-97**
Technician: **TO**

Stockpile	Percentage in Blend	Fine Aggregate Angularity (FAA)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	61.6	n/a	n/a	n/a	n/a	n/a	n/a
-#4	36.9	46.1	46.6	46.1	46.3	0.2	0.51
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a

Statistical Analysis of Blend
Sand Equivalent
(AASHTO T176)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (5-23-97)**
Other: **Blend P7**
Date: **5-29-97**
Technician: **TO**

Stockpile	Percentage in Blend	Sand Equivalent (SE)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	61.6	n/a	n/a	n/a	n/a	n/a	n/a
-#4	36.9	73	73	72	73	0.56	0.764
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend SE					73		

Statistical Analysis of Blend
Coarse Aggregate Angularity
(ASTM D5821)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (6-7-97)**
Other: **Blend F**
Date: **6-16-97**
Technician: **WC**

Stockpile	Percentage in Blend	Coarse Aggregate Angularity (CAA)											
		Sample ID						Average		Standard Deviation		Coefficient of Variation	
		1		2		3							
		One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces	One Face	Two Faces
+#4	58.6	84.4	82.8	76.3	72.5	83.1	81.0	81.3	78.8	3.60	4.50	4.43	5.71
-#4	39.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend Coarse Aggregate Angularity (CAA)								81.3	78.8				

Statistical Analysis of Blend
Fine Aggregate Angularity (FAA)
(ASTM C1252)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (6-7-97)**
Other: **Blend F**
Date: **6-16-97**
Technician: **TO**

Stockpile	Percentage in Blend	Fine Aggregate Angularity (FAA)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	58.6	n/a	n/a	n/a	n/a	n/a	n/a
-#4	39.9	46.0	46.2	46.5	46.2	0.2	0.44
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a

Statistical Analysis of Blend
Flat and Elongated Particles
(ASTM D4791)

Project: **WesTrack Rehabilitation**
Aggregate Source: **Lockwood sampled @ Patrick (6-7-97)**
Other: **Blend F**
Date: **6-12-97**
Technician: **TO**

Stockpile	Percentage in Blend	Flat and Elongated Particles (FEP)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	61.6	0.43	0.00	0.00	0.14	0.20	141.4
-#4	36.9	n/a	n/a	n/a	n/a	n/a	n/a
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend FEP					0.00		

Statistical Analysis of Blend
Sand Equivalent
(AASHTO T176)

Project:	**WesTrack Rehabilitation**
Aggregate Source:	**Lockwood sampled @ Patrick (6-7-97)**
Other:	**Blend F**
Date:	**6-13-97**
Technician:	**TO**

Stockpile	Percentage in Blend	Sand Equivalent (SE)					
		Sample ID			Average All Samples	Standard Deviation	Coefficient of Variation
		1	2	3			
+#4	61.6	n/a	n/a	n/a	n/a	n/a	n/a
-#4	36.9	71	74	76	73	1.93	2.621
HL	1.5	n/a	n/a	n/a	n/a	n/a	n/a
Calculated Blend SE					73		

Original Construction Mix Designs for the WesTrack Project

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-6
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research project was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June of 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

BACKGROUND

Based on the objectives of the WesTrack project, an experimental plan was developed to evaluate the performance of 21 different HMA mixtures (five replicate sections were included in the experimental design). The WesTrack mixtures were designed based on the Superpave volumetric mixture design method. The Superpave mixture design and analysis system was used to predict pavement performance. Performance monitoring information was used to compare predictions with actual pavement performance. Improved performance-related specifications were developed from the study.

A review of currently used quality control/quality assurance (QC/QA) types of specifications indicated that HMA material quality is most often measured by asphalt binder content; aggregate gradation; field-mixed, laboratory-compacted air voids, stability, and (cores or nuclear gauge) air voids; and smoothness determinations. Due to the length of the test sections, the impact of smoothness on performance could not be included in the experimental plan. Asphalt binder content, aggregate gradation, and air void content were included in the experimental plan.

Existing specifications normally limit the number of sieve sizes upon which pay adjustments are based. The most common of all sieves presently used is the 0.075-mm (No. 200) sieve. Another common sieve size is the 2.36-mm (No. 8). Three different aggregate gradations were included

in the experimental design to determine the effect of aggregate gradation on mixture performance.

Field experience indicates that performance of some types of HMA are more affected by changes in asphalt content, gradation, and in-place air voids than other types of HMA. Thus, an attempt was made to select aggregate gradations and aggregate characteristics that produced mixtures that displayed both high- and low-sensitivity to the variability of materials.

Pay factors for air voids are more commonly based on field-mixed, field-compacted samples (cores), rather than on field-mixed, laboratory-compacted samples. Thus, the experiment's design, shown in table 1, includes the main variables of asphalt content, aggregate gradation, and in-place (field-mixed, field-compacted) air voids. Note that sections were not constructed at low asphalt content and low air voids, or at high asphalt content and high air voids. Normal construction operations with low asphalt content mixtures will not produce low air void mixtures and normal construction operations with high asphalt contents will not produce high air void mixtures.

The materials selected for the WesTrack Project and the mixture design process and testing associated with selecting the aggregate gradations and asphalt contents for the project are discussed below. Additional details and test results are available in other WesTrack reports.

MATERIALS

ASPHALT BINDER

One of the objectives of the WesTrack Project was validation of the Superpave mix design and analysis system. The Superpave binder specification was developed for both nonmodified and modified binders, but the field verification upon which the specification limits were based were established on pavements constructed with nonmodified binders only.[4] For this reason, and because of difficulties associated with using Superpave binder tests on modified asphalts, a nonmodified binder was used for the project.

A PG 64-28 binder met the Superpave 98 percent reliability requirements for the project site.[5] Because the pavement was only to be exposed to the environment for about 3 years and because thermal cracking cannot be reasonably evaluated in 70-m (230-ft) test sections (cold joints every 70 m), meeting the 98 percent reliability for the low-temperature grade was not considered critical. A PG 64-22 provides 98 percent reliability for the high-temperature grade and 94 percent reliability for the low-temperature grade. Nonmodified PG 64-22 binder was used for the entire project and all the mix designs. The asphalt binder also met the specifications of ASTM D3381 Table II for AC-20.[6]

Mix designs were started with an asphalt binder produced from a blend of foreign and domestic crudes, but the foreign crude became unavailable early in the mix design process and a second binder blended from domestic crudes was used for the remainder of the mix designs. The binder met the AASHTO MP1 provisional specification for PG 64-22 binders with the exception of the fatigue requirement ($G^*\sin\delta$) at 25°C on the pressure aging vessel residue.[6,7]

HOT-MIX ASPHALT AGGREGATES

Aggregate types and gradations were selected to produce HMA mixtures whose performance was more or less affected by material variability. The concept of a nonsensitive, sensitive, and supersensitive mixture was identified and defined in the project. A nonsensitive mixture is identified as HMA whose physical properties and performance are not greatly affected by variability in asphalt binder content and/or changes in aggregate gradation. A sensitive mixture is identified as HMA whose physical properties and performance are affected by variability in asphalt binder content and/or changes in aggregate gradation. A supersensitive mixture is identified as HMA whose physical properties and performance are greatly affected by variability in asphalt binder content and/or changes in aggregate gradation. Nontarget mixtures are mixtures that deviate from the job mix formula of the target nonsensitive and sensitive mixtures relative to asphalt content and gradation. (Note: Initially in the WesTrack Project the sensitive mixture was referred to as the "critical" mixture, and the nonsensitive mixture was referred to as the "noncritical" mixture. Some figures and tables in this report still include the terms critical and noncritical.)

Nonsensitive mixtures typically result from the use of one or more of the following:

- Block-shaped aggregates.
- Aggregates with rough surface textures.
- Aggregate blends with low fines contents (material passing the 4.75-mm sieve).
- Aggregate blends with high contents of crushed fine aggregate.
- Aggregate blends with low-to-intermediate sand contents.
- Hard asphalt cements.

Sensitive mixtures typically result from the use of one or more of the following:

- Rounded or subrounded shaped aggregates.
- Aggregate with smooth surface texture.
- Aggregate blends with high fines contents (material passing the 4.75-mm sieve).
- Aggregate blends with high natural sand contents.
- Aggregate blends with high-to-intermediate sand contents.
- Soft asphalt cements.

From a mix design standpoint, this required that one target nonsensitive and one target sensitive mixture be designed in the laboratory. The supersensitive mixture was developed by incorporating a relatively high percentage of fines (material passing the 0.075-mm sieve) into the gradation of the target sensitive mixture. This established the three levels of aggregate gradation. The three levels of asphalt cement content (AC) – low, medium, and high – for each mixture are based on the optimum and the optimum plus and minus 0.7 percent. In-place air void content levels were established considering the level typically obtained at laydown and compaction and a level above and below the typical i.e., 4, 8, and 12 percent.

The nonsensitive mixture incorporated a standard coarse Superpave gradation (below the restricted zone [coarse-graded]) targeted at producing optimum mixture stability. The critical mixture incorporated a fine Superpave gradation (above the restricted zone [fine-graded]) similar to more conventional gradations that would be susceptible from a performance standpoint to changes in materials and construction factors, particularly asphalt content and aggregate gradation. The supersensitive mixture, the target sensitive mixture with a high percentage of fines (fine plus graded), would be established outside of the Superpave gradation criteria to demonstrate the effect of high fines on mixture performance.

The magnitude of the differences in levels of asphalt content (optimum and optimum plus and minus 0.7 percent) and of in-place air void content (4, 8, and 12 percent) were established to ensure that, as constructed under field conditions, test sections would be statistically significantly different from each other. The levels selected represented approximately normal construction variability plus and minus two standard deviations.

Two aggregate sources were selected to develop the nonsensitive and sensitive mixtures, Watsonville granite and Dayton aggregate. Watsonville granite was to be used for the development of the nonsensitive mixture and the Dayton aggregate was to be used for the development of the sensitive mixtures.

The Watsonville granite, produced by Graniterock in Watsonville, California, is a 100 percent crushed quarry material that was available in four sizes (stockpiles): 19-mm x 12-mm (3/4-in. x 1/2-in.), 12-mm x 6-mm (1/2-in. x 1/4-in.), 6-mm x 2-mm (1/4-in. x No.10), and crushed washed sand. This material was used extensively during the Strategic Highway Research Program (SHRP) in the research laboratories of the University of California, Texas A&M University, and the University of Nevada, and has been successfully used by the California Department of Transportation for over 50 years.[8] The material is very blocky.

The Dayton aggregate, produced by Granite Construction in Dayton, Nevada, is a partially crushed gravel material composed primarily of weathered andesite, and was available in four sizes (stockpiles): 19-mm (3/4-in.) crushed gravel, 12-mm (1/2-in.) crushed gravel, 9-mm (3/8-in.) crushed gravel, and crushed fines. In addition to the crushed material, two natural sands (Dayton and Wadsworth) were available for mix designs. Although both sands were primarily granitic, the Wadsworth sand was cleaner than the Dayton sand.

Five samples of each of the proposed Dayton and Watsonville aggregate stockpiles were taken and gradations were performed. Typical size distribution and variability were established from the gradations. Tables 2 and 3 summarize the gradations.[9] The Watsonville materials were cleaner (less material passing the 0.075-mm sieve) than the Dayton materials.

Specific gravities and Superpave consensus tests also were performed on aggregate stockpile samples. Table 4 summarizes the specific gravity test results.[9] Tables 5 and 6 summarize the Superpave consensus test results and specifications, respectively.[9] The specification limits on the Superpave consensus aggregate properties are a function of traffic, or traffic and the depth below the surface at which the material is to be incorporated. The planned traffic over the accelerated 2-year loading period for the project was 10 million 80-kN (18,000-lb) ESALs and,

because the same material would be used for the entire 150-mm (6-in.) thick AC surface layer, the property requirements must be those for material less than 100 mm below the surface.

A review of the consensus properties suggested that any combination of the Watsonville granite stockpiles, would meet all of the Superpave consensus specifications for the project because each component exceeded the minimum specification limits. The Dayton aggregate components, with the exception of the sands, met all of the consensus property specifications. Both the Dayton and Wadsworth sands fell slightly below the fine aggregate angularity specification of 45 (44.5 and 44.0, respectively) and the sand equivalent of the Dayton sand, 31, was below the specification minimum of 45. The Wadsworth sand was much cleaner than the Dayton sand (3.0 and 11.5 percent, respectively, passing 0.075-mm sieve) and the bulk specific gravity of the Wadsworth sand also was higher than that of the Dayton sand (2.569 versus 2.472), suggesting that achieving voids in mineral aggregate would be easier with the Wadsworth sand.

Superpave requires that consensus tests be performed on blends rather than on stockpiles, but performing the tests on the stockpiles and using weighted averages is a useful tool in the mix design process, especially if multiple blends are required in order to obtain an acceptable mix. Additionally, if a particular stockpile has properties below allowable specifications, the designer knows that little or none of the material may be used in a blend. For example, because the sand equivalent of the Dayton sand is 31 percent, which is well below the specification minimum of 45 percent, it is obvious that it would be necessary to use a high percentage of Wadsworth sand or crushed fines with a small percentage of Dayton sand in a blend. One should also keep in mind that when, for example, a sand-equivalent test is performed on a blend, material from coarse aggregate stockpiles may affect the results because a small percentage of the material from coarse stockpiles would contribute to the blend.

ANTISTRIP ADDITIVE

Hydrated lime was used as an antistrip additive in all of the mix designs. The Watsonville granite is a moderate stripper. The Nevada Department of Transportation (DOT) experience with the Dayton aggregate suggested that it had the potential to strip. In order to prevent the addition of another variable into the experimental design, all mixtures were treated with 1.5 percent hydrated lime. Hydrated lime was obtained from the Chemical Lime Company.[10]

MIXTURE DESIGN

The initial mix design process was a cooperative effort between FHWA's Office of Technology Applications and the University of Nevada, Reno (UNR). All of the mix designs were conducted on the UNR campus in the Pavement/Materials Laboratory and in one of the FHWA mobile Superpave laboratories. Both Superpave and Hveem mix designs were performed in accordance with FHWA-SA-95-003 and Asphalt Institute MS-2, respectively.[12] FHWA performed the Superpave mix designs while UNR performed Hveem mix designs. It is important to realize that the initial mix design process included only the Superpave mix design (formerly Level I); Superpave mix analyses (formerly Levels II and III) were to be performed after target nonsensitive, sensitive, and supersensitive mixtures had been established.

Performing both mix design methods served several purposes. The Superpave method was performed because one of the project objectives was validation of the Superpave mix design and analysis systems. The Hveem method was used to help determine the degree of criticality of the mixtures, to include a mechanical test (stabilometer test), and, because the Superpave system was relatively new, to provide the designers a tie to one of the previous widely used procedures.

SUPERPAVE MIX DESIGN METHOD

The Superpave mix design method is a performance-based mix design method. In this method, materials requirements are a function of traffic, climate, and the depth below the surface at which the material is to be incorporated. Gradation requirements are a function of nominal maximum size aggregate. The number of gyrations applied in the gyratory compactor is a function of traffic and climate. Final mixture properties must meet specifications that are a function of nominal maximum aggregate size and traffic, along with a dust-to-binder proportion specification and a moisture sensitivity test requirement.[(11)]

HVEEM MIX DESIGN METHOD

The traditional Hveem mix design method, as defined by the Asphalt Institute,[(12)] requires a minimum stability value that is a function of traffic level and minimum air voids. It is also suggested that volumetric properties, such as voids in mineral aggregate and voids filled with asphalt, be considered when selecting the final design asphalt content.

Because Superpave mixtures were required, the material properties and mixture requirements of Superpave mixtures were applied to the Hveem mixtures also (volumetrics, dust proportion, and moisture sensitivity specifications).

MIXTURE TRIAL BLENDS

Figure 1 represents the Superpave gradation specification for 19-mm nominal maximum size aggregate blends; this is the specification all WesTrack mixtures were required to meet. Note the control points and the restricted zone on the 0.45 power chart. In the Superpave mix design method, the number of gyrations applied in the gyratory compactor is a function of climate and traffic. The planned traffic over the accelerated 3-year loading period was 10 million 80-kN (18,000-lb) ESALs, and the average design high air temperature is <39°C. Because fatigue cracking is expected in some test sections at approximately 3.5 million 80-kN (18,000-lb) ESALs, the number of initial, design, and maximum gyrations for 3 to 10 million 80-kN (18,000-lb) ESALs (8, 109, and 152, respectively) were selected for the designs. All of the Superpave mixture specifications for the project are provided in table 7.

Numerous blends of both the Watsonville and Dayton aggregates were prepared and mix design data were obtained. Complete Hveem mix designs were performed and Superpave trial compactions were performed at the estimated optimum asphalt content. Calculations were made based on the trial compactions and Superpave mix designs were performed if the estimates

suggested that a satisfactory Superpave mix would be obtained. In general, the stockpile blends were determined to:

- Produce gradations on the coarse and fine sides of the restricted zone.
- Provide different blends of natural and crushed fines.
- Use different types and/or blends of natural fines.
- Alter gradations in the 9.5-mm to 4.75-mm and 1.18-mm to 0.60-mm range.

The upper portion of table 8 represents trial blends of Watsonville material for which mix design information was obtained. The upper portion of table 9 represents fine (above the restricted zone) trial blends of Dayton material for which mix design information was obtained. The upper portion of table 10 represents the coarse (below the restricted zone) trial blends of Dayton material for which mix design information was obtained.

EXCESS FINES

Each individual stockpile was dry sieved into individual fractions and recombined to produce blends. Initially when batched, however, the blends were not adjusted for adhesion of fines to coarse aggregate, resulting in excess fines (ranging from 1.5 to 3.2 percent excess minus 0.075-mm material) in the blends. Dayton aggregate blends SPD1 to SPD11 and Watsonville aggregate blends SPW1 to SPW7 were blended without checking the washed sieve analysis of dry separated and dry blended aggregates, resulting in excess fines in the blend. This problem was recognized and corrections were made for adhesion on all subsequent mixtures; the more promising mixtures that contained the excess fines were rerun after correcting the blends for adhesion.

Low air voids, low voids in mineral aggregate, low Hveem stabilities, densities greater than 89 percent at $N_{initial}$ and greater than 98 percent at N_{max}, high dust-to-binder ratios, and general data interpretation were predominant problems in all of the mixtures with high minus 0.075-mm contents.

Tables 8, 9, and 10 reflect the actual gradations, including the excess fines. The “A” after the blend identification (e.g., SPD18A) in the tables indicates that the correction for adhesion was made. The last row in the tables indicates the percent material passing the 0.075-mm sieve that was excess, or, in other words, how much extra was in the blend. Note that the excess passing the 0.075-mm cells indicate zero for the blends with an “A” in the blend identification.

Due to the excess fines, some of the blends for which mix design data were obtained did not meet the Superpave gradation requirements. The shaded cells in tables 8 to 10 indicate where the Superpave gradation criteria were violated. Four of the Watsonville blends with excess fines encroached the restricted zone on the 1.18-mm to 0.60-mm sieves by 0.1 to 1.1 percent. Five of the fine Dayton aggregate blends exceeded the upper control point on the 0.075-mm sieve by 0.2 to 2.8 percent. Four of the coarse Dayton aggregate blends encroached the restricted zone on the 0.60-mm sieve by 0.4 to 1.7 percent; one of these blends also exceeded the upper control point on the 0.075-mm sieve by 1.1 percent.

The lower portion of tables 8, 9, and 10 summarize mix design data for the Watsonville blends, fine Dayton blends, and coarse Dayton blends, respectively. The upper portion of the tables restate the stockpile percentages and the actual blends. The lower portion represents the Superpave and Hveem mix design data. The section labeled "Superpave Actual" is data on compacted specimens at the initial estimated optimum asphalt content. The "Superpave Estimated" section represents mixture properties based on the compacted specimens. The Hveem mix design data represent properties at the optimum asphalt content from Hveem mix designs.

WATSONVILLE GRANITE MIXTURES

Superpave mix design results suggested that a Watsonville granite nonsensitive mixture would most likely be produced on the coarse side of the restricted zone even though several of the blends attempted contained higher minus 0.075-mm than the stockpile blend percentages suggested. Common problems included low air voids, low voids in mineral aggregate, excess density at $N_{initial}$ and N_{max}, and low asphalt contents and high dust-to-binder ratios.

Similar problems, along with low stability, existed for the Hveem mix designs that contained excess fines. Two of the mixtures (SPW7A and SPW9A) that were corrected for fines had adequate stability, air voids, and asphalt contents, but low voids in mineral aggregate (VMA). The low VMA is partially a result of using a low bulk specific gravity for the fine aggregate. There is probably no geologic or other reason why the specific gravity of the fine aggregate was lower than the coarse, other than the bias of the fine aggregate specific gravity test method. The FHWA, UNR, and the Asphalt Institute all performed specific gravity tests that produced similar results.

A third mixture (SPW19A) appeared to be adequate from a Hveem mix design standpoint, with the exception of voids in mineral aggregate being 0.2 percentage points below the Superpave specification of 13. The gradation is an exaggerated "S" curve on the 0.45 power chart, which would produce an "open" mixture.

The Asphalt Institute had been performing Superpave mixture designs for industry with the Watsonville granite at the same time. At that time, the closest the Asphalt Institute had come to producing a Superpave mix was with a blend identical to that of SPW19A, with the exclusion of the 1.5 percent hydrated lime. The mixture did not meet the Superpave VMA criteria and had a relatively low asphalt content.

The University of California at Berkeley (UCB) had used the Watsonville granite for research over the last 30 years in addition to using it during the Strategic Highway Research Program. A limited study using identical gradations and asphalt cements to those used during the SHRP research compared Hveem mix design results with the 1995 production of Watsonville aggregates to Hveem mix design results from SHRP research. The comparison indicated that the 1995-produced Watsonville granite resulted in mixtures with stability values of about 30, compared to the high 30s for the aggregate produced during the SHRP research. At that point, the decision was made to abandon the use of the Watsonville granite and to produce all the mixtures with Dayton aggregates.

FINE DAYTON AGGREGATE MIXTURES

Fine Dayton aggregate blends were selected to produce the sensitive and supersensitive or higher fines content mixture. The ideal sensitive mixture would have adequate stability at the design asphalt cement content and would rapidly drop in stability as asphalt content increased. A sensitive mixture also is characterized by rapid decreases in air voids with an increase in asphalt content and marginal VMA.

The Superpave mix design results on fine Dayton aggregate mixtures with excess fines (SPD1, SPD2, SPD3, and SPD6) exhibited low air voids, low voids in mineral aggregate, excess density at $N_{initial}$ and N_{max}, low asphalt contents, and high dust-to-binder ratios. The Hveem results (SPD4, SPD5, SPD7, and SPD11) were, in general, characterized by low stability, rapid drops in stability, low VMA, and high dust-to-binder ratios. When the excess fines were removed from some of the mixtures (SPD7 and SPD7A, SPD8 and SPD8A, and SPD11 and SPD11A), large changes in stability, and in some cases air voids, occurred. Table 9 summarizes the mix design data. The removal of the excess fines also reduced the stability loss as a function of an increase in asphalt cement content. The Hveem results suggested that sensitive mixtures, as defined by Hveem criteria, could be designed with these aggregates. Mixtures SPD8A, SPD16A, and SPD22A were all high-stability mixtures and came close to meeting other mix design criteria at the optimum asphalt content as determined by the Hveem method. These mixtures, along with SPD10A, were targeted for further analysis with the Superpave mix design method.

Because the removal of excess fines substantially improved mixture properties, it was decided that fines in addition to the excess fines would be removed in order to produce mixtures that met all Superpave criteria. The removal of material passing the 0.075-mm sieve was easily achieved in the laboratory during the aggregate batching process. During construction, the baghouse return system could be used to remove material passing the 0.075-mm sieve. Table 11 summarizes gradation and mix design results for the fine Dayton aggregate mixtures with fines removed. The blend identifications have a minus sign and a number following the adjusted blend identification (e.g., SPD16A-2.0), which indicates the percent material passing the 0.075-mm sieve removed from the blend. Note the last two rows of the gradation: the excess passing the 0.075-mm cells are all zeroes and the 0.075-mm removed cells indicate the percent removed from the blend. This produced a fine mixture (SPD16A-2.0) that met all of the Superpave criteria.

In obtaining a fine Superpave mixture, the sensitivity of the mixture became an issue. With the fines removed (SPD16A-2.0), the mixture was no longer as sensitive as was hoped. Figure 2 summarizes the Superpave mix design data. The mixture does not appear to be very sensitive and little change in Hveem stability was observed with increased asphalt content.

Based on experience with the effects of fines on these mixtures and considering that one of the project objectives was to evaluate the impact on performance of deviations in materials, it was decided that the supersensitive, or high fines, mixture would be developed by increasing the amount of material passing the 0.075-mm sieve in mixture SPD16A while holding the optimum asphalt content constant. One percent passing the 0.075-mm sieve was added to mixture SPD16A to develop the supersensitive mixture (see SPD16A+1.0 in table 11). It should be

noted that the supersensitive mixture did not meet all of the Superpave specifications. The mixture met Hveem requirements, but the dust-to-binder ratio and percent density at $N_{initial}$ and N_{design} were slightly violated in the Superpave mix design.

COARSE DAYTON AGGREGATE MIXTURES

The Superpave mix designs on coarse Dayton aggregate mixtures with excess fines exhibited low air voids, low voids in mineral aggregate, excess density at $N_{initial}$ and N_{max}, and high dust-to-binder ratios. Mixtures SPD3 and SPD18A were the most promising from a Superpave perspective.

The Hveem results on mixtures with excess fines were characterized by low stability, low air voids, low VMA, and high dust-to-binder ratios. With excess fines removed, many of the mixture (SPD6A, SPD15A, SPD19A, SPD20A, and SPD21A) tests in the Hveem method met all of the volumetric criteria, but failed the minimum stability criteria of 37. Only SPD18A met the stability criteria. Because the stabilometer test criteria were developed around dense mixtures, it may not have been appropriate for more open or exaggerated "S" shaped gradations similar to coarse (below the restricted zone) Superpave mixtures. Although SPD18A met all the Hveem criteria, it was marginal on VMA and failed the dust-to-binder ratio specification in the Superpave mix design method. Table 10 summarizes both the Superpave and Hveem mix design data.

It was again decided that the removal of fines would be necessary in order to produce an acceptable Superpave mixture. Mixtures SPD3A and SPD18A were further investigated with the Superpave method. Estimates based on trial compactions suggested that both SPD3 and SPD18A would produce acceptable mixes, but that SPD3A would require a higher optimum asphalt content. SPD18A with 2.5 percent of the material passing the 0.075-mm sieve removed from the blend (SPD18A-2.5) produced a mixture that met the Superpave criteria. Table 12 summarizes the mix design results on coarse Dayton mixtures with material in addition to the excess removed from the blends, and figure 3 represents the Superpave mix plots for SPD18A-2.5.

The three final blends selected are presented in figure 4. The Hveem mix design data at the optimum asphalt content, as established by the Superpave mix designs, are presented in table 13.

MOISTURE SENSITIVITY TESTING

Moisture sensitivity testing at the optimum asphalt content was performed on the three mixtures. All of the mixtures had retained strength ratios greater than 80 percent when hydrated lime was used as an antistrip agent.

SUMMARY

This report presented the development of target nonsensitive, sensitive, and supersensitive mix designs for the WesTrack project. Two aggregate sources and over 25 19-mm maximum

nominal size Superpave aggregate blends were evaluated in Superpave and/or Hveem mix design methods before two Superpave mixtures were produced.

Early in the mix design process, each individual stockpile was dry-sieved into individual fractions and recombined to produce blends for mix designs. However, when batched, the blends were not adjusted for adhesion of fines to coarse aggregate, resulting in excess fines (ranging from 1.5 to 3.2 percent excess 0.075-mm materials) in the blends. The problem was recognized and corrected.

Mixtures with these excess "adhesion fines" revealed sensitivity of mixture properties to the percent material passing the 0.075-mm (No. 200) sieve in the Superpave mix design system, regardless of whether the mixtures were coarse or fine. Air voids; voids in mineral aggregate; density at $N_{initial}$, N_{design}, and N_{max}; and dust-to-binder ratio, along with Hveem stability, were affected by excess fines. Significant changes in mixture properties were observed when adjustments (corrections for excess) of 1.5 to 2.5 percent material passing the 0.075-mm sieve were made.

This prompted the designers to remove fines from blends in addition to the excess adhesion fines in an attempt to improve marginal mixture properties. The approach was successful in producing both coarse and fine mixtures that met all Superpave and Hveem criteria. The removal of material passing the 0.075-mm sieve was easily achieved in the laboratory while batching; during construction the return on the baghouse system could be employed to remove material passing the 0.075-mm sieve.

It is important to note that when developing fine mixtures to meet Superpave requirements, a clean (washed) sand had to be introduced, in lieu of crushed fine or natural sand, at the 25 percent level. This 25 percent level is at the high side or exceeds current specification levels.

The final mixtures were produced by removal of 2.0 and 2.5 percent of the material passing the 0.075-mm sieve from the sensitive and nonsensitive mixtures (blends SPD16A and SPD18A), respectively. It should be noted that the sensitive mix was much less sensitive than desired when the adjustment in material passing the 0.075-mm sieve was made to achieve acceptable Superpave properties. This is a very positive aspect of Superpave, but not a positive aspect for evaluating the impact on performance of deviations in materials properties from design values. One percent passing the 0.075-mm sieve was added to the critical mix (SPD16A) blend. This closed the voids to produce the supersensitive mixture at the same optimum percent asphalt. The mixture met Hveem requirements, but the dust-to-binder ratio and percent density at $N_{initial}$ and N_{design} were slightly violated in the Superpave mix design.

Of the two aggregate sources evaluated, only the Dayton aggregate source was used to produce the final mix designs. Surprisingly, it was not possible to obtain a Superpave mix with the Watsonville granite, which greatly exceeded all of the Superpave consensus aggregate test requirements. The Watsonville granite aggregate has been successfully used by the California DOT for years. The aggregate is very blocky and even with the use of exaggerated "S-shape" blends, which typically help increase VMA, the Watsonville granite generated mixes with low VMA and low asphalt contents. This suggested that meeting all Superpave aggregate

specifications did not necessarily guarantee a Superpave mixture could be produced with the aggregate.

VMA is determined using the bulk specific gravity of an aggregate blend. Because of the difficulty in accurately measuring the bulk specific gravity of highly crushed absorptive aggregates, artificially low bulk specific gravities are typically reported. This leads to low VMA values.

Mixture design designations and field mixture designations are different. During the mixture design process, the terms sensitive, supersensitive, and nonsensitive were used to describe the desired mixture response to changes in asphalt binder content, percent passing 0.075-mm sieve, etc., as described above. At the conclusion of the mixture design process and based primarily on the Hveem test results over a range of asphalt contents, it was apparent that the "sensitive" mix was not sensitive and the "nonsensitive" mix was sensitive. Mixture designations were, therefore, changed during the conduct of the research, as shown in table 14. The terms fine, fine plus, and coarse were utilized to describe the relative amounts of aggregate in the gradations utilized.

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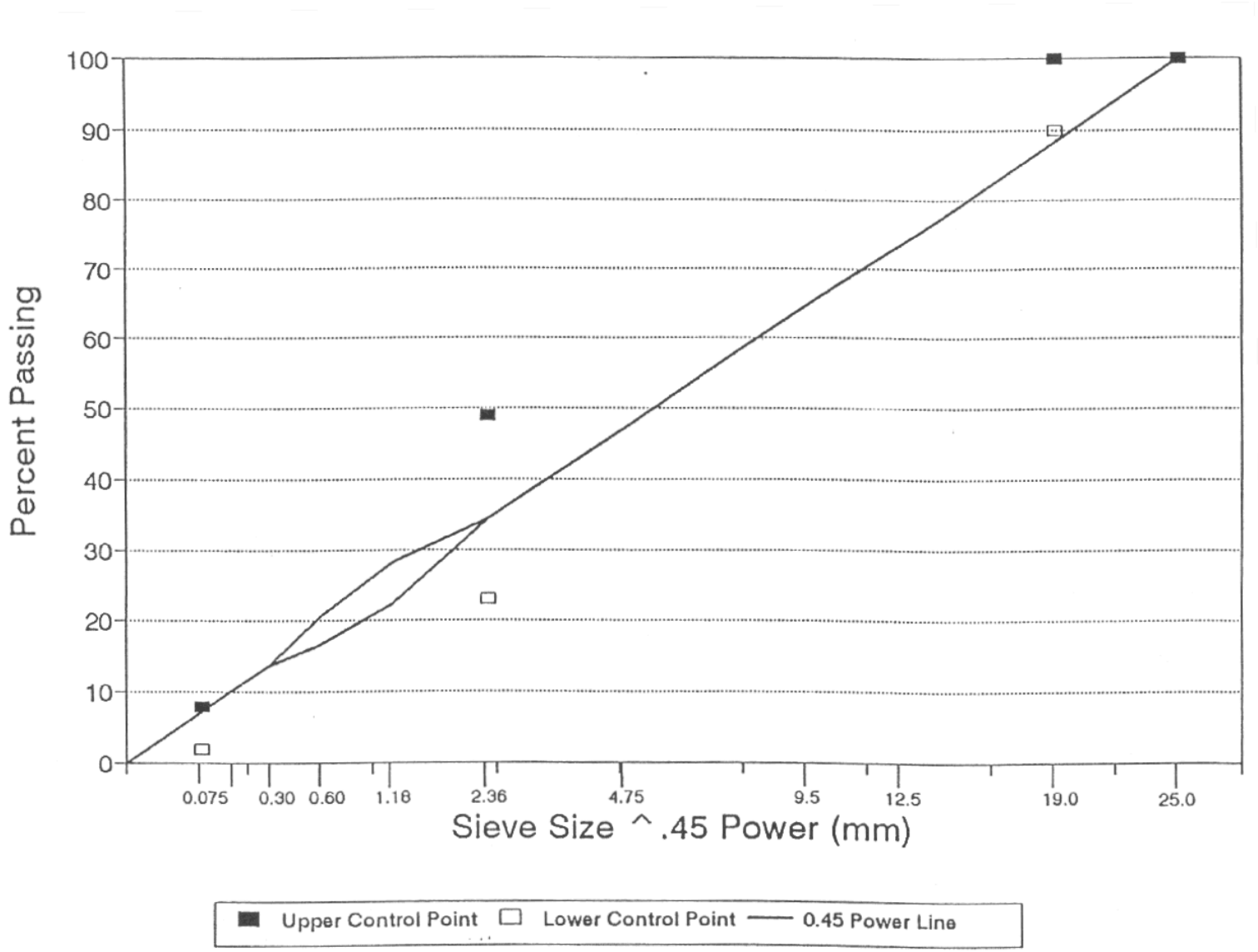


Figure 1. Superpave 19-mm nominal maximum size gradation specification.

FHWA

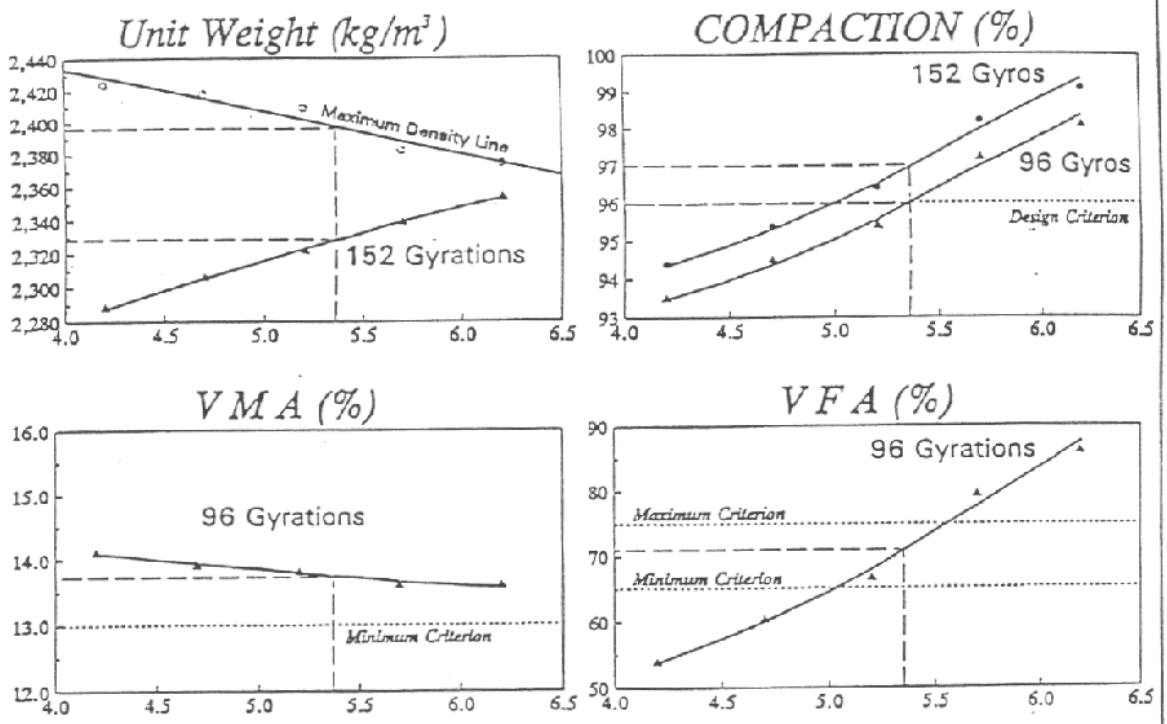
SUPERPAVE™

OTA

LEVEL 1 MIX DESIGN

PROJECT #9511B, Blend #(16A-2.0)

Critical (Fine) Mix, 19mm Surface



			COMPACTION				
AC % of Total Mix	Unit Wt. kg/m³	Max.Den. kg/m³	Initial (%)	Design (%)	Maximum (%)	VMA (%)	VFA (%)
4.2	2,288	2,424	87.6	93.5	94.4	14.1	53.9
4.7	2,306	2,418	88.4	94.5	95.4	13.9	60.4
5.2	2,322	2,409	89.2	95.4	96.4	13.8	66.7
5.7	2,339	2,383	90.7	97.2	98.2	13.6	79.4
6.2	2,354	2,375	91.4	98.1	99.1	13.6	86.0

VALUES AT DESIGN AC CONTENT

5.4	*2329*	*2397*	*89.8*	*96.0*	*97.0*	*13.7*	*71.0*
Design Criteria =			*< 89*	*= 96*	*< 98*	*> 13*	*65-75*

Figure 2. SPD16A-2.0 Superpave mix design plots.

FHWA

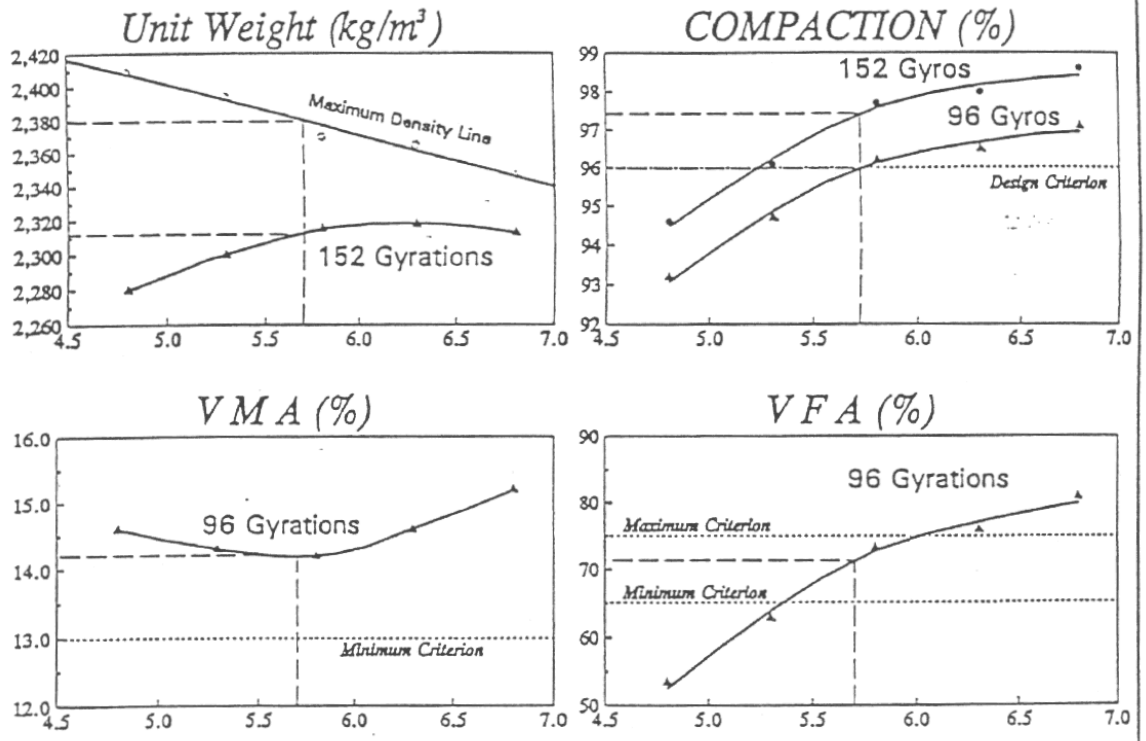
SUPERPAVE™

OTA

LEVEL 1 MIX DESIGN

PROJECT #9511B, Blend #(18A-2.5)

Non-Critical (Coarse) Mix, 19mm Surface



			COMPACTION				
AC % of Total Mix	Unit Wt. kg/m³	Max.Den. kg/m³	Initial (%)	Design (%)	Maximum (%)	VMA (%)	VFA (%)
4.8	2,280	2,409	84.0	93.2	94.6	14.6	53.4
5.3	2,300	2,394	85.4	94.7	96.1	14.3	62.9
5.8	2,315	2,370	86.6	96.2	97.7	14.2	73.2
6.3	2,318	2,365	86.9	96.5	98.0	14.6	76.0
6.8	2,313	2,347	88.0	97.1	98.6	15.2	80.9

VALUES AT DESIGN AC CONTENT

5.7	*2312*	*2380*	*86.3*	*96.0*	*97.3*	*14.2*	*71.0*
Design Criteria =			*< 89*	*= 96*	*< 98*	*> 13*	*65-75*

Figure 3. SPD18A-2.5 Superpave mix design plots.
Figure 4. Final mixture gradations.

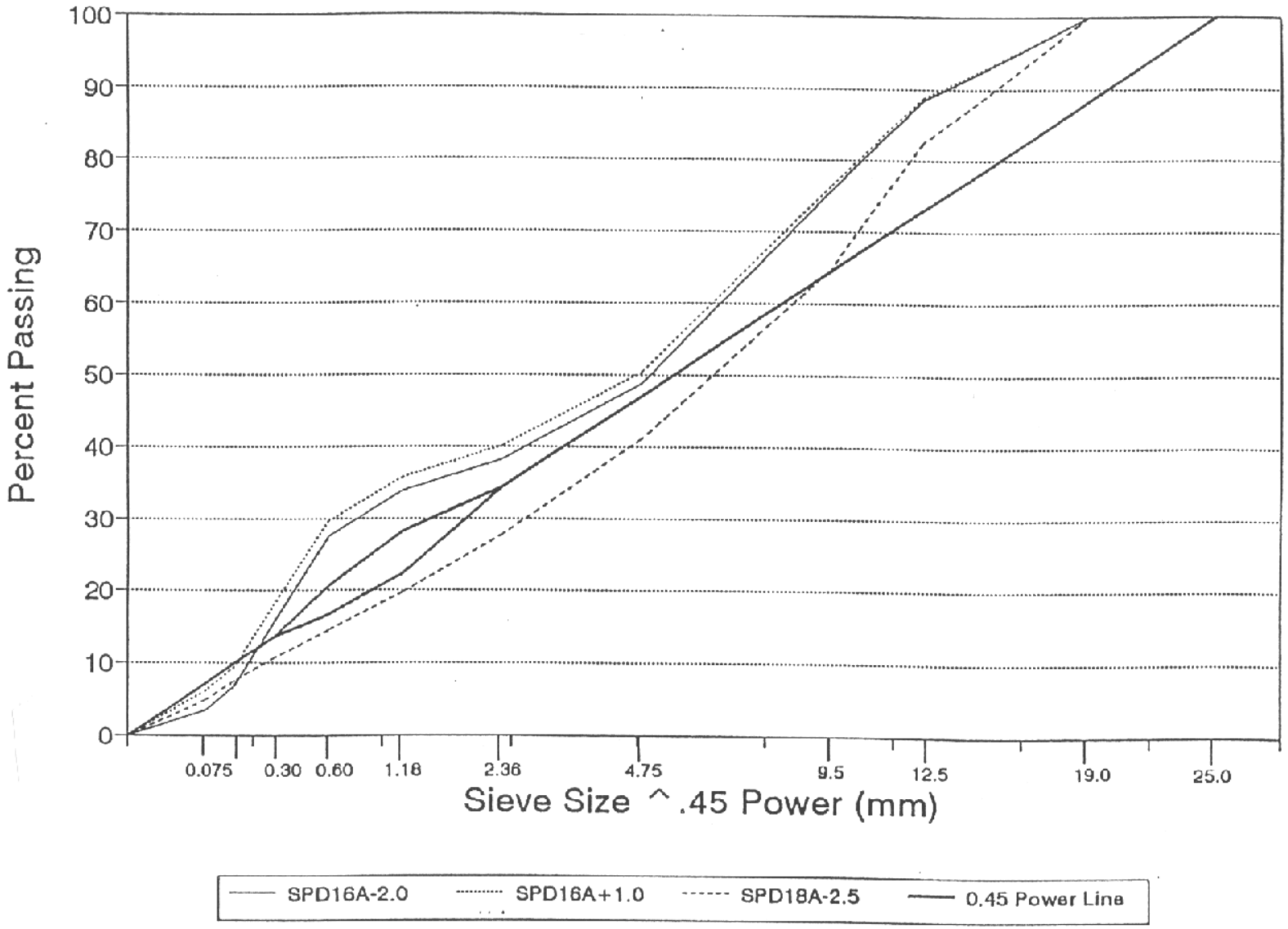

100
90
80
70
60
50
40
30
20
10
0
Percent Passing
0.075
0.30
0.60
1.18
2.36
4.75
9.5
12.5
19.0
25.0
Sieve Size ^ .45 Power (mm)
SPD16A-2.0
SPD16A+1.0
SPD18A-2.5
0.45 Power Line

Table 1. WesTrack factorial experiment design.

Target Air Void Content	Aggregate Gradation								
	Nonsensitive			Sensitive			Supersensitive		
	Target Asphalt Content								
	Low	Med	High	Low	Med	High	Low	Med	High
Low		23*	25		04	18		12	09,21
Med	08	05,24	07	02	01,15	14	22	11,19	13
High	26	06		03,16	17		10	20	

*Indicates section number.

Table 2. Dayton aggregate average stockpile gradations.

Sieve Size		Material					
		19-mm Gravel	12-mm Gravel	9-mm Gravel	Crushed Fines	Dayton Sand	Wadsworth Sand
mm	US	Cumulative Percent Passing					
25	1”	100	100	100	100	100	100
19	3/4”	99.8	100	100	100	100	100
12.5	1/2”	63.5	99.9	100	100	100	100
9.5	3/8”	33.7	82.6	97.7	100	100	100
4.75	#4	10.8	19.5	29.8	99.1	96.5	99.7
2.36	#8	5.0	4.3	6.4	76.6	78.9	99.0
1.18	#16	4.3	3.2	5.0	54.1	62.1	96.0
0.60	#30	4.0	2.9	4.4	39.2	45.0	79.9
0.30	#50	3.7	2.6	3.9	28.7	28.9	40.1
0.15	#100	3.4	2.4	3.4	20.3	17.9	11.0
0.075	#200	3.0	2.0	2.8	13.9	11.5	3.0

Table 3. Watsonville aggregate average stockpile gradations.

Sieve Size		Material			
		19-mm x 12-mm	12-mm x 6-mm	6-mm x 2-mm	Crushed Washed Sand
mm	US	Cumulative Percent Passing			
25	1”	100	100	100	100
19	3/4”	81.7	100	100	100
12.5	1/2”	30.0	94.7	100	100
9.5	3/8”	12.0	69.7	100	100
4.75	#4	4.2	6.6	71.0	99.9
2.36	#8	2.7	2.7	23.2	91.6
1.18	#16	2.3	2.1	14.5	66.0
0.60	#30	2.1	1.8	11.4	43.2
0.30	#50	1.9	1.6	9.5	23.8
0.15	#100	1.6	1.4	7.7	8.3
0.075	#200	1.1	1.0	5.7	3.6

Table 4. Average aggregate specific gravities.

Dayton Aggregates	
Material	**Bulk Specific Gravity**
19 mm gravel	2.539
12 mm gravel	2.553
9 mm gravel	2.519
Crushed fines	2.438
Dayton sand	2.472
Wadsworth sand	2.569
Watsonville Aggregates	
19 mm x 12 mm	2.774
12 mm x 6 mm	2.724
6 mm x 2 mm	2.537
Crushed washed sand	2.570

Table 5. Average aggregate consensus properties.

Material	Fine Aggregate Angularity (%)	Coarse Aggregate Angularity (%)	Flat or Elongated Particles (%)	Sand Equivalent (%)
Dayton Aggregates				
19 mm gravel	n/a	98.9 / 95.4	0.2	n/a
12 mm gravel	n/a	99.7 / 98.9	2.0	n/a
9 mm gravel	n/a	98.2 / 96.4	n/a	n/a
Crushed fines	47.6	n/a	n/a	49.0
Dayton sand	44.5	n/a	n/a	31.0
Wadsworth sand	44.0	n/a	n/a	74.0
Watsonville Aggregates				
19 mm x 12 mm	n/a	100 / 100	0.7	n/a
12 mm x 6 mm	n/a	100 / 100	0.3	n/a
6 mm x 2 mm	45.6	n/a	n/a	n/a
Crushed washed sand	46.8	n/a	n/a	81

Table 6. Superpave aggregate consensus specifications for WesTrack Project.

Property	Specification (%)*
Fine aggregate angularity	$\geq$ 45
Coarse aggregate angularity	$\geq$ 85 / 80
Flat and elongated particles	$\leq$ 10
Sand equivalent	$\geq$ 45

*3 to 10 million ESALs.

Table 7. Superpave mix specifications.*

Mixture Property	Criteria
% Air voids	4%
% Voids in mineral aggregate	13% minimum
% Voids filled with asphalt	65% - 75%
Dust-to-binder ratio	0.6 - 1.2
% Gmm @ $N_{initial}$ = 8	less than 89%
% Gmm @ N_{design} = 96	96%
% Gmm @ N_{max} = 152	less than 98%

*3 to 10 million ESALs.

Table 8. Gradation and mixture design data for trial blends of Watstonville aggregate.

	BLEND ID											
	SPW1	SPW2	SPW3	SPW4	SPW5	SPW6	SPW7	SPW7A	SPW8	SPW9	SPW9A	SPW19A
STOCKPILE	STOCKPILE PERCENTAGES											
19mm x 12mm	18.5	15.5	45.0	47.0	37.5	20.5	47.0	47.0	35.0	12.0	12.0	15.0
12mm x 6mm	10.0	35.0	15.0	24.0	5.0	30.0	24.0	24.0	0.0	30.0	30.0	40.0
6mm x 2mm	30.0	30.0	18.5	0.0	34.0	25.0	8.0	8.0	25.0	35.0	35.0	28.5
Crushed Washed Sand	40.0	18.0	20.0	27.5	22.0	23.0	19.5	19.5	38.5	21.5	21.5	15.0
Hydrated Lime	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Coarse or Fine	F	C	C	C	C	C	C	C	F	C	C	C

SIEVE SIZE		BLEND ID											
		SPW1	SPW2	SPW3	SPW4	SPW5	SPW6	SPW7	SPW7A	SPW8	SPW9	SPW9A	SPW19A
(mm)	(US)	(CUMULATIVE PERCENT PASSING)											
25.0	1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	3/4"	96.7	97.3	91.9	91.5	93.2	96.3	91.5	91.4	93.8	97.8	97.8	97.3
12.5	1/2"	86.9	87.8	68.2	68.3	73.9	84.4	66.3	65.8	76.2	90.2	90.0	87.4
9.50	3/8"	81.3	76.3	56.6	52.1	68.1	73.4	52.1	51.4	70.1	80.7	80.4	74.7
4.75	#4	65.3	44.9	38.5	33.5	50.3	46.1	31.2	30.2	60.4	51.1	50.3	40.0
2.36	#8	47.8	27.8	26.9	29.7	31.9	30.9	24.2	23.1	45.1	31.5	30.4	23.3
1.18	#16	35.0	20.5	20.0	22.4	21.2	22.8	18.3	17.1	33.3	22.9	21.7	16.7
0.60	#30	25.2	15.4	14.9	16.1	17.2	16.8	13.6	12.3	24.0	16.5	15.6	12.3
0.30	#50	17.0	11.3	10.5	10.6	12.2	11.8	9.5	8.1	16.2	12.0	10.6	8.7
0.15	#100	10.3	7.5	6.9	6.1	8.1	7.8	6.1	4.7	9.7	7.9	6.4	5.6
0.075	#200	7.7	6.1	5.1	4.4	6.0	5.7	4.5	3.1	7.2	5.9	4.4	3.9
Excess p0.075mm		3.2	2.1	1.8	1.5	1.7	1.8	1.5	0.0	3.0	1.8	0.0	0.0

Superpave	BLEND ID											
Actual	SPW1	SPW2	SPW3	SPW4	SPW5	SPW6	SPW7	SPW7A	SPW8	SPW9	SPW9A	SPW19A
% AC (twm)	5.0	5.0	5.0	5.0	4.7	4.7	4.7		4.7	4.7		
% Air Voids	1.5	1.0	0.3	0.3	0.3	0.9	1.2		1.2	1.2		
% Gmm @ Ni	90.5	88.6	91.1	90.6	92.6	90.1	87.3		91.3	88.6		
% Gmm @ Nm	99.8	100.0	100.0	100.0	100.0	99.8	100.0		99.8	100.0		
% VMA	10.4	9.8	9.5	10.2	8.5	9.0	11.0		10.3	10.1		
Superpave	BLEND ID											
Estimated	SPW1	SPW2	SPW3	SPW4	SPW5	SPW6	SPW7	SPW7A	SPW8	SPW9	SPW9A	SPW19A
% AC	4.0	3.8	3.5	3.5	3.2	3.5	3.8		3.8	3.6		
% Air Voids	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0		
% Gmm @ Ni	88.0	85.6	87.4	86.9	88.9	87.0	84.5		88.5	85.8		
% Gmm @ Nm	97.1	97.0	96.3	96.3	96.3	96.7	97.2		97.0	97.2		
% VMA	10.7	10.1	9.9	10.8	8.9	9.3	11.3		10.6	10.4		
% VFA	62.0	60.0	59.0	62.0	55.0	57.0	65.0		62.0	61.0		
% Effective AC	2.7	2.4	2.2	2.5	1.8	2.0	2.9		2.7	2.6		
Fines/Eff AC	1.71	1.69	1.61	1.20	2.41	1.97	1.08		1.66	1.71		
Hveem Mix	BLEND ID											
Design	SPW1	SPW2	SPW3	SPW4	SPW5	SPW6	SPW7	SPW7A	SPW8	SPW9	SPW9A	SPW19A
% AC (dwa)	4.5	4.0	4.0				4.0	4.0		4.2	4.4	4.5
% Air Voids	4.0	3.0	2.8				3.0	4.0		4.0	4.0	4.0
% VMA	10.7	8.7	9.5				10.8	10.8		10.4	10.6	12.8
% VFA	62.0	67.0	71.0				76.0	63.0		55.0	65.0	68.0
Stability	37	24	17				32	37		45	40	42

Table 9. Gradation and mixture design data for fine trial blends of Dayton aggregate (above the restricted zone).

	B BLEND ID															
	SPD4	SPD5	SPD7	SPD7A	SPD8	SPD8A	SPD9	SPD10	SPD10A	SPD11	SPD11A	SPD12A	SPD13A	SPD16A	SPD22A	SPD23A
STOCKPILE	STOCKPILE PERCENTAGES															
19mm gravel	33.5	38.5	43.5	43.5	31.0	31.0	30.5	28.0	28.0	35.0	35.0	30.0	28.0	31.0	28.5	39.0
12mm gravel	15.0	0.0	10.0	10.0	19.0	19.0	15.0	12.0	12.0	0.0	0.0	7.0	12.0	19.0	19.0	10.0
6mm gravel	10.0	15.0	10.0	10.0	10.0	10.0	15.0	16.0	16.0	21.0	21.0	21.0	16.0	10.0	10.0	10.0
Crushed Fines	20.0	20.0	10.0	10.0	18.5	18.5	6.0	14.0	14.0	33.5	33.5	32.5	14.0	13.5	26.0	22.5
Dayton Sand	10.0	15.0	5.0	5.0	0.0	0.0	0.0	28.5	28.5	0.0	0.0	0.0	20.0	0.0	0.0	0.0
Wadsworth Sand	10.0	10.0	20.0	20.0	20.0	20.0	32.0	0.0	0.0	9.0	9.0	8.0	8.5	25.0	15.0	17.0
Hydrated Lime	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

SIEVE SIZE		BLEND ID															
		SPD4	SPD5	SPD7	SPD7A	SPD8	SPD8A	SPD9	SPD10	SPD10A	SPD11	SPD11A	SPD12A	SPD13A	SPD16A	SPD22A	SPD23A
(mm)	(US)	(CUMULATIVE PERCENT PASSING)															
25.0	1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	3/4"	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
12.5	1/2"	88.2	86.3	84.5	84.1	89.0	88.7	89.1	90.1	89.8	87.5	87.2	89.0	89.8	88.7	89.6	85.8
9.50	3/8"	75.6	74.9	69.9	69.2	76.5	75.9	77.3	79.6	79.0	76.8	76.3	78.4	79.0	75.9	77.6	72.2
4.75	#4	52.0	56.0	47.2	45.9	51.2	50.0	51.2	54.5	53.1	54.9	54.0	52.8	53.4	49.9	52.2	50.1
2.36	#8	39.4	43.2	37.7	36.2	39.9	38.5	42.2	39.6	37.7	40.4	39.2	37.5	39.4	39.6	39.1	38.6
1.18	#16	32.6	35.7	33.5	31.9	34.7	33.1	39.3	31.3	29.2	32.2	30.8	29.3	32.0	35.2	32.3	32.5
0.60	#30	26.2	28.6	27.8	26.1	28.7	27.0	33.2	24.3	22.0	25.8	24.1	23.0	24.9	29.0	25.8	26.2
0.30	#50	18.5	20.2	18.1	16.1	18.8	16.8	19.9	18.2	15.7	18.4	16.8	16.1	16.8	17.4	16.8	16.8
0.15	#100	12.7	13.8	10.8	8.5	11.3	9.2	10.0	13.8	11.1	12.7	11.0	10.7	10.5	8.7	10.0	9.7
0.075	#200	9.6	10.5	7.8	5.6	8.2	6.0	6.8	10.8	8.0	9.6	7.8	7.6	7.3	5.5	6.8	6.6
Excess p0.075mm		3.0	3.2	2.4	0.0	2.4	0.0	2.2	3.2	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0

Superpave Actual	BLEND ID															
	SPD4	SPD5	SPD7	SPD7A	SPD8	SPD8A	SPD9	SPD10	SPD10A	SPD11	SPD11A	SPD12A	SPD13A	SPD16A	SPD22A	SPD23A
% AC (twm)			5.8		5.8	5.0	5.5		5.5			5.5			5.0	
% Air Voids			0.5		1.0	2.7	0.7		1.5			0.4			1.4	
% Gmm @ Ni			93.0		91.9	89.8	92.7		89.5			91.6			90.8	
% Gmm @ Nm			99.9		99.8	98.3	100.0		99.7			100.0			99.5	
% VMA			11.1		11.5	11.1	10.0		12.5			10.0			9.8	

Superpave Estimated	BLEND ID															
	SPD4	SPD5	SPD7	SPD7A	SPD8	SPD8A	SPD9	SPD10	SPD10A	SPD11	SPD11A	SPD12A	SPD13A	SPD16A	SPD22A	SPD23A
% AC			4.4		4.6	4.6	4.2		4.5			4.1			4.0	
% Air Voids			4.0		4.0	4.0	4.0		4.0			4.0			4.0	
% Gmm @ Ni			89.5		88.9	88.8	89.4		87.0			88.0			88.2	
% Gmm @ Nm			96.4		96.8	97.0	96.7		97.2			96.4			96.9	
% VMA			11.5		11.8	11.5	10.3		12.8			10.4			10.1	
% VFA			65.0		66.0	65.0	61.0		69.0			61.0			60.0	
% Effective AC			3.2		3.4	3.3	3.3		3.9			2.7			2.8	
Fines/Eff AC			1.75		1.78	1.84	1.44		1.54			2.24			2.66	

Hveem Mix Design	BLEND ID															
	SPD4	SPD5	SPD7	SPD7A	SPD8	SPD8A	SPD9	SPD10	SPD10A	SPD11	SPD11A	SPD12A	SPD13A	SPD16A	SPD22A	SPD23A
% AC (dwa)	4.5	4.5	5.0	4.5	4.5	5.0		5.5		5.0	5.5		5.5	4.7	5.2	4.5
% Air Voids	3.6	4.1	2.0	3.6	4.2	4.0		4.2		4.1	4.0		4.0	4.0	4.0	3.4
% VMA	11.1	11.0	10.6	11.5	12.1	12.5		14.0		12.0	13.3		13.7	12.4	12.0	11.3
% VFA	68.0	62.8	84.6	68.2	66.0	66.0		59.0		62.0	66.0		65.0	64.0	66.0	71.0
Stability	23	34	10	39	36	40		44		42	40		41	44	39	44

Table 10. Gradation and mixture design data for coarse trial blends of Dayton aggregate (below the restricted zone).

	BLEND ID											
	SPD1	SPD2	SPD2A	SPD3	SPD3A	SPD6	SPD6A	SPD15A	SPD18A	SPD19A	SPD20A	SPD21A
STOCKPILE	STOCKPILE PERCENTAGES											
19mm gravel	33.0	43.5	43.5	40.5	40.5	28.0	28.0	35.0	47.0	30.0	34.0	30.0
12mm gravel	21.5	15.0	15.0	18.0	18.0	30.5	30.5	18.5	19.0	31.5	20.5	27.5
6mm gravel	21.0	15.0	15.0	20.0	20.0	18.0	18.0	15.0	0.0	8.0	14.0	10.0
Crushed Fines	8.0	15.0	15.0	10.0	10.0	8.0	8.0	32.0	32.5	9.0	15.0	21.0
Dayton Sand	10.0	10.0	10.0	0.0	0.0	8.0	8.0	0.0	0.0	20.0	15.0	10.0
Wadsworth Sand	5.0	0.0	0.0	10.0	10.0	8.0	8.0	0.0	0.0	0.0	0.0	0.0
Hydrated Lime	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

SIEVE SIZE		BLEND ID											
		SPD1	SPD2	SPD2A	SPD3	SPD3A	SPD6	SPD6A	SPD15A	SPD18A	SPD19A	SPD20A	SPD21A
(mm)	(US)	(CUMULATIVE PERCENT PASSING)											
25.0	1"	100	100	100	100	100	100	100	100	100	100	100	100
19.0	3/4"	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
12.5	1/2"	88.2	84.5	84.1	85.8	85.2	89.9	89.7	87.2	82.8	89.0	87.6	89.0
9.50	3/8"	74.5	69.1	68.2	70.3	69.6	76.2	75.7	73.6	65.5	74.4	73.6	75.1
4.75	#4	39.6	39.9	38.2	36.9	35.3	38.8	37.5	44.9	42.7	41.6	42.8	43.7
2.36	#8	26.2	26.8	24.7	25.0	23.1	25.3	23.7	29.4	29.8	27.5	28.3	28.8
1.18	#16	21.9	21.2	18.9	21.8	19.8	21.3	19.6	21.6	21.7	21.5	21.7	21.7
0.60	#30	18.0	17.1	14.7	18.4	16.4	17.8	15.8	16.5	16.7	16.5	16.7	16.7
0.30	#50	13.3	13.7	11.2	13.3	11.1	12.9	11.0	13.0	13.0	12.1	12.4	12.6
0.15	#100	9.9	11.1	8.5	9.3	7.0	9.4	7.4	9.9	10.0	8.8	9.2	9.4
0.075	#200	7.9	9.1	6.5	7.4	5.1	7.4	5.4	7.5	7.5	6.5	6.9	7.0
Excess p0.075mm		2.4	2.9	0.0	2.5	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0

Superpave	BLEND ID											
Actual	SPD1	SPD2	SPD2A	SPD3	SPD3A	SPD6	SPD6A	SPD15A	SPD18A	SPD19A	SPD20A	SPD21A
% AC (twm)	5.8	5.8		5.8	6.0	5.8	5.8					
% Air Voids	3.4	3.9		3.3	4.3	3.8	4.3					
% Gmm @ Ni	85.9	85.3		86.5	86.6	85.1	85.1					
% Gmm @ Nm	98.3	97.7		98.2	97.3	97.9	97.4					
% VMA	14.1	14.0		14.1	15.3	14.5	14.9					
Superpave	BLEND ID											
Estimated	SPD1	SPD2	SPD2A	SPD3	SPD3A	SPD6	SPD6A	SPD15A	SPD18A	SPD19A	SPD20A	SPD21A
% AC	5.8	5.8		5.5	6.1	5.7	5.9					
% Air Voids	4.0	4.0		4.0	4.0	4.0	4.0					
% Gmm @ Ni	85.3	85.2		85.8	86.8	84.9	85.4					
% Gmm @ Nm	97.7	97.6		97.5	97.5	97.7	97.7					
% VMA	14.2	14.0		14.2	15.3	14.5	14.8					
% VFA	72.0	71.0		72.0	74.0	72.0	73.0					
% Effective AC	4.5	4.5		4.8	5.1	4.7	4.9					
Fines/Eff AC	1.44	1.62		1.26	1.00	1.15	1.10					
Hveem Mix	BLEND ID											
Design	SPD1	SPD2	SPD2A	SPD3	SPD3A	SPD6	SPD6A	SPD15A	SPD18A	SPD19A	SPD20A	SPD21A
% AC (dwa)	5.0		5.8	5.5		5.5	5.8	5.8	5.8	5.5	5.8	5.8
% Air Voids	4.0		5.4	4.0		3.9	4.9	5.1	4.2	5.7	5.0	4.9
% VMA	13.1		14.8	14.5		13.9	15.7	15.0	13.9	15.1	14.7	14.4
% VFA	67.0		64.0	75.0		72.1	68.0	67.0	69.0	62.0	67.0	66.0
Stability	38		29	32		31	30	31	37	33	35	35

Table 11. Gradation and mixture design data for fine trial blends of Dayton aggregate with fines removed from adjusted blends.

	BLEND ID													
STOCKPILE	SP08A	SP08A-2.0	SP010A	SP010A-0.5	SP010A-0.5	SP010A-2.5	SP010A-5.0	SP016A	SP016A-0.5	SP016A-1.0	SP016A-2.0	SP016A+1.0	SP022A	SP022A-2.0
	STOCKPILE PERCENTAGES													
19mm gravel	31.0	31.0	28.0	28.0	28.0	28.0	28.0	31.0	31.0	31.0	31.0	31.0	28.5	28.5
12mm gravel	19.0	19.0	12.0	12.0	12.0	12.0	12.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
6mm gravel	10.0	10.0	16.0	16.0	16.0	16.0	16.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Crushed Fines	18.5	18.5	14.0	14.0	14.0	14.0	14.0	13.5	13.5	13.5	13.5	13.5	26.0	26.0
Dayton Sand	0.0	0.0	28.5	28.5	28.5	28.5	28.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wadsworth Sand	20.0	20.0	0.0	0.0	0.0	0.0	0.0	25.0	25.0	25.0	25.0	25.0	15.0	15.0
Hydrated Lime	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

SIEVE SIZE		BLEND ID							BLEND ID						
(mm)	(US)	SP08A	SP08A-2.0	SP010A	SP010A-0.5	SP010A-0.5	SP010A-2.5	SP010A-5.0	SP016A	SP016A-0.5	SP016A-1.0	SP016A-2.0	SP016A+1.0	SP022A	SP022A-2.0
		(CUMULATIVE PERCENT PASSING)													
25.0	1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	3/4"	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
12.5	1/2"	88.7	88.5	89.8	89.7	89.7	89.5	89.3	88.7	88.6	88.6	88.5	88.3	89.6	89.4
9.50	3/8"	75.9	75.4	79.0	78.9	78.9	78.5	77.9	75.9	75.8	75.7	75.4	76.1	77.6	77.1
4.75	#4	50.0	49.0	53.1	52.9	52.9	51.9	50.5	49.9	49.6	49.4	48.9	50.4	52.2	51.2
2.36	#8	38.5	37.2	37.7	37.4	37.4	36.1	34.4	39.6	39.3	39.0	38.4	40.2	39.1	37.8
1.18	#16	33.1	31.7	29.2	28.8	28.8	27.4	25.5	35.2	34.9	34.5	33.9	35.8	32.3	30.8
0.60	#30	27.0	25.5	22.0	21.6	21.6	20.0	17.9	29.0	28.8	28.3	27.5	29.7	25.8	24.2
0.30	#50	16.8	15.1	15.7	15.3	15.3	13.5	11.3	17.4	17.0	16.6	15.7	18.2	16.8	15.5
0.15	#100	9.2	7.3	11.1	10.7	10.7	8.8	6.4	8.7	8.2	7.8	6.8	9.6	10.0	8.7
0.075	#200	6.0	4.0	8.0	7.5	7.5	5.5	3.0	5.5	5.0	4.5	3.5	6.4	6.8	4.7
.075mm Removed		0.0	2.0	0.0	0.5	0.5	2.5	5.0	0.0	0.5	1.0	2.0	-1.0	0.0	2.0
Excess p0.075mm		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Superpave	BLEND ID													
Actual	SP08A	SP08A-2.0	SP010A	SP010A-0.5	SP010A-0.5	SP010A-2.5	SP010A-5.0	SP016A	SP016A-0.5	SP016A-1.0	SP016A-2.0	SP016A+1.0	SP022A	SP022A-2.0
% AC (twm)	5.0	4.7	5.5	5.5	4.5	5.3	5.5		4.5	4.7	5.0		5.0	5.3
% Air Voids	2.7	4.7	1.5	1.9	3.0	2.2	3.7		4.8	5.5	4.4		1.7	4.1
% Gmm @ Ni	89.5	88.3	89.5	89.5	88.9	89.3	87.5		88.9	88.3	89.5		90.5	88.8
% Gmm @ Nm	98.3	96.3	99.7	99.4	98.3	98.8	97.6		98.1	95.4	96.6		99.2	96.9
% VMA	11.1	12.5	12.5	12.9	12.6	12.4	13.4		12.8	13.3	13.6		10.1	12.2
Superpave	BLEND ID													
Estimated	SP08A	SP08A-2.0	SP010A	SP010A-0.5	SP010A-0.5	SP010A-2.5	SP010A-5.0	SP016A	SP016A-0.5	SP016A-1.0	SP016A-2.0	SP016A+1.0	SP022A	SP022A-2.0
% AC	4.5	5.0	4.5	4.7	4.1	5.1	5.4		4.8	5.3	5.2		4.1	5.1
% Air Voids	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0	4.0		4.0	4.0
% Gmm @ Ni	88.5	89.5	87.0	87.4	87.9	87.5	87.5		89.7	89.5	89.9		88.5	89.1
% Gmm @ Nm	97.0	97.0	97.2	97.3	97.3	97.0	97.3		96.9	96.9	97.0		96.9	97.1
% VMA	11.2	12.4	12.5	13.1	12.7	12.8	13.4		12.5	13.0	13.5		10.3	12.1
% VFA	64.0	68.0	69.0	69.0	69.0	68.0	70.0		68.0	69.0	70.0		61.0	67.0
% Effective AC	3.1	3.7	3.9	4.1	3.9	3.8	4.2		3.8	4.1	4.3		2.7	3.1
Fines/Eff AC	1.91	1.07	1.64	1.58	1.65	1.45	0.71		1.32	1.11	0.92		2.54	1.61
Hveem Mix	BLEND ID													
Design	SP08A	SP08A-2.0	SP010A	SP010A-0.5	SP010A-0.5	SP010A-2.5	SP010A-5.0	SP016A	SP016A-0.5	SP016A-1.0	SP016A-2.0	SP016A+1.0	SP022A	SP022A-2.0
% AC (dwa)	5.0							4.7			5.9	6.0	5.2	
% Air Voids	4.0							12.4			4.2	4.0	4.0	
% VMA	12.5							5.5			14.5	13.6	12.0	
% VFA	68.0							64.0			70.0	75.0	66.0	
Stability	40							44.0			43.0	41.0	39.0	

Table 12. Gradation and mixture design data for coarse trial blends of Dayton aggregate with fines removed from adjusted blends.

	BLEND ID							
	SPD3A	SPD3A-1.0	SPD3A-1.0	SPD18A	SPD18A-1.5	SPD18A-2.0	SPD18A-2.5	SPD18A-2.5
STOCKPILE	STOCKPILE PERCENTAGES							
19mm gravel	40.5	40.5	40.5	47.0	47.0	47.0	47.0	47.0
12mm gravel	18.0	18.0	18.0	19.0	19.0	19.0	19.0	19.0
6mm gravel	20.0	20.0	20.0	0.0	0.0	0.0	0.0	0.0
Crushed Fines	10.0	10.0	10.0	32.5	32.5	32.5	32.5	32.5
Dayton Sand	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wadsworth Sand	10.0	10.0	10.0	0.0	0.0	0.0	0.0	0.0
Hydrated Lime	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

		BLEND ID							
SIEVE SIZE		SPD3A	SPD3A-1.0	SPD3A-1.0	SPD18A	SPD18A-1.5	SPD18A-2.0	SPD18A-2.5	SPD18A-2.5
(mm)	(US)	(CUMULATIVE PERCENT PASSING)							
25.0	1"	100.0	100.0	100.0	100	100.0	100.0	100.0	100.0
19.0	3/4"	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
12.5	1/2"	85.2	85.1	85.1	82.8	85.7	82.4	82.4	82.4
9.50	3/8"	69.6	69.3	69.3	65.5	73.7	64.8	64.6	64.6
4.75	#4	35.3	34.6	34.6	42.7	53.9	41.5	41.2	41.2
2.36	#8	23.1	22.3	22.3	29.6	40.5	28.2	27.8	27.8
1.18	#16	19.8	19.0	19.0	21.7	32.6	20.1	19.7	19.7
0.60	#30	16.4	15.6	15.6	16.7	25.2	15.0	14.6	14.6
0.30	#50	11.1	10.2	10.2	13.0	16.3	11.2	10.8	10.8
0.15	#100	7.0	6.1	6.1	10.0	9.6	8.2	7.7	7.7
0.075	#200	5.1	4.1	4.1	7.5	6.1	5.5	5.0	5.0
.075mm Removed		0.0	1.0	1.0	0.0	1.5	2.0	2.5	2.5
Excess p0.075mm		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Superpave	BLEND ID							
Actual	SPD3A	SPD3A-1.0	SPD3A-1.0	SPD18A	SPD18A-1.5	SPD18A-2.0	SPD18A-2.5	SPD18A-2.5
% AC (twm)	6.0	5.0	5.5		5.0	5.5	5.0	5.8
% Air Voids	4.3	7.4	7.2		5.2	4.1	7.3	3.5
% Gmm @ Ni	86.6	83.4	84.2		85.2	86.1	83.2	86.8
% Gmm @ Nm	97.3	94.0	94.2		96.3	97.4	94.0	97.9
% VMA	15.3	15.6	16.7		13.0	13.3	15.1	14.2
Superpave	BLEND ID							
Estimated	SPD3A	SPD3A-1.0	SPD3A-1.0	SPD18A	SPD18A-1.5	SPD18A-2.0	SPD18A-2.5	SPD18A-2.5
% AC	6.1	5.4	6.8		5.5	5.5	6.3	5.8
% Air Voids	4.0	4.0	4.0		4.0	4.0	4.0	4.0
% Gmm @ Ni	86.8	86.8	87.4		86.4	86.2	86.5	86.3
% Gmm @ Nm	97.5	97.4	97.4		97.5	97.5	97.3	97.4
% VMA	15.3	14.9	16.1		12.8	13.3	14.4	14.3
% VFA	74.0	73.0	75.0		69.0	70.0	72.0	72.0
% Effective AC	5.1	5.2	5.7		4.0	4.2	4.9	4.5
Fines/Eff AC	1.00	0.79	0.72		1.51	1.32	1.01	1.09
Hveem Mix	BLEND ID							
Design	SPD3A	SPD3A-1.0	SPD3A-1.0	SPD18A	SPD18A-1.5	SPD18A-2.0	SPD18A-2.5	SPD18A-2.5
% AC (dwa)				5.8			6.2	
% Air Voids				4.2			4.2	
% VMA				13.9			14.5	
% VFA				69.0			70.0	
Stability				37			38	

Table 13. Final mixtures Hveem mixture design properties.

Mixture ID	% AC*	Stability	% Air Voids	% VMA	% VFA
SPD16A-2.0	5.4	43	4.1	14.8	72
SPD16A+1.0	5.4	41	4.0	13.8	70
SPD18A-2.5	5.7	38	4.2	14.3	68

* Optimum asphalt content as established by Superpave mix design.

Table 14. Mixture designation.

Mixture Design Designation		Project Mixture Designation	
ID	Name	Name	Description
SPD16A-2.0	Sensitive	Fine	Gradation above restricted zone (relatively large amount of fine aggregate)
SPD16A+1.0	Supersensitive	Fine Plus	Gradation above restricted zone (relatively large amount of fine aggregate) plus additional minus 0.075-mm material
SPD18A-2.5	Nonsensitive	Coarse	Gradation below restricted zone (relatively large amount of coarse aggregate)

Hot-Mix Asphalt Mixture Design—Replacement Sections

U.S. Department of Transportation
Federal Highway Administration

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WesTrack Report UNR-7
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research project was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June of 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on the HMA mixture designs associated with the replacement sections placed at WesTrack. Physical properties of the asphalt binder and aggregates used in these mixture designs are contained in WesTrack Technical Reports UNR-2 and UNR-5.[4,5] This report describes the historic background information associated with the development of the mixture designs, as well as the optimum asphalt contents and their associated volumetrics.

BACKGROUND

ASPHALT BINDER AND AGGREGATE SELECTION

The binder selected for use on WesTrack was a Superpave PG 64-22 neat asphalt cement. This asphalt binder was selected based on the climate conditions and the traffic expected at WesTrack as described in WesTrack Technical Report UNR-1.[6] An asphalt binder supplied by Huntway Refining was used for the construction of the original test sections at WesTrack. Samples of this asphalt binder obtained during construction of the original sections were used for the initial mixture designs associated with the replacement sections. Huntway notified the WesTrack team that the same PG 64-22 would not be available for the replacement sections and a new source of a neat PG 64-22 was obtained from Idaho Asphalt Supply. Several mixture designs, including the final mixture design, were developed with the Idaho asphalt.

An aggregate from Granite Construction's Lockwood, Nevada, quarry was selected for the replacement sections. The aggregate was a nearly 100-percent crushed andesite.[5]

SCHEDULE OF ACTIVITIES

Tables 1, 2, and 3 present a time schedule of activities associated with materials selection, mixture design, and construction of the replacement sections at WesTrack. The FHWA mobile asphalt binder and mixture laboratory was set up at the University of Nevada in March 1997. An HMA mixture design was developed by the FHWA and was presented to the WesTrack Technical Advisory Committee on April 4, 1997. This mixture design is identified in WesTrack technical reports as the mixture design of March 28, 1997.

A series of changes in asphalt binder availability, aggregate crushing operations, and importing/blending operations occurred between the time the initial mix design work was completed and the final mix design and construction were completed. Tables 1 and 2 summarize these activities.

The FHWA initial mixture design was performed with aggregates sampled on March 14, 1997. The aggregates were most likely produced at the end of the 1996 construction season and were produced with a cone and vertical shaft impact crusher at the lower plant crushing area. At the beginning of the 1997 construction season, Granite Construction removed the cone crusher and installed a second vertical shaft impact crusher in the lower plant area. In addition, the pit raw material feed was changed during this same time period as the mining area in the pit was changed.

The 1997 production aggregate was sampled at the Lockwood quarry site on April 14, 1997, and a new mixture design was developed by the University of Nevada. An effort was made to use a blend of aggregates to produce a gradation as close as possible to that of the FHWA mixture design. The change in the raw material feed to the crushing operation and the use of a second vertical shaft impact crusher changed the rock dust stockpile material. Since the rock dust stockpile controlled the gradation of the mixture on the 2.36-mm (No. 8) sieve and the 0.075-mm (No. 200) sieve, a new mixture design was developed and designated as "E." The sensitivity of this mixture to the amount of material passing the 0.075-mm (No. 200) sieve was established on May 6, 1997. The stockpile blends used to produce the FHWA and the initial University of Nevada mixture designs are shown in table 4. Gradations for these mixtures are shown in table 5.

On May 12, 1997, Huntway notified the WesTrack team that the company would be unable to supply an asphalt binder with the same properties as that used for the original construction of WesTrack. A new asphalt binder was obtained from Idaho Asphalt on May 18, 1997, and was used for subsequent mixture designs. On May 20, 1997, the new "TBE" Superpave mixture design was verified with the Idaho Asphalt binder by the University of Nevada.

As indicated above, the aggregate was produced at Granite Construction's Lockwood facility. The HMA was produced at the company’s facility at Patrick, Nevada, which is located a few miles from the Lockwood quarry. The aggregate was transported from the Lockwood facility to

the hot-mix production site at Patrick during the period from May 19 through 22, 1997. Samples of the stockpiled materials were taken and gradations were performed by Granite Construction during this period. The sieve analysis indicated that the gradations of some of the stockpiles were different than those of the material sampled on April 14, 1997, and used for the "TBE" mixture design with the Idaho Asphalt binder. Granite Construction indicated that the materials transported to the Patrick site were obtained when portland cement concrete and HMA aggregates were being produced simultaneously at the plant. Production of portland cement concrete aggregate can vary the gradations of other products and, thus, is the likely reason for the difference in stockpile gradations from the April 14 through May 19, 1997, sampling dates.

Trial section paving was scheduled for May 23, 1997. Since it was not possible to perform a new mixture design prior to the placement of the first trial sections, a paper blend was performed to determine the stockpile percentages for matching the design gradation (as closely as possible).

After placement of the bottom lift of the trial sections on May 23, 1997, five samples of the hot mix were taken from the stockpiles at the Patrick hot-mix plant area and sieve analyses were performed (table 2, May 23, 1997, sampling date). The sieve analyses data was used to develop a new mixture design, designated "P7" and completed on May 28, 1997. The sieve analysis test results indicated non-uniformity in the coarse aggregate stockpiles and the stockpiles were blended with a front-end loader prior to paving of trial sections on May 30, 1997. The "P7" mixture design was used for paving on May 30, 1997.

After paving the top lift of the trial sections on May 30, 1997, five samples were taken per stockpile and sieve analyses were performed. The test results indicated some non-uniformity of the coarse stockpiles and a visual inspection suggested that the stockpiles did not have enough material to complete the project. Additional material was imported to the hot-mix production facility area at Patrick.

A mixture design designated as "T1" was completed on June 6, 1997, based on the average gradation of the mixture (determined by ignition oven) placed on May 30, 1997. The mix design resulted in high voids in the mineral aggregate (VMA). Draindown of this mixture was also noted in the field during the May 30, 1997, production and placement.

On June 7, 1997, additional material was imported and each stockpile was thoroughly blended. When the blending operation was completed, ten samples were taken from each stockpile and sieve analyses were performed. Granite Construction and the University of Nevada performed five sieve analyses per stockpile. Independent samples were taken by each laboratory.

The mixture design completed on June 12, 1997, was based on the aggregate stockpiles and their gradations obtained on June 7, 1997. The new mixture design was designated as "F" and was used for construction of the test lane sections on the track.

Based on the sieve analyses conducted on the material sampled on June 7, 1997, additional blending of the stockpiles was performed by a front-end loader. This blending was performed prior to placement of the third trial sections on June 17, 1997. No additional material or blending was performed on the stockpiles after June 17, 1997. The test lane sections were placed on the track on June 23 and 28, 1997, as shown in table 3. The stockpile blends for the various mixture designs are shown in table 4 and the gradations for the various blends are shown in table 5.

MIXTURE DESIGN TEST RESULTS

Tables 6 through 12 contain a summary of the mixture design information developed for the replacement sections. Appendices A through F contain more detailed information and graphs of the relationships among asphalt binder content and weight and volumetric properties. Table 5 shows the gradations used in the various mixture designs and table 13 shows the optimum asphalt content at 4 percent air voids and other volumetric properties for the various mixture designs. Mixture "F" was used for the construction of the test lane replacement sections at WesTrack.

FHWA AND UNIVERSITY OF NEVADA MIX "E"

The FHWA and UNR mixture designs "E" were prepared with the same asphalt binder (Huntway) and aggregate from the same source, but the two laboratories used aggregate that was processed differently and different numbers of gyrations were used in the Superpave gyratory compactor. The aggregate used by the FHWA was produced by performing the finishing crushing with a cone crusher and a single vertical shaft impact crusher. The aggregate used by the University of Nevada-Reno was produced by performing the finishing crushing with two vertical shaft impact crushers. The pit location from which the rock feed was being obtained also changed between the aggregate sample dates used by the FHWA and UNR.

The FHWA mixture design was based on the number of gyrations associated with traffic levels (ESALs) in the range of 10 to 30 million. UNR test results were based on traffic levels of 3 to 10 million, the same levels as were used for the mixture design for the original test sections.

Tables 4 and 5 indicate that less rock dust had to be used in the University of Nevada-Reno mixture design "E" than in the FHWA mixture design because the as-provided rock dust contained a higher percent of fine material after installation of the second vertical shaft impact crusher. The University of Nevada-Reno mixture “E” contained about 1 percent more minus No. 200 material than the FHWA mixture.

Table 12 indicates that the optimum asphalt binder content in the University of Nevada-Reno mixture "E" was 5.75 as compared to 5.5 percent by total weight of aggregate for the FHWA mixture. Unfortunately, several changes (as noted above) were responsible for this change in optimum binder content and no single factor could be isolated.

MIXTURE "E" SENSITIVITY

The sensitivity of the University of Nevada-Reno mixture "E" to asphalt binder content and minus No. 200 material was also studied during the mixture design process. This additional mixture design study was conducted to determine the sensitivity (in terms of volumetrics) of the designed mixture to changes in the minus No. 200 material that can occur during construction. After the original construction was completed, a mixture sensitivity study was conducted. The coarse-graded HMA placed during original construction was sensitive to small changes in the No. 200 material.

The gradations of University of Nevada-Reno mixture "E" with the addition and the removal of 1.5 percent minus No. 200 is shown in table 14. These changes in the gradation of the aggregate resulted in air voids ranging from 3.4 to 5.3 percent when the asphalt binder content was held constant at 5.75 percent (table 13). Figures contained in appendix B indicate that the optimum asphalt binder content would change from approximately 5.2 percent to approximately 6.7 percent with a change in the minus No. 200 material from 1.5 percent above the target to 1.5 percent below the target (design asphalt binder content selected at 4 percent air void content). Except for the dust-to-binder ratio of the mixture that contained a relatively high percentage of minus No. 200 material, all other volumetric properties were met for the mixtures with these very different binder contents.

UNIVERSITY OF NEVADA MIXTURE "TBE"

Mixture design "TBE" was prepared when the asphalt binder supply was changed. Both the Huntway and Idaho Asphalt binders were Superpave PG 64-22 grades. Mixture "TBE" was made with the Idaho Asphalt binder and mixture "E" was made with the Huntway Refining binder (table 2). The aggregates used for these two mixtures were obtained at the same sampling time and their combined gradations were identical (table 5). Table 13 indicates that the design asphalt binder content was the same for both mixtures. For this aggregate and gradation, the change in the asphalt binders did not affect the optimum asphalt binder content and the majority of the volumetics.

UNIVERSITY OF NEVADA MIXTURES "P7" AND "T1"

University of Nevada mixtures "P7" and "T1" were developed as the stockpile gradations changed from the development of mixture "TBE" and the placement of the first trial sections on May 23, 1997 (table 1), and subsequent trial sections on May 30, 1997. The stockpile blends used for mixtures "P7" and "T1" were the same and are shown in table 4. A comparison of gradations for these two mixtures is shown in table 5. The same asphalt binder was used for the two mixtures. Table 13 indicates that the optimum asphalt binder content as determined at 4 percent air voids changed from 5.8 percent for mixture "TBE" to 5.5 percent for mixture "P7" and to 6.2 percent for mixture "T1." In addition, a substantial change in the VMA was noted in these mixtures (from 14.8 percent to 16.6 percent).

UNIVERSITY OF NEVADA MIXTURE "F"

After hauling additional aggregate from the quarry to the HMA production facility and blending the aggregate into each of the stockpiles, additional samples were obtained and mixture design "F" was developed. The stockpile blends are shown in table 4 and the gradation is shown in table 5. The design asphalt binder content for this mixture was 5.7 percent, VMA was 15.0, VFA was 73.0, and dust-to-binder ratio was 1.18. This was the mixture design used to construct the third trial section and to place the test lane sections on the track.

A mixture sensitivity study was conducted on this mixture by reducing the amount of minus No. 200 by 1 percent. The gradations of the mixtures studied in this sensitivity study are shown in table 15. The air void content and volumetrics were only slightly changed by altering the minus No. 200 material (table 13 and appendix F).

WATER SENSITIVITY

The water sensitivities of the FHWA-designed mixture and the UNR mixture "F" were determined and the results are shown in table 16. The tensile strength ratios for the samples subject to AASHTO T 283 with a freeze-thaw cycle are above 90 for both of these mixtures. The Superpave volumetric mixture design requires a minimum of 80 for the tensile strength ratio.[7]

HVEEM STABILITY

Hveem stability values were determined on HMA samples prepared with the aggregates and gradations associated with UNR mixture "TBE." At the Superpave volumetric design asphalt content of 5.8 percent for this mixture (table 17), the Hveem stability was about 30. No other Hveem or Marshall properties were determined on the replacement mixtures.

SUMMARY

The job mix formula and the mixture volumetrics at the design asphalt binder content were determined after several mixture designs. UNR mixture "F" was utilized for the project. The job mix formula and the mixture volumetrics are shown in table 18.

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Table 1. WesTrack rehabilitation schedule .
May 1997

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
4	5	6	7	8	9 UNR TBE mix designs completed.	10
11	12 Huntway cannot supply binder hot plant visit.	13	14	15	16	17
18 Idaho Asphalt binder arrives.	19	20 Hot plant visit.	21 Stop trafficking. Postmortem monitoring and sampling begins.	22 Postmortem monitoring and sampling.	23 Trial lane paving - bottom lift.	24
25	26	27 Postmortem monitoring and sampling.	28 Postmortem monitoring and sampling.	29 Data review meeting (May 23, 1997, results).	30 Trial lane paving - top lift.	31

Table 1. WesTrack rehabilitation schedule (continued).

June 1997

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3 Data review meeting (May 28, 1997, results).	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20 Trial mix paving (day 3).	21
22 Data review meeting (June 20, 1997, data).	23 Test lane bottom lift paving.	24	25	26	27 Data review meeting (June 23, 1997, data).	28 Test lane top lift paving.
29	30					

Table 2. Summary of HMA gyratory mix designs – Lockwood aggregates.

Mix Design Designation	Date of Mix Design	Asphalt Cement Source	Aggregate Sampling Data	Comments
FHWA	3-28-97	Huntway	3-14-97	• Stockpiles sampled at Lockwood. • Cone crusher, not vertical shaft impact crusher.
University of Nevada, Reno - E	4-29-97 5-6-97 5-9-97	Huntway Huntway Huntway	4-14-97 4-14-97 4-14-97	• Stockpiles sampled at Lockwood. • Vertical impact crusher in place. • Selected blend gradation. • Determined influence of minus #200 material.
University of Nevada, Reno - TBE	5-20-97	Idaho Asphalt	4-14-97	• Stockpiles sampled at Lockwood.
University of Nevada, Reno - P7	5-28-97	Idaho Asphalt	5-23-97	• Stockpiles sampled at Patrick.
University of Nevada, Reno - T1	6-6-97	Idaho Asphalt	5-30-97	• Stockpiles sampled at Patrick. • Used 5-30-97 core ignition gradation.
University of Nevada, Reno - F	6-12-97	Idaho Asphalt	6-7-97	• Stockpiles sampled at Patrick. • Selected blend gradation. • Determined influence of minus #200 material.

Table 3. Aggregate samples and test lane sections.

Asphalt Binder Sampling Date	Lane-Lift Paved	Section Number	Mixture Designation
06-23-97	Test lane bottom lift	35, 36, 37, 38, 39, 54, 55, 56	Coarse replacement
06-28-97	Test lane top lift	35, 36, 37, 38, 39, 54, 55, 56	Coarse replacement

Table 4. Stockpile blends for mixture designs.

Stockpile Designations	FHWA	E and TBE	P7 and T	F
3/4-in.	35	28.0	25.0	24.0
1/2 -in.	10.5	10.0	13.5	15.5
3/8-in.	16.0	31.5	30.5	27.5
Rock Dust	37.0	29.0	29.5	31.5
Hydrated Lime	1.5	1.5	1.5	1.5

Table 5. HMA blends in chronological order.

Sieve Size (US)	Sieve Size (mm)	Blend ID (Cumulative Percent Passing)				
		FHWA-E (04-03-97)	E and TBE (04-29-97)	P7 (05-23-97)	T1 (06-06-97)	F (06-12-97)
1-in.	25	100.0	100.0	100.0	100.0	100.0
3/4-in.	19	100.0	100.0	99.5	99.9	99.2
1/2 -in.	12.5	83.0	83.2	83.3	86.7	82.8
3/8-in.	9.5	67.4	66.8	68.1	71.7	69.5
No. 4	4.75	42.5	37.6	38.4	39.6	41.4
No. 8	2.36	26.7	24.4	24.1	23.9	25.6
No. 16	1.18	17.2	16.6	16.4	15.9	16.8
No. 30	0.60	11.6	11.9	11.8	11.5	12.1
No. 50	0.30	8.8	9.0	8.9	8.7	9.1
No. 100	0.15	7.0	7.1	7.2	6.8	7.2
No. 200	0.075	4.7	5.8	5.8	5.4	5.8

Table 6. Gyratory volumetrics summary for FHWA mixture.

	Project: WesTrack Rehab Mixture ID: FHWA Other: Huntway AC, Lockwood Aggregate Old Crushing Date: March 28, 1997 Technician:							
	% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
	4.80*	94.3	5.7	15.4	63.0	84.4	95.5	1.11
	5.30*	95.5	4.5	14.9	69.8	85.6	96.9	1.04
	5.80*	96.8	3.2	15.1	78.8	86.5	98.0	0.91
	6.30	96.6	3.4	15.5	78.1	86.4	97.8	0.90
	6.31*	97.7	2.3	15.6	85.3	87.5	99.0	0.82
Optimum	5.52	96.0	4.0	15.2	73.7	85.9	97.3	1.00

*Data used to select optimum binder content.

Table 7. Gyratory volumetrics summary for mixture "E."

Project:	WesTrack Rehab
Mixture ID:	E
Other:	Lockwood - New Crushing
Date:	April 29, 1997
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.00							
4.25	92.8	7.2	14.9	51.8	83.8	94.1	1.68
4.75	94.4	5.6	14.5	61.7	85.2	95.6	1.47
5.25	94.9	5.1	15.2	66.3	85.7	96.1	1.30
5.75	96.0	4.0	15.3	73.6	86.9	97.2	1.17
6.25	96.4	3.6	15.9	77.6	87.5	97.7	1.06
6.75	97.3	2.7	16.2	83.3	88.2	98.5	0.97
7.00							

Properties at E optimum asphalt content.

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	96.0	4.0	15.3	73.6	86.9	97.2	1.17

E + 1.5% properties at TBE optimum asphalt content.

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	96.6	3.4	14.7	76.9	87.1	97.9	1.47

E - 1.5% properties at TBE optimum asphalt content.

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	94.7	5.3	16	68.8	85.9	95.9	0.90

Table 7. Gyratory volumetrics summary for mixture "E" (continued).

Project:	WesTrack Rehab
Mixture ID:	Trial Blend E + 1.5% p200 (TBEP)
Other:	Lockwood - New VSIs
Date:	May 6, 1997
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.00							
4.25							
4.75	95.0	5.0	14.0	64.3	85.6	96.3	1.85
5.25	95.9	4.1	14.3	71.2	86.6	97.2	1.64
5.75	96.6	3.4	14.7	76.9	87.1	97.9	1.47
6.25	97.6	2.4	14.9	83.9	88.4	98.9	1.34
6.75	97.4	2.6	16.1	84.1	88.4	98.6	1.22
7.00							

TBE + 1.5% properties at TBE optimum asphalt content.

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	96.6	3.4	14.7	76.9	87.1	97.9	1.47

Table 7. Gyratory volumetrics summary for mixture "E" (continued).

Project:	WesTrack Rehab
Mixture ID:	Trial Blend E + 1.5% p200 (TBEM)
Other:	Lockwood - New VSIs
Date:	May 9, 1997
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.00							
4.25							
4.75	92.3	7.7	16.0	52.1	83.7	93.5	1.15
5.25	93.3	6.7	16.2	58.7	84.8	94.6	1.01
5.75	94.7	5.3	16.0	68.8	85.9	95.9	0.90
6.25	95.2	4.8	16.6	71.1	86.2	97.0	0.82
6.75	96.0	4.0	17.0	76.2	86.7	97.2	0.75
7.00							

TBE + 1.5% properties at TBE optimum asphalt content.

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	94.7	5.3	16	68.8	85.9	95.9	0.90

Table 8. Gyratory volumetrics summary for mixture "TBE."

Project:	WesTrack Rehab
Mixture ID:	TBE
Other:	Idaho AC, Lockwood - New Crushing
Date:	May 20, 1997
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.00							
4.25							
4.75	93.3	6.7	15.2	56.1	84.3	94.6	1.53
5.25	94.0	6.0	15.6	61.6	84.9	95.3	1.35
5.75	95.5	4.5	15.3	70.7	86.3	96.8	1.21
6.25	96.7	3.3	15.4	78.5	87.6	98.0	1.10
6.75	97.4	2.6	15.8	83.3	88.3	98.6	1.00
7.00							

Table 9. Gyratory volumetrics summary for mixture "P7."

Project:	WesTrack Rehab
Mixture ID:	P7
Other:	Idaho AC, Lockwood at Patrick
Date:	May 23, 1997
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
3.80							
4.30							
4.80	94.1	5.9	15.3	61.6	84.7	95.5	1.38
5.30	95.8	4.2	14.8	71.9	86.3	97.1	1.23
5.80	96.4	3.6	15.4	76.6	86.7	97.7	1.11
6.30	97.5	2.5	15.5	83.8	87.9	98.9	1.02
6.80	98.0	2.0	16.1	87.7	88.2	99.4	0.93
7.30							

Properties at TBE optimum asphalt content.

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.5	96.0	4.0	14.8	74	86.8	97.5	1.18

Table 10. Gyratory volumetrics summary for mixture "T1."

Project:	WesTrack Rehab
Mixture ID:	T1 (May 30, 1997 Core Gradations)
Other:	Lockwood - New Crushing
Date:	June 6, 1997
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.0							
4.5	92.6	7.4	15.6	52.8	83.1	94.0	1.46
5.0	93.8	6.2	15.8	60.7	84.4	95.0	1.26
5.5	94.5	5.5	16.1	65.6	84.9	95.8	1.14
6.0	94.7	5.3	16.9	86.6	85.4	96.0	1.03
6.5	96.6	3.4	16.3	78.9	86.9	97.9	0.94
7.0							

Table 11. Gyratory volumetrics summary for mixture "F."

Project:	WesTrack Rehab
Mixture ID:	F
Other:	Lockwood at Patrick (June 7, 1997 sampling)
Date:	June 12, 1997
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.0							
4.5	93.8	6.2	14.6	57.6	84.4	95.2	1.56
5.0	95.1	4.9	14.6	66.8	85.5	96.6	1.35
5.5	95.8	4.2	14.9	72.0	86.5	97.2	1.23
6.0	96.3	3.7	15.4	75.9	87.6	97.6	1.12
6.5	97.0	3.0	15.9	81.5	87.3	98.3	1.01
7.0							

Properties at optimum asphalt content.

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.65	96.0	4.0	15	73	86.6	97.5	1.18

Table 12. Gyratory volumetrics summary for mixture "F"
less 1-percent passing No. 200 sieve

Project:	WesTrack Rehab
Mixture ID:	F - 1.0% p 200 (F-1)
Other:	Lockwood at Patrick (June 7, 1997 sampling)
Date:	June 19, 1997
Technician:	WC/TO Based on Measured Rices

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.0							
4.5	93.6	6.4	15.2	58.2	84.4	95.0	1.21
5.0	94.5	5.5	15.3	64.4	85.1	95.9	1.09
5.5	95.8	4.2	15.5	73.1	86.1	97.2	0.95
6.0	96.4	3.6	15.9	77.6	86.5	97.9	0.88
6.5	97.6	2.4	15.9	85.2	87.5	99.1	0.80
7.0							

F - 1.0% properties at F optimum asphalt content.

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.65	96.2	3.8	15.5	73.5	86.2	97.4	0.95

Table 13. Laboratory mixture design volumetrics.

Mix Design/Date	Bulk Sp. Gr.	No. of Gyrations			Weight-Volume Properties*							
		Ni	Nd	Nm	Minus No. 200	Asphalt Content, %	Air Voids, %	VMA, %	VFA, %	Gmmi, %	Gmmm, %	F/A
FHWA 03-28-97	2.638	8	109	174	4.7	5.52	4.0	15.2	73.7	85.9	97.3	1.00
E 04-29-97	2.599	8	96	152	7.3	5.75	3.4	14.7	76.9	87.1	97.9	1.47
					5.8	5.75	4.0	15.3	73.6	86.9	97.2	1.17
					4.3	5.75	5.3	16.0	68.8	85.9	95.9	0.90
TBE 05-20-97	2.599	8	96	152	5.8	5.8	4.0	15.3	72.6	86.7	97.3	1.17
P7 05-23-97	2.599	8	96	152	5.8	5.5	4.0	14.8	74.0	86.8	97.5	1.18
T1 06-06-97	2.599	8	96	152	5.4	6.2	4.0	16.6	74.5	86.3	97.2	0.98
F 06-12-97	2.599	8	96	152	5.8	5.65	4.0	15.0	73.0	86.6	97.5	1.18
					4.8	5.65	3.8	15.5	73.5	86.2	97.4	0.95
Superpave acceptance criteria							4.0	Min. 13	65-75	Max. 89	Max. 98	0.6-1.2

*At optimum asphalt content.

Table 14. Trial blend "E" replacement mix design gradations considered in sensitivity study.

Sieve Size		Trial Blend E*	Trial Blend E Minus 1.5% p0.075mm	Trial Blend E Plus 1.5% p0.075mm
(US)	(mm)			
1-in.	25.0	100	100	100
3/4-in.	19.0	100	100	100
1/2 -in.	12.5	83.2	82.9	83.4
3/8-in.	9.5	66.8	66.3	67.3
No. 4	4.75	37.6	36.6	38.5
No. 8	2.36	24.4	23.2	25.5
No. 16	1.18	16.6	15.3	17.8
No. 30	0.60	11.9	10.6	13.2
No. 50	0.30	9.0	7.6	10.3
No. 100	0.150	7.1	5.7	8.5
No. 200	0.075	5.8	4.4	7.2

*Based on mean of five sieve analyses per stockpile (20 total).

Table 15. Replacement gradations for trial mix "F."

Sieve Size		Replacement Coarse Mix Target*	Replacement Coarse Mix Minus 1.0% p0.075mm	Replacement Coarse Mix Plus 1.0% p0.075mm
(US)	(mm)			
1-in.	25.0	100	100	100
3/4-in.	19.0	99.2	99.2	99.2
1/2 -in.	12.5	82.8	82.6	830
3/8-in.	9.5	69.5	69.2	69.8
No. 4	4.75	41.4	40.8	42.0
No. 8	2.36	25.6	24.8	26.3
No. 16	1.18	16.8	16.0	17.6
No. 30	0.60	12.1	11.2	13.0
No. 50	0.30	9.1	8.2	10.0
No. 100	0.150	7.2	6.3	8.1
No. 200	0.075	5.8	4.8	6.7

*Based on mean of ten sieve analyses per stockpile (40 total).

Table 16. Water sensitivity of laboratory mixture designs*.

Mix Design/Date	Tensile Strength Ratio, Percent
FHWA 3-28-97	90.1
F 6-12-97	94.9
Acceptance criteria	Min. 80

*AASHTO T283 with freeze-thaw cycle.

Table 17. Hveem stability test results - TBE mixture - Idaho Asphalt binder*.

Asphalt Binder Content, Percent by Total Weight	**Hveem Stability**
4.75	35.3
5.25	32.2
5.75	30.5
6.25	29.4

*Mix design TBE.

Table 18. Job mix formula and mix design volumetric properties for replacement sections.

Property	Property Value
Gradation	
1-in.	100
3/4-in.	99.2
1/2-in.	82.8
3/8-in.	69.5
No. 4	41.4
No. 8	25.6
No. 16	16.8
No. 30	12.1
No. 50	9.1
No. 100	7.2
No. 200	5.8
Stockpile blend	
3/4-in.	24.0
1/2-in.	15.5
3/8-in.	27.5
Rock dust	31.5
Hydrated lime	1.5
Weight-volumes	
Asphalt content, %	5.65 by total weight of aggregate
Air voids, %	4.0
VMA, %	15.0
VFA, %	73.0
Gmmi	86.6
Gmmm	97.5
Fines/asphalt	1.18

APPENDIX A

FHWA MIXTURE DESIGN
HUNTWAY ASPHALT
LOCKWOOD AGGREGATE
SAMPLED AT LOCKWOOD

MARCH 28, 1997

Gyratory Volumetrics Summary

Project : WesTrack Rehab
Mixture ID: FHWA
Other: ~~Idaho AC, Lockwood - New Crushing~~ HUNTWAY AC, LOCKWOOD AGGREGATE OLD CRUSHING
Date: MARCH 28, 1997
Technician:

	% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
	4.80*	94.3	5.7	15.4	63.0	84.4	95.5	1.11
	5.30*	95.5	4.5	14.9	69.8	85.6	96.9	1.04
	5.80*	96.8	3.2	15.1	78.8	86.5	98.0	0.91
	6.30	96.6	3.4	15.5	78.1	86.4	97.8	0.90
	6.31*	97.7	2.3	15.6	85.3	87.5	95.0	0.82
OPTIMUM	5.52	96.0	4.0	15.2	73.7	85.9	97.3	1.00

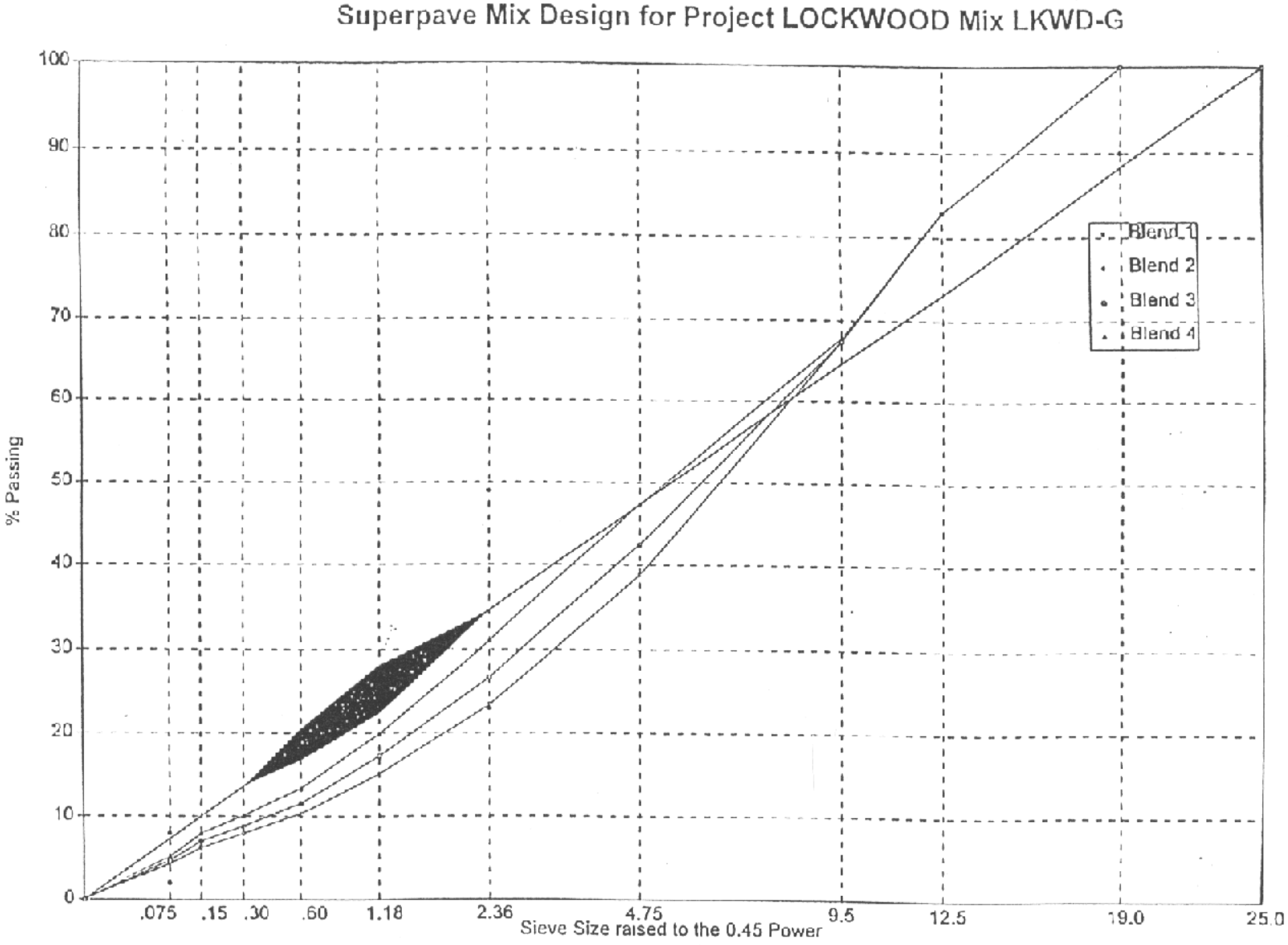
* DATA USED TO SELECT OPTIMUM BINDER CONTENT

FHWA SUPERPAVE ASPHALT OTA

Project LOCKWOOD	Mix Design ID LKWD-G

Trial Blend No.	Stockpile Percentages							
	G 1/2	G 3/8	G ROCKDUST	G3/4	LIME			
1	10.5	21.0	32.0	35.0	1.5			
2	10.0	10.0	43.5	35.0	1.5			
3	10.5	16.0	37.0	35.0	1.5			
4	10.0	10.0	43.5	35.0	1.5			

Sieve (mm)	Trial Blend Gradations							
	1	2	3	4				
50.0	100.0	100.0	100.0	100.0				
37.5	100.0	100.0	100.0	100.0				
25.0	100.0	100.0	100.0	100.0				
19.0	100.0	100.0	100.0	100.0				
12.5	83.0	83.0	83.0	83.0				
9.5	67.4	67.8	67.4	67.8				
4.75	38.8	47.4	42.5	47.4				
2.36	23.4	31.0	26.7	31.0				
1.18	15.1	19.9	17.2	19.9				
0.60	10.3	13.4	11.6	13.4				
0.30	7.9	10.1	8.8	10.1				
0.15	6.2	7.9	7.0	7.9				
0.075	4.3	5.2	4.7	5.2				


Superpave Mix Design for Project LOCKWOOD Mix LKWD-G
% Passing
100
90
80
70
60
50
40
30
20
10
0
.075
.15
.30
.60
1.18
2.36
4.75
9.5
12.5
19.0
25.0
Sieve Size raised to the 0.45 Power
Blend 1
Blend 2
Blend 3
Blend 4

FHWA | SUPERPAVE ASHPALT | OTA

Project LOCKWOOD	Mix Design ID LKWD-G

Trial Blends - Superpave Gyratory Compaction Data

Blend		Binder		Rice Results, Gmm	
Trial blend	1	Estimated Pb	5.47	Test "A"	2.468
-0.075 mm	4.3	Actual Pb	5.50	Test "B"	2.453
Bulk Sp.Gr., Gsb	2.640	Binder Sp.Gr., Gb	1.023	Average	2.461

Compaction Data

Specimen	"A"	"B"	"C"		
Height @ Nini 8	131.2	128.6	129.6	Effective Asphalt, Pbe	4.9
Height @ Ndes 109	118.1	115.6	116.6	Fines / Pbe	0.87
Height @ Nmax 174	116.6	114.2	115.2	Effective Aggregate, Gse	2.680
Mass in Air	4683.8	4605.4	4624.7		
Mass in H_2O	2668.9	2643.3	2638.6		
Mass @ SSD	4692.3	4614.4	4631.0	Average	
Bulk Sp.Gr.,Gmb	2.315	2.336	2.321	2.324	
% of Gmm @ Nini	83.6	84.3	83.8	83.9	
% of Gmm @ Ndes	92.9	93.8	93.2	93.3	
% of Gmm @ Nmax	94.1	94.9	94.3	94.4	

Calculated Average Values at Design Number of Gyrations (Ndes)

% Voids, Va 6.7	% VMA 17.8	% VFA 62.4

FHWA SUPERPAVE ASHPALT OT

Project LOCKWOOD	Mix Design ID LKWD-G

Trial Blends - Superpave Gyratory Compaction Data

Blend		Binder		Rice Results, Gmm	
Trial blend	2	Estimated Pb	5.53	Test "A"	2.460
-0.075 mm	5.2	Actual Pb	5.50	Test "B"	2.452
Bulk Sp.Gr., Gsb	2.635	Binder Sp.Gr., Gb	1.023	Average	2.456

Compaction Data

Specimen	"A"	"B"	"C"		
Height @ Nini 8	122.3	128.9	131.2	Effective Asphalt, Pbe	5.0
Height @ Ndes 109	109.9	115.6	117.4	Fines / Pbe	1.05
Height @ Nmax 174	108.5	114.2	115.8	Effective Aggregate, Gse	2.674
Mass in Air	4616.5	4885.2	4947.7		
Mass in H_2O	2729.8	2891.2	2929.3		
Mass @ SSD	4617.3	4885.9	4949.5	Average	
Bulk Sp.Gr.,Gmb	2.446	2.449	2.449	2.448	
% of Gmm @ Nini	88.4	88.3	88.0	88.2	
% of Gmm @ Ndes	98.3	98.5	98.3	98.4	
% of Gmm @ Nmax	99.6	99.7	99.7	99.7	

Calculated Average Values at Design Number of Gyrations (Ndes)

% Voids, Va 1.6	% VMA 13.3	% VFA 88.0

FHWA | SUPERPAVE ASHPALT | OT

Project LOCKWOOD	Mix Design ID LKWD-G

Trial Blends - Superpave Gyratory Compaction Data

Blend		Binder		Rice Results, Gmm	
Trial blend	3	Estimated Pb	5.48	Test "A"	2.474
-0.075 mm	4.7	Actual Pb	5.30	Test "B"	2.473
Bulk Sp.Gr., Gsb	2.638	Binder Sp.Gr., Gb	1.023	Average	2.474

Compaction Data

Specimen	"A"	"B"	"C"		
Height @ Nini 8	130.9	129.6	131.1	Effective Asphalt, Pbe	4.6
Height @ Ndes 109	117.0	116.2	117.7	Fines / Pbe —	1.02
Height @ Nmax 174	115.5	114.5	116.0	Effective Aggregate, Gse	2.687
Mass in Air	4794.5	4774.1	4792.8		
Mass in H_2O	2806.8	2800.1	2798.0		
Mass @ SSD	4800.2	4779.3	4800.5	Average	
Bulk Sp.Gr.,Gmb	2.405	2.412	2.393	2.403	
% of Gmm @ Nini	85.8	86.1	85.6	85.8	
% of Gmm @ Ndes	96.0	96.1	95.3	95.8	
% of Gmm @ Nmax	97.2	97.5	96.7	97.1	

Calculated Average Values at Design Number of Gyrations (Ndes)

% Voids, Va 4.2	% VMA 14.9	% VFA 71.8

FHWA SUPERPAVE ASHPALT OT

Project LOCKWOOD	Mix Design ID LKWD-G

Trial Blends - Superpave Gyratory Compaction Data

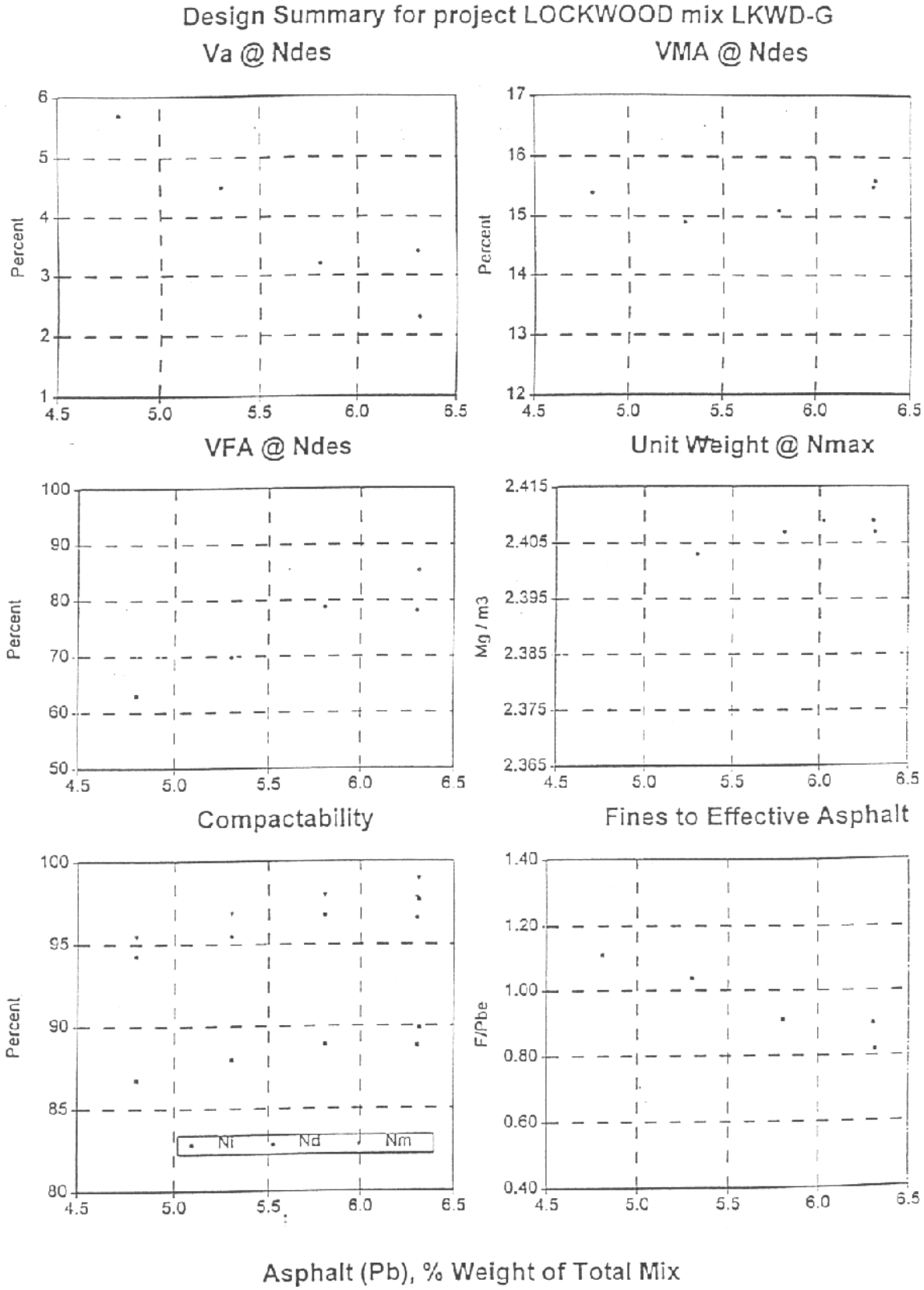
Blend		Binder		Rice Results, Gmm	
Trial blend	4	Estimated Pb	5.53	Test "A"	2.482
-0.075 mm	5.2	Actual Pb	4.80	Test "B"	2.506
Bulk Sp.Gr., Gsb	2.635	Binder Sp.Gr., Gb	1.023	Average	2.494

Compaction Data

Specimen	"A"	"B"	"C"		
Height @ Nini 8	130.0	129.9	131.4	Effective Asphalt, Pbe	4.1
Height @ Ndes 109	115.9	116.0	117.1	Fines / Pbe	1.28
Height @ Nmax 174	114.4	114.5	115.5	Effective Aggregate,Gse	2.689
Mass in Air	4817.7	4827.7	4834.7		
Mass in H_2O	2841.4	2847.7	2846.3		
Mass @ SSD	4822.1	4835.9	4839.5	Average	
Bulk Sp.Gr.,Gmb	2.432	2.428	2.426	2.429	
% of Gmm @ Nini	85.8	85.9	85.5	85.7	
% of Gmm @ Ndes	96.2	96.1	96.0	96.1	
% of Gmm @ Nmax	97.5	97.4	97.3	97.4	

Calculated Average Values at Design Number of Gyrations (Ndes)

% Voids, Va 3.9	% VMA 13.4	% VFA 70.9


Design Summary for project LOCKWOOD mix LKWD-G
Va @ Ndes
VMA @ Ndes
Percent
VFA @ Ndes
Unit Weight @ Nmax
Mg / m3
Compactability
Fines to Effective Asphalt
F/Pbe
Ni
Nd
Nm
Asphalt (Pb), % Weight of Total Mix

APPENDIX B

REPLACEMENT SECTIONS
HUNTWAY ASPHALT
LOCKWOOD AGGREGATE - NEW CRUSHING
SAMPLED AT LOCKWOOD

APRIL 29, 1997

"E" (TBE) MIX DESIGN

Gyratory Volumetrics Summary

Project :	WesTrack Rehab
Mixture ID:	TBE
Other:	Lockwood - New Crushing
Date:	4-29-97
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.00							
4.25	92.8	7.2	14.9	51.8	83.8	94.1	1.68
4.75	94.4	5.6	14.5	61.7	85.2	95.6	1.47
5.25	94.9	5.1	15.2	66.3	85.7	96.1	1.30
5.75	96.0	4.0	15.3	73.6	86.9	97.2	1.17
6.25	96.4	3.6	15.9	77.6	87.5	97.7	1.06
6.75	97.3	2.7	16.2	83.3	88.2	98.5	0.97
7.00							

Properties at TBE Optimum Asphalt Content

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	96.0	4.0	15.3	73.6	86.9	97.2	1.17

TBE+1.5% Properties at TBE Optimum Asphalt Content

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	96.6	3.4	14.7	76.9	87.1	97.9	1.47

TBE-1.5% Properties at TBE Optimum Asphalt Content

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	94.7	5.3	16	68.8	85.9	95.9	0.90

Gyratory Volumetrics Summary

Project :	WesTrack Rehab
Mixture ID:	Trial Blend E + 1.5% p200 (TBEP)
Other:	Lockwood - New VSI's
Date:	5-6-97
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.00							
4.25							
4.75	95.0	5.0	14.0	64.3	85.6	96.3	1.85
5.25	95.9	4.1	14.3	71.2	86.6	97.2	1.64
5.75	96.6	3.4	14.7	76.9	87.1	97.9	1.47
6.25	97.6	2.4	14.9	83.9	88.4	98.9	1.34
6.75	97.4	2.6	16.1	84.1	88.4	98.6	1.22
7.00							

TBE+1.5% Properties at TBE Optimum Asphalt Content

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	96.6	3.4	14.7	76.9	87.1	97.9	1.47

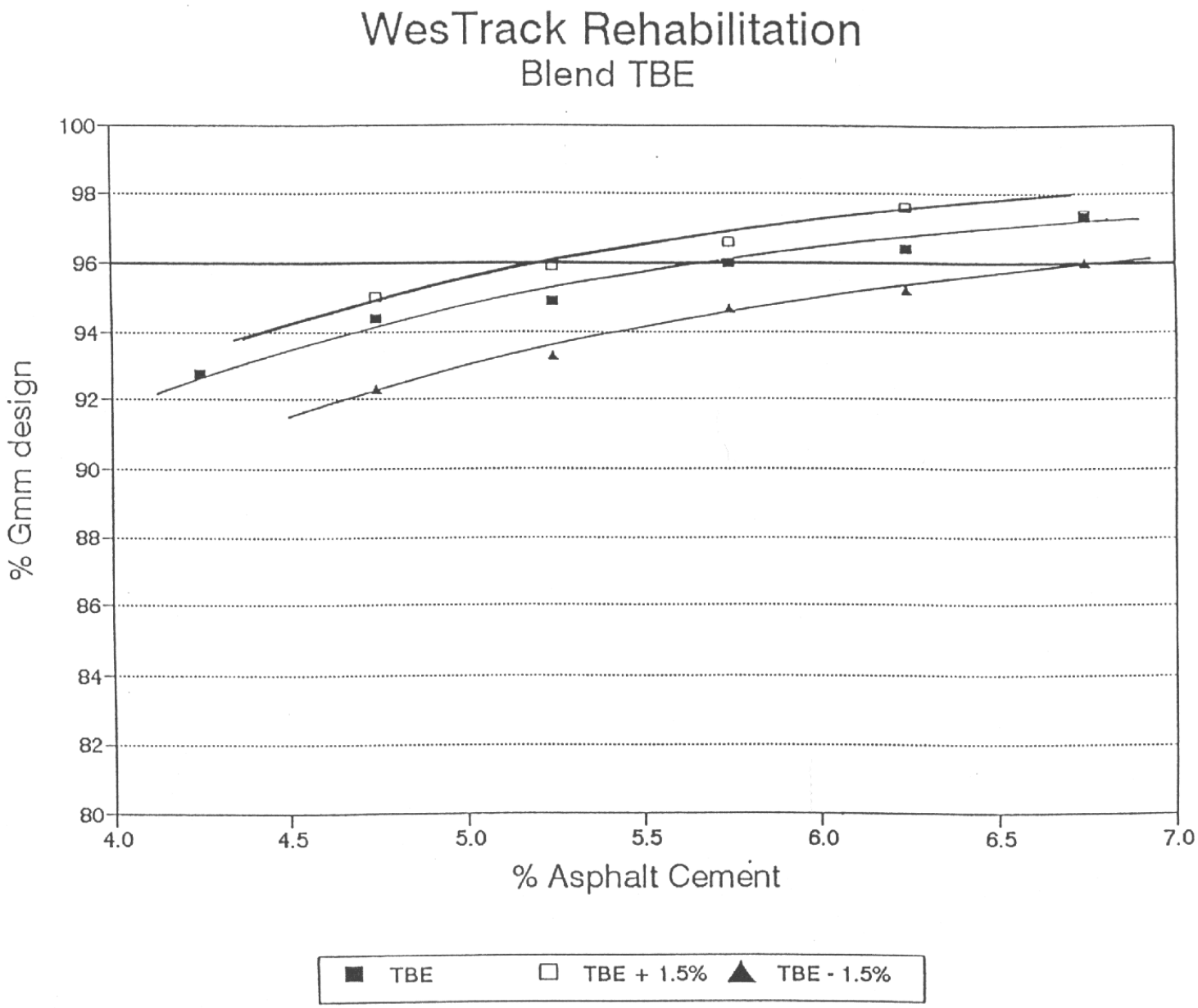
Gyratory Volumetrics Summary

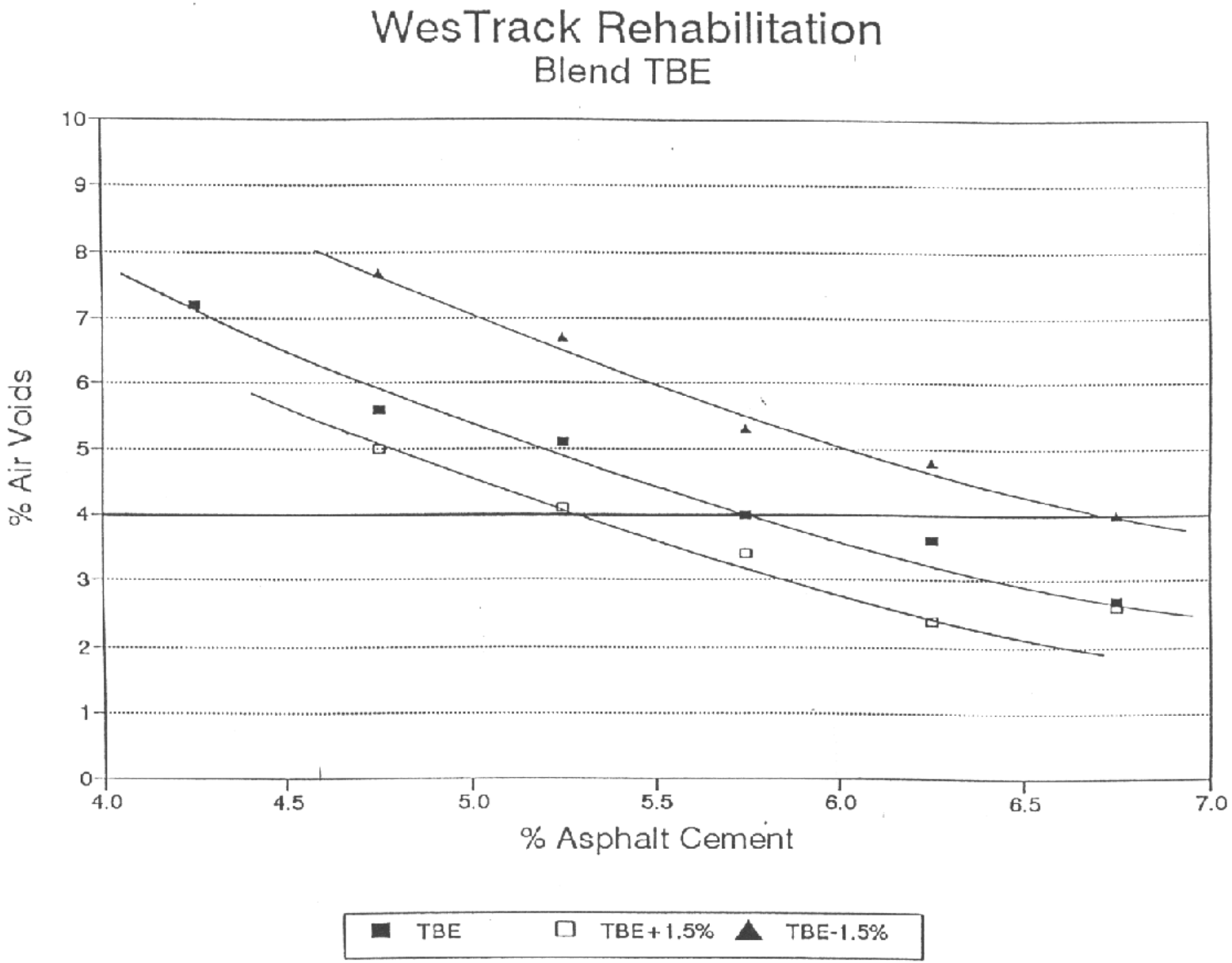
Project :	WesTrack Rehab
Mixture ID:	Trial Blend E - 1.5% p200 (TBEM)
Other:	Lockwood - New VSI's
Date:	5-9-97
Technician:	TO

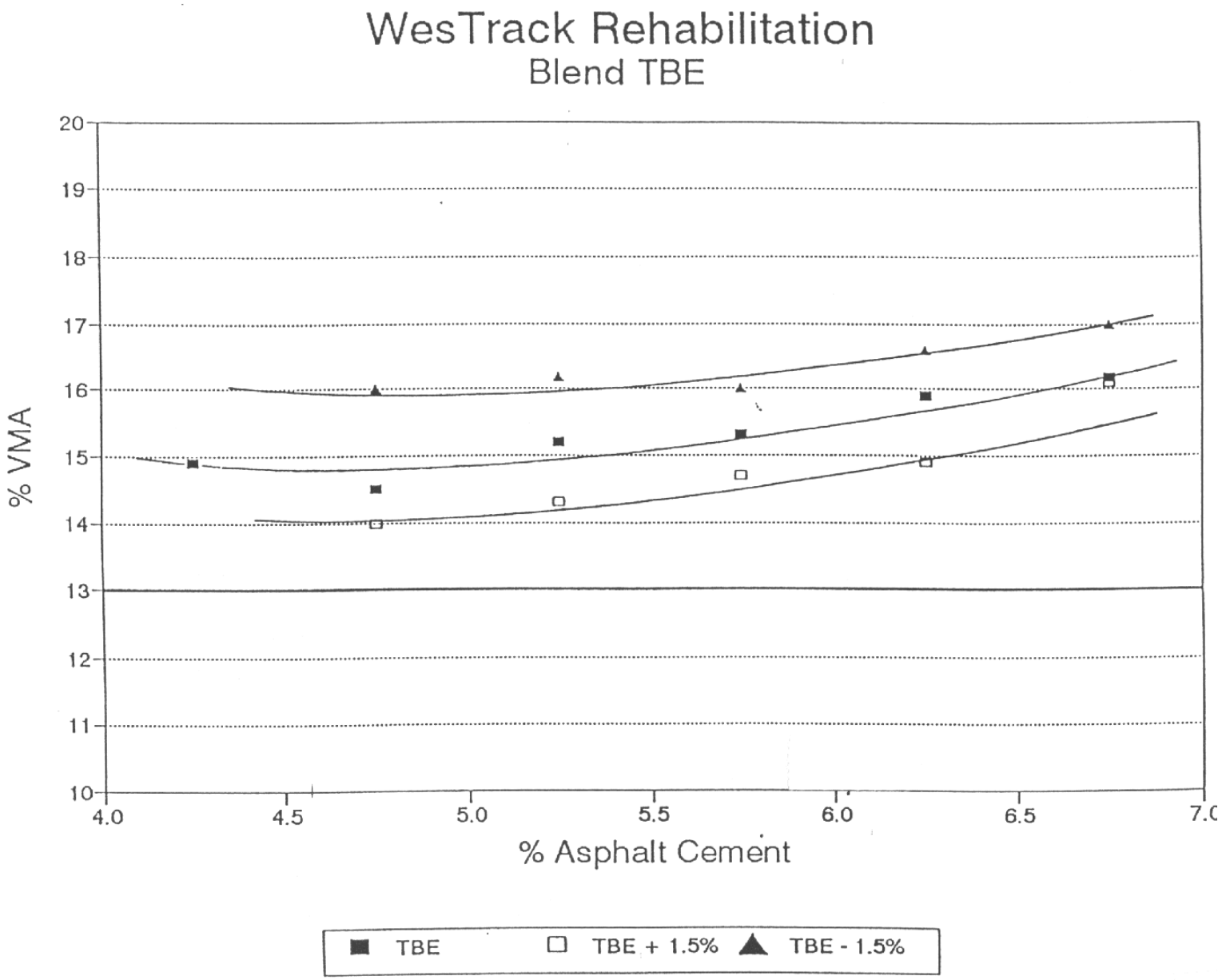
% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.00							
4.25							
4.75	92.3	7.7	16.0	52.1	83.7	93.5	1.15
5.25	93.3	6.7	16.2	58.7	84.8	94.6	1.01
5.75	94.7	5.3	16.0	68.8	85.9	95.9	0.90
6.25	95.2	4.8	16.6	71.1	86.2	97.0	0.82
6.75	96.0	4.0	17.0	76.2	86.7	97.2	0.75
7.00							

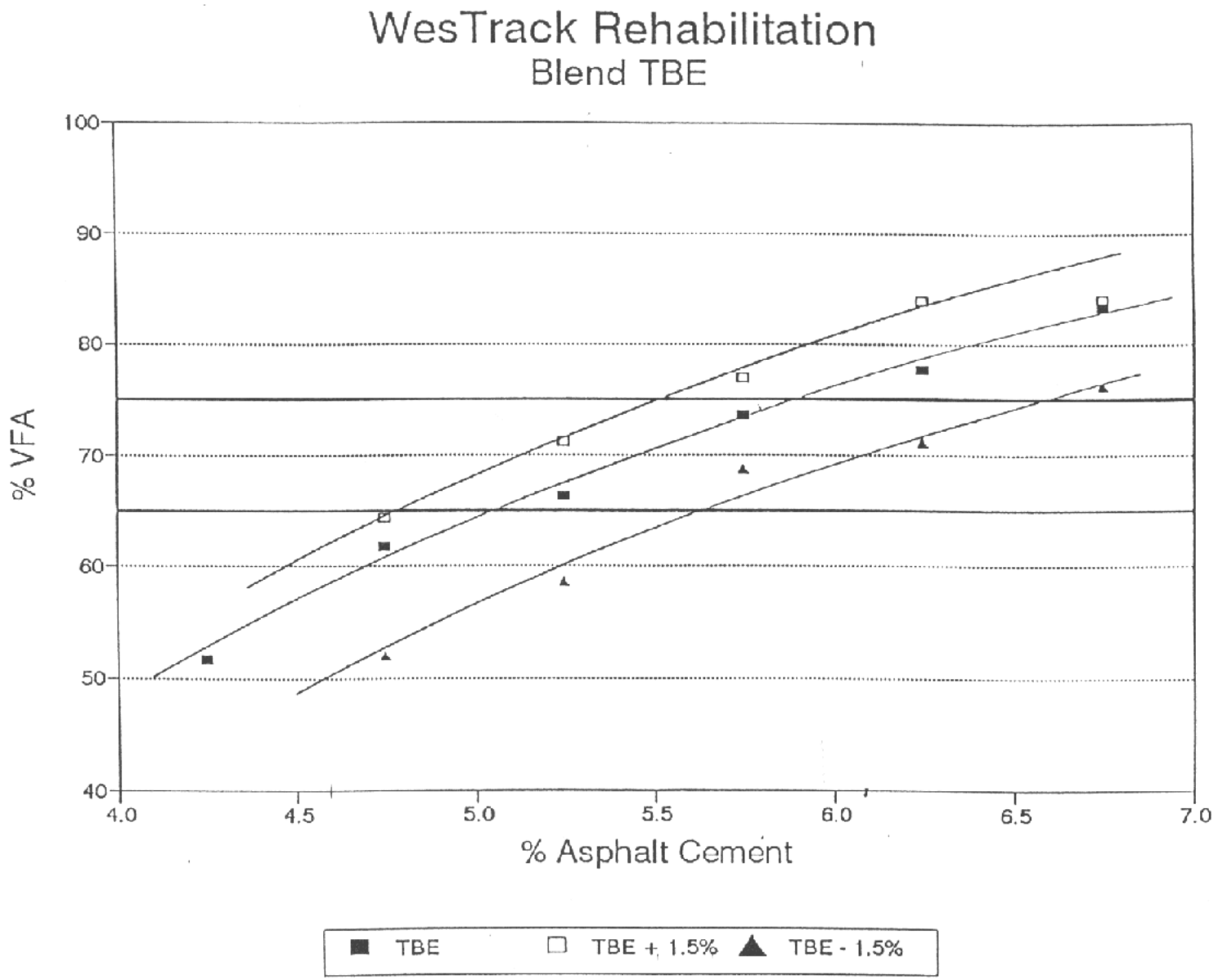
TBE-1.5% Properties at TBE Optimum Asphalt Content

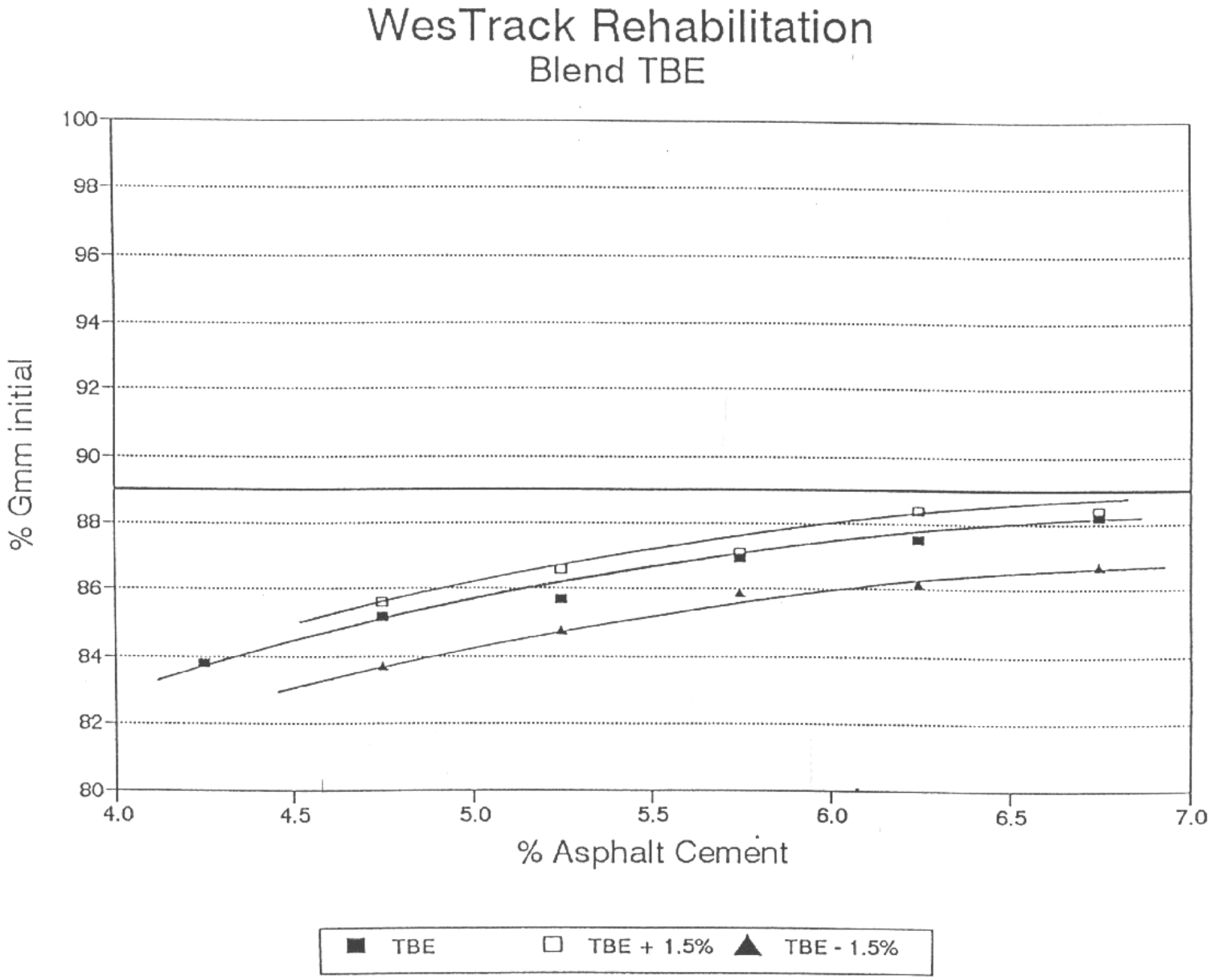
% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.75	94.7	5.3	16	68.8	85.9	95.9	0.90

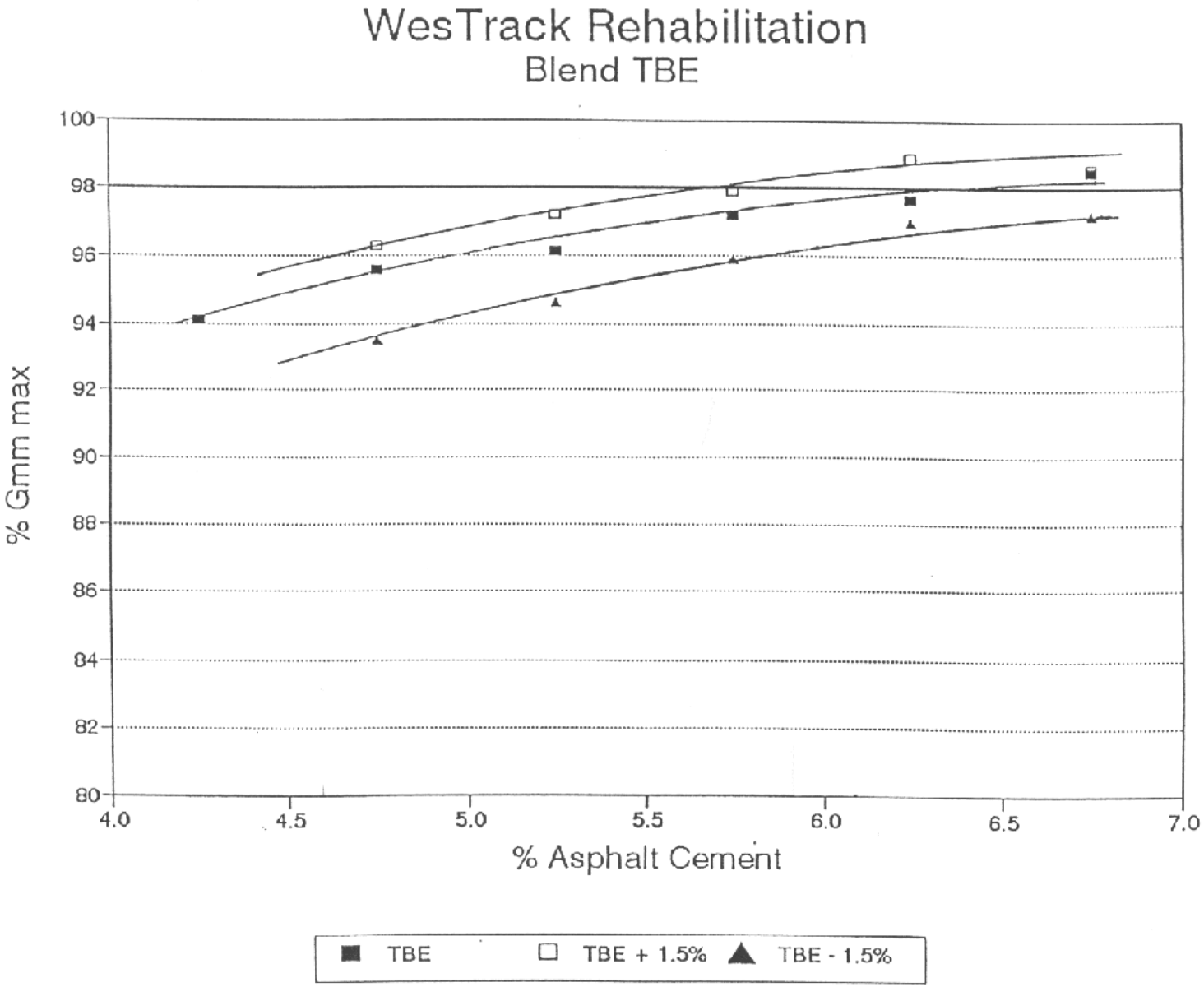

WesTrack Rehabilitation
Blend TBE
% Gmm design
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE
TBE + 1.5%
TBE - 1.5%

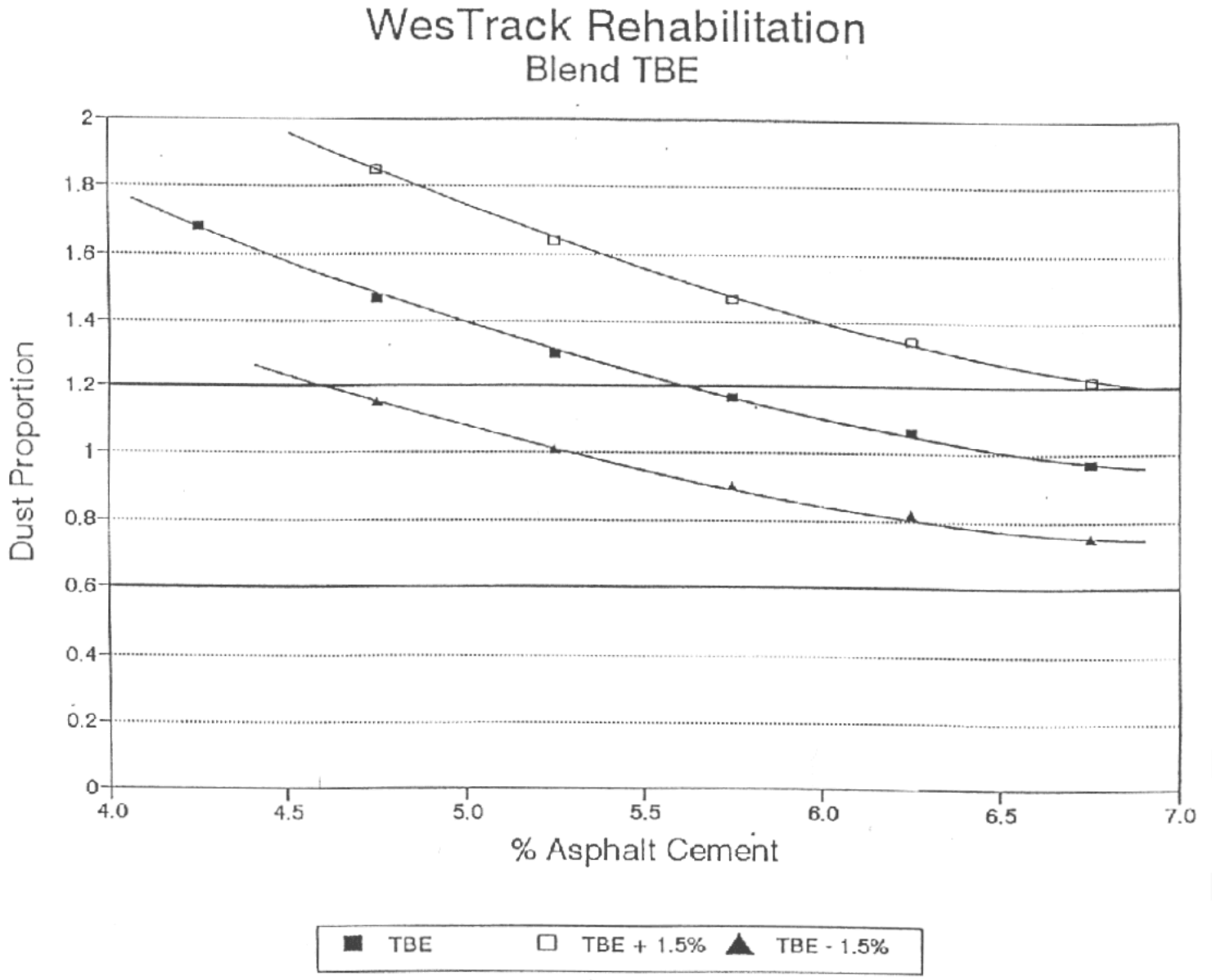

WesTrack Rehabilitation
Blend TBE
% Air Voids
10
9
8
7
6
5
4
3
2
1
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE
TBE+1.5%
TBE-1.5%


WesTrack Rehabilitation
Blend TBE
% VMA
20
19
18
17
16
15
14
13
12
11
10
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE
TBE + 1.5%
TBE - 1.5%


WesTrack Rehabilitation
Blend TBE
100
90
80
70
60
50
40
% VFA
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE
TBE + 1.5%
TBE - 1.5%


WesTrack Rehabilitation
Blend TBE
% Gmm initial
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE
TBE + 1.5%
TBE - 1.5%


WesTrack Rehabilitation
Blend TBE
100
98
96
94
92
90
88
86
84
82
80
% Gmm max
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE
TBE + 1.5%
TBE - 1.5%


WesTrack Rehabilitation
Blend TBE
Dust Proportion
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE
TBE + 1.5%
TBE - 1.5%

APPENDIX C

REPLACEMENT SECTIONS
IDAHO ASPHALT
LOCKWOOD AGGREGATE - NEW CRUSHING
SAMPLED AT LOCKWOOD

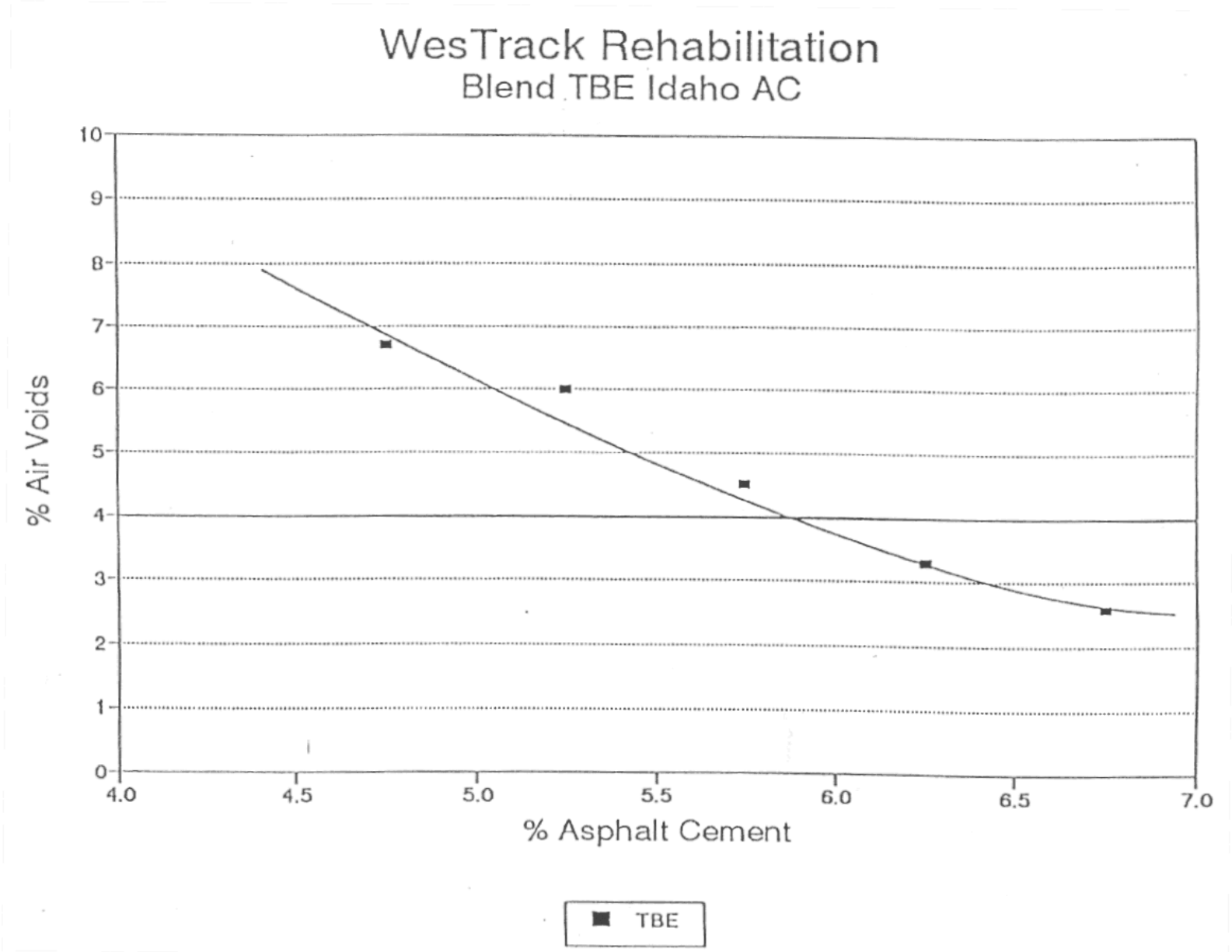
MAY 20, 1997

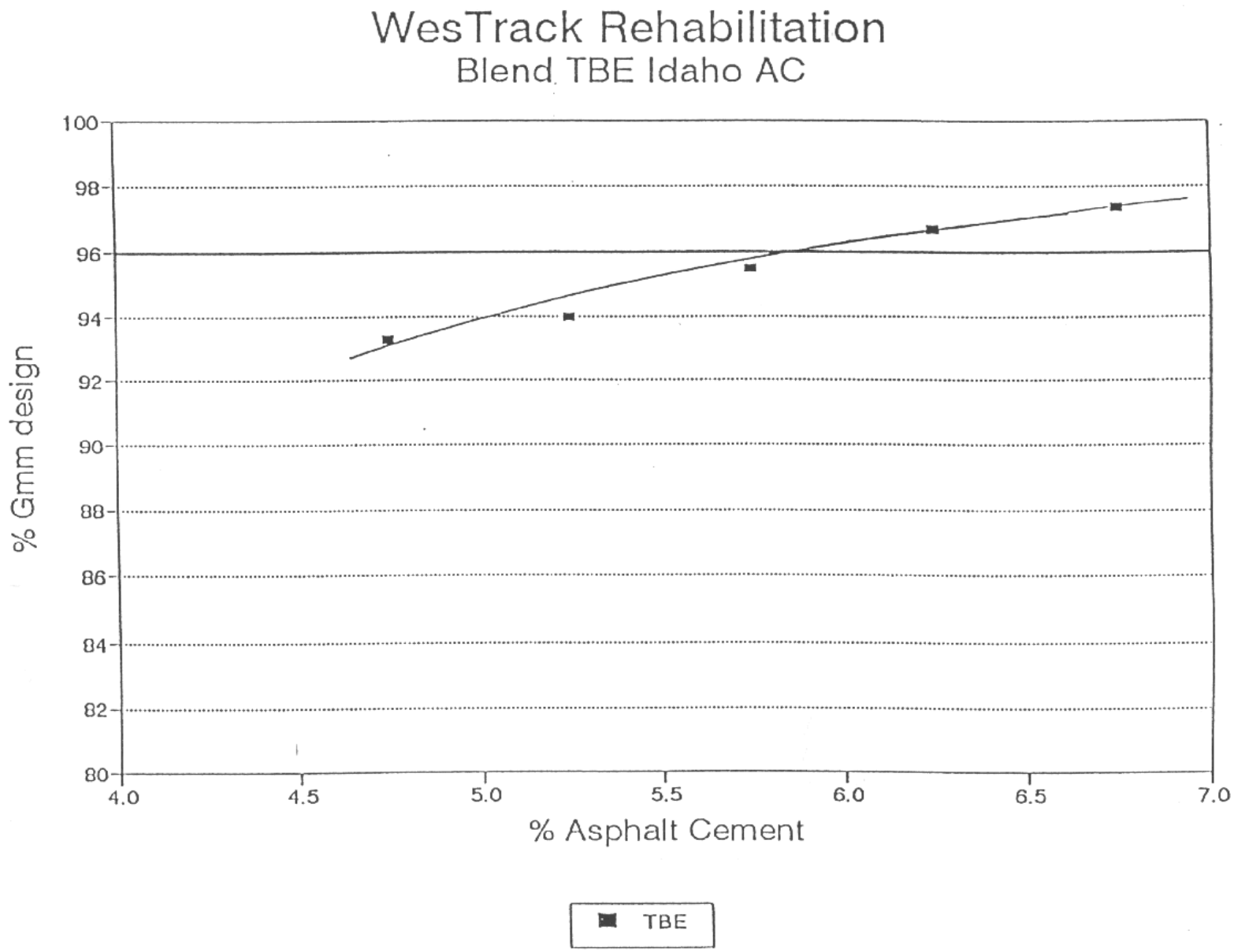
"TBE" MIX DESIGN

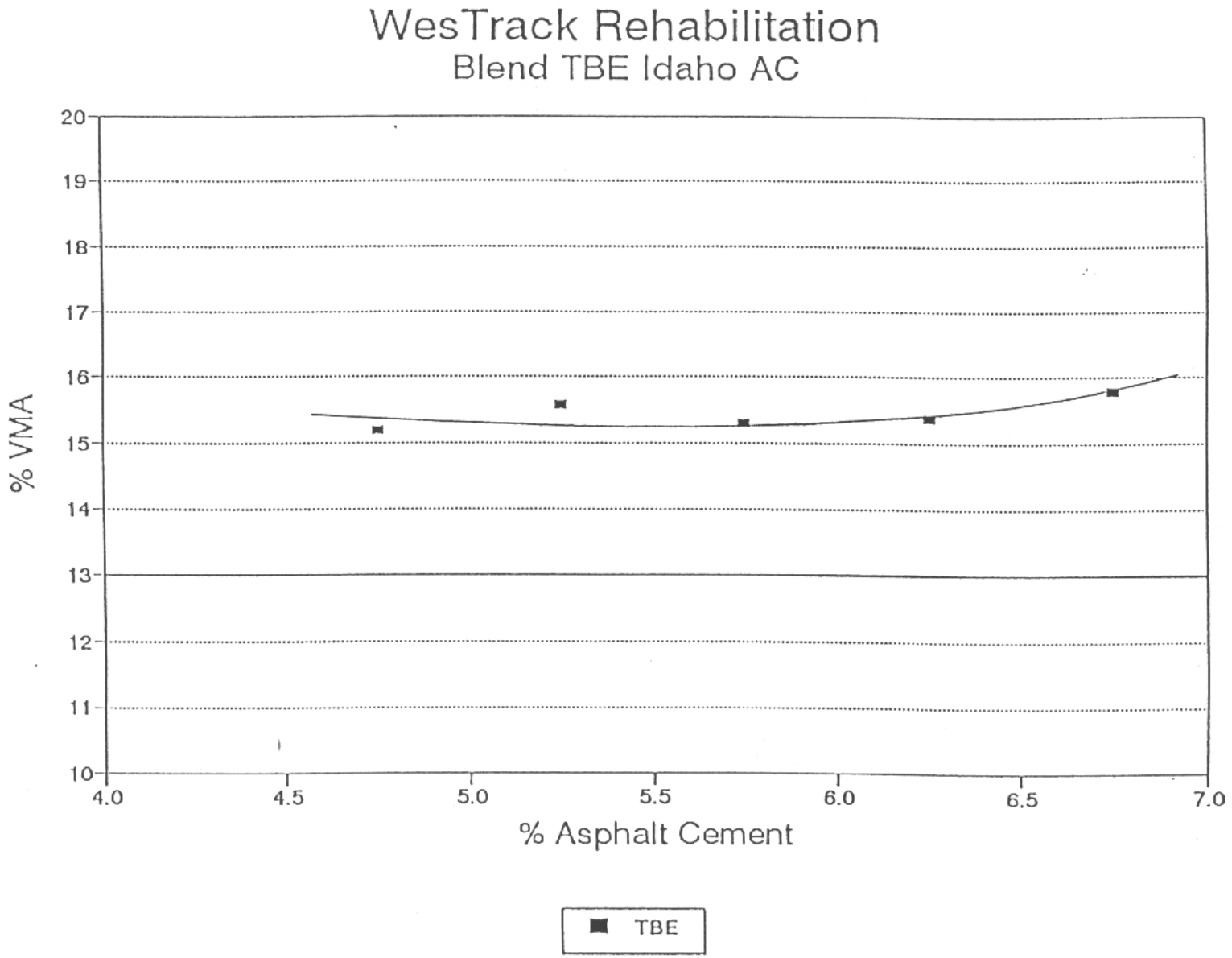
Gyratory Volumetrics Summary

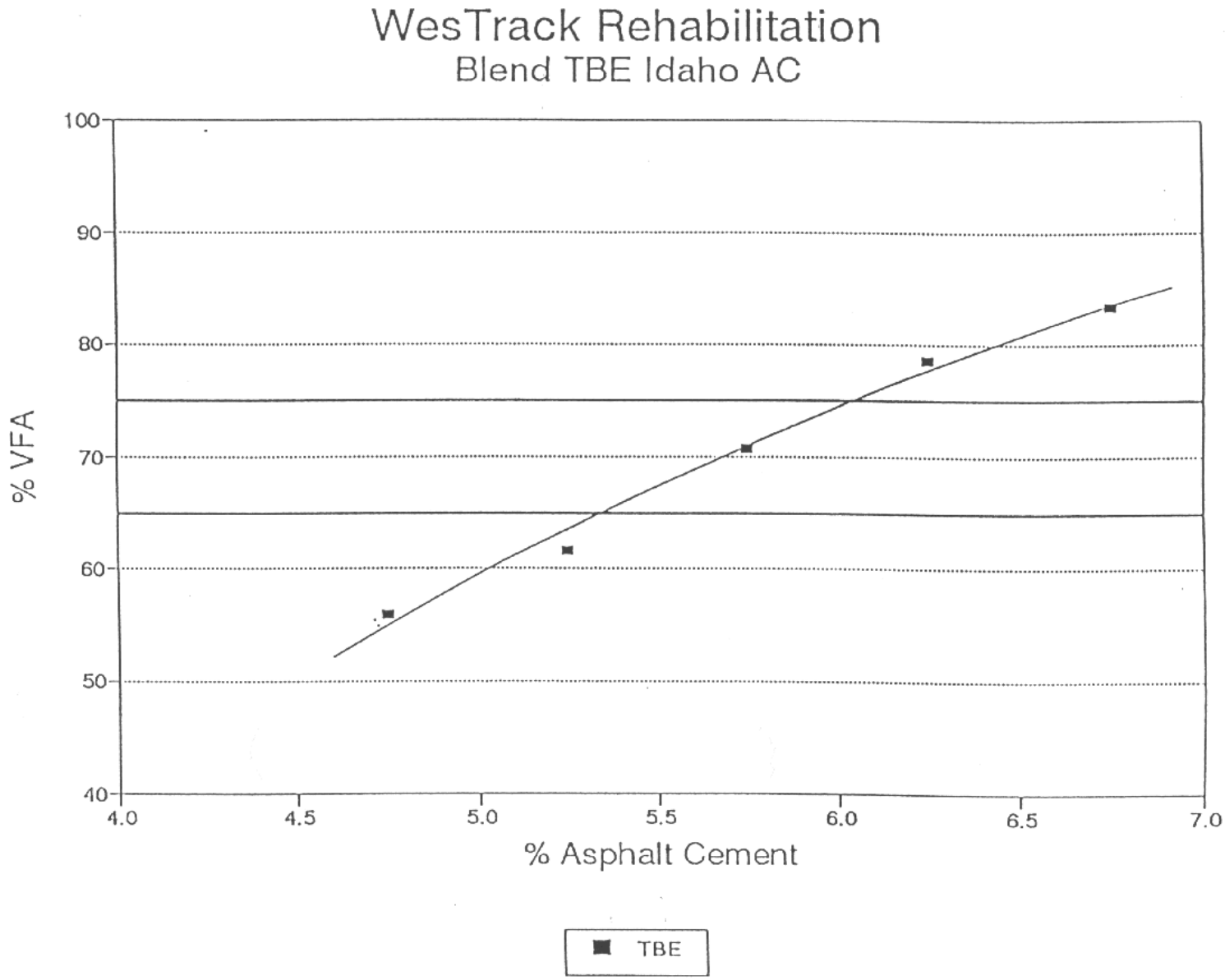
Project :	WesTrack Rehab
Mixture ID:	TBE
Other:	Idaho AC, Lockwood - New Crushing
Date:	5-20-97
Technician:	TO

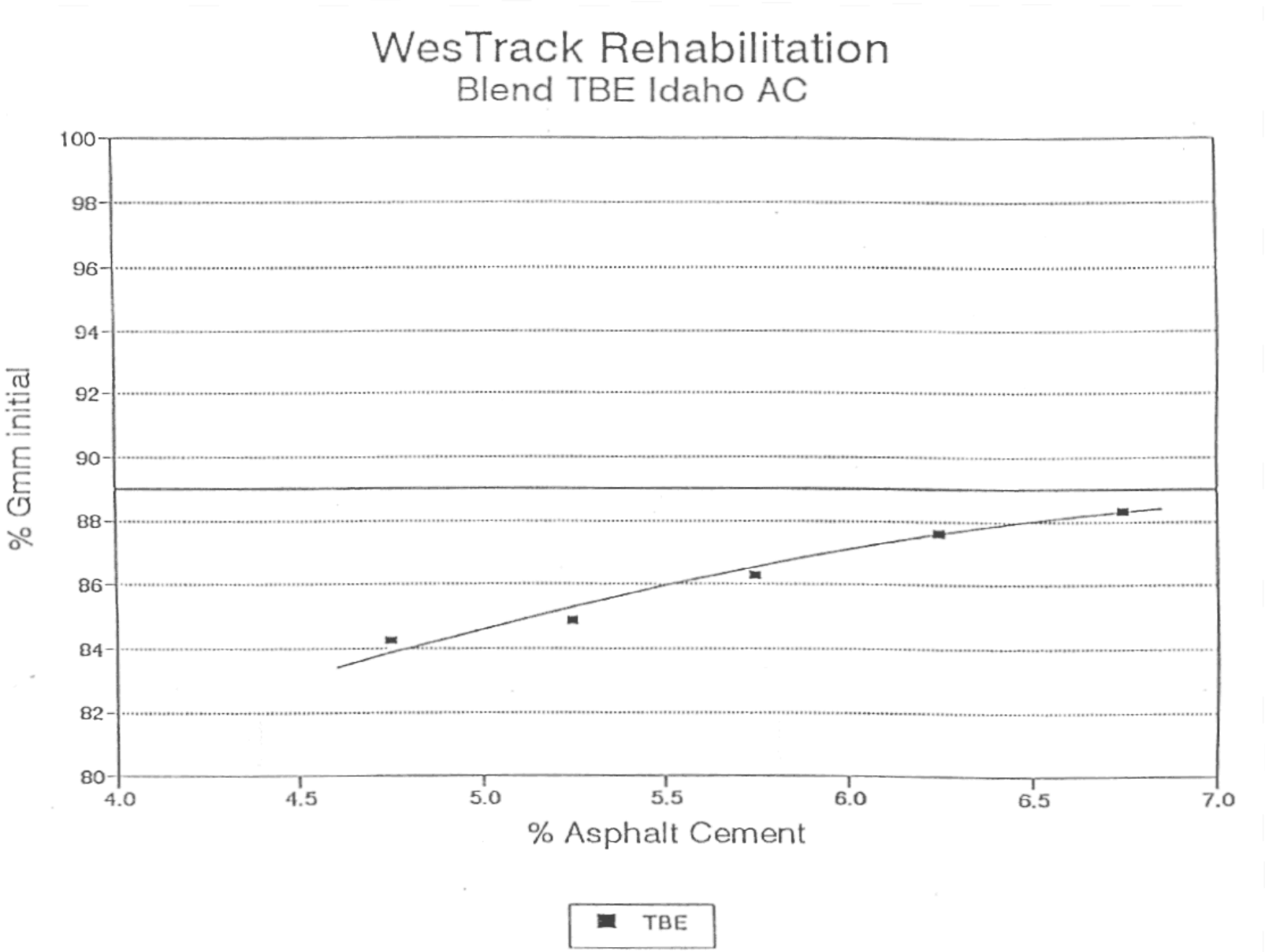
% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.00							
4.25							
4.75	93.3	6.7	15.2	56.1	84.3	94.6	1.53
5.25	94.0	6.0	15.6	61.6	84.9	95.3	1.35
5.75	95.5	4.5	15.3	70.7	86.3	96.8	1.21
6.25	96.7	3.3	15.4	78.5	87.6	98.0	1.10
6.75	97.4	2.6	15.8	83.3	88.3	98.6	1.00
7.00							

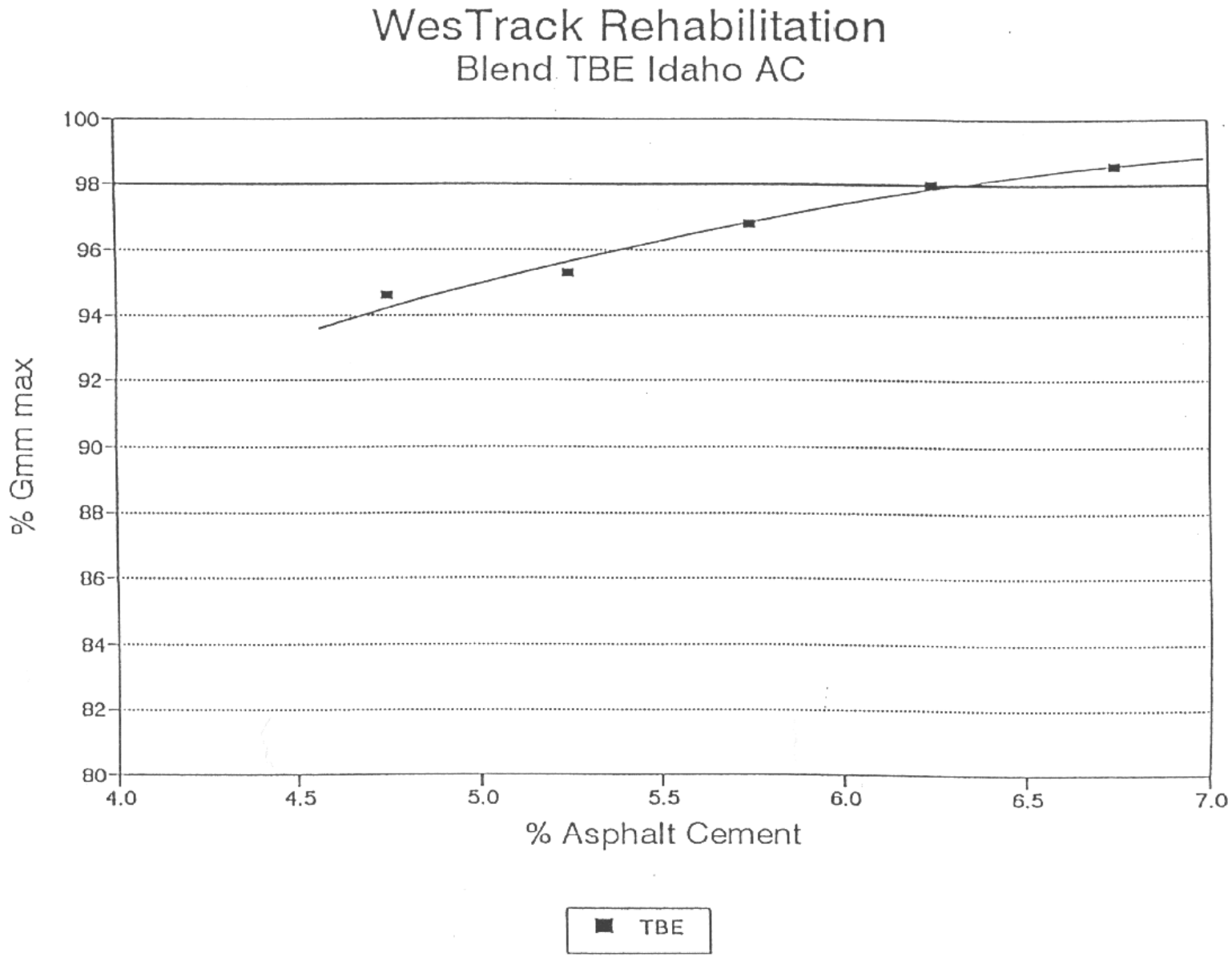

WesTrack Rehabilitation
Blend TBE Idaho AC
% Air Voids
10
9
8
7
6
5
4
3
2
1
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE

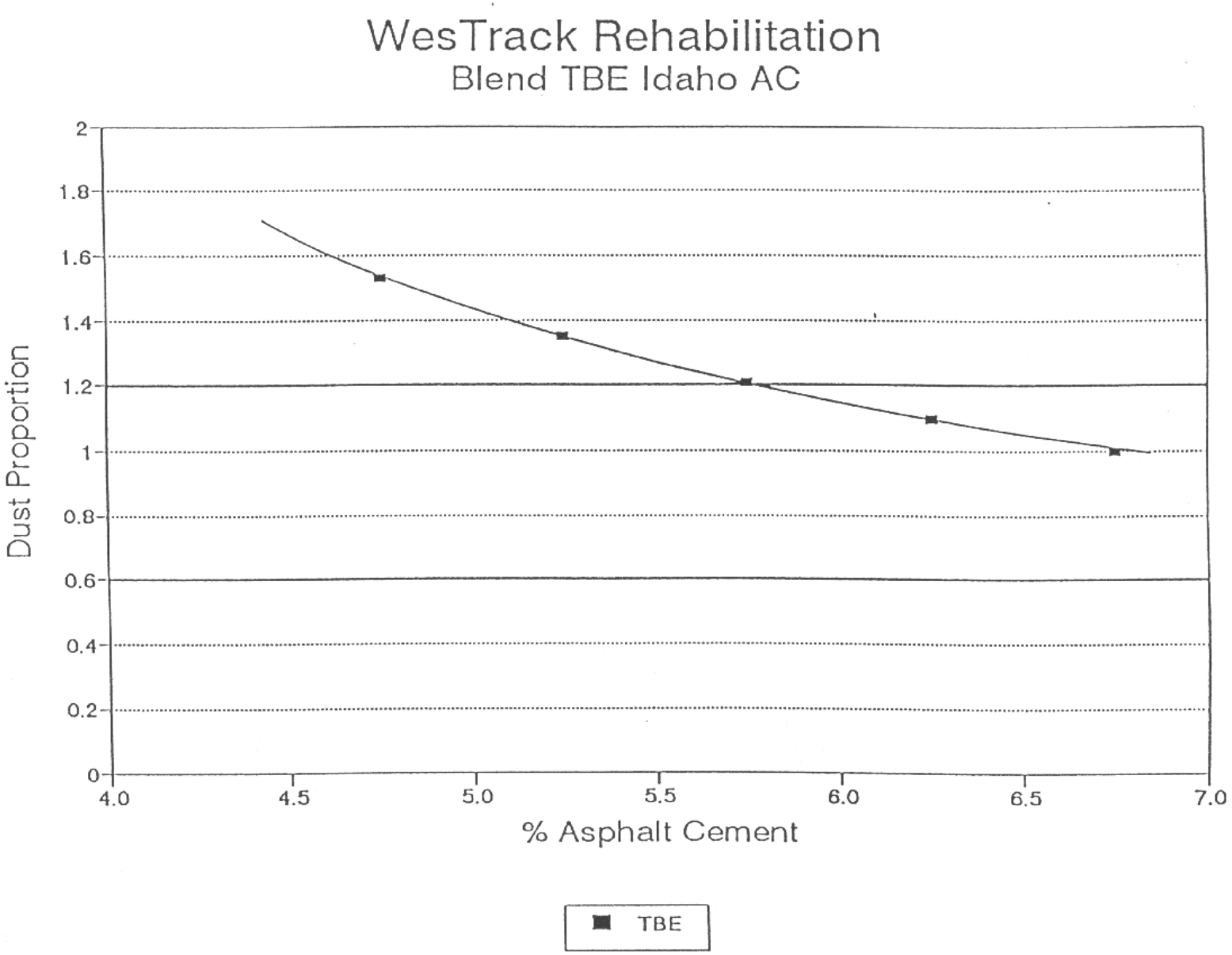

WesTrack Rehabilitation
Blend TBE Idaho AC
% Gmm design
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE


WesTrack Rehabilitation
Blend TBE Idaho AC
% VMA
20
19
18
17
16
15
14
13
12
11
10
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE


WesTrack Rehabilitation
Blend TBE Idaho AC
100
90
80
70
60
50
40
% VFA
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE


WesTrack Rehabilitation
Blend TBE Idaho AC
% Gmm initial
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE


WesTrack Rehabilitation
Blend TBE Idaho AC
% Gmm max
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE


WesTrack Rehabilitation
Blend TBE Idaho AC
Dust Proportion
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
TBE

APPENDIX D

REPLACEMENT SECTIONS
IDAHO ASPHALT
LOCKWOOD AGGREGATE
SAMPLED AT PATRICK

MAY 23, 1997

"P7" MIX DESIGN

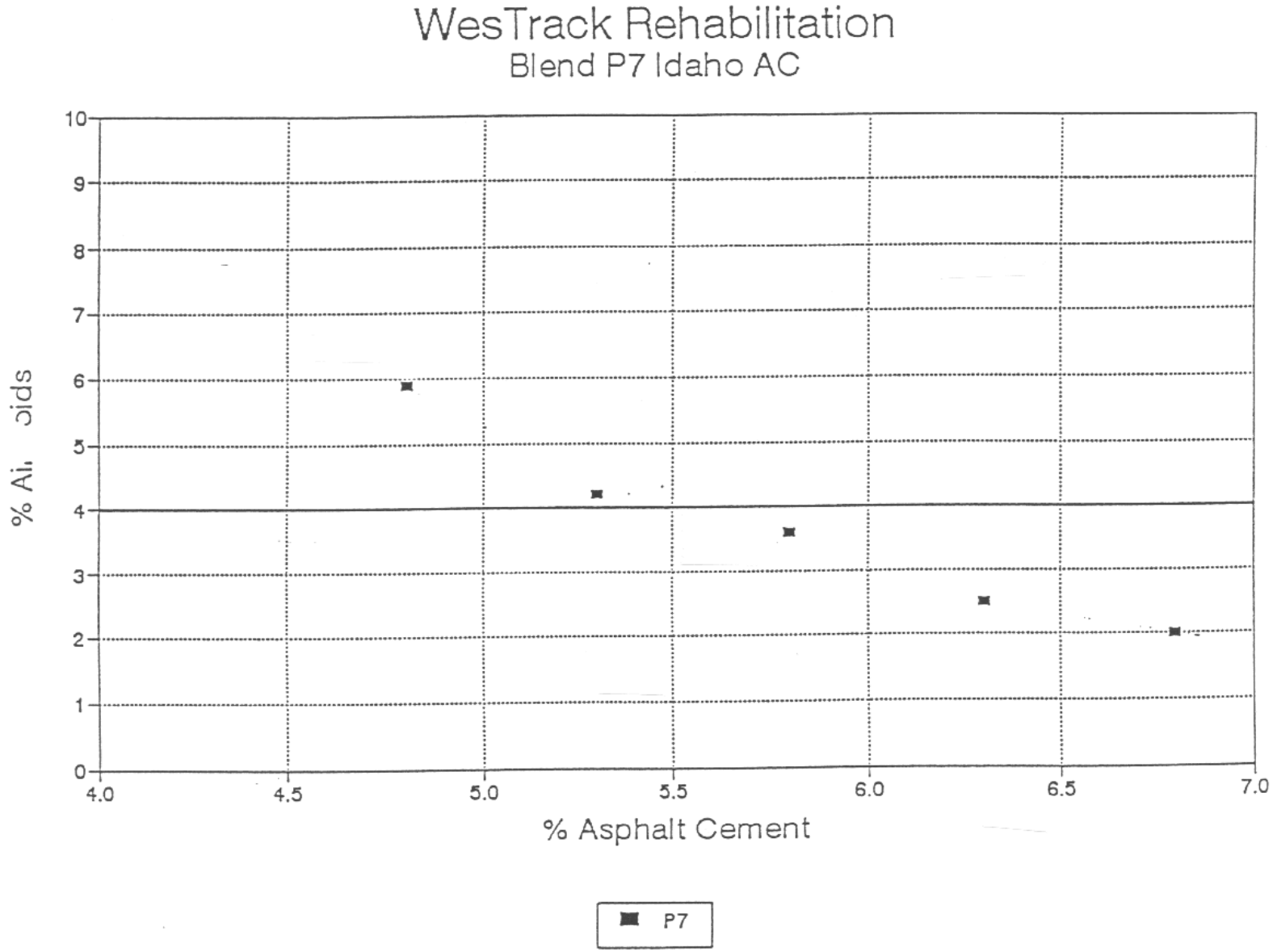
Gyratory Volumetrics Summary

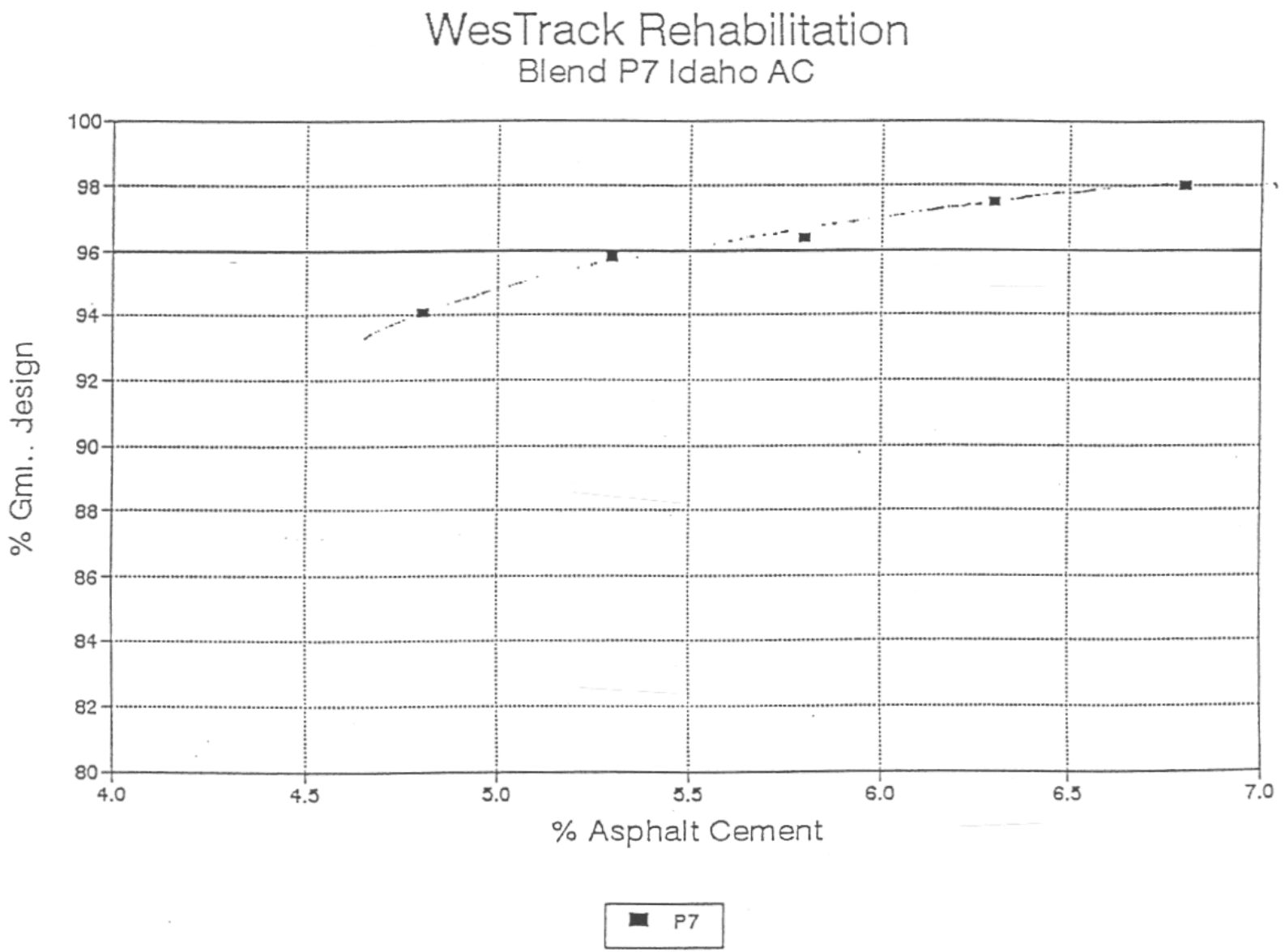
Project :	WesTrack Rehab
Mixture ID:	P7
Other:	Idaho AC, Lockwood@Patrick
Date:	5-23-97
Technician:	TO

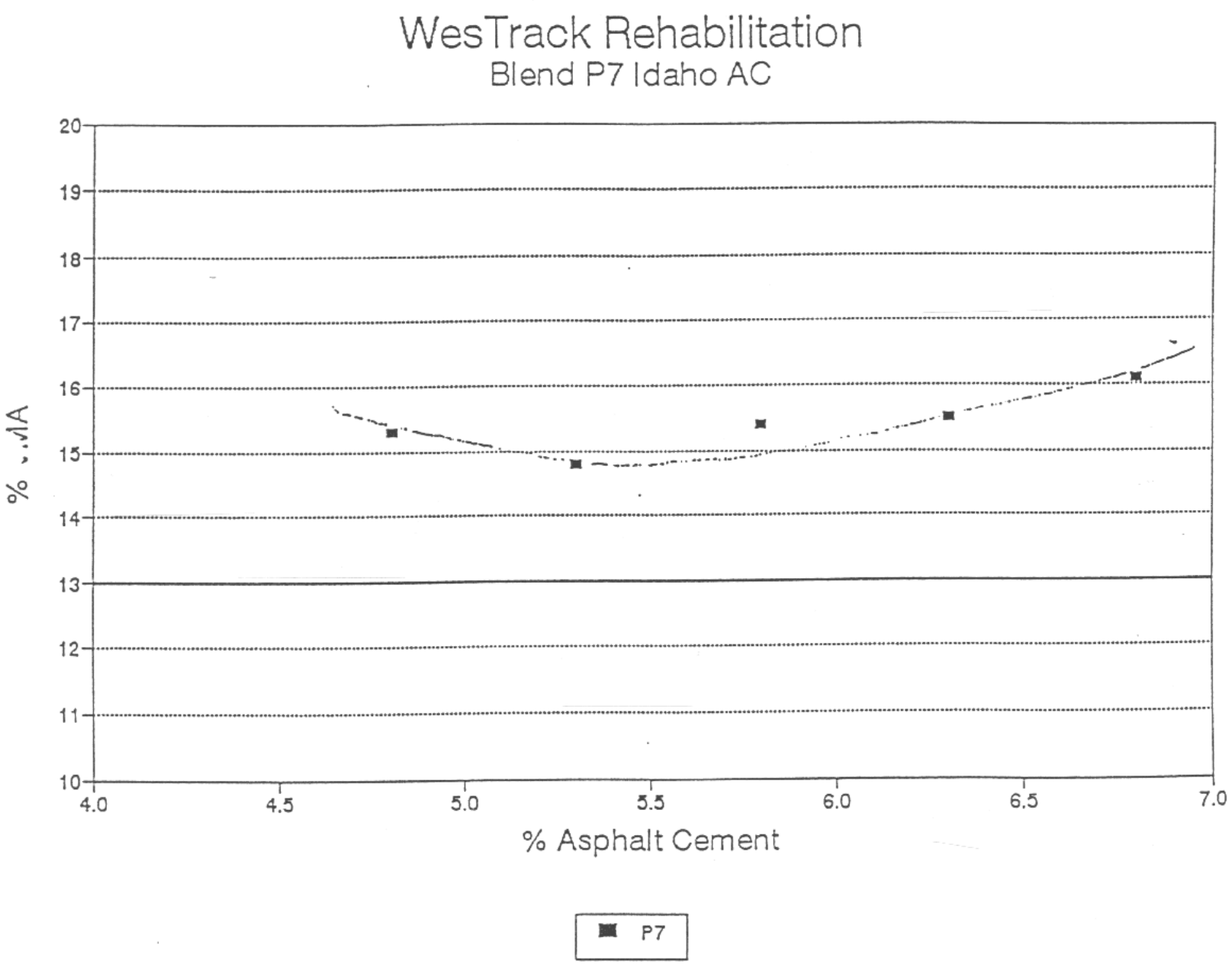
% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
3.80							
4.30							
4.80	94.1	5.9	15.3	61.6	84.7	95.5	1.38
5.30	95.8	4.2	14.8	71.9	86.3	97.1	1.23
5.80	96.4	3.6	15.4	76.6	86.7	97.7	1.11
6.30	97.5	2.5	15.5	83.8	87.9	98.9	1.02
6.80	98.0	2.0	16.1	87.7	88.2	99.4	0.93
7.30							

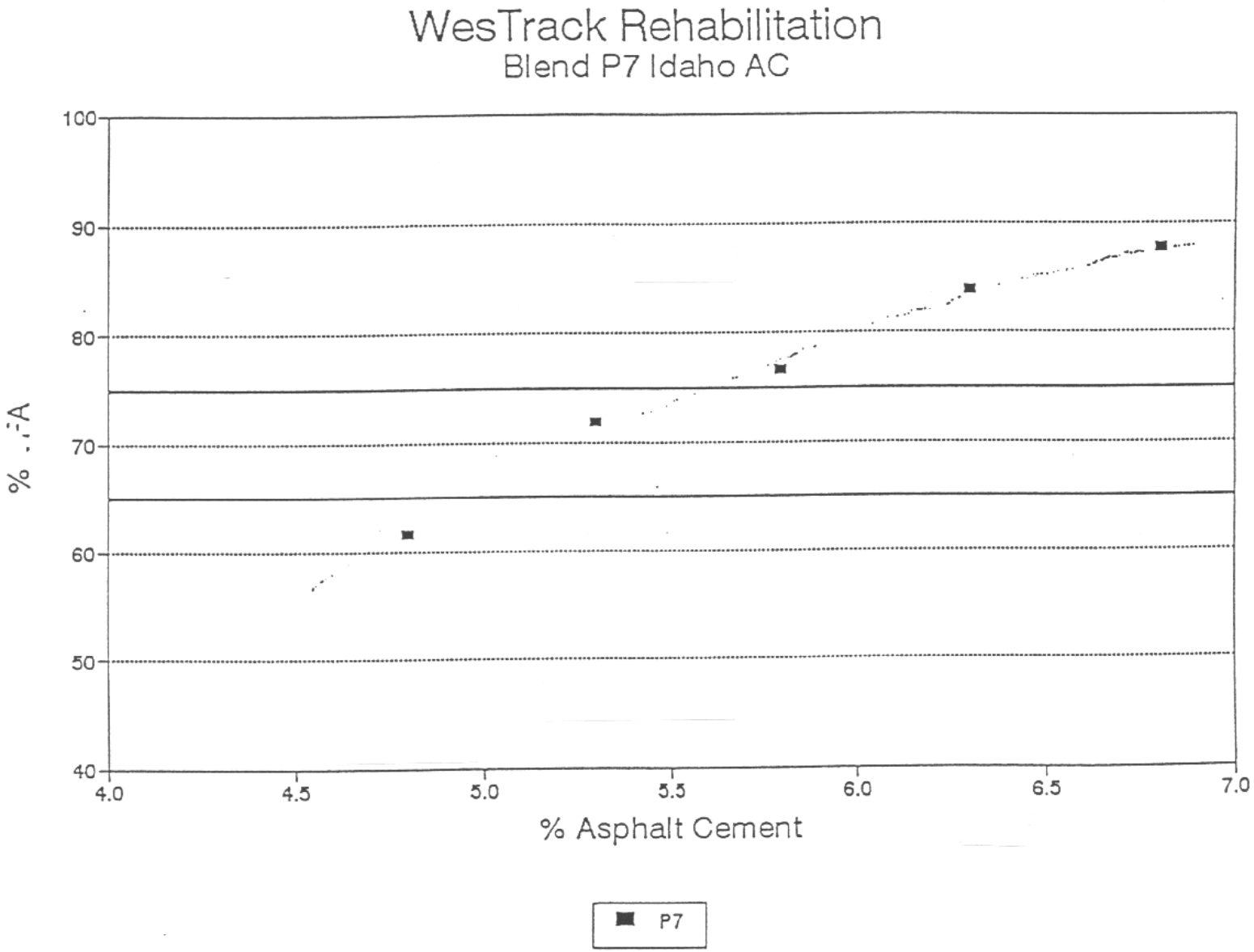
Properties at TBE Optimum Asphalt Content

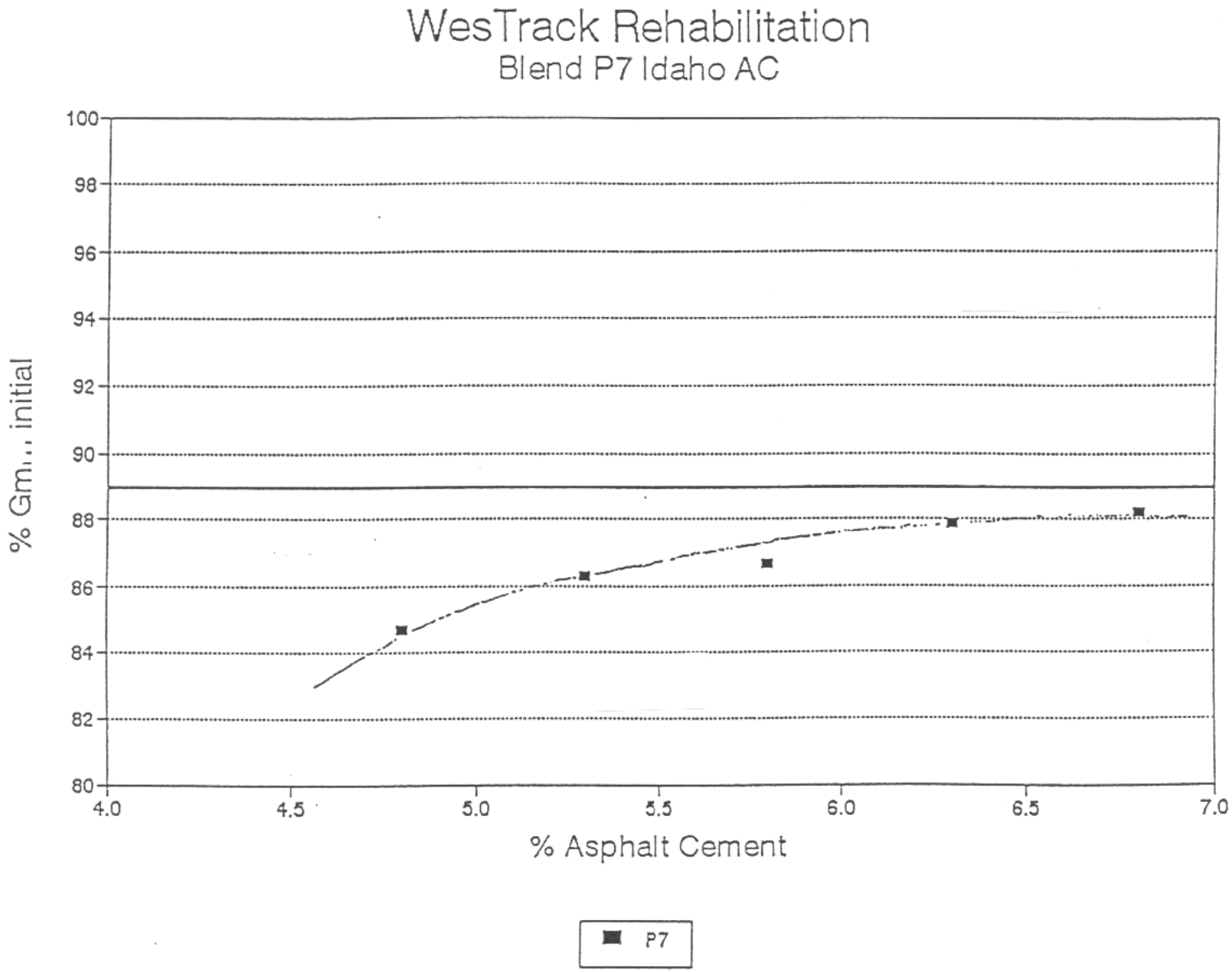
% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.5	96.0	4.0	14.8	74	86.2	97.6	1.18

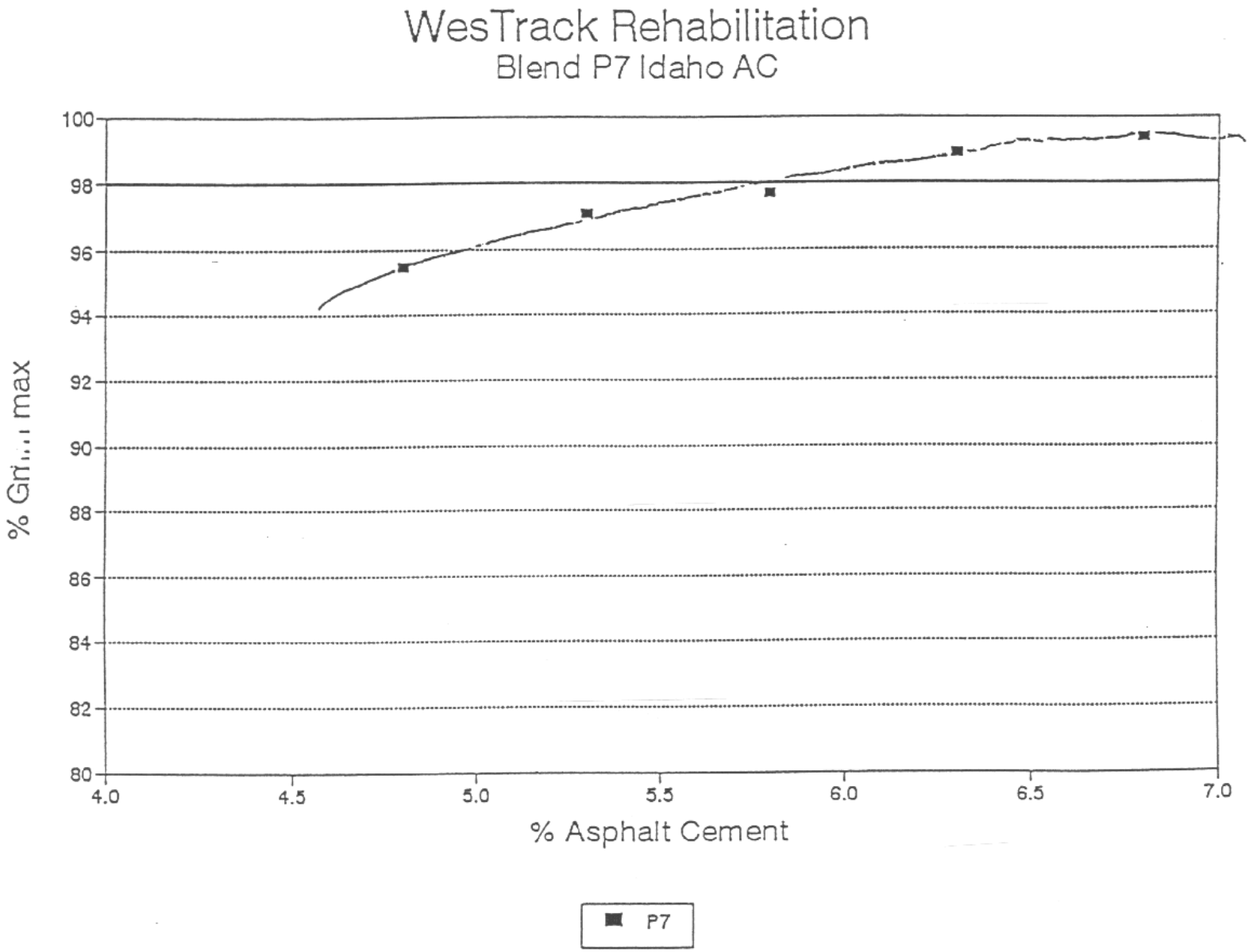

WesTrack Rehabilitation
Blend P7 Idaho AC
% Ai, oids
10
9
8
7
6
5
4
3
2
1
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
P7

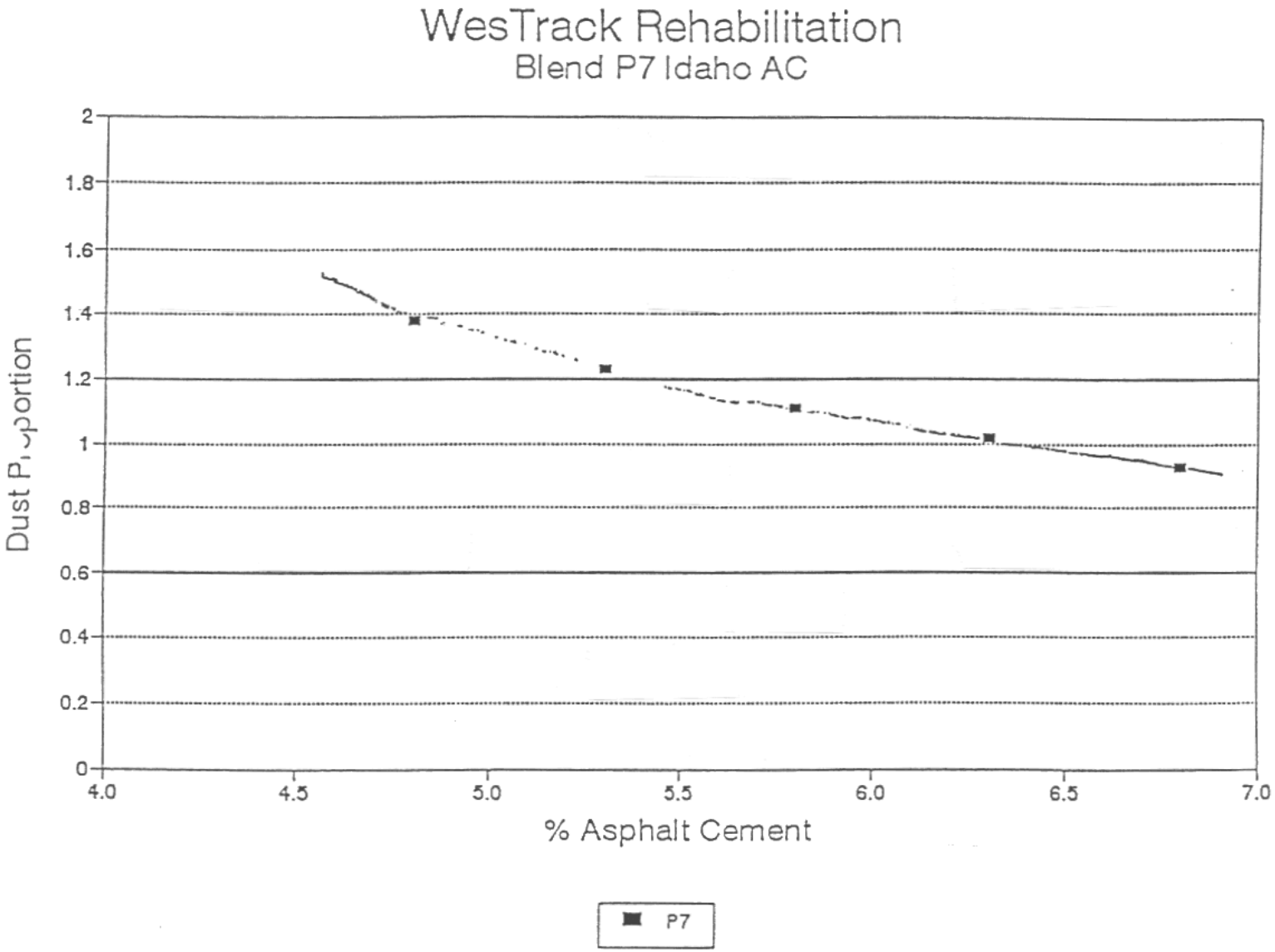

WesTrack Rehabilitation
Blend P7 Idaho AC
% Gmm @ Design
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
P7


WesTrack Rehabilitation
Blend P7 Idaho AC
20
19
18
17
16
15
14
13
12
11
10
% VMA
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
P7


WesTrack Rehabilitation
Blend P7 Idaho AC
100
90
80
70
60
50
40
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
P7


WesTrack Rehabilitation
Blend P7 Idaho AC
% Gmm, initial
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
P7


WesTrack Rehabilitation
Blend P7 Idaho AC
100
98
96
94
92
90
88
86
84
82
80
% Gmm max
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
P7


WesTrack Rehabilitation
Blend P7 Idaho AC
Dust Proportion
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
P7

APPENDIX E

REPLACEMENT SECTIONS
IDAHO ASPHALT
LOCKWOOD AGGREGATE
SAMPLED AT PATRICK

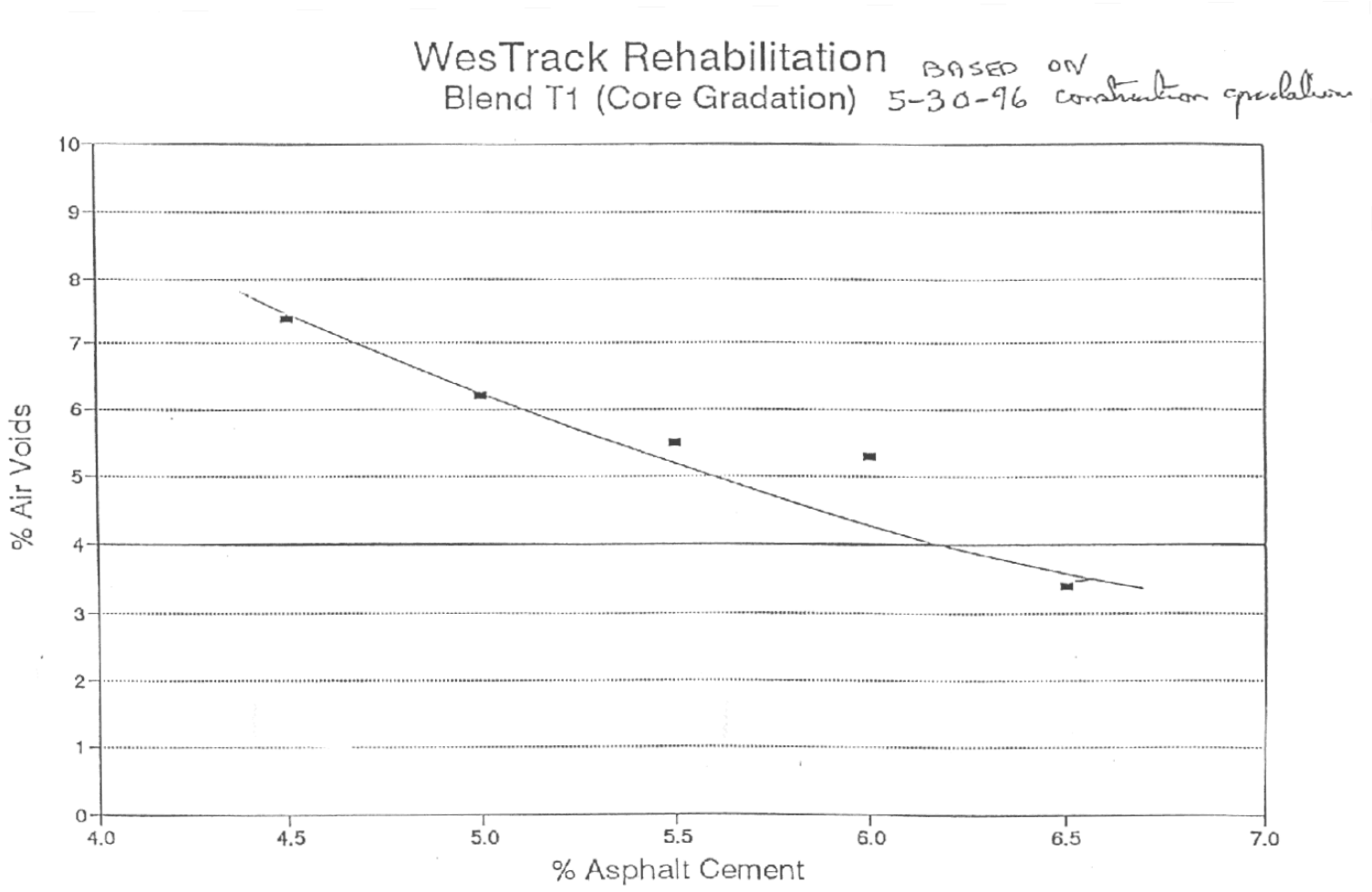
JUNE 6, 1997

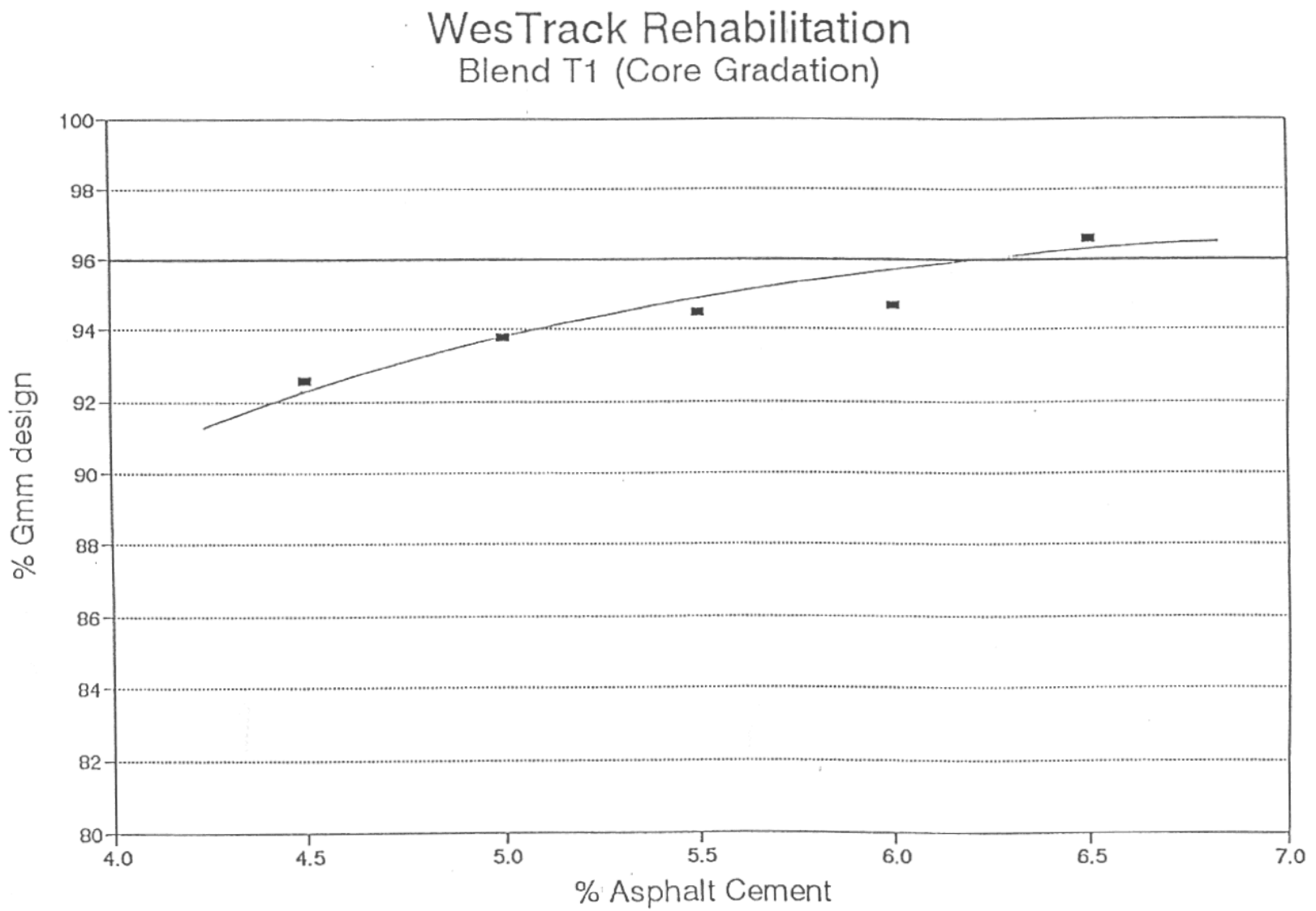
"T" MIX DESIGN

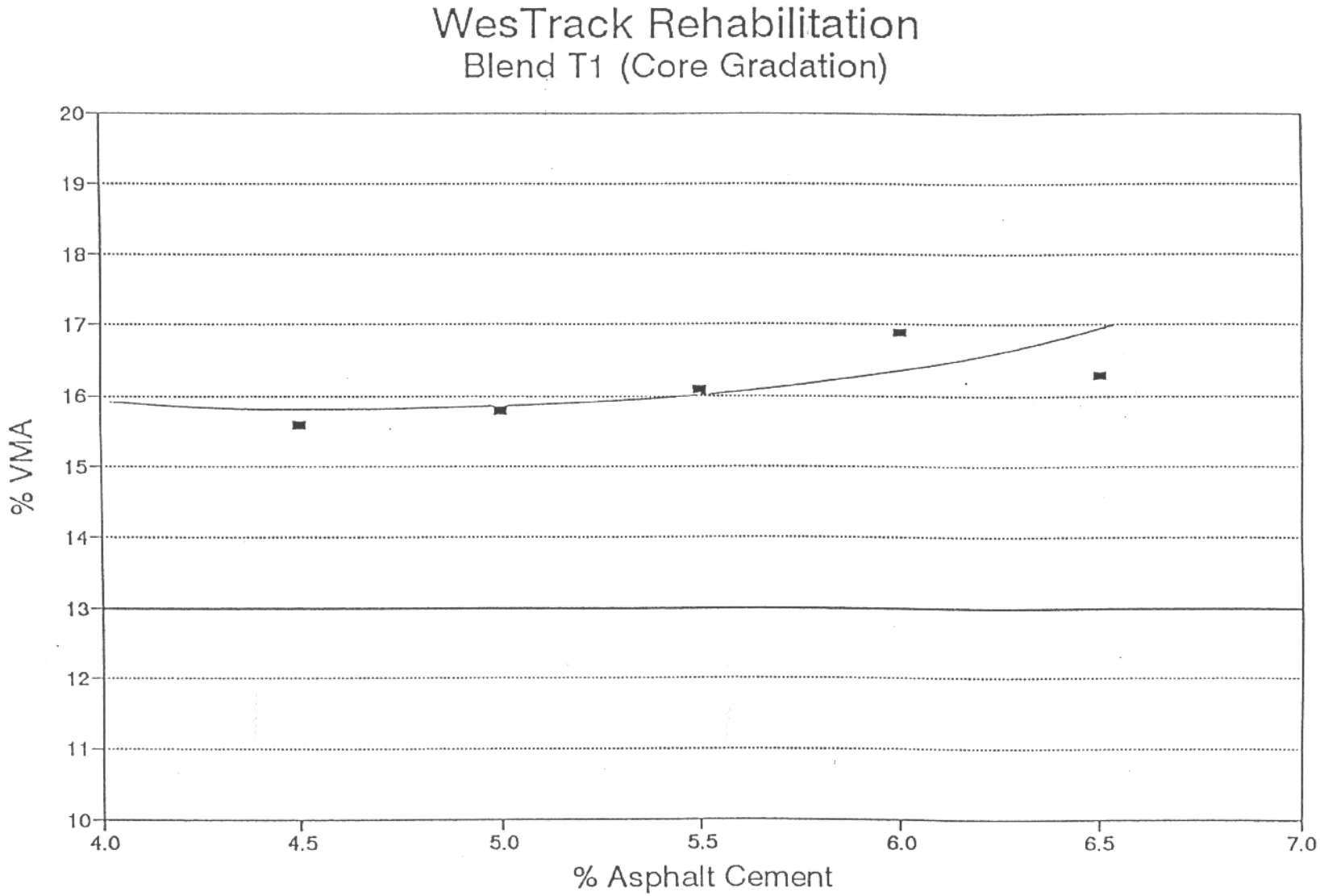
Gyratory Volumetrics Summary

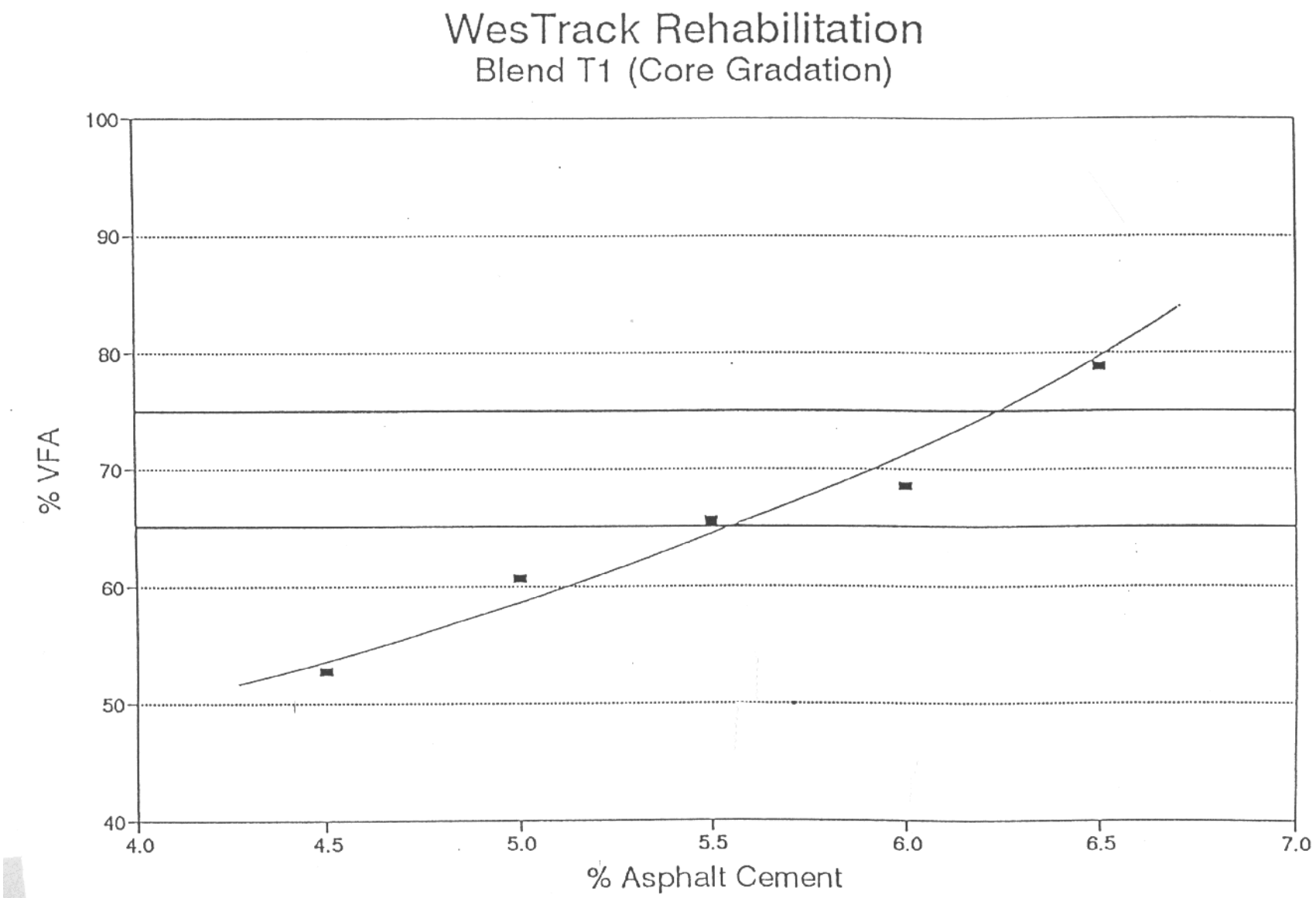
Project :	WesTrack Rehab
Mixture ID:	T1 (5-30-97 Core Gradations)
Other:	Lockwood - New Crushing
Date:	6-6-97
Technician:	TO

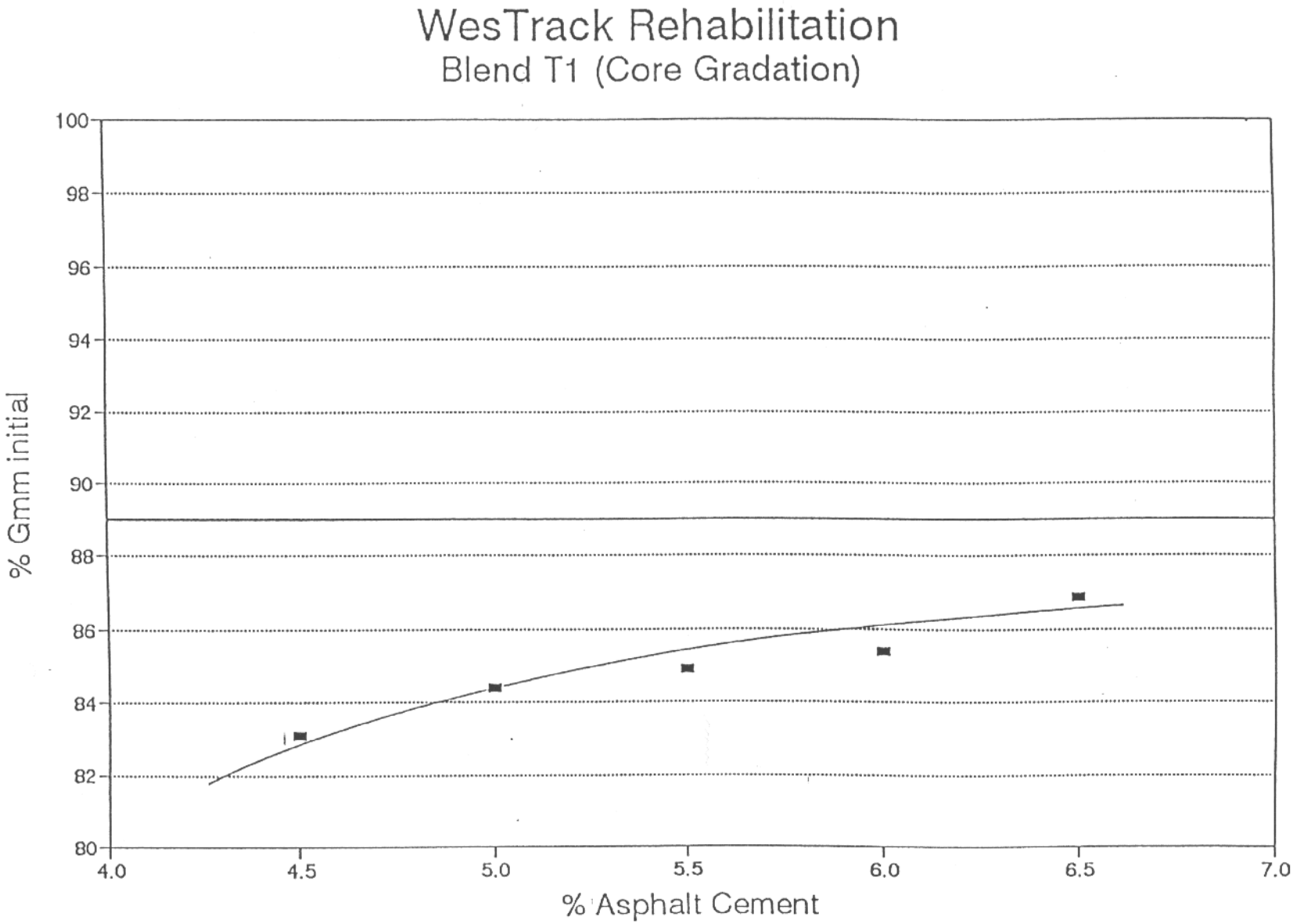
% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.0							
4.5	92.6	7.4	15.6	52.8	83.1	94.0	1.46
5.0	93.8	6.2	15.8	60.7	84.4	95.0	1.26
5.5	94.5	5.5	16.1	65.6	84.9	95.8	1.14
6.0	94.7	5.3	16.9	68.6	85.4	96.0	1.03
6.5	96.6	3.4	16.3	78.9	86.9	97.9	0.94
7.0							

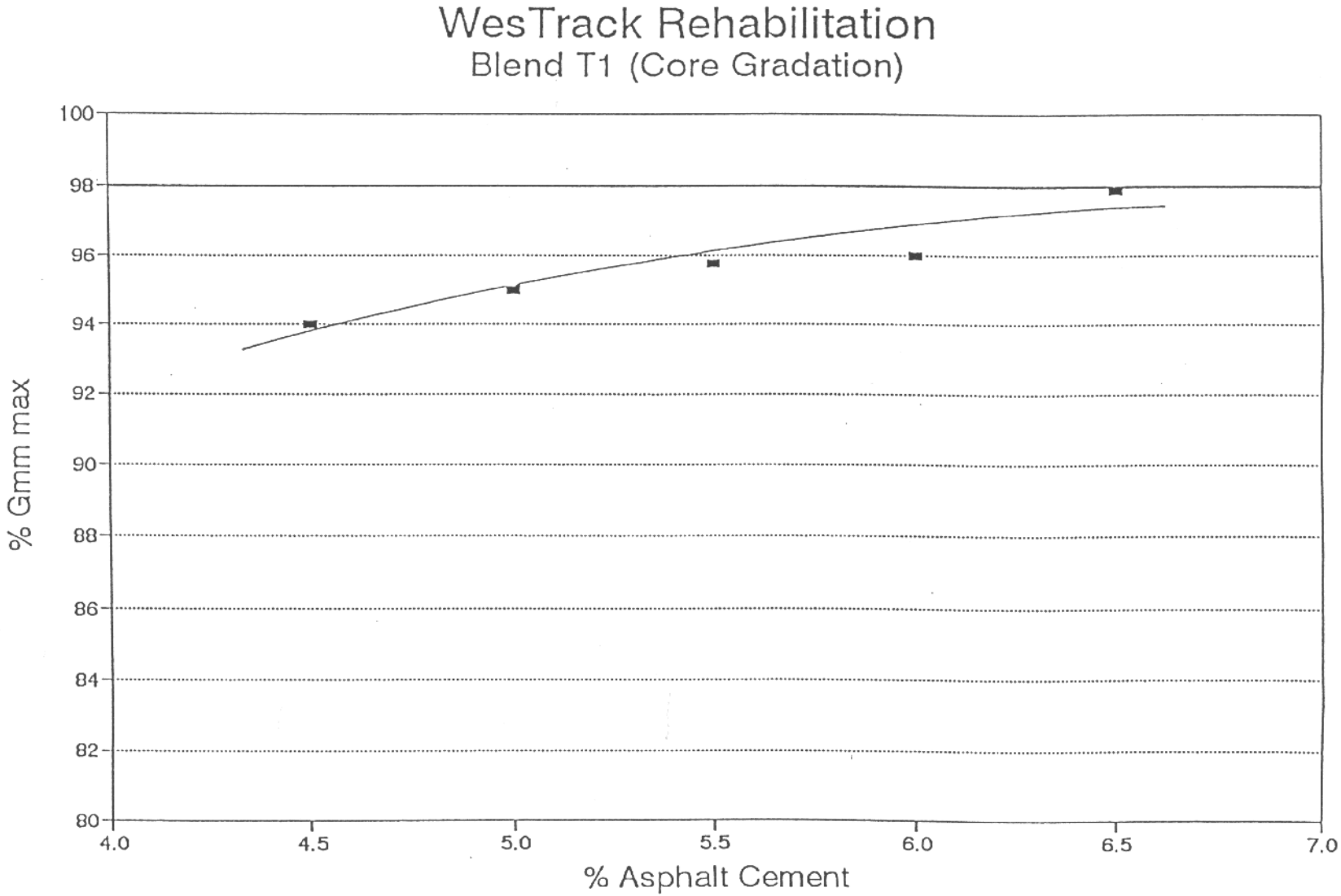

WesTrack Rehabilitation BASED ON
Blend T1 (Core Gradation) 5-30-96 construction specification
% Air Voids
10
9
8
7
6
5
4
3
2
1
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement

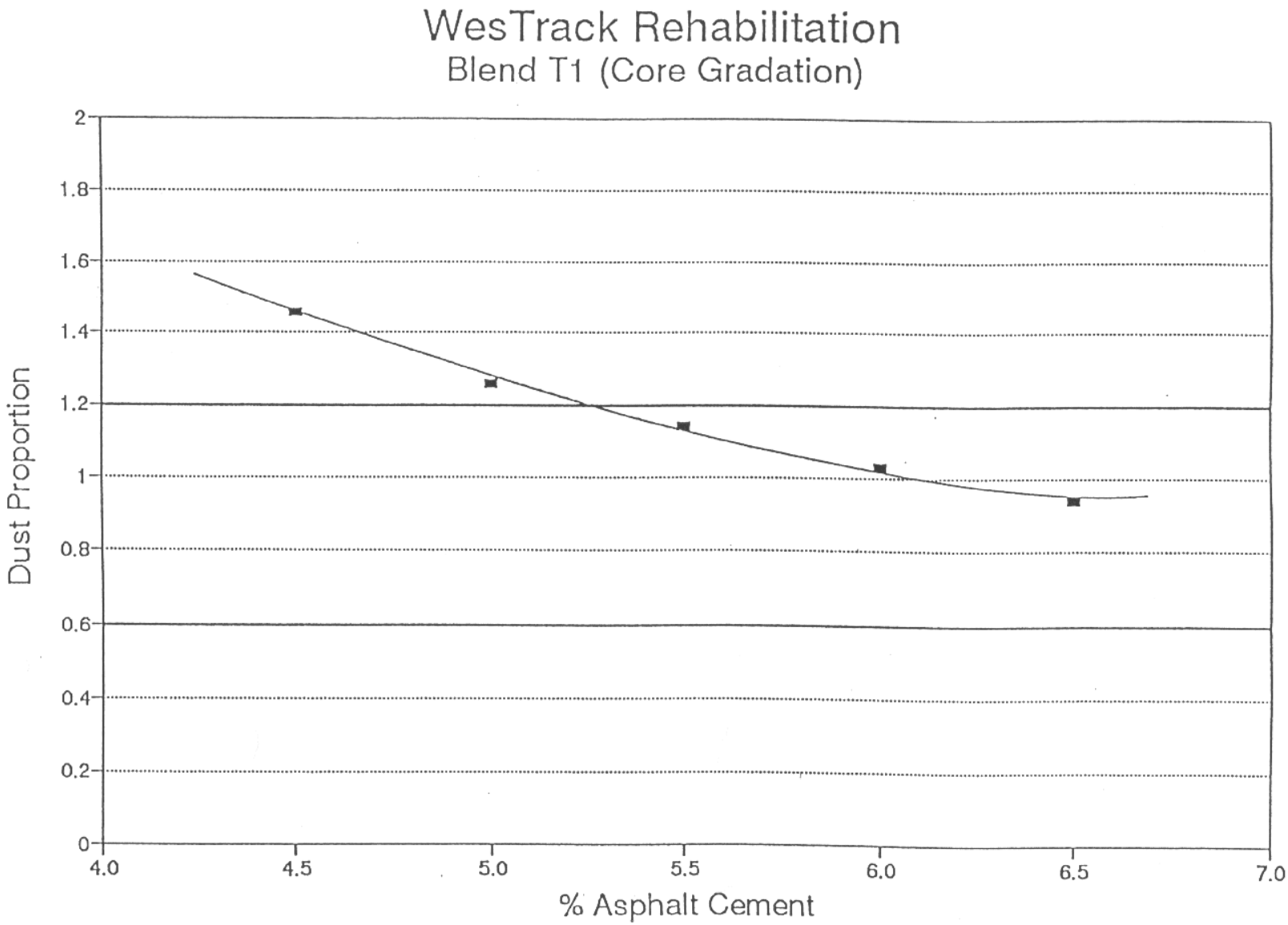

WesTrack Rehabilitation
Blend T1 (Core Gradation)
% Gmm design
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement


WesTrack Rehabilitation
Blend T1 (Core Gradation)
% VMA
20
19
18
17
16
15
14
13
12
11
10
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement


WesTrack Rehabilitation
Blend T1 (Core Gradation)
100
90
80
70
60
50
40
% VFA
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement


WesTrack Rehabilitation
Blend T1 (Core Gradation)
% Gmm initial
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement


WesTrack Rehabilitation
Blend T1 (Core Gradation)
100
98
96
94
92
90
88
86
84
82
80
% Gmm max
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement


WesTrack Rehabilitation
Blend T1 (Core Gradation)
Dust Proportion
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement

APPENDIX F

REPLACEMENT SECTIONS
IDAHO ASPHALT
LOCKWOOD AGGREGATE
SAMPLED AT PATRICK

JUNE 12, 1997

"F" MIX DESIGN

Gyratory Volumetrics Summary

Project :	WesTrack Rehab
Mixture ID:	F
Other:	Lockwood @ Patrick (6-7-97 sampling)
Date:	6-12-97
Technician:	TO

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.0							
4.5	93.8	6.2	14.6	57.6	84.4	95.2	1.56
5.0	95.1	4.9	14.6	66.8	85.5	96.6	1.35
5.5	95.8	4.2	14.9	72.0	86.5	97.2	1.23
6.0	96.3	3.7	15.4	75.9	87.6	97.6	1.12
6.5	97.0	3.0	15.9	81.5	87.3	98.3	1.01
7.0							

Properties at Optimum Asphalt Content

% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.65	96.0	4.0	15	73	86.6	97.5	1.18

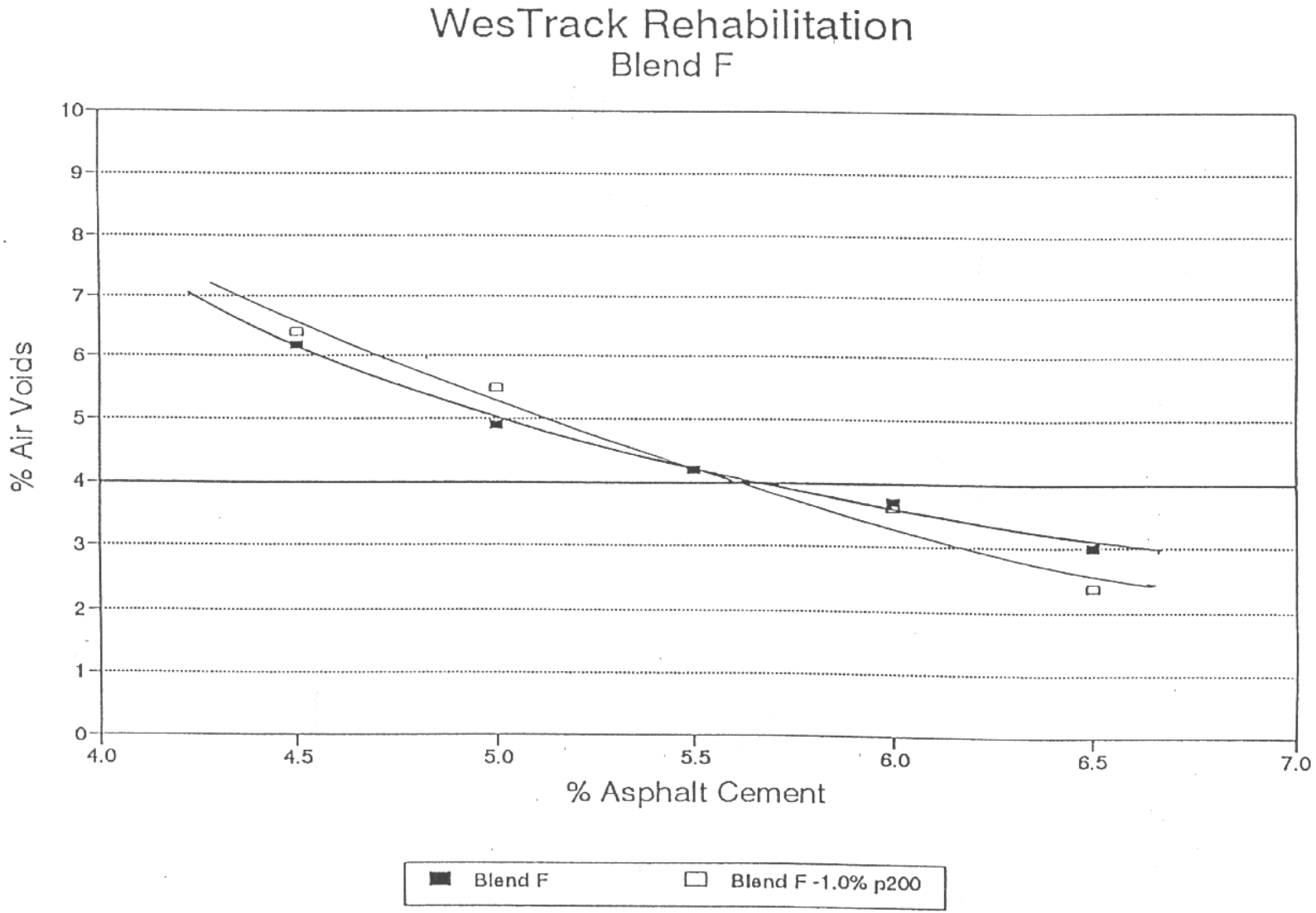
Gyratory Volumetrics Summary

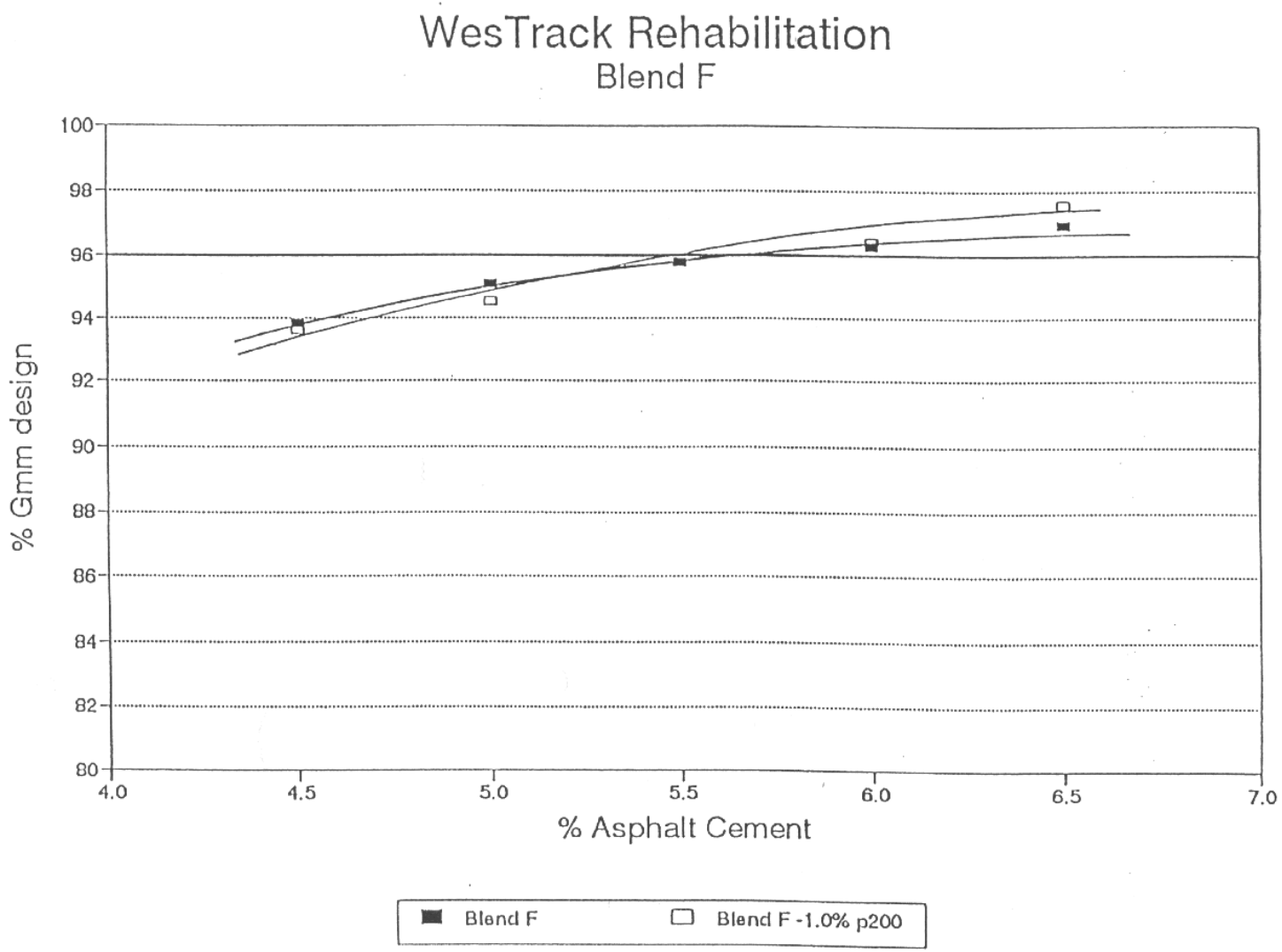
Project :	WesTrack Rehab
Mixture ID:	F - 1.0% p200 (F-1)
Other:	Lockwood @ Patrick (6-7-97 sampling)
Date:	6-19-97
Technician:	WC/TO Based on Measured Rices

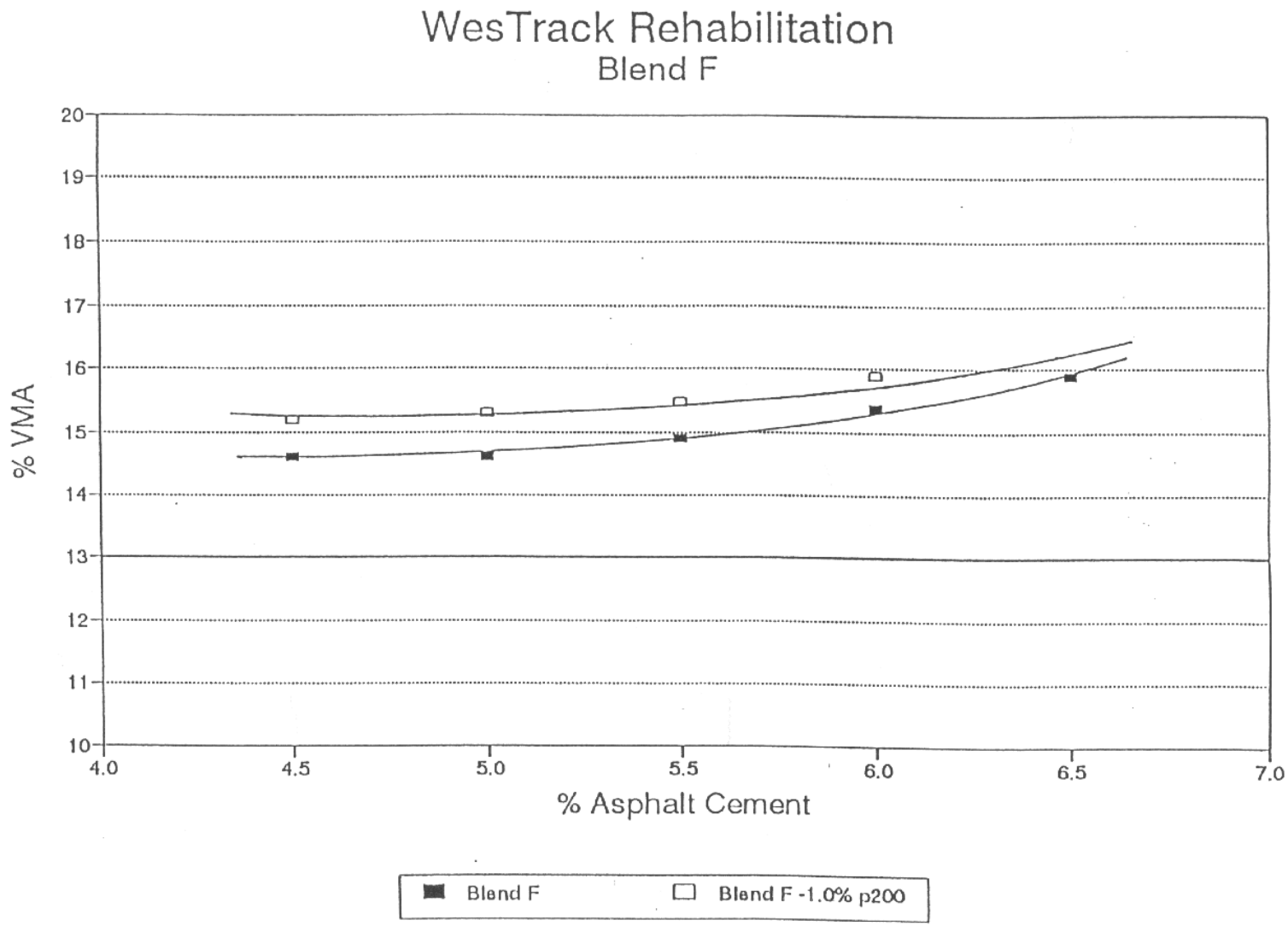
% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
4.0							
4.5	93.6	6.4	15.2	58.2	84.4	95.0	1.21
5.0	94.5	5.5	15.3	64.4	85.1	95.9	1.09
5.5	95.8	4.2	15.5	73.1	86.1	97.2	0.95
6.0	96.4	3.6	15.9	77.6	86.5	97.9	0.88
6.5	97.6	2.4	15.9	85.2	87.5	99.1	0.80
7.0							

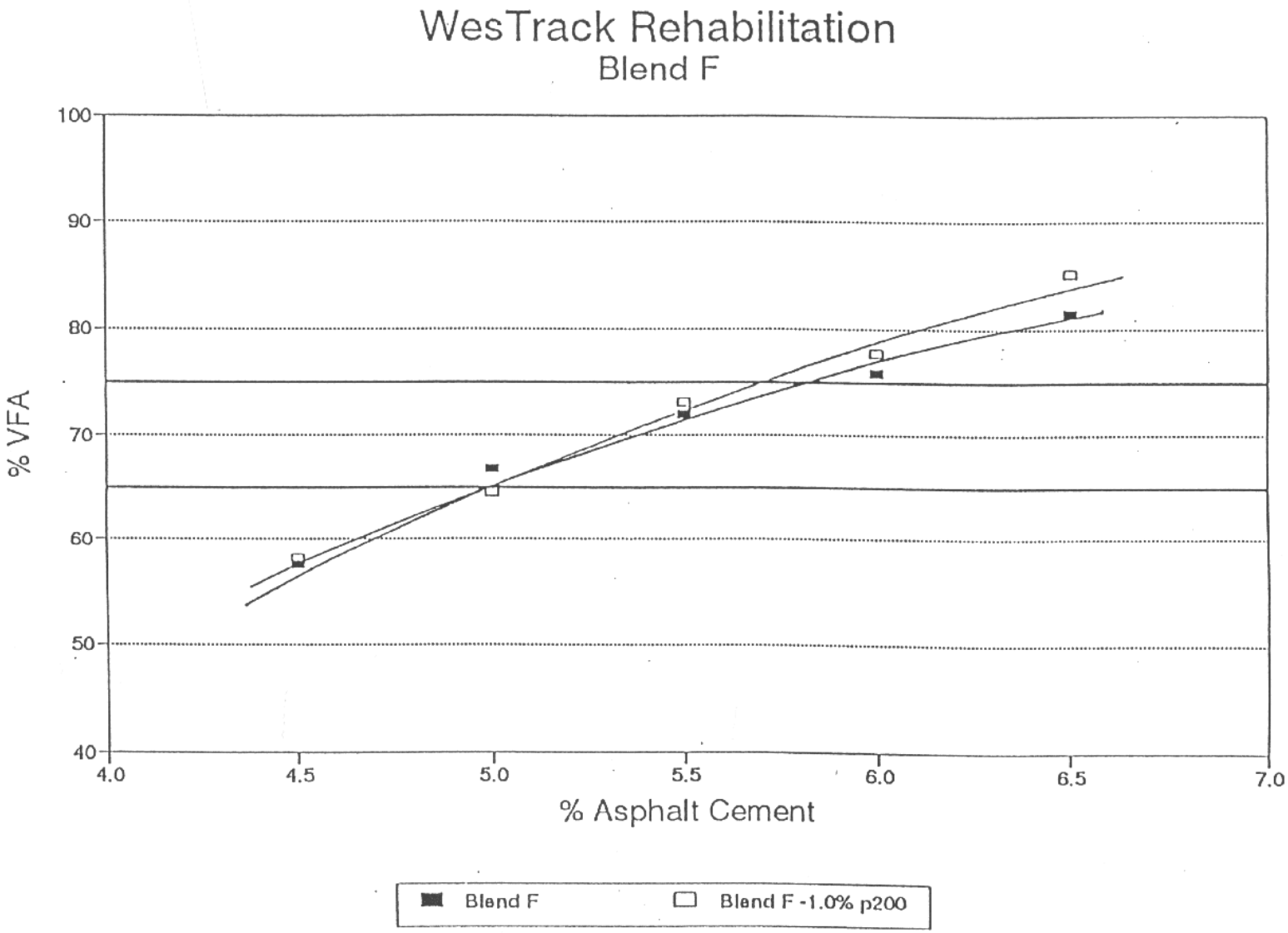
F-1.0% Properties at F Optimum Asphalt Content

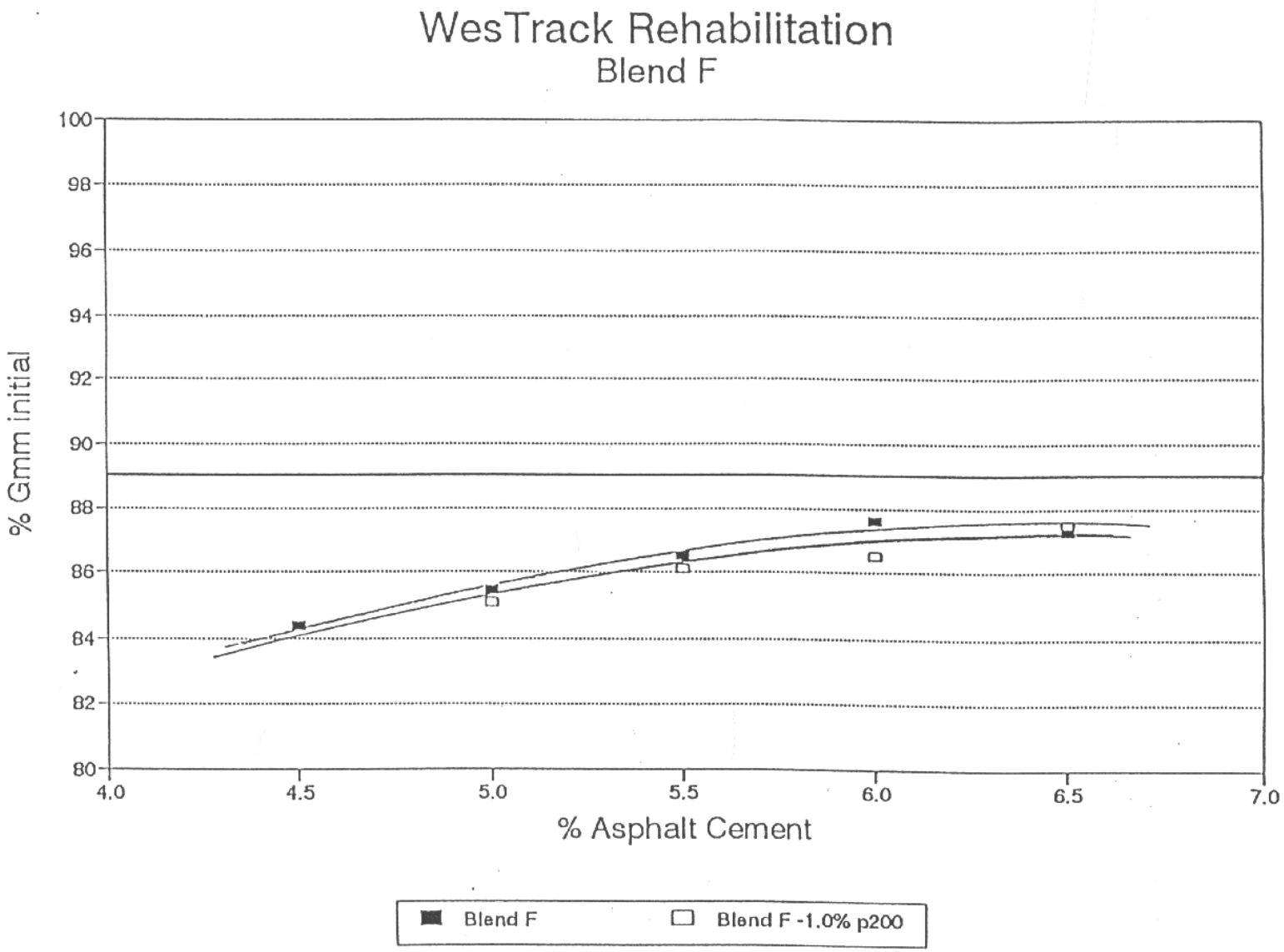
% AC	% Gmmd	% AV	% VMA	% VFA	% Gmmi	% Gmmm	F/A
5.65	96.2	3.8	15.5	73.5	86.2	97.4	0.95

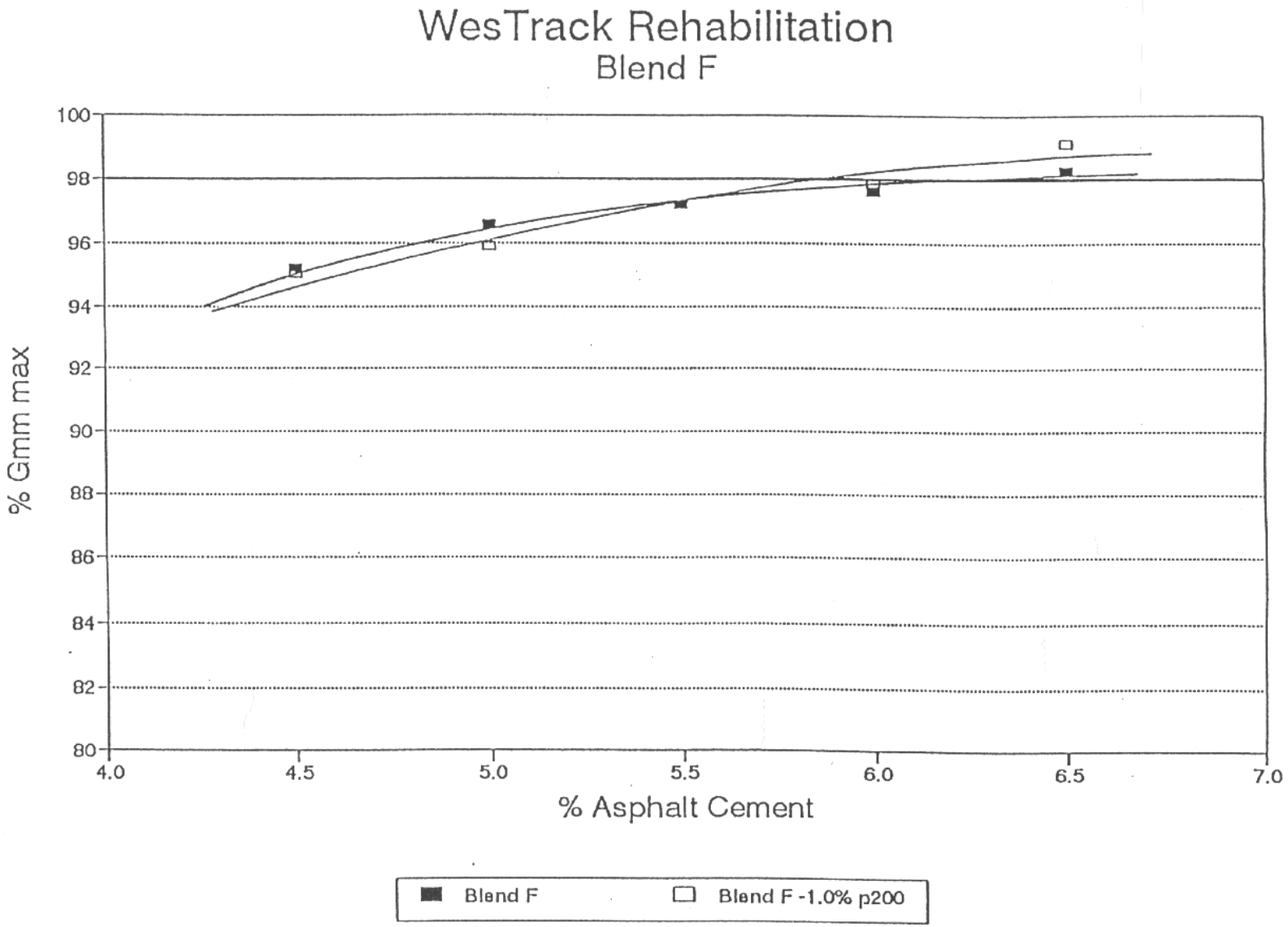

WesTrack Rehabilitation
Blend F
% Air Voids
10
9
8
7
6
5
4
3
2
1
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
Blend F
Blend F -1.0% p200

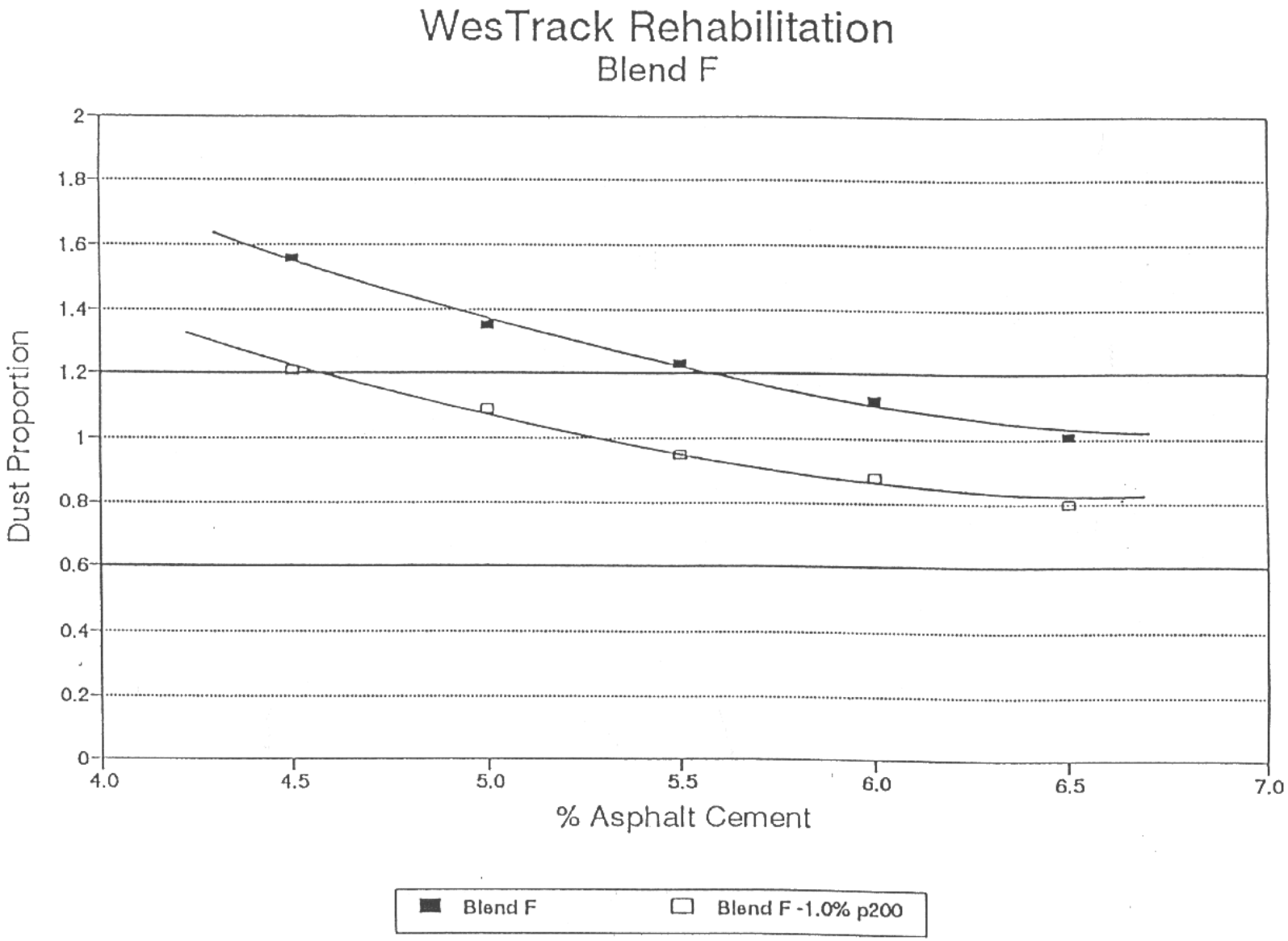

WesTrack Rehabilitation
Blend F
100
98
96
94
92
90
88
86
84
82
80
% Gmm design
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
Blend F
Blend F -1.0% p200


WesTrack Rehabilitation
Blend F
% VMA
20
19
18
17
16
15
14
13
12
11
10
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
Blend F
Blend F -1.0% p200


WesTrack Rehabilitation
Blend F
100
90
80
70
60
50
40
% VFA
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
Blend F
Blend F -1.0% p200


WesTrack Rehabilitation
Blend F
% Gmm initial
100
98
96
94
92
90
88
86
84
82
80
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
Blend F
Blend F -1.0% p200


WesTrack Rehabilitation
Blend F
100
98
96
94
92
90
88
86
84
82
80
% Gmm max
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
Blend F
Blend F -1.0% p200


WesTrack Rehabilitation
Blend F
Dust Proportion
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
% Asphalt Cement
Blend F
Blend F -1.0% p200

Quality Control Volumetrics—Original Construction

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-8
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research project was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June of 1997. Approximately 5 million 80-kN (18,000- lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on the HMA Superpave gyratory compactor volumetrics obtained during original construction. This information was obtained by FHWA's mobile HMA testing laboratory and by BRE engineers. This information was used to adjust asphalt contents and gradations during the construction and is referred to as quality control data.

Due to difficulties in obtaining accurate asphalt binder contents during this quality control testing, an extensive laboratory program was undertaken to define the asphalt content in the test sections at WesTrack. These quality control volumetric data have been revised based on the corrected asphalt content information and new volumetric data determined and reported in WesTrack Technical Report UNR-9.[4] The quality assurance volumetrics reported in UNR-9 are the most accurate values available and were used to develop the performance models.

BACKGROUND

Prior to the start of production of the HMA, the HMA production facility was calibrated. This included determination of individual cold-feed rates for each aggregate, calibration of the scale belt, and calibration of the asphalt binder delivery system. During the placement of the hot mixes at WesTrack, additional calibrations were performed. The initial calibration was

performed on September 8, 1995. Additional calibrations were performed on September 25, 26, 28, and 29, 1995.

HMA mixtures were placed on the ramps to the test track on September 9 and 13, 1995, to determine the constructability of the HMA, and to determine the gradation, asphalt binder contents, and volumetrics.

The "trial lane" and the "test lane" of the track were constructed on the dates shown in table 1. The bottom lift of the trial lane was placed first, followed by placement of the bottom lift of the test lane. The top lift of the trial lane was placed prior to the top lift of the test lane. Placement of the trial lanes prior to placement of the test lanes allowed for adjustments in the binder contents and gradations as well as in the construction operation. The test lanes are the lanes on which the traffic was placed and the WesTrack performance information obtained.

SAMPLING

Superpave gyratory compaction was performed on samples of HMA obtained from truck samples. These samples were split and used for both quality control and quality assurance testing. The detailed sampling and testing plan for the original construction can be found in WesTrack Technical Report UNR-18.[5]

TEST METHODS

The Superpave gyratory compactor was used to compact all field-mixed, laboratory-compacted (FMLC) samples during this quality control testing portion of the project. FHWA and BRE performed the compaction and the associated testing to determine the mixture volumetrics. The test methods used were those identified in reference 6 and summarized in table 2.

For each section, the theoretical maximum specific gravity was determined from a single sample with two test results. A single value was obtained for the asphalt binder content for each section. Three Superpave gyratory compacted samples were obtained for each section. The aggregate bulk specific gravity values reported in table 17 of WesTrack Technical Report UNR-4[7] were used for the volumetric calculations.

The asphalt contents reported during the quality control testing were obtained by FHWA with an ignition oven calibrated with a WesTrack mixture placed on the ramps at the test track. This calibration factor was used for all mixtures placed at the track. The asphalt content was used in the calculations to determine the volumetrics. Calibration errors associated with the determination of the asphalt content required that the quality control volumetrics be recalculated with the corrected asphalt contents. These corrected data are shown in WesTrack Technical Report UNR-9.[4]

During the placement of the top lift of the coarse graded "test lane," the FHWA gyratory compactor lost its calibration. The influence of this problem on the reported volumetric data for this lift and mixture is not known. WesTrack Technical Report UNR-9[4] contains the quality

assurance data for mixture volumetrics. This quality assurance information was used for development of the performance models.

VOLUMETRIC TEST RESULTS

FINE GRADED MIXTURE

Asphalt binder content, theoretical maximum specific gravity of the mixture, and mixture volumetrics of FMLC samples are reported for the fine graded mixture in tables 3 and 4 and appendix A. In general, an increase in asphalt binder content was noted as the target asphalt binder content was increased. As expected, the theoretical maximum specific gravity decreased, the air void content decreased, and the voids filled with asphalt (VFA) increased with an increase in asphalt binder content.

Table 4 provides data for the test lane fine graded mixtures with an optimum asphalt binder content (sections 1, 4, 15, and 17). An examination of these data indicates an air void content on the high side of the 3 to 5 percent requirement, voids in the mineral aggregate (VMA) above the 13 minimum requirement, and most of the VFA values in the desired range of 65 to 75.

FINE PLUS GRADED MIXTURE

Asphalt binder content, theoretical maximum specific gravity for the mixture, and mixture volumetrics of FMLC samples are reported for the fine plus graded mixture in tables 5 and 6 and appendix A. In general, an increase in asphalt binder content was noted as the target asphalt binder content was increased. As expected, the theoretical maximum specific gravity decreased, the air void content decreased, and the VFA increased with an increase in asphalt binder content.

The fine plus graded mixture was produced by adding approximately 1.5 to 2.0 percent by weight additional baghouse fines to the fine graded mixture. A comparison of tables 3 and 4 with tables 5 and 6 indicates that, when the baghouse fines were increased, the air void content decreased, the VMA decreased, and the VFA increased as expected.

Table 6 provides data for the test lane fine plus graded mixtures with an optimum asphalt binder content (sections 11, 12, 19, and 20). An examination of these data indicates an air void content on the low side of the 3 to 5 percent requirement, VMA at or slightly below the 13 minimum requirement, and the VFA above the desired range of 65 to 75.

COARSE GRADED MIXTURE

Asphalt binder content, theoretical maximum specific gravity for the mixture, and mixture volumetrics of FMLC samples are reported for the coarse graded mixture in tables 7 and 8 and appendix A. In general, the theoretical maximum specific gravity decreased, the air void content decreased, and the VFA increased with an increase in the asphalt binder content.

Table 8 provides data for the test lane coarse graded mixtures with an optimum asphalt binder content (sections 5, 6, 23, and 24). An examination of these data indicates considerable variability in test results. The air void content was variable and exceeded the range of 3 to 5 percent air voids. The VMA values were mostly above 13. The VFA values were highly variable and spanned the desired range of 65 to 75.

SUMMARY

Tables 4, 6, and 8 present the Superpave gyratory volumetric data obtained during construction (quality control data). These data were used to adjust the gradations and asphalt binder contents during construction. These data should not be used for performance modeling as corrections have been made based on adjustments in asphalt binder contents. WesTrack Technical Report UNR-9[4] should be used to obtain the corrected volumetric information.

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3. "Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction," *Task G Interim Report*, Final Draft, WesTrack Team, March 1996.

4. Hand, A., Epps, J., and Sebaaly, P., "WesTrack Quality Assurance Volumetrics – Original Construction," WesTrack Technical Report UNR-9, July 2000.

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6. McGennis, R., Anderson, R., Kennedy, J., and Solaimanian, M., "Background of Superpave Asphalt Mixture Design and Analysis," Publication No. FHWA-SA-95-003, Federal Highway Administration, Washington, D.C.

7. Epps, J., Hand, A., and Sebaaly, P., "WesTrack Aggregate Properties – Original Construction," WesTrack Technical Report UNR-4, July 2000.

Table 1. Construction schedule for original construction.

Date	Mixture	Lift	Lane	Section Numbers*
9-14-95	Fine	Bottom	Trial	1, 2, 3, 4, 14, 15, 16, 17, 18
9-15-95	Fine Plus	Bottom	Trial	19, 20, 21, 22, 9, 10, 11, 12, 13
9-16-95	Coarse	Bottom	Trial	5, 6, 7
9-18-95	Coarse	Bottom	Trial	8, 23, 24, 25, 26
9-20-95	Fine	Bottom	Test	1, 2, 3, 4, 14, 15, 16, 17, 18
9-21-95	Fine Plus	Bottom	Test	19, 20, 21, 22, 9, 10, 11, 12, 13
9-22-95	Fine	Top	Trial	1, 2, 3, 4, 14, 15, 16, 17, 18
9-27-95	Fine Plus	Top	Trial	19, 20, 21, 22, 9, 10, 11, 12, 13
9-27-95	Fine Plus	Bottom	Test	13
9-30-95	Coarse	Bottom	Test	5, 6, 7, 8, 23, 24, 25, 26
10-1-95	Coarse	Top	Trial	5, 6, 7, 8, 23, 24, 25, 26
10-2-95	Fine	Top	Test	1, 2, 3, 4, 14, 15, 16, 17, 18
10-3-95	Fine Plus	Top	Test	19, 20, 21, 22, 9, 10, 11, 12, 13
10-4-95	Coarse	Top	Test	5, 6, 7, 8, 23, 24, 25, 26

*Section numbers follow order of placement.

Table 2. Superpave gyratory compactor volumetric test methods.

Description	Designation	
	AASHTO	ASTM
Superpave gyratory compactor	TP 4	
Practice for volumetric analysis of compacted HMA	PP 19	
Bulk specific gravity of compacted bituminous mixtures	T 166	D 2726
Maximum specific gravity of compacted bituminous mixtures	T 209	D 2041
Percent air voids in compacted dense- and open-graded paving mixtures	T 269	D 3203
Water sensitivity	TP 34 T 283	D 4867
Asphalt content by nuclear method	T 287	D 4125
Asphalt content by ignition method		D 6307
Specific gravity and absorption of fine aggregate	T 84	C 128
Specific gravity and absorption of coarse aggregate	T 85	C 127

Table 3. Construction quality control volumetrics – gyratory compaction of fine graded mixture (trial lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Theoretical Max. Specific Gravity	Air Void Content %	VMA %	VFA %	Lab Compactor
2 LM	Fine	Top	4.7	4.94	2.413	4.3	13.2	67.3	BRE
		Bottom	4.7	5.10	2.441*	7.0	14.8	52.9	BRE
3 LH	Fine	Top	4.7	5.33	2.401	3.4	13.1	74.5	BRE
		Bottom	4.7	4.73	2.455*	6.9	13.9	50.3	BRE
16 LH	Fine	Top	4.7	5.14	2.420	4.5	13.3	66.3	BRE
		Bottom	4.7	4.76	2.443*	7.2	14.6	50.7	BRE
1 MM	Fine	Top	5.4	6.07	2.382	2.1	13.3	84.6	FHWA
		Bottom	5.4	5.72	2.399	4.6	14.7	68.7	FHWA
4 ML	Fine	Top	5.4	5.83	2.401	3.1	13.4	76.7	FHWA
		Bottom	5.4	5.44	2.396	3.6	13.7	73.5	FHWA
15 MM	Fine	Top	5.4	6.10	2.384	2.0	13.3	84.9	FHWA
		Bottom	5.4	4.85	2.404	4.7	13.8	65.7	FHWA
17 MH	Fine	Top	5.4	5.74	2.385	2.5	13.4	81.2	FHWA
		Bottom	5.4	5.29	2.392	3.7	13.7	73.3	FHWA
14 HM	Fine	Top	6.1	6.79	2.367	0.4	13.1	96.9	BRE
		Bottom	6.1	6.25	2.385	2.4	13.7	82.4	FHWA
18 HL	Fine	Top	6.1	6.83	2.369	0.6	13.3	95.6	FHWA
		Bottom	6.1	6.48	2.375	2.3	14.2	84.0	FHWA

*Without moisture correction or dry back.

Table 4. Construction quality control volumetrics – gyratory compaction of fine graded mixture (test lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Theoretical Max. Specific Gravity	Air Void Content %	VMA %	VFA %	Lab Compactor
2 LM	Fine	Top	4.7	4.50	2.450	6.0	13.0	54.2	FHWA
		Bottom	4.7	5.07	2.415	4.6	13.6	65.7	BRE
3 LH	Fine	Top	4.7	4.57	2.425	5.6	13.6	59.1	FHWA
		Bottom	4.7	3.94	2.443	5.8	12.6	54.0	BRE
16 LH	Fine	Top	4.7	4.28	2.429	5.6	13.3	57.4	FHWA
		Bottom	4.7	4.98	2.425*	5.2	13.6	61.8	BRE
1 MM	Fine	Top	5.4	5.10	2.427	5.7	14.1	59.7	FHWA
		Bottom	5.4	5.71	2.404	3.7	13.7	73.2	FHWA
4 ML	Fine	Top	5.4	4.83	2.429	7.6	15.6	51.0	FHWA
		Bottom	5.4	5.10	2.412	5.1	14.1	63.9	FHWA
15 MM	Fine	Top	5.4	5.27	2.427	5.7	14.3	60.3	FHWA
		Bottom	5.4	5.17	2.414	4.4	13.5	67.1	FHWA
17 MH	Fine	Top	5.4	5.47	2.417	5.3	14.5	63.2	FHWA
		Bottom	5.4	5.35	2.407	4.6	14.1	67.3	FHWA
14 HM	Fine	Top	6.1	5.90	2.402	2.3	12.7	82.1	BRE
		Bottom	6.1	6.18	2.379	1.2	12.8	90.5	FHWA
18 HL	Fine	Top	6.1	5.98	2.408	3.8	13.8	72.9	FHWA
		Bottom	6.1	5.48	2.405	3.9	13.6	71.5	FHWA

*Without moisture correction or dry back.

Table 5. Construction quality control volumetrics – gyratory compaction of fine plus graded mixture (trial lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Theoretical Max. Specific Gravity	Air Void Content %	VMA %	VFA %	Lab Compactor
22 LM	Fine Plus	Top	4.7	5.14	2.414	4.1	13.2	68.8	BRE
		Bottom	4.7	4.96	2.445*	6.5	14.1	54.0	BRE
10 LH	Fine Plus	Top	4.7	5.00	2.413	3.9	13.0	69.5	BRE
		Bottom	4.7	5.03	2.421**	5.1	13.7	63.0	BRE
19 MM	Fine Plus	Top	5.4	5.54	2.411	3.7	13.3	72.3	FHWA
		Bottom	5.4	5.81	2.364	1.8	13.6	86.5	FHWA
20 MH	Fine Plus	Top	5.4	5.91	2.391	2.3	13.1	82.1	FHWA
		Bottom	5.4	5.27	2.374	2.4	13.2	82.2	FHWA
11 MM	Fine Plus	Top	5.4	5.62	2.396	3.2	13.5	76.0	FHWA
		Bottom	5.4	5.88	2.386	2.6	13.5	81.0	FHWA
12 ML	Fine Plus	Top	5.4	5.80	2.424	4.0	13.3	70.0	FHWA
		Bottom	5.4	5.43	2.365	2.1	13.4	84.5	FHWA
21 HL	Fine Plus	Top	6.1	6.09	2.370	0.1	12.1	99.0	BRE
		Bottom	6.1	6.34	2.370**	1.0	13.1	92.4	BRE
9 HL	Fine Plus	Top	6.1	6.22	2.378	1.2	12.8	90.9	FHWA
		Bottom	6.1	6.37	2.369	0.9	13.1	93.3	FHWA
13 HM	Fine Plus	Top	6.1	6.31	2.375	0.4	12.4	96.9	BRE
		Bottom	6.1	6.51	2.375**	1.0	13.1	92.2	BRE

*Without moisture correction or dry back.
**Without moisture correction.

Table 6. Construction quality control volumetrics – gyratory compaction of fine plus graded mixture (test lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Theoretical Max. Specific Gravity	Air Void Content %	VMA %	VFA %	Lab Compactor
22 LM	Fine Plus	Top	4.7	5.12	2.411	2.8	12.0	77.1	BRE
		Bottom	4.7	5.10	2.419	4.6	13.5	65.7	BRE
10 LH	Fine Plus	Top	4.7	5.29	2.413	3.3	12.6	74.1	BRE
		Bottom	4.7	4.66	2.422	4.5	12.9	64.6	BRE
19 MM	Fine Plus	Top	5.4	5.93	2.391	2.0	12.8	84.6	FHWA
		Bottom	5.4	5.85	2.405	3.4	13.5	74.8	FHWA
20 MH	Fine Plus	Top	5.4	6.08	2.393	2.1	13.1	83.6	FHWA
		Bottom	5.4	5.96	2.391	1.7	12.6	86.3	FHWA
11 MM	Fine Plus	Top	5.4	5.94	2.401	3.2	13.5	76.7	FHWA
		Bottom	5.4	5.78	2.394	2.3	12.9	81.8	FHWA
12 ML	Fine Plus	Top	5.4	6.04	2.410	3.2	13.3	76.3	FHWA
		Bottom	5.4	5.37	2.404	3.2	12.9	75.3	FHWA
21 HL	Fine Plus	Top	6.1	6.82	2.387	0.9	12.8	93.3	BRE
		Bottom	6.1	5.92	2.382	0.9	12.2	92.2	BRE
9 HL	Fine Plus	Top	6.1	6.72	2.366	0.2	12.9	98.2	FHWA
		Bottom	6.1	6.44	2.350	0.2	12.9	100	FHWA
13 HM	Fine Plus	Top	6.1	6.60	2.379	0.2	12.3	98.8	BRE
		Bottom	6.1	6.37	2.391	0.6	12.0	95.3	BRE

Table 7. Construction quality control volumetrics – gyratory compaction of coarse graded mixture (trial lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Theoretical Max. Specific Gravity	Air Void Content %	VMA %	VFA %	Lab Compactor
8 LM	Coarse	Top	5.0	5.35	2.389	2.8	12.3	76.8	BRE
		Bottom	5.0	5.79	2.396**	4.0	13.5	70.2	BRE
26 LH	Coarse	Top	5.0	5.34	2.413	3.5	12.0	70.6	BRE
		Bottom	5.0	5.45	2.401**	4.3	13.2	67.8	BRE
5 MM	Coarse	Top	5.7	6.07	2.392	4.4	14.2	68.9	FHWA
		Bottom	5.7	6.10	2.382	3.9	14.2	72.6	FHWA
6 MH	Coarse	Top	5.7	5.95	2.404	4.5	13.8	67.2	FHWA
		Bottom	5.7	6.83	2.365	1.9	13.7	86.0	FHWA
23 ML	Coarse	Top	5.7	5.91	2.392	5.4	15.0	64.0	FHWA
		Bottom	5.7	5.43	2.396	5.4	14.4	62.7	FHWA
24 MM	Coarse	Top	5.7	6.01	2.393	4.0	13.8	70.8	FHWA
		Bottom	5.7	5.82	2.379	5.8	15.7	63.3	FHWA
7 HM	Coarse	Top	6.4	6.85	2.372	1.1	12.8	91.0	BRE
		Bottom	6.4	7.64	2.335*	0.3	14.2	97.7	BRE
25 HL	Coarse	Top	6.4	6.24	2.381	2.1	12.7	83.6	FHWA
		Bottom	6.4	6.09	2.375	4.2	14.7	71.5	FHWA

*Without moisture correction or dry back.
**Without moisture correction.

Table 8. Construction quality control volumetrics – gyratory compaction of coarse graded mixture (test lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Theoretical Max. Specific Gravity	Air Void Content %	VMA %	VFA %	Lab Compactor
8 LM	Coarse	Top	5.0	4.89	2.434	4.8	12.0	60.0	BRE
		Bottom	5.0	5.32	2.404	4.7	13.4	64.9	BRE
26 LH	Coarse	Top	5.0	4.98	2.436	6.5	13.6	52.3	BRE
		Bottom	5.0	5.34	2.386	3.8	13.2	71.3	BRE
5 MM	Coarse	Top	5.7	4.89	2.403	3.8	12.2	68.6	FHWA
		Bottom	5.7	5.26	2.413	6.2	14.4	56.8	FHWA
6 MH	Coarse	Top	5.7	5.55	2.413	4.2	12.8	67.3	FHWA
		Bottom	5.7	5.05	2.422	7.5	15.1	50.1	FHWA
23 ML	Coarse	Top***	5.7	5.81	2.398	1.7	11.3	85.3	FHWA
		Bottom	5.7	5.05	2.421	8.2	15.8	47.7	FHWA
24 MM	Coarse	Top***	5.7	6.31	2.389	2.0	12.4	83.7	FHWA
		Bottom	5.7	5.11	2.412	7.9	15.9	49.9	FHWA
7 HM	Coarse	Top	6.4	6.58	2.377	0.6	11.9	94.8	BRE
		Bottom	6.4	6.44	2.374	4.8	15.6	69.1	BRE
25 HL	Coarse	Top	6.4	6.06	2.382	1.1	11.6	90.4	FHWA
		Bottom	6.4	6.09	2.370	2.7	13.5	79.9	FHWA

***Compacted in Asphalt Institute compactor.

APPENDIX A

FHWA AND BRE
SUPERPAVE GYRATORY COMPACTOR VOLUMETRICS

WesTrack Volumetric Data Sheet
Fine Graded

range name: Critical

If VMA, VFA not shown % Gmm Estimated

Date	Mix ID	LAB	AC Target	Ign AC	Rice	%Gmm, Ni	%Gmm, Nd	%Gmm, Nm	VTM, Nd	VMA, Nd	VFA, Nd
09/13/95	TM 8 / M	FHWA	5.40	5.21	2.404	89.1%	95.7%	96.8%	4.3%	13.8%	68.9%
09/13	w/o dry back	BRE	5.40		2.441	86.8%	94.1%	95.2%	5.9%	9.2%	35.5%
09/14	1 / M	FHWA	5.40	5.72	2.399	88.5%	95.4%	96.5%	4.6%	14.7%	68.7%
09/14	2 / L	BRE	4.70	5.10	2.441	86.5%	93.0%	94.0%	7.0%	14.8%	52.9%
09/14	3 / L	BRE	4.70	4.73	2.455	86.5%	93.1%	94.1%	6.9%	13.9%	50.3%
09/14	4 / M	FHWA	5.40	5.44	2.396	89.8%	96.4%	97.4%	3.6%	13.7%	73.5%
09/14	5 / H	BRE	6.10	6.25	2.385	90.1%	97.6%	98.8%	2.4%	13.7%	82.4%
09/14	6 / M	FHWA	5.40	4.85	2.404	88.5%	95.3%	96.3%	4.7%	13.8%	65.7%
09/14	7 / L	BRE	4.70	4.76	2.443	86.2%	92.8%	93.8%	7.2%	14.6%	50.7%
09/14	8 / M	FHWA	5.40	5.29	2.392	89.6%	96.3%	97.4%	3.7%	13.7%	73.3%
09/14	9 / H	FHWA	6.10	6.48	2.375	90.8%	97.7%	98.9%	2.3%	14.2%	84.0%
09/14	9 / H	BRE	6.10	6.48	2.372	90.9%	98.2%	99.3%	1.8%	13.9%	87.1%
09/20	1 / M	FHWA	5.40	5.71	2.404	89.8%	96.3%	97.3%	3.7%	13.7%	73.2%
09/20	2 / L	BRE	4.70	5.07	2.415	88.5%	95.4%	96.4%	4.6%	13.6%	65.7%
09/20	3 / L	BRE	4.70	3.94	2.443	87.5%	94.2%	95.2%	5.8%	12.6%	54.0%
09/20	4 / M	FHWA	5.40	5.10	2.412	87.9%	94.9%	96.0%	5.1%	14.1%	63.9%
09/20	5 / H	BRE	6.10	6.18	2.379	91.3%	98.8%	99.9%	1.2%	12.8%	90.5%
09/20	6 / M	FHWA	5.40	5.17	2.414	88.8%	95.6%	96.7%	4.4%	13.5%	67.1%
09/20	7 / L	BRE	4.70	4.98	2.425	88.0%	94.8%	95.8%	5.2%	13.6%	61.8%
09/20	8 / M	FHWA	5.40	5.35	2.407	88.8%	95.4%	96.4%	4.6%	14.1%	67.3%
09/20	9 / H	FHWA	6.10	5.48	2.405	88.6%	96.1%	97.4%	3.9%	13.6%	71.5%
09/22	1 / M	FHWA	5.40	6.07	2.382	91.0%	97.9%	99.1%	2.1%	13.3%	84.6%
09/22	2 / L	BRE	4.70	4.94	2.413	88.5%	95.7%	96.8%	4.3%	13.2%	67.3%
09/22	3 / L	BRE	4.70	5.33	2.401	89.6%	96.6%	97.7%	3.4%	13.1%	74.5%
09/22	4 / M	FHWA	5.40	5.83	2.401	89.8%	96.9%	98.0%	3.1%	13.4%	76.7%
09/22	5 / H	BRE	6.10	6.79	2.367	92.7%	99.6%	99.8%	0.4%	13.1%	96.9%
09/22	6 / M	FHWA	5.40	6.10	2.384	91.0%	98.0%	99.1%	2.0%	13.3%	84.9%
09/22	7 / L	BRE	4.70	5.14	2.420	88.5%	95.5%	96.6%	4.5%	13.3%	66.3%
09/22	8 / M	FHWA	5.40	5.74	2.385	90.5%	97.5%	98.6%	2.5%	13.4%	81.2%
09/22	9 / H	FHWA	6.10	6.83	2.369	91.9%	99.4%	100.2%	0.6%	13.3%	95.6%
10/2	1 / M	FHWA	5.40	5.10	2.427	87.7%	94.3%	95.3%	5.7%	14.1%	59.7%
10/2	2 / L	BRE	4.70	4.50	2.450	87.5%	94.0%	95.0%	6.0%	13.0%	54.2%
10/2	3 / L	BRE	4.70	4.57	2.425	87.9%	94.4%	95.4%	5.6%	13.6%	59.1%
10/2	4 / M	FHWA	5.40	4.83	2.429	86.3%	92.4%	93.3%	7.6%	15.6%	51.0%
10/2	5 / H	BRE	6.10	5.90	2.402	90.8%	97.7%	98.6%	2.3%	12.7%	82.1%
10/2	6 / M	FHWA	5.40	5.27	2.427	88.3%	94.3%	95.3%	5.7%	14.3%	60.3%
10/2	7 / L	BRE	4.70	4.28	2.429	87.8%	94.4%	95.3%	5.6%	13.3%	57.4%
10/2	8 / M	FHWA	5.40	5.47	2.417	88.7%	94.7%	95.6%	5.3%	14.5%	63.2%
10/2	9 / H	FHWA	6.10	5.98	2.408	89.8%	96.2%	97.3%	3.8%	13.8%	72.9%

LARGE BOLD without moisture correction or Dryback

LARGE without moisture correction

WesTrack Volumetric Data Sheet

Fine Plus Graded

range name: Super_Critical

If VMA, VFA not shown % Gmm Estimated

Date	Mix ID	LAB	AC Target	Ign AC	Rice	%Gmm. Ni	%Gmm. Nd	%Gmm. Nm	VTM, Nd	VMA, Nd	VFA, Nd
09/13/95	TM 9 / M	FHWA	5.40	5.27	2.370	91.3%	98.3%	99.4%	1.7%	12.7%	86.9%
09/13	w/o DB	BRE	5.40	5.31	2.419	88.6%	95.8%	96.9%	4.2%	13.2%	68.2%
09/15	10/M	BRE	5.40	5.81	2.403	89.3%	96.4%	97.5%	3.6%	13.7%	73.8%
09/15	10/M	FHWA	5.40	5.81	2.364	91.1%	98.2%	99.2%	1.8%	13.6%	86.5%
09/15	11/M	FHWA	5.40	5.27	2.374	90.7%	97.6%	98.7%	2.4%	13.2%	82.2%
09/15	12/H	BRE	6.10	6.34	2.370	91.7%	99.0%	99.9%	1.0%	13.1%	92.4%
09/15	13/L	BRE	4.70	4.96	2.445	86.7%	93.5%	94.6%	6.5%	14.1%	54.0%
09/15	14/H	FHWA	6.10	6.37	2.369	92.0%	99.1%	100.0%	0.9%	13.1%	93.3%
09/15	15/L	BRE	4.70	5.03	2.421	88.0%	94.9%	96.0%	5.1%	13.7%	63.0%
09/15	16/M	FHWA	5.40	5.88	2.386	90.5%	97.4%	98.6%	2.6%	13.5%	81.0%
09/15	17/M	FHWA	5.40	5.43	2.365	90.9%	97.9%	99.0%	2.1%	13.4%	84.5%
09/15	18/H	BRE	6.10	6.51	2.375	91.5%	99.0%	99.8%	1.0%	13.1%	92.2%
09/18	TM27	BRE	5.40	5.39	2.390	89.8%	97.3%	98.5%	2.7%	13.0%	79.4%
09/21	10/M	FHWA	5.40	5.85	2.405	89.7%	96.6%	97.7%	3.4%	13.5%	74.8%
09/21	11/M	FHWA	5.40	5.96	2.391	91.4%	98.3%	99.2%	1.7%	12.6%	86.3%
09/21	12/H	BRE	6.10	5.92	2.382	91.3%	99.1%	100.1%	0.9%	12.2%	92.2%
09/21	13/L	BRE	4.70	5.15	2.419	88.2%	95.4%	96.5%	4.6%	13.5%	65.7%
09/21	14/H	FHWA	6.10	6.44	2.350	93.1%	100.2%	100.8%	-0.2%	12.9%	101.2%
09/21	15/L	BRE	4.70	4.66	2.422	88.3%	95.5%	96.5%	4.5%	12.9%	64.6%
09/21	16/M	FHWA	5.40	5.78	2.394	90.5%	97.7%	98.7%	2.3%	12.9%	81.8%
09/21	17/M	FHWA	5.40	5.37	2.404	90.0%	96.8%	98.0%	3.2%	12.9%	75.3%
10/04	18/H	BRE	6.10	6.37	2.391	93.2%	99.4%	99.7%	0.6%	12.0%	95.3%
09/27	10/M	FHWA	5.40	5.54	2.411	89.4%	96.3%	97.4%	3.7%	13.3%	72.3%
09/27	11/M	FHWA	5.40	5.91	2.391	90.8%	97.7%	98.7%	2.3%	13.1%	82.1%
09/27	12/H	BRE	6.10	6.09	2.370	92.6%	99.9%	100.6%	0.1%	12.1%	99.0%
09/27	13/L	BRE	4.70	5.14	2.414	89.0%	95.9%	96.9%	4.1%	13.2%	68.8%
09/27	14/H	FHWA	6.10	6.22	2.378	91.6%	98.8%	99.8%	1.2%	12.8%	90.9%
09/27	15/L	BRE	4.70	5.00	2.413	89.1%	96.1%	97.1%	3.9%	13.0%	69.5%
09/27	16/M	FHWA	5.40	5.62	2.396	90.1%	96.8%	97.8%	3.2%	13.5%	76.0%
09/27	17/M	FHWA	5.40	5.80	2.424	89.4%	96.0%	97.0%	4.0%	13.3%	70.0%
09/27	18/H	BRE	6.10	6.31	2.375	92.6%	99.6%	100.0%	0.4%	12.4%	96.9%
10/3	10/M	FHWA	5.40	5.93	2.391	91.2%	98.0%	99.1%	2.0%	12.8%	84.6%
10/3	11/M	FHWA	5.40	6.08	2.393	91.1%	97.9%	98.8%	2.1%	13.1%	83.6%
10/3	12/H	BRE	6.10	6.82	2.387	93.6%	99.1%	99.4%	0.9%	12.8%	93.3%
10/3	13/L	BRE	4.70	5.12	2.411	90.5%	97.2%	98.2%	2.8%	12.0%	77.1%
10/3	14/H	FHWA	6.10	6.72	2.366	93.3%	99.8%	100.1%	0.2%	12.9%	98.2%
10/3	15/L	BRE	4.70	5.29	2.413	90.0%	96.7%	97.7%	3.3%	12.6%	74.1%
10/3	16/M	FHWA	5.40	5.94	2.401	90.0%	96.8%	97.9%	3.2%	13.5%	76.7%
10/3	17/M	FHWA	5.40	6.04	2.410	90.1%	96.8%	97.9%	3.2%	13.3%	76.3%
10/3	18/H	BRE	6.10	6.60	2.379	93.5%	99.8%	100.3%	0.2%	12.3%	98.8%

LARGE BOLD without moisture correction or Dryback

LARGE without moisture correction

WesTrack Volumetric Data Sheet

Coarse Graded

range name: Non_Critical

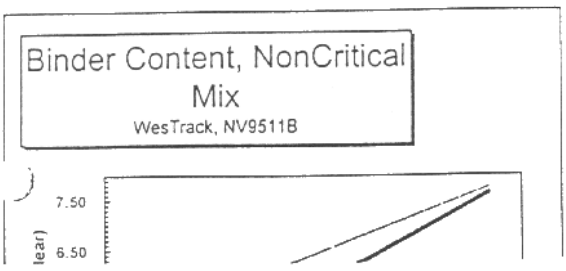
If VMA, VFA not shown % Gmm Estimated

Date	Mix ID	LAB	AC Target	Ign AC	Rice	%Gmm, Ni	%Gmm, Nd	%Gmm, Nm	VTM, Nd	VMA, Nd	VFA, Nd
09/13/95	TM 7 / M	FHWA	5.70	5.97	2.387	86.4%	96.1%	97.6%	3.9%	13.9%	71.8%
09/13	w/o DB	BRE	5.70		2.393	85.3%	95.4%	97.1%	4.6%	8.8%	48.1%
09/16	19/M	FHWA	5.7	6.10	2.382	86.2%	96.1%	97.6%	3.9%	14.2%	72.6%
09/16	20/M	FHWA	5.7	6.83	2.365	88.4%	98.1%	99.3%	1.9%	13.7%	86.0%
09/16	21/H	BRE	6.4	7.64	2.335	89.7%	99.7%	100.0%	0.3%	14.2%	97.7%
09/18	22/L	BRE	5.0	5.79	2.396	86.1%	96.0%	97.5%	4.0%	13.5%	70.2%
09/18	23/M	FHWA	5.7	5.43	2.396	85.2%	94.6%	96.2%	5.4%	14.4%	62.7%
09/18	24/M	FHWA	5.7	5.82	2.379	84.8%	94.2%	95.8%	5.8%	15.7%	63.3%
09/18	25/H	FHWA	6.4	6.09	2.375	86.0%	95.8%	97.4%	4.2%	14.7%	71.5%
09/18	26/L	BRE	5.0	5.45	2.401	85.9%	95.7%	97.3%	4.3%	13.2%	67.8%
09/30	19/M	FHWA	5.7	5.26	2.413	84.7%	93.8%	95.3%	6.2%	14.4%	56.8%
09/30	20/M	FHWA	5.7	5.05	2.422	83.3%	92.5%	94.0%	7.5%	15.1%	50.1%
09/30	21/H	BRE	6.4	6.44	2.374	85.3%	95.2%	96.8%	4.8%	15.6%	69.1%
09/30	22/L	BRE	5.0	5.32	2.404	85.7%	95.3%	96.8%	4.7%	13.4%	64.9%
09/30	23/M	FHWA	5.7	5.05	2.421	83.0%	91.8%	93.3%	8.2%	15.8%	47.7%
09/30	24/M	FHWA	5.7	5.11	2.412	83.0%	92.1%	93.5%	7.9%	15.9%	49.9%
09/30	25/H	FHWA	6.4	6.09	2.370	87.0%	97.3%	98.9%	2.7%	13.5%	79.9%
09/30	26/L	BRE	5.0	5.34	2.386	86.3%	96.2%	97.8%	3.8%	13.2%	71.3%
10/1	19/M	FHWA	5.7	6.07	2.392	86.2%	95.6%	97.1%	4.4%	14.2%	68.9%
10/1	20/M	FHWA	5.7	5.95	2.404	86.1%	95.5%	97.0%	4.5%	13.8%	67.2%
10/1	21/H	BRE	6.4	6.85	2.372	88.7%	98.9%	99.9%	1.1%	12.8%	91.0%
10/1	22/L	BRE	5.0	5.35	2.389	87.4%	97.2%	98.6%	2.8%	12.3%	76.8%
10/1	23/M	FHWA	5.7	5.91	2.392	85.4%	94.6%	96.0%	5.4%	15.0%	64.0%
10/1	24/M	FHWA	5.7	6.01	2.393	86.7%	96.0%	97.5%	4.0%	13.8%	70.8%
10/1	25/H	FHWA	6.4	6.24	2.381	87.3%	97.9%	99.4%	2.1%	12.7%	83.6%
10/1	26/L	BRE	5.0	5.34	2.413	86.6%	96.5%	97.9%	3.5%	12.0%	70.6%
10/4	19/M	FHWA	5.7	4.89	2.403	86.9%	96.2%	97.7%	3.8%	12.2%	68.6%
10/4	20/M	FHWA	5.7	5.55	2.413	86.5%	95.8%	97.3%	4.2%	12.8%	67.3%
10/4	21/H	BRE	6.4	6.58	2.377	90.2%	99.4%	99.7%	0.6%	11.9%	94.8%
10/4	22/L	BRE	5.0	4.89	2.434	85.8%	95.2%	96.7%	4.8%	12.0%	60.0%
10/4	*23/M	FHWA	5.7	5.81	2.398	88.4%	98.3%	99.8%	1.7%	11.3%	85.3%
10/4	24/M	FHWA	5.7	6.31	2.389	88.0%	98.0%	99.6%	2.0%	12.4%	83.7%
10/4	25/H	FHWA	6.4	6.06	2.382	90.5%	98.9%	99.1%	1.1%	11.6%	90.4%
10/4	26/L	BRE	5.0	4.98	2.436	84.1%	93.5%	95.1%	6.5%	13.6%	52.3%

tory specimen compacted in the A.I. SGC, as were the #24M (10/4) specimens.

LARGE BOLD without moisture correction or Dryback

LARGE without moisture correction



Ignition AC	Nuc. AC	Regressn. Per. Corrln.	
6.10	6.64	6.670481	6.10
6.83	7.37	7.18388	6.83
7.64	7.61	7.753542	7.64
5.79	6.52	6.452463	5.79
5.43	6.34	6.19928	5.43
5.82	6.34	6.473561	5.82
6.09	6.83	6.663448	6.09
5.45	5.96	6.213345	5.45

Quality Assurance Volumetrics—Original Construction

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-9
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replace patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides quality assurance information on HMA volumetric properties for the original construction mixtures. The reader is referred to WesTrack Technical Report UNR-8[4] for original construction HMA quality control Superpave volumetric properties information and WesTrack Technical Reports UNR-18[5] and UNR-19[6] for original construction and replacement HMA quality control/quality assurance (QC/QA) materials sampling and testing plans, respectively.

The primary purpose of this document is to summarize HMA quality assurance Superpave volumetric properties data and, thus, to provide a set of volumetrics for the original construction mixtures. Some would refer to the volumetrics as field-mixed laboratory-compacted (FMLC) volumetric properties, as the material used is produced in the field (at the hot plant), sampled in the loose state, and compacted in a laboratory compaction device. The volumetric properties reported are based on measurements performed on 520 specimens compacted in a Superpave gyratory compactor (SGC) manufactured by Pine Instruments. The same model compactor was used for field quality control purposes. The data are also reported in the final project report and are based on the quality assurance asphalt content and gradation data in WesTrack Technical Reports UNR-15[7] and UNR-22[8] (core ignition data set), respectively. The data also were used for all performance modeling and specification development.

BACKGROUND

This section of the report provides information on the Superpave volumetric mix design for the specific WesTrack project conditions; the type of compactors used in mix design, quality control, and quality assurance operations; the material properties and mixture source; and the types and numbers (replicates) of tests performed.

VOLUMETRIC SPECIFICATIONS

The Superpave volumetric mix design method was used to design the mixtures placed at WesTrack.[1,2,9] Thus, the quality assurance FMLC volumetric properties should be evaluated relative to the original mix designs and the Superpave volumetric mix design specifications. The Superpave volumetric mix design method is a performance-based mix design method. The system materials requirements are a function of traffic, climate, and the depth below the surface at which the material is to be incorporated. Gradation requirements are a function of nominal maximum size aggregate. The number of gyrations applied in the gyratory compactor is a function of expected traffic and climate. Final mixture properties must meet specifications that are a function of nominal maximum aggregate size and traffic and also include a dust proportion restriction and moisture sensitivity testing.[10,11,12]

The planned traffic over the accelerated 3-year loading period was 10 million 80-kN (18,000 lb) ESALs and the average design high air temperature was less than 39° C.[2,3] Because fatigue cracking was expected in some test sections at approximately 3.5 million 80-kN (18,000 lb) ESALs (based on structural design), the number of initial, design, and maximum gyrations for 3 to 10 million 80-kN ESALs were set at 8, 109, and 152, respectively for the mix designs. The same numbers of gyrations were also used for QC/QA compaction efforts. The Superpave mixture specifications relative to the project are stated in table 1.

GYRATORY COMPACTION

The original construction Superpave mix design specimens were compacted using a Pine Instruments SGC. The compactor was owned by FHWA and was installed in one of the FHWA Superpave mobile laboratories. Exactly the same compactor was used in the QC operations at the hot plant during construction. The compactor used for QA purposes was the same Pine Instruments model as the FHWA compactor, but it was owned by the University of Nevada, Reno (UNR). The quality assurance compaction was performed by Harding Lawson and Associates (HLA) technicians in Reno, Nevada, using the UNR compactor.

MATERIAL PROPERTIES AND SOURCES

Six material properties are required to calculate the volumetric properties of FMLC specimens. The properties are:

- Asphalt content.
- Asphalt cement specific gravity.
- Amount of material passing the 0.075-mm sieve.

- Combined aggregate bulk specific gravity.
- Bulk specific gravity of the compacted specimen.
- Theoretical maximum specific gravity of the mix.

For the purpose of this report, QA asphalt binder content, gradation, and aggregate specific gravities were used for volumetric calculations. The asphalt binder content data were obtained from WesTrack Technical Report UNR-15.[7] The asphalt specific gravity used was that reported by the asphalt producer, verified and reported in WesTrack Technical Report UNR-1.[13] The gradation data were obtained from WesTrack Technical Report UNR-22[8] and are based on sieve analyses performed on the aggregate remains of five ignition asphalt content tests per individual section and lift. The ignition asphalt content tests were performed on field cores. The bulk specific gravities of the aggregate blends were the same as those used in mix design and QC calculations.[14,15] Those data were used in the QA volumetric calculations and are reported in references 14 and 15. The other two properties needed to establish mixture volumetrics were the bulk specific gravity of the compacted specimens and the theoretical maximum specific gravity of the mix. These properties were determined on 520 individual gyratory-compacted specimens and 520 individual loose mix samples, respectively. The quality assurance test plan is described to establish an understanding of what materials were used, where they were sampled, and how many specimens were tested.

Quality Assurance Test Plan

The quality assurance test plan is presented in table 2. The HMA volumetrics quality assurance test plan dictated that Superpave volumetric properties be established on five sublots per lot. A lot was defined as one lift of a section. Five sublots were to be sampled per lot and two loose samples were to be compacted per sublot sample. In other words, a total of 10 specimens were to be compacted per lift and test section. The HMA was placed in two 75- mm (3-in.) lifts. The lifts have been referred to as “top” and “bottom.”

HLA performed the original construction QA testing. The data reported by HLA for each sublot were the average properties established on two replicate gyratory-compacted samples. The materials tested were sampled from transport trucks at the hot plant. Approximately 70 tons of HMA were produced for each test section. The HMA was transported to the track in two triple trailer trucks. Material in only five of the six trailers was sampled because the sixth trailer normally contained only a partial load. The bulk material samples were transported to the FHWA Materials Reference Library (MRL) in Reno immediately after construction and stored until needed for testing.

Each bulk truck sample weighed approximately 34 kg (75 lb) and was stored in a sealed 5-gallon (19-L) metal bucket. For each test section, five bulk truck samples were randomly selected for volumetric determinations. The five buckets used were actually selected from a set of over 50 buckets per section that were sampled at the hot plant from the trucks during construction. Material for two theoretical maximum specific gravity (Rice) and two gyratory compaction specimens were split from each of the five bulk samples selected per section.

One theoretical maximum specific gravity (Rice) was established per sublot. Two tests were actually performed, in accordance with AASHTO T209, and the average of the two was reported.

HLA conducted the bulk of the testing outlined in table 2, so multiple samples from a given section were in the HLA laboratory at the same time. Unfortunately, the material used for Rice determinations for the original construction was sampled from the same 70-ton production, but not necessarily split from the bulk sample from which the individual gyratory compaction sublots samples were split. This was not the plan, but it is not possible to discern from the data which Rice value coincides with which set of gyratory compaction samples due to the method used to identify samples. This means that it is possible that the materials used for Rices may have been sampled from completely different transport trucks in some cases. For this reason, the five Rices reported per lot were averaged and the average was then used in all of the volumetric calculations for a given lot. Thus, the original construction individual sublot QA volumetrics were determined using the average Rice for all sublots.

VOLUMETRIC DATA

The QA Superpave volumetric properties calculated based on the above discussion are presented in summary form in tables 3 through 8. Top and bottom lift data for each section are reported separately. It is important to note that top lift data have been used for permanent deformation modeling and bottom lift data have been used for fatigue cracking modeling. The data reported in each summary table represent the average of the five sublots (i.e., the average of 10 gyratory-compacted specimens). All 520 individual gyratory specimens are provided in appendix A. All volumetric properties reported are at the design number of gyrations, with the exception of percent compaction at the initial and maximum numbers of gyrations.

The summary tables include data on the following properties:

- Asphalt content (%AC).
- Theoretical maximum specific gravity (Rice).
- Percent air voids (%VTM).
- Percent voids in mineral aggregate (%VMA).
- Percent voids filled with asphalt (%VFA).
- Percent compaction at initial ($\%Gmm_i$), design ($\%Gmm_d$), and maximum ($\%Gmm_m$) gyrations.
- Filler-to-asphalt ratio (F/A) or dust-to-binder ratio.

Summary statistics are also provided in the tables for each of the above listed properties. The statistics include average, standard deviation, coefficient of variation, minimum and maximum values, range, and the number of replicate specimens tested. For a limited number of lifts and sections, less than 10 gyratory-compacted replicates were available. It is important to note for these sections that the data were not removed, but simply had not been reported. No data were removed prior to developing the summary statistics based on outlier detection methods.

Figures 1 through 6 are plots of percent air voids, at the design number of gyrations, versus section number and asphalt content. One plot is shown for each mix type and lift combination. Note that the x-axes of the plots show section number with asphalt content in parentheses. The section numbers are grouped by target asphalt content levels (low [L], medium [M], and high [H]). Therefore, the asphalt values along the x-axes are in order by group from low to high, but the actual asphalt contents are not necessarily in order within a target asphalt level.

The mix design optimum asphalt contents should theoretically be represented by the medium asphalt content level sections. This assumes that the asphalt contents of the field sections were at the target values. The field-observed asphalt contents were generally within 0.3 percent of the target values at the medium level. The laboratory (mix design) optimum asphalt contents were 5.4 percent and 5.7 percent for the fine and coarse mixes, respectively. The medium-level asphalt content for the fine plus mix was set equal to that of the fine mix (5.4 percent), although the mix design actually suggested a slightly lower optimum. It was held at the same level as the fine mix because the fine plus mix was produced simply by adding some baghouse fine material to the fine mix. The objective was to simulate the situation where a baghouse fines return control system was out of control and introducing too much fine material back into the mix. In real- world conditions, the plant operator would not know that the problem existed, so he/she would not reduce the asphalt content.

The trends in each plot are reasonable because, as asphalt content level increases, percent air voids decrease for all mixes and lifts. The air voids at the medium asphalt content level are also within 1.0 to 1.5 percent of the target value of 4.0 percent. This is reasonable when one considers that asphalt contents may have deviated from the optimum level by up to 0.3 percent at the medium level. The air voids drop significantly over the range of all asphalt contents from the bottom to the top lift for the coarse mix. This is evident from the plots for the fine plus mix also. For the fine mix, the air voids are approximately the same for the bottom and the top lifts. However, the asphalt contents are consistently higher for the bottom lift than the top lift at each target level for the fine mix.

This drop in air voids from the bottom to the top lift for the mixes is explained by the fact that the amount of material passing the 0.075-mm sieve increased from the bottom to the top lift for the mixes. The increase from bottom to top lift for the coarse mix was greater than 1 percent.

It should be noted that the variability in all volumetric properties is greatest for the coarse mixtures. For example, the range of air voids at the design number of gyrations is typically about 1.0 percent for the fine and fine plus mixtures, but it is well over 2.0 percent for most of the coarse mixtures. This is the case for both the top and bottom lift data. Possible reasons for the higher variability associated with the coarse mixtures include greater segregation and difficulty in obtaining the saturated surface dry condition when performing bulk specific gravity determinations.

A review of the data in the tables presented in appendix A leads to the same conclusion. A conservative rule of thumb that is commonly used for outlier detection is to multiply the standard deviation for a property by two, then add and subtract that value from the mean. Any individual value that falls outside the range of the mean plus and minus two times the standard deviation is considered an outlier. When this procedure was applied to the percent air voids data number of

outliers, one outlier was detected in the fine mix data set, which was composed of 180 test results. The same was observed for the 180 results in the fine plus mix data set. However, when the coarse mix data set was reviewed, 6 of 120 values were identified as outliers (i.e., 5 percent of the coarse mix data set). For the fine and fine plus data sets, the outliers represent about 0.5 percent of the data sets. The individual outlying test results are summarized in table 9.

SUMMARY

Original construction HMA quality assurance field-mixed, laboratory-compacted volumetric data are summarized, providing an "official" set of original construction volumetrics data. The Superpave volumetric specifications specific to the WesTrack Project nominal maximum size aggregate, traffic, and environmental conditions were presented. The materials tested were compacted with a Pine Instruments SGC. The same model of Pine SGC was also used in the mix design and quality control operations.

A total of 520 specimens were compacted. They represented five bulk samples per lift and test section. The bulk samples were taken from transfer trucks at the hot plant and stored in sealed metal buckets in the FHWA MRL prior to testing. Two gyratory compaction and two theoretical maximum specific gravity specimens were split from each bucket for testing. The testing was conducted by HLA.

In addition to the bulk specific gravity of the compacted specimens and the theoretical maximum specific gravity of the loose mixes, several other material properties were needed to establish volumetric properties. Quality assurance asphalt content, gradation (based on core samples after ignition asphalt content determinations), and blended aggregate specific gravities were employed. The blended aggregate bulk specific gravities were identical to those used for the mix design and quality control FMLC volumetric determinations. The specific gravity of the asphalt cement reported by the supplier and verified during and after construction was used. The seven standard Superpave volumetric properties for every compacted specimen are presented in appendix A. The properties are summarized in six tables (tables 3 through 8) that include several summary statistics. The summary statistics reveal significant variability in the coarse mix test results.

Plots of percent air voids versus target asphalt content level (figures 1 through 6) show the expected trends for all mixes. The percent air voids at the medium asphalt content level were within 1.0 to 1.5 percent of the mix design target of 4.0 percent. A decrease in air voids was observed from the bottom lift to the top lift for most of the mixes. This was due to an increase in the amount of material passing the 0.075-mm sieve from the bottom to the top lift for most of the mixes. This was most obvious for the coarse mix.

The variability associated with the coarse mix test results was more than double that observed for the fine and fine plus mix test results. When a conservative outlier detection procedure was applied to the data, 0.5 percent of both the fine and fine plus mixture test results were identified as outliers; 5 percent of the coarse mix test results were identified as outliers when the same procedure was applied.

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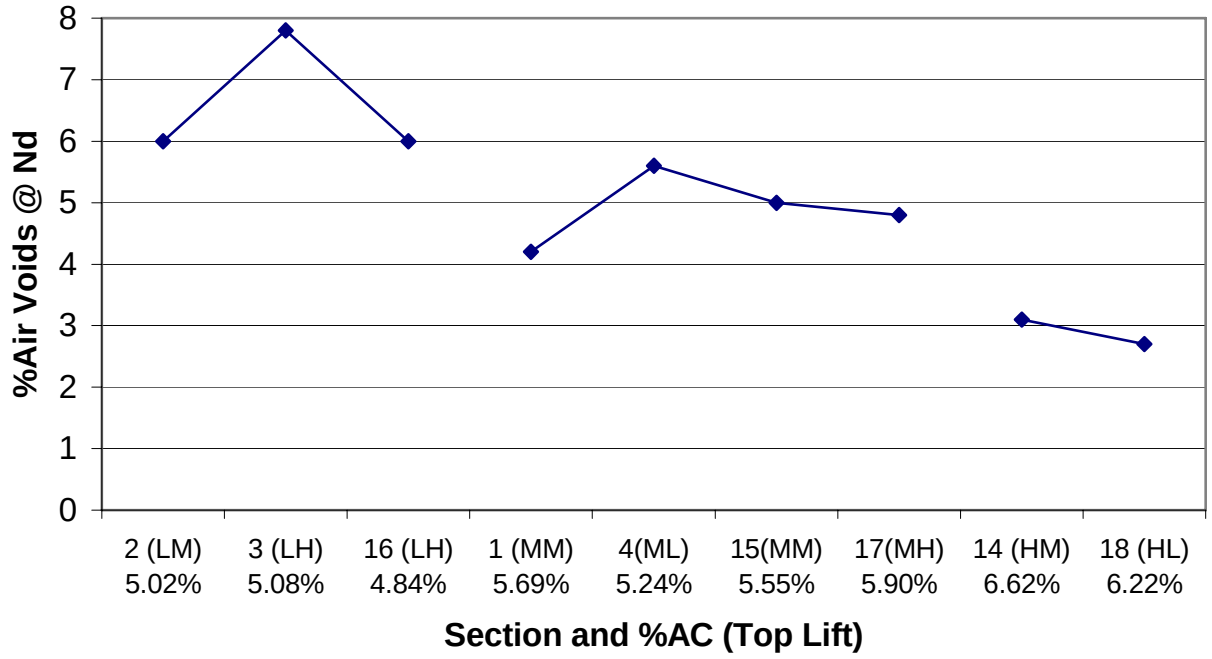

Figure 1. Fine mix – top lift air voids.

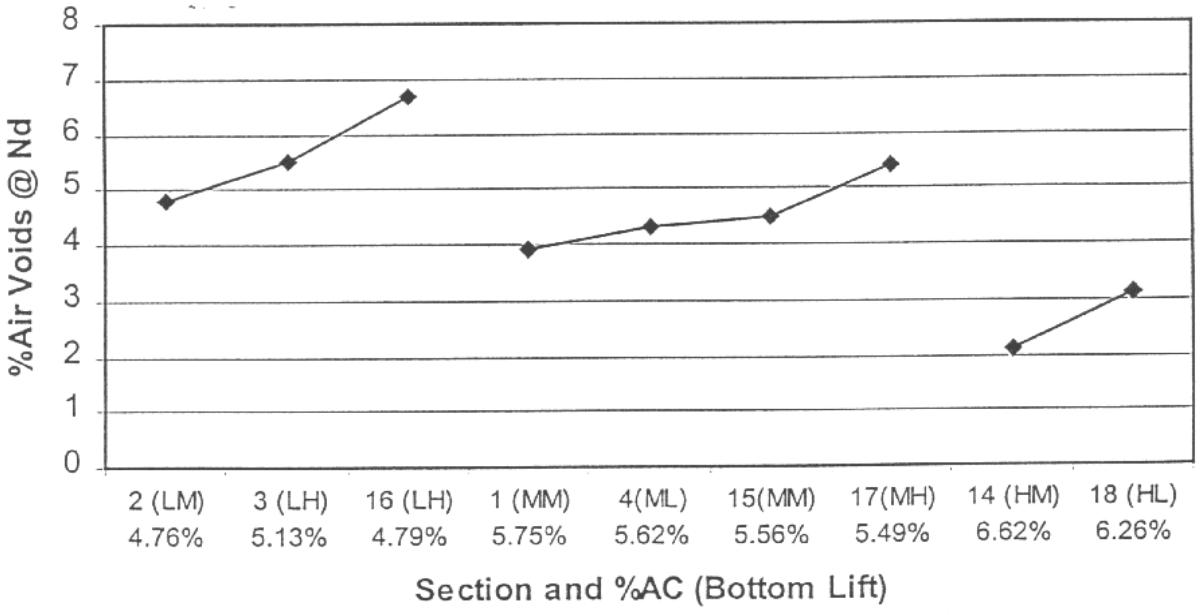

Figure 2. Fine mix – bottom lift air voids.

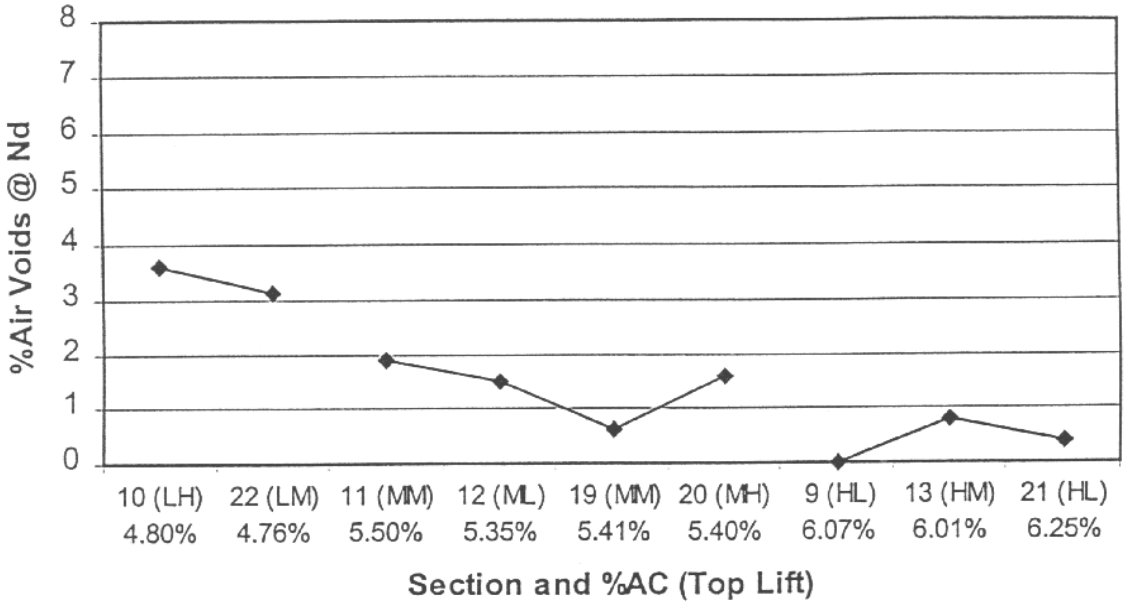

Figure 3. Fine plus mix – top lift air voids.

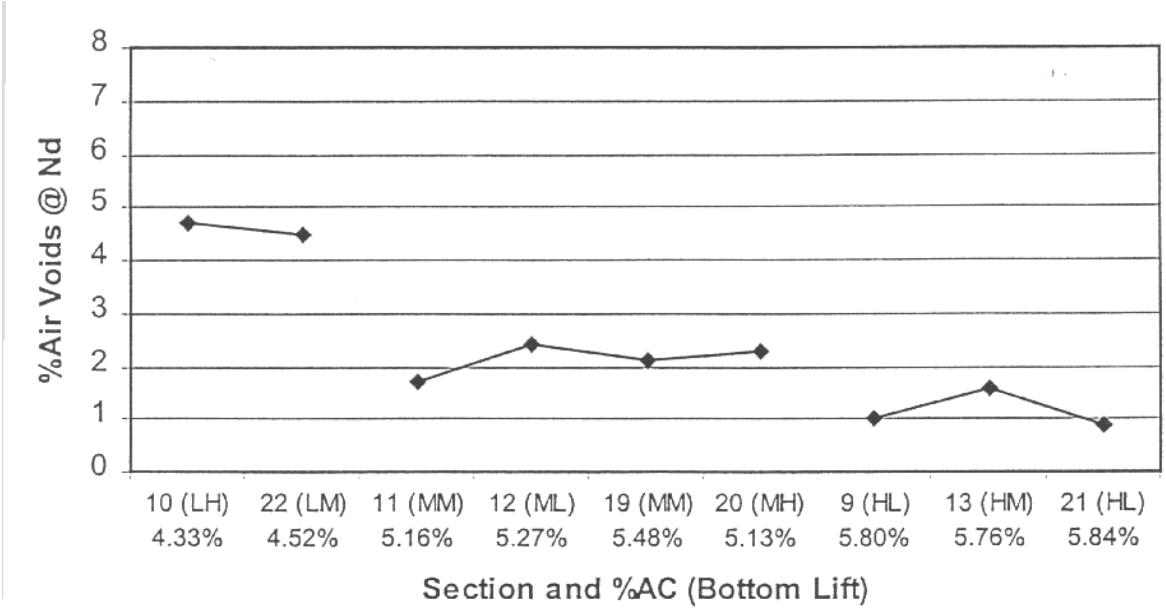

Figure 4. Fine plus mix – bottom lift air voids.

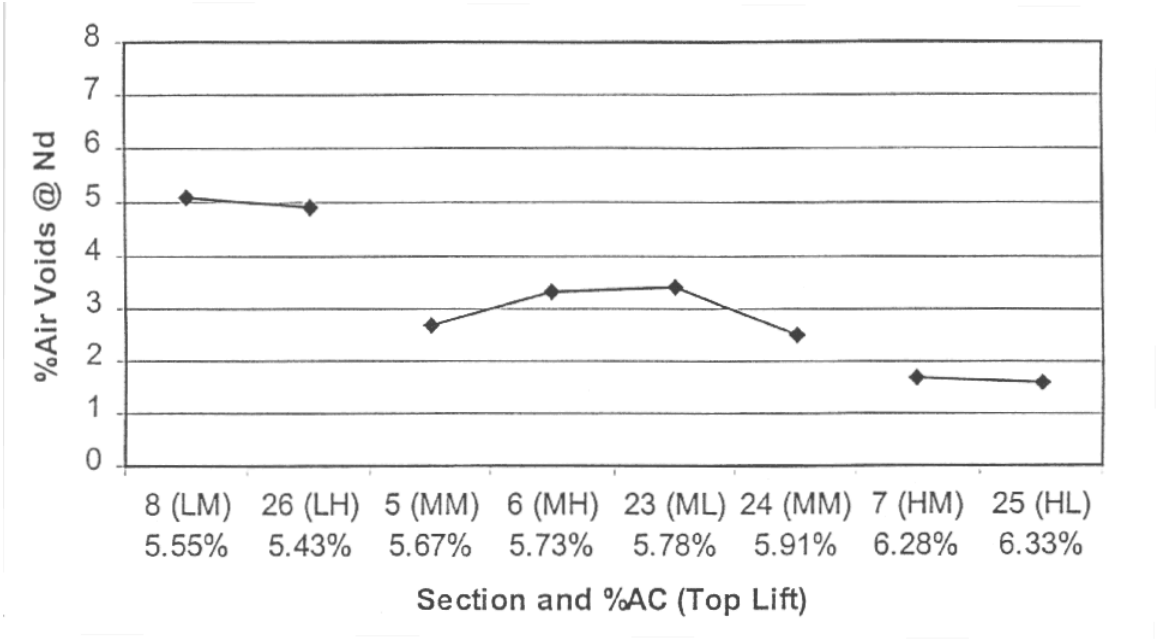

Figure 5. Coarse mix – top lift air voids.

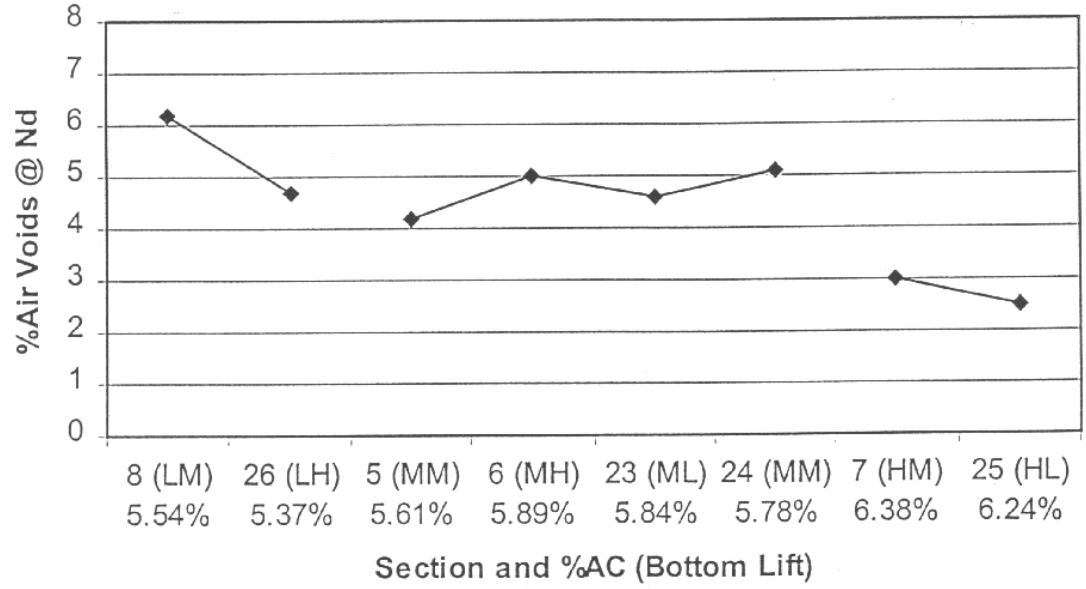

Figure 6. Coarse mix – bottom lift air voids.

Table 1. Superpave volumetric mixture specifications.

Mixture Property	**Criteria***
% Air Voids (AV or VTM)	4%
% Voids in Mineral Aggregate (VMA)	13% minimum
% Voids Filled with Asphalt (VFA)	65% - 75%
Dust-to-Binder Ratio (F/A)	0.6 - 1.2
% Gmm @ $N_{initial}$ = 8 (GMMi)	< 89%
% Gmm @ N_{design} = 96 (GMMd)	96%
% Gmm @ N_{max} = 152 (GMMm)	< 98%

*3 to 10 million ESALs.

Table 2. Quality assurance test plan.

General Property	Test Method	Tests/ Sublot	Sublots/ Lot	Number of Lots or Sections to be Tested	Number of Lifts
Asphalt Content	Nuclear	1	5	26	2
	Extraction	1	1	26	2
	Ignition	1	5	26	2
Gradation	Cold Feed	1	5	26	2
	Extraction	1	1	26	2
	Ignition	1	5	26	2
Superpave Gyratory Compaction (N_{max})	Bulk SP GR	2	5	26	2
	Volumetrics	2	5	26	2
Superpave Gyratory Compaction (N_{design})	Bulk SP GR	1	5	26	2
	Volumetrics	1	5	26	2
	M_R	1	5	26	2
Marshall Compaction	Bulk SP GR	3	1	26	2
	Volumetrics	3	1	26	2
	Stability & Flow	3	1	26	2
Hveem Compaction	Bulk SP GR	3	1	26	2
	Volumetrics	3	1	26	2
	Stability	3	1	26	2
Theo. Max. Spec. Grav.		1	5	26	2
Plant HMA Temperature		1	5	26	2
Laydown HMA Temperature		1	5	26	2
In-Place Air Voids	Nuclear	2	5	26	2
	Cores	1	5	26	2

Table 3. Fine – mix top lift gyratory volumetrics summary (QA).

Section 1 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.69	2.434	4.2	13.0	68.1	89.1	95.8	96.8	1.31
Standard Deviation	0.22	0.000	0.8	0.7	4.1	0.9	0.8	0.8	0.00
Coefficient of Variation	3.87	0.000	19.1	5.6	6.1	1.0	0.8	0.8	0.00
Max	5.88	2.434	5.8	14.5	72.3	90.2	96.6	97.5	1.31
Min	5.35	2.434	3.4	12.3	60.0	87.4	94.2	95.3	1.31
Range	0.53	0.000	2.4	2.1	12.2	2.7	2.4	2.3	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 2 (LM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.02	2.436	6.0	14.0	57.2	87.6	94.0	95.0	1.39
Standard Deviation	0.06	0.000	0.4	0.4	1.8	0.5	0.4	0.4	0.00
Coefficient of Variation	1.20	0.000	6.9	2.7	3.1	0.6	0.4	0.4	0.00
Max	5.08	2.436	6.7	14.6	59.7	88.3	94.6	95.5	1.39
Min	4.93	2.436	5.4	13.5	54.4	86.9	93.3	94.3	1.39
Range	0.15	0.000	1.2	1.1	5.4	1.4	1.2	1.2	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 3 (LH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.08	2.479	7.8	14.2	45.2	86.4	92.2	93.1	1.76
Standard Deviation	0.15	0.000	0.4	0.4	1.5	1.3	0.4	0.4	0.00
Coefficient of Variation	2.95	0.000	5.5	2.8	3.3	1.5	0.5	0.4	0.00
Max	5.30	2.479	8.5	14.9	47.2	89.7	92.8	93.6	1.76
Min	4.93	2.479	7.2	13.7	42.7	85.0	91.5	92.5	1.76
Range	0.37	0.000	1.3	1.2	4.6	4.7	1.3	1.2	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 4 (ML)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.24	2.422	5.6	14.3	61.1	88.2	94.4	95.4	1.12
Standard Deviation	0.29	0.000	0.3	0.2	1.2	0.2	0.3	0.3	0.00
Coefficient of Variation	5.53	0.000	4.8	1.7	2.0	0.2	0.3	0.3	0.00
Max	5.67	2.422	5.9	14.6	63.5	88.6	95.0	95.9	1.12
Min	4.89	2.422	5.0	13.8	59.5	87.9	94.1	95.0	1.12
Range	0.78	0.000	0.9	0.8	4.1	0.8	0.9	0.8	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 14 (HM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.62	2.407	3.1	13.9	77.7	90.3	96.9	97.9	1.03
Standard Deviation	0.12	0.000	0.3	0.3	1.6	0.4	0.3	0.3	0.00
Coefficient of Variation	1.81	0.000	9.2	1.8	2.1	0.4	0.3	0.3	0.00
Max	6.38	2.407	3.4	14.2	79.8	90.9	97.3	98.2	1.03
Min	6.10	2.407	2.7	13.6	75.9	90.0	96.6	97.5	1.03
Range	0.28	0.000	0.7	0.6	3.9	0.9	0.7	0.7	0.00
Number of Replicates	5	3	6	6	6	6	6	6	6

Table 3. Fine mix – top lift gyratory volumetrics summary (QA) (continued).

Section 15 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.55	2.433	5.0	13.7	63.5	88.6	95.0	96.0	1.34
Standard Deviation	0.21	0.000	0.4	0.4	2.0	0.4	0.4	0.4	0.00
Coefficient of Variation	3.78	0.000	8.3	2.7	3.2	0.5	0.4	0.4	0.00
Max	5.85	2.433	5.7	14.3	66.6	89.2	95.6	96.5	1.34
Min	5.35	2.433	4.4	13.1	60.1	88.0	94.3	95.2	1.34
Range	0.50	0.000	1.3	1.2	6.5	1.2	1.3	1.4	0.00
Number of Replicates	5	4	8	8	8	8	8	8	8
Section 16 (LH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	4.84	2.427	6.0	14.2	57.6	87.7	94.0	95.0	1.33
Standard Deviation	0.12	0.000	0.3	0.3	1.3	0.3	0.3	0.3	0.00
Coefficient of Variation	2.48	0.000	5.1	2.0	2.3	0.4	0.3	0.3	0.00
Max	5.00	2.427	6.6	14.7	59.6	88.1	94.4	95.3	1.33
Min	4.73	2.427	5.6	13.7	55.1	87.1	93.4	94.4	1.33
Range	0.27	0.000	1.0	1.0	4.5	1.0	1.0	0.9	0.00
Number of Replicates	5	4	8	8	8	8	8	8	8
Section 17 (MH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.90	2.426	4.8	14.0	66.0	88.9	95.2	96.2	1.23
Standard Deviation	0.16	0.000	0.3	0.2	1.3	0.4	0.3	0.3	0.00
Coefficient of Variation	2.71	0.000	5.8	1.8	2.0	0.5	0.3	0.3	0.00
Max	6.03	2.426	5.3	14.5	67.5	89.3	95.5	96.5	1.23
Min	5.65	2.426	4.5	13.8	63.6	88.0	94.7	95.7	1.23
Range	0.38	0.000	0.8	0.7	3.9	1.3	0.8	0.8	0.00
Number of Replicates	5	4	8	8	8	8	8	8	8
Section 18 (HL)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.22	2.401	2.7	13.4	80.0	90.7	97.3	98.3	1.1
Standard Deviation	0.08	0.000	0.5	0.4	3.0	0.5	0.5	0.5	0.0
Coefficient of Variation	1.29	0.000	18.6	3.3	3.8	0.5	0.5	0.5	0.0
Max	6.36	2.401	3.5	14.1	83.7	91.3	97.9	98.9	1.1
Min	6.16	2.401	2.1	12.8	75.3	89.9	96.5	97.5	1.1
Range	0.20	0.000	1.4	1.2	8.4	1.5	1.4	1.3	0.0
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 4. Fine mix – bottom lift gyratory volumetrics summary (QA).

Section 1 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.75	2.409	3.9	13.7	71.6	89.3	96.1	97.1	0.94
Standard Deviation	0.39	0.000	0.2	0.2	1.3	0.4	0.2	0.2	0.00
Coefficient of Variation	6.78	0.000	6.0	1.5	1.8	0.4	0.2	0.2	0.00
Max	6.09	2.409	4.3	14.0	73.7	89.8	96.5	97.5	0.00
Min	5.23	2.409	3.5	13.4	69.7	88.7	95.7	96.8	0.00
Range	0.86	0.000	0.7	0.7	4.0	1.1	0.7	0.7	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 2 (LM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	4.76	2.408	4.8	13.7	64.9	88.5	95.2	96.2	1.05
Standard Deviation	0.30	0.000	0.6	0.5	2.8	0.7	0.6	0.5	0.00
Coefficient of Variation	6.30	0.000	11.6	3.7	4.3	0.8	0.6	0.5	0.00
Max	5.07	2.408	5.6	14.4	69.3	89.7	96.0	97.0	0.00
Min	4.40	2.408	4.0	12.9	61.2	87.4	94.4	95.6	0.00
Range	0.67	0.000	1.6	1.5	8.1	2.3	1.6	1.4	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 3 (LH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.13	2.434	5.5	13.7	60.1	87.9	94.5	95.5	1.14
Standard Deviation	0.25	0.000	0.2	0.1	0.7	0.4	0.2	0.2	0.00
Coefficient of Variation	4.87	0.000	2.9	1.1	1.2	0.5	0.2	0.2	0.00
Max	5.44	2.434	5.7	13.9	61.3	88.3	94.8	95.8	0.00
Min	4.88	2.434	5.2	13.4	59.1	86.8	94.3	95.3	0.00
Range	0.56	0.000	0.5	0.4	2.3	1.5	0.5	0.5	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 4 (ML)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.62	2.413	4.3	13.8	68.9	88.9	95.7	96.8	1.01
Standard Deviation	0.05	0.000	0.4	0.3	1.8	0.5	0.4	0.3	0.00
Coefficient of Variation	0.89	0.000	8.3	2.3	2.7	0.5	0.4	0.4	0.00
Max	5.69	2.413	5.0	14.5	71.1	89.3	96.1	97.1	0.00
Min	5.56	2.413	3.9	13.4	65.2	87.9	95.0	96.1	0.00
Range	0.13	0.000	1.2	1.0	6.0	1.4	1.2	1.0	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 14 (HM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.62	2.401	2.1	13.2	84.3	91.0	97.9	98.9	0.92
Standard Deviation	0.14	0.000	0.2	0.2	1.4	0.3	0.2	0.2	0.00
Coefficient of Variation	2.11	0.000	10.7	1.5	1.7	0.3	0.2	0.2	0.00
Max	6.73	2.401	2.4	13.5	86.4	91.5	98.2	99.1	0.00
Min	6.43	2.401	1.8	12.9	82.0	90.7	97.6	98.6	0.00
Range	0.30	0.000	0.7	0.6	4.3	0.8	0.7	0.5	0.00
Number of Replicates	5	4	8	8	8	8	8	8	8

Table 4. Fine mix – bottom lift gyratory volumetrics summary (QA) (continued).

Section 15 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.56	2.418	4.5	13.8	67.3	88.5	95.5	96.6	1.14
Standard Deviation	0.22	0.000	0.3	0.3	1.6	0.4	0.3	0.3	0.00
Coefficient of Variation	3.96	0.000	6.9	2.0	2.4	0.4	0.3	0.3	0.00
Max	5.90	2.418	4.9	14.2	70.0	89.3	96.0	97.0	0.00
Min	5.28	2.418	4.0	13.3	65.2	88.0	95.1	96.2	0.00
Range	0.62	0.000	0.9	0.8	4.8	1.3	0.9	0.8	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 16 (LH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	4.79	2.449	6.7	13.9	52.2	86.9	93.3	94.3	1.34
Standard Deviation	0.30	0.000	0.3	0.3	1.2	0.4	0.3	0.3	0.00
Coefficient of Variation	6.26	0.000	4.7	2.1	2.4	0.4	0.3	0.3	0.00
Max	5.12	2.449	7.2	14.4	53.7	87.4	93.7	94.7	0.00
Min	4.33	2.449	6.3	13.6	50.3	86.3	92.8	93.9	0.00
Range	0.79	0.000	0.9	0.8	3.4	1.1	0.9	0.8	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 17 (MH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.49	2.426	5.4	13.8	60.7	87.9	94.6	95.6	1.23
Standard Deviation	0.23	0.000	0.2	0.2	1.0	0.3	0.2	0.2	0.00
Coefficient of Variation	4.19	0.000	3.9	1.4	1.6	0.3	0.2	0.2	0.00
Max	5.80	2.426	5.8	14.1	61.6	88.2	94.8	95.8	0.00
Min	5.17	2.426	5.2	13.6	59.1	87.4	94.2	95.2	0.00
Range	0.63	0.000	0.6	0.5	2.6	0.8	0.6	0.6	0.00
Number of Replicates	5	5	8	8	8	8	8	8	8
Section 18 (HL)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.26	2.412	3.1	13.3	77.0	89.8	96.9	98.0	1.0
Standard Deviation	0.19	0.000	0.4	0.4	2.5	0.7	0.4	0.4	0.0
Coefficient of Variation	3.04	0.000	13.4	2.8	3.2	0.7	0.4	0.4	0.0
Max	6.45	2.412	3.8	14.0	81.6	90.7	97.7	98.5	0.0
Min	5.97	2.412	2.3	12.7	73.1	88.4	96.2	97.4	0.0
Range	0.48	0.000	1.4	1.3	8.5	2.4	1.4	1.1	0.0
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 5. Fine plus mix – top lift gyratory volumetrics summary (QA).

Section 9 (HL)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.07	2.356	-0.2	12.3	102.0	95.0	100.2	100.5	0.95
Standard Deviation	0.29	0.000	0.2	0.2	1.8	0.2	0.2	0.2	0.00
Coefficient of Variation	4.78	0.000	-87.1	1.5	1.7	0.2	0.2	0.2	0.00
Max	6.42	2.356	0.1	12.5	104.9	95.4	100.6	100.8	0.95
Min	5.78	2.356	-0.6	12.0	99.5	94.6	99.9	100.4	0.95
Range	0.64	0.000	0.6	0.6	5.4	0.8	0.6	0.5	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 10 (LH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	4.80	2.415	3.6	12.3	71.2	89.8	96.4	97.4	1.44
Standard Deviation	0.18	0.000	0.5	0.5	3.0	0.5	0.5	0.5	0.00
Coefficient of Variation	3.75	0.000	14.3	3.7	4.3	0.5	0.5	0.5	0.00
Max	5.01	2.415	4.3	13.0	75.8	90.4	97.2	98.1	1.44
Min	4.52	2.415	2.8	11.7	66.8	89.1	95.7	96.7	1.44
Range	0.49	0.000	1.5	1.4	9.0	1.3	1.5	1.4	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 11 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.50	2.407	1.9	11.8	84.0	91.2	98.1	99.0	1.28
Standard Deviation	0.14	0.000	0.3	0.2	1.9	0.4	0.3	0.2	0.00
Coefficient of Variation	2.55	0.000	13.8	2.0	2.3	0.5	0.3	0.2	0.00
Max	5.68	2.407	2.3	12.1	88.1	92.2	98.7	99.4	1.28
Min	5.31	2.407	1.3	11.3	81.1	90.6	97.7	98.8	1.28
Range	0.37	0.000	1.0	0.9	7.0	1.6	1.0	0.6	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 12 (ML)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.35	2.396	1.5	11.6	87.5	91.8	98.5	99.4	1.35
Standard Deviation	0.16	0.000	0.1	0.1	1.0	0.2	0.1	0.2	0.00
Coefficient of Variation	2.99	0.000	9.3	1.0	1.2	0.2	0.1	0.2	0.00
Max	5.53	2.396	1.7	11.8	88.9	92.0	98.7	99.8	1.35
Min	5.18	2.396	1.3	11.5	85.9	91.4	98.3	99.1	1.35
Range	0.35	0.000	0.4	0.4	3.0	0.6	0.4	0.7	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 13 (HM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.01	2.394	0.8	11.8	93.1	92.5	99.2	99.8	1.20
Standard Deviation	0.21	0.000	0.3	0.2	2.1	0.7	0.3	0.1	0.00
Coefficient of Variation	3.49	0.000	33.0	2.0	2.3	0.7	0.3	0.1	0.00
Max	6.24	2.394	1.4	12.2	95.7	93.4	99.5	100.1	1.20
Min	5.71	2.394	0.5	11.5	88.9	91.2	98.6	99.7	1.20
Range	0.53	0.000	0.9	0.8	6.8	2.2	0.9	0.4	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 5. Fine plus mix – top lift gyratory volumetrics summary (QA) (continued).

Section 19(MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.41	2.374	0.6	11.7	95.1	92.7	99.4	100.3	1.19
Standard Deviation	0.17	0.000	0.2	0.2	1.8	0.2	0.2	0.2	0.00
Coefficient of Variation	3.14	0.000	38.3	1.7	1.9	0.2	0.2	0.2	0.00
Max	5.55	2.374	0.8	12.0	97.6	92.9	99.7	100.7	1.19
Min	5.13	2.374	0.3	11.5	92.9	92.3	99.2	100.0	1.19
Range	0.42	0.000	0.6	0.5	4.7	0.6	0.6	0.7	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 20 (MH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.40	2.389	1.6	12.1	87.1	91.6	98.4	99.3	1.13
Standard Deviation	0.11	0.000	0.9	0.8	5.8	1.0	0.9	0.9	0.00
Coefficient of Variation	2.04	0.000	55.8	6.6	6.7	1.1	0.9	0.9	0.00
Max	5.58	2.389	3.7	14.0	90.6	92.1	98.9	99.8	1.13
Min	5.30	2.389	1.1	11.6	73.2	89.2	96.3	97.2	1.13
Range	0.28	0.000	2.6	2.4	17.3	2.9	2.6	2.6	0.00
Number of Replicates	5	5	8	8	8	8	8	8	8
Section 21 (HL)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.25	2.380	0.4	12.1	96.7	93.0	99.6	100.2	1.06
Standard Deviation	0.12	0.000	0.2	0.2	2.0	0.3	0.2	0.4	0.00
Coefficient of Variation	1.92	0.000	61.4	1.8	2.1	0.3	0.3	0.4	0.00
Max	6.41	2.380	0.8	12.5	99.4	93.6	99.9	100.8	1.06
Min	6.08	2.380	0.1	11.8	93.4	92.6	99.2	99.7	1.06
Range	0.33	0.000	0.8	0.7	6.1	1.0	0.8	1.1	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 22 (LM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	4.76	2.408	3.1	12.1	74.7	90.3	96.9	97.9	1.3
Standard Deviation	0.10	0.000	0.4	0.3	2.3	0.3	0.4	0.4	0.0
Coefficient of Variation	2.10	0.000	12.3	2.8	3.1	0.4	0.4	0.4	0.0
Max	4.87	2.408	3.9	12.9	77.3	90.6	97.3	98.3	1.3
Min	4.64	2.408	2.7	11.7	69.6	89.4	96.1	97.1	1.3
Range	0.23	0.000	1.3	1.1	7.8	1.2	1.3	1.2	0.0
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 6. Fine plus mix – bottom lift gyratory volumetrics summary (QA).

Section 9 (HL)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.80	2.374	1.0	12.4	92.1	92.8	99.0	99.5	1.23
Standard Deviation	0.15	0.000	0.2	0.2	1.4	0.4	0.2	0.3	0.00
Coefficient of Variation	2.59	0.000	19.3	1.4	1.6	0.5	0.2	0.3	0.00
Max	5.93	2.374	1.3	12.7	94.7	93.2	99.4	99.9	1.23
Min	5.54	2.374	0.6	12.1	90.0	92.0	98.7	99.2	1.23
Range	0.39	0.000	0.6	0.6	4.7	1.2	0.6	0.8	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 10 (LH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	4.33	2.424	4.7	12.6	62.9	88.2	95.3	96.4	1.47
Standard Deviation	0.13	0.000	0.3	0.3	1.6	0.4	0.3	0.3	0.00
Coefficient of Variation	3.00	0.000	6.8	2.3	2.6	0.4	0.3	0.3	0.00
Max	4.51	2.424	5.2	13.1	64.7	88.6	95.7	96.7	1.47
Min	4.21	2.424	4.3	12.3	60.0	87.6	94.8	95.9	1.47
Range	0.30	0.000	0.9	0.8	4.7	1.0	0.9	0.8	0.00
Number of Replicates	5	5	8	8	8	8	8	8	8
Section 11 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.16	2.390	1.7	11.9	85.5	91.2	98.3	99.1	1.45
Standard Deviation	0.35	0.000	0.3	0.3	2.4	0.4	0.3	0.3	0.00
Coefficient of Variation	6.78	0.000	19.3	2.5	2.8	0.4	0.3	0.3	0.00
Max	5.49	2.390	2.2	12.4	88.2	91.6	98.6	99.5	1.45
Min	4.61	2.390	1.4	11.6	82.0	90.6	97.8	98.7	1.45
Range	0.88	0.000	0.9	0.8	6.3	1.0	0.9	0.8	0.00
Number of Replicates	5	5	8	8	8	8	8	8	8
Section 12 (ML)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.27	2.404	2.4	12.1	80.2	90.5	97.6	98.6	1.27
Standard Deviation	0.32	0.000	0.3	0.3	2.3	0.4	0.3	0.3	0.00
Coefficient of Variation	6.07	0.000	14.2	2.5	2.9	0.5	0.4	0.3	0.00
Max	5.77	2.404	3.0	12.6	83.1	91.1	98.0	99.0	1.27
Min	4.92	2.404	2.0	11.7	76.5	90.0	97.0	98.0	1.27
Range	0.85	0.000	1.0	0.9	6.6	1.1	1.0	1.1	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 13 (HM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.76	2.400	1.6	12.0	87.1	91.7	98.4	99.1	1.21
Standard Deviation	0.28	0.000	0.3	0.3	2.4	0.5	0.3	0.2	0.00
Coefficient of Variation	4.86	0.000	21.1	2.4	2.8	0.5	0.3	0.2	0.00
Max	6.19	2.400	2.1	12.4	90.1	92.1	98.9	99.5	1.21
Min	5.46	2.400	1.1	11.6	83.3	91.0	97.9	98.8	1.21
Range	0.73	0.000	0.9	0.8	6.8	1.1	0.9	0.7	0.00
Number of Replicates	5	5	8	8	8	8	8	8	8

Table 6. Fine plus mix – bottom lift gyratory volumetrics summary (QA) (continued).

Section 19 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.48	2.401	2.1	12.1	83.1	90.8	97.9	98.8	1.29
Standard Deviation	0.14	0.000	0.4	0.3	2.5	0.5	0.4	0.3	0.00
Coefficient of Variation	2.55	0.000	17.6	2.7	3.0	0.5	0.4	0.3	0.00
Max	5.66	2.401	2.6	12.6	86.9	91.6	98.5	99.2	1.29
Min	5.35	2.401	1.5	11.6	79.7	90.1	97.4	98.5	1.29
Range	0.31	0.000	1.0	0.9	7.2	1.5	1.0	0.7	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 20 (MH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.13	2.409	2.3	11.7	80.6	90.7	97.7	98.6	1.24
Standard Deviation	0.35	0.000	0.5	0.4	3.1	0.7	0.5	0.4	0.00
Coefficient of Variation	6.82	0.000	19.8	3.5	3.8	0.8	0.5	0.4	0.00
Max	5.68	2.409	3.2	12.6	83.9	91.7	98.2	99.0	1.24
Min	4.76	2.409	1.8	11.3	74.2	89.3	96.8	97.8	1.24
Range	0.92	0.000	1.4	1.3	9.7	2.4	1.4	1.1	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 21 (HL)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.84	2.386	0.9	11.9	92.9	92.3	99.1	99.7	1.10
Standard Deviation	0.24	0.000	0.4	0.3	3.0	0.7	0.4	0.2	0.00
Coefficient of Variation	4.11	0.000	45.7	2.9	3.3	0.8	0.4	0.2	0.00
Max	6.05	2.386	1.5	12.5	95.6	93.3	99.5	100.0	1.10
Min	5.46	2.386	0.5	11.6	88.3	91.1	98.5	99.2	1.10
Range	0.59	0.000	0.9	0.8	7.3	2.2	0.9	0.8	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 22 (LM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	4.52	2.414	4.5	12.9	65.6	88.5	95.5	96.6	1.3
Standard Deviation	0.19	0.000	0.4	0.3	1.9	0.4	0.4	0.3	0.0
Coefficient of Variation	4.20	0.000	8.1	2.5	2.9	0.4	0.4	0.3	0.0
Max	4.74	2.414	5.1	13.5	69.3	89.1	96.2	97.2	1.3
Min	4.24	2.414	3.8	12.3	62.5	87.9	94.9	96.0	1.3
Range	0.50	0.000	1.3	1.2	6.9	1.2	1.3	1.2	0.0
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 7. Coarse mix – top lift gyratory volumetrics summary (QA).

Section 5 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.67	2.399	2.7	12.1	77.6	87.8	97.3	98.7	1.57
Standard Deviation	0.15	0.000	0.3	0.3	2.1	0.8	0.3	0.3	0.00
Coefficient of Variation	2.65	0.000	12.0	2.4	2.7	0.9	0.3	0.3	0.00
Max	5.90	2.399	4.1	13.3	80.4	89.4	97.7	99.2	1.57
Min	5.50	2.399	2.3	11.7	69.4	86.2	95.9	97.5	1.57
Range	0.40	0.000	1.8	1.6	11.0	3.3	1.8	1.7	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 6 (MH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.73	2.411	3.3	12.2	73.5	86.8	96.7	98.2	1.60
Standard Deviation	0.10	0.000	0.8	0.7	4.6	0.9	0.8	0.7	0.00
Coefficient of Variation	1.75	0.000	23.9	5.8	6.3	1.0	0.8	0.7	0.00
Max	5.88	2.411	4.7	13.5	79.2	87.7	97.6	99.0	1.60
Min	5.63	2.411	2.4	11.4	65.1	84.9	95.3	96.8	1.60
Range	0.25	0.000	2.3	2.1	14.1	2.8	2.3	2.2	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 7 (HM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.28	2.382	1.7	12.3	86.5	88.5	98.3	99.6	1.36
Standard Deviation	0.15	0.000	0.2	0.2	1.8	0.4	0.2	0.4	0.00
Coefficient of Variation	2.39	0.000	14.7	1.8	2.0	0.5	0.2	0.4	0.00
Max	6.39	2.382	2.0	12.6	88.9	89.2	98.7	100.0	1.36
Min	6.03	2.382	1.3	12.0	84.3	87.8	98.0	98.7	1.36
Range	0.36	0.000	0.7	0.6	4.7	1.4	0.7	1.3	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 8 (LM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.55	2.430	5.1	13.0	61.1	85.8	94.9	96.4	1.90
Standard Deviation	0.11	0.000	0.7	0.6	3.2	0.5	0.7	0.6	0.00
Coefficient of Variation	1.98	0.000	12.9	4.6	5.2	0.6	0.7	0.7	0.00
Max	5.68	2.430	6.3	14.1	65.4	86.4	95.8	97.2	1.90
Min	5.39	2.430	4.2	12.2	55.2	84.8	93.7	95.2	1.90
Range	0.29	0.000	2.1	1.9	10.1	1.6	2.1	2.0	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 23 (ML)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.78	2.420	3.4	12.0	71.8	86.8	96.6	98.1	1.84
Standard Deviation	0.14	0.000	0.3	0.3	2.0	0.4	0.3	0.3	0.00
Coefficient of Variation	2.42	0.000	9.4	2.4	2.7	0.4	0.3	0.3	0.00
Max	5.92	2.420	4.0	12.6	74.6	87.3	97.0	98.4	1.84
Min	5.59	2.420	3.0	11.6	68.3	85.9	96.0	97.6	1.84
Range	0.33	0.000	1.0	0.9	6.3	1.3	1.0	0.8	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 7. Coarse mix – top lift gyratory volumetrics summary (QA) (continued).

Section 24 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.91	2.399	2.5	12.1	79.2	87.7	97.5	98.9	1.56
Standard Deviation	0.12	0.000	0.4	0.4	2.8	0.5	0.4	0.4	0.00
Coefficient of Variation	2.03	0.000	16.3	3.1	3.5	0.6	0.4	0.4	0.00
Max	6.03	2.399	3.2	12.8	82.6	88.4	98.0	99.4	1.56
Min	5.76	2.399	2.0	11.7	74.6	87.0	96.8	98.2	1.56
Range	0.27	0.000	1.2	1.1	8.0	1.5	1.2	1.2	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 25 (HL)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.33	2.377	1.6	12.5	87.6	88.3	98.4	99.8	1.40
Standard Deviation	0.06	0.000	0.9	0.8	6.0	1.0	0.9	0.7	0.00
Coefficient of Variation	0.95	0.000	54.5	6.2	6.8	1.1	0.9	0.7	0.00
Max	6.38	2.377	3.1	13.8	96.0	89.3	99.5	100.6	1.40
Min	6.22	2.377	0.5	11.5	77.5	86.6	96.9	98.6	1.40
Range	0.16	0.000	2.7	2.4	18.5	2.7	2.7	2.1	0.00
Number of Replicates	5	5	8	8	8	8	8	8	8
Section 26 (LH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.43	2.424	4.9	13.0	62.3	85.9	95.1	96.4	1.75
Standard Deviation	0.23	0.000	1.0	0.9	4.9	1.0	1.0	1.0	0.00
Coefficient of Variation	4.24	0.000	20.4	7.1	7.9	1.2	1.1	1.0	0.00
Max	5.69	2.424	6.2	14.2	67.7	87.5	96.1	97.4	1.75
Min	5.17	2.424	3.9	12.0	56.0	84.6	93.8	95.1	1.75
Range	0.52	0.000	2.4	2.2	11.7	2.9	2.4	2.3	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 8. Coarse mix – bottom lift gyratory volumetrics summary (QA).

Section 5 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.61	2.395	4.2	13.5	69.1	85.9	95.8	97.4	1.36
Standard Deviation	0.08	0.000	0.5	0.4	2.5	0.5	0.5	0.4	0.00
Coefficient of Variation	1.43	0.000	10.8	3.0	3.6	0.5	0.5	0.4	0.00
Max	5.69	2.395	4.7	13.9	76.8	87.3	97.1	98.7	1.36
Min	5.49	2.395	2.9	12.3	66.5	85.1	95.3	96.9	1.36
Range	0.20	0.000	1.8	1.6	10.3	2.2	1.8	1.8	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 6 (MH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.89	2.404	5.0	14.1	65.6	85.1	95.0	96.6	1.31
Standard Deviation	0.18	0.000	1.8	1.6	7.5	1.9	1.8	1.7	0.00
Coefficient of Variation	3.06	0.000	35.5	11.3	11.4	2.3	1.9	1.7	0.00
Max	6.06	2.404	8.5	17.3	71.7	86.4	96.3	97.9	1.31
Min	5.64	2.404	3.7	13.0	50.9	81.4	91.5	93.1	1.31
Range	0.42	0.000	4.9	4.4	20.8	5.0	4.9	4.7	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 7 (HM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.38	2.383	3.0	13.6	77.9	86.6	97.0	98.4	1.15
Standard Deviation	0.10	0.000	0.9	0.8	5.3	1.0	0.9	0.6	0.00
Coefficient of Variation	1.57	0.000	29.1	5.8	6.8	1.1	0.9	0.7	0.00
Max	6.55	2.383	4.3	14.8	88.1	88.3	98.6	99.2	1.15
Min	6.27	2.383	1.4	12.2	70.6	85.2	95.7	97.4	1.15
Range	0.28	0.000	2.9	2.6	17.6	3.1	2.9	1.8	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 8 (LM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.54	2.429	6.2	14.0	56.6	84.2	93.8	95.2	1.61
Standard Deviation	0.12	0.000	1.7	1.6	6.3	1.5	1.7	1.7	0.00
Coefficient of Variation	2.17	0.000	28.2	11.4	11.1	1.8	1.9	1.8	0.00
Max	5.64	2.429	10.8	18.3	65.2	85.5	95.7	96.4	1.61
Min	5.37	2.429	4.3	12.3	40.8	80.1	89.2	90.6	1.61
Range	0.27	0.000	6.6	6.0	24.5	5.4	6.6	5.8	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 23 (ML)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.84	2.394	4.6	14.1	67.8	85.4	95.4	97.0	1.30
Standard Deviation	0.09	0.000	1.2	1.0	5.9	1.3	1.2	1.1	0.00
Coefficient of Variation	1.54	0.000	25.2	7.4	8.6	1.5	1.2	1.1	0.00
Max	5.98	2.394	6.4	15.7	78.1	87.2	97.3	98.7	1.30
Min	5.73	2.394	2.7	12.4	59.5	83.5	93.6	95.4	1.30
Range	0.25	0.000	3.6	3.3	18.6	3.7	3.6	3.4	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 8. Coarse mix – bottom lift gyratory volumetrics summary (QA) (continued).

Section 24 (MM)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.78	2.409	5.1	14.0	63.7	84.8	94.9	96.5	1.38
Standard Deviation	0.13	0.000	1.1	1.0	5.1	1.0	1.1	1.1	0.00
Coefficient of Variation	2.25	0.000	21.0	7.0	8.0	1.2	1.1	1.1	0.00
Max	5.92	2.409	6.7	15.5	70.3	86.0	96.2	97.8	1.38
Min	5.61	2.409	3.8	12.8	56.4	83.3	93.3	94.9	1.38
Range	0.31	0.000	2.9	2.7	13.9	2.7	2.9	2.9	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 25 (HL)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.24	2.376	2.5	13.3	81.3	87.2	97.5	99.0	1.17
Standard Deviation	0.09	0.000	1.1	1.0	6.6	1.2	1.1	1.1	0.00
Coefficient of Variation	1.44.	0.000	44.9	7.6	8.1	1.4	1.2	1.1	0.00
Max	6.34	2.376	4.4	14.9	85.9	88.1	98.2	99.7	1.17
Min	6.12	2.376	1.8	12.6	70.6	85.1	95.6	97.2	1.17
Range	0.22	0.000	2.6	2.3	15.2	3.0	2.6	2.6	0.00
Number of Replicates	5	5	8	8	8	8	8	8	8
Section 26 (LH)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.37	2.389	4.7	13.9	66.6	85.8	95.3	96.9	1.27
Standard Deviation	0.21	0.000	0.9	0.8	4.1	0.9	0.9	0.8	0.00
Coefficient of Variation	3.91	0.000	18.5	5.6	6.2	1.0	0.9	0.8	0.00
Max	5.57	2.389	6.4	15.5	72.0	86.6	96.4	97.8	1.27
Min	5.01	2.389	3.6	13.0	58.5	84.2	93.6	95.2	1.27
Range	0.56	0.000	2.8	2.5	13.5	2.4	2.8	2.6	0.00
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 9. Outliers identified based on percent air voids data.

Mix Type	Section	Lift	Specimen	Appendix A Table No.
Fine	1	Top	1-2-B	1
Fine Plus	20	Top	2-1-B	25
Coarse	5	Top	2-2-A	37
	5	Bottom	2-2-A	45
	5	Bottom	2-2-B	45
	6	Bottom	2-1-B	46
	8	Bottom	2-2-A	48
	26	Bottom	1-3-A	52

APPENDIX A

QUALITY ASSURANCE VOLUMETRIC TEST RESULTS — ORIGINAL CONSTRUCTION

Table 1. Section 1 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	Gmm	%Gmm	Gmm	F/A
1	1	2	A	1-2-A	5.69	2.434	5.0	13.8	63.6	88.1	95.0	96.1	1.31
	1	2	B	1-2-B	5.69	2.434	5.8	14.5	60.0	87.4	94.2	95.3	1.31
	1	3	A	1-3-A	5.69	2.434	3.4	12.3	72.3	90.2	96.6	97.5	1.31
	1	3	B	1-3-B	5.69	2.434	3.6	12.5	71.0	89.9	96.4	97.4	1.31
	2	1	A	2-1-A	5.69	2.434	4.2	13.1	67.7	89.0	95.8	96.6	1.31
	2	1	B	2-1-B	5.69	2.434	4.9	13.7	64.3	88.5	95.1	96.2	1.31
	2	1	C	2-1-C	5.69	2.434	4.0	12.9	68.8	89.3	96.0	97.0	1.31
	2	1	D	2-1-D	5.69	2.434	4.0	12.8	69.0	89.5	96.0	97.0	1.31
	2	2	A	2-2-A	5.69	2.434	4.6	13.4	65.8	88.8	95.4	96.5	1.31
	2	2	B	2-2-B	5.69	2.434	4.5	13.3	66.2	88.5	95.5	96.6	1.31
Average					5.69	2.434	4.2	13.0	68.1	89.1	95.8	96.8	1.31
Standard Deviation					0.22	0.000	0.8	0.7	4.1	0.9	0.8	0.8	0.00
Coefficient of Variation					3.87	0.000	19.1	5.6	6.1	1.0	0.8	0.8	0.00
Max					5.88	2.434	5.8	14.5	72.3	90.2	96.6	97.5	1.31
Min					5.35	2.434	3.4	12.3	60.0	87.4	94.2	95.3	1.31
Range					0.53	0.000	2.4	2.1	12.2	2.7	2.4	2.3	0.00
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 2. Section 2 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
2	1	2	A	1-2-A	5.02	2.436	5.5	13.5	59.6	88.2	94.5	95.5	1.4
	1	2	B	1-2-B	5.02	2.436	5.7	13.8	58.3	87.9	94.3	95.2	1.4
	1	3	A	1-3-A	5.02	2.436	5.9	13.9	57.4	87.3	94.1	95.0	1.4
	1	3	B	1-3-B	5.02	2.436	6.3	14.3	55.9	86.9	93.7	94.9	1.4
	2	1	A	2-1-A	5.02	2.436	6.4	14.3	55.6	87.3	93.6	94.6	1.4
	2	1	B	2-1-B	5.02	2.436	6.7	14.6	54.4	86.9	93.3	94.3	1.4
	2	1	C	2-1-C	5.02	2.436	6.3	14.3	55.8	87.7	93.7	94.6	1.4
	2	1	D	2-1-D	5.02	2.436	6.1	14.1	56.8	87.8	93.9	94.8	1.4
	2	2	A	2-2-A	5.02	2.436	5.7	13.7	58.4	88.1	94.3	95.3	1.4
	2	2	B	2-2-B	5.02	2.436	5.4	13.5	59.7	88.3	94.6	95.5	1.4
Average					5.02	2.436	6.0	14.0	57.2	87.6	94.0	95.0	1.4
Standard Deviation					0.06	0.000	0.4	0.4	1.8	0.5	0.4	0.4	0.0
Coefficient of Variation					1.20	0.000	6.9	2.7	3.1	0.6	0.4	0.4	0.0
Max					5.08	2.436	6.7	14.6	59.7	88.3	94.6	95.5	1.4
Min					4.93	2.436	5.4	13.5	54.4	86.9	93.3	94.3	1.4
Range					0.15	0.000	1.2	1.1	5.4	1.4	1.2	1.2	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 3. Section 3 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmm	F/A
3	1	2	A	1-2-A	5.08	2.479	8.1	14.5	44.1	85.8	91.9	92.9	1.8
	1	2	B	1-2-B	5.08	2.479	7.4	13.9	46.4	86.6	92.6	93.5	1.8
	1	3	A	1-3-A	5.08	2.479	7.6	14.0	45.9	86.3	92.4	93.4	1.8
	1	3	B	1-3-B	5.08	2.479	7.3	13.8	46.7	86.7	92.7	93.6	1.8
	2	1	A	2-1-A	5.08	2.479	7.2	13.7	47.2	89.7	92.8	93.5	1.8
	2	1	B	2-1-B	5.08	2.479	8.0	14.4	44.3	85.6	92.0	93.0	1.8
	2	1	C	2-1-C	5.08	2.479	8.5	14.9	42.7	85.0	91.5	92.5	1.8
	2	1	D	2-1-D	5.08	2.479	8.2	14.6	43.7	85.5	91.8	92.7	1.8
	2	2	A	2-2-A	5.08	2.479	7.7	14.2	45.3	86.1	92.3	93.1	1.8
	2	2	B	2-2-B	5.08	2.479	7.6	14.0	45.7	86.3	92.4	93.3	1.8
Average					5.08	2.479	7.8	14.2	45.2	86.4	92.2	93.1	1.8
Standard Deviation					0.15	0.000	0.4	0.4	1.5	1.3	0.4	0.4	0.0
Coefficient of Variation					2.95	0.000	5.5	2.8	3.3	1.5	0.5	0.4	0.0
Max					5.30	2.479	8.5	14.9	47.2	89.7	92.8	93.6	1.8
Min					4.93	2.479	7.2	13.7	42.7	85.0	91.5	92.5	1.8
Range					0.37	0.000	1.3	1.2	4.6	4.7	1.3	1.2	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 4. Section 4 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
4	1	2	A	1-2-A	5.24	2.422	5.7	14.4	60.4	88.2	94.3	95.3	1.1
	1	2	B	1-2-B	5.24	2.422	5.9	14.6	59.5	87.9	94.1	95.0	1.1
	1	3	A	1-3-A	5.24	2.422	5.2	14.0	62.7	88.4	94.8	95.8	1.1
	1	3	B	1-3-B	5.24	2.422	5.0	13.8	63.5	88.6	95.0	95.9	1.1
	2	1	A	2-1-A	5.24	2.422	5.6	14.3	60.9	88.1	94.4	95.4	1.1
	2	1	B	2-1-B	5.24	2.422	5.5	14.2	61.5	88.0	94.5	95.4	1.1
	2	1	C	2-1-C	5.24	2.422	5.7	14.4	60.7	88.2	94.3	95.3	1.1
	2	1	D	2-1-D	5.24	2.422	5.5	14.2	61.4	88.3	94.5	95.4	1.1
	2	2	A	2-2-A	5.24	2.422	5.8	14.5	60.0	88.2	94.2	95.1	1.1
	2	2	B	2-2-B	5.24	2.422	5.6	14.3	60.9	88.3	94.4	95.3	1.1
Average					5.24	2.422	5.6	14.3	61.1	88.2	94.4	95.4	1.1
Standard Deviation					0.29	0.000	0.3	0.2	1.2	0.2	0.3	0.3	0.0
Coefficient of Variation					5.53	0.000	4.8	1.7	2.0	0.2	0.3	0.3	0.0
Max					5.67	2.422	5.9	14.6	63.5	88.6	95.0	95.9	1.1
Min					4.89	2.422	5.0	13.8	59.5	87.9	94.1	95.0	1.1
Range					0.78	0.000	0.9	0.8	4.1	0.8	0.9	0.8	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 5. Section 14 top lift gyratory volumetrics summary (QA).

Seaction	Truck	Trailer	Spec I	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmm	%Gmm	%Gmm	F/A
14	1	2	A	1-2-A	6.62	2.407	3.4	14.2	75.9	90.0	96.6	97.5	1.0
	1	2	B	1-2-B	6.62	2.407	2.9	13.7	79.0	90.5	97.1	98.1	1.0
	1	3	A	1-3-A	6.62	2.407	2.7	13.6	79.8	90.9	97.3	98.2	1.0
	1	3	B	1-3-B	6.62	2.407	2.9	13.7	78.6	90.4	97.1	98.0	1.0
	2	1	A	2-1-A	6.62	2.407	3.3	14.0	76.7	90.0	96.7	97.8	1.0
	2	1	B	2-1-B	6.62	2.407	3.4	14.1	76.2	90.0	96.6	97.6	1.0
	2	1	C	2-1-C									
	2	1	D	2-1-D									
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					6.62	1.444	3.1	13.9	77.7	90.3	96.9	97.9	1.0
Standard Deviation					0.12	1.318	0.3	0.3	1.6	0.4	0.3	0.3	0.0
Coefficient of Variation					1.81	######	9.2	1.8	2.1	0.4	0.3	0.3	0.0
Max					6.38	2.407	3.4	14.2	79.8	90.9	97.3	98.2	1.0
Min					6.10	2.407	2.7	13.6	75.9	90.0	96.6	97.5	1.0
Range					0.28	0.000	0.7	0.6	3.9	0.9	0.7	0.7	0.0
Number of Replicates					5	5	6	6	6	6	6	6	6

Table 6. Section 15 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	Gmm	F/A
15	1	2	A	1-2-A	5.55	2.433	4.8	13.5	64.3	88.8	95.2	96.1	1.3
	1	2	B	1-2-B	5.55	2.433	4.7	13.4	64.9	88.9	95.3	96.3	1.3
	1	3	A	1-3-A	5.55	2.433	5.0	13.7	63.5	88.4	95.0	96.0	1.3
	1	3	B	1-3-B	5.55	2.433	5.4	14.0	61.6	88.2	94.6	95.7	1.3
	2	1	A	2-1-A	5.55	2.433	5.1	13.8	63.0	88.3	94.9	95.9	1.3
	2	1	B	2-1-B	5.55	2.433	4.4	13.1	66.6	89.2	95.6	96.5	1.3
	2	1	C	2-1-C	5.55	2.433	5.7	14.3	60.1	88.0	94.3	95.2	1.3
	2	1	D	2-1-D	5.55	2.433	4.9	13.6	63.9	88.6	95.1	96.0	1.3
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					5.55	1.946	5.0	13.7	63.5	88.6	95.0	96.0	1.3
Standard Deviation					0.21	1.088	0.4	0.4	2.0	0.4	0.4	0.4	0.0
Coefficient of Variation					3.78	######	8.3	2.7	3.2	0.5	0.4	0.4	0.0
Max					5.85	2.433	5.7	14.3	66.6	89.2	95.6	96.5	1.3
Min					5.35	2.433	4.4	13.1	60.1	88.0	94.3	95.2	1.3
Range					0.50	0.000	1.3	1.2	6.5	1.2	1.3	1.4	0.0
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 7. Section 16 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID		%AC	Rice	%VTM	%VMA	%VFA	%Gmm	Gmm	Gmm	F/A
16	1	2	A	1-2-A	4.84	2.427	5.6	13.7	59.6	88.1	94.4	95.3	1.3
	1	2	B	1-2-B	4.84	2.427	5.9	14.1	58.0	87.8	94.1	95.1	1.3
	1	3	A	1-3-A	4.84	2.427	6.0	14.2	57.6	87.8	94.0	94.9	1.3
	1	3	B	1-3-B	4.84	2.427	6.1	14.2	57.3	87.7	93.9	94.8	1.3
	2	1	A	2-1-A	4.84	2.427	6.0	14.2	57.6	87.7	94.0	95.0	1.3
	2	1	B	2-1-B	4.84	2.427	5.7	13.9	58.9	88.0	94.3	95.3	1.3
	2	1	C	2-1-C	4.84	2.427	6.1	14.3	57.1	87.5	93.9	94.8	1.3
	2	1	D	2-1-D	4.84	2.427	6.6	14.7	55.1	87.1	93.4	94.4	1.3
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					4.84	1.942	6.0	14.2	57.6	87.7	94.0	95.0	1.3
Standard Deviation					0.12	1.085	0.3	0.3	1.3	0.3	0.3	0.3	0.0
Coefficient of Variation					2.48	#####	5.1	2.0	2.3	0.4	0.3	0.3	0.0
Max					5.00	2.427	6.6	14.7	59.6	88.1	94.4	95.3	1.3
Min					4.73	2.427	5.6	13.7	55.1	87.1	93.4	94.4	1.3
Range					0.27	0.000	1.0	1.0	4.5	1.0	1.0	0.9	0.0
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 8. Section 17 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
17	1	2	A	1-2-A	5.90	2.426	4.8	14.1	65.9	88.9	95.2	96.0	1.2
	1	2	B	1-2-B	5.90	2.426	4.8	14.1	65.7	89.0	95.2	96.2	1.2
	1	3	A	1-3-A	5.90	2.426	5.0	14.3	64.7	88.4	95.0	96.0	1.2
	1	3	B	1-3-B	5.90	2.426	5.3	14.5	63.6	88.0	94.7	95.7	1.2
	2	1	A	2-1-A	5.90	2.426	4.6	13.9	66.9	89.0	95.4	96.3	1.2
	2	1	B	2-1-B	5.90	2.426	4.6	13.9	66.7	89.3	95.4	96.3	1.2
	2	1	C	2-1-C	5.90	2.426	4.5	13.8	67.5	89.1	95.5	96.5	1.2
	2	1	D	2-1-D	5.90	2.426	4.5	13.8	67.3	89.3	95.5	96.5	1.2
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					5.90	1.941	4.8	14.0	66.0	88.9	95.2	96.2	1.2
Standard Deviation					0.16	1.085	0.3	0.2	1.3	0.4	0.3	0.3	0.0
Coefficient of Variation					2.71	######	5.8	1.8	2.0	0.5	0.3	0.3	0.0
Max					6.03	2.426	5.3	14.5	67.5	89.3	95.5	96.5	1.2
Min					5.65	2.426	4.5	13.8	63.6	88.0	94.7	95.7	1.2
Range					0.38	0.000	0.8	0.7	3.9	1.3	0.8	0.8	0.0
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 9. Section 18 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
18	1	2	A	1-2-A	6.22	2.401	2.1	12.8	83.7	91.3	97.9	98.9	1.1
	1	2	B	1-2-B	6.22	2.401	2.2	12.9	83.2	91.3	97.8	98.8	1.1
	1	3	A	1-3-A	6.22	2.401	3.4	14.0	75.5	90.7	96.6	97.6	1.1
	1	3	B	1-3-B	6.22	2.401	2.5	13.2	80.8	90.6	97.5	98.6	1.1
	2	1	A	2-1-A	6.22	2.401	3.2	13.8	76.9	90.1	96.8	97.8	1.1
	2	1	B	2-1-B	6.22	2.401	3.5	14.1	75.3	89.9	96.5	97.5	1.1
	2	1	C	2-1-C	6.22	2.401	2.5	13.2	81.3	90.9	97.5	98.6	1.1
	2	1	D	2-1-D	6.22	2.401	2.6	13.3	80.3	90.5	97.4	98.5	1.1
	2	2	A	2-2-A	6.22	2.401	2.4	13.1	81.8	91.0	97.6	98.7	1.1
	2	2	B	2-2-B	6.22	2.401	2.5	13.2	80.8	90.9	97.5	98.5	1.1
Average					6.22	2.401	2.7	13.4	80.0	90.7	97.3	98.3	1.1
Standard Deviation					0.08	0.000	0.5	0.4	3.0	0.5	0.5	0.5	0.0
Coefficient of Variation					1.29	0.000	18.6	3.3	3.8	0.5	0.5	0.5	0.0
Max					6.36	2.401	3.5	14.1	83.7	91.3	97.9	98.9	1.1
Min					6.16	2.401	2.1	12.8	75.3	89.9	96.5	97.5	1.1
Range					0.20	0.000	1.4	1.2	8.4	1.5	1.4	1.3	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 10. Section 1 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	Gmm	%Gmm	Gmm	F/A
1	1	2	A	1-2-A	5.75	2.409	4.3	14.0	69.7	88.7	95.7	96.8	0.94
	1	2	B	1-2-B	5.75	2.409	4.1	13.9	70.6	88.9	95.9	96.9	0.94
	1	3	A	1-3-A	5.75	2.409	3.8	13.6	72.1	89.4	96.2	97.1	0.94
	1	3	B	1-3-B	5.75	2.409	3.8	13.6	72.2	89.2	96.2	97.3	0.94
	2	1	A	2-1-A	5.75	2.409	4.0	13.9	70.8	89.2	96.0	96.9	0.94
	2	1	B	2-1-B	5.75	2.409	3.8	13.6	72.1	89.4	96.2	97.2	0.94
	2	1	C	2-1-C	5.75	2.409	3.5	13.4	73.7	89.8	96.5	97.5	0.94
	2	1	D	2-1-D	5.75	2.409	3.7	13.5	72.7	89.7	96.3	97.3	0.94
	2	2	A	2-2-A	5.75	2.409	3.7	13.6	72.6	89.3	96.3	97.4	0.94
	2	2	B	2-2-B	5.75	2.409	3.6	13.4	73.4	89.8	96.4	97.5	0.94
Average					5.75	2.409	3.9	13.7	71.6	89.3	96.1	97.1	0.94
Standard Deviation					0.39		0.2	0.2	1.3	0.4	0.2	0.2	
Coefficient of Variation					6.78		6.0	1.5	1.8	0.4	0.2	0.2	
Max					6.09		4.3	14.0	73.7	89.8	96.5	97.5	
Min					5.23		3.5	13.4	69.7	88.7	95.7	96.8	
Range					0.86		0.7	0.7	4.0	1.1	0.7	0.7	
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 11. Section 2 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
2	1	2	A	1-2-A	4.76	2.408	4.4	13.3	66.8	89.2	95.6	96.6	1.1
	1	2	B	1-2-B	4.76	2.408	5.4	14.2	61.8	88.0	94.6	95.9	1.1
	1	3	A	1-3-A	4.76	2.408	4.0	12.9	69.3	89.7	96.0	97.0	1.1
	1	3	B	1-3-B	4.76	2.408	4.4	13.3	67.0	89.1	95.6	96.6	1.1
	2	1	A	2-1-A	4.76	2.408	4.5	13.4	66.5	88.8	95.5	96.5	1.1
	2	1	B	2-1-B	4.76	2.408	4.6	13.5	66.0	88.7	95.4	96.4	1.1
	2	1	C	2-1-C	4.76	2.408	5.2	14.0	63.1	88.1	94.8	95.8	1.1
	2	1	D	2-1-D	4.76	2.408	4.7	13.6	65.4	88.7	95.3	96.3	1.1
	2	2	A	2-2-A	4.76	2.408	5.6	14.4	61.2	87.4	94.4	95.6	1.1
	2	2	B	2-2-B	4.76	2.408	5.5	14.3	61.5	87.4	94.5	95.6	1.1
Average					4.76	2.408	4.8	13.7	64.9	88.5	95.2	96.2	1.1
Standard Deviation					0.30		0.6	0.5	2.8	0.7	0.6	0.5	
Coefficient of Variation					6.30		11.6	3.7	4.3	0.8	0.6	0.5	
Max					5.07		5.6	14.4	69.3	89.7	96.0	97.0	
Min					4.40		4.0	12.9	61.2	87.4	94.4	95.6	
Range					0.67		1.6	1.5	8.1	2.3	1.6	1.4	
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 12. Section 3 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmm	F/A
3	1	2	A	1-2-A	5.13	2.434	5.7	13.9	59.1	88.0	94.3	95.3	1.1
	1	2	B	1-2-B	5.13	2.434	5.5	13.7	60.0	88.3	94.5	95.5	1.1
	1	3	A	1-3-A	5.13	2.434	5.4	13.6	60.6	88.1	94.6	95.6	1.1
	1	3	B	1-3-B	5.13	2.434	5.3	13.5	60.8	86.8	94.7	95.7	1.1
	2	1	A	2-1-A	5.13	2.434	5.7	13.9	59.1	87.9	94.3	95.3	1.1
	2	1	B	2-1-B	5.13	2.434	5.5	13.7	59.8	88.2	94.5	95.5	1.1
	2	1	C	2-1-C	5.13	2.434	5.5	13.7	60.0	87.8	94.5	95.6	1.1
	2	1	D	2-1-D	5.13	2.434	5.6	13.8	59.5	88.0	94.4	95.4	1.1
	2	2	A	2-2-A	5.13	2.434	5.4	13.6	60.6	88.0	94.6	95.6	1.1
	2	2	B	2-2-B	5.13	2.434	5.2	13.4	61.3	88.3	94.8	95.8	1.1
Average					5.13	2.434	5.5	13.7	60.1	87.9	94.5	95.5	1.1
Standard Deviation					0.25		0.2	0.1	0.7	0.4	0.2	0.2	
Coefficient of Variation					4.87		2.9	1.1	1.2	0.5	0.2	0.2	
Max					5.44		5.7	13.9	61.3	88.3	94.8	95.8	
Min					4.88		5.2	13.4	59.1	86.8	94.3	95.3	
Range					0.56		0.5	0.4	2.3	1.5	0.5	0.5	
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 13. Section 4 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
4	1	2	A	1-2-A	5.62	2.413	3.9	13.4	71.1	89.2	96.1	97.1	1.0
	1	2	B	1-2-B	5.62	2.413	4.3	13.8	68.9	89.0	95.7	96.7	1.0
	1	3	A	1-3-A	5.62	2.413	4.0	13.6	70.4	89.2	96.0	97.0	1.0
	1	3	B	1-3-B	5.62	2.413	4.4	13.9	68.5	89.3	95.6	97.1	1.0
	2	1	A	2-1-A	5.62	2.413	5.0	14.5	65.2	87.9	95.0	96.1	1.0
	2	1	B	2-1-B	5.62	2.413	4.0	13.6	70.5	89.2	96.0	97.1	1.0
	2	1	C	2-1-C	5.62	2.413	4.4	14.0	68.1	88.8	95.6	96.6	1.0
	2	1	D	2-1-D	5.62	2.413	4.4	14.0	68.1	88.9	95.6	96.6	1.0
	2	2	A	2-2-A	5.62	2.413	4.0	13.5	70.5	88.9	96.0	97.0	1.0
	2	2	B	2-2-B	5.62	2.413	4.6	14.1	67.3	88.1	95.4	96.5	1.0
Average					5.62	2.413	4.3	13.8	68.9	88.9	95.7	96.8	1.0
Standard Deviation					0.05		0.4	0.3	1.8	0.5	0.4	0.3	
Coefficient of Variation					0.89		8.3	2.3	2.7	0.5	0.4	0.4	
Max					5.69		5.0	14.5	71.1	89.3	96.1	97.1	
Min					5.56		3.9	13.4	65.2	87.9	95.0	96.1	
Range					0.13		1.2	1.0	6.0	1.4	1.2	1.0	
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 14. Section 14 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec I	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmm	%Gmm	%Gmm	F/A
14	1	2	A	1-2-A	6.62	2.401	2.1	13.2	84.0	90.9	97.9	99.0	0.9
	1	2	B	1-2-B	6.62	2.401	2.1	13.2	83.8	90.7	97.9	98.9	0.9
	1	3	A	1-3-A	6.62	2.401	1.8	12.9	86.4	91.5	98.2	99.0	0.9
	1	3	B	1-3-B	6.62	2.401	2.3	13.4	82.8	91.0	97.7	98.6	0.9
	2	1	A	2-1-A	6.62	2.401	2.0	13.1	84.6	90.8	98.0	99.0	0.9
	2	1	B	2-1-B	6.62	2.401	1.9	13.0	85.5	91.2	98.1	99.0	0.9
	2	1	C	2-1-C	6.62	2.401	2.4	13.5	82.0	90.8	97.6	98.6	0.9
	2	1	D	2-1-D	6.62	2.401	1.9	13.0	85.5	91.1	98.1	99.1	0.9
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					6.62	1.921	2.1	13.2	84.3	91.0	97.9	98.9	0.9
Standard Deviation					0.14		0.2	0.2	1.4	0.3	0.2	0.2	
Coefficient of Variation					2.11		10.7	1.5	1.7	0.3	0.2	0.2	
Max					6.73		2.4	13.5	86.4	91.5	98.2	99.1	
Min					6.43		1.8	12.9	82.0	90.7	97.6	98.6	
Range					0.30		0.7	0.6	4.3	0.8	0.7	0.5	
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 15. Section 15 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	Gmm	F/A
15	1	2	A	1-2-A	5.56	2.418	4.8	14.0	65.8	88.2	95.2	96.3	1.1
	1	2	B	1-2-B	5.56	2.418	4.7	13.9	66.4	88.4	95.3	96.4	1.1
	1	3	A	1-3-A	5.56	2.418	4.2	13.5	68.7	89.0	95.8	96.8	1.1
	1	3	B	1-3-B	5.56	2.418	4.0	13.3	70.0	89.3	96.0	97.0	1.1
	2	1	A	2-1-A	5.56	2.418	4.4	13.7	67.6	88.4	95.6	96.7	1.1
	2	1	B	2-1-B	5.56	2.418	4.3	13.6	68.3	88.8	95.7	96.7	1.1
	2	1	C	2-1-C	5.56	2.418	4.9	14.2	65.2	88.0	95.1	96.2	1.1
	2	1	D	2-1-D	5.56	2.418	4.2	13.5	68.8	88.8	95.8	96.9	1.1
	2	2	A	2-2-A	5.56	2.418	4.7	14.0	66.2	88.3	95.3	96.4	1.1
	2	2	B	2-2-B	5.56	2.418	4.8	14.0	66.0	88.2	95.2	96.4	1.1
Average					5.56	2.418	4.5	13.8	67.3	88.5	95.5	96.6	1.1
Standard Deviation					0.22		0.3	0.3	1.6	0.4	0.3	0.3	
Coefficient of Variation					3.96		6.9	2.0	2.4	0.4	0.3	0.3	
Max					5.90		4.9	14.2	70.0	89.3	96.0	97.0	
Min					5.28		4.0	13.3	65.2	88.0	95.1	96.2	
Range					0.62		0.9	0.8	4.8	1.3	0.9	0.8	
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 16. Section 16 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID		%AC	Rice	%VTM	%VMA	%VFA	%Gmm	Gmm	Gmm	F/A
16	1	2	A	1-2-A	4.79	2.449	7.0	14.2	51.0	86.5	93.0	94.0	1.3
	1	2	B	1-2-B	4.79	2.449	7.1	14.3	50.5	86.5	92.9	94.1	1.3
	1	3	A	1-3-A	4.79	2.449	6.7	14.0	52.1	86.9	93.3	94.3	1.3
	1	3	B	1-3-B	4.79	2.449	6.3	13.6	53.7	87.4	93.7	94.7	1.3
	2	1	A	2-1-A	4.79	2.449	7.2	14.4	50.3	86.3	92.8	93.9	1.3
	2	1	B	2-1-B	4.79	2.449	6.6	13.9	52.4	87.0	93.4	94.4	1.3
	2	1	C	2-1-C	4.79	2.449	6.5	13.8	52.7	87.1	93.5	94.4	1.3
	2	1	D	2-1-D	4.79	2.449	6.4	13.7	53.4	87.3	93.6	94.6	1.3
	2	2	A	2-2-A	4.79	2.449	6.5	13.8	52.7	86.9	93.5	94.4	1.3
	2	2	B	2-2-B	4.79	2.449	6.3	13.6	53.6	87.2	93.7	94.7	1.3
Average					4.79	2.449	6.7	13.9	52.2	86.9	93.3	94.3	1.3
Standard Deviation					0.30		0.3	0.3	1.2	0.4	0.3	0.3	
Coefficient of Variation					6.26		4.7	2.1	2.4	0.4	0.3	0.3	
Max					5.12		7.2	14.4	53.7	87.4	93.7	94.7	
Min					4.33		6.3	13.6	50.3	86.3	92.8	93.9	
Range					0.79		0.9	0.8	3.4	1.1	0.9	0.8	
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 17. Section 17 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
17	1	2	A	1-2-A	5.49	2.439	5.7	14.1	59.4	87.4	94.3	95.4	1.2
	1	2	B	1-2-B	5.49	2.439	5.3	13.7	61.0	87.8	94.7	95.7	1.2
	1	3	A	1-3-A	5.49	2.439	5.8	14.1	59.1	87.7	94.2	95.2	1.2
	1	3	B	1-3-B	5.49	2.439	5.2	13.6	61.6	88.1	94.8	95.8	1.2
	2	1	A	2-1-A	5.49	2.439	5.5	13.9	60.3	87.9	94.5	95.6	1.2
	2	1	B	2-1-B	5.49	2.439	5.2	13.6	61.6	88.2	94.8	95.8	1.2
	2	1	C	2-1-C	5.49	2.439	5.4	13.8	60.9	87.7	94.6	95.7	1.2
	2	1	D	2-1-D	5.49	2.439	5.3	13.7	61.4	88.2	94.7	95.7	1.2
	2	2	A	2-2-A	5.49	0.000							
	2	2	B	2-2-B	5.49	0.000							
Average					5.49	1.951	5.4	13.8	60.7	87.9	94.6	95.6	1.2
Standard Deviation					0.23		0.2	0.2	1.0	0.3	0.2	0.2	
Coefficient of Variation					4.19		3.9	1.4	1.6	0.3	0.2	0.2	
Max					5.80		5.8	14.1	61.6	88.2	94.8	95.8	
Min					5.17		5.2	13.6	59.1	87.4	94.2	95.2	
Range					0.63		0.6	0.5	2.6	0.8	0.6	0.6	
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 18. Section 18 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
18	1	2	A	1-2-A	6.26	2.412	2.3	12.7	81.6	90.7	97.7	98.5	1.0
	1	2	B	1-2-B	6.26	2.412	2.9	13.2	78.2	90.0	97.1	98.3	1.0
	1	3	A	1-3-A	6.26	2.412	3.6	13.8	74.0	89.3	96.4	97.5	1.0
	1	3	B	1-3-B	6.26	2.412	3.0	13.2	77.7	90.2	97.0	98.1	1.0
	2	1	A	2-1-A	6.26	2.412	2.9	13.2	77.7	90.0	97.1	98.1	1.0
	2	1	B	2-1-B	6.26	2.412	2.8	13.1	78.9	90.2	97.2	98.3	1.0
	2	1	C	2-1-C	6.26	2.412	3.3	13.6	75.6	89.6	96.7	97.7	1.0
	2	1	D	2-1-D	6.26	2.412	3.0	13.3	77.2	89.9	97.0	98.0	1.0
	2	2	A	2-2-A	6.26	2.412	3.8	14.0	73.1	88.4	96.2	97.4	1.0
	2	2	B	2-2-B	6.26	2.412	3.2	13.5	76.3	89.3	96.8	97.9	1.0
Average					6.26	2.412	3.1	13.3	77.0	89.8	96.9	98.0	1.0
Standard Deviation					0.19		0.4	0.4	2.5	0.7	0.4	0.4	
Coefficient of Variation					3.04		13.4	2.8	3.2	0.7	0.4	0.4	
Max					6.45		3.8	14.0	81.6	90.7	97.7	98.5	
Min					5.97		2.3	12.7	73.1	88.4	96.2	97.4	
Range					0.48		1.4	1.3	8.5	2.4	1.4	1.1	
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 19. Section 9 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	Gmm	%Gmm	Gmm	F/A
9	1	2	A	1-2-A	6.07	2.356	0.1	12.5	99.5	95.1	99.9	100.4	0.95
	1	2	B	1-2-B	6.07	2.356	-0.6	12.0	104.9	95.4	100.6	100.8	0.95
	1	3	A	1-3-A	6.07	2.356	-0.2	12.3	102.0	94.9	100.2	100.5	0.95
	1	3	B	1-3-B	6.07	2.356	-0.6	12.0	104.9	95.3	100.6	100.8	0.95
	2	1	A	2-1-A	6.07	2.356	-0.4	12.2	103.1	95.1	100.4	100.6	0.95
	2	1	B	2-1-B	6.07	2.356	-0.3	12.2	102.6	95.0	100.3	100.6	0.95
	2	1	C	2-1-C	6.07	2.356	-0.4	12.1	103.4	95.0	100.4	100.6	0.95
	2	1	D	2-1-D	6.07	2.356	-0.2	12.3	101.6	95.4	100.2	100.4	0.95
	2	2	A	2-2-A	6.07	2.356	-0.5	12.1	103.7	95.0	100.5	100.7	0.95
	2	2	B	2-2-B	6.07	2.356	-0.4	12.1	103.3	94.6	100.4	100.8	0.95
Average					6.07	2.356	-0.2	12.3	102.0	95.0	100.2	100.5	0.95
Standard Deviation					0.29	0.000	0.2	0.2	1.8	0.2	0.2	0.2	0.00
Coefficient of Variation					4.78	0.000	-87.1	1.5	1.7	0.2	0.2	0.2	0.00
Max					6.42	2.356	0.1	12.5	104.9	95.4	100.6	100.8	0.95
Min					5.78	2.356	-0.6	12.0	99.5	94.6	99.9	100.4	0.95
Range					0.64	0.000	0.6	0.6	5.4	0.8	0.6	0.5	0.00
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 20. Section 10 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
10	1	2	A	1-2-A	4.80	2.415	3.1	12.0	73.7	90.1	96.9	97.9	1.4
	1	2	B	1-2-B	4.80	2.415	2.8	11.7	75.8	90.4	97.2	98.1	1.4
	1	3	A	1-3-A	4.80	2.415	4.2	12.9	67.7	89.3	95.8	96.9	1.4
	1	3	B	1-3-B	4.80	2.415	4.3	13.0	66.8	89.1	95.7	96.7	1.4
	2	1	A	2-1-A	4.80	2.415	4.1	12.8	67.9	89.1	95.9	96.9	1.4
	2	1	B	2-1-B	4.80	2.415	3.7	12.4	70.5	89.9	96.3	97.3	1.4
	2	1	C	2-1-C	4.80	2.415	3.3	12.1	72.7	90.1	96.7	97.7	1.4
	2	1	D	2-1-D	4.80	2.415	3.6	12.4	70.9	89.8	96.4	97.4	1.4
	2	2	A	2-2-A	4.80	2.415	3.5	12.2	71.7	89.7	96.5	97.5	1.4
	2	2	B	2-2-B	4.80	2.415	3.0	11.8	74.5	90.2	97.0	97.9	1.4
Average					4.80	2.415	3.6	12.3	71.2	89.8	96.4	97.4	1.4
Standard Deviation					0.18	0.000	0.5	0.5	3.0	0.5	0.5	0.5	0.0
Coefficient of Variation					3.75	0.000	14.3	3.7	4.3	0.5	0.5	0.5	0.0
Max					5.01	2.415	4.3	13.0	75.8	90.4	97.2	98.1	1.4
Min					4.52	2.415	2.8	11.7	66.8	89.1	95.7	96.7	1.4
Range					0.49	0.000	1.5	1.4	9.0	1.3	1.5	1.4	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 21. Section 11 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmm	F/A
11	1	2	A	1-2-A	5.50	2.407	2.2	12.0	81.6	91.0	97.8	98.8	1.3
	1	2	B	1-2-B	5.50	2.407	2.3	12.1	81.1	90.6	97.7	98.8	1.3
	1	3	A	1-3-A	5.50	2.407	1.9	11.8	83.9	91.3	98.1	99.0	1.3
	1	3	B	1-3-B	5.50	2.407	1.8	11.7	84.5	91.1	98.2	99.1	1.3
	2	1	A	2-1-A	5.50	2.407	1.8	11.7	84.2	91.1	98.2	99.1	1.3
	2	1	B	2-1-B	5.50	2.407	1.8	11.7	84.3	91.3	98.2	99.0	1.3
	2	1	C	2-1-C	5.50	2.407	1.9	11.8	83.9	91.1	98.1	99.2	1.3
	2	1	D	2-1-D	5.50	2.407	2.0	11.8	83.3	91.1	98.0	99.1	1.3
	2	2	A	2-2-A	5.50	2.407	1.7	11.6	85.0	91.7	98.3	99.0	1.3
	2	2	B	2-2-B	5.50	2.407	1.3	11.3	88.1	92.2	98.7	99.4	1.3
Average					5.50	2.407	1.9	11.8	84.0	91.2	98.1	99.0	1.3
Standard Deviation					0.14	0.000	0.3	0.2	1.9	0.4	0.3	0.2	0.0
Coefficient of Variation					2.55	0.000	13.8	2.0	2.3	0.5	0.3	0.2	0.0
Max					5.68	2.407	2.3	12.1	88.1	92.2	98.7	99.4	1.3
Min					5.31	2.407	1.3	11.3	81.1	90.6	97.7	98.8	1.3
Range					0.37	0.000	1.0	0.9	7.0	1.6	1.0	0.6	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 22. Section 12 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
12	1	2	A	1-2-A	5.35	2.396	1.5	11.7	86.8	91.4	98.5	99.4	1.4
	1	2	B	1-2-B	5.35	2.396	1.4	11.6	88.0	91.5	98.6	99.5	1.4
	1	3	A	1-3-A	5.35	2.396	1.6	11.8	86.1	91.7	98.4	99.2	1.4
	1	3	B	1-3-B	5.35	2.396	1.4	11.6	87.7	91.9	98.6	99.4	1.4
	2	1	A	2-1-A	5.35	2.396	1.3	11.5	88.9	92.0	98.7	99.6	1.4
	2	1	B	2-1-B	5.35	2.396	1.3	11.5	88.9	91.8	98.7	99.8	1.4
	2	1	C	2-1-C	5.35	2.396	1.7	11.8	85.9	91.9	98.3	99.1	1.4
	2	1	D	2-1-D	5.35	2.396	1.5	11.6	87.4	92.0	98.5	99.3	1.4
	2	2	A	2-2-A	5.35	2.396	1.4	11.6	88.0	91.9	98.6	99.5	1.4
	2	2	B	2-2-B	5.35	2.396	1.4	11.6	87.7	91.8	98.6	99.5	1.4
Average					5.35	2.396	1.5	11.6	87.5	91.8	98.5	99.4	1.4
Standard Deviation					0.16	0.000	0.1	0.1	1.0	0.2	0.1	0.2	0.0
Coefficient of Variation					2.99	0.000	9.3	1.0	1.2	0.2	0.1	0.2	0.0
Max					5.53	2.396	1.7	11.8	88.9	92.0	98.7	99.8	1.4
Min					5.18	2.396	1.3	11.5	85.9	91.4	98.3	99.1	1.4
Range					0.35	0.000	0.4	0.4	3.0	0.6	0.4	0.7	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 23. Section 13 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec I	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmm	%Gmm	%Gmm	F/A
13	1	2	A	1-2-A	6.01	2.394	1.4	12.2	88.9	91.2	98.6	99.7	1.2
	1	2	B	1-2-B	6.01	2.394	0.9	11.8	92.4	91.9	99.1	100.1	1.2
	1	3	A	1-3-A	6.01	2.394	1.1	12.0	90.8	91.9	98.9	99.7	1.2
	1	3	B	1-3-B	6.01	2.394	0.5	11.5	95.7	92.9	99.5	99.9	1.2
	2	1	A	2-1-A	6.01	2.394	0.8	11.7	93.6	92.7	99.2	99.8	1.2
	2	1	B	2-1-B	6.01	2.394	0.9	11.8	92.2	92.2	99.1	99.7	1.2
	2	1	C	2-1-C	6.01	2.394	0.7	11.6	94.3	92.6	99.3	99.8	1.2
	2	1	D	2-1-D	6.01	2.394	0.8	11.7	93.2	92.7	99.2	99.8	1.2
	2	2	A	2-2-A	6.01	2.394	0.5	11.5	95.7	93.1	99.5	99.9	1.2
	2	2	B	2-2-B	6.01	2.394	0.7	11.6	94.0	93.4	99.3	99.7	1.2
Average					6.01	2.394	0.8	11.8	93.1	92.5	99.2	99.8	1.2
Standard Deviation					0.21	0.000	0.3	0.2	2.1	0.7	0.3	0.1	0.0
Coefficient of Variation					3.49	0.000	33.0	2.0	2.3	0.7	0.3	0.1	0.0
Max					6.24	2.394	1.4	12.2	95.7	93.4	99.5	100.1	1.2
Min					5.71	2.394	0.5	11.5	88.9	91.2	98.6	99.7	1.2
Range					0.53	0.000	0.9	0.8	6.8	2.2	0.9	0.4	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 24. Section 19 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	Gmm	F/A
19	1	2	A	1-2-A	5.41	2.374	0.7	11.8	94.1	92.3	99.3	100.3	1.2
	1	2	B	1-2-B	5.41	2.374	0.4	11.6	96.5	92.9	99.6	100.3	1.2
	1	3	A	1-3-A	5.41	2.374	0.5	11.6	96.0	92.9	99.5	100.3	1.2
	1	3	B	1-3-B	5.41	2.374	0.3	11.5	97.4	92.9	99.7	100.4	1.2
	2	1	A	2-1-A	5.41	2.374	0.8	11.9	93.6	92.8	99.2	100.1	1.2
	2	1	B	2-1-B	5.41	2.374	0.8	11.9	93.5	92.6	99.2	100.1	1.2
	2	1	C	2-1-C	5.41	2.374	0.8	11.9	93.3	92.5	99.2	100.0	1.2
	2	1	D	2-1-D	5.41	2.374	0.8	12.0	92.9	92.8	99.2	100.0	1.2
	2	2	A	2-2-A	5.41	2.374	0.3	11.5	97.6	92.7	99.7	100.7	1.2
	2	2	B	2-2-B	5.41	2.374	0.4	11.6	96.2	92.4	99.6	100.5	1.2
Average					5.41	2.374	0.6	11.7	95.1	92.7	99.4	100.3	1.2
Standard Deviation					0.17	0.000	0.2	0.2	1.8	0.2	0.2	0.2	0.0
Coefficient of Variation					3.14	0.000	38.3	1.7	1.9	0.2	0.2	0.2	0.0
Max					5.55	2.374	0.8	12.0	97.6	92.9	99.7	100.7	1.2
Min					5.13	2.374	0.3	11.5	92.9	92.3	99.2	100.0	1.2
Range					0.42	0.000	0.6	0.5	4.7	0.6	0.6	0.7	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 25. Section 20 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID		%AC	Rice	%VTM	%VMA	%VFA	%Gmm	Gmm	Gmm	F/A
20	1	2	A	1-2-A	5.40	2.389	1.1	11.6	90.6	92.1	98.9	99.7	1.1
	1	2	B	1-2-B	5.40	2.389	1.1	11.6	90.5	92.0	98.9	99.8	1.1
	1	3	A	1-3-A	5.40	2.389	1.1	11.6	90.6	92.1	98.9	99.7	1.1
	1	3	B	1-3-B	5.40	2.389	1.2	11.7	89.5	91.9	98.8	99.7	1.1
	2	1	A	2-1-A	5.40	2.389	1.7	12.1	86.2	91.5	98.3	99.2	1.1
	2	1	B	2-1-B	5.40	2.389	3.7	14.0	73.2	89.2	96.3	97.2	1.1
	2	1	C	2-1-C	5.40	2.389	1.4	11.9	88.3	91.8	98.6	99.6	1.1
	2	1	D	2-1-D	5.40	2.389	1.4	11.9	88.0	91.9	98.6	99.5	1.1
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					5.40	1.911	1.6	12.1	87.1	91.6	98.4	99.3	1.1
Standard Deviation					0.11	1.068	0.9	0.8	5.8	1.0	0.9	0.9	0.0
Coefficient of Variation					2.04	#####	55.8	6.6	6.7	1.1	0.9	0.9	0.0
Max					5.58	2.389	3.7	14.0	90.6	92.1	98.9	99.8	1.1
Min					5.30	2.389	1.1	11.6	73.2	89.2	96.3	97.2	1.1
Range					0.28	0.000	2.6	2.4	17.3	2.9	2.6	2.6	0.0
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 26. Section 21 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
21	1	2	A	1-2-A	6.25	2.380	0.3	12.1	97.1	92.7	99.7	100.4	1.1
	1	2	B	1-2-B	6.25	2.380	0.6	12.3	95.1	92.6	99.4	100.2	1.1
	1	3	A	1-3-A	6.25	2.380	0.3	12.0	97.6	93.3	99.7	100.2	1.1
	1	3	B	1-3-B	6.25	2.380	0.8	12.5	93.4	93.2	99.2	99.7	1.1
	2	1	A	2-1-A	6.25	2.380	0.5	12.2	96.0	93.6	99.5	100.0	1.1
	2	1	B	2-1-B	6.25	2.380	0.7	12.4	94.7	93.3	99.3	99.8	1.1
	2	1	C	2-1-C	6.25	2.380	0.5	12.2	96.0	93.0	99.5	100.0	1.1
	2	1	D	2-1-D	6.25	2.380	0.2	11.9	98.7	93.2	99.8	100.2	1.1
	2	2	A	2-2-A	6.25	2.380	0.1	11.8	99.4	92.7	99.9	100.8	1.1
	2	2	B	2-2-B	6.25	2.380	0.1	11.9	98.8	92.9	99.9	100.7	1.1
Average					6.25	2.380	0.4	12.1	96.7	93.0	99.6	100.2	1.1
Standard Deviation					0.12	0.000	0.2	0.2	2.0	0.3	0.2	0.4	0.0
Coefficient of Variation					1.92	0.000	61.4	1.8	2.1	0.3	0.3	0.4	0.0
Max					6.41	2.380	0.8	12.5	99.4	93.6	99.9	100.8	1.1
Min					6.08	2.380	0.1	11.8	93.4	92.6	99.2	99.7	1.1
Range					0.33	0.000	0.8	0.7	6.1	1.0	0.8	1.1	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 27. Section 22 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
22	1	2	A	1-2-A	4.76	2.408	2.9	11.9	75.7	90.4	97.1	98.1	1.3
	1	2	B	1-2-B	4.76	2.408	2.9	12.0	75.6	90.4	97.1	98.0	1.3
	1	3	A	1-3-A	4.76	2.408	2.9	12.0	75.7	90.3	97.1	98.1	1.3
	1	3	B	1-3-B	4.76	2.408	2.7	11.8	77.1	90.5	97.3	98.2	1.3
	2	1	A	2-1-A	4.76	2.408	3.2	12.2	73.7	90.4	96.8	97.7	1.3
	2	1	B	2-1-B	4.76	2.408	3.1	12.2	74.2	90.3	96.9	97.8	1.3
	2	1	C	2-1-C	4.76	2.408	3.4	12.4	72.4	90.1	96.6	97.6	1.3
	2	1	D	2-1-D	4.76	2.408	3.9	12.9	69.6	89.4	96.1	97.1	1.3
	2	2	A	2-2-A	4.76	2.408	2.9	11.9	75.7	90.3	97.1	98.0	1.3
	2	2	B	2-2-B	4.76	2.408	2.7	11.7	77.3	90.6	97.3	98.3	1.3
Average					4.76	2.408	3.1	12.1	74.7	90.3	96.9	97.9	1.3
Standard Deviation					0.10	0.000	0.4	0.3	2.3	0.3	0.4	0.4	0.0
Coefficient of Variation					2.10	0.000	12.3	2.8	3.1	0.4	0.4	0.4	0.0
Max					4.87	2.408	3.9	12.9	77.3	90.6	97.3	98.3	1.3
Min					4.64	2.408	2.7	11.7	69.6	89.4	96.1	97.1	1.3
Range					0.23	0.000	1.3	1.1	7.8	1.2	1.3	1.2	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 28. Section 9 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	Gmm	%Gmm	Gmm	F/A
9	1	2	A	1-2-A	5.80	2.374	1.0	12.5	91.8	92.4	99.0	99.6	1.23
	1	2	B	1-2-B	5.80	2.374	0.9	12.3	93.0	92.0	99.1	99.9	1.23
	1	3	A	1-3-A	5.80	2.374	1.1	12.5	91.2	92.8	98.9	99.2	1.23
	1	3	B	1-3-B	5.80	2.374	1.3	12.7	90.0	92.5	98.7	99.2	1.23
	2	1	A	2-1-A	5.80	2.374	0.7	12.2	94.0	93.1	99.3	99.8	1.23
	2	1	B	2-1-B	5.80	2.374	0.7	12.2	94.0	93.0	99.3	99.8	1.23
	2	1	C	2-1-C	5.80	2.374	1.1	12.5	91.2	93.2	98.9	99.2	1.23
	2	1	D	2-1-D	5.80	2.374	1.0	12.4	92.2	93.2	99.0	99.3	1.23
	2	2	A	2-2-A	5.80	2.374	0.6	12.1	94.7	93.2	99.4	99.7	1.23
	2	2	B	2-2-B	5.80	2.374	0.6	12.1	94.7	93.0	99.4	99.9	1.23
Average					5.80	2.374	1.0	12.4	92.1	92.8	99.0	99.5	1.23
Standard Deviation					0.15	0.000	0.2	0.2	1.4	0.4	0.2	0.3	0.00
Coefficient of Variation					2.59	0.000	19.3	1.4	1.6	0.5	0.2	0.3	0.00
Max					5.93	2.374	1.3	12.7	94.7	93.2	99.4	99.9	1.23
Min					5.54	2.374	0.6	12.1	90.0	92.0	98.7	99.2	1.23
Range					0.39	0.000	0.6	0.6	4.7	1.2	0.6	0.8	0.00
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 29. Section 10 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
10	1	2	A	1-2-A	4.33	2.424	4.3	12.3	64.7	88.6	95.7	96.7	1.5
	1	2	B	1-2-B	4.33	2.424	4.7	12.6	62.6	88.1	95.3	96.2	1.5
	1	3	A	1-3-A	4.33	2.424	4.9	12.8	61.5	87.8	95.1	96.1	1.5
	1	3	B	1-3-B	4.33	2.424	4.5	12.4	63.8	88.3	95.5	96.5	1.5
	2	1	A	2-1-A	4.33	2.424	4.4	12.3	64.5	88.6	95.6	96.7	1.5
	2	1	B	2-1-B	4.33	2.424	4.4	12.4	64.1	88.6	95.6	96.6	1.5
	2	1	C	2-1-C	4.33	2.424	5.2	13.1	60.0	87.6	94.8	95.9	1.5
	2	1	D	2-1-D	4.33	2.424	4.8	12.7	62.1	88.1	95.2	96.2	1.5
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					4.33	1.939	4.7	12.6	62.9	88.2	95.3	96.4	1.5
Standard Deviation					0.13	1.084	0.3	0.3	1.6	0.4	0.3	0.3	0.0
Coefficient of Variation					3.00	######	6.8	2.3	2.6	0.4	0.3	0.3	0.0
Max					4.51	2.424	5.2	13.1	64.7	88.6	95.7	96.7	1.5
Min					4.21	2.424	4.3	12.3	60.0	87.6	94.8	95.9	1.5
Range					0.30	0.000	0.9	0.8	4.7	1.0	0.9	0.8	0.0
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 30. Section 11 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmm	F/A
11	1	2	A	1-2-A	5.16	2.390	1.4	11.6	87.9	91.6	98.6	99.5	1.5
	1	2	B	1-2-B	5.16	2.390	1.4	11.6	88.2	91.6	98.6	99.4	1.5
	1	3	A	1-3-A	5.16	2.390	1.4	11.7	87.6	91.4	98.6	99.4	1.5
	1	3	B	1-3-B	5.16	2.390	1.7	11.9	85.7	90.9	98.3	99.3	1.5
	2	1	A	2-1-A	5.16	2.390	1.8	12.0	84.9	91.4	98.2	98.9	1.5
	2	1	B	2-1-B	5.16	2.390	1.7	11.9	85.5	91.3	98.3	99.0	1.5
	2	1	C	2-1-C	5.16	2.390	2.2	12.3	82.3	90.7	97.8	98.7	1.5
	2	1	D	2-1-D	5.16	2.390	2.2	12.4	82.0	90.6	97.8	98.7	1.5
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					5.16	1.912	1.7	11.9	85.5	91.2	98.3	99.1	1.5
Standard Deviation					0.35		0.3	0.3	2.4	0.4	0.3	0.3	0.0
Coefficient of Variation					6.78	0.000	19.3	2.5	2.8	0.4	0.3	0.3	0.0
Max					5.49	2.390	2.2	12.4	88.2	91.6	98.6	99.5	1.5
Min					4.61	2.390	1.4	11.6	82.0	90.6	97.8	98.7	1.5
Range					0.88	0.000	0.9	0.8	6.3	1.0	0.9	0.8	0.0
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 31. Section 12 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
12	1	2	A	1-2-A	5.27	2.404	2.8	12.5	77.6	90.1	97.2	98.3	1.3
	1	2	B	1-2-B	5.27	2.404	2.8	12.4	77.8	90.0	97.2	98.3	1.3
	1	3	A	1-3-A	5.27	2.404	2.2	11.9	81.8	90.8	97.8	98.8	1.3
	1	3	B	1-3-B	5.27	2.404	2.5	12.2	79.7	90.4	97.5	98.5	1.3
	2	1	A	2-1-A	5.27	2.404	2.1	11.8	82.3	91.1	97.9	98.8	1.3
	2	1	B	2-1-B	5.27	2.404	3.0	12.6	76.5	90.0	97.0	98.0	1.3
	2	1	C	2-1-C	5.27	2.404	2.1	11.8	82.3	90.8	97.9	98.8	1.3
	2	1	D	2-1-D	5.27	2.404	2.2	12.0	81.3	90.9	97.8	98.9	1.3
	2	2	A	2-2-A	5.27	2.404	2.5	12.2	79.4	90.2	97.5	98.6	1.3
	2	2	B	2-2-B	5.27	2.404	2.0	11.7	83.1	90.9	98.0	99.0	1.3
Average					5.27	2.404	2.4	12.1	80.2	90.5	97.6	98.6	1.3
Standard Deviation					0.32	0.000	0.3	0.3	2.3	0.4	0.3	0.3	0.0
Coefficient of Variation					6.07	0.000	14.2	2.5	2.9	0.5	0.4	0.3	0.0
Max					5.77	2.404	3.0	12.6	83.1	91.1	98.0	99.0	1.3
Min					4.92	2.404	2.0	11.7	76.5	90.0	97.0	98.0	1.3
Range					0.85	0.000	1.0	0.9	6.6	1.1	1.0	1.1	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 32. Section 13 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec I	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmm	%Gmm	%Gmm	F/A
13	1	2	A	1-2-A	5.76	2.400	1.6	12.0	86.4	91.9	98.4	98.8	1.2
	1	2	B	1-2-B	5.76	2.400	1.6	12.0	86.4	91.8	98.4	98.9	1.2
	1	3	A	1-3-A	5.76	2.400	1.5	11.9	87.2	91.5	98.5	99.3	1.2
	1	3	B	1-3-B	5.76	2.400	1.3	11.7	89.1	92.0	98.7	99.3	1.2
	2	1	A	2-1-A	5.76	2.400	1.9	12.3	84.5	91.0	98.1	99.1	1.2
	2	1	B	2-1-B	5.76	2.400	2.1	12.4	83.3	91.0	97.9	99.0	1.2
	2	1	C	2-1-C	5.76	2.400	1.1	11.6	90.1	92.0	98.9	99.5	1.2
	2	1	D	2-1-D	5.76	2.400	1.2	11.7	89.5	92.1	98.8	99.3	1.2
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					5.76	1.920	1.6	12.0	87.1	91.7	98.4	99.1	1.2
Standard Deviation					0.28	1.073	0.3	0.3	2.4	0.5	0.3	0.2	0.0
Coefficient of Variation					4.86	######	21.1	2.4	2.8	0.5	0.3	0.2	0.0
Max					6.19	2.400	2.1	12.4	90.1	92.1	98.9	99.5	1.2
Min					5.46	2.400	1.1	11.6	83.3	91.0	97.9	98.8	1.2
Range					0.73	0.000	0.9	0.8	6.8	1.1	0.9	0.7	0.0
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 33. Section 19 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	Gmm	F/A
19	1	2	A	1-2-A	5.48	2.401	2.5	12.5	80.2	90.4	97.5	98.5	1.3
	1	2	B	1-2-B	5.48	2.401	2.6	12.6	79.7	90.1	97.4	98.5	1.3
	1	3	A	1-3-A	5.48	2.401	1.5	11.6	86.9	91.6	98.5	99.2	1.3
	1	3	B	1-3-B	5.48	2.401	1.8	11.9	85.1	91.2	98.2	98.9	1.3
	2	1	A	2-1-A	5.48	2.401	2.4	12.4	80.5	90.3	97.6	98.6	1.3
	2	1	B	2-1-B	5.48	2.401	2.0	12.1	83.2	90.8	98.0	98.9	1.3
	2	1	C	2-1-C	5.48	2.401	2.3	12.3	81.3	90.5	97.7	98.6	1.3
	2	1	D	2-1-D	5.48	2.401	1.8	11.9	85.0	91.2	98.2	99.2	1.3
	2	2	A	2-2-A	5.48	2.401	1.9	12.0	84.1	90.9	98.1	99.0	1.3
	2	2	B	2-2-B	5.48	2.401	1.8	11.9	85.0	91.2	98.2	99.2	1.3
Average					5.48	2.401	2.1	12.1	83.1	90.8	97.9	98.8	1.3
Standard Deviation					0.14	0.000	0.4	0.3	2.5	0.5	0.4	0.3	0.0
Coefficient of Variation					2.55	0.000	17.6	2.7	3.0	0.5	0.4	0.3	0.0
Max					5.66	2.401	2.6	12.6	86.9	91.6	98.5	99.2	1.3
Min					5.35	2.401	1.5	11.6	79.7	90.1	97.4	98.5	1.3
Range					0.31	0.000	1.0	0.9	7.2	1.5	1.0	0.7	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 34. Section 20 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID		%AC	Rice	%VTM	%VMA	%VFA	%Gmm	Gmm	Gmm	F/A
20	1	2	A	1-2-A	5.13	2.409	3.2	12.6	74.2	89.3	96.8	97.8	1.2
	1	2	B	1-2-B	5.13	2.409	2.9	12.2	76.5	89.8	97.1	98.2	1.2
	1	3	A	1-3-A	5.13	2.409	1.9	11.3	83.6	91.7	98.1	98.8	1.2
	1	3	B	1-3-B	5.13	2.409	2.0	11.5	82.4	91.2	98.0	98.8	1.2
	2	1	A	2-1-A	5.13	2.409	2.3	11.7	80.6	90.5	97.7	98.8	1.2
	2	1	B	2-1-B	5.13	2.409	2.1	11.6	81.5	90.5	97.9	98.9	1.2
	2	1	C	2-1-C	5.13	2.409	1.8	11.3	83.9	91.1	98.2	99.0	1.2
	2	1	D	2-1-D	5.13	2.409	2.1	11.5	81.8	90.8	97.9	98.8	1.2
	2	2	A	2-2-A	5.13	2.409	2.1	11.5	81.8	91.2	97.9	98.6	1.2
	2	2	B	2-2-B	5.13	2.409	2.4	11.8	79.5	90.7	97.6	98.3	1.2
Average					5.13	2.409	2.3	11.7	80.6	90.7	97.7	98.6	1.2
Standard Deviation					0.35	0.000	0.5	0.4	3.1	0.7	0.5	0.4	0.0
Coefficient of Variation					6.82	0.000	19.8	3.5	3.8	0.8	0.5	0.4	0.0
Max					5.68	2.409	3.2	12.6	83.9	91.7	98.2	99.0	1.2
Min					4.76	2.409	1.8	11.3	74.2	89.3	96.8	97.8	1.2
Range					0.92	0.000	1.4	1.3	9.7	2.4	1.4	1.1	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 35. Section 21 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
21	1	2	A	1-2-A	5.84	2.386	0.6	11.7	95.2	92.7	99.4	99.9	1.1
	1	2	B	1-2-B	5.84	2.386	0.6	11.7	94.8	92.5	99.4	99.8	1.1
	1	3	A	1-3-A	5.84	2.386	0.5	11.6	95.6	93.3	99.5	99.7	1.1
	1	3	B	1-3-B	5.84	2.386	0.5	11.6	95.5	92.8	99.5	99.9	1.1
	2	1	A	2-1-A	5.84	2.386	0.7	11.8	93.8	92.6	99.3	99.7	1.1
	2	1	B	2-1-B	5.84	2.386	0.5	11.6	95.5	92.8	99.5	99.8	1.1
	2	1	C	2-1-C	5.84	2.386	1.4	12.4	89.0	91.1	98.6	99.6	1.1
	2	1	D	2-1-D	5.84	2.386	1.0	12.1	91.7	91.5	99.0	100.0	1.1
	2	2	A	2-2-A	5.84	2.386	1.3	12.4	89.1	91.6	98.7	99.5	1.1
	2	2	B	2-2-B	5.84	2.386	1.5	12.5	88.3	91.8	98.5	99.2	1.1
Average					5.84	2.386	0.9	11.9	92.9	92.3	99.1	99.7	1.1
Standard Deviation					0.24	0.000	0.4	0.3	3.0	0.7	0.4	0.2	0.0
Coefficient of Variation					4.11	0.000	45.7	2.9	3.3	0.8	0.4	0.2	0.0
Max					6.05	2.386	1.5	12.5	95.6	93.3	99.5	100.0	1.1
Min					5.46	2.386	0.5	11.6	88.3	91.1	98.5	99.2	1.1
Range					0.59	0.000	0.9	0.8	7.3	2.2	0.9	0.8	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 36. Section 22 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
22	1	2	A	1-2-A	4.52	2.414	4.5	12.9	65.5	88.4	95.5	96.5	1.3
	1	2	B	1-2-B	4.52	2.414	4.5	12.9	65.5	88.4	95.5	96.6	1.3
	1	3	A	1-3-A	4.52	2.414	4.7	13.1	64.2	88.2	95.3	96.4	1.3
	1	3	B	1-3-B	4.52	2.414	4.8	13.3	63.6	88.1	95.2	96.2	1.3
	2	1	A	2-1-A	4.52	2.414	4.3	12.8	66.4	88.4	95.7	96.8	1.3
	2	1	B	2-1-B	4.52	2.414	4.2	12.7	66.8	88.8	95.8	96.8	1.3
	2	1	C	2-1-C	4.52	2.414	3.8	12.3	69.3	89.1	96.2	97.2	1.3
	2	1	D	2-1-D	4.52	2.414	4.2	12.7	66.8	88.8	95.8	96.8	1.3
	2	2	A	2-2-A	4.52	2.414	5.1	13.5	62.5	87.9	94.9	96.0	1.3
	2	2	B	2-2-B	4.52	2.414	4.5	13.0	65.1	88.4	95.5	96.5	1.3
Average					4.52	2.414	4.5	12.9	65.6	88.5	95.5	96.6	1.3
Standard Deviation					0.19	0.000	0.4	0.3	1.9	0.4	0.4	0.3	0.0
Coefficient of Variation					4.20	0.000	8.1	2.5	2.9	0.4	0.4	0.3	0.0
Max					4.74	2.414	5.1	13.5	69.3	89.1	96.2	97.2	1.3
Min					4.24	2.414	3.8	12.3	62.5	87.9	94.9	96.0	1.3
Range					0.50	0.000	1.3	1.2	6.9	1.2	1.3	1.2	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 37. Section 5 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	Gmm	%Gmm	Gmm	F/A
5	1	2	A	1-2-A	5.67	2.399	3.3	12.6	73.9	86.7	96.7	98.2	1.57
	1	2	B	1-2-B	5.67	2.399	3.1	12.4	74.9	86.9	96.9	98.3	1.57
	1	3	A	1-3-A	5.67	2.399	2.7	12.1	77.5	89.4	97.3	98.7	1.57
	1	3	B	1-3-B	5.67	2.399	2.8	12.2	76.9	87.5	97.2	98.7	1.57
	2	1	A	2-1-A	5.67	2.399	2.5	11.9	78.6	87.6	97.5	98.7	1.57
	2	1	B	2-1-B	5.67	2.399	2.7	12.0	77.8	87.6	97.3	98.6	1.57
	2	1	C	2-1-C	5.67	2.399	2.3	11.7	80.4	87.5	97.7	99.2	1.57
	2	1	D	2-1-D	5.67	2.399	2.5	11.9	78.9	87.5	97.5	99.0	1.57
	2	2	A	2-2-A	5.67	2.399	4.1	13.3	69.4	86.2	95.9	97.5	1.57
	2	2	B	2-2-B	5.67	2.399	3.4	12.7	73.2	86.4	96.6	98.1	1.57
Average					5.67	2.399	2.7	12.1	77.6	87.8	97.3	98.7	1.57
Standard Deviation					0.15	0.000	0.3	0.3	2.1	0.8	0.3	0.3	0.00
Coefficient of Variation					2.65	0.000	12.0	2.4	2.7	0.9	0.3	0.3	0.00
Max					5.90	2.399	4.1	13.3	80.4	89.4	97.7	99.2	1.57
Min					5.50	2.399	2.3	11.7	69.4	86.2	95.9	97.5	1.57
Range					0.40	0.000	1.8	1.6	11.0	3.3	1.8	1.7	0.00
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 38. Section 6 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
6	1	2	A	1-2-A	5.73	2.411	2.9	11.9	75.4	86.9	97.1	98.5	1.6
	1	2	B	1-2-B	5.73	2.411	2.8	11.7	76.4	87.2	97.2	98.7	1.6
	1	3	A	1-3-A	5.73	2.411	3.5	12.4	72.0	86.8	96.5	98.0	1.6
	1	3	B	1-3-B	5.73	2.411	3.0	12.0	74.7	87.4	97.0	98.4	1.6
	2	1	A	2-1-A	5.73	2.411	2.6	11.6	77.8	87.6	97.4	98.8	1.6
	2	1	B	2-1-B	5.73	2.411	2.4	11.4	79.2	87.7	97.6	99.0	1.6
	2	1	C	2-1-C	5.73	2.411	3.2	12.1	73.9	86.5	96.8	98.3	1.6
	2	1	D	2-1-D	5.73	2.411	3.1	12.0	74.4	87.0	96.9	98.4	1.6
	2	2	A	2-2-A	5.73	2.411	4.7	13.5	65.1	84.9	95.3	96.8	1.6
	2	2	B	2-2-B	5.73	2.411	4.5	13.3	66.2	85.6	95.5	97.2	1.6
Average					5.73	2.411	3.3	12.2	73.5	86.8	96.7	98.2	1.6
Standard Deviation					0.10	0.000	0.8	0.7	4.6	0.9	0.8	0.7	0.0
Coefficient of Variation					1.75	0.000	23.9	5.8	6.3	1.0	0.8	0.7	0.0
Max					5.88	2.411	4.7	13.5	79.2	87.7	97.6	99.0	1.6
Min					5.63	2.411	2.4	11.4	65.1	84.9	95.3	96.8	1.6
Range					0.25	0.000	2.3	2.1	14.1	2.8	2.3	2.2	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 39. Section 7 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmm	F/A
7	1	2	A	1-2-A	6.28	2.382	1.4	12.1	88.3	88.8	98.6	99.8	1.4
	1	2	B	1-2-B	6.28	2.382	1.4	12.1	88.5	88.7	98.6	100.0	1.4
	1	3	A	1-3-A	6.28	2.382	2.0	12.6	84.3	87.8	98.0	99.6	1.4
	1	3	B	1-3-B	6.28	2.382	1.9	12.5	84.8	88.1	98.1	99.6	1.4
	2	1	A	2-1-A	6.28	2.382	1.5	12.2	87.4	89.2	98.5	99.1	1.4
	2	1	B	2-1-B	6.28	2.382	1.9	12.5	85.0	88.5	98.1	98.7	1.4
	2	1	C	2-1-C	6.28	2.382	1.7	12.4	85.9	88.4	98.3	99.6	1.4
	2	1	D	2-1-D	6.28	2.382	1.9	12.5	84.8	88.1	98.1	99.5	1.4
	2	2	A	2-2-A	6.28	2.382	1.6	12.3	87.1	88.5	98.4	99.8	1.4
	2	2	B	2-2-B	6.28	2.382	1.3	12.0	88.9	88.9	98.7	100.0	1.4
Average					6.28	2.382	1.7	12.3	86.5	88.5	98.3	99.6	1.4
Standard Deviation					0.15	0.000	0.2	0.2	1.8	0.4	0.2	0.4	0.0
Coefficient of Variation					2.39	0.000	14.7	1.8	2.0	0.5	0.2	0.4	0.0
Max					6.39	2.382	2.0	12.6	88.9	89.2	98.7	100.0	1.4
Min					6.03	2.382	1.3	12.0	84.3	87.8	98.0	98.7	1.4
Range					0.36	0.000	0.7	0.6	4.7	1.4	0.7	1.3	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 40. Section 8 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
8	1	2	A	1-2-A	5.55	2.430	4.2	12.2	65.4	86.4	95.8	97.2	1.9
	1	2	B	1-2-B	5.55	2.430	4.4	12.4	64.3	86.2	95.6	97.0	1.9
	1	3	A	1-3-A	5.55	2.430	4.7	12.7	62.8	86.3	95.3	96.6	1.9
	1	3	B	1-3-B	5.55	2.430	5.3	13.2	59.8	85.6	94.7	96.2	1.9
	2	1	A	2-1-A	5.55	2.430	4.5	12.4	64.1	86.2	95.5	97.0	1.9
	2	1	B	2-1-B	5.55	2.430	5.0	12.9	61.4	85.7	95.0	96.5	1.9
	2	1	C	2-1-C	5.55	2.430	5.6	13.4	58.6	85.4	94.4	95.9	1.9
	2	1	D	2-1-D	5.55	2.430	5.0	12.9	61.5	86.0	95.0	96.5	1.9
	2	2	A	2-2-A	5.55	2.430	5.7	13.5	58.2	85.7	94.3	95.8	1.9
	2	2	B	2-2-B	5.55	2.430	6.3	14.1	55.2	84.8	93.7	95.2	1.9
Average					5.55	2.430	5.1	13.0	61.1	85.8	94.9	96.4	1.9
Standard Deviation					0.11	0.000	0.7	0.6	3.2	0.5	0.7	0.6	0.0
Coefficient of Variation					1.98	0.000	12.9	4.6	5.2	0.6	0.7	0.7	0.0
Max					5.68	2.430	6.3	14.1	65.4	86.4	95.8	97.2	1.9
Min					5.39	2.430	4.2	12.2	55.2	84.8	93.7	95.2	1.9
Range					0.29	0.000	2.1	1.9	10.1	1.6	2.1	2.0	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 41. Section 23 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec I	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmm	%Gmm	%Gmm	F/A
23	1	2	A	1-2-A	5.78	2.420	3.7	12.3	70.1	86.5	96.3	97.9	1.8
	1	2	B	1-2-B	5.78	2.420	4.0	12.6	68.3	85.9	96.0	97.6	1.8
	1	3	A	1-3-A	5.78	2.420	3.6	12.2	70.5	86.8	96.4	97.9	1.8
	1	3	B	1-3-B	5.78	2.420	3.2	11.9	73.0	87.0	96.8	98.2	1.8
	2	1	A	2-1-A	5.78	2.420	3.0	11.7	74.0	87.2	97.0	98.4	1.8
	2	1	B	2-1-B	5.78	2.420	3.0	11.6	74.6	87.3	97.0	98.4	1.8
	2	1	C	2-1-C	5.78	2.420	3.1	11.8	73.5	87.1	96.9	98.3	1.8
	2	1	D	2-1-D	5.78	2.420	3.4	12.1	71.5	86.7	96.6	97.9	1.8
	2	2	A	2-2-A	5.78	2.420	3.5	12.1	71.0	86.9	96.5	97.9	1.8
	2	2	B	2-2-B	5.78	2.420	3.5	12.1	71.3	86.6	96.5	98.0	1.8
Average					5.78	2.420	3.4	12.0	71.8	86.8	96.6	98.1	1.8
Standard Deviation					0.14	0.000	0.3	0.3	2.0	0.4	0.3	0.3	0.0
Coefficient of Variation					2.42	0.000	9.4	2.4	2.7	0.4	0.3	0.3	0.0
Max					5.92	2.420	4.0	12.6	74.6	87.3	97.0	98.4	1.8
Min					5.59	2.420	3.0	11.6	68.3	85.9	96.0	97.6	1.8
Range					0.33	0.000	1.0	0.9	6.3	1.3	1.0	0.8	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 42. Section 24 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	Gmm	F/A
24	1	2	A	1-2-A	5.91	2.399	2.5	12.1	79.5	87.3	97.5	99.0	1.6
	1	2	B	1-2-B	5.91	2.399	2.8	12.4	77.3	87.4	97.2	98.7	1.6
	1	3	A	1-3-A	5.91	2.399	2.1	11.8	82.0	88.1	97.9	99.4	1.6
	1	3	B	1-3-B	5.91	2.399	2.4	12.0	80.3	87.8	97.6	99.1	1.6
	2	1	A	2-1-A	5.91	2.399	2.0	11.7	82.6	88.4	98.0	99.2	1.6
	2	1	B	2-1-B	5.91	2.399	2.0	11.7	82.6	88.4	98.0	99.4	1.6
	2	1	C	2-1-C	5.91	2.399	2.5	12.1	79.1	87.7	97.5	98.9	1.6
	2	1	D	2-1-D	5.91	2.399	2.8	12.4	77.3	87.4	97.2	98.7	1.6
	2	2	A	2-2-A	5.91	2.399	3.0	12.5	76.4	87.4	97.0	98.5	1.6
	2	2	B	2-2-B	5.91	2.399	3.2	12.8	74.6	87.0	96.8	98.2	1.6
Average					5.91	2.399	2.5	12.1	79.2	87.7	97.5	98.9	1.6
Standard Deviation					0.12	0.000	0.4	0.4	2.8	0.5	0.4	0.4	0.0
Coefficient of Variation					2.03	0.000	16.3	3.1	3.5	0.6	0.4	0.4	0.0
Max					6.03	2.399	3.2	12.8	82.6	88.4	98.0	99.4	1.6
Min					5.76	2.399	2.0	11.7	74.6	87.0	96.8	98.2	1.6
Range					0.27	0.000	1.2	1.1	8.0	1.5	1.2	1.2	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 43. Section 25 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID		%AC	Rice	%VTM	%VMA	%VFA	%Gmm	Gmm	Gmm	F/A
25	1	2	A	1-2-A	6.33	2.377	1.4	12.3	88.8	88.5	98.6	100.0	1.4
	1	2	B	1-2-B	6.33	2.377	1.9	12.7	85.3	88.1	98.1	99.5	1.4
	1	3	A	1-3-A	6.33	2.377	2.5	13.3	81.2	87.0	97.5	99.1	1.4
	1	3	B	1-3-B	6.33	2.377	3.1	13.8	77.5	86.6	96.9	98.6	1.4
	2	1	A	2-1-A	6.33	2.377	0.5	11.5	96.0	89.3	99.5	100.6	1.4
	2	1	B	2-1-B	6.33	2.377	1.1	12.0	91.0	88.8	98.9	100.2	1.4
	2	1	C	2-1-C	6.33	2.377	1.0	12.0	91.4	88.8	99.0	100.2	1.4
	2	1	D	2-1-D	6.33	2.377	1.2	12.2	89.8	88.9	98.8	100.1	1.4
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					6.33	1.902	1.6	12.5	87.6	88.3	98.4	99.8	1.4
Standard Deviation					0.06	1.063	0.9	0.8	6.0	1.0	0.9	0.7	0.0
Coefficient of Variation					0.95	######	54.5	6.2	6.8	1.1	0.9	0.7	0.0
Max					6.38	2.377	3.1	13.8	96.0	89.3	99.5	100.6	1.4
Min					6.22	2.377	0.5	11.5	77.5	86.6	96.9	98.6	1.4
Range					0.16	0.000	2.7	2.4	18.5	2.7	2.7	2.1	0.0
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 44. Section 26 top lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
26	1	2	A	1-2-A	5.43	2.424	6.2	14.2	56.0	84.6	93.8	95.2	1.8
	1	2	B	1-2-B	5.43	2.424	6.2	14.1	56.2	84.6	93.8	95.3	1.8
	1	3	A	1-3-A	5.43	2.424	3.9	12.0	67.7	87.5	96.1	97.4	1.8
	1	3	B	1-3-B	5.43	2.424	4.0	12.1	67.2	86.7	96.0	97.4	1.8
	2	1	A	2-1-A	5.43	2.424	4.2	12.3	65.9	86.6	95.8	97.1	1.8
	2	1	B	2-1-B	5.43	2.424	4.5	12.6	64.1	86.2	95.5	96.8	1.8
	2	1	C	2-1-C	5.43	2.424	5.6	13.5	59.0	85.3	94.4	95.8	1.8
	2	1	D	2-1-D	5.43	2.424	6.2	14.2	56.0	84.8	93.8	95.1	1.8
	2	2	A	2-2-A	5.43	2.424	4.1	12.2	66.3	86.5	95.9	97.2	1.8
	2	2	B	2-2-B	5.43	2.424	4.4	12.5	64.8	86.2	95.6	97.0	1.8
Average					5.43	2.424	4.9	13.0	62.3	85.9	95.1	96.4	1.8
Standard Deviation					0.23	0.000	1.0	0.9	4.9	1.0	1.0	1.0	0.0
Coefficient of Variation					4.24	0.000	20.4	7.1	7.9	1.2	1.1	1.0	0.0
Max					5.69	2.424	6.2	14.2	67.7	87.5	96.1	97.4	1.8
Min					5.17	2.424	3.9	12.0	56.0	84.6	93.8	95.1	1.8
Range					0.52	0.000	2.4	2.2	11.7	2.9	2.4	2.3	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 45. Section 5 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	Gmm	%Gmm	Gmm	F/A
5	1	2	A	1-2-A	5.61	2.395	4.7	13.9	66.5	85.1	95.3	96.9	1.36
	1	2	B	1-2-B	5.61	2.395	4.3	13.6	68.5	85.9	95.7	97.2	1.36
	1	3	A	1-3-A	5.61	2.395	4.3	13.6	68.3	85.9	95.7	97.2	1.36
	1	3	B	1-3-B	5.61	2.395	4.2	13.5	68.7	86.2	95.8	97.3	1.36
	2	1	A	2-1-A	5.61	2.395	3.4	12.8	73.3	86.6	96.6	98.1	1.36
	2	1	B	2-1-B	5.61	2.395	3.5	12.9	72.6	86.5	96.5	97.9	1.36
	2	1	C	2-1-C	5.61	2.395	4.3	13.6	68.4	85.8	95.7	97.3	1.36
	2	1	D	2-1-D	5.61	2.395	3.7	13.0	71.9	86.3	96.3	97.9	1.36
	2	2	A	2-2-A	5.61	2.395	3.0	12.4	76.0	87.3	97.0	98.5	1.36
	2	2	B	2-2-B	5.61	2.395	2.9	12.3	76.8	87.2	97.1	98.7	1.36
Average					5.61	2.395	4.2	13.5	69.1	85.9	95.8	97.4	1.36
Standard Deviation					0.08	0.000	0.5	0.4	2.5	0.5	0.5	0.4	0.00
Coefficient of Variation					1.43	0.000	10.8	3.0	3.6	0.5	0.5	0.4	0.00
Max					5.69	2.395	4.7	13.9	76.8	87.3	97.1	98.7	1.36
Min					5.49	2.395	2.9	12.3	66.5	85.1	95.3	96.9	1.36
Range					0.20	0.000	1.8	1.6	10.3	2.2	1.8	1.8	0.00
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 46. Section 6 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
6	1	2	A	1-2-A	5.89	2.404	4.9	14.1	65.1	85.4	95.1	96.7	1.3
	1	2	B	1-2-B	5.89	2.404	4.1	13.4	69.0	86.0	95.9	97.4	1.3
	1	3	A	1-3-A	5.89	2.404	4.2	13.5	68.7	86.0	95.8	97.3	1.3
	1	3	B	1-3-B	5.89	2.404	4.0	13.2	70.1	86.4	96.0	97.5	1.3
	2	1	A	2-1-A	5.89	2.404	8.0	16.9	52.6	81.6	92.0	93.8	1.3
	2	1	B	2-1-B	5.89	2.404	8.5	17.3	50.9	81.4	91.5	93.1	1.3
	2	1	C	2-1-C	5.89	2.404	4.1	13.4	69.1	86.1	95.9	97.3	1.3
	2	1	D	2-1-D	5.89	2.404	3.7	13.0	71.7	86.3	96.3	97.9	1.3
	2	2	A	2-2-A	5.89	2.404	4.4	13.6	67.9	85.7	95.6	97.1	1.3
	2	2	B	2-2-B	5.89	2.404	3.9	13.1	70.5	86.2	96.1	97.6	1.3
Average					5.89	2.404	5.0	14.1	65.6	85.1	95.0	96.6	1.3
Standard Deviation					0.18	0.000	1.8	1.6	7.5	1.9	1.8	1.7	0.0
Coefficient of Variation					3.06	0.000	35.5	11.3	11.4	2.3	1.9	1.7	0.0
Max					6.06	2.404	8.5	17.3	71.7	86.4	96.3	97.9	1.3
Min					5.64	2.404	3.7	13.0	50.9	81.4	91.5	93.1	1.3
Range					0.42	0.000	4.9	4.4	20.8	5.0	4.9	4.7	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 47. Section 7 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmm	F/A
7	1	2	A	1-2-A	6.38	2.383	4.3	14.8	70.6	85.2	95.7	97.4	1.1
	1	2	B	1-2-B	6.38	2.383	3.9	14.4	72.8	85.6	96.1	97.8	1.1
	1	3	A	1-3-A	6.38	2.383	1.4	12.2	88.1	88.3	98.6	99.2	1.1
	1	3	B	1-3-B	6.38	2.383	2.3	13.0	82.0	87.4	97.7	99.0	1.1
	2	1	A	2-1-A	6.38	2.383	2.5	13.2	80.8	87.1	97.5	99.0	1.1
	2	1	B	2-1-B	6.38	2.383	3.0	13.6	78.0	86.7	97.0	98.7	1.1
	2	1	C	2-1-C	6.38	2.383	3.9	14.4	72.8	85.5	96.1	97.8	1.1
	2	1	D	2-1-D	6.38	2.383	3.5	14.0	75.2	86.1	96.5	98.2	1.1
	2	2	A	2-2-A	6.38	2.383	3.0	13.6	77.7	86.7	97.0	98.4	1.1
	2	2	B	2-2-B	6.38	2.383	2.5	13.1	81.2	87.3	97.5	99.1	1.1
Average					6.38	2.383	3.0	13.6	77.9	86.6	97.0	98.4	1.1
Standard Deviation					0.10	0.000	0.9	0.8	5.3	1.0	0.9	0.6	0.0
Coefficient of Variation					1.57	0.000	29.1	5.8	6.8	1.1	0.9	0.7	0.0
Max					6.55	2.383	4.3	14.8	88.1	88.3	98.6	99.2	1.1
Min					6.27	2.383	1.4	12.2	70.6	85.2	95.7	97.4	1.1
Range					0.28	0.000	2.9	2.6	17.6	3.1	2.9	1.8	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 48. Section 8 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
8	1	2	A	1-2-A	5.54	2.429	6.2	14.0	55.9	84.5	93.8	95.2	1.6
	1	2	B	1-2-B	5.54	2.429	5.9	13.8	57.0	84.3	94.1	95.6	1.6
	1	3	A	1-3-A	5.54	2.429	6.0	13.8	56.8	84.9	94.0	95.4	1.6
	1	3	B	1-3-B	5.54	2.429	6.3	14.1	55.6	84.1	93.7	95.2	1.6
	2	1	A	2-1-A	5.54	2.429	4.3	12.3	65.2	85.5	95.7	96.3	1.6
	2	1	B	2-1-B	5.54	2.429	5.1	13.0	61.0	85.4	94.9	96.4	1.6
	2	1	C	2-1-C	5.54	2.429	6.0	13.9	56.8	84.3	94.0	95.5	1.6
	2	1	D	2-1-D	5.54	2.429	6.0	13.9	56.6	84.2	94.0	95.6	1.6
	2	2	A	2-2-A	5.54	2.429	10.8	18.3	40.8	80.1	89.2	90.6	1.6
	2	2	B	2-2-B	5.54	2.429	5.3	13.2	59.8	84.9	94.7	96.2	1.6
Average					5.54	2.429	6.2	14.0	56.6	84.2	93.8	95.2	1.6
Standard Deviation					0.12	0.000	1.7	1.6	6.3	1.5	1.7	1.7	0.0
Coefficient of Variation					2.17	0.000	28.2	11.4	11.1	1.8	1.9	1.8	0.0
Max					5.64	2.429	10.8	18.3	65.2	85.5	95.7	96.4	1.6
Min					5.37	2.429	4.3	12.3	40.8	80.1	89.2	90.6	1.6
Range					0.27	0.000	6.6	6.0	24.5	5.4	6.6	5.8	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 49. Section 23 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec I	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmm	%Gmm	%Gmm	F/A
23	1	2	A	1-2-A	5.84	2.394	6.4	15.7	59.5	83.6	93.6	95.4	1.3
	1	2	B	1-2-B	5.84	2.394	6.0	15.4	61.1	83.5	94.0	95.6	1.3
	1	3	A	1-3-A	5.84	2.394	3.5	13.1	73.4	86.6	96.5	98.0	1.3
	1	3	B	1-3-B	5.84	2.394	2.7	12.4	78.1	87.2	97.3	98.7	1.3
	2	1	A	2-1-A	5.84	2.394	4.1	13.7	70.0	86.0	95.9	97.4	1.3
	2	1	B	2-1-B	5.84	2.394	3.8	13.4	71.5	86.2	96.2	97.7	1.3
	2	1	C	2-1-C	5.84	2.394	4.3	13.8	69.2	86.0	95.7	97.2	1.3
	2	1	D	2-1-D	5.84	2.394	4.4	13.9	68.4	85.4	95.6	97.2	1.3
	2	2	A	2-2-A	5.84	2.394	5.2	14.7	64.3	84.8	94.8	96.3	1.3
	2	2	B	2-2-B	5.84	2.394	5.6	15.0	62.8	84.3	94.4	95.9	1.3
Average					5.84	2.394	4.6	14.1	67.8	85.4	95.4	97.0	1.3
Standard Deviation					0.09	0.000	1.2	1.0	5.9	1.3	1.2	1.1	0.0
Coefficient of Variation					1.54	0.000	25.2	7.4	8.6	1.5	1.2	1.1	0.0
Max					5.98	2.394	6.4	15.7	78.1	87.2	97.3	98.7	1.3
Min					5.73	2.394	2.7	12.4	59.5	83.5	93.6	95.4	1.3
Range					0.25	0.000	3.6	3.3	18.6	3.7	3.6	3.4	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 50. Section 24 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	Sample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	Gmm	F/A
24	1	2	A	1-2-A	5.78	2.409	4.1	13.1	68.5	85.9	95.9	97.5	1.4
	1	2	B	1-2-B	5.78	2.409	3.8	12.8	70.3	86.0	96.2	97.8	1.4
	1	3	A	1-3-A	5.78	2.409	4.3	13.2	67.8	85.5	95.7	97.3	1.4
	1	3	B	1-3-B	5.78	2.409	4.3	13.2	67.6	85.7	95.7	97.3	1.4
	2	1	A	2-1-A	5.78	2.409	6.2	14.9	58.7	83.9	93.8	95.4	1.4
	2	1	B	2-1-B	5.78	2.409	6.1	14.9	58.9	83.6	93.9	95.5	1.4
	2	1	C	2-1-C	5.78	2.409	4.9	13.8	64.7	85.4	95.1	96.6	1.4
	2	1	D	2-1-D	5.78	2.409	4.7	13.6	65.5	85.4	95.3	96.8	1.4
	2	2	A	2-2-A	5.78	2.409	6.3	15.0	58.4	83.8	93.7	95.4	1.4
	2	2	B	2-2-B	5.78	2.409	6.7	15.5	56.4	83.3	93.3	94.9	1.4
Average					5.78	2.409	5.1	14.0	63.7	84.8	94.9	96.5	1.4
Standard Deviation					0.13	0.000	1.1	1.0	5.1	1.0	1.1	1.1	0.0
Coefficient of Variation					2.25	0.000	21.0	7.0	8.0	1.2	1.1	1.1	0.0
Max					5.92	2.409	6.7	15.5	70.3	86.0	96.2	97.8	1.4
Min					5.61	2.409	3.8	12.8	56.4	83.3	93.3	94.9	1.4
Range					0.31	0.000	2.9	2.7	13.9	2.7	2.9	2.9	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Table 51. Section 25 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID		%AC	Rice	%VTM	%VMA	%VFA	%Gmm	Gmm	Gmm	F/A
25	1	2	A	1-2-A	6.24	2.376	1.9	12.8	84.8	87.8	98.1	99.6	1.2
	1	2	B	1-2-B	6.24	2.376	2.1	12.9	84.0	87.8	97.9	99.5	1.2
	1	3	A	1-3-A	6.24	2.376	1.9	12.7	85.3	88.1	98.1	99.6	1.2
	1	3	B	1-3-B	6.24	2.376	1.8	12.6	85.8	87.9	98.2	99.7	1.2
	2	1	A	2-1-A	6.24	2.376	2.1	12.9	83.6	87.7	97.9	99.6	1.2
	2	1	B	2-1-B	6.24	2.376	1.8	12.6	85.9	87.8	98.2	99.7	1.2
	2	1	C	2-1-C	6.24	2.376	4.4	14.9	70.7	85.1	95.6	97.2	1.2
	2	1	D	2-1-D	6.24	2.376	4.4	14.9	70.6	85.4	95.6	97.3	1.2
	2	2	A	2-2-A									
	2	2	B	2-2-B									
Average					6.24	1.901	2.5	13.3	81.3	87.2	97.5	99.0	1.2
Standard Deviation					0.09	1.063	1.1	1.0	6.6	1.2	1.1	1.1	0.0
Coefficient of Variation					1.44	######	44.9	7.6	8.1	1.4	1.2	1.1	0.0
Max					6.34	2.376	4.4	14.9	85.9	88.1	98.2	99.7	1.2
Min					6.12	2.376	1.8	12.6	70.6	85.1	95.6	97.2	1.2
Range					0.22	0.000	2.6	2.3	15.2	3.0	2.6	2.6	0.0
Number of Replicates					5	5	8	8	8	8	8	8	8

Table 52. Section 26 bottom lift gyratory volumetrics summary (QA).

Section	Truck	Trailer	Spec ID	ample I	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmm	%Gmm	F/A
26	1	2	A	1-2-A	5.37	2.389	4.5	13.8	67.4	86.2	95.5	97.0	1.3
	1	2	B	1-2-B	5.37	2.389	3.6	13.0	72.0	86.6	96.4	97.8	1.3
	1	3	A	1-3-A	5.37	2.389	6.4	15.5	58.5	84.2	93.6	95.2	1.3
	1	3	B	1-3-B	5.37	2.389	5.8	15.0	61.2	84.3	94.2	95.9	1.3
	2	1	A	2-1-A	5.37	2.389	4.4	13.7	67.7	86.4	95.6	97.1	1.3
	2	1	B	2-1-B	5.37	2.389	4.2	13.5	69.1	86.3	95.8	97.3	1.3
	2	1	C	2-1-C	5.37	2.389	4.3	13.6	68.6	86.1	95.7	97.3	1.3
	2	1	D	2-1-D	5.37	2.389	4.2	13.5	69.1	86.1	95.8	97.4	1.3
	2	2	A	2-2-A	5.37	2.389	5.2	14.4	63.8	85.2	94.8	96.3	1.3
	2	2	B	2-2-B	5.37	2.389	4.3	13.6	68.6	86.2	95.7	97.2	1.3
Average					5.37	2.389	4.7	13.9	66.6	85.8	95.3	96.9	1.3
Standard Deviation					0.21	0.000	0.9	0.8	4.1	0.9	0.9	0.8	0.0
Coefficient of Variation					3.91	0.000	18.5	5.6	6.2	1.0	0.9	0.8	0.0
Max					5.57	2.389	6.4	15.5	72.0	86.6	96.4	97.8	1.3
Min					5.01	2.389	3.6	13.0	58.5	84.2	93.6	95.2	1.3
Range					0.56	0.000	2.8	2.5	13.5	2.4	2.8	2.6	0.0
Number of Replicates					5	5	10	10	10	10	10	10	10

Quality Control Volumetrics—Replacement Sections

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the SHRP Superpave HMA volumetric design method.

This WesTrack technical report provides information on the HMA Superpave gyratory compactor volumetrics obtained during construction of the WesTrack replacement sections. This information was obtained by technicians employed by FHWA and assigned to the agency's mobile HMA testing laboratory and by a Nevada Department of Transportation (DOT) technician assigned to the Western Regional Superpave Center. This information was used to adjust asphalt contents and gradations during the construction and is referred to as quality control data.

Due to difficulties in obtaining accurate asphalt binder contents during this quality control testing, additional laboratory testing was conducted on retained samples and the volumetric data were recalculated. The quality control volumetric data have been revised based on the corrected asphalt content information and new volumetric data determined and reported in WesTrack Technical Report UNR-11.[4] The quality assurance volumetrics are the most accurate values available and were used to develop the performance models.

BACKGROUND

The replacement sections were placed at WesTrack to repair failed sections initially constructed during September and October 1995, and to provide performance information on an additional coarse-graded Superpave mixture. Mixture design information is contained in WesTrack

Technical Report UNR-7.[5] These replacement sections were constructed during May and June 1997.

Prior to the start of production, the HMA production facility was calibrated. This calibration included determination of individual cold-feed rates for each aggregate, calibration of the scale belt, and calibration of the asphalt binder delivery system. During the placement of the hot mixes at WesTrack, additional calibrations were performed.

HMA "trial sections" were placed on the ramps to the test track on May 23 and 30, 1997, to determine the constructability of the HMA, and to determine the gradation, asphalt binder contents, and volumetrics. Additional trial sections were placed on the access road to WesTrack on June 20, 1997 (table 1). Adjustments in the amount of fines returned from the baghouse, in cold feeds to obtain the desired gradation, in asphalt binder content, and in the roller pattern to obtain the desired air void content were undertaken during the placement of these trial sections.

The "test lane" of the track was constructed on June 23 and 28, 1997 (table 1). The test lanes are the lanes on which the traffic was placed and the WesTrack performance information obtained.

SAMPLING

Superpave gyratory compaction was performed on samples of HMA obtained from loose, behind-the-paver samples. In each section loose HMA was obtained at five locations behind the paver for quality control and quality assurance testing. One of these five locations was selected for Superpave gyratory compaction during construction (quality control testing). The samples from this one location were split and used for both quality control and quality assurance testing. The detailed sampling and testing plan for the construction of the replacement sections can be found in WesTrack Technical Report UNR-19.[6]

TEST METHODS

The Superpave gyratory compactor was used to compact all field-mixed, laboratory-compacted samples during this quality control testing portion of the project. A single Pine Superpave gyratory compactor was used for the quality control testing. As indicated above, technicians from the FHWA and the Nevada DOT performed the gyratory compaction and the associated testing to determine the mixture volumetrics. The test methods used were those identified in reference 7 and summarized in table 2.

For each section, the theoretical maximum specific gravity was determined from a single sample with two test results. A single value was obtained for the asphalt binder content for each section. Three Superpave gyratory compacted samples were prepared for each section. The aggregate bulk specific gravity values reported in WesTrack Technical Report UNR-5, table 2, were used for the volumetric calculations. [8]

The asphalt contents reported during the quality control testing were obtained from an ignition oven calibrated with the WesTrack replacement mixture. Additional asphalt calibration work and additional samples were tested for asphalt binder content after construction was complete. The revised asphalt binder contents, based on additional sample testing, were used in the calculations to determine the volumetrics associated with the quality assurance testing. These corrected data are shown in WesTrack Technical Report UNR-11.[4] This quality assurance information was used for development of the performance models.

VOLUMETRIC TEST RESULTS

TRIAL SECTION PAVING

Asphalt contents, theoretical maximum specific gravities of the mixtures, and mixture volumetrics of field- mixed, laboratory-compacted (FMLC) samples are reported for the trial sections in table 3 and appendices A and B. In general, an increase in asphalt content was noted as the target asphalt content was increased. As expected, the theoretical maximum specific gravity decreased, the air void content decreased, and the voids filled with asphalt (VFA) increased with an increase in asphalt binder content.

Appendices A and B show the volumetric data in figures and include information on individual gyratory compacted samples. Adjustments in baghouse fines were made during placement of the trial sections in an attempt to control the volumetrics of the mixtures. Baghouse return plant settings are indicated on the figures in these appendices. In general, the removal of baghouse fines increased the air void content in the FMLC samples.

TEST SECTION PAVING

Asphalt contents, theoretical maximum specific gravities of the mixtures, and mixture volumetrics of FMLC samples are reported for the test sections in table 3 and appendices C, D, and E. In general, an increase in asphalt content was noted as the target asphalt content was increased. As expected, the theoretical maximum specific gravity decreased, the air void content decreased, and the VFA increased with an increase in asphalt binder content.

An examination of data for the test lane with the optimum asphalt binder content (table 4) (sections 35, 36, 39, and 54) indicates an air void content within the 3 to 5 percent required; voids in the mineral aggregate (VMA) in a range of 15 to 16 percent, which is above the 13 percent minimum required; and VFA within the desired range of 65 to 75 percent.

SUMMARY

Tables 3 and 4 present the Superpave gyratory volumetric data obtained during construction (quality control data). These data were used to adjust the gradations and asphalt binder contents during construction. These data should not be used for performance modeling because

corrections have been made based on adjustments in asphalt binder contents. WesTrack Technical Report UNR-11[4] should be used to obtain the corrected volumetric information.

REFERENCES

1. Epps, J., Monismith, C., Seeds, S., Alavi, S., Ashmore, C., Leahy, R., and Mitchell, T., "WesTrack Performance — Interim Findings," *Journal of the Association of Asphalt Paving Technologists*, Volume 67, 1998.

2. Epps, J., Monismith, C., Seeds, S., Alavi, S., Ashmore, C., and Mitchell, T., "WesTrack Full-Scale Test Track: Interim Findings," *Proceedings*, Eighth International Conference on Asphalt Pavements, Volume III, August 10-14, 1997, Seattle, WA.

3. "Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction," *Task G Interim Report*, Final Draft, WesTrack Team, March 1996.

4. Epps, J., Hand, A., and Sebaaly, P., "WesTrack Quality Assurance Volumetrics – Replacement Sections," WesTrack Technical Report UNR-11, July 2000.

5. Epps, J., Hand, A., and Sebaaly, P., "Hot-Mix Asphalt Mixture Design – Replacement Sections," WesTrack Technical Report UNR-7, July 2000.

6. Hand, A., and Epps, J., "WesTrack Replacement Sections Hot-Mix Asphalt Pre-Construction, Construction, and Post-Construction Materials Sampling and Testing Plan," WesTrack Technical Report UNR-19, February 2000.

7. McGennis, R.B., Anderson, R. M., Kennedy, J.W., and Solaimanian, M., "Background of Superpave Asphalt Mixture Design and Analysis," Publication No. FHWA-SA-95-003, Federal Highway Administration, Washington, D.C.

8. Epps, J., Hand, A., and Sebaaly, P., "WesTrack Aggregate Properties – Replacement Sections," WesTrack Technical Report UNR-5, July 2000.

Table 1. Construction schedule – replacement sections.

Date	Lift	Lane	Section Numbers
5-23-97	Bottom	Trial	35,37,38,39,55,56
5-30-97	Top	Trial	35,37,38,39,55,56
6-20-97	Bottom	Trial*	A,B,C
6-23-97	Bottom	Test	35,36,37,38,39,54,55,56
6-28-97	Top	Test	35,36,37,38,39,54,55,56

*Access road.

Table 2. Superpave gyratory compactor volumetric test methods.

Description	Designation	
	AASHTO	**ASTM**
Superpave gyratory compactor	TP 4	
Practice for volumetric analysis of compacted hot-mix asphalt (HMA)	PP 19	
Bulk specific gravity of compacted bituminous mixtures	T 166	D 2726
Maximum specific gravity of compacted bituminous mixtures	T 209	D 2041
Percent air voids in compacted dense-graded and open-graded paving mixtures	T 269	D 3203
Water sensitivity	TP 34 T 283	D 4867
Asphalt content by nuclear method	T 287	D 4125
Asphalt content by ignition method		D 6307
Specific gravity and absorption of fine aggregate	T 84	C 128
Specific gravity and absorption of coarse aggregate	T 85	C 127

Table 3. Construction quality control volumetrics – gyratory compaction coarse graded mixture (trial lane).

Compaction No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Theoretical Max. Specific Gravity	Air Void Content %	VMA %	VFA %	Fines to Asphalt Ratio
38 LM	Coarse	Top	5.0	4.87	2.477	8.3	16.8	50.9	1.4
		Bottom	5.0	6.55	2.440	5.3	16.9	68.7	1.4
56 LH	Coarse	Top	5.0	4.87	2.463	7.9	17.0	53.5	1.2
		Bottom	5.0	6.99	2.456	4.6	16.2	71.5	1.3
35 MM	Coarse	Top	5.7	5.49	2.444	6.9	17.3	60.0	1.6
		Bottom	5.7	7.12	2.435	4.1	16.5	75.4	1.1
36 MH	Coarse	Top	5.7						
		Bottom	5.7						
39 ML	Coarse	Top	5.7	5.49	2.452	7.7	17.7	56.7	1.2
		Bottom	5.7	6.74	2.428	3.9	16.3	76.1	1.1
54 MM	Coarse	Top	5.7						
		Bottom	5.7						
37 HM	Coarse	Top	6.4	6.11	2.434	6.7	18.0	63.0	1.1
		Bottom	6.4	7.36	2.432	4.5	17.2	73.8	1.3
55 HL	Coarse	Top	6.4	6.11	2.424	4.4	16.3	85.7	0.9
		Bottom	6.4	8.07	2.424	4.8	18.4	73.3	1.0

Table 4. Construction quality control volumetrics – gyratory compaction coarse graded mixture (test lane).

Compaction No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Theoretical Max. Specific Gravity	Air Void Content %	VMA %	VFA %	Fines to Asphalt Ratio
38 LM	Coarse	Top	5.0	5.15	2.459	4.1	13.9	70.7	1.44
		Bottom	5.0	5.42	2.451	5.0	15.3	67.0	1.21
56 LH	Coarse	Top	5.0	5.26	2.452	4.0	14.2	71.6	1.37
		Bottom	5.0	5.28	2.448	5.1	15.4	66.6	1.25
35 MM	Coarse	Top	5.7	5.87	2.429	4.3	15.8	72.8	1.1
		Bottom	5.7	5.71	2.433	4.6	15.8	70.9	1.02
36 MH	Coarse	Top	5.7	5.76	2.447	4.0	14.8	73.0	1.22
		Bottom	5.7	5.61	2.436	4.8	15.7	69.8	1.09
39 ML	Coarse	Top	5.7	5.75	2.441	5.3	16.1	67.8	1.17
		Bottom	5.7	5.58	2.424	4.1	15.6	73.5	0.94
54 MM	Coarse	Top	5.7	5.89	2.424	3.3	15.1	78.4	1.11
		Bottom	5.7	5.75	2.436	4.8	15.9	70.0	1.13
37 HM	Coarse	Top	6.4	6.14	2.417	3.9	16.2	75.8	1.05
		Bottom	6.4	6.06	2.407	3.6	16.6	85.2	0.97
55 HL	Coarse	Top	6.4	6.24	2.419	3.7	15.9	77.1	1.1
		Bottom	6.4	6.11	2.410	3.9	16.3	76.4	0.92

APPENDIX A

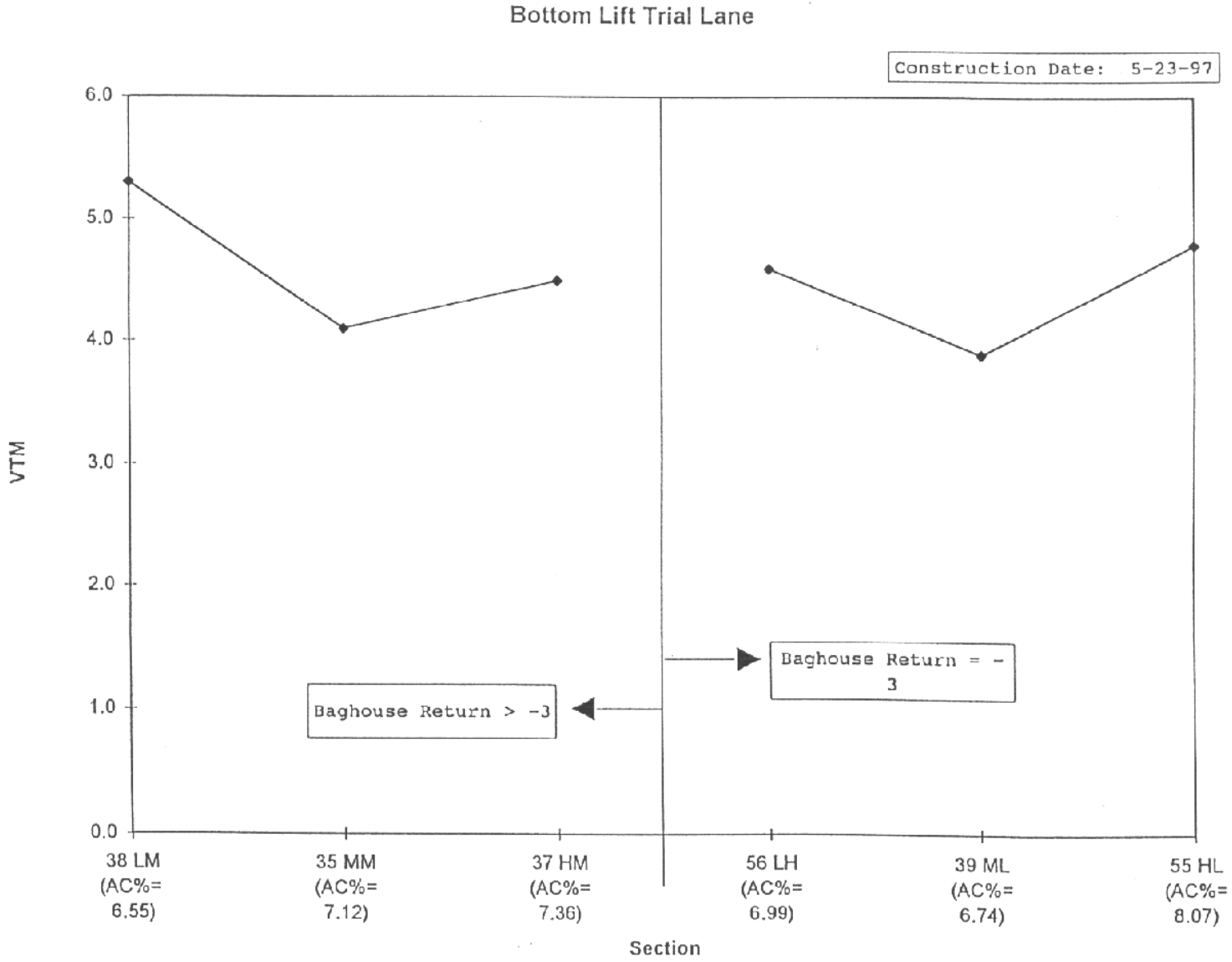
SUPERPAVE COMPACTOR VOLUMETRICS

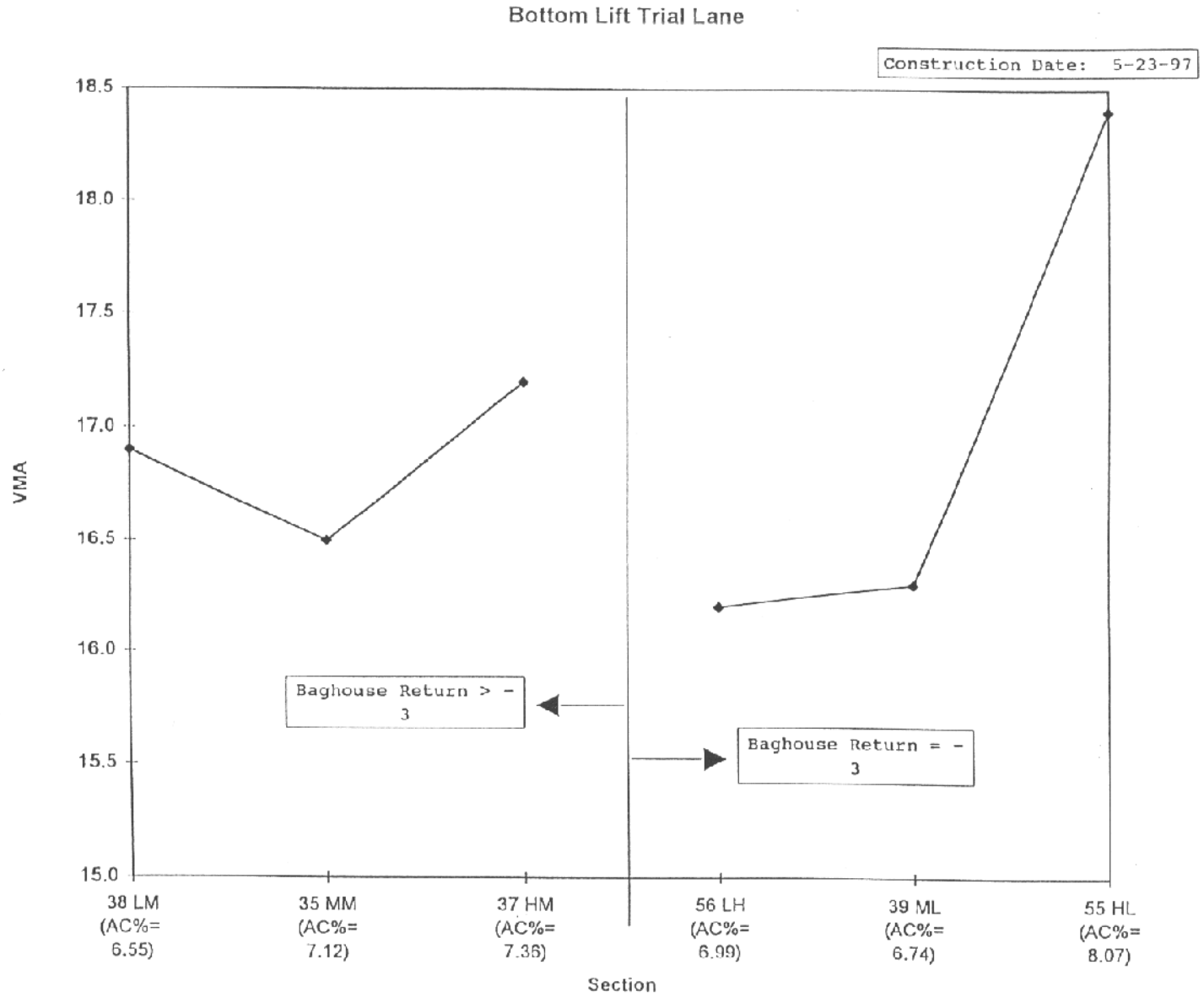
BOTTOM LIFT
TRIAL LANE
CONSTRUCTED MAY 23, 1997

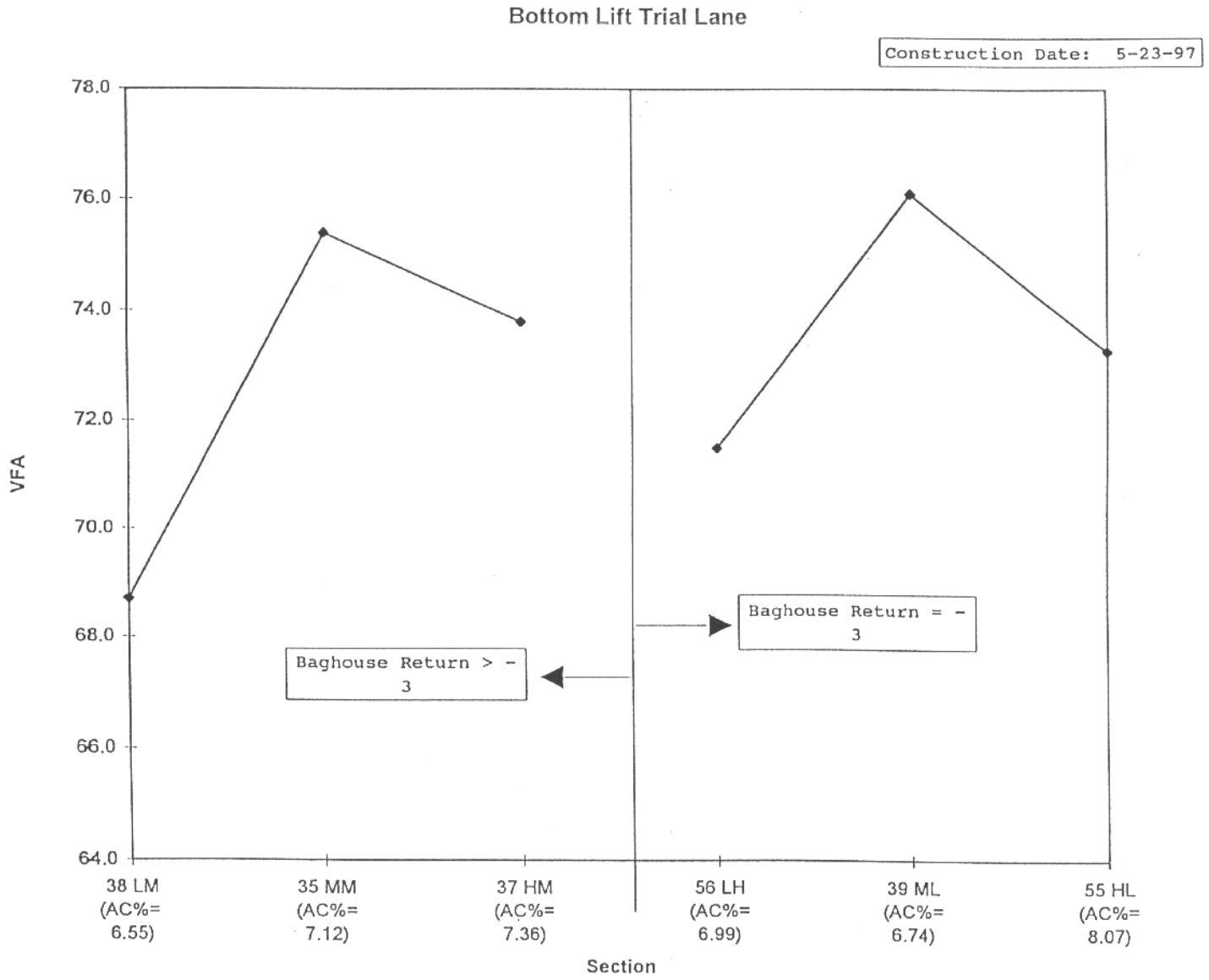
ASPHALT CONTENT AND GRADATION
DETERMINED BY IGNITION TEST

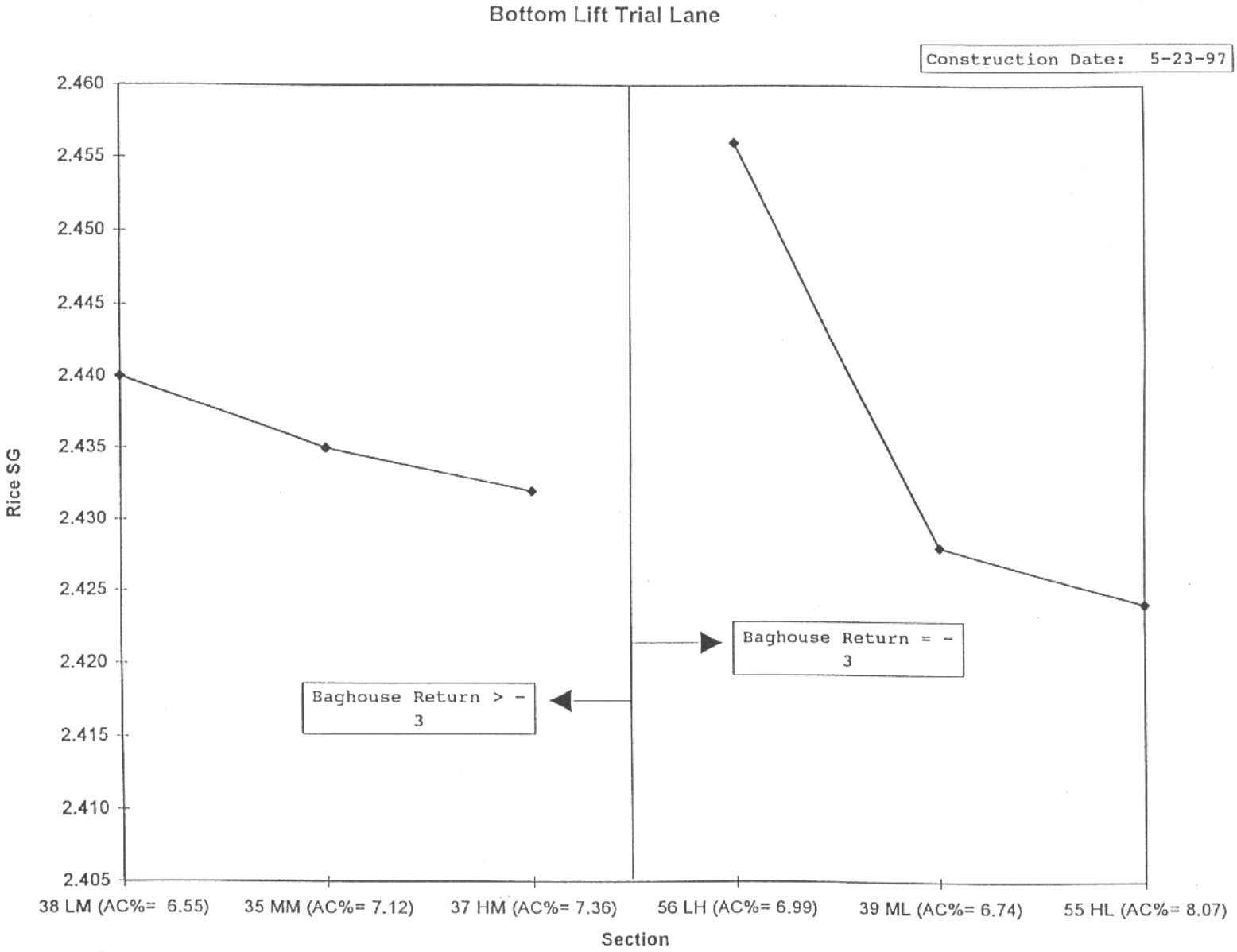
WesTrack - New Experiment Sections - Volumetric Data Summary
Trial Lane Bottom
Construction Date: 5-23-97

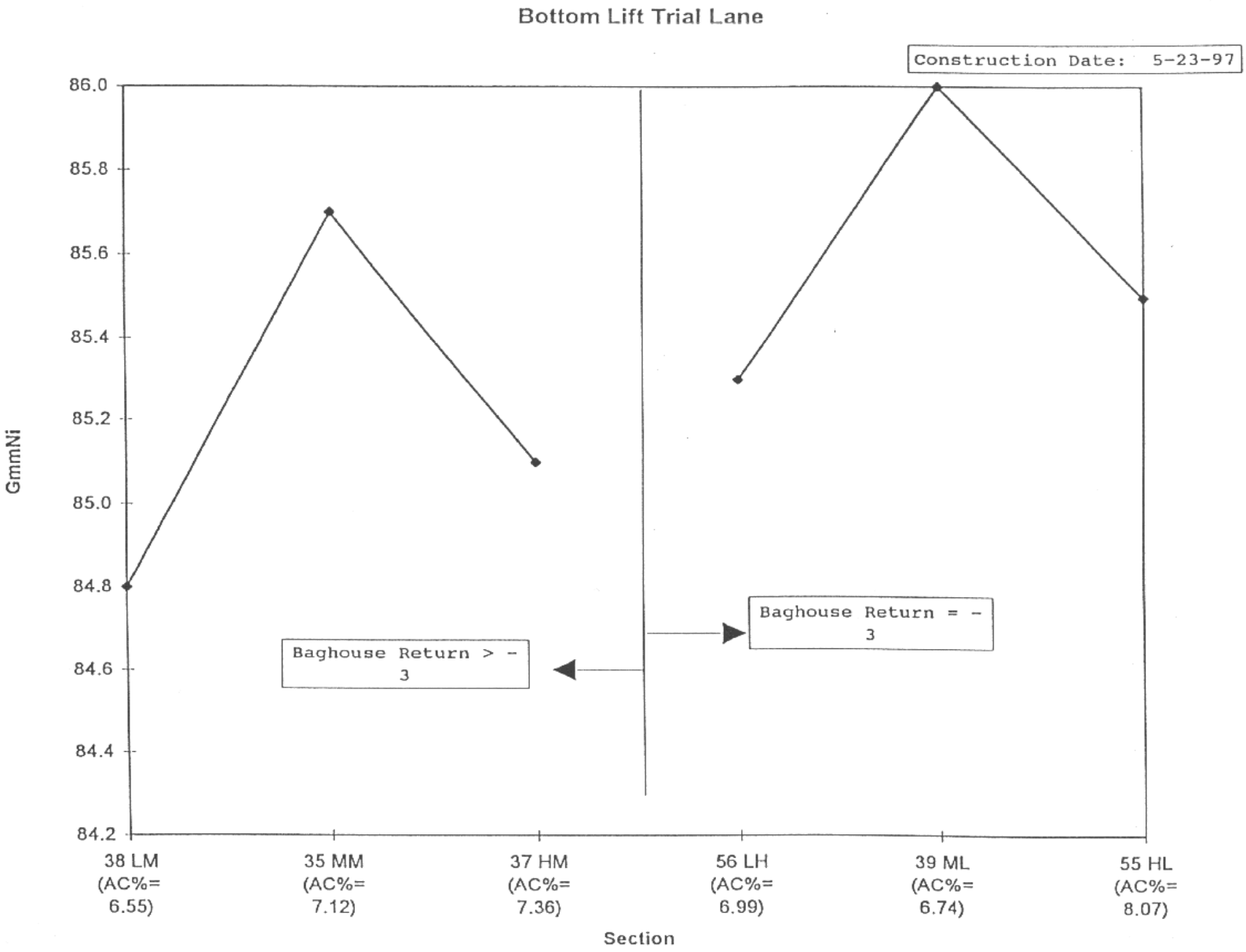
Baghouse Return Cont	Section	AC	VTM	VMA	VFA	Rice SG	% GmmNi	%GmmNm	F/A
0	38 LM (AC%= 6.55)	6.55	5.3	16.9	68.7	2.440	84.8	96.1	1.4
0	35 MM (AC%= 7.12)	7.12	4.1	16.5	75.4	2.435	85.7	97.5	1.1
0	37 HM (AC%= 7.36)	7.36	4.5	17.2	73.8	2.432	85.1	97.1	1.3
-1	56 LH (AC%= 6.99)	6.99	4.6	16.2	71.5	2.456	85.3	96.9	1.3
-1	39 ML (AC%= 6.74)	6.74	3.9	16.3	76.1	2.428	86.0	97.6	1.1
-1	55 HL (AC%= 8.07)	8.07	4.8	18.4	73.3	2.424	85.5	96.5	1

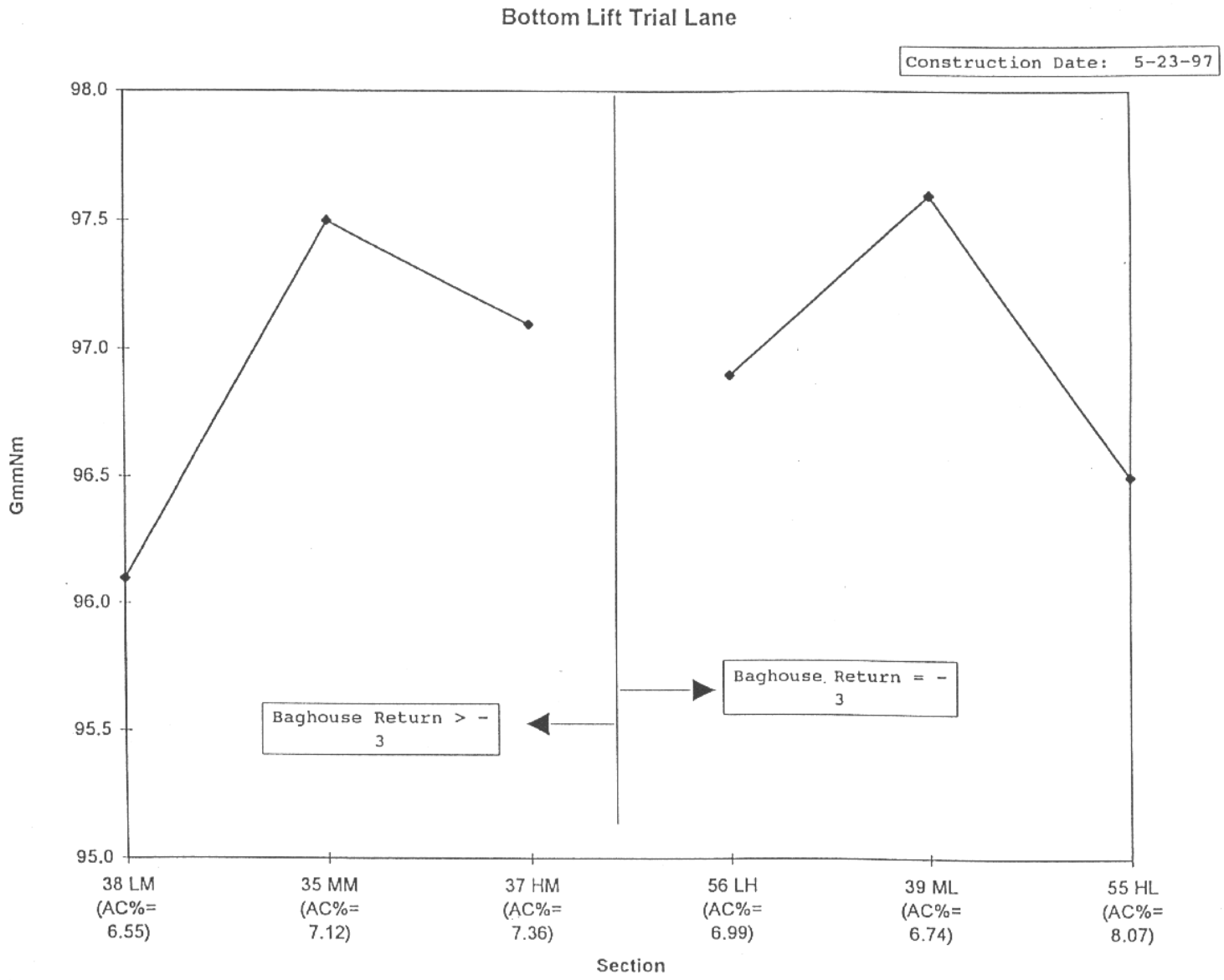

Bottom Lift Trial Lane
Construction Date: 5-23-97
6.0
5.0
4.0
3.0
2.0
1.0
0.0
VTM
Baghouse Return > -3
Baghouse Return = -3
38 LM (AC%= 6.55)
35 MM (AC%= 7.12)
37 HM (AC%= 7.36)
56 LH (AC%= 6.99)
39 ML (AC%= 6.74)
55 HL (AC%= 8.07)
Section

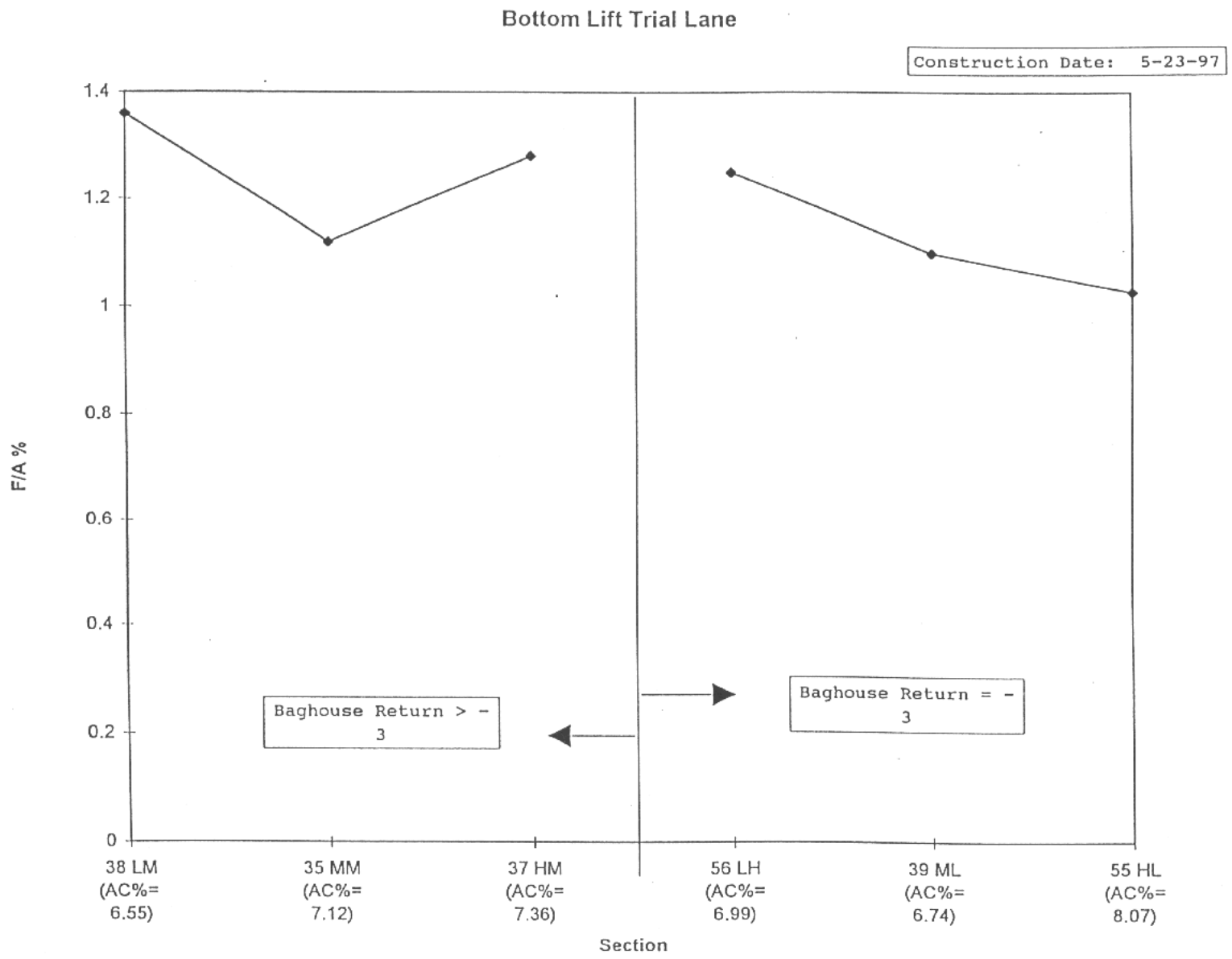

Bottom Lift Trial Lane
Construction Date: 5-23-97
18.5
18.0
17.5
17.0
16.5
16.0
15.5
15.0
VMA
Baghouse Return > - 3
Baghouse Return = - 3
38 LM (AC%= 6.55)
35 MM (AC%= 7.12)
37 HM (AC%= 7.36)
56 LH (AC%= 6.99)
39 ML (AC%= 6.74)
55 HL (AC%= 8.07)
Section


Bottom Lift Trial Lane
Construction Date: 5-23-97
78.0
76.0
74.0
72.0
70.0
68.0
66.0
64.0
VFA
Baghouse Return > -3
Baghouse Return = -3
38 LM (AC%= 6.55)
35 MM (AC%= 7.12)
37 HM (AC%= 7.36)
56 LH (AC%= 6.99)
39 ML (AC%= 6.74)
55 HL (AC%= 8.07)
Section


Bottom Lift Trial Lane
Construction Date: 5-23-97
Rice SG
2.460
2.455
2.450
2.445
2.440
2.435
2.430
2.425
2.420
2.415
2.410
2.405
Baghouse Return > -3
Baghouse Return = -3
38 LM (AC%= 6.55)
35 MM (AC%= 7.12)
37 HM (AC%= 7.36)
56 LH (AC%= 6.99)
39 ML (AC%= 6.74)
55 HL (AC%= 8.07)
Section


Bottom Lift Trial Lane
Construction Date: 5-23-97
GmmNi
86.0
85.8
85.6
85.4
85.2
85.0
84.8
84.6
84.4
84.2
Baghouse Return > -3
Baghouse Return = -3
38 LM (AC%= 6.55)
35 MM (AC%= 7.12)
37 HM (AC%= 7.36)
56 LH (AC%= 6.99)
39 ML (AC%= 6.74)
55 HL (AC%= 8.07)
Section


Bottom Lift Trial Lane
Construction Date: 5-23-97
98.0
97.5
97.0
96.5
96.0
95.5
95.0
GmmNm
Baghouse Return > -3
Baghouse Return = -3
38 LM (AC%= 6.55)
35 MM (AC%= 7.12)
37 HM (AC%= 7.36)
56 LH (AC%= 6.99)
39 ML (AC%= 6.74)
55 HL (AC%= 8.07)
Section


Bottom Lift Trial Lane
Construction Date: 5-23-97
F/A %
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Baghouse Return > -3
Baghouse Return = -3
38 LM (AC%= 6.55)
35 MM (AC%= 7.12)
37 HM (AC%= 7.36)
56 LH (AC%= 6.99)
39 ML (AC%= 6.74)
55 HL (AC%= 8.07)
Section

Gyratory Compaction Data Summary

Section:	56	N initial:	8	**Mixture Moisture Determination**	
Lift:	bottom	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	1	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4716.3	4744.3	4752.9
Weight in Wate	2732.1	2756.4	2781.1
SSD Weight	4723.6	4755.3	4761.8
BSG	2.368	2.373	2.400

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	6.99
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.740	% Agg by Total Weight of Mix (Ps):	93.01
Absorbed Asphalt (Pba):	2.05	Percent Passing #200 Sieve:	6.4
Effective AC Content (Pbe):	5.09	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.456

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4716.3	132.8	2345.6	2.011		1.039	2.088	85.0
2	4744.3	133.5	2357.9	2.012		1.038	2.089	85.1
3	4752.9	134.1	2368.5	2.007		1.051	2.110	85.9
Average	4737.8	133.5	2357.4	2.010		1.043	2.096	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4716.3	119	2101.8	2.244		1.039	2.330	5.1	16.6	69.2	94.9
2	4744.3	119.4	2108.9	2.250		1.038	2.336	4.9	16.4	70.2	95.1
3	4752.9	119.8	2116.0	2.246		1.051	2.362	3.8	15.5	75.2	96.2
Average	4737.8	119.4	2108.9	2.247		1.043	2.343				95.4

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4716.3	117.1	2068.3	2.280	2.368	1.039	2.368	96.4
2	4744.3	117.5	2075.3	2.286	2.373	1.038	2.373	96.6
3	4752.9	117.9	2082.4	2.282	2.400	1.051	2.400	97.7
Average	4737.8	117.5	2075.3	2.283	2.380	1.043	2.380	

Comments:

Gyratory Compaction Data Summary

Section:	55	N initial:	8	**Mixture Moisture Determination**	
Lift:	bottom	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	1	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4668.7	4695.4	4682.5
Weight in Wate	2680.9	2703.8	2679.3
SSD Weight	4675.2	4701.2	4690.4
BSG	2.341	2.351	2.328

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	8.07
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.750	% Agg by Total Weight of Mix (Ps):	91.93
Absorbed Asphalt (Pba):	2.17	Percent Passing #200 Sieve:	6.2
Effective AC Content (Pbe):	6.07	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.424

Properties at N Initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4668.7	132.1	2333.2	2.001		1.035	2.072	85.5
2	4695.4	132.5	2340.3	2.006		1.037	2.081	85.9
3	4682.5	132.8	2345.6	1.996		1.035	2.065	85.2
Average	4682.2	132.5	2339.7	2.001		1.036	2.073	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4668.7	118.6	2094.8	2.229		1.035	2.307	4.8	18.4	73.8	95.2
2	4695.4	119	2101.8	2.234		1.037	2.317	4.4	18.0	75.6	95.6
3	4682.5	119.5	2110.7	2.218		1.035	2.295	5.3	18.8	71.8	94.7
Average	4682.2	119.0	2102.4	2.227		1.036	2.307				95.2

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4668.7	116.9	2064.7	2.261	2.341	1.035	2.341	96.6
2	4695.4	117.3	2071.8	2.266	2.351	1.037	2.351	97.0
3	4682.5	117.8	2080.6	2.251	2.328	1.035	2.328	96.1
Average	4682.2	117.3	2072.4	2.259	2.340	1.036	2.340	

Comments:

Gyratory Compaction Data Summary

Section:	39	N initial:	8	**Mixture Moisture Determination**	
Lift:	bottom	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	1	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4696.6	4715.6	4670.1
Weight in Wate	2722	2732.5	2700.3
SSD Weight	4703.2	4718.9	4674.4
BSG	2.371	2.374	2.366

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	6.74
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.691	% Agg by Total Weight of Mix (Ps):	93.26
Absorbed Asphalt (Pba):	1.36	Percent Passing #200 Sieve:	6.1
Effective AC Content (Pbe):	5.47	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.428

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4696.6	131.4	2320.9	2.024		1.032	2.089	86.0
2	4715.6	131.5	2322.6	2.030		1.029	2.089	86.0
3	4670.1	130.4	2303.2	2.028		1.030	2.088	86.0
Average	4694.1	131.1	2315.6	2.027		1.030	2.089	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4696.6	117.6	2077.1	2.261		1.032	2.334	3.9	16.2	76.2	96.1
2	4715.6	117.5	2075.3	2.272		1.029	2.338	3.7	16.1	76.9	96.3
3	4670.1	116.9	2064.7	2.262		1.030	2.329	4.1	16.4	75.2	95.9
Average	4694.1	117.3	2072.4	2.265		1.030	2.334				96.1

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4696.6	115.8	2045.3	2.296	2.371	1.032	2.371	97.6
2	4715.6	115.7	2043.6	2.308	2.374	1.029	2.374	97.8
3	4670.1	115.1	2033.0	2.297	2.366	1.030	2.366	97.4
Average	4694.1	115.5	2040.6	2.300	2.370	1.030	2.370	

Comments:

Gyratory Compaction Data Summary

Section:	38	N initial:	8	**Mixture Moisture Determination**	
Lift:	bottom	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	1	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4768.5	4762.7	
Weight in Wate	2746.9	2732.3	
SSD Weight	4775.5	4766.7	
BSG	2.351	2.341	#DIV/0!

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	6.55
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.698	% Agg by Total Weight of Mix (Ps):	93.45
Absorbed Asphalt (Pba):	1.46	Percent Passing #200 Sieve:	7.0
Effective AC Content (Pbe):	5.19	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.440

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4768.5	135.1	2386.2	1.998		1.037	2.072	84.9
2	4762.7	134.3	2372.1	2.008		1.030	2.067	84.7
Average	4765.6	134.7	2379.1	2.003		1.033	2.070	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4768.5	121	2137.2	2.231		1.037	2.314	5.2	16.8	69.2	94.8
2	4762.7	120.3	2124.8	2.241		1.030	2.308	5.4	17.0	68.2	94.6
Average	4765.6	120.7	2131.0	2.236		1.033	2.311				94.7

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4768.5	119.1	2103.6	2.267	2.351	1.037	2.351	96.3
2	4762.7	118.6	2094.8	2.274	2.341	1.030	2.341	95.9
Average	4765.6	118.9	2099.2	2.270	2.346	1.033	2.346	

Comments:

Gyratory Compaction Data Summary

Section:	35	N Initial:	8	**Mixture Moisture Determination**	
Lift:	bottom	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	1	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4990.6	4966.5	4650.8
Weight in Wate	2896	2877.2	2694.7
SSD Weight	4998.7	4971.1	4654
BSG	2.373	2.372	2.374

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	7.12
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.718	% Agg by Total Weight of Mix (Ps):	92.88
Absorbed Asphalt (Pba):	1.74	Percent Passing #200 Sieve:	6.2
Effective AC Content (Pbe):	5.50	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.435

Properties at N Initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4990.6	140.3	2478.0	2.014		1.035	2.084	85.6
2	4966.5	139.1	2456.9	2.021		1.034	2.091	85.9
3	4650.8	130.3	2301.4	2.021		1.033	2.088	85.7
Average	4869.3	136.6	2412.1	2.019		1.034	2.087	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4990.6	125.2	2211.3	2.257		1.035	2.336	4.1	16.5	75.3	95.9
2	4966.5	124.5	2199.0	2.259		1.034	2.336	4.1	16.5	75.3	95.9
3	4650.8	116.4	2055.9	2.262		1.033	2.337	4.0	16.5	75.6	96.0
Average	4869.3	122.0	2155.4	2.259		1.034	2.336				95.9

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4990.6	123.2	2176.0	2.293	2.373	1.035	2.373	97.5
2	4966.5	122.6	2165.4	2.294	2.372	1.034	2.372	97.4
3	4650.8	114.6	2024.1	2.298	2.374	1.033	2.374	97.5
Average	4869.3	120.1	2121.9	2.295	2.373	1.034	2.373	

Comments:

APPENDIX B

SUPERPAVE COMPACTOR VOLUMETRICS

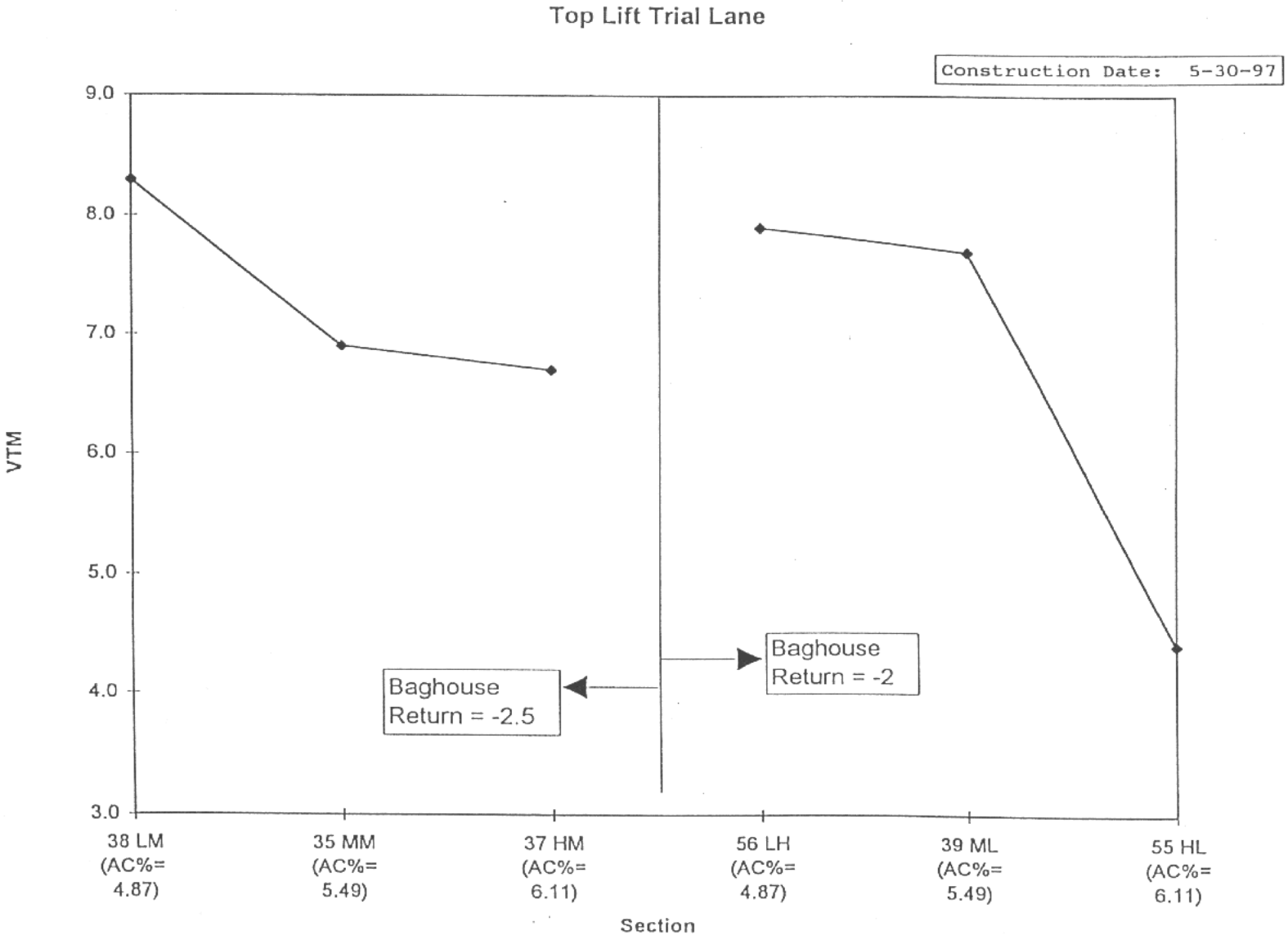
TOP LIFT
TRIAL LANE
CONSTRUCTED MAY 30, 1997

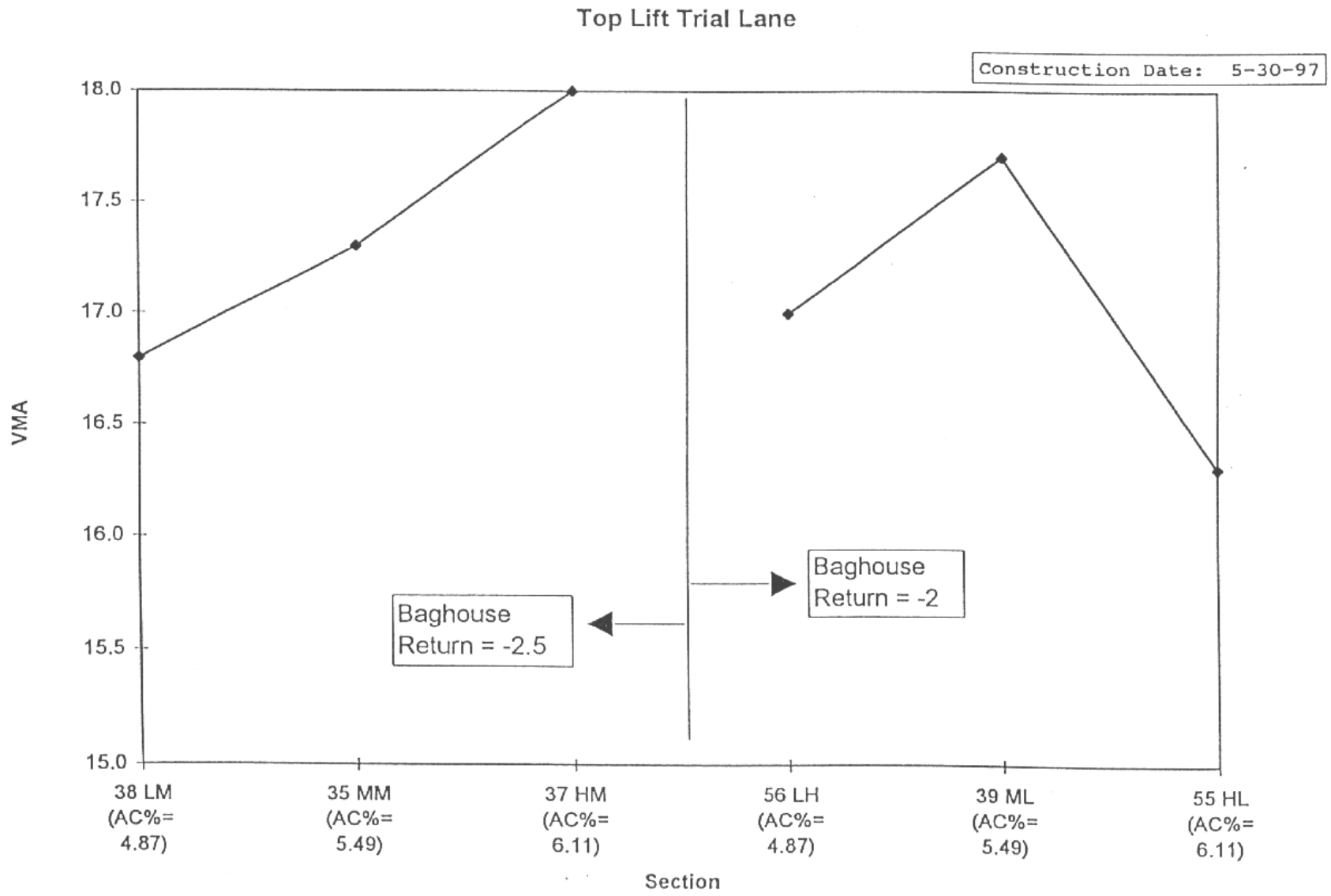
ASPHALT CONTENT AND GRADATION DETERMINED BY IGNITION TEST

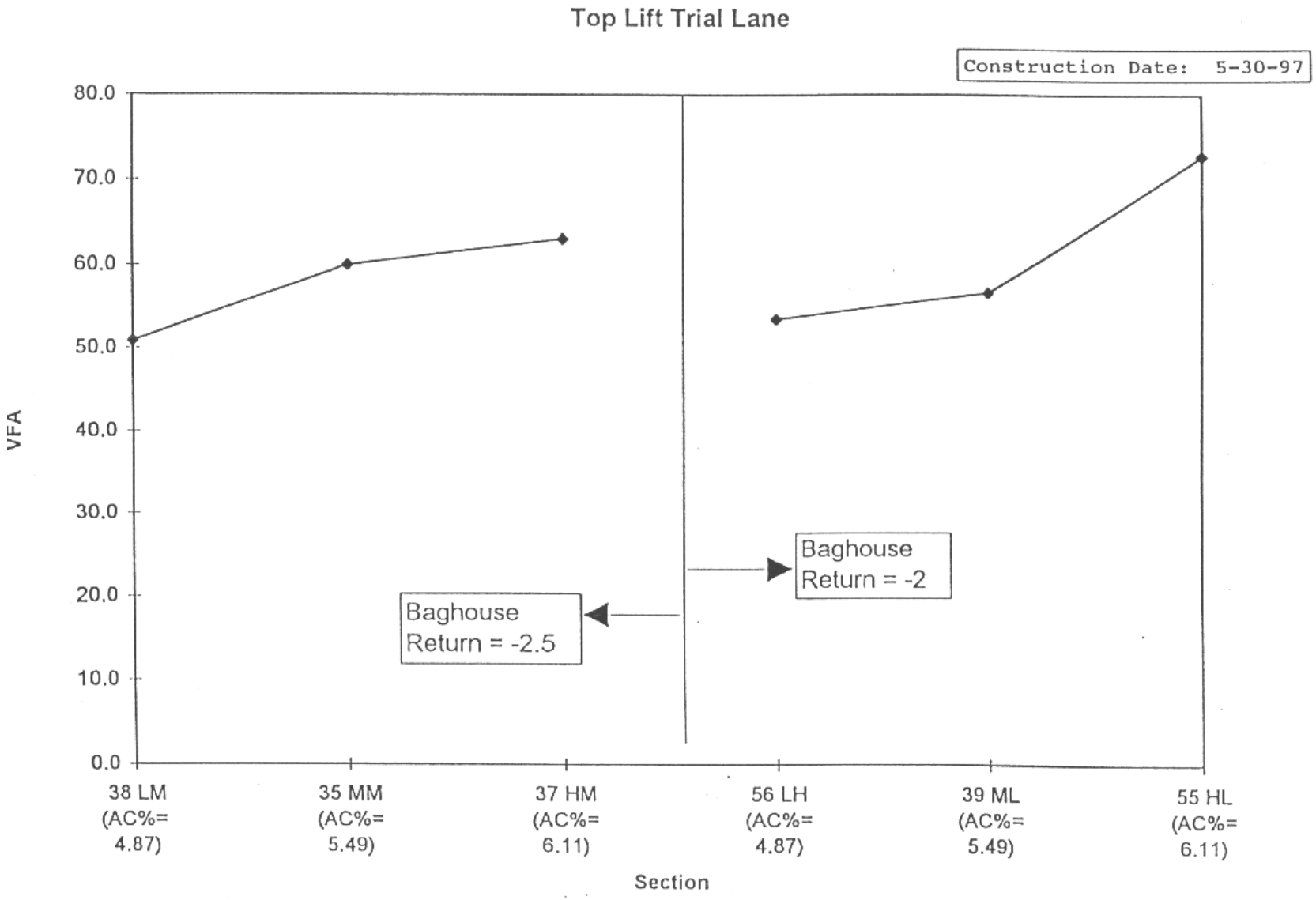
WesTrack - New Experiment Sections - Volumetric Data Summary
Trial Lane Top
Construction Date: 5-30-97

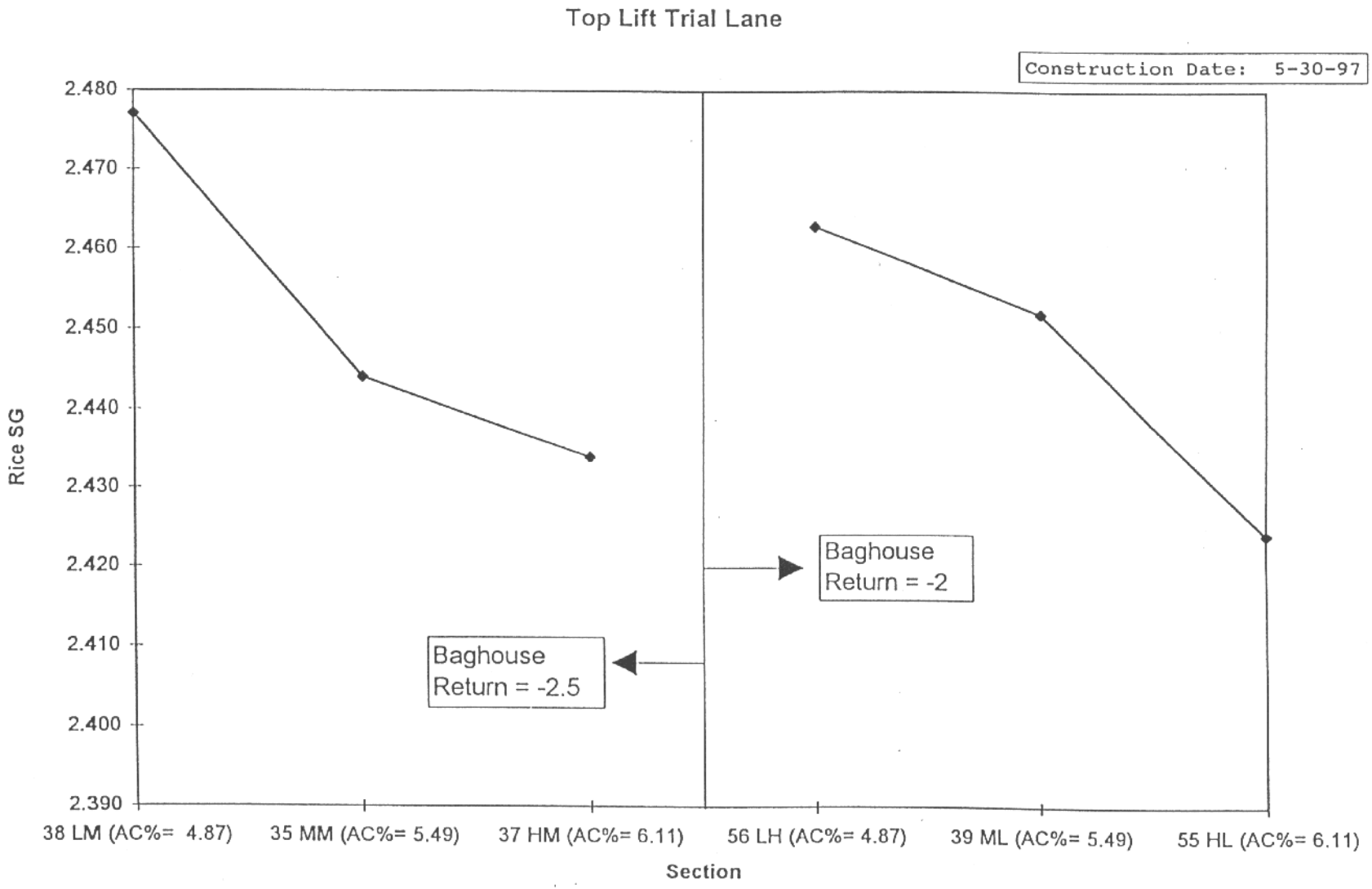
TWM

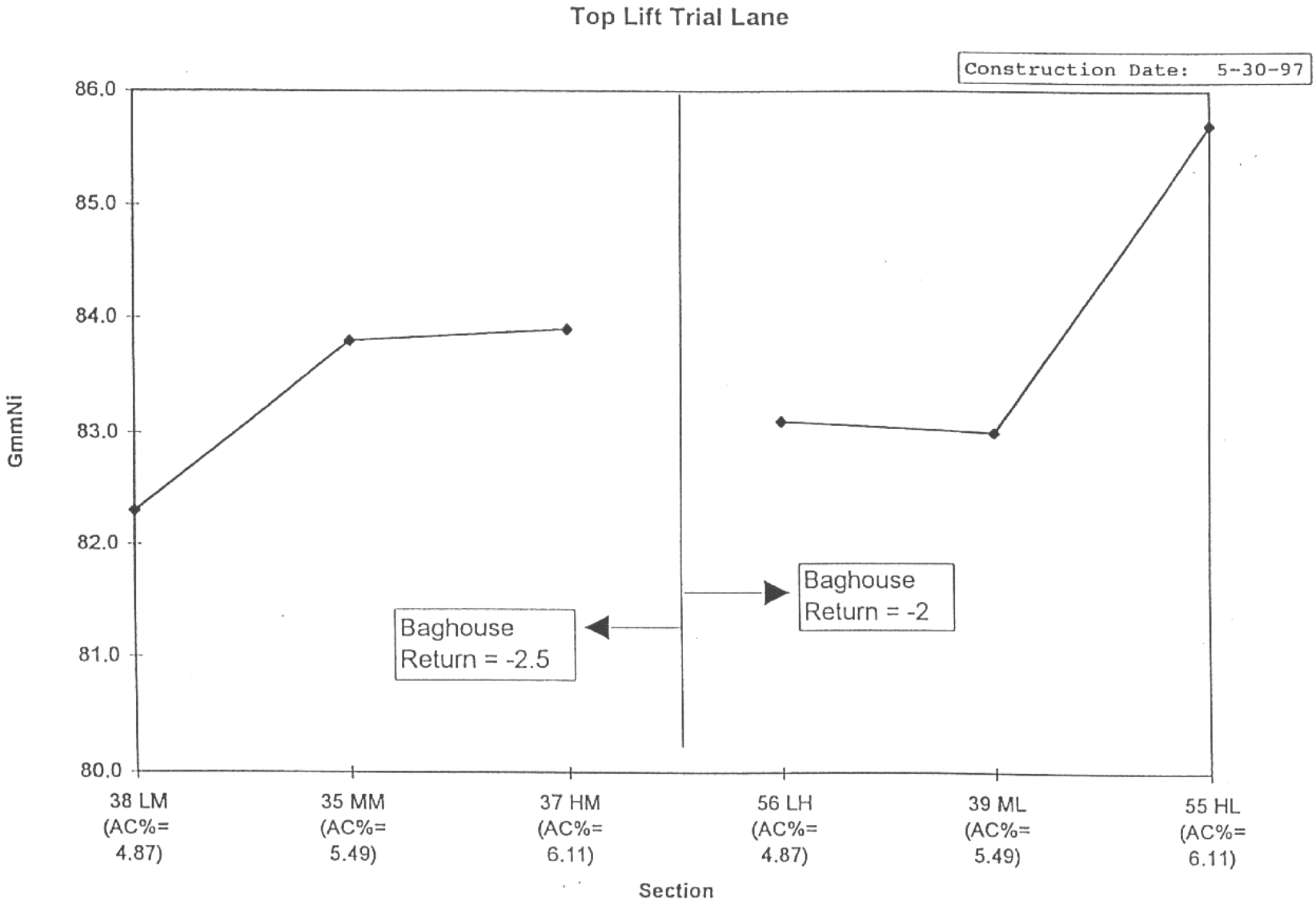
Baghouse Return Cont	Section	AC	VTM	VMA	VFA	Rice SG	% GmmNi	%GmmNm	F/A
	38 LM (AC%= 4.87)	4.87	8.3	16.8	50.9	2.477	82.3	93.2	1.4
	35 MM (AC%= 5.49)	5.49	6.9	17.3	60.0	2.444	83.8	94.5	1.6
	37 HM (AC%= 6.11)	6.1	6.7	18.0	63.0	2.434	83.9	94.7	1.1
	56 LH (AC%= 4.87)	4.87	7.9	17.0	53.5	2.463	83.1	93.6	1.2
	39 ML (AC%= 5.49)	5.5	7.7	17.7	56.7	2.452	83.0	93.7	1.2
	55 HL (AC%= 6.11)	6.1	4.4	16.3	72.8	2.424	85.7	97.0	0.9

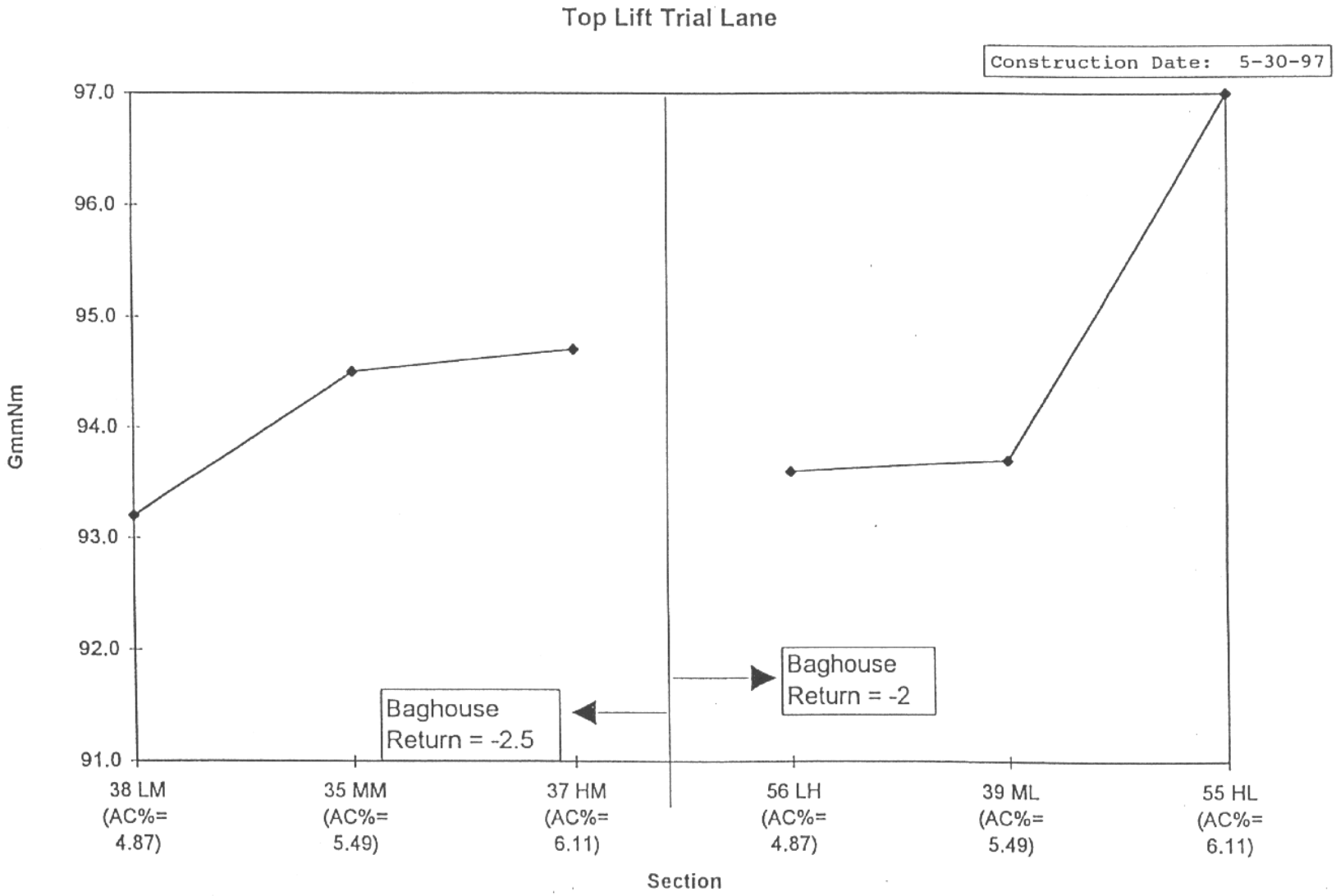

Top Lift Trial Lane
Construction Date: 5-30-97
VTM
9.0
8.0
7.0
6.0
5.0
4.0
3.0
Baghouse Return = -2.5
Baghouse Return = -2
38 LM (AC%= 4.87)
35 MM (AC%= 5.49)
37 HM (AC%= 6.11)
56 LH (AC%= 4.87)
39 ML (AC%= 5.49)
55 HL (AC%= 6.11)
Section

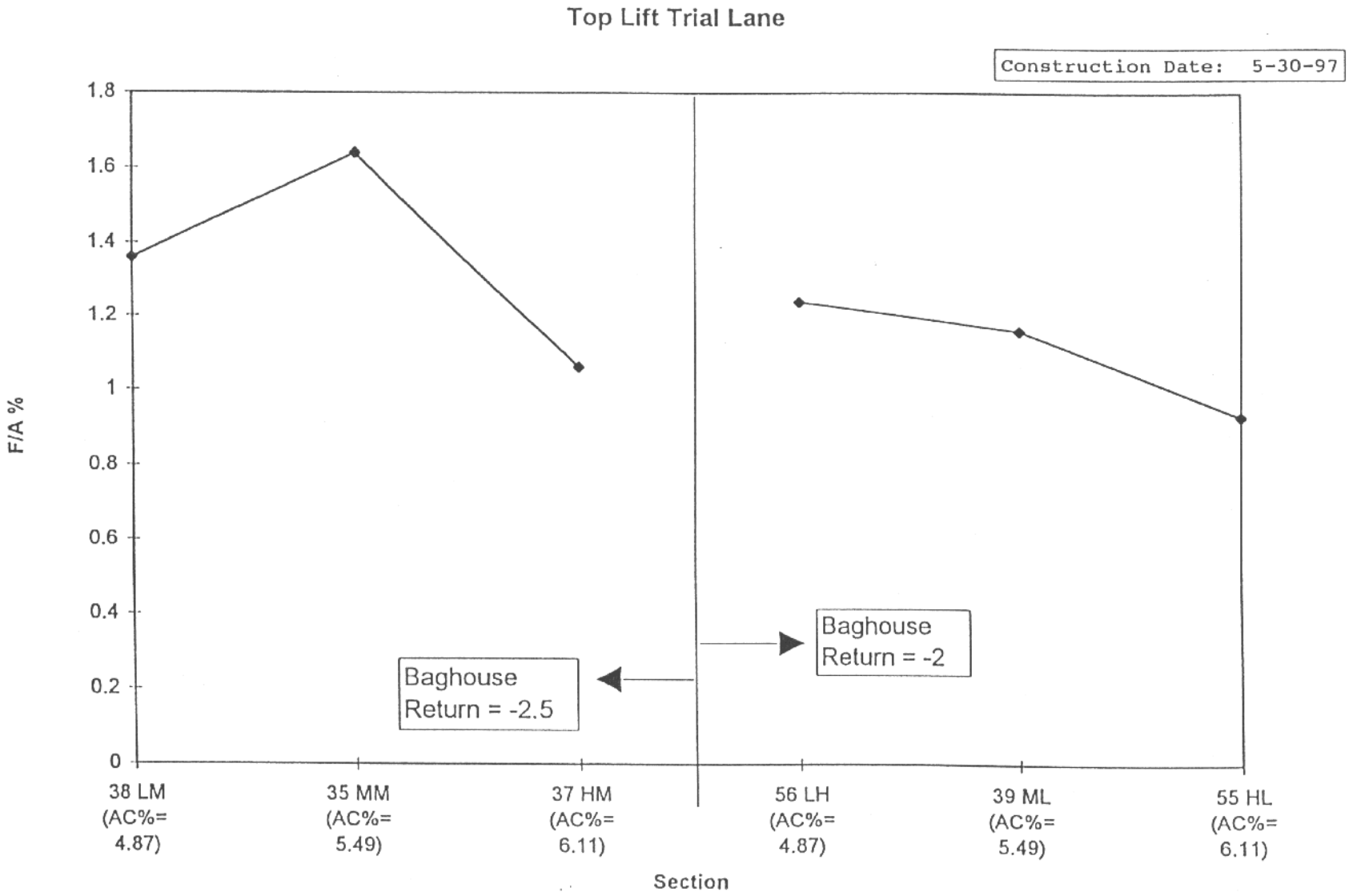

Top Lift Trial Lane
Construction Date: 5-30-97
18.0
17.5
17.0
16.5
16.0
15.5
15.0
VMA
Baghouse
Return = -2.5
Baghouse
Return = -2
38 LM
(AC%=
4.87)
35 MM
(AC%=
5.49)
37 HM
(AC%=
6.11)
56 LH
(AC%=
4.87)
39 ML
(AC%=
5.49)
55 HL
(AC%=
6.11)
Section


Top Lift Trial Lane
Construction Date: 5-30-97
VFA
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Baghouse
Return = -2.5
Baghouse
Return = -2
38 LM
(AC%=
4.87)
35 MM
(AC%=
5.49)
37 HM
(AC%=
6.11)
56 LH
(AC%=
4.87)
39 ML
(AC%=
5.49)
55 HL
(AC%=
6.11)
Section


Top Lift Trial Lane
Construction Date: 5-30-97
Rice SG
2.480
2.470
2.460
2.450
2.440
2.430
2.420
2.410
2.400
2.390
Baghouse
Return = -2.5
Baghouse
Return = -2
38 LM (AC%= 4.87)
35 MM (AC%= 5.49)
37 HM (AC%= 6.11)
56 LH (AC%= 4.87)
39 ML (AC%= 5.49)
55 HL (AC%= 6.11)
Section


Top Lift Trial Lane
Construction Date: 5-30-97
GmmNi
86.0
85.0
84.0
83.0
82.0
81.0
80.0
Baghouse
Return = -2.5
Baghouse
Return = -2
38 LM
(AC%=
4.87)
35 MM
(AC%=
5.49)
37 HM
(AC%=
6.11)
56 LH
(AC%=
4.87)
39 ML
(AC%=
5.49)
55 HL
(AC%=
6.11)
Section


Top Lift Trial Lane
Construction Date: 5-30-97
GmmNm
97.0
96.0
95.0
94.0
93.0
92.0
91.0
Baghouse
Return = -2.5
Baghouse
Return = -2
38 LM
(AC%=
4.87)
35 MM
(AC%=
5.49)
37 HM
(AC%=
6.11)
56 LH
(AC%=
4.87)
39 ML
(AC%=
5.49)
55 HL
(AC%=
6.11)
Section


Top Lift Trial Lane
Construction Date: 5-30-97
F/A %
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Baghouse Return = -2.5
Baghouse Return = -2
38 LM (AC%= 4.87)
35 MM (AC%= 5.49)
37 HM (AC%= 6.11)
56 LH (AC%= 4.87)
39 ML (AC%= 5.49)
55 HL (AC%= 6.11)
Section

Gyratory Compaction Data Summary

Section:	35	N initial:	8	**Mixture Moisture Determination**	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	2	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4732	4651.8	4664.3
Weight in Wate	2691.7	2642.6	2658.9
SSD Weight	4740.6	4662	4675.2
BSG	2.310	2.304	2.313

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	5.49
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.655	% Agg by Total Weight of Mix (Ps):	94.51
Absorbed Asphalt (Pba):	0.84	Percent Passing #200 Sieve:	7.7
Effective AC Content (Pbe):	4.70	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.444

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4732	134.5	2375.6	1.992		1.028	2.049	83.8
2	4651.8	132.5	2340.3	1.988		1.029	2.045	83.7
3	4664.3	133.9	2365.0	1.972		1.040	2.051	83.9
Average	4682.7	133.6	2360.3	1.984		1.032	2.048	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4732.0	121.1	2138.9	2.212		1.028	2.275	6.9	17.3	60.0	93.1
2	4651.8	119.3	2107.1	2.208		1.029	2.271	7.1	17.4	59.3	92.9
3	4664.3	120.5	2128.3	2.192		1.040	2.279	6.8	17.1	60.5	93.2
Average	4682.7	120.3	2124.8	2.204		1.032	2.275				93.1

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4732.0	119.3	2107.1	2.246	2.310	1.028	2.310	94.5
2	4651.8	117.6	2077.1	2.240	2.304	1.029	2.304	94.3
3	4664.3	118.7	2096.5	2.225	2.313	1.040	2.313	94.7
Average	4682.7	118.5	2093.6	2.237	2.309	1.032	2.309	

Comments:

Gyratory Compaction Data Summary

Section:	37	N initial:	8	**Mixture Moisture Determination**	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	2	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4680.7	4724.8	4497.8
Weight in Wate	2677.5	2697.3	2530.3
SSD Weight	4687.7	4731.2	4518.2
BSG	2.328	2.323	2.263

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	6.11
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.670	% Agg by Total Weight of Mix (Ps):	93.89
Absorbed Asphalt (Pba):	1.06	Percent Passing #200 Sieve:	5.4
Effective AC Content (Pbe):	5.12	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.434

Properties at N Initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4680.7	133.7	2361.5	1.982		1.039	2.059	84.6
2	4724.8	134.1	2368.5	1.995		1.032	2.058	84.6
3	4497.8	129.7	2290.8	1.963		1.024	2.011	82.6
Average	4634.4	132.5	2340.3	1.980		1.032	2.043	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4680.7	120	2119.5	2.208		1.039	2.294	5.8	17.1	66.3	94.2
2	4724.8	120.6	2130.1	2.218		1.032	2.288	6.0	17.3	65.5	94.0
3	4497.8	116.9	2064.7	2.178		1.024	2.232	8.3	19.4	57.1	91.7
Average	4634.4	119.2	2104.8	2.202		1.032	2.271				93.3

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4680.7	118.2	2087.7	2.242	2.328	1.039	2.328	95.7
2	4724.8	118.8	2098.3	2.252	2.323	1.032	2.323	95.4
3	4497.8	115.3	2036.5	2.209	2.263	1.024	2.263	93.0
Average	4634.4	117.4	2074.2	2.234	2.305	1.032	2.305	

Comments:

Gyratory Compaction Data Summary

Section:	38	N initial:	8	**Mixture Moisture Determination**	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	2	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4671.7	4646.4	4598.8
Weight in Wate	2668.7	2650.6	2619.3
SSD Weight	4684.7	4661.9	4619.9
BSG	2.317	2.310	2.299

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	4.87
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.668	% Agg by Total Weight of Mix (Ps):	95.13
Absorbed Asphalt (Pba):	1.03	Percent Passing #200 Sieve:	5.3
Effective AC Content (Pbe):	3.89	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.477

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4671.7	134.3	2372.1	1.969		1.037	2.043	82.5
2	4646.4	134	2366.8	1.963		1.039	2.039	82.3
3	4598.8	133.9	2365.0	1.945		1.044	2.031	82.0
Average	4639.0	134.1	2368.0	1.959		1.040	2.038	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4671.7	120.3	2124.8	2.199		1.037	2.281	7.9	16.5	52.0	92.1
2	4646.4	120.2	2123.0	2.189		1.039	2.274	8.2	16.8	51.1	91.8
3	4598.8	120.2	2123.0	2.166		1.044	2.262	8.7	17.2	49.6	91.3
Average	4639.0	120.2	2123.6	2.184		1.040	2.272				91.7

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4671.7	118.4	2091.2	2.234	2.317	1.037	2.317	93.6
2	4646.4	118.3	2089.5	2.224	2.310	1.039	2.310	93.3
3	4598.8	118.3	2089.5	2.201	2.299	1.044	2.299	92.8
Average	4639.0	118.3	2090.1	2.220	2.309	1.040	2.309	

Comments:

Gyratory Compaction Data Summary

Section:	39	N initial:	8	**Mixture Moisture Determination**	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	2	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4684.1	4679.8	4620.7
Weight in Wate	2657.9	2662	2611.5
SSD Weight	4690.9	4691.6	4633
BSG	2.304	2.306	2.286

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	5.49
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.665	% Agg by Total Weight of Mix (Ps):	94.51
Absorbed Asphalt (Pba):	0.98	Percent Passing #200 Sieve:	5.3
Effective AC Content (Pbe):	4.56	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.452

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4684.1	134.9	2382.7	1.966		1.036	2.036	83.0
2	4679.8	134.7	2379.1	1.967		1.038	2.042	83.3
3	4620.7	133.5	2357.9	1.960		1.035	2.029	82.7
Average	4661.5	134.4	2373.3	1.964		1.036	2.036	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4684.1	121	2137.2	2.192		1.036	2.270	7.4	17.5	57.4	92.6
2	4679.8	121.1	2138.9	2.188		1.038	2.272	7.4	17.4	57.7	92.6
3	4620.7	120.3	2124.8	2.175		1.035	2.252	8.2	18.1	54.9	91.8
Average	4661.5	120.8	2133.6	2.185		1.036	2.264				92.3

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4684.1	119.2	2105.4	2.225	2.304	1.036	2.304	94.0
2	4679.8	119.3	2107.1	2.221	2.306	1.038	2.306	94.0
3	4620.7	118.5	2093.0	2.208	2.286	1.035	2.286	93.2
Average	4661.5	119.0	2101.8	2.218	2.299	1.036	2.299	

Comments:

Gyratory Compaction Data Summary

Section:	55	N initial:	8	**Mixture Moisture Determination**	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	2	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4786.6	4742.1	4738.3
Weight in Wate	2764.3	2721.9	2726
SSD Weight	4789	4745.5	4742.6
BSG	2.364	2.343	2.350

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	6.11
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.657	% Agg by Total Weight of Mix (Ps):	93.89
Absorbed Asphalt (Pba):	0.87	Percent Passing #200 Sieve:	4.9
Effective AC Content (Pbe):	5.29	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.424

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4786.6	133.8	2359.7	2.028		1.028	2.085	86.0
2	4742.1	134	2366.8	2.004		1.033	2.069	85.3
3	4738.3	133.3	2354.4	2.013		1.034	2.082	85.9
Average	4755.7	133.6	2360.3	2.015		1.032	2.078	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4786.6	119.6	2112.4	2.266		1.028	2.329	3.9	15.9	75.2	96.1
2	4742.1	120.2	2123.0	2.234		1.033	2.306	4.9	16.7	70.9	95.1
3	4738.3	119.9	2117.7	2.237		1.034	2.314	4.5	16.4	72.4	95.5
Average	4755.7	119.9	2117.7	2.246		1.032	2.316				95.6

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4786.6	117.8	2080.6	2.301	2.364	1.028	2.364	97.5
2	4742.1	118.3	2089.5	2.270	2.343	1.033	2.343	96.7
3	4738.3	118.1	2085.9	2.272	2.350	1.034	2.350	96.9
Average	4755.7	118.1	2085.4	2.281	2.352	1.032	2.352	

Comments:

Gyratory Compaction Data Summary

Section:	56	N initial:	8	**Mixture Moisture Determination**	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	trial	N max:	152	Dry Weight of Mix:	
Paving Day:	2	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C):	140		

	Specimen ID		
	1	2	3
Dry Mass	4632.3	4663.8	4650.2
Weight in Wate	2631.5	2653.3	2645.3
SSD Weight	4646.8	4673.6	4661
BSG	2.299	2.308	2.307

Specific Gravity of AC (Gb):	1.032	% AC by Total Weight of Mix (Pb):	4.87
Bulk Dry Specific Gravity of Agg (Gsb):	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity of Agg (Gse):	2.651	% Agg by Total Weight of Mix (Ps):	95.13
Absorbed Asphalt (Pba):	0.78	Percent Passing #200 Sieve:	5.1
Effective AC Content (Pbe):	4.13	Filler/Effective AC Ratio (F/A):	
Specimen Diameter (mm):	150	Maximum Specific Gravity (Gmm):	2.463

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4632.3	133.4	2356.2	1.966		1.039	2.044	83.0
2	4663.8	134.2	2370.3	1.968		1.040	2.047	83.1
3	4650.2	132.9	2347.3	1.981		1.036	2.052	83.3
Average	4648.8	133.5	2357.9	1.972		1.039	2.047	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4632.3	120.5	2128.3	2.176		1.039	2.262	8.1	17.2	52.6	91.9
2	4663.8	120.9	2135.4	2.184		1.040	2.272	7.7	16.8	54.0	92.3
3	4650.2	120	2119.5	2.194		1.036	2.272	7.7	16.8	54.0	92.3
Average	4648.8	120.5	2127.7	2.185		1.039	2.269				92.1

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4632.3	118.6	2094.8	2.211	2.299	1.039	2.299	93.3
2	4663.8	119	2101.8	2.219	2.308	1.040	2.308	93.7
3	4650.2	118.2	2087.7	2.227	2.307	1.036	2.307	93.7
Average	4648.8	118.6	2094.8	2.219	2.305	1.039	2.305	

Comments:

APPENDIX C

SUPERPAVE COMPACTOR VOLUMETRICS

BOTTOM LIFT
TEST LANE
CONSTRUCTED JUNE 23, 1997

ASPHALT CONTENT AND GRADATION DETERMINED BY IGNITION TEST

WesTrack - New Experiment Sections - Volumetric Data Summary

Test Lane, Bottom Lift

Construction Date: 6/23/97

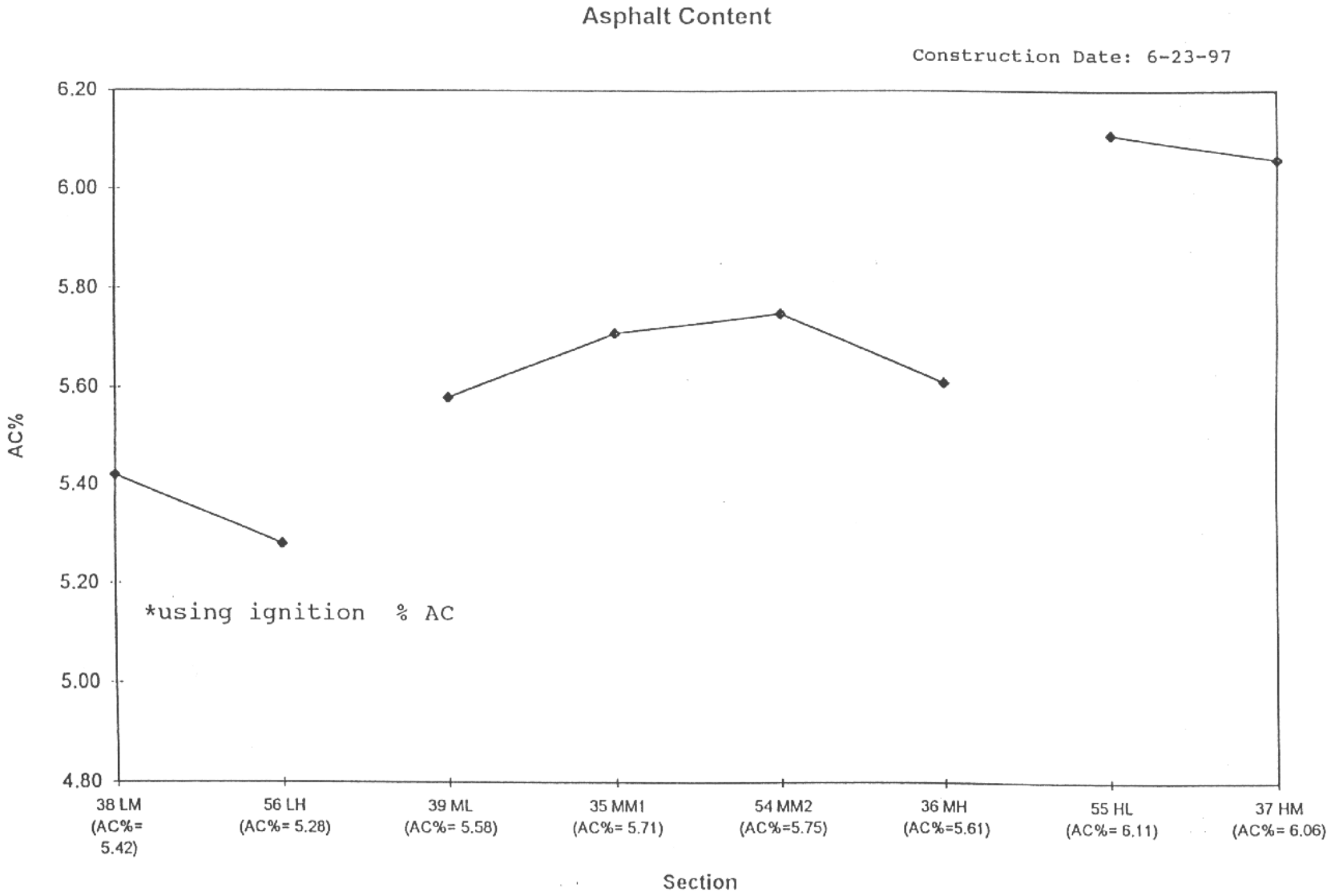
Section	AC	VTM	VMA	VFA	Rice SG	% GmmNi	%GmmNm	F/A
38 LM (AC%= 5.42)	5.42	5.0	15.3	67.0	2.451	85.4	96.4	1.21
56 LH (AC%= 5.28)	5.28	5.1	15.4	66.6	2.448	85.4	96.3	1.25
39 ML (AC%= 5.58)	5.58	4.1	15.6	73.5	2.424	86.3	97.3	0.94
35 MM1 (AC%= 5.71)	5.71	4.6	15.8	70.9	2.433	85.8	96.9	1.02
54 MM2 (AC%=5.75)	5.75	4.8	15.9	70.0	2.436	85.8	96.7	1.13
36 MH (AC%=5.61)	5.61	4.8	15.7	69.8	2.436	85.6	96.7	1.09
55 HL (AC%= 6.11)	6.11	3.9	16.3	76.4	2.410	86.6	97.5	0.92
37 HM (AC%= 6.06)	6.06	3.6	16.6	85.2	2.407	86.2	97.2	0.97

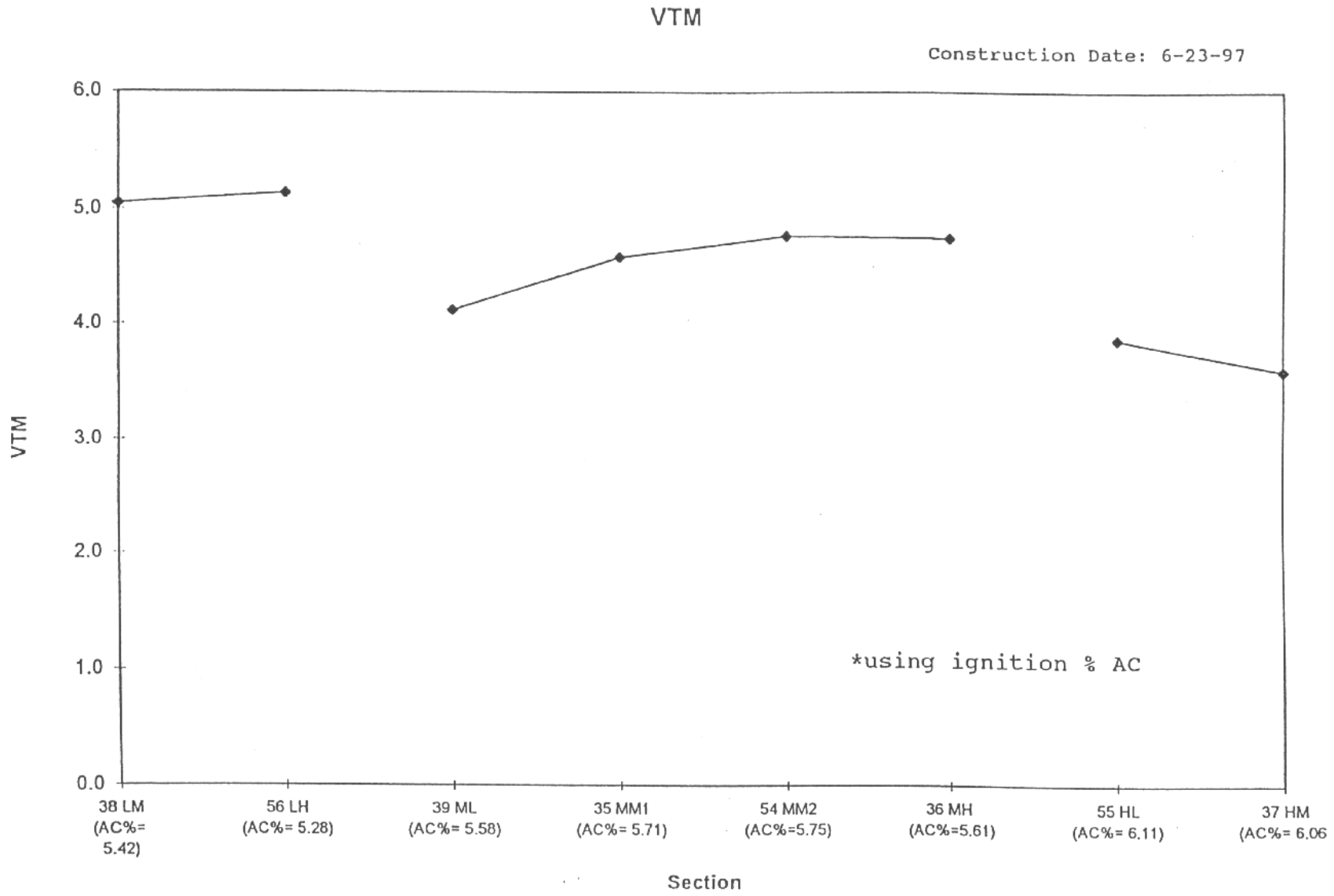
WesTrack - New Experiment Sections - Volumetric Data Summary
Test Lane, Bottom Lift

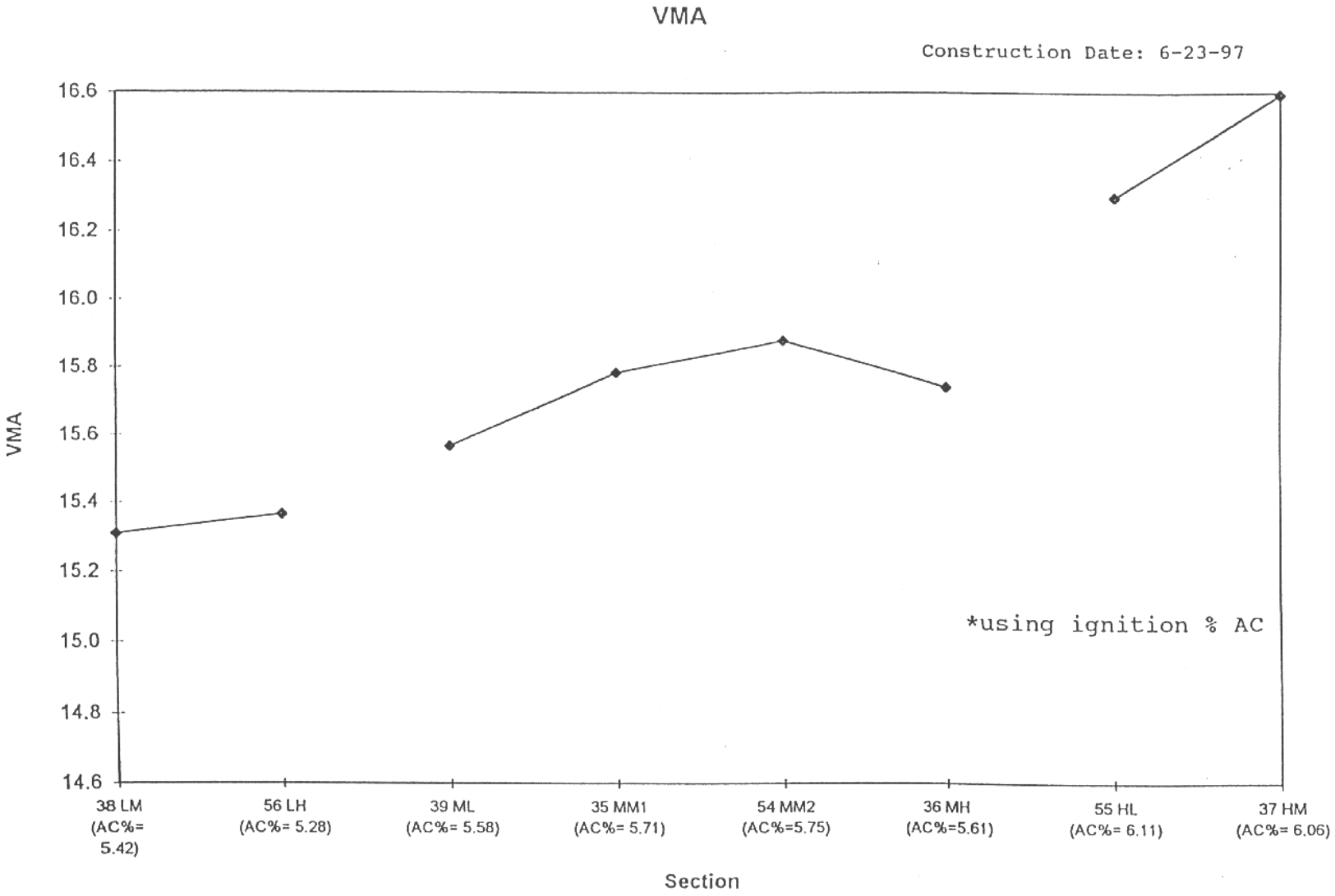
Construction Date: 6/23/97

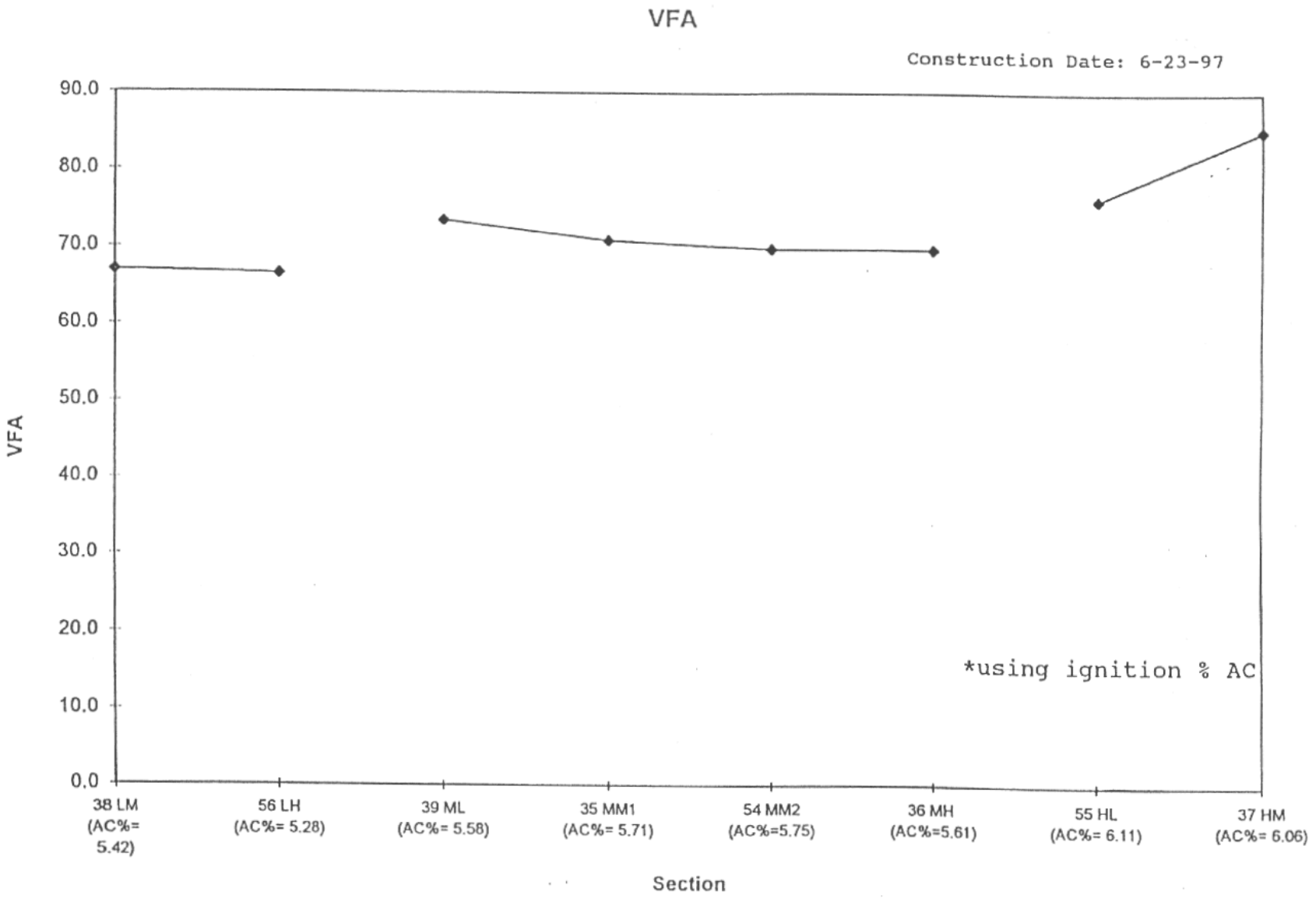
**using ignition % AC , and ignition -#200*

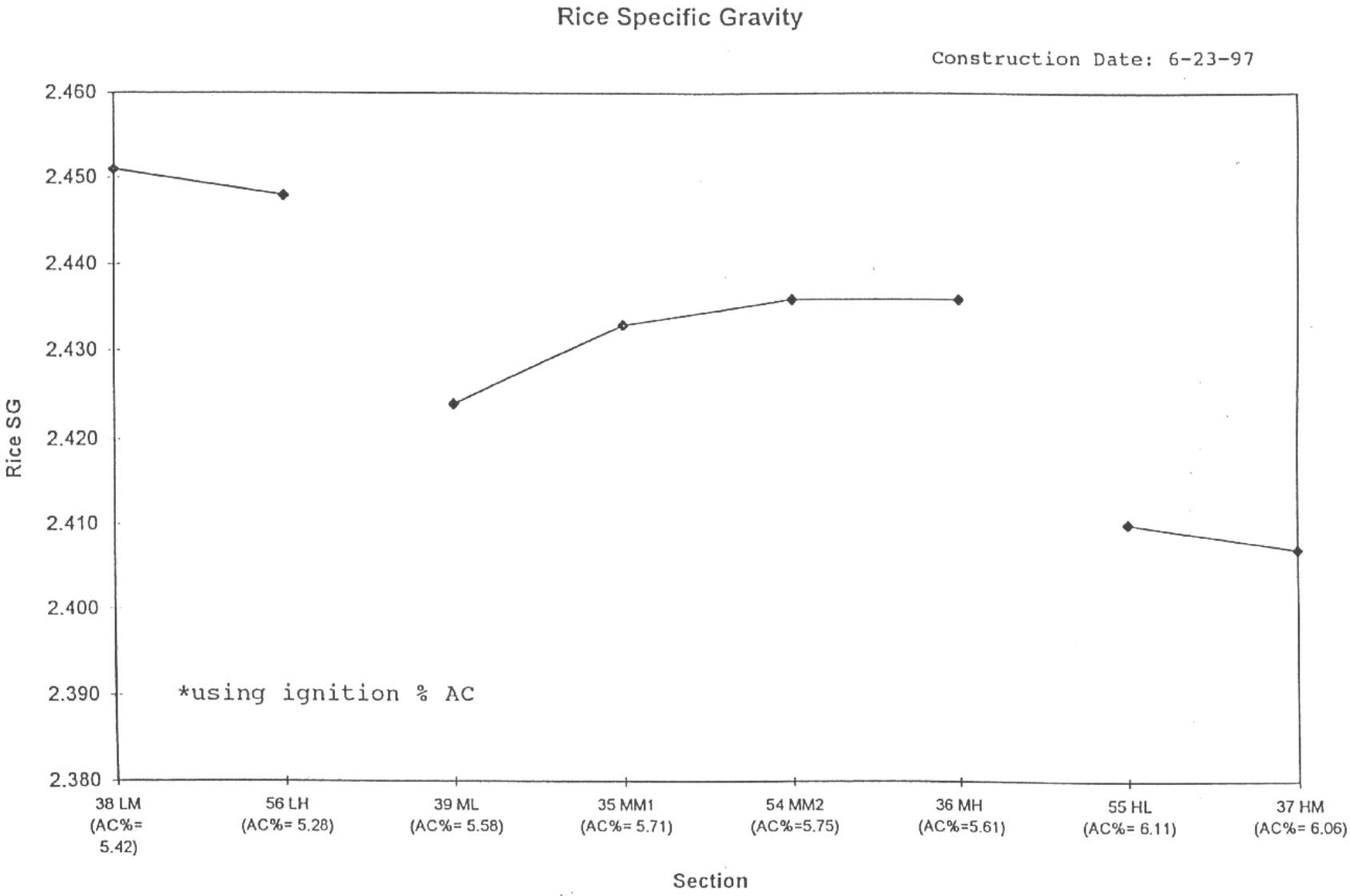
	Low AC		Medium AC				High AC	
Sec #	38 LM	56 LH	39 ML	35 MM1	54 MM2	36 MH	55 HL	37 HM
AC	5.42	5.28	5.58	5.71	5.75	5.61	6.11	6.06
VTM	5.0	5.1	4.1	4.6	4.8	4.8	3.9	3.6
VMA	15.3	15.4	15.6	15.8	15.9	15.7	16.3	16.6
VFA	67.0	66.6	73.5	70.9	70.0	69.8	76.4	85.2
Rice SG	2.451	2.448	2.424	2.433	2.436	2.436	2.410	2.407
% GmmNi	85.4	85.4	86.3	85.8	85.8	85.6	86.6	86.2
%GmmNm	96.4	96.3	97.3	96.9	96.7	96.7	97.5	97.2
F/A	1.209	1.254	0.944	1.025	1.134	1.085	0.921	0.969

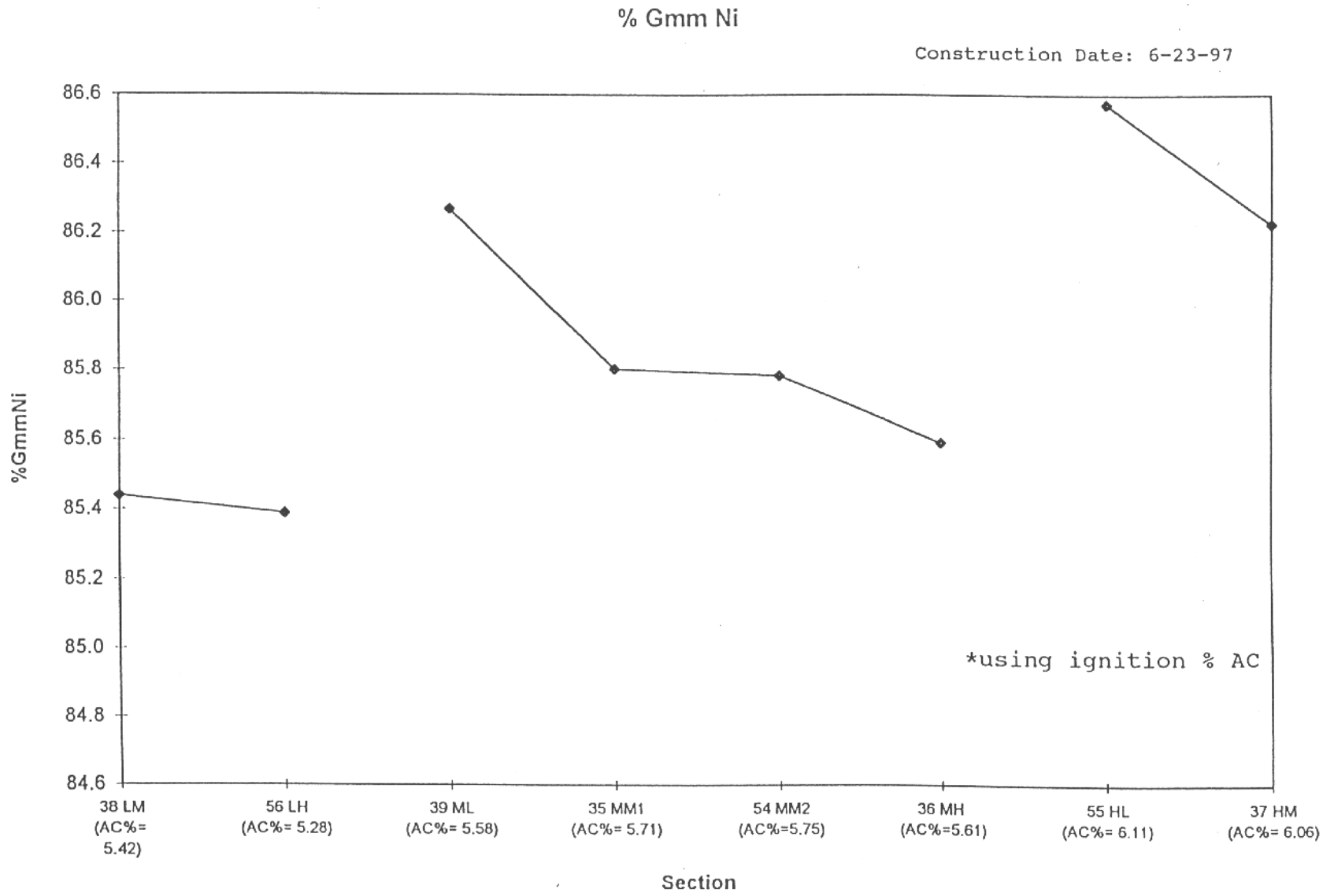

Asphalt Content
Construction Date: 6-23-97
AC%
6.20
6.00
5.80
5.60
5.40
5.20
5.00
4.80
*using ignition % AC
38 LM (AC%= 5.42)
56 LH (AC%= 5.28)
39 ML (AC%= 5.58)
35 MM1 (AC%= 5.71)
54 MM2 (AC%=5.75)
36 MH (AC%=5.61)
55 HL (AC%= 6.11)
37 HM (AC%= 6.06)
Section

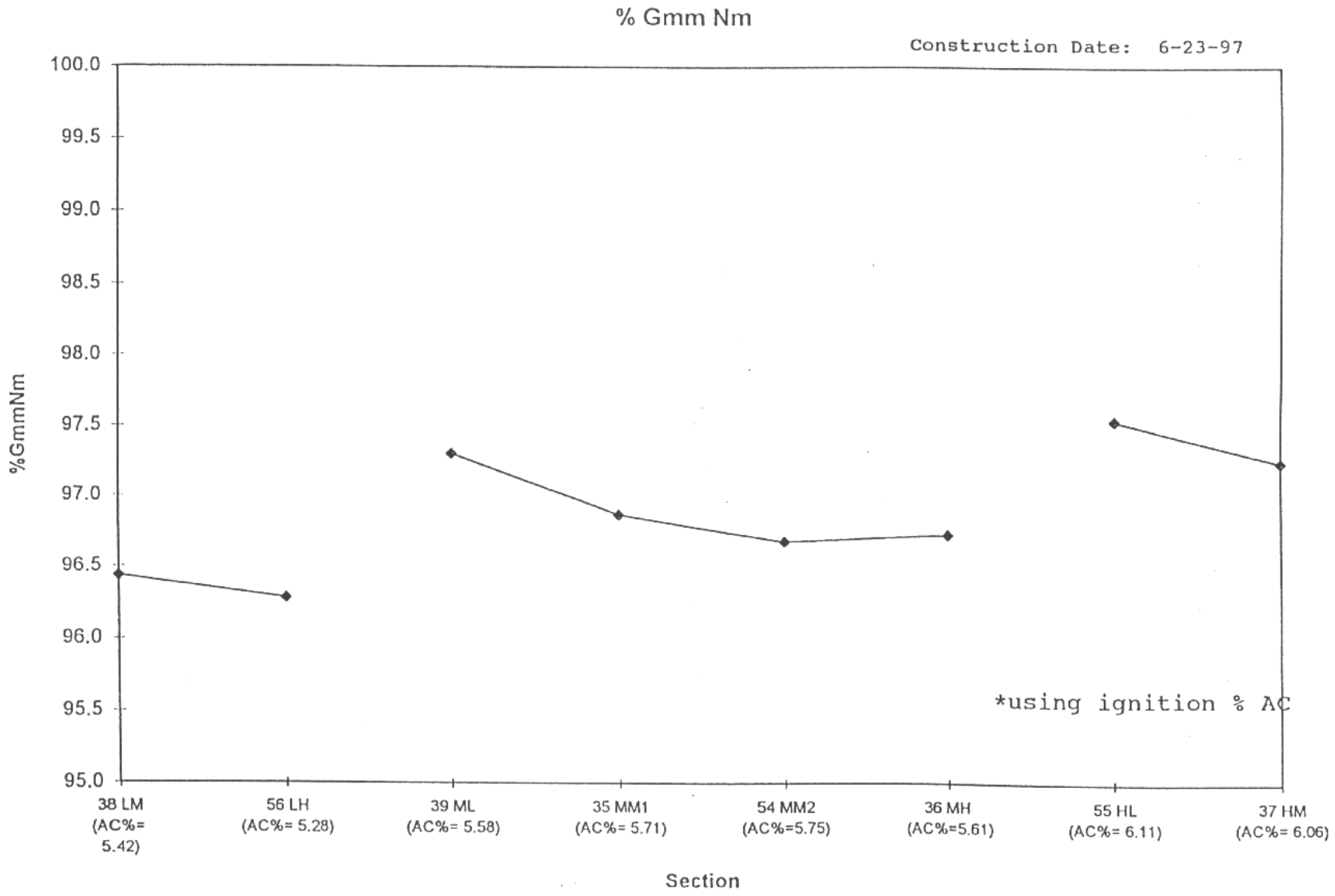

VTM
Construction Date: 6-23-97
6.0
5.0
4.0
3.0
2.0
1.0
0.0
VTM
*using ignition % AC
38 LM (AC%= 5.42)
56 LH (AC%= 5.28)
39 ML (AC%= 5.58)
35 MM1 (AC%= 5.71)
54 MM2 (AC%=5.75)
36 MH (AC%=5.61)
55 HL (AC%= 6.11)
37 HM (AC%= 6.06
Section

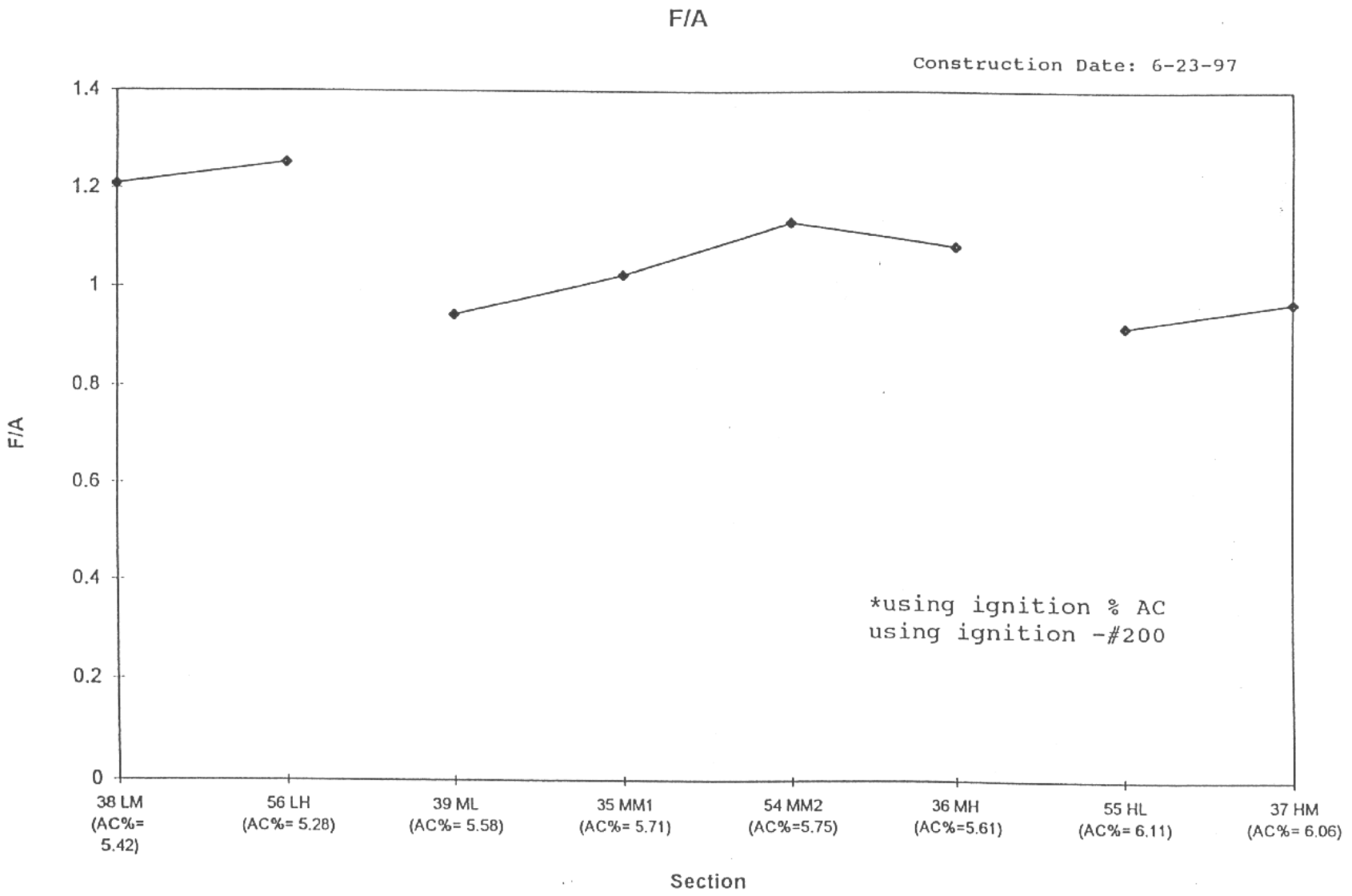

VMA
Construction Date: 6-23-97
16.6
16.4
16.2
16.0
15.8
15.6
15.4
15.2
15.0
14.8
14.6
VMA
*using ignition % AC
38 LM (AC%= 5.42)
56 LH (AC%= 5.28)
39 ML (AC%= 5.58)
35 MM1 (AC%= 5.71)
54 MM2 (AC%=5.75)
36 MH (AC%=5.61)
55 HL (AC%= 6.11)
37 HM (AC%= 6.06)
Section


VFA
Construction Date: 6-23-97
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
VFA
*using ignition % AC
38 LM (AC%= 5.42)
56 LH (AC%= 5.28)
39 ML (AC%= 5.58)
35 MM1 (AC%= 5.71)
54 MM2 (AC%=5.75)
36 MH (AC%=5.61)
55 HL (AC%= 6.11)
37 HM (AC%= 6.06)
Section


Rice Specific Gravity
Construction Date: 6-23-97
Rice SG
2.460
2.450
2.440
2.430
2.420
2.410
2.400
2.390
2.380
*using ignition % AC
38 LM (AC%= 5.42)
56 LH (AC%= 5.28)
39 ML (AC%= 5.58)
35 MM1 (AC%= 5.71)
54 MM2 (AC%=5.75)
36 MH (AC%=5.61)
55 HL (AC%= 6.11)
37 HM (AC%= 6.06)
Section


% Gmm Ni
Construction Date: 6-23-97
%GmmNi
86.6
86.4
86.2
86.0
85.8
85.6
85.4
85.2
85.0
84.8
84.6
*using ignition % AC
38 LM (AC%= 5.42)
56 LH (AC%= 5.28)
39 ML (AC%= 5.58)
35 MM1 (AC%= 5.71)
54 MM2 (AC%=5.75)
36 MH (AC%=5.61)
55 HL (AC%= 6.11)
37 HM (AC%= 6.06)
Section


% Gmm Nm
Construction Date: 6-23-97
100.0
99.5
99.0
98.5
98.0
97.5
97.0
96.5
96.0
95.5
95.0
%GmmNm
*using ignition % AC
38 LM (AC%= 5.42)
56 LH (AC%= 5.28)
39 ML (AC%= 5.58)
35 MM1 (AC%= 5.71)
54 MM2 (AC%=5.75)
36 MH (AC%=5.61)
55 HL (AC%= 6.11)
37 HM (AC%= 6.06)
Section


F/A
Construction Date: 6-23-97
1.4
1.2
1
0.8
0.6
0.4
0.2
0
F/A
*using ignition % AC
using ignition -#200
38 LM (AC%= 5.42)
56 LH (AC%= 5.28)
39 ML (AC%= 5.58)
35 MM1 (AC%= 5.71)
54 MM2 (AC%=5.75)
36 MH (AC%=5.61)
55 HL (AC%= 6.11)
37 HM (AC%= 6.06)
Section

Gyratory Compaction Data Summary

Section:	35	N initial:	8	Mixture Moisture Determination	
Lift:	Bottom	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/23/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4687.8	4741.4	4633.2
Weight in	2706.5	2739.9	2675.2
SSD Weigh	4691.3	4760.0	4637.2
BSG	2.362	2.347	2.361

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.71
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.651	% Agg by Total Weight of M	94.29
Absorbed Asphalt (Pba):	0.78	Percent Passing #200 Sieve	5.1
Effective AC Content (Pbe):	4.98	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.433

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4687.8	130.7	2308.5	2.031		1.030	2.091	85.9
2	4741.4	131.6	2324.4	2.040		1.019	2.080	85.5
3	4633.2	129.0	2278.5	2.033		1.029	2.092	86.0
Average	4687.5	130.4	2303.8	2.035		1.026	2.088	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4687.8	117.4	2073.6	2.261		1.030	2.328	4.3	15.6	72.2	95.7
2	4741.4	118.4	2091.2	2.267		1.019	2.311	5.0	16.1	69.0	95.0
3	4633.2	116.1	2050.6	2.259		1.029	2.325	4.4	15.7	71.6	95.6
Average	4687.5	117.3	2071.8	2.262		1.026	2.321				95.4

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4687.8	115.7	2043.6	2.294	2.362	1.030	2.362	97.1
2	4741.4	116.6	2059.4	2.302	2.347	1.019	2.347	96.5
3	4633.2	114.3	2018.8	2.295	2.361	1.029	2.361	97.1
Average	4687.5	115.5	2040.6	2.297	2.357	1.026	2.357	

Comments:

Gyratory Compaction Data Summary

Section:	36	N initial:	8
Lift:	Bottom	N design:	96
Lane:	Test	N max:	152
Paving Day:	6/23/97	Mix Temp (C):	150
		Compaction Temp (C)	140

Mixture Moisture Determination
Moist Weight of Mix:
Dry Weight of Mix:
% Moisture: #DIV/0!

	Specimen ID 1	2	3
Dry Mass	4689.6	4616.6	4624.7
Weight in	2714.8	2649.7	2667.8
SSD Weigh	4693.9	4622.0	4628.4
BSG	2.370	2.341	2.359

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.61
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.650	% Agg by Total Weight of M	94.39
Absorbed Asphalt (Pba):	0.77	Percent Passing #200 Sieve	5.3
Effective AC Content (Pbe):	4.88	Filler/Effective AC Ratio	1.07
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.436

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4689.6	130.7	2308.5	2.031		1.030	2.092	85.9
2	4616.6	130.0	2296.1	2.011		1.029	2.069	84.9
3	4624.7	129.2	2282.0	2.027		1.033	2.094	86.0
Average	4643.6	130.0	2295.5	2.023		1.031	2.085	85.6

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4689.6	117.2	2070.0	2.265		1.030	2.333	4.2	15.3	72.3	95.8
2	4616.6	116.8	2063.0	2.238		1.029	2.303	5.5	16.4	66.6	94.5
3	4624.7	116.4	2055.9	2.249		1.033	2.324	4.6	15.6	70.6	95.4
Average	4643.6	116.8	2063.0	2.251		1.031	2.320	4.8	15.7	69.8	95.2

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4689.6	115.4	2038.3	2.301	2.370	1.030	2.370	97.3
2	4616.6	114.9	2029.4	2.275	2.341	1.029	2.341	96.1
3	4624.7	114.7	2025.9	2.283	2.359	1.033	2.359	96.8
Average	4643.6	115.0	2031.2	2.286	2.356	1.031	2.356	96.7

Comments:

Gyratory Compaction Data Summary

Section:	37	N initial:	8	Mixture Moisture Determination	
Lift:	Bottom	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/23/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4666.8	4535.6	4496.8
Weight in	2692.2	2608.7	2561.0
SSD Weigh	4670.1	4539.5	4504.7
BSG	2.359	2.349	2.314 ◀

*repeated, bad test

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.06
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.633	% Agg by Total Weight of M	93.94
Absorbed Asphalt (Pba):	0.52	Percent Passing #200 Sieve	5.4
Effective AC Content (Pbe):	5.57	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.407

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4666.8	129.9	2294.4	2.034		1.027	2.089	86.8
2	4535.6	127.1	2244.9	2.020		1.030	2.081	86.5
3	4496.8	127.9	2259.0	1.991		1.033	2.057	85.4
Average	4566.4	128.3	2266.1	2.015		1.030	2.076	86.2

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4666.8	116.7	2061.2	2.264		1.027	2.325	3.4	16.0	78.7	96.6
2	4535.6	114.2	2017.1	2.249		1.030	2.316	3.8	16.3	76.8	96.2
3	4496.8	115.3	2036.5	2.208		1.033	2.281		17.5	100.0	94.8
Average	4566.4	115.4	2038.3	2.240		1.030	2.308	4.9	16.6	48.2	95.9

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4666.8	115.0	2031.2	2.298	2.359	1.027	2.359	98.0
2	4535.6	112.6	1988.8	2.281	2.349	1.030	2.349	97.6
3	4496.8	113.7	2008.2	2.239	2.314	1.033	2.314	96.1
Average	4566.4	113.8	2009.4	2.272	2.341	1.030	2.341	92.2

Comments:

Gyratory Compaction Data Summary

Section:	38	N initial:	8	Mixture Moisture Determination	
Lift:	Bottom	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/23/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4740.3	4750.0	4800.6
Weight in	2735.4	2748.8	2772.9
SSD Weigh	4744.3	4754.0	4805.0
BSG	2.360	2.369	2.362

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.42
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.661	% Agg by Total Weight of M	94.58
Absorbed Asphalt (Pba):	0.92	Percent Passing #200 Sieve	5.5
Effective AC Content (Pbe):	4.55	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.451

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4740.3	132.2	2335.0	2.030		1.029	2.088	85.2
2	4750	132.0	2331.5	2.037		1.031	2.100	85.7
3	4800.6	133.1	2350.9	2.042		1.026	2.094	85.4
Average	4763.6	132.4	2339.1	2.037		1.028	2.094	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4740.3	118.7	2096.5	2.261		1.029	2.326	5.1	15.4	66.8	94.9
2	4750.0	118.9	2100.1	2.262		1.031	2.331	4.9	15.2	67.7	95.1
3	4800.6	119.9	2117.7	2.267		1.026	2.325	5.1	15.4	66.6	94.9
Average	4763.6	119.2	2104.8	2.263		1.028	2.327				95.0

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4740.3	117.0	2066.5	2.294	2.360	1.029	2.360	96.3
2	4750.0	117.0	2066.5	2.299	2.369	1.031	2.369	96.6
3	4800.6	118.0	2084.2	2.303	2.362	1.026	2.362	96.4
Average	4763.6	117.3	2072.4	2.299	2.364	1.028	2.364	

Comments:

Gyratory Compaction Data Summary

Section:	39	N initial:	8	Mixture Moisture Determination	
Lift:	Bottom	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/23/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4707.9	4761.2	4714.1
Weight in	2718.6	2745.3	2717.0
SSD Weigh	4711.3	4764.8	4718.2
BSG	2.363	2.358	2.356

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.58
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.634	% Agg by Total Weight of M	94.42
Absorbed Asphalt (Pba):	0.53	Percent Passing #200 Sieve	4.8
Effective AC Content (Pbe):	5.08	Filler/Effective AC Ratio	0.84
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.424

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4707.9	131.2	2317.3	2.032		1.028	2.089	86.2
2	4761.2	132.5	2340.3	2.034		1.026	2.087	86.1
3	4714.1	131.4	2320.9	2.031		1.033	2.097	86.5
Average	4727.7	131.7	2326.2	2.032		1.029	2.091	86.3

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4707.9	117.7	2078.9	2.265		1.028	2.328	3.9	15.4	74.4	96.1
2	4761.2	119.1	2103.6	2.263		1.026	2.322	4.2	15.6	73.1	95.8
3	4714.1	118.7	2096.5	2.249		1.033	2.322	4.2	15.6	73.1	95.8
Average	4727.7	118.5	2093.0	2.259		1.029	2.324	4.1	15.5	73.5	95.9

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4707.9	116.0	2048.9	2.298	2.363	1.028	2.363	97.5
2	4761.2	117.3	2071.8	2.298	2.358	1.026	2.358	97.3
3	4714.1	117.0	2066.5	2.281	2.356	1.033	2.356	97.2
Average	4727.7	116.8	2062.4	2.292	2.359	1.029	2.359	97.3

Comments:

Gyratory Compaction Data Summary

Section:	54	N initial:	8	Mixture Moisture Determination	
Lift:	Bottom	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/23/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4723.4	4502.3	4757.3
Weight in	2732.3	2586.9	2742.9
SSD Weigh	4728.1	4509.7	4761.1
BSG	2.367	2.342	2.357

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.75
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.656	% Agg by Total Weight of M	94.25
Absorbed Asphalt (Pba):	0.86	Percent Passing #200 Sieve	5.6
Effective AC Content (Pbe):	4.94	Filler/Effective AC Ratio	#VALUE!
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.436

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4723.4	131.4	2320.9	2.035		1.028	2.093	85.9
2	4502.3	126.0	2225.5	2.023		1.030	2.083	85.5
3	4757.3	132.9	2347.3	2.027		1.033	2.093	85.9
Average	4661.0	130.1	2297.9	2.028		1.030	2.090	85.8

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4723.4	118.0	2084.2	2.266		1.028	2.331	4.3	15.5	72.0	95.7
2	4502.3	113.8	2010.0	2.240		1.030	2.307	5.3	16.4	67.5	94.7
3	4757.3	119.8	2116.0	2.248		1.033	2.322	4.7	15.8	70.3	95.3
Average	4661.0	117.2	2070.0	2.252		1.030	2.320	4.8	15.9	70.0	95.2

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4723.4	116.2	2052.4	2.301	2.367	1.028	2.367	97.2
2	4502.3	112.1	1980.0	2.274	2.342	1.030	2.342	96.1
3	4757.3	118.0	2084.2	2.283	2.357	1.033	2.357	96.8
Average	4661.0	115.4	2038.8	2.286	2.355	1.030	2.355	96.7

Comments:

Gyratory Compaction Data Summary

Section:	55	N initial:	8	Mixture Moisture Determination	
Lift:	Bottom	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/23/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4628.2	4582.0	4535.1
Weight in	2675.8	2636.5	2597.5
SSD Weigh	4630.2	4586.2	4540.3
BSG	2.368	2.350	2.334

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.11
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.639	% Agg by Total Weight of M	93.89
Absorbed Asphalt (Pba):	0.61	Percent Passing #200 Sieve	5.1
Effective AC Content (Pbe):	5.54	Filler/Effective AC Ratio	[illegible]
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.41

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4628.2	128.5	2269.6	2.039		1.028	2.097	87.0
2	4582	128.2	2264.3	2.024		1.031	2.086	86.6
3	4535.1	127.4	2250.2	2.015		1.030	2.076	86.1
Average	4581.8	128.0	2261.4	2.026		1.030	2.086	[illegible]

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4628.2	115.5	2040.0	2.269		1.028	2.333	3.2	15.7	79.7	96.8
2	4582.0	115.4	2038.3	2.248		1.031	2.318	3.8	16.3	76.4	96.2
3	4535.1	115.0	2031.2	2.233		1.030	2.300	4.6	16.9	73.0	95.4
Average	4581.8	115.3	2036.5	2.250		1.030	2.317	[illegible]			96.1

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4628.2	113.8	2010.0	2.303	2.368	1.028	2.368	98.3
2	4582.0	113.8	2010.0	2.280	2.350	1.031	2.350	97.5
3	4535.1	113.3	2001.2	2.266	2.334	1.030	2.334	96.9
Average	4581.8	113.6	2007.0	2.283	2.351	1.030	2.351	[illegible]

Comments:

Gyratory Compaction Data Summary

Section:	56	N initial:	8	Mixture Moisture Determination	
Lift:	Bottom	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/23/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4750.9	4717.5	4609.8
Weight in	2739.8	2724.3	2652.8
SSD Weigh	4754.5	4721.1	4614.0
BSG	2.358	2.363	2.350

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.28
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.651	% Agg by Total Weight of M	94.72
Absorbed Asphalt (Pba):	0.78	Percent Passing #200 Sieve	5.7
Effective AC Content (Pbe):	4.55	Filler/Effective AC Ratio	1.24
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.448

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4750.9	131.7	2326.2	2.042		1.026	2.095	85.6
2	4717.5	131.1	2315.6	2.037		1.027	2.092	85.5
3	4609.8	128.7	2273.2	2.028		1.028	2.084	85.1
Average	4692.7	130.5	2305.0	2.036		1.027	2.090	85.4

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4750.9	118.8	2098.3	2.264		1.026	2.322	5.1	15.4	66.6	94.9
2	4717.5	117.8	2080.6	2.267		1.027	2.328	4.9	15.1	67.7	95.1
3	4609.8	115.8	2045.3	2.254		1.028	2.316	5.4	15.6	65.4	94.6
Average	4692.7	117.5	2074.8	2.262		1.027	2.322	5.1	15.4	66.6	94.9

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4750.9	117.0	2066.5	2.299	2.358	1.026	2.358	96.3
2	4717.5	116.1	2050.6	2.301	2.363	1.027	2.363	96.5
3	4609.8	114.1	2015.3	2.287	2.350	1.028	2.350	96.0
Average	4692.7	115.7	2044.1	2.296	2.357	1.027	2.357	96.3

Comments:

APPENDIX D

SUPERPAVE COMPACTOR VOLUMETRICS

TOP LIFT
TEST LANE
CONSTRUCTED JUNE 28, 1997

ASPHALT CONTENT AND GRADATION DETERMINED BY IGNITION TEST

WesTrack - New Experiment Sections - Volumetric Data Summary
Test Lane, top Lift

Construction Date: 6/28/97

**using ignition % AC , and -#200*

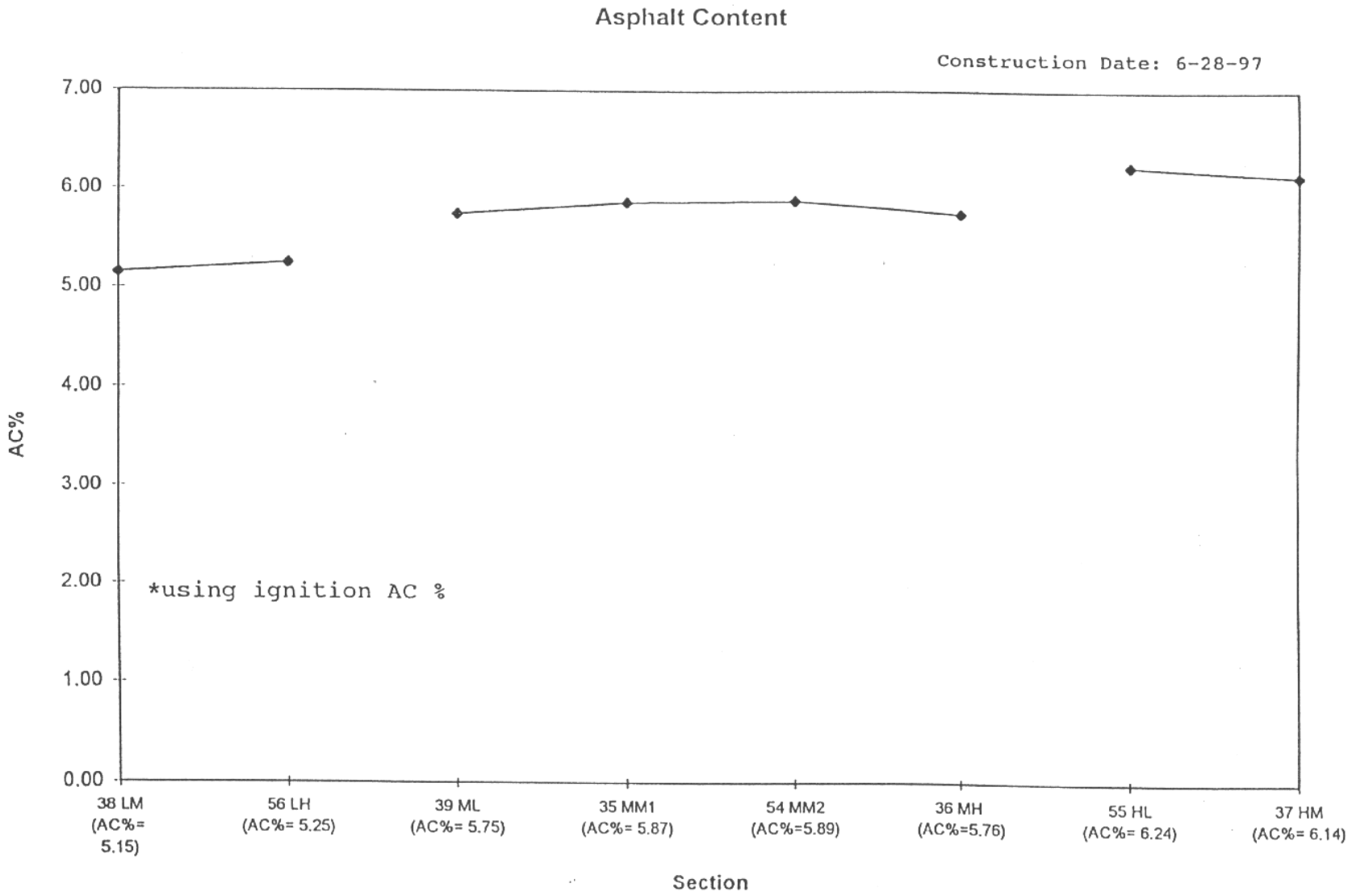
	Low AC		Medium AC				High AC	
Sec #	38 LM	56 LH	39 ML	35 MM1	54 MM2	36 MH	55 HL	37 HM
AC	5.15	5.25	5.75	5.87	5.89	5.76	6.24	6.14
VTM	4.1	4.0	5.3	4.3	3.3	4.0	3.7	3.9
VMA	13.9	14.2	16.1	15.8	15.1	14.8	15.9	16.2
VFA	70.7	71.6	67.8	72.8	78.4	73.0	77.1	75.8
Rice SG	2.459	2.452	2.441	2.429	2.424	2.447	2.419	2.417
% GmmNi	86.1	86.2	85.3	86.0	86.8	86.2	86.5	86.3
%GmmNm	97.5	97.4	96.2	97.1	98.2	97.5	97.9	97.6
F/A	1.440	1.366	1.174	1.096	1.114	1.220	1.104	1.050

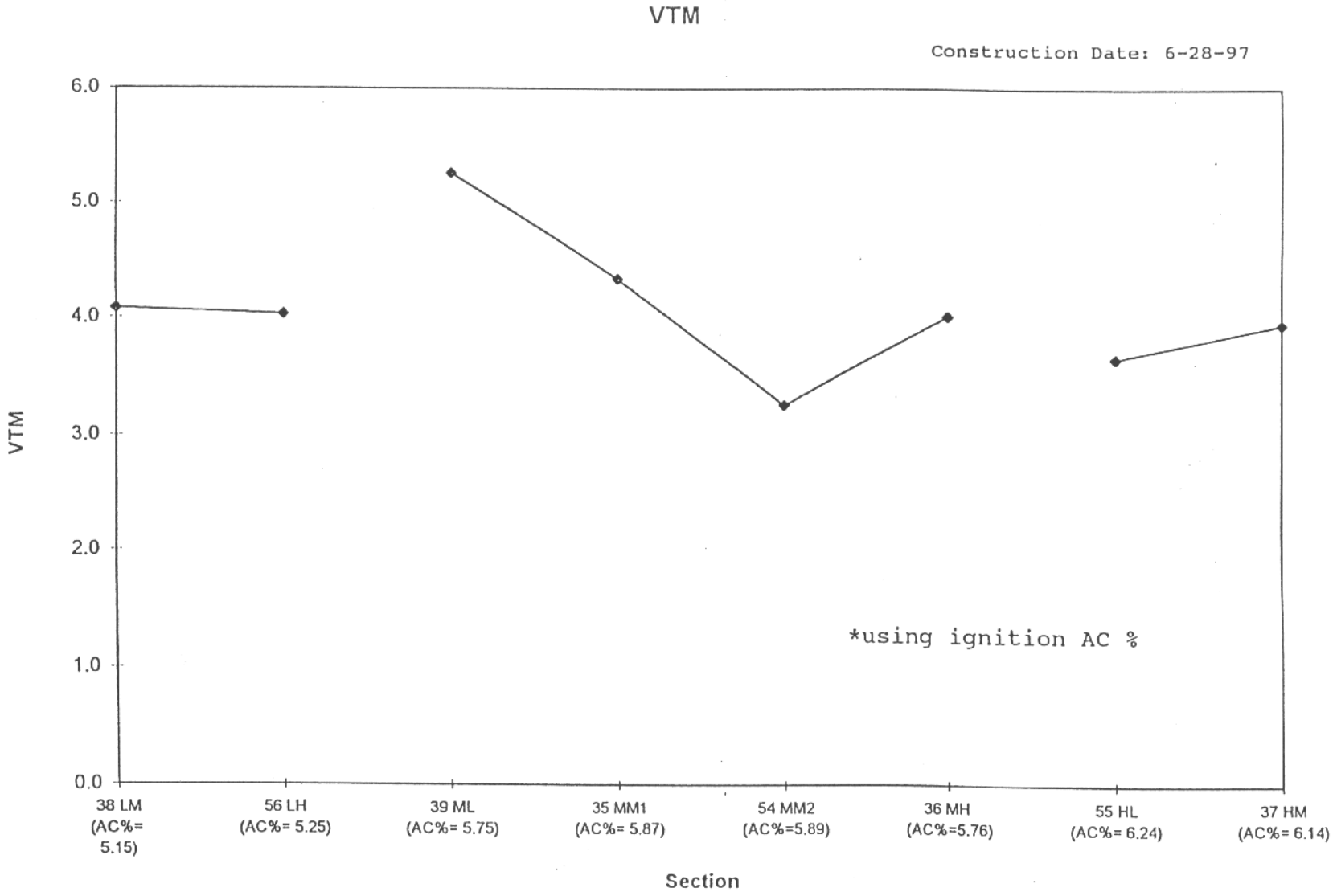
WesTrack - New Experiment Sections - Volumetric Data Summary

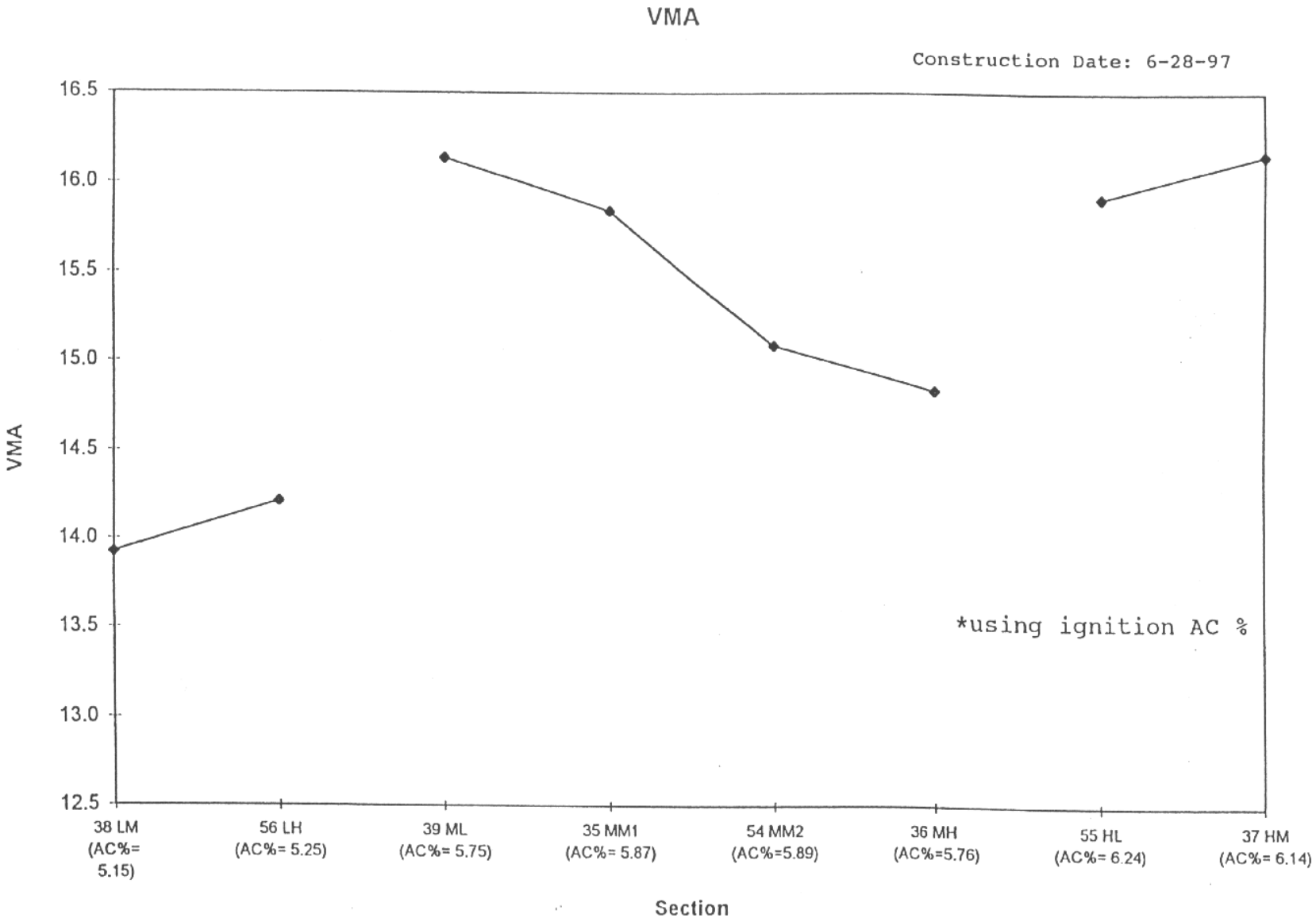
Test Lane, Top Lift

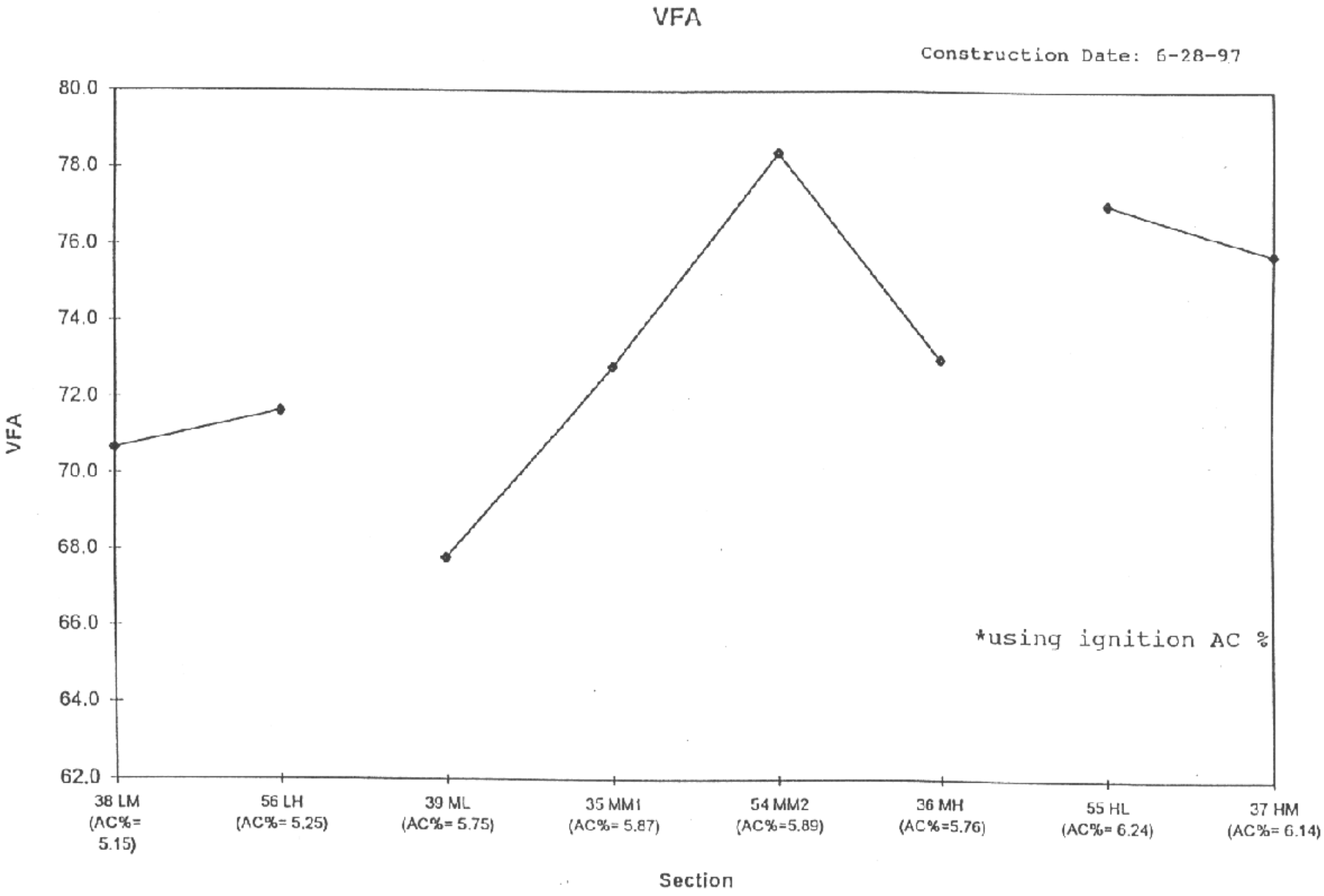
Construction Date: 6/28/97

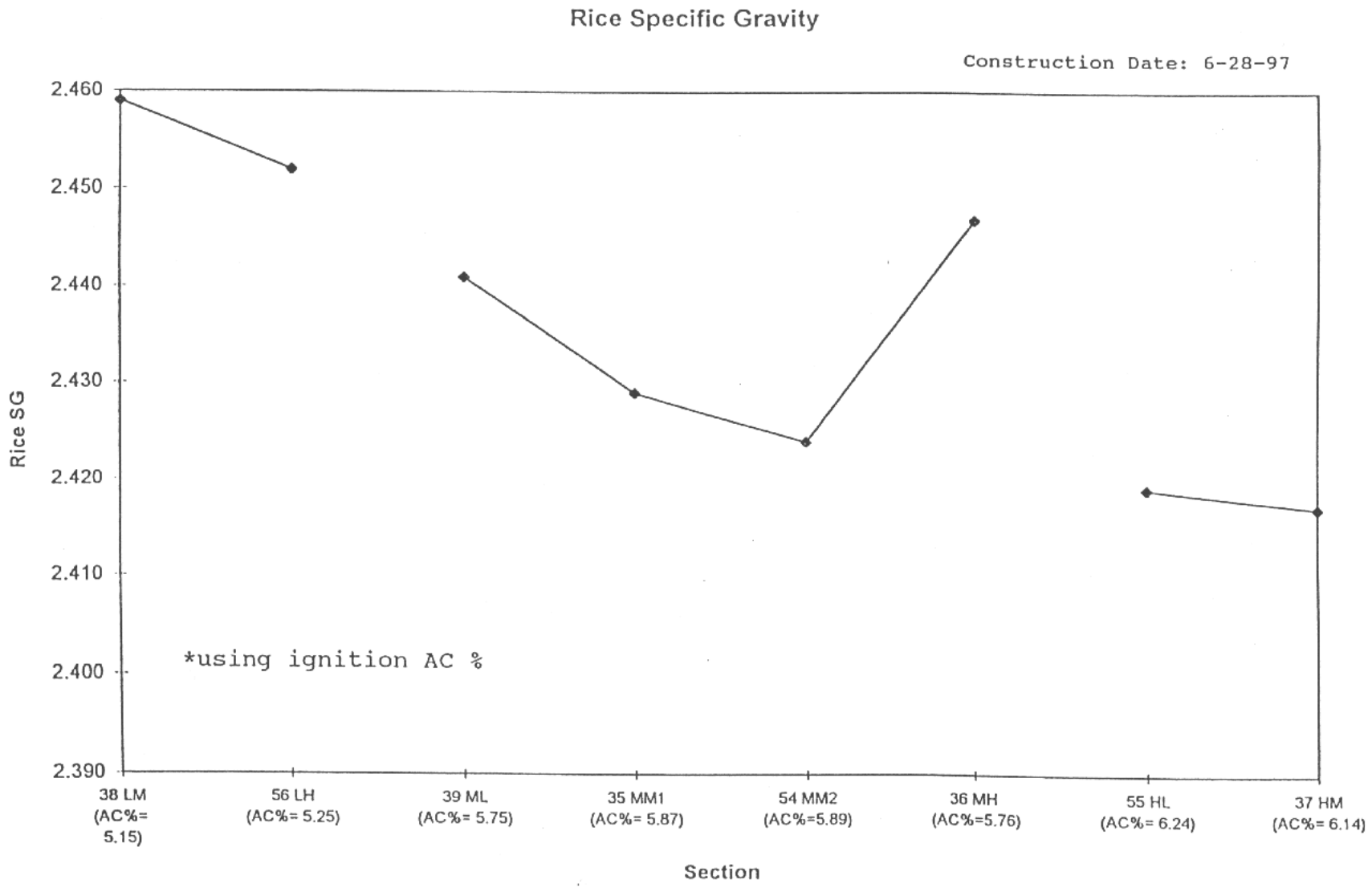
Section	AC	VTM	VMA	VFA	Rice SG	% GmmNi	%GmmNm	F/A
38 LM (AC%= 5.15)	5.15	4.1	13.9	70.7	2.459	86.1	97.5	1.44
56 LH (AC%= 5.25)	5.25	4.0	14.2	71.6	2.452	86.2	97.4	1.37
39 ML (AC%= 5.75)	5.75	5.3	16.1	67.8	2.441	85.3	96.2	1.17
35 MM1 (AC%= 5.87)	5.87	4.3	15.8	72.8	2.429	86.0	97.1	1.1
54 MM2 (AC%=5.89)	5.89	3.3	15.1	78.4	2.424	86.8	98.2	1.11
36 MH (AC%=5.76)	5.76	4.0	14.8	73.0	2.447	86.2	97.5	1.22
55 HL (AC%= 6.24)	6.24	3.7	15.9	77.1	2.419	86.5	97.9	1.1
37 HM (AC%= 6.14)	6.14	3.9	16.2	75.8	2.417	86.3	97.6	1.05

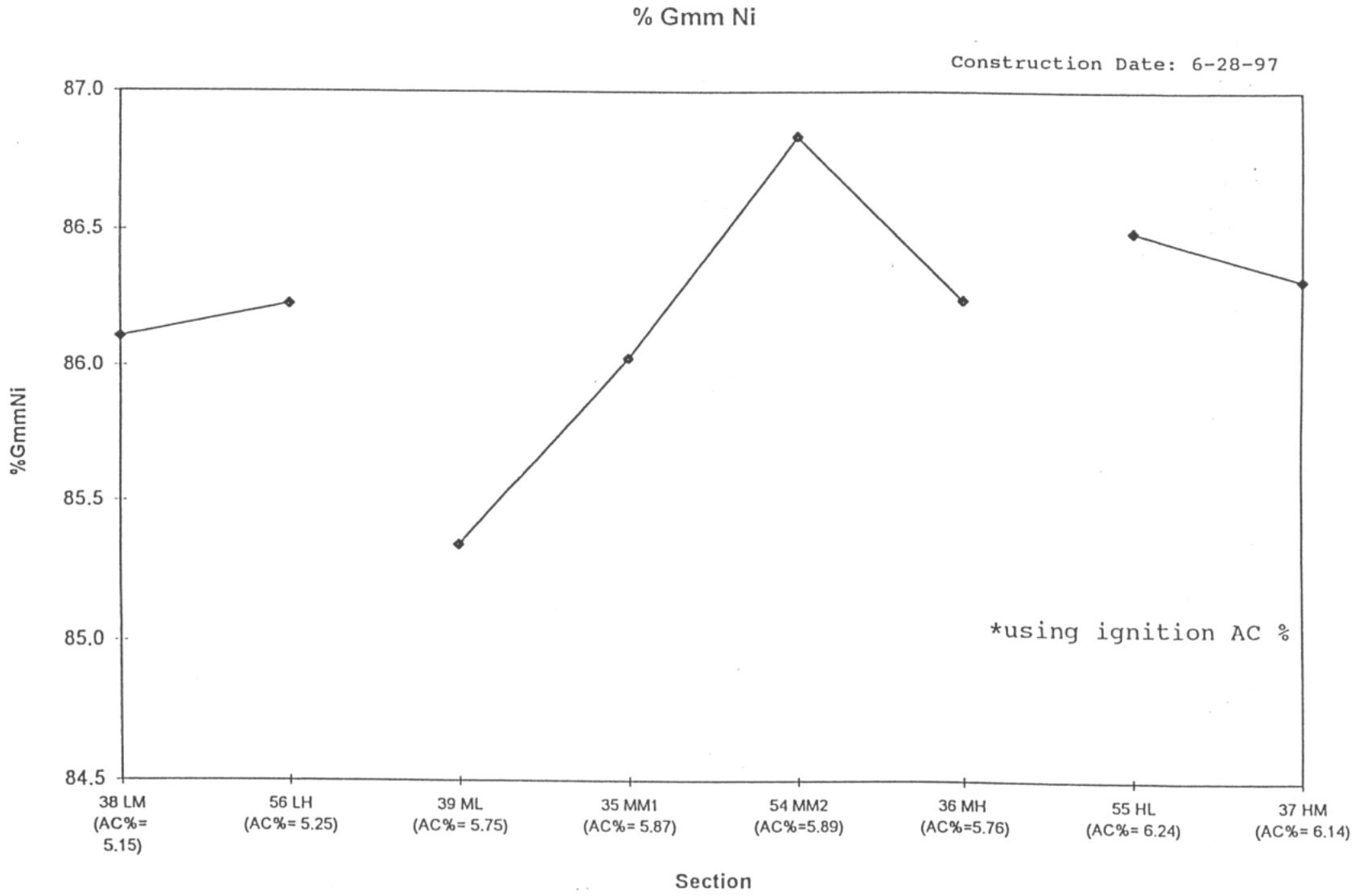

Asphalt Content
Construction Date: 6-28-97
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
AC%
*using ignition AC %
38 LM (AC%= 5.15)
56 LH (AC%= 5.25)
39 ML (AC%= 5.75)
35 MM1 (AC%= 5.87)
54 MM2 (AC%=5.89)
36 MH (AC%=5.76)
55 HL (AC%= 6.24)
37 HM (AC%= 6.14)
Section

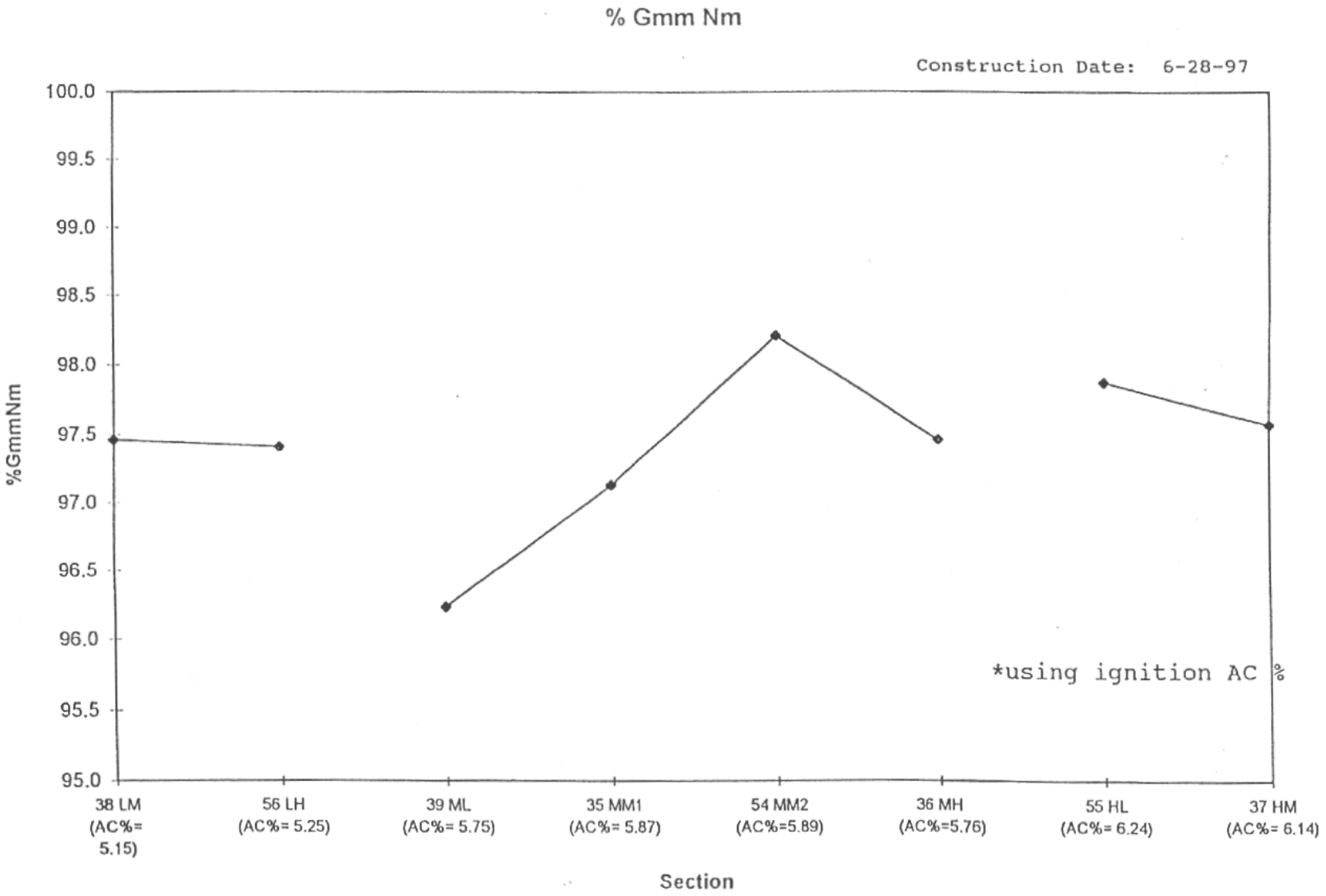

VTM
Construction Date: 6-28-97
6.0
5.0
4.0
3.0
2.0
1.0
0.0
VTM
*using ignition AC %
38 LM (AC%= 5.15)
56 LH (AC%= 5.25)
39 ML (AC%= 5.75)
35 MM1 (AC%= 5.87)
54 MM2 (AC%=5.89)
36 MH (AC%=5.76)
55 HL (AC%= 6.24)
37 HM (AC%= 6.14)
Section

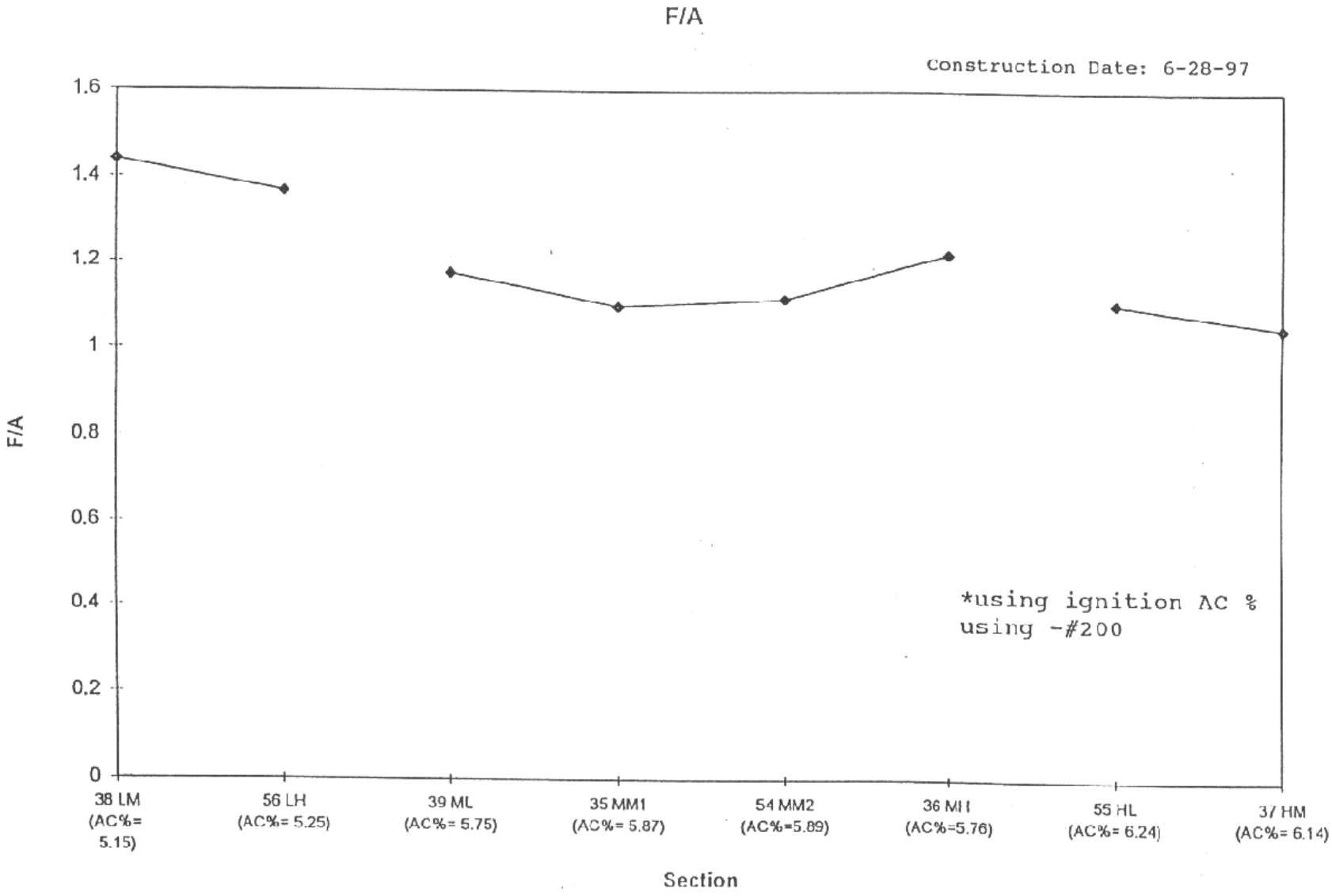

VMA
Construction Date: 6-28-97
16.5
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
VMA
*using ignition AC %
38 LM (AC%= 5.15)
56 LH (AC%= 5.25)
39 ML (AC%= 5.75)
35 MM1 (AC%= 5.87)
54 MM2 (AC%=5.89)
36 MH (AC%=5.76)
55 HL (AC%= 6.24)
37 HM (AC%= 6.14)
Section


VFA
Construction Date: 6-28-97
80.0
78.0
76.0
74.0
72.0
70.0
68.0
66.0
64.0
62.0
VFA
*using ignition AC %
38 LM (AC%= 5.15)
56 LH (AC%= 5.25)
39 ML (AC%= 5.75)
35 MM1 (AC%= 5.87)
54 MM2 (AC%=5.89)
36 MH (AC%=5.76)
55 HL (AC%= 6.24)
37 HM (AC%= 6.14)
Section


Rice Specific Gravity
Construction Date: 6-28-97
Rice SG
2.460
2.450
2.440
2.430
2.420
2.410
2.400
2.390
*using ignition AC %
38 LM (AC%= 5.15)
56 LH (AC%= 5.25)
39 ML (AC%= 5.75)
35 MM1 (AC%= 5.87)
54 MM2 (AC%=5.89)
36 MH (AC%=5.76)
55 HL (AC%= 6.24)
37 HM (AC%= 6.14)
Section


% Gmm Ni
Construction Date: 6-28-97
87.0
86.5
86.0
85.5
85.0
84.5
%GmmNi
*using ignition AC %
38 LM (AC%= 5.15)
56 LH (AC%= 5.25)
39 ML (AC%= 5.75)
35 MM1 (AC%= 5.87)
54 MM2 (AC%=5.89)
36 MH (AC%=5.76)
55 HL (AC%= 6.24)
37 HM (AC%= 6.14)
Section


% Gmm Nm
Construction Date: 6-28-97
100.0
99.5
99.0
98.5
98.0
97.5
97.0
96.5
96.0
95.5
95.0
%GmmNm
*using ignition AC %
38 LM (AC%= 5.15)
56 LH (AC%= 5.25)
39 ML (AC%= 5.75)
35 MM1 (AC%= 5.87)
54 MM2 (AC%=5.89)
36 MH (AC%=5.76)
55 HL (AC%= 6.24)
37 HM (AC%= 6.14)
Section


F/A
Construction Date: 6-28-97
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
F/A
*using ignition AC %
using -#200
38 LM
(AC%=
5.15)
56 LH
(AC%= 5.25)
39 ML
(AC%= 5.75)
35 MM1
(AC%= 5.87)
54 MM2
(AC%=5.89)
36 MH
(AC%=5.76)
55 HL
(AC%= 6.24)
37 HM
(AC%= 6.14)
Section

Gyratory Compaction Data Summary

Section:	35	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4643.0	4641.2	4441.9
Weight in	2694.6	2686.3	2546.9
SSD Weigh	4646.9	4643.4	4454.8
BSG	2.378	2.371	2.328

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.87
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.653	% Agg by Total Weight of M	94.13
Absorbed Asphalt (Pba):	0.81	Percent Passing #200 Sieve	5.6
Effective AC Content (Pbe):	5.11	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.429

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4643	128.5	2269.6	2.046		1.030	2.106	86.7
2	4641.2	128.7	2273.2	2.042		1.025	2.093	86.2
3	4441.9	124.2	2193.7	2.025		1.022	2.069	85.2
Average	4575.4	127.1	2245.5	2.037		1.026	2.090	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4643.0	115.5	2040.0	2.276		1.030	2.343	3.5	15.1	76.7	96.5
2	4641.2	115.4	2038.3	2.277		1.025	2.334	3.9	15.5	74.8	96.1
3	4441.9	112.1	1980.0	2.243		1.022	2.293	5.6	17.0	66.9	94.4
Average	4575.4	114.3	2019.4	2.265		1.026	2.324				95.7

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4643.0	113.8	2010.0	2.310	2.378	1.030	2.378	97.9
2	4641.2	113.6	2006.5	2.313	2.371	1.025	2.371	97.6
3	4441.9	110.4	1949.9	2.278	2.328	1.022	2.328	95.8
Average	4575.4	112.6	1988.8	2.300	2.359	1.026	2.359	

Comments:

Gyratory Compaction Data Summary

Section:	36	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4729.8	4759.5	4629.9
Weight in	2752.1	2775.1	2680.3
SSD Weigh	4732.9	4761.5	4633.4
BSG	2.388	2.396	2.371

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.76
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.671	% Agg by Total Weight of M	94.24
Absorbed Asphalt (Pba):	1.07	Percent Passing #200 Sieve	5.8
Effective AC Content (Pbe):	4.75	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.447

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4729.8	130.8	2310.3	2.047		1.030	2.109	86.2
2	4759.5	131.0	2313.8	2.057		1.028	2.114	86.4
3	4629.9	128.4	2267.9	2.042		1.033	2.108	86.2
Average	4706.4	130.1	2297.3	2.049		1.030	2.110	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4729.8	117.3	2071.8	2.283		1.030	2.351	3.9	14.7	73.4	96.1
2	4759.5	117.4	2073.6	2.295		1.028	2.359	3.6	14.5	75.2	96.4
3	4629.9	115.9	2047.1	2.262		1.033	2.336	4.5	15.3	70.3	95.5
Average	4706.4	116.9	2064.2	2.280		1.030	2.349				96.0

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4729.8	115.5	2040.0	2.319	2.388	1.030	2.388	97.6
2	4759.5	115.6	2041.8	2.331	2.396	1.028	2.396	97.9
3	4629.9	114.2	2017.1	2.295	2.371	1.033	2.371	96.9
Average	4706.4	115.1	2033.0	2.315	2.385	1.030	2.385	

Comments:

Gyratory Compaction Data Summary

Section:	37	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4614.5	4487.9	4201.5
Weight in	2682.5	2582.0	2408.9
SSD Weigh	4616.2	4490.4	4207.0
BSG	2.386	2.352	2.337

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.14
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.650	% Agg by Total Weight of M	93.86
Absorbed Asphalt (Pba):	0.76	Percent Passing #200 Sieve	5.7
Effective AC Content (Pbe):	5.43	Filler/Effective AC Ratio	#DIV/0!
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.417

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4614.5	127.4	2250.2	2.051		1.031	2.115	87.5
2	4487.9	125.8	2221.9	2.020		1.028	2.077	85.9
3	4201.5	118.9	2100.1	2.001		1.033	2.067	85.5
Average	4434.6	124.0	2190.7	2.024		1.031	2.086	85.7

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4614.5	114.6	2024.1	2.280		1.031	2.351	2.7	15.1	81.9	97.3
2	4487.9	113.0	1995.9	2.249		1.028	2.312	4.3	16.5	73.7	95.7
3	4201.5	106.8	1886.4	2.227		1.033	2.302	4.8	16.9	71.7	95.2
Average	4434.6	111.5	1968.8	2.252		1.031	2.322	3.9	16.2	75.8	96.1

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4614.5	112.9	1994.1	2.314	2.386	1.031	2.386	98.7
2	4487.9	111.1	1962.3	2.287	2.352	1.028	2.352	97.3
3	4201.5	105.2	1858.1	2.261	2.337	1.033	2.337	96.7
Average	4434.6	109.7	1938.2	2.287	2.358	1.031	2.358	97.6

Comments:

Gyratory Compaction Data Summary

Section:	38	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4697.9	4691.5	4684.1
Weight in	2739.1	2736.5	2734.5
SSD Weigh	4700.1	4694.6	4687.8
BSG	2.396	2.396	2.398

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.15
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.659	% Agg by Total Weight of M	94.85
Absorbed Asphalt (Pba):	0.89	Percent Passing #200 Sieve	6.2
Effective AC Content (Pbe):	4.31	Filler/Effective AC Ratio	1.44
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.459

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4697.9	129.3	2283.8	2.057		1.027	2.112	85.9
2	4691.5	129.0	2278.5	2.059		1.030	2.121	86.3
3	4684.1	128.9	2276.7	2.057		1.030	2.119	86.2
Average	4691.2	129.1	2279.6	2.058		1.029	2.117	86.1

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4697.9	115.9	2047.1	2.295		1.027	2.356	4.2	14.0	70.2	95.8
2	4691.5	116.0	2048.9	2.290		1.030	2.359	4.1	13.9	70.7	95.9
3	4684.1	115.7	2043.6	2.292		1.030	2.361	4.0	13.8	71.1	96.0
Average	4691.2	115.9	2046.5	2.292		1.029	2.359	4.1	13.9	70.7	95.9

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4697.9	114.0	2013.5	2.333	2.396	1.027	2.396	97.4
2	4691.5	114.2	2017.1	2.326	2.396	1.030	2.396	97.4
3	4684.1	113.9	2011.8	2.328	2.398	1.030	2.398	97.5
Average	4691.2	114.0	2014.1	2.329	2.397	1.029	2.397	97.5

Comments:

Gyratory Compaction Data Summary

Section:	39	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4692.9	4748.9	4692.8
Weight in	2717.1	2705.9	2717.4
SSD Weigh	4696.7	4766.9	4695.6
BSG	2.371	2.304	2.372

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.75
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.663	% Agg by Total Weight of M	94.25
Absorbed Asphalt (Pba):	0.95	Percent Passing #200 Sieve	5.7
Effective AC Content (Pbe):	4.85	Filler/Effective AC Ratio	1.2
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.441

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4692.9	130.1	2297.9	2.042		1.030	2.103	86.1
2	4748.9	133.3	2354.4	2.017		1.014	2.045	83.8
3	4692.8	129.9	2294.4	2.045		1.028	2.102	86.1
Average	4711.5	131.1	2315.6	2.035		1.024	2.083	85.3

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4692.9	117.2	2070.0	2.267		1.030	2.334	4.4	15.4	71.5	95.6
2	4748.9	120.2	2123.0	2.237		1.014	2.268	7.1	17.8	60.0	92.9
3	4692.8	116.9	2064.7	2.273		1.028	2.336	4.3	15.3	71.8	95.7
Average	4711.5	118.1	2085.9	2.259		1.024	2.313	5.3	16.1	67.8	94.7

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4692.9	115.4	2038.3	2.302	2.371	1.030	2.371	97.1
2	4748.9	118.3	2089.5	2.273	2.304	1.014	2.304	94.4
3	4692.8	115.1	2033.0	2.308	2.372	1.028	2.372	97.2
Average	4711.5	116.3	2053.6	2.295	2.349	1.024	2.349	96.2

Comments:

Gyratory Compaction Data Summary

Section:	54	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4727.0	5191.6	4881.7
Weight in	2744.8	3011.9	2834.1
SSD Weigh	4729.0	5195.3	4883.7
BSG	2.382	2.378	2.382

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.89
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.647	% Agg by Total Weight of M	94.11
Absorbed Asphalt (Pba):	0.73	Percent Passing #200 Sieve	5.8
Effective AC Content (Pbe):	5.21	Filler/Effective AC Ratio	1.11
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.424

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4727	130.4	2303.2	2.052		1.025	2.105	86.8
2	5191.6	143.6	2536.3	2.047		1.027	2.101	86.7
3	4881.7	134.5	2375.6	2.055		1.026	2.109	87.0
Average	4933.4	136.2	2405.0	2.051		1.026	2.105	86.8

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4727.0	116.9	2064.7	2.289		1.025	2.348	3.1	15.0	79.0	96.9
2	5191.6	128.9	2276.7	2.280		1.027	2.341	3.4	15.2	77.5	96.6
3	4881.7	120.9	2135.4	2.286		1.026	2.346	3.2	15.0	78.7	96.8
Average	4933.4	122.2	2158.9	2.285		1.026	2.345	3.2	15.1	78.4	96.7

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4727.0	115.2	2034.7	2.323	2.382	1.025	2.382	98.3
2	5191.6	126.9	2241.4	2.316	2.378	1.027	2.378	98.1
3	4881.7	119.1	2103.6	2.321	2.382	1.026	2.382	98.3
Average	4933.4	120.4	2126.6	2.320	2.381	1.026	2.381	98.2

Comments:

Gyratory Compaction Data Summary

Section:	55	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4767.3	4669.9	4732.8
Weight in	2761.6	2697.8	2735.6
SSD Weigh	4770.4	4673.3	4736.6
BSG	2.373	2.364	2.365

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.24
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.657	% Agg by Total Weight of M	93.76
Absorbed Asphalt (Pba):	0.86	Percent Passing #200 Sieve	6.0
Effective AC Content (Pbe):	5.43	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.419

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4767.3	132.5	2340.3	2.037		1.030	2.097	86.7
2	4669.9	129.6	2289.1	2.040		1.026	2.094	86.6
3	4732.8	132.0	2331.5	2.030		1.027	2.086	86.2
Average	4723.3	131.4	2320.3	2.036		1.028	2.092	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4767.3	118.9	2100.1	2.270		1.030	2.337	3.4	15.7	78.5	96.6
2	4669.9	116.6	2059.4	2.268		1.026	2.327	3.8	16.0	76.4	96.2
3	4732.8	118.3	2089.5	2.265		1.027	2.327	3.8	16.0	76.4	96.2
Average	4723.3	117.9	2083.0	2.268		1.028	2.331				96.3

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4767.3	117.1	2068.3	2.305	2.373	1.030	2.373	98.1
2	4669.9	114.8	2027.7	2.303	2.364	1.026	2.364	97.7
3	4732.8	116.4	2055.9	2.302	2.365	1.027	2.365	97.8
Average	4723.3	116.1	2050.6	2.303	2.367	1.028	2.367	

Comments:

Gyratory Compaction Data Summary

Section:	56	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4740.9	4774.5	4711.6
Weight in	2759.9	2777.6	2741.6
SSD Weigh	4743.9	4777.5	4714.3
BSG	2.390	2.387	2.388

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.25
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.654	% Agg by Total Weight of M	94.75
Absorbed Asphalt (Pba):	0.83	Percent Passing #200 Sieve	6.1
Effective AC Content (Pbe):	4.47	Filler/Effective AC Ratio	1.37
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.452

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4740.9	130.7	2308.5	2.054		1.028	2.112	86.1
2	4774.5	131.6	2324.4	2.054		1.029	2.113	86.2
3	4711.6	129.8	2292.6	2.055		1.031	2.118	86.4
Average	4742.3	130.7	2308.5	2.054		1.029	2.114	86.2

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4740.9	117.2	2070.0	2.290		1.028	2.355	4.0	14.1	72.0	96.0
2	4774.5	118.3	2089.5	2.285		1.029	2.351	4.1	14.3	71.2	95.9
3	4711.6	116.8	2063.0	2.284		1.031	2.354	4.0	14.2	71.7	96.0
Average	4742.3	117.4	2074.2	2.286		1.029	2.353	4.0	14.2	71.7	96.0

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4740.9	115.5	2040.0	2.324	2.390	1.028	2.390	97.5
2	4774.5	116.5	2057.7	2.320	2.387	1.029	2.387	97.4
3	4711.6	115.1	2033.0	2.318	2.388	1.031	2.388	97.4
Average	4742.3	115.7	2043.6	2.321	2.388	1.029	2.388	97.4

Comments:

APPENDIX E

SUPERPAVE COMPACTOR VOLUMETRICS

TOP LIFT
TEST LANE
CONSTRUCTED JUNE 28, 1997

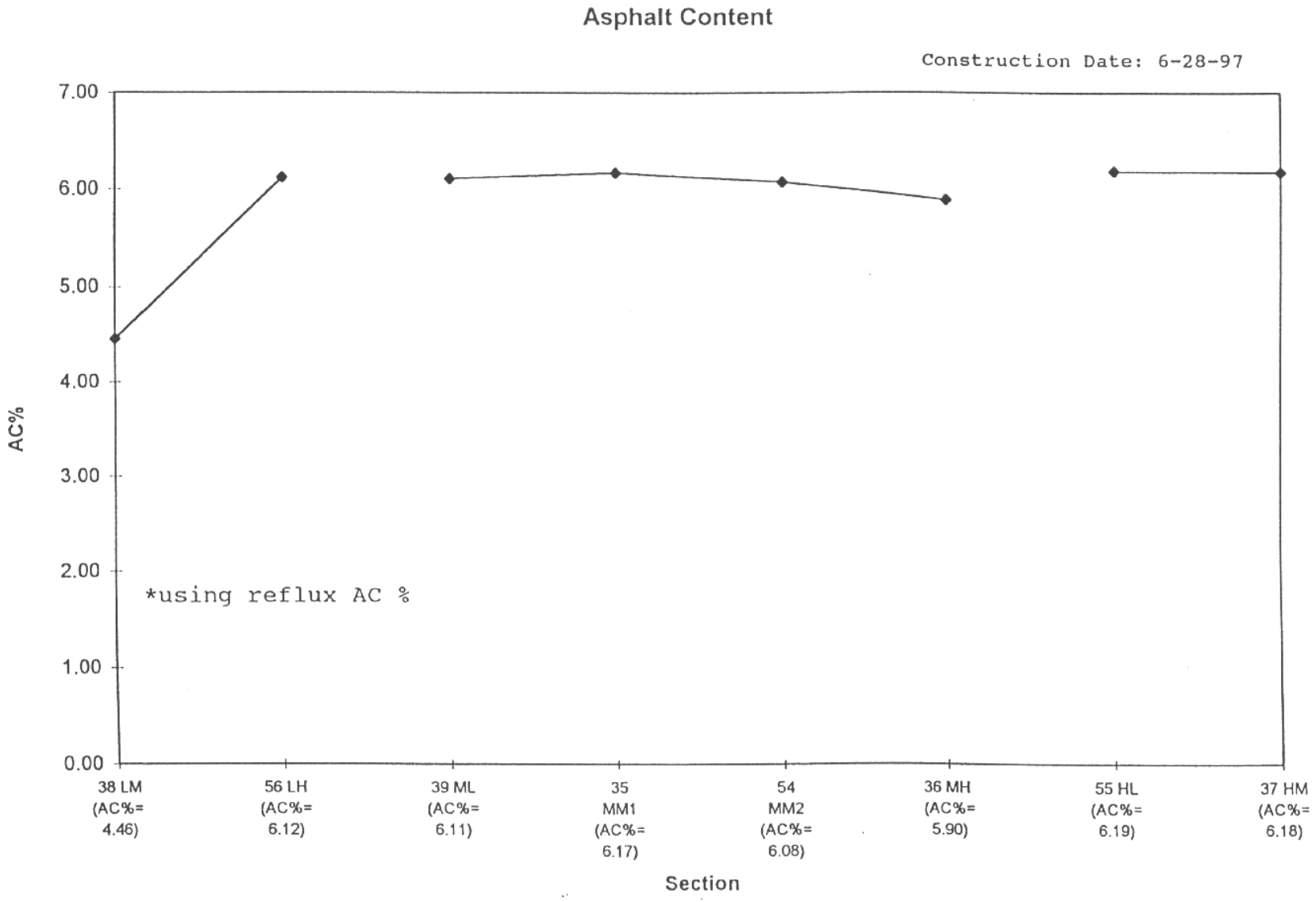
ASPHALT CONTENT AND GRADATION
DETERMINED BY REFLUX EXTRACTION

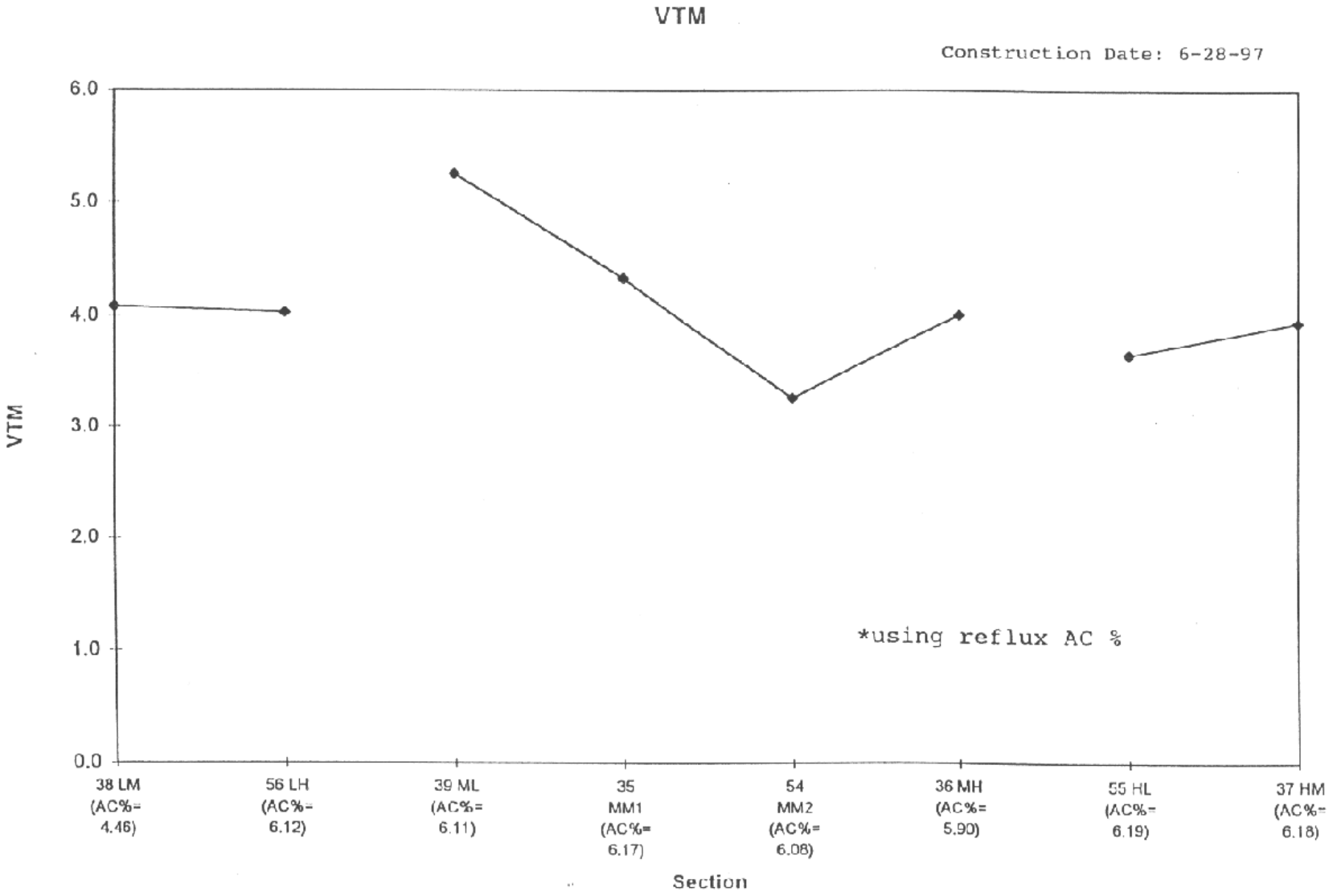
WesTrack - New Experiment Sections - Volumetric Data Summary
Test Lane, Top Lift

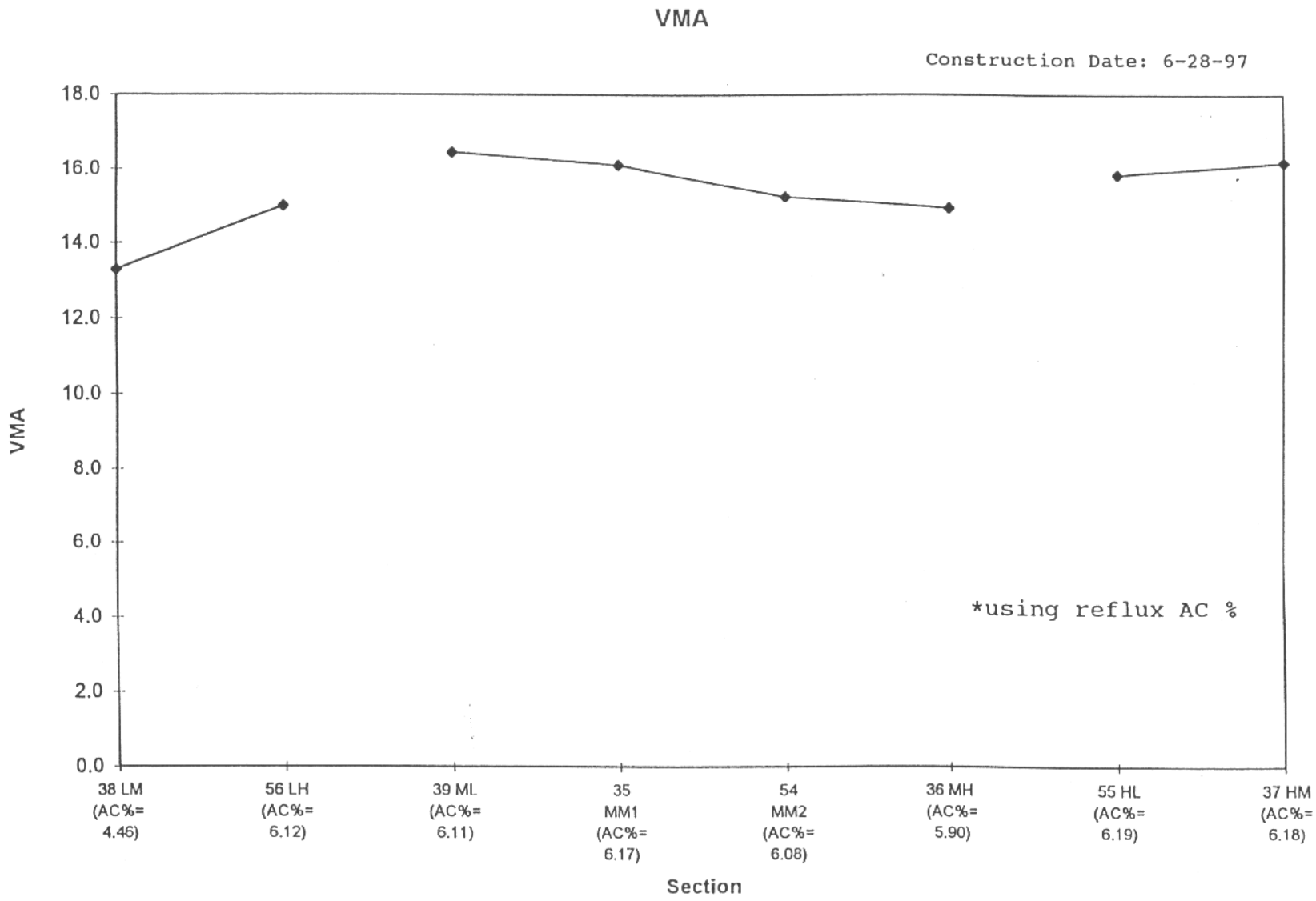
Construction Date: 6/28/97

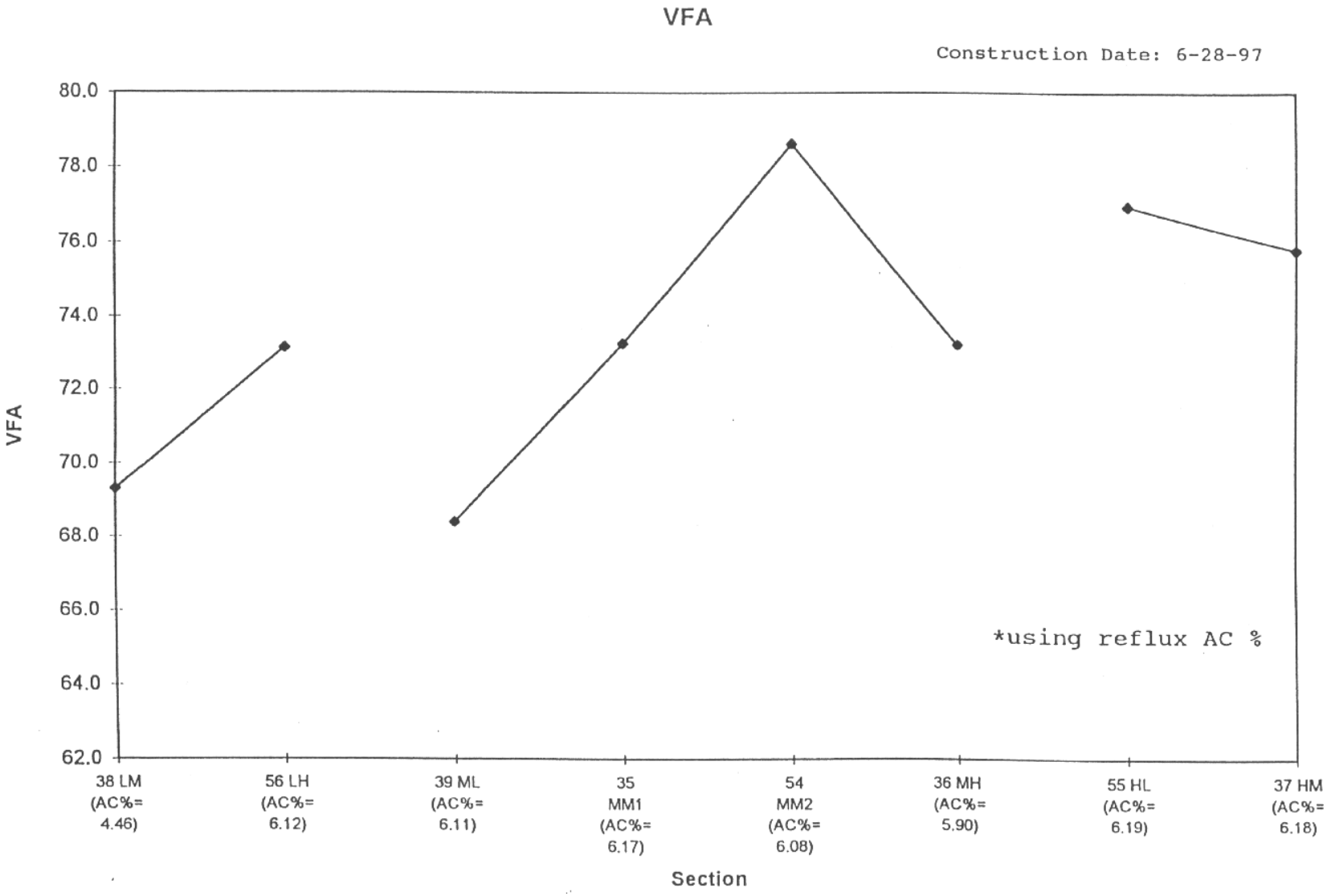
**using reflux % AC , and -#200*

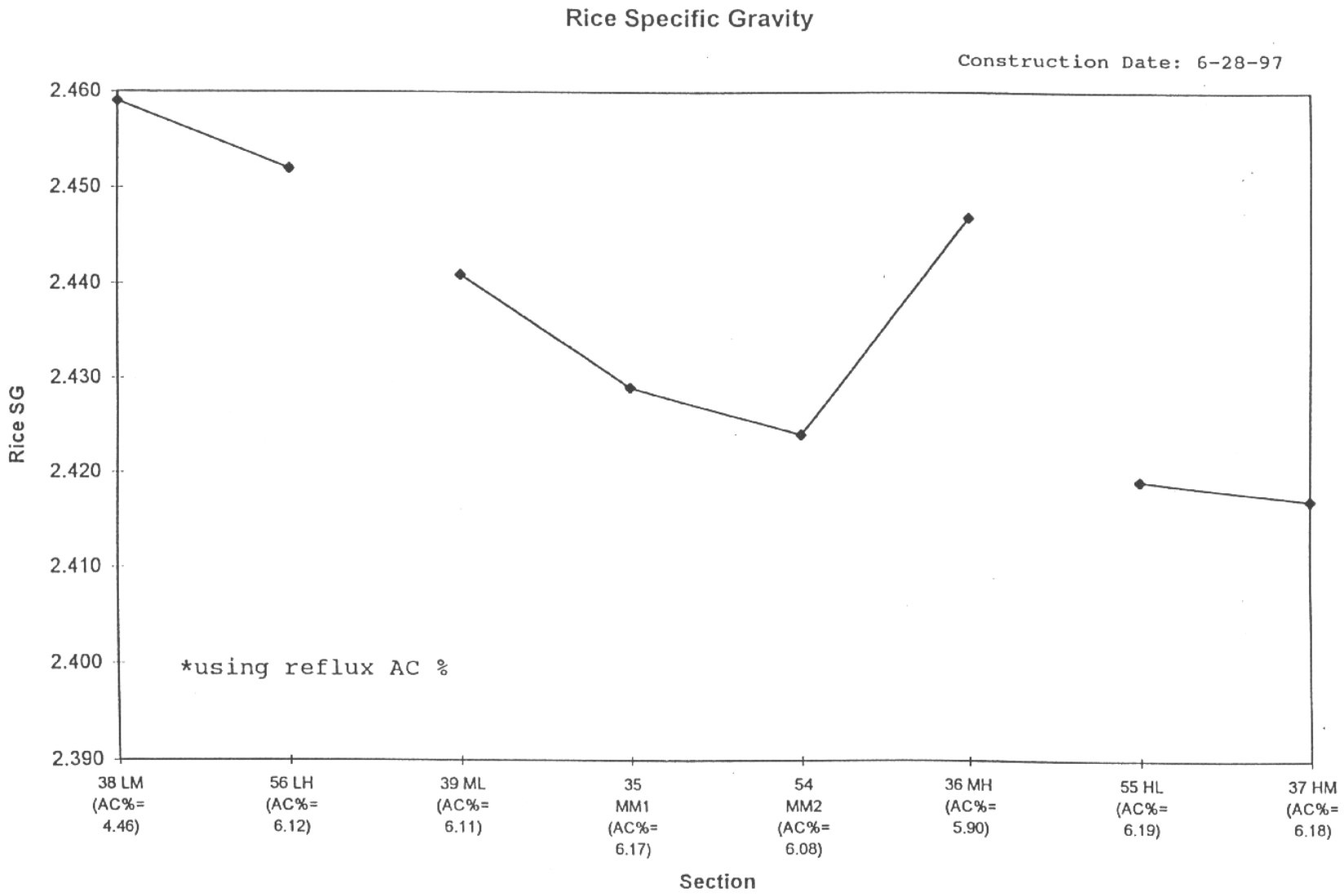
	Low AC		Medium AC				High AC	
Sec #	38 LM	56 LH	39 ML	35 MM1	54 MM2	36 MH	55 HL	37 HM
AC	4.46	6.12	6.11	6.17	6.08	5.90	6.19	6.18
VTM	4.1	4.0	5.3	4.3	3.3	4.0	3.7	3.9
VMA	13.3	15.0	16.5	16.1	15.3	15.0	15.9	16.2
VFA	69.3	73.1	68.4	73.3	78.6	73.2	77.0	75.8
Rice SG	2.459	2.452	2.441	2.429	2.424	2.447	2.419	2.417
% GmmNi	86.1	86.2	85.3	86.0	86.8	86.2	86.5	86.3
%GmmNm	97.5	97.4	96.2	97.1	98.2	97.5	97.9	97.6
F/A	1.935	1.164	1.221	1.109	1.079	1.248	1.035	1.121

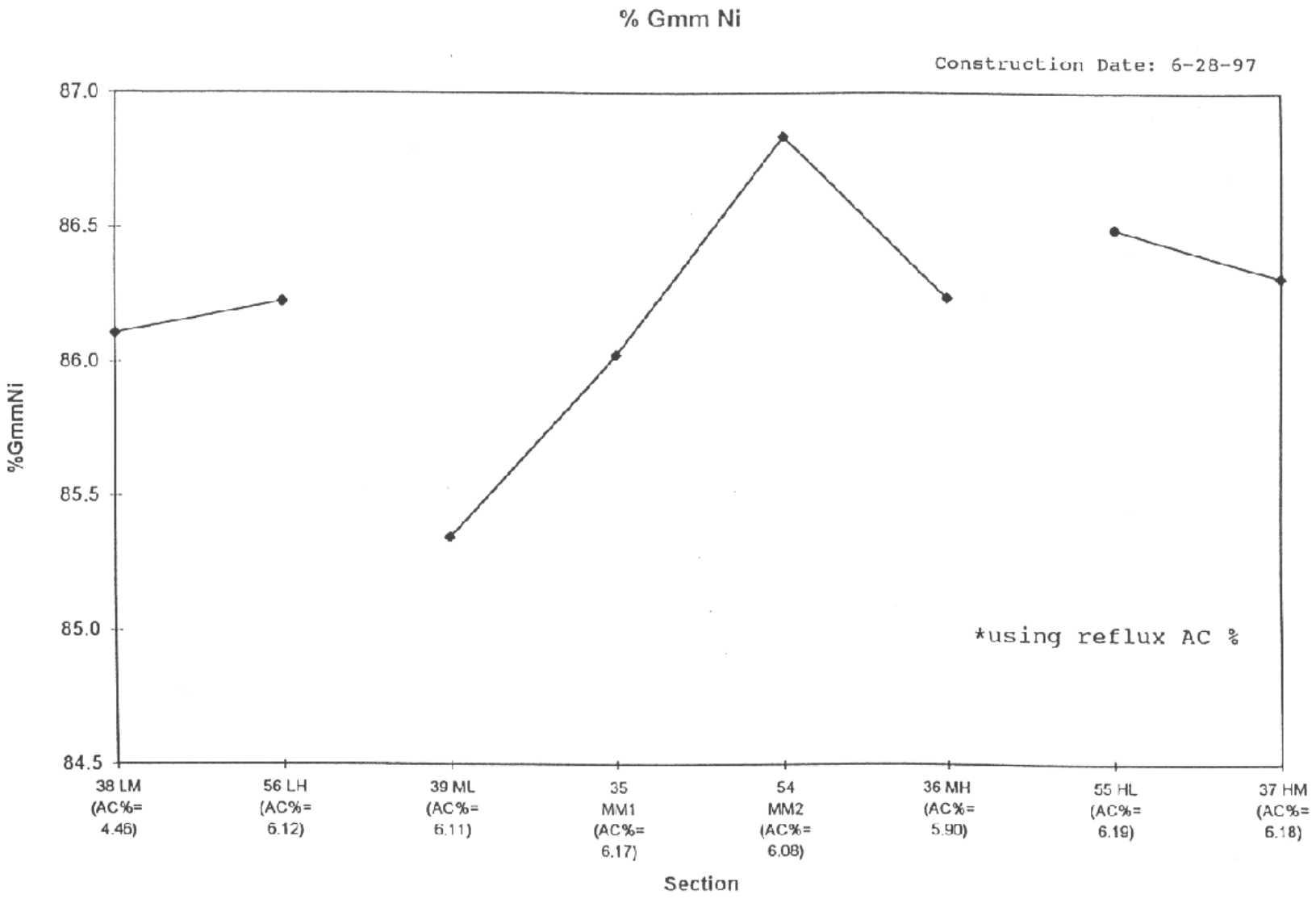

Asphalt Content
Construction Date: 6-28-97
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
AC%
*using reflux AC %
38 LM (AC%= 4.46)
56 LH (AC%= 6.12)
39 ML (AC%= 6.11)
35 MM1 (AC%= 6.17)
54 MM2 (AC%= 6.08)
36 MH (AC%= 5.90)
55 HL (AC%= 6.19)
37 HM (AC%= 6.18)
Section

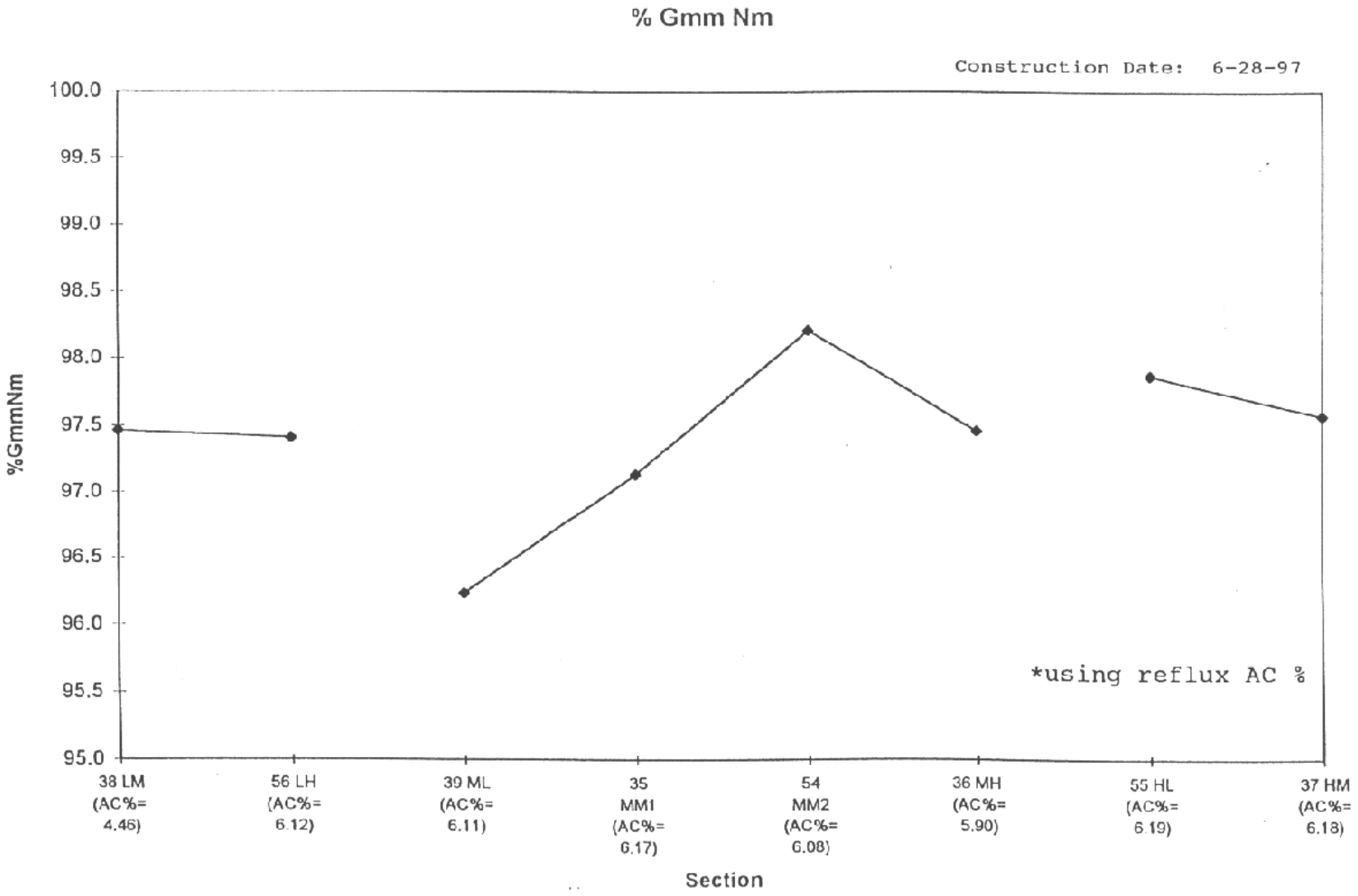

VTM
Construction Date: 6-28-97
6.0
5.0
4.0
3.0
2.0
1.0
0.0
VTM
*using reflux AC %
38 LM (AC%= 4.46)
56 LH (AC%= 6.12)
39 ML (AC%= 6.11)
35 MM1 (AC%= 6.17)
54 MM2 (AC%= 6.08)
36 MH (AC%= 5.90)
55 HL (AC%= 6.19)
37 HM (AC%= 6.18)
Section

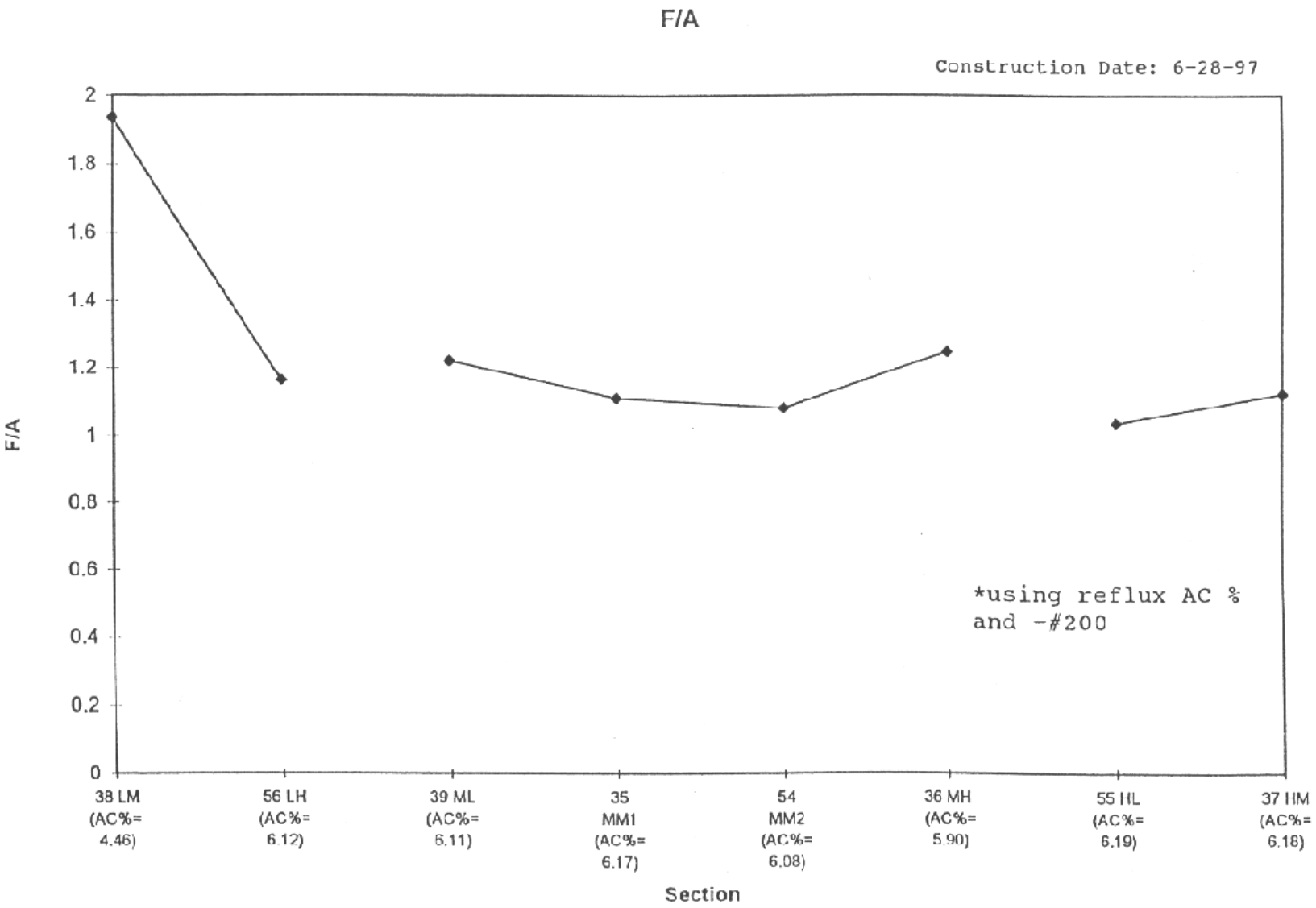

VMA
Construction Date: 6-28-97
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
VMA
*using reflux AC %
38 LM (AC%= 4.46)
56 LH (AC%= 6.12)
39 ML (AC%= 6.11)
35 MM1 (AC%= 6.17)
54 MM2 (AC%= 6.08)
36 MH (AC%= 5.90)
55 HL (AC%= 6.19)
37 HM (AC%= 6.18)
Section


VFA
Construction Date: 6-28-97
80.0
78.0
76.0
74.0
72.0
70.0
68.0
66.0
64.0
62.0
VFA
*using reflux AC %
38 LM (AC%= 4.46)
56 LH (AC%= 6.12)
39 ML (AC%= 6.11)
35 MM1 (AC%= 6.17)
54 MM2 (AC%= 6.08)
36 MH (AC%= 5.90)
55 HL (AC%= 6.19)
37 HM (AC%= 6.18)
Section


Rice Specific Gravity
Construction Date: 6-28-97
Rice SG
2.460
2.450
2.440
2.430
2.420
2.410
2.400
2.390
*using reflux AC %
38 LM (AC%= 4.46)
56 LH (AC%= 6.12)
39 ML (AC%= 6.11)
35 MM1 (AC%= 6.17)
54 MM2 (AC%= 6.08)
36 MH (AC%= 5.90)
55 HL (AC%= 6.19)
37 HM (AC%= 6.18)
Section


% Gmm Ni
Construction Date: 6-28-97
87.0
86.5
86.0
85.5
85.0
84.5
%GmmNi
*using reflux AC %
38 LM (AC%= 4.46)
56 LH (AC%= 6.12)
39 ML (AC%= 6.11)
35 MM1 (AC%= 6.17)
54 MM2 (AC%= 6.08)
36 MH (AC%= 5.90)
55 HL (AC%= 6.19)
37 HM (AC%= 6.18)
Section


% Gmm Nm
Construction Date: 6-28-97
100.0
99.5
99.0
98.5
98.0
97.5
97.0
96.5
96.0
95.5
95.0
%GmmNm
*using reflux AC %
38 LM (AC%= 4.46)
56 LH (AC%= 6.12)
39 ML (AC%= 6.11)
35 MM1 (AC%= 6.17)
54 MM2 (AC%= 6.08)
36 MH (AC%= 5.90)
55 HL (AC%= 6.19)
37 HM (AC%= 6.18)
Section


F/A
Construction Date: 6-28-97
F/A
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
*using reflux AC %
and -#200
38 LM
(AC%=
4.46)
56 LH
(AC%=
6.12)
39 ML
(AC%=
6.11)
35
MM1
(AC%=
6.17)
54
MM2
(AC%=
6.08)
36 MH
(AC%=
5.90)
55 HL
(AC%=
6.19)
37 HM
(AC%=
6.18)
Section

WesTrack - New Experiment Sections - Volumetric Data Summary

Test Lane, Top Lift

Construction Date: 6/28/97

Section	*AC	VTM	VMA	VFA	Rice SG	% GmmNi	%GmmNm	F/A
38 LM (AC%= 4.46)	4.46	4.1	13.3	69.3	2.459	86.1	97.5	1.93
56 LH (AC%= 6.12)	6.12	4.0	15.0	73.1	2.452	86.2	97.4	1.16
39 ML (AC%= 6.11)	6.11	5.3	16.5	68.4	2.441	85.3	96.2	1.22
35 MM1 (AC%= 6.17)	6.17	4.3	16.1	73.3	2.429	86.0	97.1	1.11
54 MM2 (AC%= 6.08)	6.08	3.3	15.3	78.6	2.424	86.8	98.2	1.08
36 MH (AC%= 5.90)	5.90	4.0	15.0	73.2	2.447	86.2	97.5	1.25
55 HL (AC%= 6.19)	6.19	3.7	15.9	77.0	2.419	86.5	97.9	1.03
37 HM (AC%= 6.18)	6.18	3.9	16.2	75.8	2.417	86.3	97.6	1.12

*using reflux % AC

Gyratory Compaction Data Summary

Section:	35	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4643.0	4641.2	4441.9
Weight in	2694.6	2686.3	2546.9
SSD Weigh	4646.9	4643.4	4454.8
BSG	2.378	2.371	2.328

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.17
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.666	% Agg by Total Weight of M	93.83
Absorbed Asphalt (Pba):	1.00	Percent Passing #200 Sieve	5.8
Effective AC Content (Pbe):	5.23	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.429

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4643	128.5	2269.6	2.046		1.030	2.106	86.7
2	4641.2	128.7	2273.2	2.042		1.025	2.093	86.2
3	4441.9	124.2	2193.7	2.025		1.022	2.069	85.2
Average	4575.4	127.1	2245.5	2.037		1.026	2.090	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4643.0	115.5	2040.0	2.276		1.030	2.343	3.5	15.4	77.1	96.5
2	4641.2	115.4	2038.3	2.277		1.025	2.334	3.9	15.7	75.2	96.1
3	4441.9	112.1	1980.0	2.243		1.022	2.293	5.6	17.2	67.5	94.4
Average	4575.4	114.3	2019.4	2.265		1.026	2.324				95.7

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4643.0	113.8	2010.0	2.310	2.378	1.030	2.378	97.9
2	4641.2	113.6	2006.5	2.313	2.371	1.025	2.371	97.6
3	4441.9	110.4	1949.9	2.278	2.328	1.022	2.328	95.8
Average	4575.4	112.6	1988.8	2.300	2.359	1.026	2.359	

Comments:

Gyratory Compaction Data Summary

Section:	36	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4729.8	4759.5	4629.9
Weight in	2752.1	2775.1	2680.3
SSD Weigh	4732.9	4761.5	4633.4
BSG	2.388	2.396	2.371

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	5.90
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.677	% Agg by Total Weight of M	94.10
Absorbed Asphalt (Pba):	1.16	Percent Passing #200 Sieve	6.0
Effective AC Content (Pbe):	4.81	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.447

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4729.8	130.8	2310.3	2.047		1.030	2.109	86.2
2	4759.5	131.0	2313.8	2.057		1.028	2.114	86.4
3	4629.9	128.4	2267.9	2.042		1.033	2.108	86.2
Average	4706.4	130.1	2297.3	2.049		1.030	2.110	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4729.8	117.3	2071.8	2.283		1.030	2.351	3.9	14.9	73.7	96.1
2	4759.5	117.4	2073.6	2.295		1.028	2.359	3.6	14.6	75.4	96.4
3	4629.9	115.9	2047.1	2.262		1.033	2.336	4.5	15.4	70.5	95.5
Average	4706.4	116.9	2064.2	2.280		1.030	2.349				95.0

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4729.8	115.5	2040.0	2.319	2.388	1.030	2.388	97.6
2	4759.5	115.6	2041.8	2.331	2.396	1.028	2.396	97.9
3	4629.9	114.2	2017.1	2.295	2.371	1.033	2.371	96.9
Average	4706.4	115.1	2033.0	2.315	2.385	1.030	2.385	

Comments:

Gyratory Compaction Data Summary

Section:	37	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4614.5	4487.9	4201.5
Weight in	2602.5	2582.0	2408.9
SSD Weigh	4616.2	4490.4	4207.0
BSG	2.386	2.352	2.337

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.18
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.651	% Agg by Total Weight of M	93.82
Absorbed Asphalt (Pba):	0.78	Percent Passing #200 Sieve	6.1
Effective AC Content (Pbe):	5.44	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.417

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4614.5	127.4	2250.2	2.051		1.031	2.115	87.5
2	4487.9	125.8	2221.9	2.020		1.028	2.077	85.9
3	4201.5	118.9	2100.1	2.001		1.033	2.067	85.5
Average	4434.6	124.0	2190.7	2.024		1.031	2.086	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4614.5	114.6	2024.1	2.280		1.031	2.351	2.7	15.1	81.9	97.3
2	4487.9	113.0	1995.9	2.249		1.028	2.312	4.3	16.5	73.8	95.7
3	4201.5	106.8	1886.4	2.227		1.033	2.302	4.8	16.9	71.8	95.2
Average	4434.6	111.5	1968.8	2.252		1.031	2.322				96.1

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4614.5	112.9	1994.1	2.314	2.386	1.031	2.386	98.7
2	4487.9	111.1	1962.3	2.287	2.352	1.028	2.352	97.3
3	4201.5	105.2	1858.1	2.261	2.337	1.033	2.337	96.7
Average	4434.6	109.7	1938.2	2.287	2.358	1.031	2.358	

Comments:

Gyratory Compaction Data Summary

Section:	38	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4697.9	4691.5	4684.1
Weight in	2739.1	2736.5	2734.5
SSD Weigh	4700.1	4694.6	4687.8
BSG	2.396	2.396	2.398

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	4.46
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.629	% Agg by Total Weight of M	95.54
Absorbed Asphalt (Pba):	0.45	Percent Passing #200 Sieve	7.8
Effective AC Content (Pbe):	4.03	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.459

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4697.9	129.3	2283.8	2.057		1.027	2.112	85.9
2	4691.5	129.0	2278.5	2.059		1.030	2.121	86.3
3	4684.1	128.9	2276.7	2.057		1.030	2.119	86.2
Average	4691.2	129.1	2279.6	2.058		1.029	2.117	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4697.9	115.9	2047.1	2.295		1.027	2.356	4.2	13.4	68.8	95.8
2	4691.5	116.0	2048.9	2.290		1.030	2.359	4.1	13.3	69.3	95.9
3	4684.1	115.7	2043.6	2.292		1.030	2.361	4.0	13.2	69.8	96.0
Average	4691.2	115.9	2046.5	2.292		1.029	2.359				95.9

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4697.9	114.0	2013.5	2.333	2.396	1.027	2.396	97.4
2	4691.5	114.2	2017.1	2.326	2.396	1.030	2.396	97.4
3	4684.1	113.9	2011.8	2.328	2.398	1.030	2.398	97.5
Average	4691.2	114.0	2014.1	2.329	2.397	1.029	2.397	

Comments:

Gyratory Compaction Data Summary

Section:	39	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4692.9	4748.9	4692.8
Weight in	2717.1	2705.9	2717.4
SSD Weigh	4696.7	4766.9	4695.6
BSG	2.371	2.304	2.372

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.11
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.679	% Agg by Total Weight of M	93.89
Absorbed Asphalt (Pba):	1.19	Percent Passing #200 Sieve	6.1
Effective AC Content (Pbe):	5.00	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.441

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4692.9	130.1	2297.9	2.042		1.030	2.103	86.1
2	4748.9	133.3	2354.4	2.017		1.014	2.045	83.8
3	4692.8	129.9	2294.4	2.045		1.028	2.102	86.1
Average	4711.5	131.1	2315.6	2.035		1.024	2.083	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4692.9	117.2	2070.0	2.267		1.030	2.334	4.4	15.7	72.1	95.6
2	4748.9	120.2	2123.0	2.237		1.014	2.268	7.1	18.1	60.7	92.9
3	4692.8	116.9	2064.7	2.273		1.028	2.336	4.3	15.6	72.4	95.7
Average	4711.5	118.1	2085.9	2.259		1.024	2.313				94.7

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4692.9	115.4	2038.3	2.302	2.371	1.030	2.371	97.1
2	4748.9	118.3	2089.5	2.273	2.304	1.014	2.304	94.4
3	4692.8	115.1	2033.0	2.308	2.372	1.028	2.372	97.2
Average	4711.5	116.3	2053.6	2.295	2.349	1.024	2.349	

Comments:

Gyratory Compaction Data Summary

Section:	54	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4727.0	5191.6	4881.7
Weight in	2744.8	3011.9	2834.1
SSD Weigh	4729.0	5195.3	4883.7
BSG	2.382	2.378	2.382

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.08
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.656	% Agg by Total Weight of M	93.92
Absorbed Asphalt (Pba):	0.85	Percent Passing #200 Sieve	5.7
Effective AC Content (Pbe):	5.28	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.424

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4727	130.4	2303.2	2.052		1.025	2.105	86.8
2	5191.6	143.6	2536.3	2.047		1.027	2.101	86.7
3	4881.7	134.5	2375.6	2.055		1.026	2.109	87.0
Average	4933.4	136.2	2405.0	2.051		1.026	2.105	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4727.0	116.9	2064.7	2.289		1.025	2.348	3.1	15.2	79.2	96.9
2	5191.6	128.9	2276.7	2.280		1.027	2.341	3.4	15.4	77.7	96.6
3	4881.7	120.9	2135.4	2.286		1.026	2.346	3.2	15.2	78.9	96.8
Average	4933.4	122.2	2158.9	2.285		1.026	2.345				96.7

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4727.0	115.2	2034.7	2.323	2.382	1.025	2.382	98.3
2	5191.6	126.9	2241.4	2.316	2.378	1.027	2.378	98.1
3	4881.7	119.1	2103.6	2.321	2.382	1.026	2.382	98.3
Average	4933.4	120.4	2126.6	2.320	2.381	1.026	2.381	

Comments:

Gyratory Compaction Data Summary

Section:	55	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4767.3	4669.9	4732.8
Weight in	2761.6	2697.8	2735.6
SSD Weigh	4770.4	4673.3	4736.6
BSG	2.373	2.364	2.365

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.19
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.654	% Agg by Total Weight of M	93.81
Absorbed Asphalt (Pba):	0.83	Percent Passing #200 Sieve	5.6
Effective AC Content (Pbe):	5.41	Filler/Effective AC Ratio	
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.419

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4767.3	132.5	2340.3	2.037		1.030	2.097	86.7
2	4669.9	129.6	2289.1	2.040		1.026	2.094	86.6
3	4732.8	132.0	2331.5	2.030		1.027	2.086	86.2
Average	4723.3	131.4	2320.3	2.036		1.028	2.092	

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4767.3	118.9	2100.1	2.270		1.030	2.337	3.4	15.6	78.4	96.6
2	4669.9	116.6	2059.4	2.268		1.026	2.327	3.8	16.0	76.3	96.2
3	4732.8	118.3	2089.5	2.265		1.027	2.327	3.8	16.0	76.3	96.2
Average	4723.3	117.9	2083.0	2.268		1.028	2.331				96.3

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4767.3	117.1	2068.3	2.305	2.373	1.030	2.373	98.1
2	4669.9	114.8	2027.7	2.303	2.364	1.026	2.364	97.7
3	4732.8	116.4	2055.9	2.302	2.365	1.027	2.365	97.8
Average	4723.3	116.1	2050.6	2.303	2.367	1.028	2.367	

Comments:

Gyratory Compaction Data Summary

Section:	56	N initial:	8	Mixture Moisture Determination	
Lift:	top	N design:	96	Moist Weight of Mix:	
Lane:	Test	N max:	152	Dry Weight of Mix:	
Paving Day:	6/28/97	Mix Temp (C):	150	% Moisture:	#DIV/0!
		Compaction Temp (C)	140		

	Specimen ID 1	2	3
Dry Mass	4740.9	4774.5	4711.6
Weight in	2759.9	2777.6	2741.6
SSD Weigh	4743.9	4777.5	4714.3
BSG	2.390	2.387	2.388

Specific Gravity of AC (Gb)	1.032	% AC by Total Weight of Mi	6.12
Bulk Dry Specific Gravity o	2.599	% AC by Dry Weight of Agg:	
Effective Specific Gravity	2.694	% Agg by Total Weight of M	93.88
Absorbed Asphalt (Pba):	1.39	Percent Passing #200 Sieve	5.6
Effective AC Content (Pbe):	4.81	Filler/Effective AC Ratio	#DIV/0!
Specimen Diameter (mm):	150	Maximum Specific Gravity (	2.452

Properties at N initial

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNi
1	4740.9	130.7	2308.5	2.054		1.028	2.112	86.1
2	4774.5	131.6	2324.4	2.054		1.029	2.113	86.2
3	4711.6	129.8	2292.6	2.055		1.031	2.118	86.4
Average	4742.3	130.7	2308.5	2.054		1.029	2.114	86.2

Properties at N design

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% VTM	% VMA	% VFA	% GmmNd
1	4740.9	117.2	2070.0	2.290		1.028	2.355	4.0	14.9	73.5	96.0
2	4774.5	118.3	2089.5	2.285		1.029	2.351	4.1	15.1	72.7	95.9
3	4711.6	116.8	2063.0	2.284		1.031	2.354	4.0	15.0	73.2	96.0
Average	4742.3	117.4	2074.2	2.286		1.029	2.353	4.0	15.0	73.1	96.0

Properties at N max

Specimen ID	Mass (grams)	Height (mm)	Volume (cm^3)	Gmb (est)	Gmb (meas)	Corr	Gmb (corr)	% GmmNm
1	4740.9	115.5	2040.0	2.324	2.390	1.028	2.390	97.5
2	4774.5	116.5	2057.7	2.320	2.387	1.029	2.387	97.4
3	4711.6	115.1	2033.0	2.318	2.388	1.031	2.388	97.4
Average	4742.3	115.7	2043.6	2.321	2.388	1.029	2.388	97.4

Comments:

Replacement Construction HMA Quality Assurance Superpave Volumetric Properties

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-11
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the SHRP Superpave HMA volumetric design method.

This WesTrack technical report provides information on quality assurance HMA volumetric properties for the replacement construction mixtures. The reader is referred to WesTrack Technical Report UNR-10[4] for replacement section construction HMA quality control Superpave volumetric properties information and WesTrack Technical Reports UNR-18[5] and UNR 19[6] for original construction and replacement HMA QC/QA materials sampling and testing plans, respectively.

The primary purpose of this document is to summarize HMA quality assurance Superpave volumetric property data, providing an official set of replacement construction mixture volumetrics. Some would refer to the volumetrics as field-mixed, laboratory-compacted (FMLC) volumetric properties, as the material used was produced in the field (at the hot plant), sampled in the loose state, and subsequently compacted in a laboratory compaction device. The volumetric properties reported are based on measurements performed on 160 specimens compacted in a Superpave gyratory compactor (SGC) manufactured by Pine Instruments. A different model, a Troxler SGC, was used for field quality control and mix design purposes. The data reported in the final project report was based on the quality assurance asphalt content and gradation data as provided in WesTrack Technical Reports UNR-17[7] and UNR 24,[8] respectively. These data were also used for all performance modeling and specification development.

BACKGROUND

This section of the report provides information on the Superpave volumetric mix design specifications for the specific WesTrack project conditions; the type of compactors used in mix design, quality control and quality assurance (QC/QA) operations; the material property and mixture sources; and the types and numbers (replicates) of tests performed.

VOLUMETRIC SPECIFICATIONS

The Superpave volumetric mix design method was used to design all of the mixtures placed at WesTrack;[1,2,9] thus, the quality assurance FMLC volumetric properties should be evaluated relative to the replacement mix design and the Superpave volumetric mix design specifications. The Superpave volumetric mix design method is a performance-based mix design method; in this system, materials requirements are a function of traffic, climate, and the depth below the surface at which the material is to be incorporated. Gradation requirements are a function of nominal maximum size aggregate. The number of gyrations applied in the gyratory compactor is a function of expected traffic and climate. Final mixture properties must meet specifications that are a function of nominal maximum aggregate size and traffic, and also include a dust proportion restriction and moisture sensitivity testing.[10,11,12]

The planned traffic over the original project accelerated 2-year loading period was 10 million 80-kN (18,000-lb) ESALs and the average design high air temperature was less than 39° C.[2,3] Because fatigue cracking was expected in some test sections at approximately 3.5 million 80-kN (18,000-lb) ESALs (based on structural design), the number of initial, design, and maximum gyrations were set at the values for 3 to 10 million 80-kN (18,000-lb) ESALs, 8, 109, and 152, respectively, for the original construction mix designs. The compactive effort used for the replacement mix design was consistent with the original construction mix design compaction conditions – 8, 109, and 152 gyrations. The same numbers of gyrations were also used for replacement QC/QA compaction efforts. The Superpave mixture specifications for this project are stated in table 1.

GYRATORY COMPACTION

The original construction Superpave mix design, QC, and QA specimens were compacted using Troxler SGCs. The compactor used for mix design and QC purposes was owned by FHWA and installed in one of the FHWA Superpave mobile laboratories. A Troxler SGC owned by the University of Nevada, Reno (UNR) was used for the original construction QA testing and also was used in the mix design of the replacement mixture. It was the same model as the FHWA Troxler compactor, but it was owned by UNR. Exactly the same compactor was used in the QC operations set up at WesTrack during construction of the replacement sections. The compactor used for quality assurance purposes was a Pine Instruments SGC. The QA compaction was performed by UNR at its Pavement Materials Laboratory in Reno, Nevada, using the UNR compactor. The Nevada Department of Transportation senior technician who performed the replacement mix design also performed the QC and QA testing.

Note, an interlaboratory study (round robin) was conducted with both UNR compactors, the

FHWA compactor used in the original construction (Troxler), a Pine SGC owned by Oregon State University, and two NDOT SGCs (one each from Troxler and Pine). Analysis of the results suggested that there were no statistically significant differences in bulk specific gravities measured among the specimens compacted in the different SGCs.

MATERIAL PROPERTIES AND SOURCES

Six material properties are required to determine the volumetric properties of FMLC specimens. The properties are:

- Asphalt content.
- Asphalt cement specific gravity.
- Amount of material passing the 0.075-mm sieve.
- Combined aggregate bulk specific gravity.
- Bulk specific gravity of the compacted specimen.
- Theoretical maximum specific gravity of the mix.

For the purpose of this report, WesTrack Technical Report QA asphalt content, gradation, and aggregate specific gravities were used for volumetric calculations. The asphalt content data were obtained from WesTrack Technical Report UNR-17.[7] The asphalt specific gravity used was that reported by the asphalt producer and reported in WesTrack Technical Report UNR-2.[13] The gradation data were obtained from WesTrack Technical Report UNR-24[8] and are based on sieve analyses performed on the aggregate remains of five ignition asphalt content tests per individual section and lift. The ignition asphalt content tests were performed on loose mix sampled behind the paver. The ignition asphalt content specimens and the QC volumetric materials were split from the same bulk samples. The combined aggregate (blend) bulk specific gravity employed in the volumetric calculations was obtained from WesTrack Technical Report UNR-5.[14] The specific gravity value employed was identical to the value used in mix design and QC calculations. The other two properties needed to establish mixture volumetrics were the bulk specific gravity of the compacted specimens and the theoretical maximum specific gravity of the loose mixture. These properties were determined on 160 individual gyratory-compacted specimens and 160 individual loose mix samples, respectively. The quality assurance plan defines what materials were used, where they were sampled, and how many specimens were tested.

Quality Assurance Test Plan

A summary of the QA test plan for the replacement sections is presented in table 2. The HMA volumetrics QA test plan dictated that Superpave volumetric properties be established on five sublots per lot. (See highlighted section of QA test plan in table 2.) A lot was defined as one lift of one test section. Five sublots were sampled per lot and two tests were performed per sublot sample, i.e., a total of ten specimens were compacted per lift and test section. The HMA was placed in two 75-mm (3-in.) lifts. The lifts have been referred to as “top” and “bottom.”

All of the replacement construction HMA QA volumetric testing was conducted at UNR.

Harding Lawson and Associates (HLA) performed the original construction QA testing. The data reported from the testing for each sublot were the average properties established on two replicate gyratory compacted samples. The materials tested were sampled from trucks at the hot plant during replacement section construction. Five bulk truck samples were taken randomly for each lift of each test section from a set of three truck trailers. The bulk material samples were split into several smaller samples and transported to UNR. The QA testing was initiated as soon as the replacement construction was completed.

Each of the five bulk loose mix truck samples taken per section and lift weighed approximately 34 kg (75 lb). Immediately after sampling, each bulk sample was split into several test samples. For example, several samples of appropriate size to fill 200-mm (8-in.) square cardboard boxes were split. The boxes were labeled appropriately and shipped to UNR for QA testing. Two gyratory compaction and two theoretical maximum specific gravity (Rice) samples were split from the material placed in each cardboard box at the UNR lab, after re-heating, for QA volumetric purposes. The average of each pair of theoretical maximum specific gravity test results was reported in accordance with AASHTO T 209; thus, volumetric data summaries only show five test results.

VOLUMETRIC DATA

The QA Superpave volumetric properties calculated based on the above discussion are presented in summary form in tables 3 and 4. Top and bottom lift data for each section are reported separately. It is important to note that top lift data was used subsequently for permanent deformation modeling and bottom lift data was used for fatigue cracking modeling. The data reported in each summary table represents the average of the five sublots, or, in other words, the average of ten gyratory-compacted specimens. All 160 individual gyratory specimen data are provided in appendix A. All volumetric properties reported are at the design number of gyrations, with the exception of percent compaction at the initial and maximum numbers of gyrations.

The summary tables include data on the seven standard Superpave volumetric properties:

- Asphalt content (%AC).
- Theoretical maximum specific gravity (Rice).
- Percent air voids (%VTM).
- Percent voids in mineral aggregate (%VMA).
- Percent voids filled with asphalt (%VFA).
- Percent compaction at initial ($\%Gmm_i$), design ($\%Gmm_d$), and maximum ($\%Gmm_m$) gyrations.
- Filler-to-asphalt ratio (F/A) or dust-to-binder ratio.

Summary statistics are also provided in the tables for each of the above-listed properties. The statistics include average, standard deviation, coefficient of variation, minimum and maximum values, range, and the number of replicate specimens tested. All of the test results generated by

UNR are reported. No data were removed, based on outlier detection, prior to developing the summary statistics.

Figures 1 and 2 are plots of percent air voids, at the design number of gyrations, versus section number and asphalt content. There is one plot for each lift. Note that the x-axes of the plots show section number with asphalt content in parentheses. The section numbers are grouped by target asphalt content levels of low (L), medium (M), and high (H). Therefore, the asphalt content values along the x-axes are in order by group from low to high, but the actual asphalt contents are not necessarily in order within a target asphalt level.

Theoretically, the mix design optimum asphalt contents should be represented by the medium asphalt content level sections. This assumes that the asphalt content of the field sections was at the target value. Both the top and bottom lift field-observed asphalt contents spanned a range of approximately 0.6 percent. Overall, the bottom lift asphalt contents were slightly lower than the top lift asphalt contents. The laboratory (mix design) optimum asphalt content for the replacement mix was 5.7 percent by total weight of mix.

The trends in each plot were reasonable in that asphalt content levels were fairly flat across all sections. Thus, only small increases in percent air voids were observed with small decreases in asphalt content for all mixes and lifts. The air voids at the medium asphalt content level ranged from 3.0 to 5.5 percent for the top lift mixtures. They ranged from 4.0 to 7.0 percent for the bottom lift mixtures, which was consistent with the fact that the bottom lift asphalt contents were slightly lower than the top lift asphalt contents. The mixture appeared to have been somewhat insensitive to small changes in asphalt content.

A review of the tables in appendix A reveals that the VMA of the field-produced mixtures was quite high, ranging from 15 to 17 percent. These values were consistent with the mix design data, indicating that a significant drop in VMA was not observed from the mix design to the field. The VFA of the mixtures was not excessively high, ranging from approximately 60 to 76 percent. Something else that is apparent, even from a brief review of the data, is that the variability in all volumetric properties appears to be high. For example, the range of air voids at the design number of gyrations was from 0.8 to 4.9 percent, which is larger than the range of 2.5 percent typically reported. However, it was noted in the original construction that the coarse mix exhibited about double the variability of the fine and fine plus mixtures (approximately 1.0 percent range in air voids for the fine and fine plus mixes, versus well over 2.0 percent for most of the coarse mixtures). Therefore, it appears as though coarse-graded (below the restricted zone) Superpave mixtures exhibit greater variability in laboratory-measured volumetric properties. Potential reasons for this variability include segregation and difficulty in obtaining the saturated surface dry condition when performing bulk specific gravity determinations.

Similar to the findings with the original construction coarse mixture, several potential air void outliers were observed. A conservative rule of thumb that is commonly used for outlier detection is to multiply the standard deviation for a property by two, then add, and subtract that value from the mean. Any individual value that falls outside the range of the mean, plus or minus two times the standard deviation, is considered an outlier. When this procedure was applied to the percent air voids data, three outliers were observed, which was about 2 percent of the total. In the original construction, a similar analysis revealed that 5 percent of the coarse mix

air void observations were outliers. However, only 0.5 percent were observed for the fine and fine plus mixtures.

SUMMARY

Replacement mixture HMA QA field-mixed, laboratory-compacted volumetric data were summarized, providing an "official" set of replacement section volumetrics data. The Superpave volumetric specifications for the WesTrack project nominal maximum size aggregate, traffic, and environmental conditions were presented. The materials tested were compacted with a Pine Instruments SGC. A Troxler SGC was used in the mix design and quality control operations. An extensive experiment conducted beforehand indicated that no significant difference was exhibited in the bulk specific gravities of specimens compacted in each device.

A total of 160 specimens were compacted. They were representative of five bulk samples per lift and test section. The bulk samples were taken from transfer trucks at the hot plant and delivered to UNR almost immediately for testing. Two gyratory compaction and two theoretical maximum specific gravity specimens were split from each sample for testing.

In addition to the bulk specific gravity of the compacted specimens and the theoretical maximum specific gravity of the loose mixes, several other material properties were needed to establish volumetric properties. QA asphalt content, gradation (based on aggregate remaining from loose HMA material sampled from the mat and tested using the ignition asphalt content determination method), and blended aggregate specific gravities were employed. The blended aggregate bulk specific gravities were identical to those used for the mix design and QC field-mixed, laboratory compacted volumetric determinations. The specific gravity of the asphalt cement reported by the supplier and verified during and after construction was used. The seven standard Superpave volumetric properties for every compacted specimen are presented in appendix A. The properties were also summarized in tables that included several summary statistics. The summary statistics revealed significant variability in the coarse mix test results.

Plots of percent air voids versus target asphalt content level (figures 1 and 2) show the expected, but somewhat flat, trends for all mixes. The percent air voids at the medium asphalt content level ranged from 3.0 to 5.5 percent for the top lift mixtures and 4.0 to 7.0 percent for bottom lift mixtures. This observation was reasonable in that the asphalt contents of the bottom lift mixtures were slightly lower those of the top lift mixtures. The mixtures exhibited high VMA (15 to 17 percent) and appeared to be somewhat insensitive to small changes in asphalt content. This is likely due to the fact the mixtures had such high VMA.

The data were reported in the final project report[15] and were used for all performance modeling and specification development purposes.

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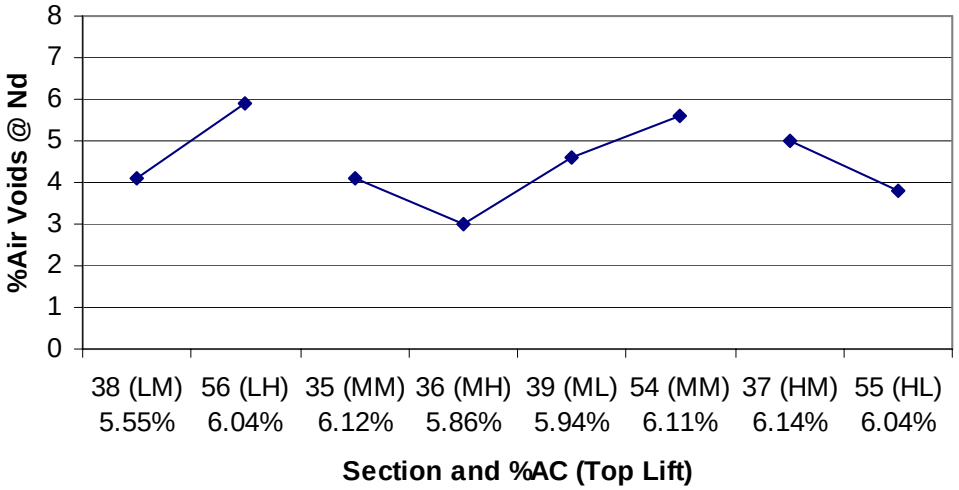

Figure 1. Replacement mixture – top lift air voids.

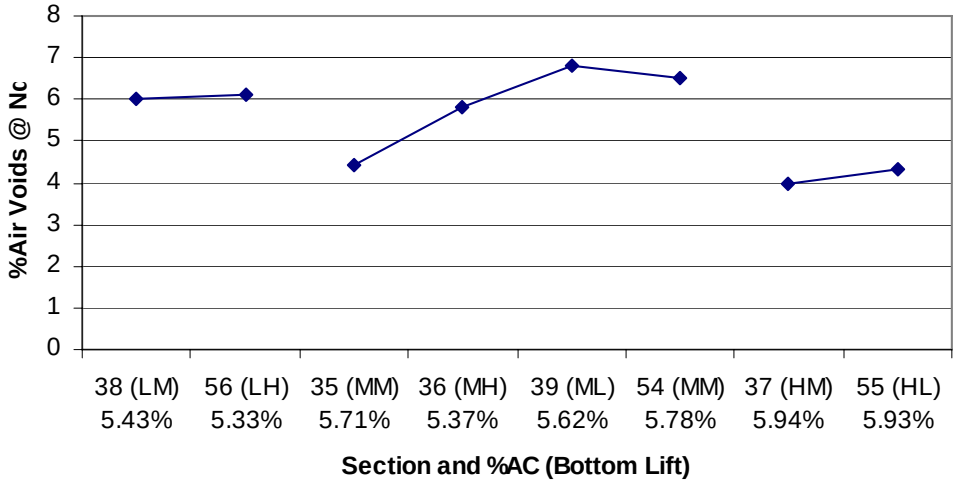

Figure 2. Replacement mixture – bottom lift air voids.

*(LM) = Low Asphalt Content/Medium Air Void Content

Table 1. Superpave volumetric mixture specifications.

Mixture Property	Criteria*
% Air Voids (AV or VTM)	4%
% Voids in Mineral Aggregate (VMA)	13% minimum
% Voids Filled with Asphalt (VFA)	65% - 75%
Dust-to-Binder (F/A)	0.6 - 1.2
% Gmm @ $N_{initial}$ = 8 (GMMi)	< 89%
% Gmm @ N_{design} = 96 (GMMd)	96%
% Gmm @ N_{max} = 152 (GMMm)	< 98%

*3 to 10 million ESALs.

Table 2. Replacement sections – quality assurance test plan (after reference 6).

General Property	Test Method	Tests/ Sublot	Sublots/ Lot	Number of Lots or Sections to be Tested	Number of Lifts
Asphalt Content	Nuclear*	1	5	8	2
	Extraction	1	1	8	2
	Ignition	1	5	8	2
Gradation	Cold feed	1	5	8	2
	Extraction	1	1	8	2
	Ignition	1	5	8	2
Superpave Gyratory Compaction (N_{max})	**Bulk SP GR**	**2**	**5**	**8**	**2**
	Volumetrics	**2**	**5**	**8**	**2**
Superpave Gyratory Compaction (N_{design})*	Bulk SP GR	1	5	8	2
	Volumetrics	1	5	8	2
	M_R	1	5	8	2
Marshall Compaction	Bulk SP GR	3	1	8	2
	Volumetrics	3	1	8	2
	Stability & Flow	3	1	8	2
Hveem Compaction	Bulk SP GR	3	1	8	2
	Volumetrics	3	1	8	2
	Stability	3	1	8	2
Theo. Maximum Spec. Grov.		1	5	8	2
Plant HMA Temperature		1	5	8	2
Laydown HMA Temperature		1	5	8	2
In-Place Air Voids	Nuclear	2	5	8	2
	Cores	1	5	8	2

*Indicates that changes were made in initially planned testing associated with these items; however, no changes were made in the FMLC Superpave gyratory compaction (N_{max}) testing.

Table 3. Replacement mixture – top lift gyratory volumetrics summary (QA).

Section 35	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.12	2.421	4.1	16.1	74.7	86.1	95.9	97.4	1.05
Standard Deviation	0.12	0.008	0.2	0.2	1.4	0.3	0.2	0.2	0.03
Coefficient of Variation	2.02	0.347	5.6	1.5	1.9	0.4	0.2	0.2	2.57
Max	6.32	2.429	4.5	16.4	77.1	86.9	96.3	97.7	1.08
Min	5.98	2.408	3.7	15.8	72.2	85.8	95.5	97.0	1.00
Range	0.34	0.021	0.8	0.7	4.8	1.1	0.8	0.7	0.07
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 36	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.86	2.416	3.0	15.1	80.3	86.8	97.0	98.3	1.09
Standard Deviation	0.10	0.011	1.2	0.7	7.3	1.2	1.2	1.0	0.04
Coefficient of Variation	1.69	0.448	40.5	4.8	9.1	1.4	1.3	1.1	3.39
Max	5.93	2.431	4.7	16.1	92.4	88.9	98.9	99.8	1.14
Min	5.69	2.401	1.1	13.9	70.5	85.1	95.3	96.7	1.04
Range	0.24	0.030	3.7	2.2	21.9	3.8	3.7	3.1	0.11
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 37	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.14	2.442	5.0	16.2	69.2	85.2	95.0	96.4	1.15
Standard Deviation	0.12	0.013	0.6	0.2	3.3	0.5	0.6	0.6	0.05
Coefficient of Variation	1.95	0.515	11.4	1.2	4.8	0.6	0.6	0.6	4.15
Max	6.29	2.460	5.8	16.5	75.4	86.2	96.1	97.5	1.22
Min	6.00	2.426	3.9	15.8	64.3	84.6	94.2	95.5	1.08
Range	0.29	0.034	2.0	0.7	11.1	1.6	2.0	2.0	0.14
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 38	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.55	2.439	4.1	15.0	73.0	86.1	95.9	97.4	1.29
Standard Deviation	0.13	0.013	1.1	0.6	6.1	1.0	1.1	1.0	0.06
Coefficient of Variation	2.34	0.515	26.0	3.7	8.4	1.2	1.1	1.1	4.27
Max	5.72	2.452	5.3	15.6	82.5	87.7	97.5	98.9	1.35
Min	5.38	2.425	2.5	14.0	66.2	84.9	94.7	96.2	1.23
Range	0.34	0.027	2.8	1.6	16.3	2.8	2.8	2.7	0.13
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 39	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.94	2.433	4.6	16.0	71.3	85.6	95.4	96.8	1.13
Standard Deviation	0.27	0.010	0.6	0.4	3.5	0.7	0.6	0.6	0.04
Coefficient of Variation	6.11	0.415	14.2	2.7	4.9	0.8	0.7	0.7	3.30
Max	6.28	2.448	5.2	16.6	77.7	86.7	96.6	98.0	1.19
Min	5.58	2.420	3.4	15.4	68.2	84.7	94.8	96.2	1.08
Range	0.70	0.028	1.7	1.2	9.4	2.0	1.7	1.7	0.11
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 54	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.11	2.442	5.6	16.7	66.9	84.7	94.4	95.8	1.17
Standard Deviation	0.08	0.012	1.4	0.9	6.4	1.3	1.4	1.4	0.05
Coefficient of Variation	1.31	0.488	24.6	5.1	9.5	1.5	1.5	1.4	3.91
Max	6.22	2.458	8.0	18.3	75.3	86.4	96.1	97.5	1.23
Min	6.03	2.425	3.9	15.8	56.4	82.4	92.0	93.4	1.10
Range	0.19	0.033	4.1	2.5	18.9	4.0	4.1	4.1	0.13
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 3. Replacement mixture – top lift gyratory volumetrics summary (QA) (continued).

Section 55	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.04	2.420	3.8	15.8	76.3	86.2	96.2	97.7	1.13
Standard Deviation	0.33	0.011	1.1	0.6	5.5	1.0	1.1	1.1	0.04
Coefficient of Variation	5.46	0.471	27.9	3.9	7.2	1.2	1.1	1.1	3.61
Max	6.53	2.437	5.8	17.0	81.3	87.3	97.1	98.6	1.19
Min	5.59	2.408	2.9	15.3	65.7	84.3	94.2	95.6	1.08
Range	0.94	0.029	3.0	1.7	15.6	3.0	3.0	3.0	0.11
Number of Replicates	5	5	10	10	10	10	10	10	10
Section 56	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	6.04	2.452	5.9	16.6	64.5	84.5	94.1	95.5	1.28
Standard Deviation	0.11	0.010	0.7	0.4	3.4	0.7	0.7	0.7	0.04
Coefficient of Variation	1.82	0.400	11.9	2.6	5.3	0.9	0.7	0.8	3.31
Max	6.14	2.465	6.9	17.3	69.0	85.4	94.9	96.4	1.34
Min	5.89	2.438	5.1	15.9	59.5	83.2	93.1	94.5	1.22
Range	0.25	0.027	1.8	1.4	9.5	2.2	1.8	1.9	0.12
Number of Replicates	5	5	10	10	10	10	10	10	10

Table 4. Replacement mixture – bottom lift gyratory volumetrics summary (QA).

Section (35)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.71	2.437	4.4	15.5	71.6	85.9	95.6	96.9	1.04
Standard Deviation	0.12	0.006	0.9	0.6	4.7	0.8	0.9	0.9	0.02
Coefficient of Variation	2.10	0.243	20.6	4.1	6.5	0.9	1.0	1.0	2.11
Max	5.79	2.445	5.8	16.4	76.7	86.8	96.5	97.9	1.07
Min	5.56	2.430	3.5	14.8	64.7	84.7	94.2	95.6	1.02
Range	0.23	0.015	2.3	1.6	11.9	2.1	2.3	2.4	0.06
Number of Replicates	3	4	8	8	8	8	8	8	8
Section (36)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.37	2.445	5.8	16.1	64.3	84.5	94.2	95.6	1.15
Standard Deviation	0.16	0.013	1.0	0.7	4.9	1.0	1.0	1.1	0.05
Coefficient of Variation	2.98	0.514	17.9	4.1	7.6	1.1	1.1	1.1	4.46
Max	5.39	2.462	7.8	17.4	68.8	85.5	95.2	96.5	1.22
Min	5.21	2.430	4.8	15.3	54.9	82.5	92.2	93.5	1.08
Range	0.18	0.032	3.0	2.1	14.0	2.9	3.0	3.1	0.14
Number of Replicates	3	5	10	10	10	10	10	10	10
Section (37)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.94	2.423	4.0	15.8	74.9	86.0	96.0	97.4	1.03
Standard Deviation	0.22	0.009	0.7	0.4	4.0	0.7	0.7	0.7	0.03
Coefficient of Variation	3.70	0.354	18.1	2.6	5.4	0.8	0.7	0.7	2.77
Max	6.15	2.437	5.0	16.3	81.6	87.1	97.2	98.6	1.08
Min	5.63	2.414	2.8	15.0	69.3	84.9	95.0	96.5	1.00
Range	0.52	0.023	2.2	1.2	12.4	2.2	2.2	2.1	0.08
Number of Replicates	5	5	10	10	10	10	10	10	10
Section (38)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.43	2.454	6.0	16.0	62.9	84.3	94.0	95.4	1.23
Standard Deviation	0.11	0.012	0.9	0.5	4.6	0.9	0.9	0.9	0.05
Coefficient of Variation	2.03	0.501	15.0	2.9	7.3	1.1	1.0	0.9	4.46
Max	5.54	2.472	7.5	16.8	69.8	85.7	95.4	96.7	1.31
Min	5.29	2.438	4.6	15.4	55.5	82.7	92.5	94.0	1.15
Range	0.25	0.034	2.8	1.4	14.4	2.9	2.8	2.6	0.16
Number of Replicates	6	5	10	10	10	10	10	10	10
Section (39)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.62	2.452	6.8	17.0	60.1	83.8	93.2	94.5	1.24
Standard Deviation	0.27	0.009	1.1	0.8	5.0	1.1	1.1	1.1	0.04
Coefficient of Variation	4.80	0.354	16.7	4.7	8.4	1.3	1.2	1.2	3.06
Max	6.03	2.464	8.0	18.0	68.5	85.6	95.0	96.3	1.29
Min	5.28	2.440	5.0	15.8	54.8	82.8	92.0	93.3	1.18
Range	0.75	0.024	3.0	2.2	13.7	2.8	3.0	3.0	0.11
Number of Replicates	6	5	10	10	10	10	10	10	10
Section (54)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.78	2.452	6.5	16.9	61.5	85.3	93.5	94.8	1.20
Standard Deviation	0.16	0.006	0.5	0.6	1.7	4.7	0.5	0.5	0.03
Coefficient of Variation	2.77	0.247	7.5	3.3	2.7	5.5	0.5	0.5	2.10
Max	5.95	2.460	7.2	17.6	64.2	98.5	94.2	95.6	1.23
Min	5.65	2.443	5.8	16.2	59.0	83.0	92.8	94.1	1.16
Range	0.30	0.017	1.4	1.4	5.2	15.4	1.4	1.4	0.07
Number of Replicates	3	5	10	10	10	10	10	10	10

Table 4. Replacement mixture – bottom lift gyratory volumetrics summary (QA) (continued).

Section (55)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.93	2.429	4.3	15.9	72.7	85.8	95.7	97.1	1.00
Standard Deviation	0.18	0.007	0.3	0.1	1.6	0.4	0.3	0.3	0.02
Coefficient of Variation	3.04	0.286	6.1	0.8	2.2	0.5	0.3	0.3	2.24
Max	6.14	2.439	4.6	16.0	76.0	86.4	96.2	97.7	1.03
Min	5.79	2.420	3.8	15.7	70.7	85.3	95.4	96.8	0.96
Range	0.35	0.019	0.9	0.3	5.3	1.1	0.9	0.8	0.06
Number of Replicates	3	5	10	10	10	10	10	10	10
Section (56)	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
Average	5.33	2.455	6.1	16.0	62.5	84.3	93.9	95.3	1.29
Standard Deviation	0.14	0.019	1.8	1.0	9.6	1.6	1.8	1.8	0.09
Coefficient of Variation	2.63	0.761	29.7	6.4	15.3	2.0	1.9	1.9	6.64
Max	5.48	2.477	7.8	16.8	79.9	87.3	97.2	98.5	1.40
Min	5.23	2.427	2.8	14.1	53.6	82.6	92.2	93.5	1.16
Range	0.25	0.050	4.9	2.7	26.2	4.6	4.9	5.0	0.24
Number of Replicates	3	5	10	10	10	10	10	10	10

APPENDIX A

INDIVIDUAL SECTION VOLUMETRICS

Table A1. Replacement mixture for section 35 – top lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample	%AC	Rice	%VT	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
35	1	2	A	1-2-A	6.12	2.424	4.0	15.9	75.0	86.2	96.0	97.4	1.1
	1	2	B	1-2-B	6.12	2.424	4.3	16.2	73.3	86.0	95.7	97.1	1.1
	1	3	A	1-3-A	6.12	2.429	4.0	15.8	74.7	86.0	96.0	97.4	1.1
	1	3	B	1-3-B	6.12	2.429	4.1	15.9	74.0	85.9	95.9	97.4	1.1
	2	1	A	2-1-A	6.12	2.417	4.2	16.4	74.2	85.9	95.8	97.3	1.0
	2	1	B	2-1-B	6.12	2.417	4.0	16.1	75.5	86.0	96.0	97.5	1.0
	2	1	C	2-1-C	6.12	2.426	4.1	15.9	74.4	86.1	95.9	97.3	1.1
	2	1	D	2-1-D	6.12	2.426	4.5	16.3	72.2	85.8	95.5	97.0	1.1
	2	2	A	2-2-A	6.12	2.408	3.9	16.4	76.1	86.3	96.1	97.6	1.0
	2	2	B	2-2-B	6.12	2.408	3.7	16.3	77.1	86.9	96.3	97.7	1.0
Average					6.12	2.421	4.1	16.1	74.7	86.1	95.9	97.4	1.0
Standard Deviation					0.12	0.008	0.2	0.2	1.4	0.3	0.2	0.2	0.0
Coefficient of Variation					2.02	0.347	5.6	1.5	1.9	0.4	0.2	0.2	2.6
Max					6.32	2.429	4.5	16.4	77.1	86.9	96.3	97.7	1.1
Min					5.98	2.408	3.7	15.8	72.2	85.8	95.5	97.0	1.0
Range					0.34	0.021	0.8	0.7	4.8	1.1	0.8	0.7	0.1
Number of Replicates					5	5	10	10	10	10	10	10	10.0

Table A2. Replacement mixture for section 36 – top lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample ID	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
36	1	2	A	1-2-A	5.86	2.431	4.7	16.1	70.5	85.1	95.3	96.7	1.1
	1	2	B	1-2-B	5.86	2.431	4.3	15.7	72.6	85.8	95.7	97.1	1.1
	1	3	A	1-3-A	5.86	2.401	1.1	13.9	92.4	88.7	98.9	99.8	1.0
	1	3	B	1-3-B	5.86	2.401	1.2	14.0	91.8	88.9	98.8	99.6	1.0
	2	1	A	2-1-A	5.86	2.419	3.8	15.7	75.7	86.1	96.2	97.6	1.1
	2	1	B	2-1-B	5.86	2.419	3.5	15.4	77.5	86.5	96.5	98.0	1.1
	2	1	C	2-1-C	5.86	2.417	3.1	15.1	79.7	87.0	96.9	98.4	1.1
	2	1	D	2-1-D	5.86	2.417	3.5	15.5	77.3	86.3	96.5	97.8	1.1
	2	2	A	2-2-A	5.86	2.413	2.6	14.9	82.2	86.9	97.4	98.9	1.1
	2	2	B	2-2-B	5.86	2.413	2.5	14.7	83.3	87.4	97.5	99.0	1.1
Average					5.86	2.416	3.0	15.1	80.3	86.8	97.0	98.3	1.1
Standard Deviation					0.10	0.011	1.2	0.7	7.3	1.2	1.2	1.0	0.0
Coefficient of Variation					1.69	0.448	40.5	4.8	9.1	1.4	1.3	1.1	3.4
Max					5.93	2.431	4.7	16.1	92.4	88.9	98.9	99.8	1.1
Min					5.69	2.401	1.1	13.9	70.5	85.1	95.3	96.7	1.0
Range					0.24	0.030	3.7	2.2	21.9	3.8	3.7	3.1	0.1
Number of Replicates					5	5	10	10	10	10	10	10	10

Table A3. Replacement mixture for section 37 – top lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample ID	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
37	1	2	A	1-2-A	6.14	2.460	5.8	16.3	64.3	84.7	94.2	95.5	1.2
	1	2	B	1-2-B	6.14	2.460	5.8	16.3	64.5	84.6	94.2	95.6	1.2
	1	3	A	1-3-A	6.14	2.446	5.2	16.3	67.9	85.0	94.8	96.3	1.2
	1	3	B	1-3-B	6.14	2.446	5.2	16.2	68.1	84.7	94.8	96.3	1.2
	2	1	A	2-1-A	6.14	2.426	3.9	15.8	75.4	86.2	96.1	97.5	1.1
	2	1	B	2-1-B	6.14	2.426	4.6	16.4	72.1	85.7	95.4	96.9	1.1
	2	1	C	2-1-C	6.14	2.443	4.8	16.0	69.9	85.2	95.2	96.6	1.1
	2	1	D	2-1-D	6.14	2.443	4.9	16.1	69.5	85.2	95.1	96.5	1.1
	2	2	A	2-2-A	6.14	2.436	5.1	16.5	69.2	85.2	94.9	96.3	1.1
	2	2	B	2-2-B	6.14	2.436	4.7	16.2	70.8	85.1	95.3	96.7	1.1
Average					6.14	2.442	5.0	16.2	69.2	85.2	95.0	96.4	1.1
Standard Deviation					0.12	0.013	0.6	0.2	3.3	0.5	0.6	0.6	0.0
Coefficient of Variation					1.95	0.515	11.4	1.2	4.8	0.6	0.6	0.6	4.1
Max					6.29	2.460	5.8	16.5	75.4	86.2	96.1	97.5	1.2
Min					6.00	2.426	3.9	15.8	64.3	84.6	94.2	95.5	1.1
Range					0.29	0.034	2.0	0.7	11.1	1.6	2.0	2.0	0.1
Number of Replicates					5	5	10	10	10	10	10	10	10

Table A4. Replacement mixture for section 38 – top lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample ID	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
38	1	2	A	1-2-A	5.55	2.452	5.2	15.5	66.6	85.1	94.8	96.3	1.4
	1	2	B	1-2-B	5.55	2.452	5.1	15.4	66.9	85.0	94.9	96.4	1.4
	1	3	A	1-3-A	5.55	2.425	2.5	14.0	82.5	87.7	97.5	98.9	1.2
	1	3	B	1-3-B	5.55	2.425	2.9	14.4	80.1	87.2	97.1	98.6	1.2
	2	1	A	2-1-A	5.55	2.428	3.3	14.7	77.3	86.6	96.7	98.1	1.2
	2	1	B	2-1-B	5.55	2.428	3.6	14.9	75.8	86.3	96.4	97.8	1.2
	2	1	C	2-1-C	5.55	2.439	4.0	14.9	73.0	86.1	96.0	97.4	1.3
	2	1	D	2-1-D	5.55	2.439	3.6	14.5	75.3	86.7	96.4	97.8	1.3
	2	2	A	2-2-A	5.55	2.451	5.2	15.5	66.7	84.9	94.8	96.2	1.3
	2	2	B	2-2-B	5.55	2.451	5.3	15.6	66.2	84.9	94.7	96.2	1.3
Average					5.55	2.439	4.1	15.0	73.0	86.1	95.9	97.4	1.3
Standard Deviation					0.13	0.013	1.1	0.6	6.1	1.0	1.1	1.0	0.1
Coefficient of Variation					2.34	0.515	26.0	3.7	8.4	1.2	1.1	1.1	4.3
Max					5.72	2.452	5.3	15.6	82.5	87.7	97.5	98.9	1.4
Min					5.38	2.425	2.5	14.0	66.2	84.9	94.7	96.2	1.2
Range					0.34	0.027	2.8	1.6	16.3	2.8	2.8	2.7	0.1
Number of Replicates					5	5	10	10	10	10	10	10	10

Table A5. Replacement mixture for section 39 – top lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample ID	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
39	1	2	A	1-2-A	5.94	2.430	5.2	16.6	68.8	85.3	94.8	96.3	1.1
	1	2	B	1-2-B	5.94	2.430	5.1	16.6	69.0	85.3	94.9	96.2	1.1
	1	3	A	1-3-A	5.94	2.448	5.0	15.9	68.2	84.7	95.0	96.5	1.2
	1	3	B	1-3-B	5.94	2.448	4.9	15.7	68.9	85.1	95.1	96.5	1.2
	2	1	A	2-1-A	5.94	2.420	3.4	15.4	77.7	86.7	96.6	98.0	1.1
	2	1	B	2-1-B	5.94	2.420	3.6	15.5	77.1	86.6	96.4	98.0	1.1
	2	1	C	2-1-C	5.94	2.434	4.3	15.7	72.4	86.0	95.7	97.0	1.1
	2	1	D	2-1-D	5.94	2.434	4.4	15.7	72.3	86.1	95.6	97.1	1.1
	2	2	A	2-2-A	5.94	2.435	4.8	16.1	70.3	85.4	95.2	96.7	1.1
	2	2	B	2-2-B	5.94	2.435	5.1	16.4	68.6	84.8	94.9	96.3	1.1
Average					5.94	2.433	4.6	16.0	71.3	85.6	95.4	96.8	1.1
Standard Deviation					0.27	0.010	0.6	0.4	3.5	0.7	0.6	0.6	0.0
Coefficient of Variation					6.11	0.415	14.2	2.7	4.9	0.8	0.7	0.7	3.3
Max					6.28	2.448	5.2	16.6	77.7	86.7	96.6	98.0	1.2
Min					5.58	2.420	3.4	15.4	68.2	84.7	94.8	96.2	1.1
Range					0.70	0.028	1.7	1.2	9.4	2.0	1.7	1.7	0.1
Number of Replicates					5	5	10	10	10	10	10	10	10

Table A6. Replacement mixture for section 54 – top lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample ID	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
54	1	2	A	1-2-A	6.11	2.458	8.0	18.3	56.4	82.4	92.0	93.4	1.2
	1	2	B	1-2-B	6.11	2.458	7.8	18.2	56.8	82.5	92.2	93.7	1.2
	1	3	A	1-3-A	6.11	2.446	5.7	16.7	65.8	84.8	94.3	95.7	1.2
	1	3	B	1-3-B	6.11	2.446	5.8	16.8	65.4	84.6	94.2	95.6	1.2
	2	1	A	2-1-A	6.11	2.425	4.0	15.9	75.0	86.1	96.0	97.4	1.1
	2	1	B	2-1-B	6.11	2.425	3.9	15.8	75.3	86.4	96.1	97.5	1.1
	2	1	C	2-1-C	6.11	2.440	5.3	16.5	67.8	84.8	94.7	96.0	1.2
	2	1	D	2-1-D	6.11	2.440	5.3	16.5	67.8	84.8	94.7	96.0	1.2
	2	2	A	2-2-A	6.11	2.440	5.0	16.2	69.4	85.2	95.0	96.4	1.2
	2	2	B	2-2-B	6.11	2.440	5.0	16.3	69.0	85.0	95.0	96.3	1.2
Average					6.11	2.442	5.6	16.7	66.9	84.7	94.4	95.8	1.2
Standard Deviation					0.08	0.012	1.4	0.9	6.4	1.3	1.4	1.4	0.0
Coefficient of Variation					1.31	0.488	24.6	5.1	9.5	1.5	1.5	1.4	3.9
Max					6.22	2.458	8.0	18.3	75.3	86.4	96.1	97.5	1.2
Min					6.03	2.425	3.9	15.8	56.4	82.4	92.0	93.4	1.1
Range					0.19	0.033	4.1	2.5	18.9	4.0	4.1	4.1	0.1
Number of Replicates					5	5	10	10	10	10	10	10	10

Table A7. Replacement mixture for section 55 – top lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample ID	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
55	1	2	A	1-2-A	6.04	2.437	5.8	17.0	65.7	84.3	94.2	95.6	1.2
	1	2	B	1-2-B	6.04	2.437	5.6	16.8	66.7	84.4	94.4	95.8	1.2
	1	3	A	1-3-A	6.04	2.411	2.9	15.3	81.3	87.3	97.1	98.6	1.1
	1	3	B	1-3-B	6.04	2.411	3.4	15.8	78.6	86.5	96.6	98.2	1.1
	2	1	A	2-1-A	6.04	2.421	3.7	15.7	76.2	86.2	96.3	97.7	1.1
	2	1	B	2-1-B	6.04	2.421	3.5	15.5	77.5	86.6	96.5	97.9	1.1
	2	1	C	2-1-C	6.04	2.422	3.3	15.3	78.6	86.6	96.7	98.2	1.1
	2	1	D	2-1-D	6.04	2.422	3.3	15.3	78.5	86.3	96.7	98.1	1.1
	2	2	A	2-2-A	6.04	2.408	3.0	15.6	80.6	87.0	97.0	98.5	1.1
	2	2	B	2-2-B	6.04	2.408	3.2	15.8	79.4	86.8	96.8	98.3	1.1
Average					6.04	2.420	3.8	15.8	76.3	86.2	96.2	97.7	1.1
Standard Deviation					0.33	0.011	1.1	0.6	5.5	1.0	1.1	1.1	0.0
Coefficient of Variation					5.46	0.471	27.9	3.9	7.2	1.2	1.1	1.1	3.6
Max					6.53	2.437	5.8	17.0	81.3	87.3	97.1	98.6	1.2
Min					5.59	2.408	2.9	15.3	65.7	84.3	94.2	95.6	1.1
Range					0.94	0.029	3.0	1.7	15.6	3.0	3.0	3.0	0.1
Number of Replicates					5	5	10	10	10	10	10	10	10

Table A8. Replacement mixture for section 56 – top lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample ID	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
56	1	2	A	1-2-A	6.04	2.438	5.1	16.4	68.7	85.4	94.9	96.3	1.22
	1	2	B	1-2-B	6.04	2.438	5.1	16.3	69.0	85.4	94.9	96.4	1.22
	1	3	A	1-3-A	6.04	2.449	5.9	16.7	64.5	84.5	94.1	95.5	1.26
	1	3	B	1-3-B	6.04	2.449	5.8	16.6	64.9	84.6	94.2	95.6	1.26
	2	1	A	2-1-A	6.04	2.455	6.2	16.7	63.1	84.3	93.8	95.2	1.29
	2	1	B	2-1-B	6.04	2.455	6.9	17.3	60.4	83.7	93.1	94.6	1.29
	2	1	C	2-1-C	6.04	2.465	6.9	17.0	59.5	83.2	93.1	94.5	1.34
	2	1	D	2-1-D	6.04	2.465	6.5	16.7	61.1	83.8	93.5	94.8	1.34
	2	2	A	2-2-A	6.04	2.453	5.4	16.1	66.6	84.9	94.6	96.1	1.28
	2	2	B	2-2-B	6.04	2.453	5.2	15.9	67.3	84.9	94.8	96.3	1.28
Average					6.04	2.452	5.9	16.6	64.5	84.5	94.1	95.5	1.3
Standard Deviation					0.11	0.010	0.7	0.4	3.4	0.7	0.7	0.7	0.0
Coefficient of Variation					1.82	0.400	11.9	2.6	5.3	0.9	0.7	0.8	3.3
Max					6.14	2.465	6.9	17.3	69.0	85.4	94.9	96.4	1.3
Min					5.89	2.438	5.1	15.9	59.5	83.2	93.1	94.5	1.2
Range					0.25	0.027	1.8	1.4	9.5	2.2	1.8	1.9	0.1
Number of Replicates					5	5	10	10	10	10	10	10	10

Table A9. Replacement mixture for section 35 – bottom lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample Id	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
35	1	2	A	1-2-A	5.71	2.438	4.8	15.8	69.4	85.6	95.2	96.5	1.04
	1	2	B	1-2-B	5.71	2.438	4.2	15.2	72.6	85.9	95.8	97.2	1.04
	1	3	A	1-3-A	5.71	2.445	5.8	16.4	64.7	84.7	94.2	95.6	1.07
	1	3	B	1-3-B	5.71	2.445	5.6	16.3	65.6	84.9	94.4	95.8	1.07
	2	1	A	2-1-A	5.71	2.434	3.7	14.9	75.5	86.6	96.3	97.7	1.03
	2	1	B	2-1-B	5.71	2.434	3.5	14.8	76.3	86.6	96.5	97.9	1.03
	2	1	C	2-1-C	5.71	2.430	3.5	14.9	76.7	86.8	96.5	97.9	1.02
	2	1	D	2-1-D	5.71	2.430	4.3	15.6	72.5	86.0	95.7	97.5	1.02
	2	2	A	2-2-A	5.71								
	2	2	B	2-2-B	5.71								
Average					5.71	2.437	4.4	15.5	71.6	85.9	95.6	96.9	1.04
Standard Deviation					0.12	0.006	0.9	0.6	4.7	0.8	0.9	0.9	0.02
Coefficient of Variation					2.10	0.243	20.6	4.1	6.5	0.9	1.0	1.0	2.11
Max					5.79	2.445	5.8	16.4	76.7	86.8	96.5	97.9	1.07
Min					5.56	2.430	3.5	14.8	64.7	84.7	94.2	95.6	1.02
Range					0.23	0.015	2.3	1.6	11.9	2.1	2.3	2.4	0.06
Number of Replicates					3	4	8	8	8	8	8	8	8

Table A10. Replacement mixture for section 36 – bottom lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample Id	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
36	1	2	A	1-2-A	5.37	2.451	5.5	15.7	64.9	84.6	94.5	95.9	1.2
	1	2	B	1-2-B	5.37	2.451	5.3	15.5	65.7	84.9	94.7	96.1	1.2
	1	3	A	1-3-A	5.37	2.462	7.8	17.4	54.9	82.5	92.2	93.5	1.2
	1	3	B	1-3-B	5.37	2.462	7.5	17.1	56.1	83.2	92.5	93.8	1.2
	2	1	A	2-1-A	5.37	2.430	5.0	15.9	68.8	85.5	95.0	96.3	1.1
	2	1	B	2-1-B	5.37	2.430	5.0	16.0	68.6	85.3	95.0	96.4	1.1
	2	1	C	2-1-C	5.37	2.444	5.5	15.9	65.3	84.8	94.5	95.9	1.1
	2	1	D	2-1-D	5.37	2.444	4.8	15.3	68.4	85.3	95.2	96.5	1.1
	2	2	A	2-2-A	5.37	2.436	5.6	16.2	65.7	84.9	94.4	95.7	1.1
	2	2	B	2-2-B	5.37	2.436	5.9	16.5	64.4	84.4	94.1	95.5	1.1
Average					5.37	2.445	5.8	16.1	64.3	84.5	94.2	95.6	1.1
Standard Deviation					0.16	0.013	1.0	0.7	4.9	1.0	1.0	1.1	0.1
Coefficient of Variation					2.98	0.514	17.9	4.1	7.6	1.1	1.1	1.1	4.5
Max					5.39	2.462	7.8	17.4	68.8	85.5	95.2	96.5	1.2
Min					5.21	2.430	4.8	15.3	54.9	82.5	92.2	93.5	1.1
Range					0.18	0.032	3.0	2.1	14.0	2.9	3.0	3.1	0.1
Number of Replicates					3	5	10	10	10	10	10	10	10

Table A11. Replacement mixture for section 37 – bottom lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample Id	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
37	1	2	A	1-2-A	5.94	2.419	4.0	16.0	74.7	86.0	96.0	97.4	1.0
	1	2	B	1-2-B	5.94	2.419	3.9	15.8	75.6	86.1	96.1	97.6	1.0
	1	3	A	1-3-A	5.94	2.422	4.0	15.8	74.8	86.2	96.0	97.4	1.0
	1	3	B	1-3-B	5.94	2.422	4.5	16.3	72.3	85.7	95.5	96.9	1.0
	2	1	A	2-1-A	5.94	2.437	5.0	16.2	69.3	84.9	95.0	96.5	1.1
	2	1	B	2-1-B	5.94	2.437	4.7	15.9	70.5	85.3	95.3	96.8	1.1
	2	1	C	2-1-C	5.94	2.422	3.9	15.8	75.1	86.1	96.1	97.5	1.0
	2	1	D	2-1-D	5.94	2.422	4.1	16.0	74.1	85.9	95.9	97.3	1.0
	2	2	A	2-2-A	5.94	2.414	2.8	15.1	81.3	87.1	97.2	98.5	1.0
	2	2	B	2-2-B	5.94	2.414	2.8	15.0	81.6	87.0	97.2	98.6	1.0
Average					5.94	2.423	4.0	15.8	74.9	86.0	96.0	97.4	1.0
Standard Deviation					0.22	0.009	0.7	0.4	4.0	0.7	0.7	0.7	0.0
Coefficient of Variation					3.70	0.354	18.1	2.6	5.4	0.8	0.7	0.7	2.8
Max					6.15	2.437	5.0	16.3	81.6	87.1	97.2	98.6	1.1
Min					5.63	2.414	2.8	15.0	69.3	84.9	95.0	96.5	1.0
Range					0.52	0.023	2.2	1.2	12.4	2.2	2.2	2.1	0.1
Number of Replicates					5	5	10	10	10	10	10	10	10

Table A12. Replacement mixture for section 38 – bottom lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample Id	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
38	1	2	A	1-2-A	5.43	2.450	6.0	16.2	63.0	84.2	94.0	95.4	1.2
	1	2	B	1-2-B	5.43	2.450	6.0	16.2	62.9	84.2	94.0	95.4	1.2
	1	3	A	1-3-A	5.43	2.438	4.9	15.6	68.7	85.3	95.1	96.5	1.2
	1	3	B	1-3-B	5.43	2.438	4.6	15.4	69.8	85.7	95.4	96.7	1.2
	2	1	A	2-1-A	5.43	2.454	6.2	16.2	62.0	84.2	93.8	95.2	1.2
	2	1	B	2-1-B	5.43	2.454	6.1	16.1	62.2	84.1	93.9	95.3	1.2
	2	1	C	2-1-C	5.43	2.457	5.5	15.5	64.3	85.0	94.5	95.8	1.2
	2	1	D	2-1-D	5.43	2.457	5.6	15.6	64.0	84.4	94.4	95.8	1.2
	2	2	A	2-2-A	5.43	2.472	7.5	16.8	55.5	82.7	92.5	94.0	1.3
	2	2	B	2-2-B	5.43	2.472	7.3	16.6	56.1	83.1	92.7	94.1	1.3
Average					5.43	2.454	6.0	16.0	62.9	84.3	94.0	95.4	1.2
Standard Deviation					0.11	0.012	0.9	0.5	4.6	0.9	0.9	0.9	0.1
Coefficient of Variation					2.03	0.501	15.0	2.9	7.3	1.1	1.0	0.9	4.5
Max					5.54	2.472	7.5	16.8	69.8	85.7	95.4	96.7	1.3
Min					5.29	2.438	4.6	15.4	55.5	82.7	92.5	94.0	1.2
Range					0.25	0.034	2.8	1.4	14.4	2.9	2.8	2.6	0.2
Number of Replicates					6	5	10	10	10	10	10	10	10

Table A13. Replacement mixture for section 39 – bottom lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample Id	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
39	1	2	A	1-2-A	5.62	2.451	6.3	16.6	62.0	84.0	93.7	95.1	1.2
	1	2	B	1-2-B	5.62	2.451	6.3	16.5	62.2	84.3	93.7	95.0	1.2
	1	3	A	1-3-A	5.62	2.455	7.2	17.3	58.3	83.2	92.8	94.2	1.3
	1	3	B	1-3-B	5.62	2.455	7.2	17.2	58.3	83.4	92.8	94.1	1.3
	2	1	A	2-1-A	5.62	2.464	7.9	17.6	54.9	82.8	92.1	93.4	1.3
	2	1	B	2-1-B	5.62	2.464	8.0	17.7	54.8	82.8	92.0	93.3	1.3
	2	1	C	2-1-C	5.62	2.450	7.8	18.0	56.5	83.1	92.2	93.5	1.2
	2	1	D	2-1-D	5.62	2.450	7.6	17.8	57.1	82.9	92.4	93.7	1.2
	2	2	A	2-2-A	5.62	2.440	5.0	15.8	68.5	85.6	95.0	96.3	1.2
	2	2	B	2-2-B	5.62	2.440	5.0	15.9	68.2	85.5	95.0	96.3	1.2
Average					5.62	2.452	6.8	17.0	60.1	83.8	93.2	94.5	1.2
Standard Deviation					0.27	0.009	1.1	0.8	5.0	1.1	1.1	1.1	0.0
Coefficient of Variation					4.80	0.354	16.7	4.7	8.4	1.3	1.2	1.2	3.1
Max					6.03	2.464	8.0	18.0	68.5	85.6	95.0	96.3	1.3
Min					5.28	2.440	5.0	15.8	54.8	82.8	92.0	93.3	1.2
Range					0.75	0.024	3.0	2.2	13.7	2.8	3.0	3.0	0.1
Number of Replicates					6	5	10	10	10	10	10	10	10

Table A14. Replacement mixture for section 54 – bottom lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample Id	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
54	1	2	A	1-2-A	5.78	2.443	6.6	17.2	61.9	83.9	93.4	94.8	1.2
	1	2	B	1-2-B	5.78	2.443	7.0	17.6	60.3	83.4	93.0	94.3	1.2
	1	3	A	1-3-A	5.78	2.453	6.0	16.4	63.5	84.2	94.0	95.4	1.2
	1	3	B	1-3-B	5.78	2.453	5.8	16.2	64.2	84.3	94.2	95.6	1.2
	2	1	A	2-1-A	5.78	2.451	6.5	17.0	61.4	83.8	93.5	94.8	1.2
	2	1	B	2-1-B	5.78	2.451	7.1	17.4	59.3	83.3	92.9	94.2	1.2
	2	1	C	2-1-C	5.78	2.460	6.1	16.3	62.4	84.0	93.9	95.2	1.2
	2	1	D	2-1-D	5.78	2.460	6.1	16.3	62.3	84.3	93.9	95.2	1.2
	2	2	A	2-2-A	5.78	2.451	6.7	17.1	60.8	98.5	93.3	94.7	1.2
	2	2	B	2-2-B	5.78	2.451	7.2	17.5	59.0	83.0	92.8	94.1	1.2
Average					5.78	2.452	6.5	16.9	61.5	85.3	93.5	94.8	1.2
Standard Deviation					0.16	0.006	0.5	0.6	1.7	4.7	0.5	0.5	0.0
Coefficient of Variation					2.77	0.247	7.5	3.3	2.7	5.5	0.5	0.5	2.1
Max					5.95	2.460	7.2	17.6	64.2	98.5	94.2	95.6	1.2
Min					5.65	2.443	5.8	16.2	59.0	83.0	92.8	94.1	1.2
Range					0.30	0.017	1.4	1.4	5.2	15.4	1.4	1.4	0.1
Number of Replicates					3	5	10	10	10	10	10	10	10

Table A15. Replacement mixture for section 55 – bottom lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample ID	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
55	1	2	A	1-2-A	5.93	2.432	4.4	15.9	72.1	85.7	95.6	96.9	1.0
	1	2	B	1-2-B	5.93	2.432	4.5	15.9	71.9	85.5	95.5	96.9	1.0
	1	3	A	1-3-A	5.93	2.427	4.1	15.7	74.0	86.3	95.9	97.2	1.0
	1	3	B	1-3-B	5.93	2.427	4.3	15.9	73.0	85.9	95.7	97.1	1.0
	2	1	A	2-1-A	5.93	2.429	4.5	16.0	72.1	85.6	95.5	96.9	1.0
	2	1	B	2-1-B	5.93	2.429	4.5	16.0	72.0	85.5	95.5	97.0	1.0
	2	1	C	2-1-C	5.93	2.439	4.6	15.8	70.7	85.3	95.4	96.8	1.0
	2	1	D	2-1-D	5.93	2.439	4.5	15.7	71.2	85.3	95.5	96.9	1.0
	2	2	A	2-2-A	5.93	2.420	3.8	15.7	76.0	86.4	96.2	97.7	1.0
	2	2	B	2-2-B	5.93	2.420	4.1	16.0	74.4	86.2	95.9	97.3	1.0
Average					5.93	2.429	4.3	15.9	72.7	85.8	95.7	97.1	1.0
Standard Deviation					0.18	0.007	0.3	0.1	1.6	0.4	0.3	0.3	0.0
Coefficient of Variation					3.04	0.286	6.1	0.8	2.2	0.5	0.3	0.3	2.2
Max					6.14	2.439	4.6	16.0	76.0	86.4	96.2	97.7	1.0
Min					5.79	2.420	3.8	15.7	70.7	85.3	95.4	96.8	1.0
Range					0.35	0.019	0.9	0.3	5.3	1.1	0.9	0.8	0.1
Number of Replicates					3	5	10	10	10	10	10	10	10

Table A16. Replacement mixture for section 56 – bottom lift gyratory volumetric QA data.

Section	Truck	Trailer	Spec ID	Sample Id	%AC	Rice	%VTM	%VMA	%VFA	%Gmmi	%Gmmd	%Gmmm	F/A
56	1	2	A	1-2-A	5.33	2.427	2.9	14.1	79.7	87.3	97.1	98.5	1.2
	1	2	B	1-2-B	5.33	2.427	2.8	14.1	79.9	87.1	97.2	98.5	1.2
	1	3	A	1-3-A	5.33	2.450	6.1	16.2	62.4	84.3	93.9	95.3	1.3
	1	3	B	1-3-B	5.33	2.450	6.0	16.1	62.9	84.4	94.0	95.4	1.3
	2	1	A	2-1-A	5.33	2.465	7.0	16.4	57.7	83.6	93.0	94.5	1.3
	2	1	B	2-1-B	5.33	2.465	7.1	16.5	57.3	83.4	92.9	94.3	1.3
	2	1	C	2-1-C	5.33	2.457	6.9	16.7	58.4	83.4	93.1	94.5	1.3
	2	1	D	2-1-D	5.33	2.457	6.6	16.4	59.8	83.7	93.4	94.8	1.3
	2	2	A	2-2-A	5.33	2.477	7.8	16.8	53.7	82.7	92.2	93.6	1.4
	2	2	B	2-2-B	5.33	2.477	7.8	16.8	53.6	82.6	92.2	93.5	1.4
Average					5.33	2.455	6.1	16.0	62.5	84.3	93.9	95.3	1.3
Standard Deviation					0.14	0.019	1.8	1.0	9.6	1.6	1.8	1.8	0.1
Coefficient of Variation					2.63	0.761	29.7	6.4	15.3	2.0	1.9	1.9	6.6
Max					5.48	2.477	7.8	16.8	79.9	87.3	97.2	98.5	1.4
Min					5.23	2.427	2.8	14.1	53.6	82.6	92.2	93.5	1.2
Range					0.25	0.050	4.9	2.7	26.2	4.6	4.9	5.0	0.2
Number of Replicates					3	5	10	10	10	10	10	10	10

In-Place Air Void Content and Thickness—Original Construction

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-12
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000 lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the SHRP Superpave HMA volumetric design method.

This WesTrack technical report provides information on the in-place air void content and thickness of the test sections originally placed at WesTrack. This information was obtained by technicians employed by Harding Lawson and Associates from randomly taken core samples. Thickness measurements were made prior to determination of the in-place air void content and the asphalt content (by the ignition method).

BACKGROUND

The original construction of the HMA occurred in September and October 1995. Trial sections of the HMA were placed prior to the test sections. The placement of the trial sections allowed for adjustments in asphalt binder content and aggregate gradations, including the baghouse fines, and adjustments in roller patterns.

HMA trial sections were placed on the ramps to the test track on September 9, 1995. Trial sections were first placed on the track on September 14, 1995, and the first test section mixture was placed September 20, 1995. The complete schedule for placement of the various lifts and sections is shown in table 1.

During the placement of the trial sections, the roller patterns and the temperature at which the rollers were used for breakdown, intermediate, and final rolling, were adjusted to produce the desired air void contents, based on data from nuclear density measuring devices and in-place air void measurements of core samples. The in-place air void contents obtained from the core samples on the test section bottom and top lifts are presented in this report.

SAMPLING AND TEST METHODS

Thickness and in-place air voids were determined on 150-mm (6-in.) diameter core samples obtained one day after placement of the mixture. Thickness and air voids were determined by the test methods shown in table 2. The bulk specific gravity of the cores was obtained by the saturated surface dry procedure. Theoretical maximum specific gravity of the mixture was determined on loose mixtures sampled from trucks and was used to determine Superpave gyratory compaction volumetrics. Cores were obtained at five random locations in each section. The detailed sampling and testing plan for the construction of the replacement sections can be found in WesTrack Technical Report UNR-18.[4]

IN-PLACE AIR VOIDS

BOTTOM LIFT

In-place air void data for the bottom lift of the fine graded mixture prior to placement of the top lift are shown in table 3. Average values and typical statistical data are shown. Table 4 shows the in-place air void content data for the bottom lift after placement of the top lift. The differences in air void contents of the bottom lift before and after placement of the top lift are shown in figure 1.

In-place air void data for the bottom lift of the fine plus graded mixture prior to placement of the top lift are shown in table 5. Average values and typical statistical data are shown. Table 6 contains the in-place air void content data for the bottom lift after placement of the top lift. The differences in air void contents of the bottom lift before and after placement of the top lift are shown in figure 1.

In-place air void data for the bottom lift of the coarse graded mixture prior to placement of the top lift are shown in table 7. Average values and typical statistical data are shown. Table 8 contains the in-place air void content data for the bottom lift after placement of the top lift. The differences in air void contents of the bottom lift before and after placement of the top lift are shown in figure 1 and table 13. Six of the 26 sections indicated a statistically significant difference between the air void contents before and after placement of the top lift.

TOP LIFT

Tables 9, 10, and 11 provide in-place air void data for the top lift of the test sections placed during original construction. Average values and typical statistical data are shown.

A statistical comparison was also made between the top and bottom lift of the same sections (table 13). Twelve of the 26 sections indicated a statistically significant difference between the top and bottom lifts. Figures 3 through 5 represent the statistical comparisons made between sections. These figures are based on average air void contents for the entire section (both bottom and top lifts). In these figures, the air void contents of mixes connected by solid lines do not differ significantly (statistically) from each other.

THICKNESS

Lift thickness data for the test lane lifts are shown in tables 1 through 11. Table 12 shows the total lift thickness. Figure 2 presents a graphical summary of the total thickness information together with variability information. Based on these data, sections 25 and 26 were diamond ground to a thickness between 152 and 159 mm (6 and 6.25 in.)

SUMMARY

In-place air void content data for the bottom lift of the test sections are shown in tables 4, 6, and 8. In-place air void content data for the top lift of the test sections are shown in tables 9, 10, and 11.

Thickness data for the test lane sections are shown in table 12.

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3. "Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction," *Task G Interim Report*, Final Draft, WesTrack Team, March 1996.

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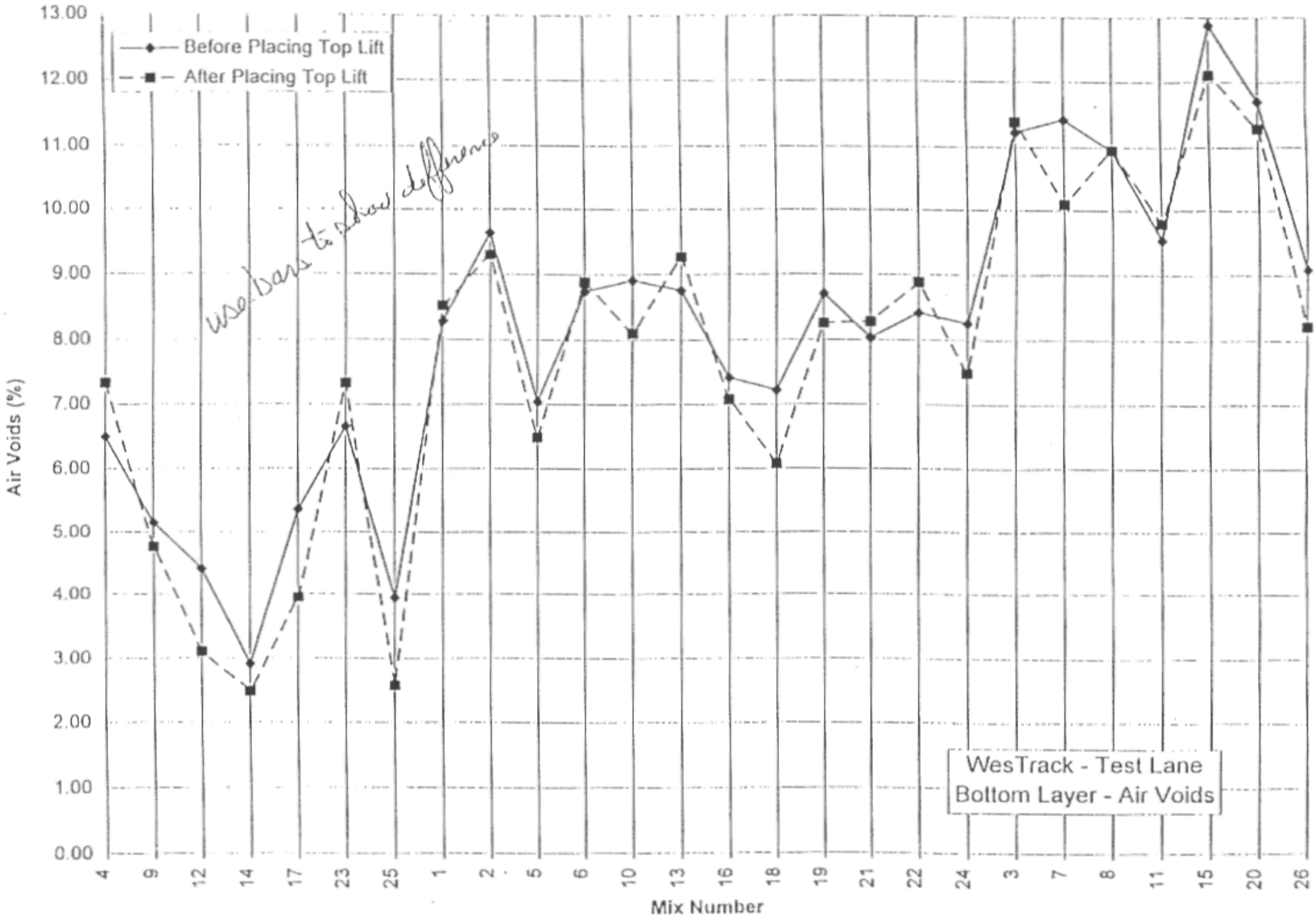

Figure 1. Test lane bottom lift – air voids before and after placement of top lift.

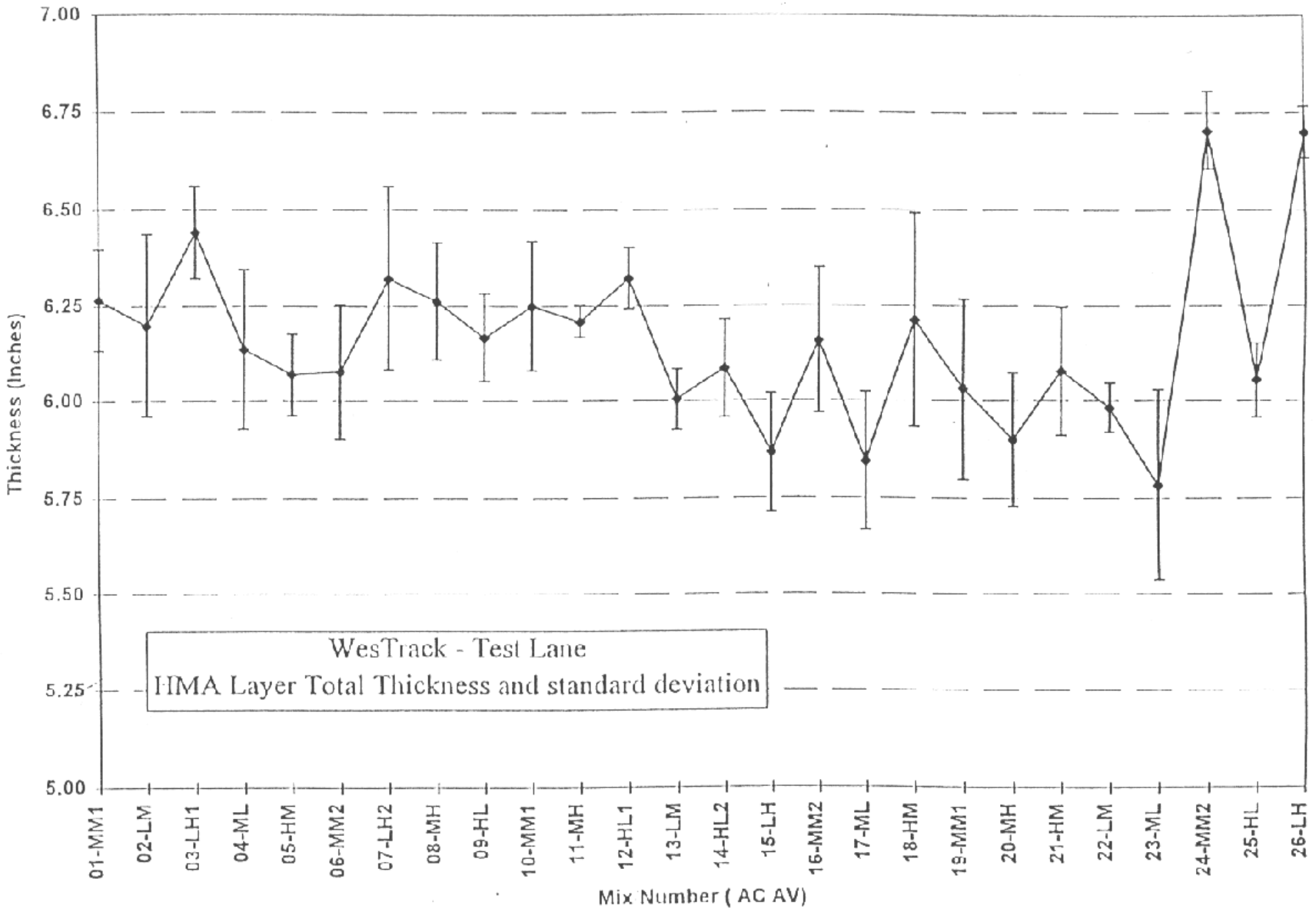

Figure 2. WesTrack test lane HMA layer total thickness and standard deviation.

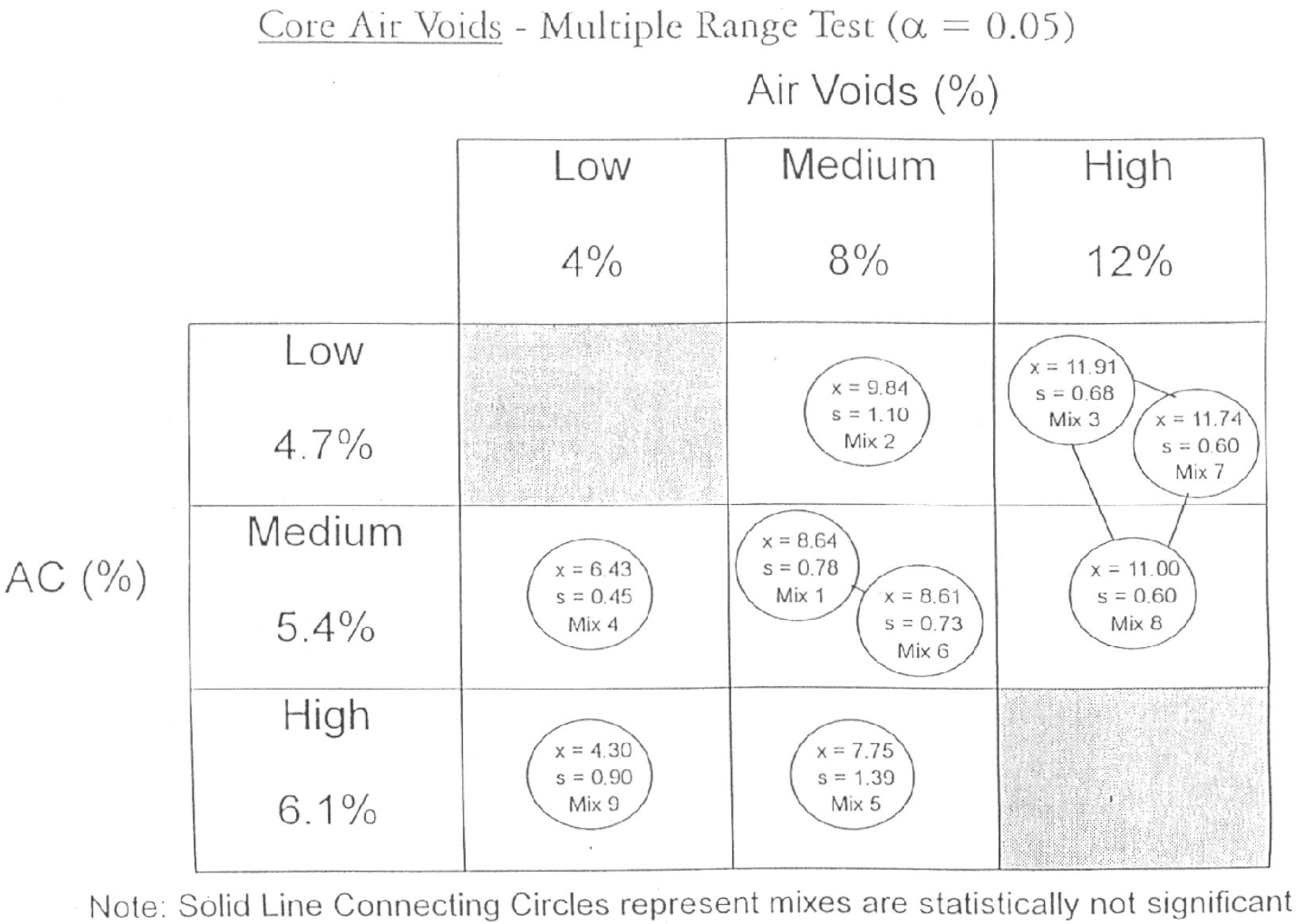

Figure 3. WesTrack fine mix – test lane – combined HMA layer.

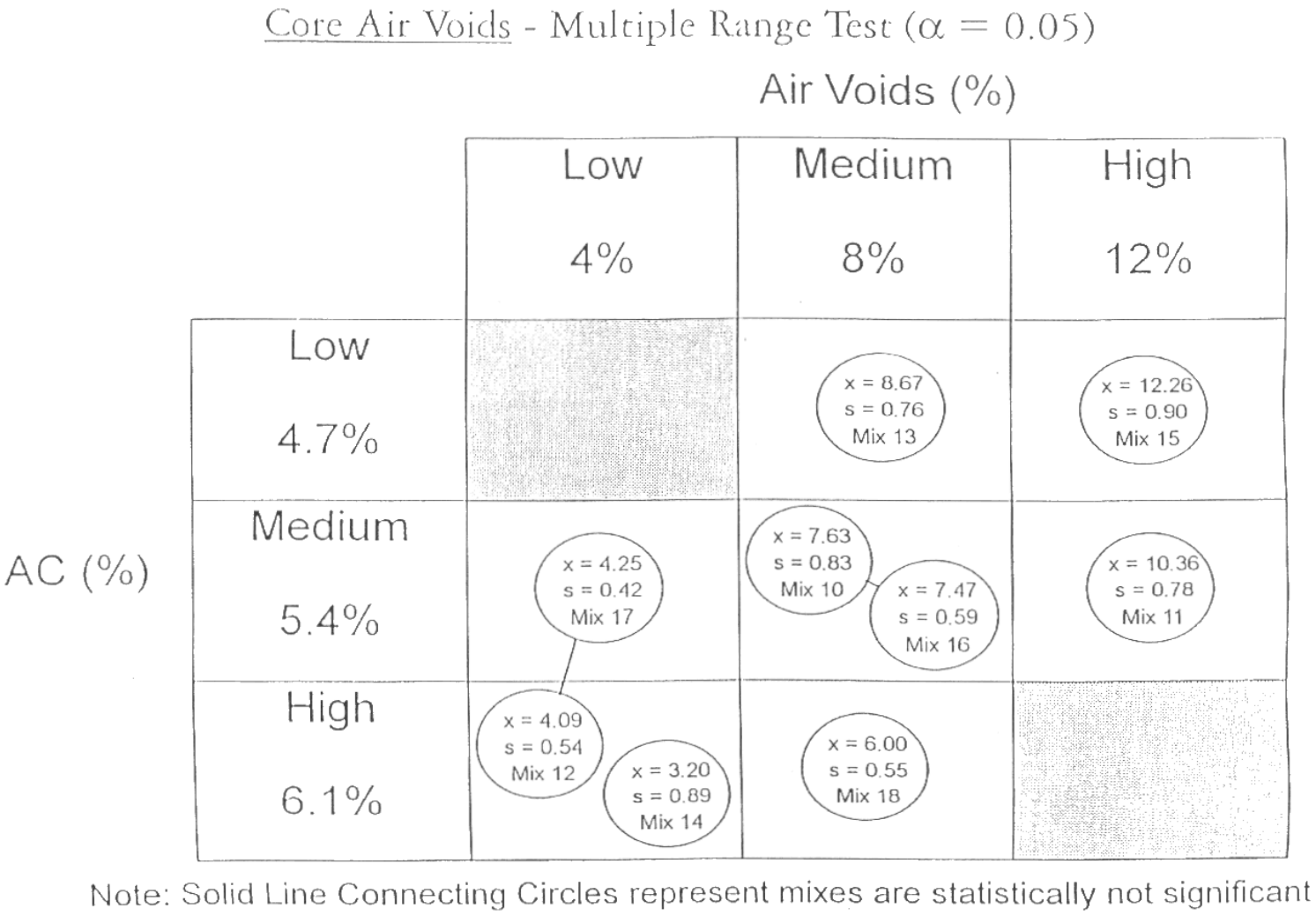

Figure 4. WesTrack fine plus mix – test lane – combined HMA layer.

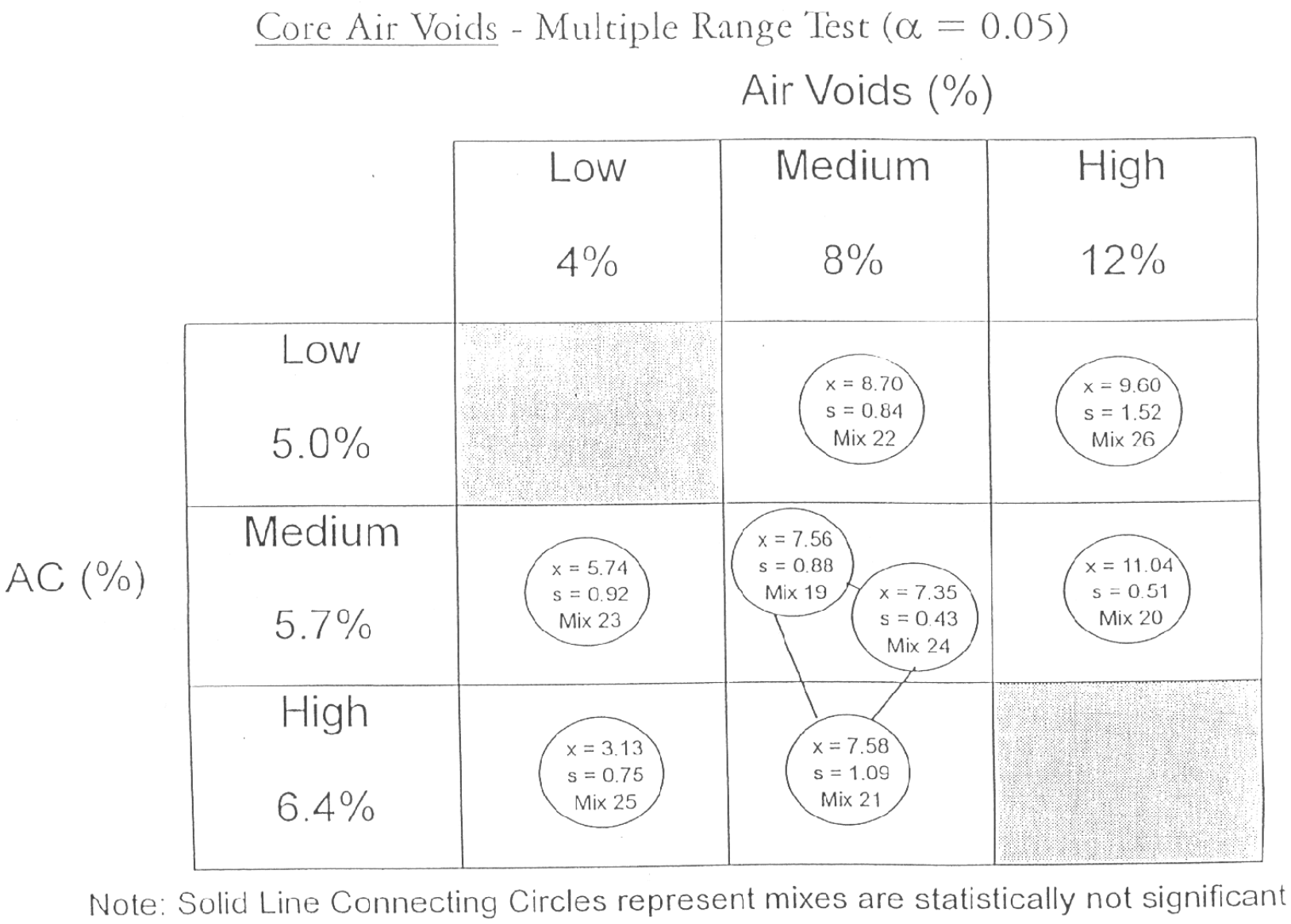

Figure 5. WesTrack coarse mix – test lane – combined HMA layer.

Table 1. Construction schedule for original 26 sections.

Date	Mixture	Lift	Lane	Section Numbers*
9-14-95	Fine	Bottom	Trial	1,2,3,4,14,15,16,17,18
9-15-95	Fine Plus	Bottom	Trial	19,20,21,22,9,10,11,12,13
9-16-95	Coarse	Bottom	Trial	5,6,7
9-18-95	Coarse	Bottom	Trial	8,23,24,25,26
9-20-95	Fine	Bottom	Test	1,2,3,4,14,15,16,17,18
9-21-95	Fine Plus	Bottom	Test	19,20,21,22,9,10,11,12,13
9-22-95	Fine	Top	Trial	1,2,3,4,14,15,16,17,18
9-27-95	Fine Plus	Top	Trial	19,20,21,22,9,10,11,12,13
9-27-95	Fine Plus	Bottom	Test	13
9-30-95	Coarse	Bottom	Test	5,6,7,8,23,24,25,26
10-1-95	Coarse	Top	Trial	5,6,7,8,23,24,25,26
10-2-95	Fine	Top	Test	1,2,3,4,14,15,16,17,18
10-3-95	Fine Plus	Top	Test	19,20,21,22,9,10,11,12,13
10-4-95	Coarse	Top	Test	5,6,7,8,23,24,25,26

*Section numbers follow order of placement.

Table 2. In-place air voids and thickness test methods.

Description	Designation	
	AASHTO	**ASTM**
Bulk specific gravity of compacted bituminous mixtures	T 166	D 2726
Theoretical maximum specific gravity of uncompacted bituminous mixtures	TP 39 T 209	D 2041
Percent air voids in compacted dense- and open-graded paving mixtures	T 269	D 3203
Thickness or height of compacted bituminous paving mixture specimens		D 3549

Table 3. Core data for test lane, bottom lift, fine mixes 1-9, construction date 9/20/95.

Mix & Core No, Dia	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV percent/ percent
							Cores	Average	Stdev	Range	
1-1-4	84.1	83.7	2.193	2.404	136.5	149.6	8.8	8.3	0.8	2.5	5.4 / 8
1-2-4	83.4		2.242		139.5		6.7				
1-3-4	83.9	(3.3")	2.217		138.0		7.8				
1-4-4	84.6		2.190		136.3		8.9				
1-5-4	87.1		2.194		136.6		8.7				
1-1-6	83.1		2.185		136.0		9.1				
1-2-6	82.9		2.216		137.9		7.8				
1-3-6	81.6		2.219		138.1		7.7				
1-4-6	85.0		2.181		135.7		9.3				
1-5-6	81.4		2.208		137.4		8.2				
2-1-4	78.1	81.6	2.207	2.415	137.4	150.3	8.6	9.6	1.0	3.0	4.7 / 8
2-2-4	82.3		2.189		136.2		9.4				
2-3-4	82.7	(3.2")	2.163		134.6		10.4				
2-4-4	81.9		2.136		132.9		11.6				
2-5-4	80.4		2.196		136.7		9.1				
2-1-6	79.7		2.208		137.4		8.6				
2-2-6	81.6		2.196		136.7		9.1				
2-3-6	85.9		2.167		134.9		10.3				
2-4-6	84.1		2.161		134.5		10.5				
2-5-6	79.2		2.197		136.7		9.0				
3-1-4	83.2	84.1	2.187	2.443	136.1	152.1	10.5	11.2	0.6	1.7	4.7 / 12
3-2-4	82.8		2.145		133.5		12.2				
3-3-4	83.6	(3.3")	2.171		135.1		11.1				
3-4-4	85.5		2.162		134.6		11.5				
3-5-4	82.9		2.162		134.6		11.5				

Table 3. Core data for test lane, bottom lift, fine mixes 1-9, construction date 9/20/95 (continued).

Mix & Core No, Dia	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
3-1-6	84.2		2.184		135.9		10.6				
3-2-6	82.5		2.151		133.9		12.0				
3-3-6	85.4		2.182		135.8		10.7				
3-4-6	86.5		2.167		134.9		11.3				
3-5-6	83.9		2.174		135.3		11.0				
4-1-4	79.2	76.6	2.261	2.412	140.7	150.1	6.3	6.5	0.8	2.1	5.4 / 4
4-2-4	72.5		2.272		141.4		5.8				
4-3-4	79.9	(3.0")	2.222		138.3		7.9				
4-4-4	78.2		2.254		140.3		6.6				
4-5-4	73.1		2.266		141.0		6.1				
4-1-6	81.3		2.256		140.4		6.5				
4-2-6	74.2		2.258		140.5		6.4				
4-3-6	78.2		2.252		140.2		6.6				
4-4-6	73.2		2.266		141.0		6.1				
4-5-6	76.8		2.255		140.4		6.5				
5-1-4	78.2	80.2	2.215	2.379	137.9	148.1	6.9	7.1	1.2	4.0	6.1 / 8
5-2-4	82.9		2.209		137.5		7.1				
5-3-4	75.7	(3.2")	2.213		137.7		7.0				
5-4-4	74.8		2.229		138.7		6.3				
5-5-4	87.4		2.170		135.1		8.8				
5-1-6	78.9		2.224		138.4		6.5				
5-2-6	82.0		2.222		138.3		6.6				
5-3-6	77.7		2.266		141.0		4.7				
5-4-6	79.1		2.175		135.4		8.6				
5-5-6	85.5		2.189		136.2		8.0				

Table 3. Core data for test lane, bottom lift, fine mixes 1-9, construction date 9/20/95 (continued).

Mix & Core No, Dia	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
6-1-4	82.2	81.8	2.197	2.414	136.7	150.2	9.0	8.7	0.7	2.4	5.4 / 8
6-2-4	79.7		2.212		137.7		8.4				
6-3-4	86.2	(3.2")	2.204		137.2		8.7				
6-4-4	81.5		2.200		136.9		8.9				
6-5-4	86.3		2.179		135.6		9.7				
6-1-6	85.3		2.195		136.6		9.1				
6-2-6	78.5		2.236		139.2		7.4				
6-3-6	79.5		2.199		136.9		8.9				
6-4-6	78.5		2.223		138.4		7.9				
6-5-6	80.4		2.184		135.9		9.5				
7-1-4	78.1	83.8	2.149	2.425	133.8	150.9	11.4	11.4	0.7	2.3	4.7 / 12
7-2-4	81.6		2.170		135.1		10.5				
7-3-4	86.5	(3.3")	2.131		132.6		12.1				
7-4-4	80.5		2.180		135.7		10.1				
7-5-4	86.4		2.125		132.3		12.4				
7-1-6	83.8		2.134		132.8		12.0				
7-2-6	81.6		2.151		133.9		11.3				
7-3-6	86.7		2.149		133.8		11.4				
7-4-6	87.1		2.151		133.9		11.3				
7-5-6	85.5		2.139		133.1		11.8				

Table 3. Core data for test lane, bottom lift, fine mixes 1-9, construction date 9/20/95 (continued).

Mix & Core No, Dia	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
8-1-4	83.0	81.6	2.168	2.407	134.9	149.8	9.9	11.0	0.7	1.9	5.4 / 12
8-2-4	85.9		2.151		133.9		10.6				
8-3-4	86.1	(3.2")	2.125		132.3		11.7				
8-4-4	77.3		2.149		133.8		10.7				
8-5-4	80.0		2.123		132.1		11.8				
8-1-6	83.2		2.167		134.9		10.0				
8-2-6	83.2		2.140		133.2		11.1				
8-3-6	81.6		2.124		132.2		11.8				
8-4-6	76.9		2.154		134.1		10.5				
8-5-6	78.8		2.132		132.7		11.4				
9-1-4	73.0	74.7	2.257	2.405	140.5	149.7	6.2	5.2	0.5	1.7	6.1 / 4
9-2-4	78.5		2.269		141.2		5.7				
9-3-4	77.7	(2.9")	2.298		143.0		4.4				
9-4-4	70.8		2.276		141.7		5.4				
9-5-4	76.3		2.277		141.7		5.3				
9-1-6	73.7		2.287		142.3		4.9				
9-2-6	76.1		2.281		142.0		5.2				
9-3-6	70.3		2.280		141.9		5.2				
9-4-6	76.4		2.293		142.7		4.7				
9-5-6	74.5		2.289		142.5		4.8				

Table 4. Core data for test lane, bottom lift, fine mixes 1-9, construction date 9/20/95 (after placing top lift).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
1-1			2.174	2.404	135.3	149.6	9.6	8.5	0.9	2.0	5.4 / 8
1-2			2.223		138.4		7.5				
1-3			2.191		136.4		8.9				
1-4			2.220		138.2		7.7				
1-5			2.186		136.1		9.1				
2-1			2.213	2.415	137.7	150.3	8.4	9.3	1.0	2.5	4.7 / 8
2-2			2.182		135.8		9.6				
2-3			2.153		134.0		10.8				
2-4			2.198		136.8		9.0				
2-5			2.205		137.2		8.7				
3-1			2.161	2.443	134.5	152.1	11.5	11.4	0.5	1.2	4.7 / 12
3-2			2.176		135.4		10.9				
3-3			2.165		134.7		11.4				
3-4			2.146		133.6		12.2				
3-5			2.175		135.4		11.0				
4-1			2.199	2.412	136.9	150.1	8.8	7.3	1.7	3.9	5.4 / 4
4-2			2.270		141.3		5.9				
4-3			2.278		141.8		5.6				
4-4			2.244		139.7		7.0				
4-5			2.184		135.9		9.5				
5-1			2.227	2.379	138.6	148.1	6.4	6.5	0.6	1.6	6.1 / 8
5-2			2.233		139.0		6.1				
5-3			2.239		139.4		5.9				
5-4			2.202		137.1		7.4				
5-5			2.221		138.2		6.6				

Table 4. Core data for test lane, bottom lift, fine mixes 1-9, construction date 9/20/95 (after placing top lift) (continued).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
6-1			2.223	2.414	138.4	150.2	7.9	8.9	1.5	3.0	5.4 / 8
6-2			2.165		134.7		10.3				
6-3			2.237		139.2		7.3				
6-4											
6-5			2.173		135.2		10.0				
7-1			2.143	2.425	133.4	150.9	11.6	10.1	2.6	6.1	4.7 / 12
7-2			2.145		133.5		11.5				
7-3			2.151		133.9		11.3				
7-4			2.169		135.0		10.6				
7-5			2.292		142.7		5.5				
8-1			2.164	2.407	134.7	149.8	10.1	11.0	0.7	1.7	5.4 / 12
8-2			2.122		132.1		11.8				
8-3			2.152		133.9		10.6				
8-4			2.142		133.3		11.0				
8-5			2.136		132.9		11.3				
9-1			2.241	2.405	139.5	149.7	6.8	4.8	1.3	3.1	6.1 / 4
9-2			2.313		144.0		3.8				
9-3			2.303		143.3		4.2				
9-4			2.277		141.7		5.3				
9-5			2.316		144.1		3.7				

Table 5. Core data for test lane, bottom lift, fine plus mixes 10-18, construction date 9/21/95.

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
10-1	80.5	79.5	2.200	2.405	136.9	149.7	8.5	8.9	2.1	5.3	5.4 / 8
10-2	76.3	3.1	2.106		131.1		12.4				
10-3	81.2		2.217		138.0		7.8				
10-4	77.2		2.234		139.0		7.1				
10-5	82.2		2.196		136.7		8.7				
11-1	85.8	84.1	2.168	2.391	134.9	148.8	9.3	9.6	0.3	0.7	5.4 / 12
11-2	84.4	3.3	2.152		133.9		10.0				
11-3	83.2		2.162		134.6		9.6				
11-4	84.7		2.163		134.6		9.5				
11-5	82.3		2.168		134.9		9.3				
12-1	74.1	74.7	2.270	2.382	141.3	148.3	4.7	4.4	0.6	1.5	6.1 / 4
12-2	75.9	2.9	2.270		141.3		4.7				
12-3	76.9		2.286		142.3		4.0				
12-4	73.1		2.296		142.9		3.6				
12-5	73.5		2.261		140.7		5.1				
13-1	85.1	83.9	2.202	2.419	137.1	150.6	9.0	8.8	0.4	0.9	4.7 / 8
13-2	81.8	3.3	2.199		136.9		9.1				
13-3	86.0		2.212		137.7		8.6				
13-4	84.0		2.201		137.0		9.0				
13-5	82.4		2.221		138.2		8.2				
14-1	85.5	88.1	2.265	2.350	141.0	146.3	3.6	2.9	0.5	1.2	6.1 / 4
14-2	89.8	3.5	2.293		142.7		2.4				
14-3	89.9		2.289		142.5		2.6				
14-4	90.9		2.279		141.8		3.0				
14-5	84.4		2.281		142.0		2.9				

Table 5. Core data for test lane, bottom lift, fine plus mixes 10-18, construction date 9/21/95 (continued).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
15-1	88.2	92.0	2.094	2.422	130.3	150.7	13.5	12.9	0.7	1.7	4.7 / 12
15-2	89.2	3.6	2.091		130.1		13.7				
15-3	96.2		2.120		131.9		12.5				
15-4	92.5		2.112		131.5		12.8				
15-5	93.7		2.132		132.7		12.0				
16-1	89.5	89.4	2.217	2.394	138.0	149.0	7.4	7.4	0.4	0.9	5.4 / 8
16-2	90.7	3.5	2.210		137.6		7.7				
16-3	90.1		2.223		138.4		7.1				
16-4	91.4		2.205		137.2		7.9				
16-5	85.5		2.227		138.6		7.0				
17-1	88.3	83.4	2.294	2.404	142.8	149.6	4.6	5.4	1.5	4.0	5.4 / 4
17-2	86.1	3.3	2.306		143.5		4.1				
17-3	83.9		2.277		141.7		5.3				
17-4	81.2		2.286		142.3		4.9				
17-5	77.6		2.211		137.6		8.0				
18-1	96.4	96.4	2.227	2.375	138.6	147.8	7.4	7.2	0.2	0.6	6.1 / 8
18-2	95.0	3.8	2.228		138.7		7.3				
18-3	101.8		2.231		138.9		7.2				
18-4	97.7		2.240		139.4		6.8				
18-5	91.1		2.226		138.5		7.4				

Table 6. Core data for test lane, bottom lift, fine plus mixes 10-18, construction date 9/21/95 (after placing top lift).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm(in)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
10-1			2.233	2.405	139.0	149.7	7.2	8.1	0.8	1.8	5.4 / 8
10-2			2.193		136.5		8.8				
10-3			2.222		138.3		7.6				
10-4			2.190		136.3		8.9				
10-5			2.212		137.7		8.0				
11-1			2.176	2.391	135.4	148.8	9.0	9.8	0.7	1.6	5.4 / 12
11-2			2.138		133.1		10.6				
11-3			2.144		133.4		10.3				
11-4			2.172		135.2		9.2				
11-5			2.152		133.9		10.0				
12-1			2.277	2.382	141.7	148.3	4.4	3.1	1.3	2.7	6.1 / 4
12-2			2.339		145.6		1.8				
12-3			2.340		145.6		1.8				
12-4			2.275		141.6		4.5				
12-5			2.308		143.6		3.1				
13-1			2.181	2.419	135.7	150.6	9.8	9.3	0.6	1.5	4.7 / 8
13-2			2.183		135.9		9.8				
13-3			2.217		138.0		8.4				
13-4			2.194		136.6		9.3				
13-5			2.198		136.8		9.1				
14-1			2.273	2.350	141.5	146.3	3.3	2.5	0.6	1.4	6.1 / 4
14-2			2.286		142.3		2.7				
14-3			2.307		143.6		1.8				
14-4			2.302		143.3		2.0				
14-5			2.289		142.5		2.6				

Table 6. Core data for test lane, bottom lift, fine plus mixes 10-18, construction date 9/21/95 (after placing top lift) (continued).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
15-1			2.188	2.422	136.2	150.7	9.7	12.1	1.6	4.4	4.7 / 12
15-2			2.120		131.9		12.5				
15-3			2.125		132.3		12.3				
15-4			2.082		129.6		14.0				
15-5			2.127		132.4		12.2				
16-1			2.202	2.394	137.1	149.0	8.0	7.1	0.6	1.7	5.4 / 8
16-2			2.223		138.4		7.1				
16-3			2.228		138.7		6.9				
16-4			2.227		138.6		7.0				
16-5			2.242		139.5		6.3				
17-1			2.306	2.404	143.5	149.6	4.1	4.0	0.3	0.8	5.4 / 4
17-2			2.316		144.1		3.7				
17-3			2.313		144.0		3.8				
17-4			2.297		143.0		4.5				
17-5			2.312		143.9		3.8				
18-1			2.241	2.375	139.5	147.8	6.8	6.1	0.9	1.7	6.1 / 8
18-2											
18-3			2.283		142.1		5.0				
18-4											
18-5			2.249		140.0		6.4				

Table 7. Core data for test lane, bottom lift, coarse mixes 19-26, construction date 9/30/95.

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
19-1	75.1	80.5	2.158	2.413	134.3	150.2	10.6	8.7	1.8	4.7	5.7 / 8
19-2	81.8	3.17	2.213		137.7		8.3				
19-3	85.2		2.195		136.6		9.0				
19-4	76.8		2.271		141.3		5.9				
19-5	83.5		2.177		135.5		9.8				
20-1	92.3	88.8	2.137	2.422	133.0	150.7	11.8	11.7	0.4	1.0	5.7 / 12
20-2	92.2	3.50	2.150		133.8		11.2				
20-3	87.6		2.126		132.3		12.2				
20-4	84.7		2.138		133.1		11.7				
20-5	87.4		2.141		133.3		11.6				
21-1	92.6	87.9	2.176	2.374	135.4	147.8	8.3	8.0	0.5	1.4	6.4 / 8
21-2	82.8	3.46	2.184		135.9		8.0				
21-3	84.1		2.202		137.1		7.2				
21-4	90.7		2.169		135.0		8.6				
21-5	89.2		2.184		135.9		8.0				
22-1	79.5	82.0	2.199	2.404	136.9	149.6	8.5	8.4	0.5	1.4	5.0 / 8
22-2	81.0	3.23	2.180		135.7		9.3				
22-3	84.6		2.214		137.8		7.9				
22-4	83.3		2.207		137.4		8.2				
22-5	81.8		2.207		137.4		8.2				
23-1	81.1	79.6	2.269	2.421	141.2	150.7	6.3	6.7	0.6	1.4	5.7 / 4
23-2	83.3	3.13	2.238		139.3		7.6				
23-3	82.6		2.272		141.4		6.2				
23-4	79.1		2.248		139.9		7.1				
23-5	71.8		2.271		141.3		6.2				

Table 7. Core data for test lane, bottom lift, coarse mixes 19-26, construction date 9/30/95 (continued).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
24-1	88.0	86.1	2.228	2.412	138.7	150.1	7.6	8.3	0.5	1.3	5.7 / 8
24-2	83.7	3.39	2.217		138.0		8.1				
24-3	85.9		2.214		137.8		8.2				
24-4	86.6		2.196		136.7		9.0				
24-5	86.2		2.208		137.4		8.5				
25-1	76.9	78.6	2.288	2.370	142.4	147.5	3.5	3.9	0.5	1.2	6.4 / 4
25-2	76.8	3.09	2.280		141.9		3.8				
25-3	78.5		2.259		140.6		4.7				
25-4	80.6		2.284		142.2		3.6				
25-5	80.0		2.271		141.3		4.2				
26-1	89.0	86.6	2.169	2.386	135.0	148.5	9.1	9.1	0.4	1.0	5.0 / 12
26-2	86.2	3.41	2.166		134.8		9.2				
26-3	84.9		2.178		135.6		8.7				
26-4	85.5		2.178		135.6		8.7				
26-5	87.4		2.154		134.1		9.7				

Table 8. Core data for test lane, bottom lift, coarse mixes 19-26, construction date 9/30/95 (after placing top lift).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
19-1	77.7	79.1	2.205	2.413	137.2	150.2	8.6	8.3	2.0	4.5	5.7 / 8
19-2	78.9	3.11	2.160		134.4		10.5				
19-3	78.9		2.179		135.6		9.7				
19-4	78.1		2.269		141.2		6.0				
19-5	81.7		2.255		140.4		6.5				
20-1	92.9	90.8	2.143	2.422	133.4	150.7	11.5	11.3	0.3	0.7	5.7 / 12
20-2	94.3	3.58	2.158		134.3		10.9				
20-3	91.7		2.142		133.3		11.6				
20-4	87.8		2.142		133.3		11.6				
20-5	87.4		2.157		134.3		10.9				
21-1	90.3	86.6	2.182	2.374	135.8	147.8	8.1	8.3	1.0	2.7	6.4 / 8
21-2	85.2	3.41	2.139		133.1		9.9				
21-3	87.1		2.175		135.4		8.4				
21-4	89.5		2.188		136.2		7.8				
21-5	80.9		2.202		137.1		7.2				
22-1	77.4	81.8	2.161	2.404	134.5	149.6	10.1	8.9	1.0	2.0	5.0 / 8
22-2	77.9	3.22	2.169		135.0		9.8				
22-3	84.1		2.205		137.2		8.3				
22-4	88.0		2.206		137.3		8.2				
22-5	81.6		2.210		137.6		8.1				
23-1			2.268	2.421	141.2	150.7	6.3	7.3	1.1	2.4	5.7 / 4
23-2			2.209		137.5		8.8				
23-3			2.221		138.2		8.3				
23-4			2.251		140.1		7.0				
23-5			2.268		141.2		6.3				

Table 8. Core data for test lane, bottom lift, coarse mixes 19-26, construction date 9/30/95 (after placing top lift) (continued).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
24-1			2.225	2.412	138.5	150.1	7.8	7.5	0.2	0.6	5.7 / 8
24-2			2.228		138.7		7.6				
24-3			2.232		138.9		7.5				
24-4			2.231		138.9		7.5				
24-5			2.240		139.4		7.1				
25-1			2.309	2.370	143.7	147.5	2.6	2.6	0.4	1.0	6.4 / 4
25-2			2.308		143.6		2.6				
25-3			2.297		143.0		3.1				
25-4			2.321		144.5		2.1				
25-5			2.309		143.7		2.6				
26-1			2.190	2.386	136.3	148.5	8.2	8.2	0.3	0.7	5.0 / 12
26-2			2.198		136.8		7.9				
26-3			2.195		136.6		8.0				
26-4			2.181		135.7		8.6				
26.5			2.185		136.0		8.4				

Table 9. Core data for test lane, bottom lift, fine mixes 1-9, construction date 10/02/95.

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
1-1	78.3	76.4	2.237	2.427	139.2	151.1	7.8	8.8	0.7	1.8	5.4 / 8
1-2	77.4	3.0	2.194		136.6		9.6				
1-3	74.7		2.210		137.6		8.9				
1-4	77.8		2.204		137.2		9.2				
1-5	73.6		2.228		138.7		8.2				
2-1	74.1	75.4	2.190	2.450	136.3	152.5	10.6	10.4	1.0	2.7	4.7 / 8
2-2	71.2	3.0	2.172		135.2		11.3				
2-3	81.6		2.181		135.7		11.0				
2-4	74.6		2.237		139.2		8.7				
2-5	75.3		2.200		136.9		10.2				
3-1	77.4	79.1	2.128	2.425	132.4	150.9	12.2	12.4	0.3	0.9	4.7 / 12
3-2	77.2	3.1	2.110		131.3		13.0				
3-3	81.9		2.127		132.4		12.3				
3-4	78.8		2.122		132.1		12.5				
3-5	80.3		2.131		132.6		12.1				
4-1	80.6	79.1	2.276	2.429	141.7	151.2	6.3	6.6	0.2	0.6	5.4 / 4
4-2	81.2	3.1	2.261		140.7		6.9				
4-3	79.5		2.270		141.3		6.5				
4-4	74.2		2.273		141.5		6.4				
4-5	80.2		2.269		141.2		6.6				
5-1	77.8	73.5	2.196	2.402	136.7	149.5	8.6	9.0	0.3	0.8	6.1 / 8
5-2	75.6	2.9	2.186		136.1		9.0				
5-3	74.2		2.176		135.4		9.4				
5-4	73.7		2.186		136.1		9.0				
5-5	66.4		2.185		136.0		9.0				

Table 9. Core data for test lane, bottom lift, fine mixes 1-9, construction date 10/02/95 (continued).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
6-1	75.6	74.0	2.222	2.427	138.3	151.1	8.4	8.7	0.4	1.0	5.4 / 8
6-2	70.2	2.9	2.214		137.8		8.8				
6-3	76.5		2.225		138.5		8.3				
6-4	74.3		2.219		138.1		8.6				
6-5	73.2		2.200		136.9		9.4				
7-1	73.5	75.6	2.130	2.429	132.6	151.2	12.3	12.2	0.2	0.5	4.7 / 12
7-2	73.6	3.0	2.128		132.4		12.4				
7-3	73.1		2.129		132.5		12.4				
7-4	72.6		2.140		133.2		11.9				
7-5	85.4		2.133		132.8		12.2				
8-1	79.6	78.3	2.138	2.417	133.1	150.4	11.5	11.0	0.6	1.4	5.4 / 12
8-2	79.6	3.1	2.132		132.7		11.8				
8-3	77.8		2.166		134.8		10.4				
8-4	79.1		2.159		134.4		10.7				
8-5	75.5		2.156		134.2		10.8				
9-1	80.4	82.5	2.274	2.408	141.5	149.9	5.6	4.3	1.2	2.7	6.1 / 4
9-2	83.1	3.2	2.340		145.6		2.8				
9-3	83.1		2.322		144.5		3.6				
9-4	80.3		2.277		141.7		5.4				
9-5	85.5		2.306		143.5		4.2				

Table 10. Core data for test lane, top lift, fine plus mixes 10-18, construction date 10/03/95.

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
10-1-6	73.3	79.3	2.210	2.391	137.6	148.8	7.6	7.2	0.6	1.5	5.4 / 8
10-2	79.8	3.1	2.235		139.1		6.5				
10-3	79.6		2.200		136.9		8.0				
10-4	81.0		2.222		138.3		7.1				
10-5	82.7		2.232		138.9		6.6				
11-1-6	71.2	73.7	2.123	2.393	132.1	148.9	11.3	10.9	0.4	0.8	5.4 / 12
11-2	75.1	2.9	2.138		133.1		10.7				
11-3	73.8		2.124		132.2		11.2				
11-4	72.7		2.133		132.8		10.9				
11-5	75.5		2.142		133.3		10.5				
12-1-6	89.8	85.9	2.268	2.387	141.2	148.6	5.0	4.2	0.6	1.3	6.1 / 4
12-2	84.3	3.4	2.300		143.2		3.6				
12-3	83.7		2.300		143.2		3.6				
12-4	85.3		2.278		141.8		4.6				
12-5	86.5		2.290		142.5		4.1				
13-1-6	70.9	68.7	2.219	2.411	138.1	150.1	8.0	8.1	0.2	0.4	4.7 / 8
13-2	69.2	2.7	2.212		137.7		8.3				
13-3	65.5		2.217		138.0		8.0				
13-4	67.6		2.212		137.7		8.3				
13-5	70.1		2.222		138.3		7.8				
14-1	66.5	66.5	2.269	2.366	141.2	147.3	4.1	3.9	0.5	1.2	6.1 / 4
14-2	65.3	2.6	2.257		140.5		4.6				
14-3	64.4		2.279		141.8		3.7				
14-4	68.9		2.286		142.3		3.4				
14-5	67.3		2.277		141.7		3.8				

Table 10. Core data for test lane, top lift, fine plus mixes 10-18, construction date 10/03/95 (continued).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
15-1	56.2	57.1	2.105	2.413	131.0	150.2	12.8	11.8	0.8	2.0	4.7 / 12
15-2	57.8	2.2	2.143		133.4		11.2				
15-3	52.2		2.125		132.3		11.9				
15-4	58.2		2.116		131.7		12.3				
15-5	60.9		2.154		134.1		10.7				
16-1	66.6	67.0	2.203	2.401	137.1	149.4	8.2	7.8	0.3	0.6	5.4 / 8
16-2	73.0	2.6	2.217		138.0		7.7				
16-3	65.4		2.218		138.0		7.6				
16-4	65.4		2.214		137.8		7.8				
16-5	64.6		2.211		137.6		7.9				
17-1	65.4	65.0	2.293	2.410	142.7	150.0	4.9	4.5	0.3	0.8	5.4 / 4
17-2	64.7	2.6	2.299		143.1		4.6				
17-3	65.3		2.299		143.1		4.6				
17-4	65.7		2.284		143.1		4.6				
17-5	64.1		2.312		143.9		4.1				
18-1	59.1	61.4	2.223	2.379	138.4	148.1	6.6	5.9	0.5	1.3	6.1 / 8
18-2	58.2	2.4	2.232		138.9		6.2				
18-3	67.5		2.238		139.3		5.9				
18-4	61.9		2.253		140.2		5.3				
18-5	60.4		2.246		139.8		5.6				

Table 11. Core data for test lane, top lift, coarse mixes 19-26, construction date 10/04/95.

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
19-1	72.3	72.7	2.203	2.403	137.1	149.6	8.3	8.1	0.4	0.9	5.7 / 8
19-2	75.2	2.86	2.199		136.9		8.5				
19-3	74.1		2.221		138.2		7.6				
19-4	69.4		2.212		137.7		7.9				
19-5	72.7		2.210		137.6		8.0				
20-1	56.2	61.0	2.151	2.413	133.9	150.2	10.9	10.8	0.6	1.4	5.7 / 12
20-2	51.2	2.40	2.170		135.1		10.1				
20-3	63.1		2.136		132.9		11.5				
20-4	66.8		2.145		133.5		11.1				
20-5	67.9		2.162		134.6		10.4				
21-1	64.9	66.5	2.213	2.377	137.7	147.9	6.9	6.9	0.6	1.6	6.4 / 8
21-2	65.7	2.62	2.191		136.4		7.8				
21-3	67.2		2.230		138.8		6.2				
21-4	67.1		2.226		138.5		6.4				
21-5	67.8		2.209		137.5		7.1				
22-1	70.2	69.9	2.203	2.434	137.1	151.5	9.5	8.5	0.8	1.8	5.0 / 8
22-2	70.7	2.75	2.212		137.7		9.1				
22-3	69.6		2.246		139.8		7.7				
22-4	69.2		2.238		139.3		8.1				
22-5	69.9		2.236		139.2		8.1				
23-1	69.8	67.3	2.279	2.398	141.8	149.3	5.0	4.9	0.4	1.0	5.7 / 4
23-2	68.4	2.65	2.287		142.3		4.6				
23-3	69.1		2.286		142.3		4.7				
23-4	60.6		2.264		140.9		5.6				
23-5	68.6		2.284		142.2		4.8				

Table 11. Core data for test lane, top lift, coarse mixes 19-26, construction date 10/04/95 (continued).

Mix & Core No	Core Thickness, mm	Avg. Thickness, mm (in.)	Core SG	Rice SG	Core Density, lbf/ft³	Rice Density, lbf/ft³	Air Voids, percent				Target AC/AV, percent/ percent
							Cores	Average	Stdev	Range	
24-1	85.6	84.2	2.194	2.389	136.6	148.7	8.2	6.8	1.1	3.1	5.7 / 8
24-2	84.2	3.32	2.221		138.2		7.0				
24-3	83.2		2.268		141.2		5.1				
24-4	85.8		2.223		138.4		6.9				
24-5	82.3		2.229		138.7		6.7				
25-1	75.3	75.2	2.271	2.382	141.3	148.3	4.7	3.7	0.6	1.6	6.4 / 4
25-2	73.9	2.96	2.290		142.5		3.9				
25-3	75.6		2.309		143.7		3.1				
25-4	76.4		2.307		143.6		3.1				
25-5	75.0		2.296		142.9		3.6				
26-1	81.9	83.6	2.173	2.436	135.2	151.6	10.8	11.0	0.6	1.6	5.0 / 12
26-2	84.6	3.29	2.157		134.3		11.5				
26-3	82.7		2.178		135.6		10.6				
26-4	84.0		2.187		136.1		10.2				
26-5	84.6		2.149		133.8		11.8				

Table 12. Core data for test lane (top and bottom lift thickness).

Fine					Fine Plus					Coarse				
Mix Core No.	Total Core Thickness	Total Thickness Average mm	Total Thickness Average in.	Total Thickness Std in.	Mix Core No.	Total Core Thickness	Total Thickness Average mm	Total Thickness Average in.	Total Thickness Std in.	Mix Core No.	Total Core Thickness	Total Thickness Average mm	Total Thickness Average in.	Total Thickness Std in.
1-1	161.4	159.2	6.3	0.13	10-1	153.8	158.8	6.3	0.17	19-1	147.4	153.2	6.0	0.24
1-2	160.3				10-2	156.1				19-2	157.0			
1-3	156.3				10-3	160.8				19-3	159.3			
1-4	162.8				10-4	158.2				19-4	146.2			
1-5	155.0				10-5	164.9				19-5	156.2			
2-1	153.8	157.5	6.2	0.24	11-1	157.0	157.7	6.2	0.04	20-1	148.5	149.9	5.9	0.17
2-2	152.8				11-2	159.5				20-2	143.4			
2-3	167.5				11-3	157.0				20-3	150.7			
2-4	158.7				11-4	157.4				20-4	151.5			
2-5	154.5				11-5	157.8				20-5	155.3			
3-1	161.6	163.6	6.4	0.12	12-1	163.9	160.6	6.3	0.08	21-1	157.5	154.4	6.1	0.17
3-2	159.7				12-2	160.2				21-2	148.5			
3-3	167.3				12-3	160.6				21-3	151.3			
3-4	165.3				12-4	158.4				21-4	157.8			
3-5	164.2				12-5	160.0				21-5	157.0			
4-1	161.9	155.9	6.1	0.21	13-1	156.0	152.5	6.0	0.08	22-1	149.7	152.0	6.0	0.06
4-2	155.4				13-2	151.0				22-2	151.7			
4-3	157.7				13-3	151.5				22-3	154.2			
4-4	147.4				13-4	151.6				22-4	152.5			
4-5	157.0				13-5	152.5				22-5	151.7			
5-1	156.7	154.2	6.1	0.11	14-1	152.0	154.6	6.1	0.13	23-1	150.9	146.9	5.8	0.25
5-2	157.6				14-2	155.1				23-2	151.7			
5-3	151.9				14-3	154.3				23-3	151.7			
5-4	152.8				14-4	159.8				23-4	139.7			
5-5	151.9				14-5	151.7				23-5	140.4			
6-1	160.9	154.4	6.1	0.18	15-1	144.4	149.0	5.9	0.15	24-1	173.6	170.3	6.7	0.10
6-2	148.7				15-2	147.0				24-2	167.9			
6-3	156.0				15-3	148.4				24-3	169.1			
6-4	152.8				15-4	150.7				24-4	172.4			
6-5	153.6				15-5	154.6				24-5	168.5			

Table 12. Core data for test lane (top and bottom lift thickness) (continued).

Fine					Fine Plus					Coarse				
Mix Core No.	Total Core Thickness	Total Thickness Average mm	Total Thickness Average in.	Total Thickness Std in.	Mix Core No.	Total Core Thickness	Total Thickness Average mm	Total Thickness Average in.	Total Thickness Std in.	Mix Core No.	Total Core Thickness	Total Thickness Average mm	Total Thickness Average in.	Total Thickness Std in.
7-1	157.3	160.6	6.3	0.24	16-1	156.1	156.4	6.2	0.19	25-1	152.2	153.8	6.1	0.10
7-2	155.2				16-2	163.7				25-2	150.7			
7-3	159.8				16-3	155.5				25-3	154.1			
7-4	159.7				16-4	156.8				25-4	157.0			
7-5	170.9				16-5	150.1				25-5	155.0			
8-1	162.8	159.1	6.3	0.15	17-1	153.7	148.5	5.8	0.18	26-1	170.9	170.2	6.7	0.07
8-2	162.8				17-2	150.8				26-2	170.8			
8-3	159.4				17-3	149.2				26-3	167.6			
8-4	156.0				17-4	146.9				26-4	169.5			
8-5	154.3				17-5	141.7				26-5	172.0			
9-1	154.1	156.7	6.2	0.12	18-1	155.5	157.8	6.2	0.28					
9-2	159.2				18-2	153.2								
9-3	153.4				18-3	169.3								
9-4	156.7				18-4	159.6								
9-5	160.0				18-5	151.5								

Critical Mix		
Average	6.2	0.17
Minimum	6.1	0.11
Maximum	6.4	0.24

Super Critical Mix		
Average	6.1	0.14
Minimum	5.8	0.04
Maximum	6.3	0.28

Non-Critical Mix		
Average	6.2	0.14
Minimum	5.8	0.06
Maximum	6.7	0.25

Table 13. WesTrack test lane – core air voids – summary statistics - 10/30/95.

Section Number and Type	Target		Core Air Voids Statistics Without Outliers										Stat. Signi. Bet. Lifts (Pooled σ) α = 0.05
			Bottom Lift						Stat. Sig. Bet. Before and After	Top Lift			
			Before Top Lift			After Top Lift							
	AC	AV	Mean	Std.	PWL	Mean	Std.	PWL	(Pooled σ) α = 0.05	Mean	Std.	PWL	
01-MM1	5.4	8	8.30	0.80	78	8.54	0.90	67	No	8.75	0.73	62	No
02-LM	4.7	8	9.65	0.99	27	9.31	0.98	39	No	10.37	1.03	7	No
03-LH1	4.7	12	11.24	0.57	65	11.40	0.50	77	No	12.43	0.34	99	Yes
04-ML	5.4	4	6.46	0.56	0	6.30	0.60	0	No	6.55	0.23	0	No
14-HM	6.1	8	7.05	1.18	50	6.50	0.60	22	No	9.00	0.29	50	Yes
15-MM2	5.4	8	8.74	0.71	63	8.53	1.01	63	No	8.69	0.40	77	No
16-LH2	4.7	12	11.43	0.70	71	11.26	0.42	71	No	12.23	0.20	100	Yes
17-MH	5.4	12	10.96	0.71	48	10.96	0.66	48	No	11.04	0.60	52	No
18-HL	6.1	4	5.17	0.50	38	4.27	0.64	88	Yes	4.33	1.18	57	No
19-MM1	5.4	8	8.03	0.63	95	8.11	0.77	83	No	7.16	0.62	59	No
20-MH	5.4	12	9.55	0.27	0	9.81	0.71	1	No	10.91	0.35	41	Yes
21-HL1	6.1	4	4.42	0.59	83	4.00	0.55	100	No	4.18	0.59	94	No
22-LM	4.7	8	8.76	0.38	72	9.28	0.60	34	No	8.07	0.18	100	Yes
9-HL2	6.1	4	2.92	0.46	44	2.49	0.57	20	No	3.91	0.47	100	Yes
10-LH	4.7	12	12.89	0.72	55	12.74	0.76	62	No	11.79	0.82	78	No
11-MM2	5.4	8	7.42	0.38	87	7.08	0.60	55	No	7.85	0.25	100	Yes
12-ML	5.4	4	4.72	0.44	72	3.96	0.31	100	Yes	4.55	0.29	97	Yes
13-HM	6.1	8	7.22	0.24	81	6.09	0.66	7	Yes	5.91	0.49	0	No
5-MM1	5.7	8	8.24	0.64	89	7.04	0.98	51	No	8.07	0.35	100	No
6-MH	5.7	12	11.71	0.36	100	11.30	0.34	80	No	10.78	0.56	36	No
7-HM	6.4	8	8.05	0.52	100	8.29	0.99	66	No	6.87	0.65	43	Yes
8-LM	5.0	8	8.43	0.54	85	8.89	0.97	54	No	8.50	0.76	73	No
23-ML	5.7	4	6.67	0.64	0	6.55	0.29	0	No	4.92	0.39	57	Yes
24-MM2	5.7	8	8.27	0.49	96	7.50	0.23	100	Yes	7.20	0.56	62	No
25-HL	6.4	4	3.95	0.49	100	2.58	0.36	12	Yes	3.67	0.64	85	Yes
26-LH	5.0	12	9.09	0.42	0	8.22	0.29	0	Yes	10.97	0.64	49	Yes

In-Place Air Void Content and Thickness—Replacement Sections

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-13
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the SHRP Superpave HMA volumetric design method.

This WesTrack technical report provides information on the in-place air void content and thickness of the replacement mixtures at WesTrack. This information was obtained by technicians employed by Harding Lawson and Associates who examined random core samples. Thickness measurements were made prior to determining the in-place air void content and the asphalt content by the ignition method. (Note: In the figures and tables in this report, letters in the section description such as LM and MH refer to target properties for the section. The first letter is the target asphalt content [Low, Medium, or High]; the second letter is the target air voids content; a number, if present is the replicate number.)

BACKGROUND

The replacement sections were placed at WesTrack to repair failed sections that were placed during original construction. The replacement sections were constructed to provide performance information on an additional coarse graded Superpave mixture. Mixture design for these sections is reported in WesTrack Technical Report UNR-7.[4] Construction of the replacement sections was performed during May and June 1997.

HMA “trial sections” were placed on the ramps to the test track on May 23 and 30, 1997, to determine the constructability of the HMA, and to determine the gradation, asphalt binder contents, and the volumetrics. Additional trial sections were placed on the access road to

WesTrack on June 20, 1997 (table 1). Adjustments in the amount of fines returned from the baghouse, cold feeds to obtain the desired gradation, asphalt binder content, and the roller pattern to obtain the desired air void content were undertaken during the placement of these trial sections. The replacement sections on the "test lane" of the track were constructed on June 23 and 28, 1997 (table 1). The test lanes are the lanes on which the traffic was placed and the WesTrack performance information obtained.

SAMPLING AND TEST METHODS

Thickness and in-place air voids were determined on 150-mm (6-in.) diameter core samples obtained one day after placement of the mixture. Thickness and air voids were determined by the test methods shown in table 2. The bulk specific gravity of the cores was obtained by the saturated surface dry procedure. Theoretical maximum specific gravity of the mixture was determined on loose mixtures sampled behind the paver and used to determine Superpave gyratory compaction volumetrics. Cores were obtained at five random locations. The detailed sampling and testing plan for the construction of the replacement sections can be found in WesTrack Technical Report UNR-19.[5]

IN-PLACE AIR VOIDS

TRIAL SECTIONS

In-place air voids were determined on all trial and test sections placed as part of the reconstruction operation. The trial sections were used to determine the roller patterns necessary to obtain the target in-place air voids. In-place air void data for the trial sections are contained in appendices A through C. Average values and typical statistics have been determined from the data obtained on five samples from each section. Graphical comparisons of the data and percent within limits have been calculated based on acceptance criteria of plus and minus 2 percent for the target values of 4 percent, 8 percent, and 12 percent for the low, moderate, and high air void targets, respectively, on the WesTrack Project and are contained in the appendices.

TEST SECTIONS

Tables 3 and 4, figures 1 through 5, and appendices D and E contain in-place air void content information on the test section lifts placed on June 23 and 28, 1997. Average values and typical statistics have been determined from the data obtained on five samples from each section. Graphical comparisons of the data are shown in figures 1 and 2 for the bottom lift and figures 3 and 4 for the top lift. Figure 5 provides a graphical comparison of in-place air void data obtained on the bottom and top lifts. In general, the in-place air void contents are close to their target values of 4 percent, 8 percent, and 12 percent.

THICKNESS

TRIAL SECTIONS

Appendices A through C also contain thickness information on the trial sections. The thickness of the top lift of the trial section placed on May 30, 1997, was placed to match the adjacent exit ramp paving. The trial sections constructed on June 20, 1997, were placed on the access road. The thicknesses were not carefully controlled as the base upon which the HMA was placed was not carefully prepared with respect to grade and compaction. The mixtures placed on this date were difficult to confine and moved in a lateral direction.

Mean and other typical statistical data are presented for the thickness determinations for the trial section paving. Appendices A through C contain these data.

TEST SECTIONS

Appendices D and E contain data that define the lift thicknesses of the test lane sections placed at WesTrack. Mean, standard deviation, range, and percent within limit information is provided in the tables in appendices D and E. The overall thickness of the constructed test sections is shown in appendix E. The thickness of the top lift has not been calculated from the difference between the total thickness and bottom lift thickness. The overall thickness value will be used to develop the performance models.

SUMMARY

Thickness and in-place air void content were determined by testing cores taken from five random locations in each of the replacement sections placed at WesTrack in June 1997. Tables 3 and 4 contain the resulting data for the replacement sections. These data were used to develop the performance models for the WesTrack project.

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3. "Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction," *Task G Interim Report*, Final Draft, WesTrack Team, March 1996.

4. Epps, J., Hand, A., and Sebaaly, P., "Hot-Mix Asphalt Mixture Design — Replacement Sections," WesTrack Technical Report UNR-7, July 2000.

5. Hand, A., and Epps, J., "WesTrack Replacement Hot-Mix Asphalt Preconstruction, Construction, and Postconstruction Material Sampling and Testing Plan," WesTrack Technical Report UNR-19, February 2000.

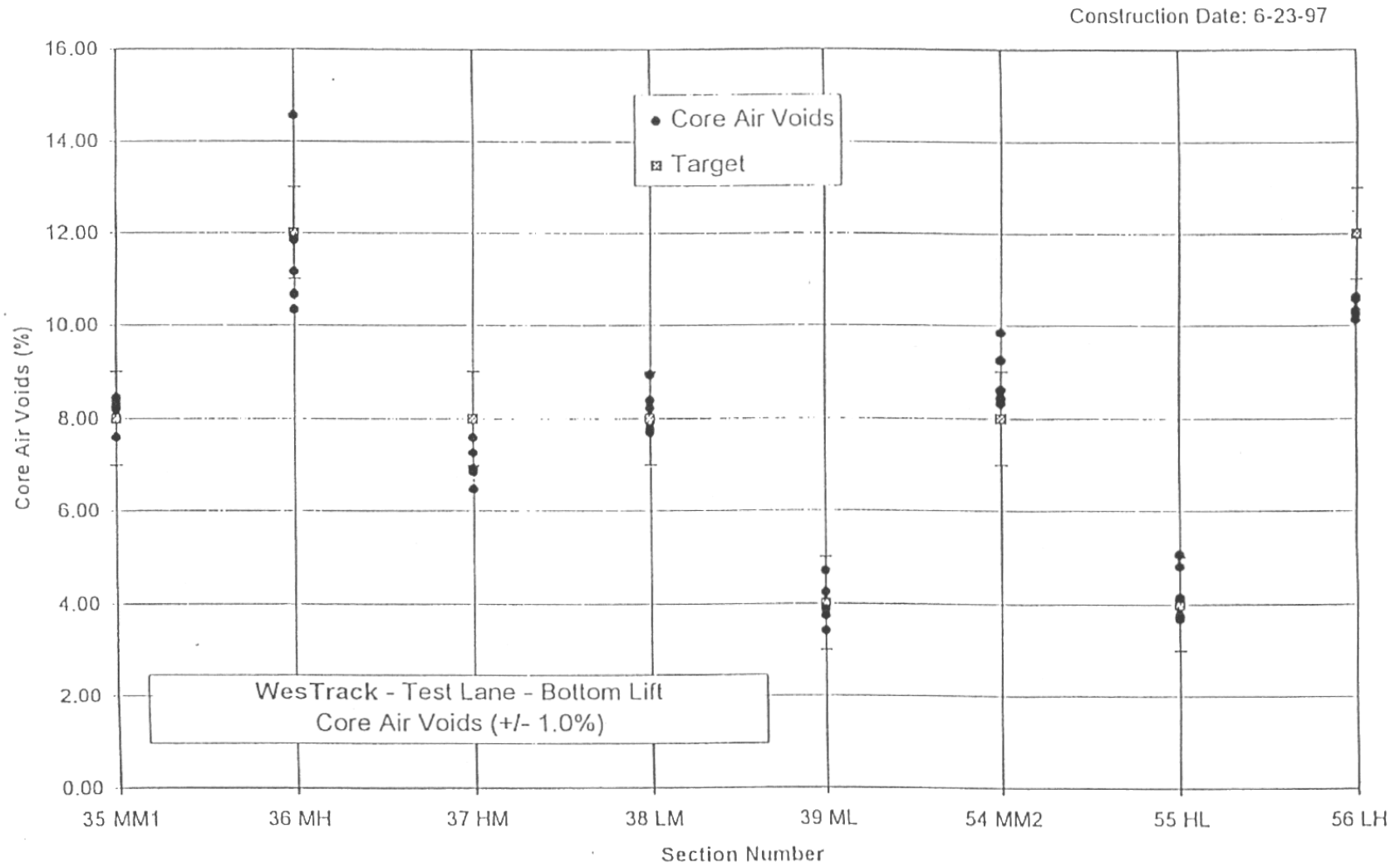


Figure 1. WesTrack new experiment sections, bottom lift, test lane.

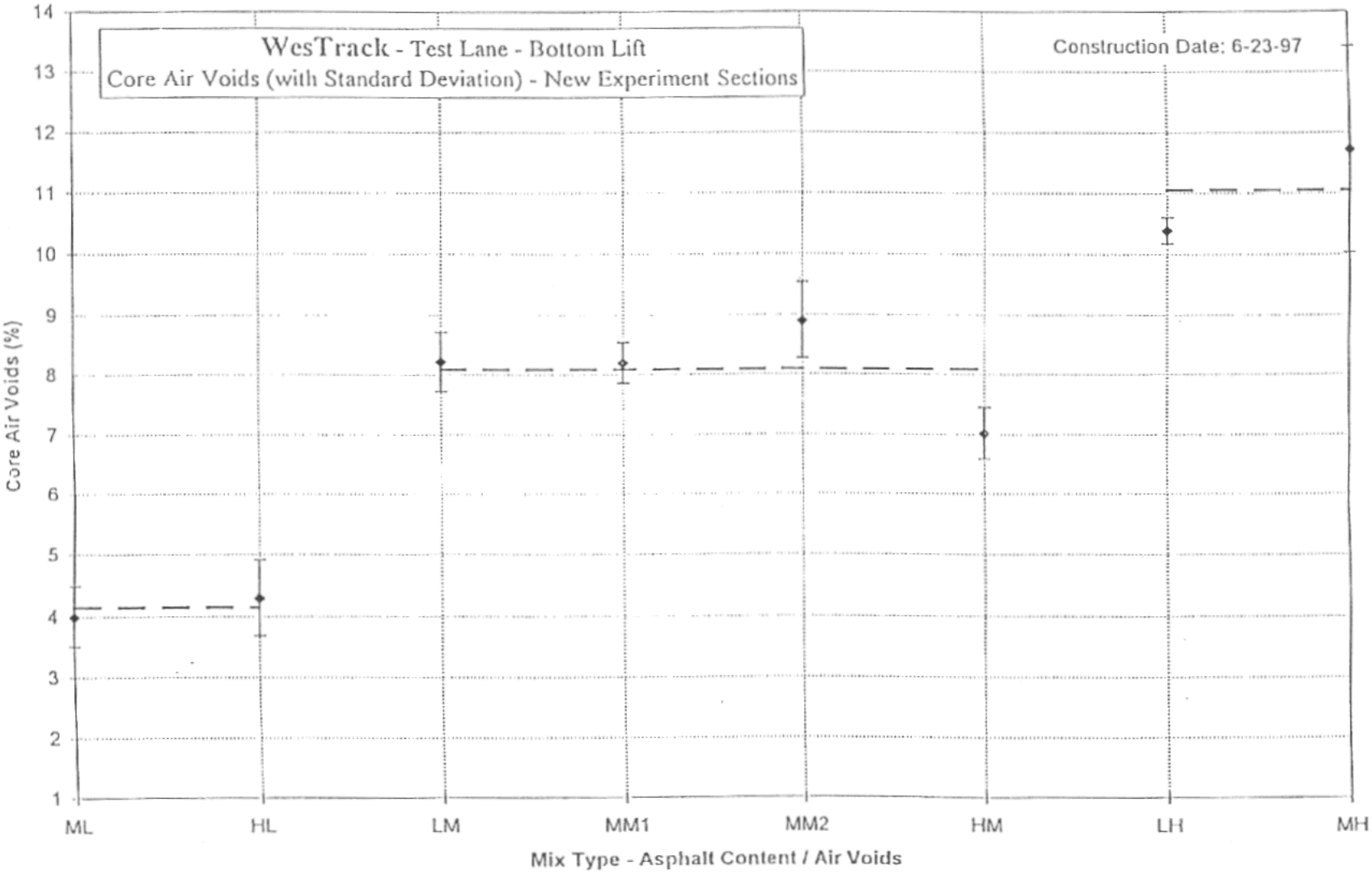


Figure 2. WesTrack test lane, bottom lift, core air voids (with standard deviation), new experiment sections.

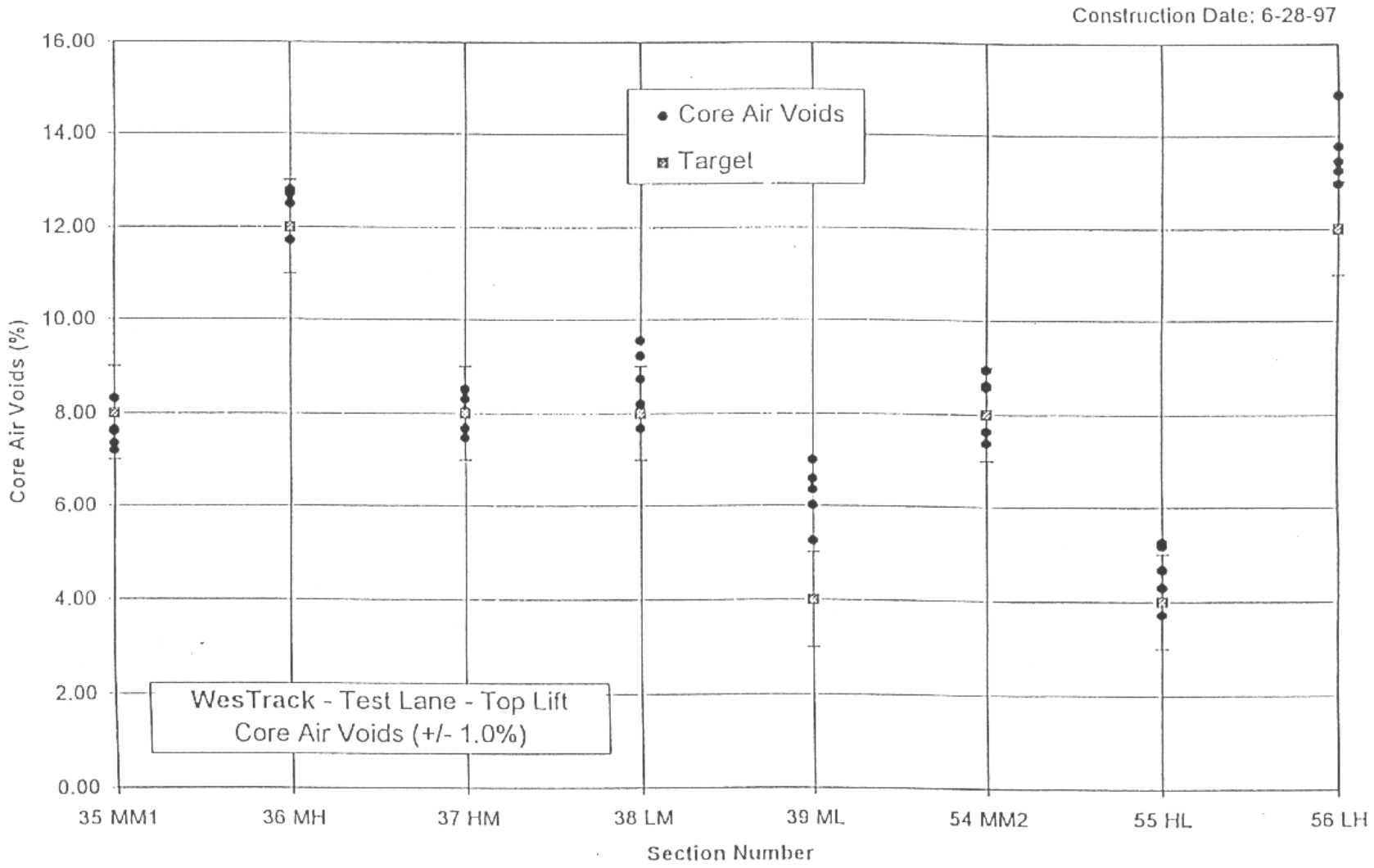


Figure 3. WesTrack new experiment sections, top lift, test lane.

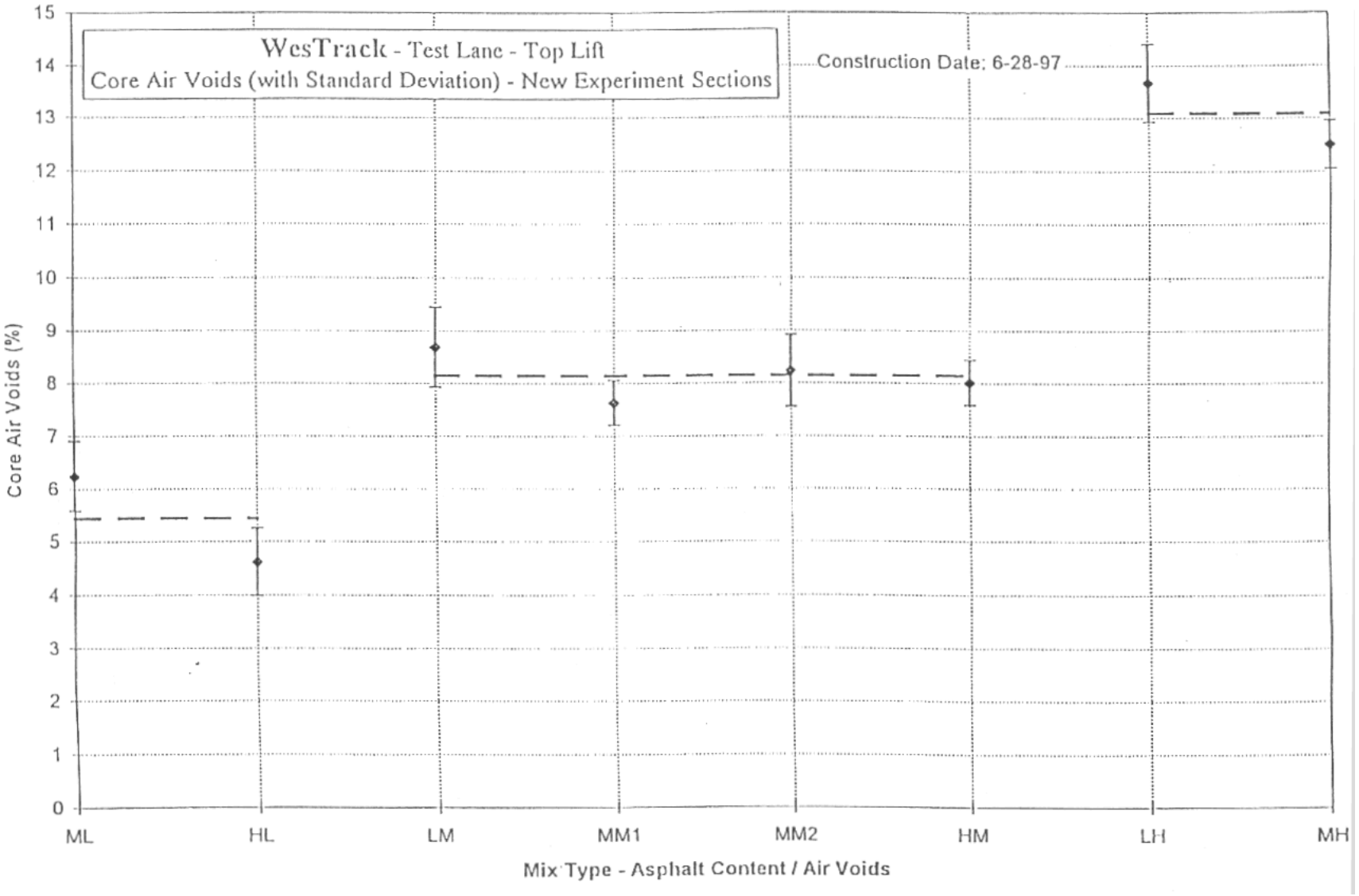


Figure 4. WesTrack test lane, top lift, core air voids (with standard deviation), new experiment sections.

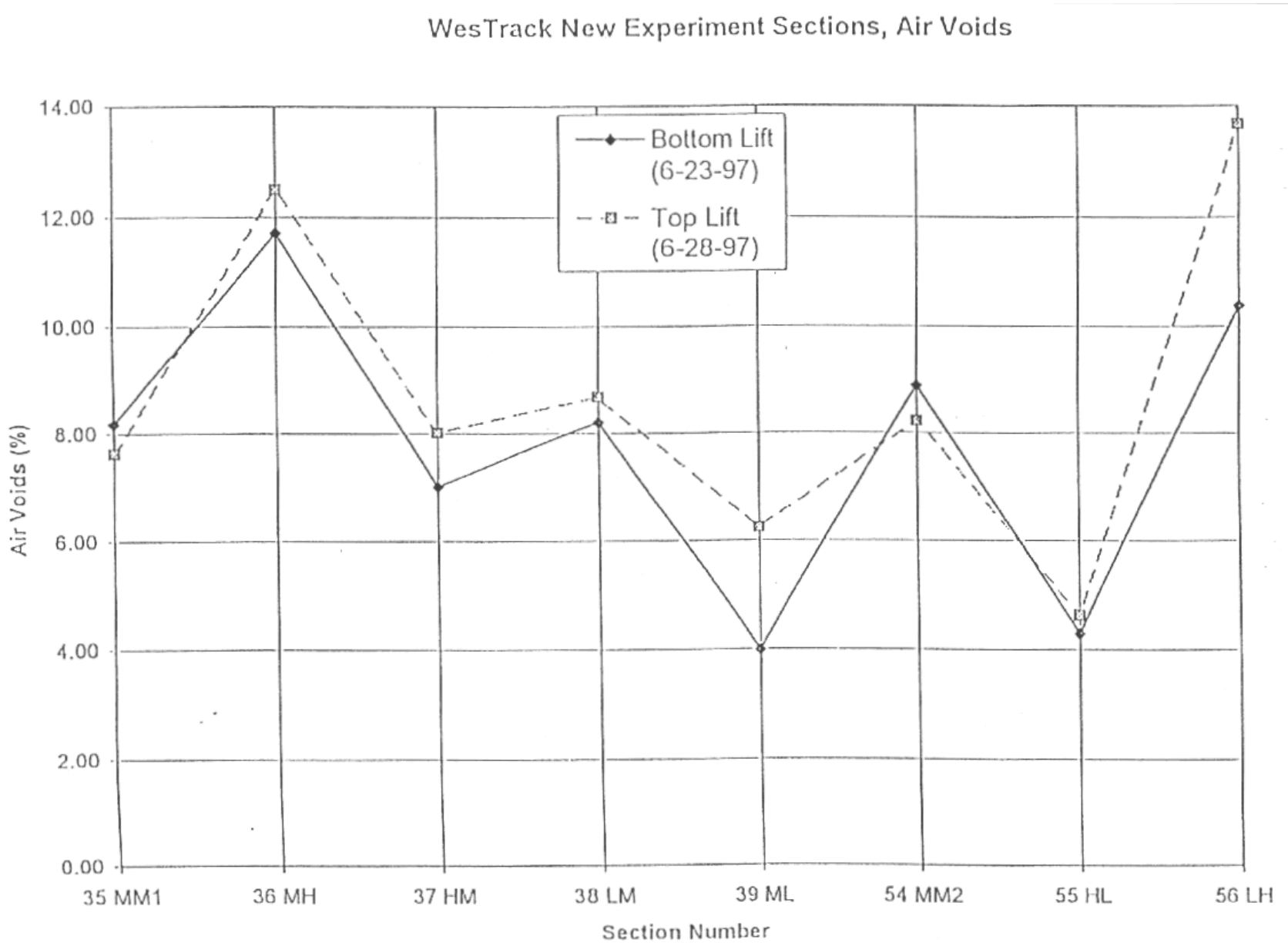


Figure 5. WesTrack new experiment sections, air voids.

Table 1. Construction schedule – replacement sections.

Date	Lift	Lane	Section Numbers
5-23-97	Bottom	Trial	35,37,38,39,55,56
5-30-97	Top	Trial	35,37,38,39,55,56
6-20-97	Bottom	Trial*	A,B,C
6-23-97	Bottom	Test	35,36,37,38,39,54,55,56
6-28-97	Top	Test	35,36,37,38,39,54,55,56

*Access road.

Table 2. In-place air voids and thickness test methods.

Description	Designation	
	AASHTO	**ASTM**
Bulk specific gravity of compacted bituminous mixtures	T 166	D 2726
Maximum specific gravity of uncompacted bituminous mixtures	TP 39 T 209	D 2041
Percent air voids in compacted dense and open graded paving mixtures	T 269	D 3203
Thickness or height of compacted bituminous paving mixture specimens		D 3549

Table 3. Core air voids for test lane, bottom lift, construction date 6/23/97.

Section & Core No.	Core Thickness, in.	Avg. Thickness, in.	Core SG	Rice SG	Core Density, lbs/ft³	Rice Density, lbs/ft³	Air Voids, percent				Target AC/AV
							Cores	Average	Stdev	Range	
35-1	3.021	3.3	2.231	2.433	138.9	151.4	8.3	8.2	0.3	0.9	MM1
35-2	3.261	0.13	2.227		138.6		8.5				
35-3	3.162		2.233		139.0		8.2				
35-4	3.627		2.248		139.9		7.6				
35-5	3.231		2.229		138.7		8.4				
36-1	2.824	2.9	2.184	2.436	135.9	151.6	10.3	11.7	1.7	4.2	MH
36-2	2.746	0.11	2.164		134.7		11.2				
36-3	3.253		2.176		135.4		10.7				
36-4	2.895		2.147		133.6		11.9				
36-5	2.689		2.081		129.5		14.6				
37-1	3.283	3.5	2.224	2.407	138.4	149.8	7.6	7.0	0.4	1.1	HM
37-2	3.645	0.14	2.232		138.9		7.3				
37-3	3.293		2.251		140.1		6.5				
37-4	3.700		2.240		139.4		6.9				
37-5	3.436		2.242		139.5		6.9				
38-1	2.966	3.4	2.232	2.451	138.9	152.6	8.9	8.2	0.5	1.2	LM
38-2	3.293	0.13	2.260		140.7		7.8				
38-3	3.392		2.262		140.8		7.7				
38-4	3.368		2.249		140.0		8.2				
38-5	3.860		2.245		139.7		8.4				
39-1	3.249	3.3	2.321	2.424	144.5	150.9	4.2	4.0	0.5	1.3	ML
39-2	3.317	0.13	2.341		145.7		3.4				
39-3	3.323		2.333		145.2		3.8				
39-4	3.292		2.330		145.0		3.9				
39-5	3.448		2.310		143.8		4.7				

Table 3. Core air voids for test lane, bottom lift, construction date 6/23/97 (continued).

Section & Core No.	Core Thickness, in.	Avg. Thickness, in.	Core SG	Rice SG	Core Density, lbs/ft³	Rice Density, lbs/ft³	Air Voids, percent				Target AC/AV
							Cores	Average	Stdev	Range	
54-1	3.298	3.2	2.226	2.436	138.5	151.6	8.6	8.9	0.6	1.5	MM2
54-2	3.057	0.13	2.196		136.7		9.9				
54-3	3.406		2.230		138.8		8.5				
54-4	3.163		2.211		137.6		9.2				
54-5	3.156		2.233		139.0		8.3				
55-1	3.295	3.3	2.288	2.410	142.4	150.0	5.1	4.3	0.6	1.4	HL
55-2	3.378	0.13	2.294		142.8		4.8				
55-3	3.194		2.321		144.5		3.7				
55-4	3.290		2.310		143.8		4.1				
55-5	3.262		2.319		144.3		3.8				
56-1	3.246	3.2	2.195	2.448	136.6	152.4	10.3	10.4	0.2	0.5	LH
56-2	3.026	0.13	2.189		136.2		10.6				
56-3	3.284		2.197		136.7		10.3				
56-4	3.172		2.200		136.9		10.1				
56-5	3.502		2.188		136.2		10.6				

Table 4. Core air voids for test lane, top lift, construction date 6/28/97.

Section & Core No.	Core Thickness, in.	Avg. Thickness, in.	Core SG	Rice SG	Core Density, lbs/ft³	Rice Density, lbs/ft³	Air Voids, percent				Target AC/AV
							Cores	Average	Stdev	Range	
35-1	2.85	2.8	2.250	2.429	140.0	151.2	7.4	7.6	0.4	1.1	MM1
35-2	2.80	0.11	2.227		138.6		8.3				
35-3	2.70		2.243		139.6		7.7				
35-4	2.68		2.244		139.7		7.6				
35-5	2.76		2.254		140.3		7.2				
36-1	3.05	3.0	2.136	2.447	132.9	152.3	12.7	12.5	0.4	1.1	MH
36-2	2.95	0.12	2.141		133.3		12.5				
36-3	3.10		2.134		132.8		12.8				
36-4	3.15		2.134		132.8		12.8				
36-5	2.90		2.160		134.4		11.7				
37-1	3.07	2.9	2.211	2.417	137.6	150.4	8.5	8.0	0.4	1.0	HM
37-2	2.51	0.11	2.236		139.2		7.5				
37-3	3.08		2.222		138.3		8.1				
37-4	3.20		2.231		138.9		7.7				
37-5	2.64		2.216		137.9		8.3				
38-1	2.72	2.7	2.232	2.459	138.9	153.0	9.2	8.7	0.8	1.9	LM
38-2	2.76	0.11	2.270		141.3		7.7				
38-3	2.65		2.224		138.4		9.6				
38-4	2.75		2.257		140.5		8.2				
38-5	2.70		2.244		139.7		8.7				
39-1	2.83	2.7	2.280	2.441	141.9	151.9	6.6	6.2	0.7	1.8	ML
39-2	2.55	0.11	2.270		141.3		7.0				
39-3	2.78		2.313		144.0		5.2				
39-4	2.71		2.286		142.3		6.3				
39-5	2.83		2.294		142.8		6.0				

Table 4. Core air voids for test lane, top lift, construction date 6/28/97 (continued).

Section & Core No.	Core Thickness, in.	Avg. Thickness, in.	Core SG	Rice SG	Core Density, lbs/ft³	Rice Density, lbs/ft³	Air Voids, percent				Target AC/AV
							Cores	Average	Stdev	Range	
54-1	2.70	2.8	2.216	2.424	137.9	150.9	8.6	8.2	0.7	1.6	MM2
54-2	2.85	0.11	2.207		137.4		9.0				
54-3	2.40		2.245		139.7		7.4				
54-4	2.93		2.239		139.4		7.6				
54-5	2.95		2.215		137.9		8.6				
55-1	2.64	2.9	2.294	2.419	142.8	150.6	5.2	4.6	0.6	1.5	HL
55-2	3.68	0.12	2.292		142.7		5.3				
55-3	2.76		2.306		143.5		4.7				
55-4	2.90		2.329		145.0		3.7				
55-5	2.75		2.315		144.1		4.3				
56-1	2.80	2.8	2.127	2.452	132.4	152.6	13.3	13.7	0.7	1.9	LH
56-2	2.80	0.11	2.122		132.1		13.5				
56-3	2.85		2.134		132.8		13.0				
56-4	2.75		2.114		131.6		13.8				
56-5	2.55		2.087		129.9		14.9				

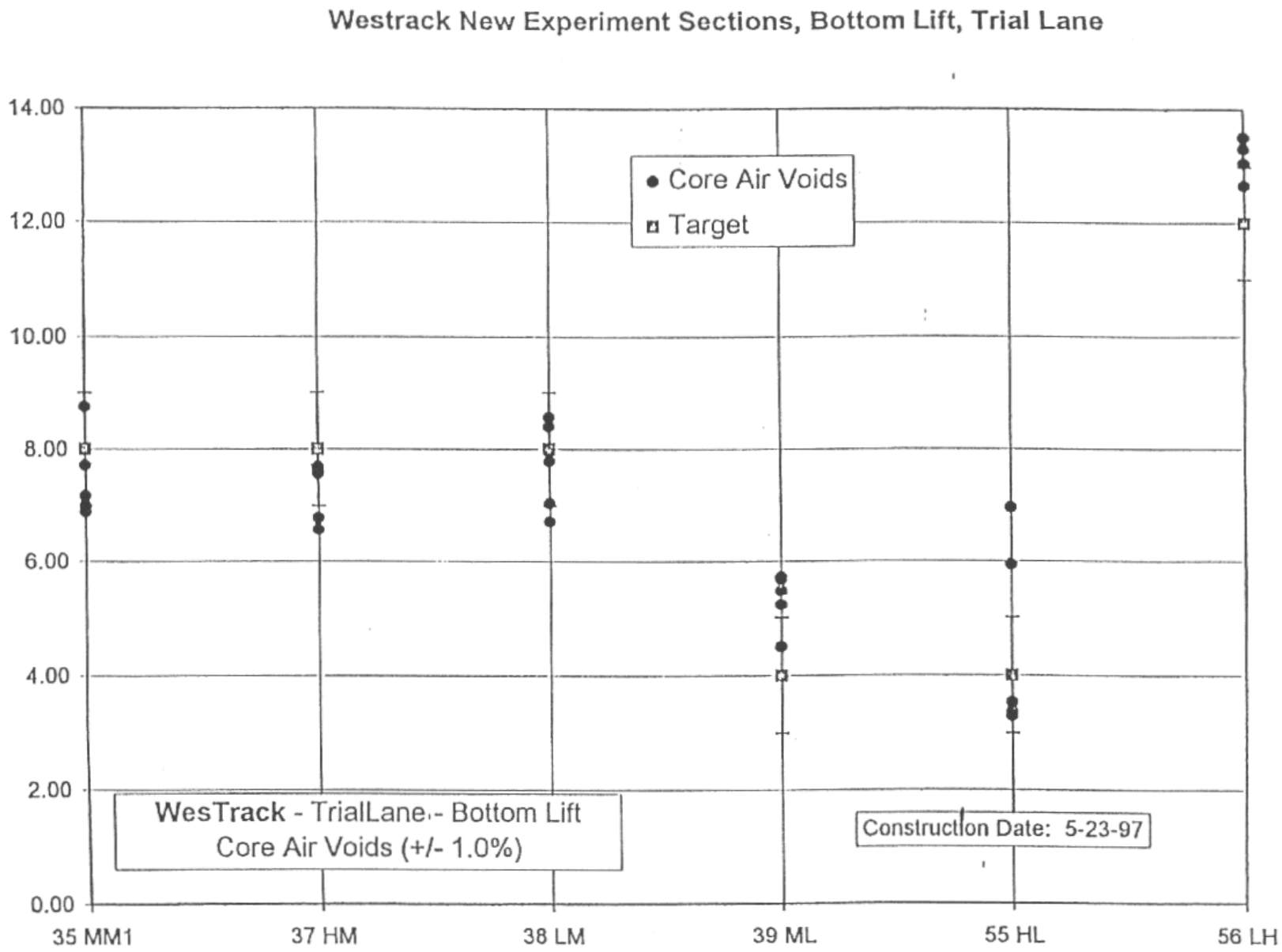
APPENDIX A

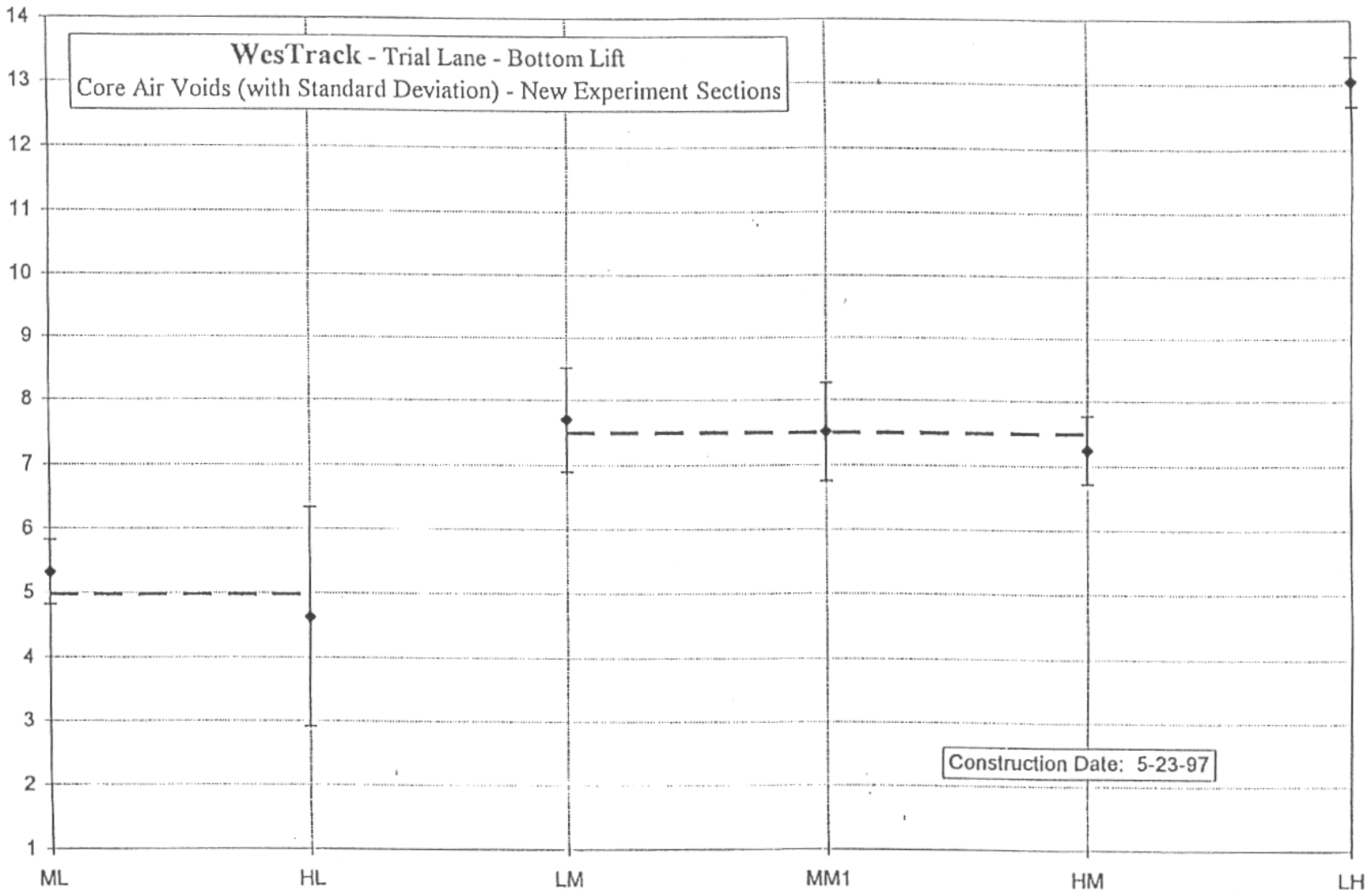
IN-PLACE AIR VOIDS AND THICKNESS – BOTTOM LIFT, TRIAL LANE, CONSTRUCTED MAY 23, 1997

Core Air Voids for Trial Lane, Bottom Lift, Construction Date: 5-23-97

62.24

Section & Core No.	Core Thickness	Average Thickness	Core SG	Rice SG	Core Density	Rice Density	Air Voids				Target AC / AV
							Cores	Average	Stdev	Range	
35-1	2.643	3.115	2.222	2.435	138.3	151.6	8.7	7.5	0.8	1.8	5.8 / 8
35-2	3.277	0.123	2.267		141.1		6.9				
35-3	3.111		2.260		140.7		7.2				
35-4	3.393		2.264		140.9		7.0				
35-5	3.153		2.247		139.9		7.7				
37-1	2.616	3.000	2.267	2.432	141.1	151.4	6.8	7.2	0.5	1.1	6.5 / 8
37-2	3.373	0.118	2.248		139.9		7.6				
37-3	2.997		2.245		139.7		7.7				
37-4	2.566		2.247		139.9		7.6				
37-5	3.450		2.272		141.4		6.6				
38-1	3.061	3.038	2.276	2.440	141.7	151.9	6.7	7.7	0.8	1.8	5.1 / 8
38-2	2.882	0.120	2.235		139.1		8.4				
38-3	2.994		2.250		140.0		7.8				
38-4	3.444		2.231		138.9		8.6				
38-5	2.809		2.268		141.2		7.0				
39-1	2.829	3.053	2.290	2.428	142.5	151.1	5.7	5.3	0.5	1.2	5.8 / 4
39-2	2.930	0.120	2.289		142.5		5.7				
39-3	3.317		2.319		144.3		4.5				
39-4	3.115		2.301		143.2		5.2				
39-5	3.073		2.295		142.8		5.5				
55-1	3.249	3.120	2.255	2.424	140.4	150.9	7.0	4.6	1.7	3.7	6.5 / 4
55-2	3.048	0.123	2.280		141.9		5.9				
55-3	3.321		2.344		145.9		3.3				
55-4	2.982		2.342		145.8		3.4				
55-5	2.998		2.338		145.5		3.5				
56-1	3.303	3.203	2.145	2.456	133.5	152.9	12.7	13.0	0.4	0.9	5.1 / 12
56-2	3.413	0.126	2.145		133.5		12.7				
56-3	3.026		2.129		132.5		13.3				
56-4	3.297		2.135		132.9		13.1				
56-5	2.976		2.124		132.2		13.5				


Westrack New Experiment Sections, Bottom Lift, Trial Lane
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Core Air Voids
Target
WesTrack - TrialLane - Bottom Lift
Core Air Voids (+/- 1.0%)
Construction Date: 5-23-97
35 MM1
37 HM
38 LM
39 ML
55 HL
56 LH


WesTrack - Trial Lane - Bottom Lift
Core Air Voids (with Standard Deviation) - New Experiment Sections
Construction Date: 5-23-97
14
13
12
11
10
9
8
7
6
5
4
3
2
1
ML
HL
LM
MM1
HM
LH

WesTrack - Core Air Voids - Trial Lane - Bottom Lift

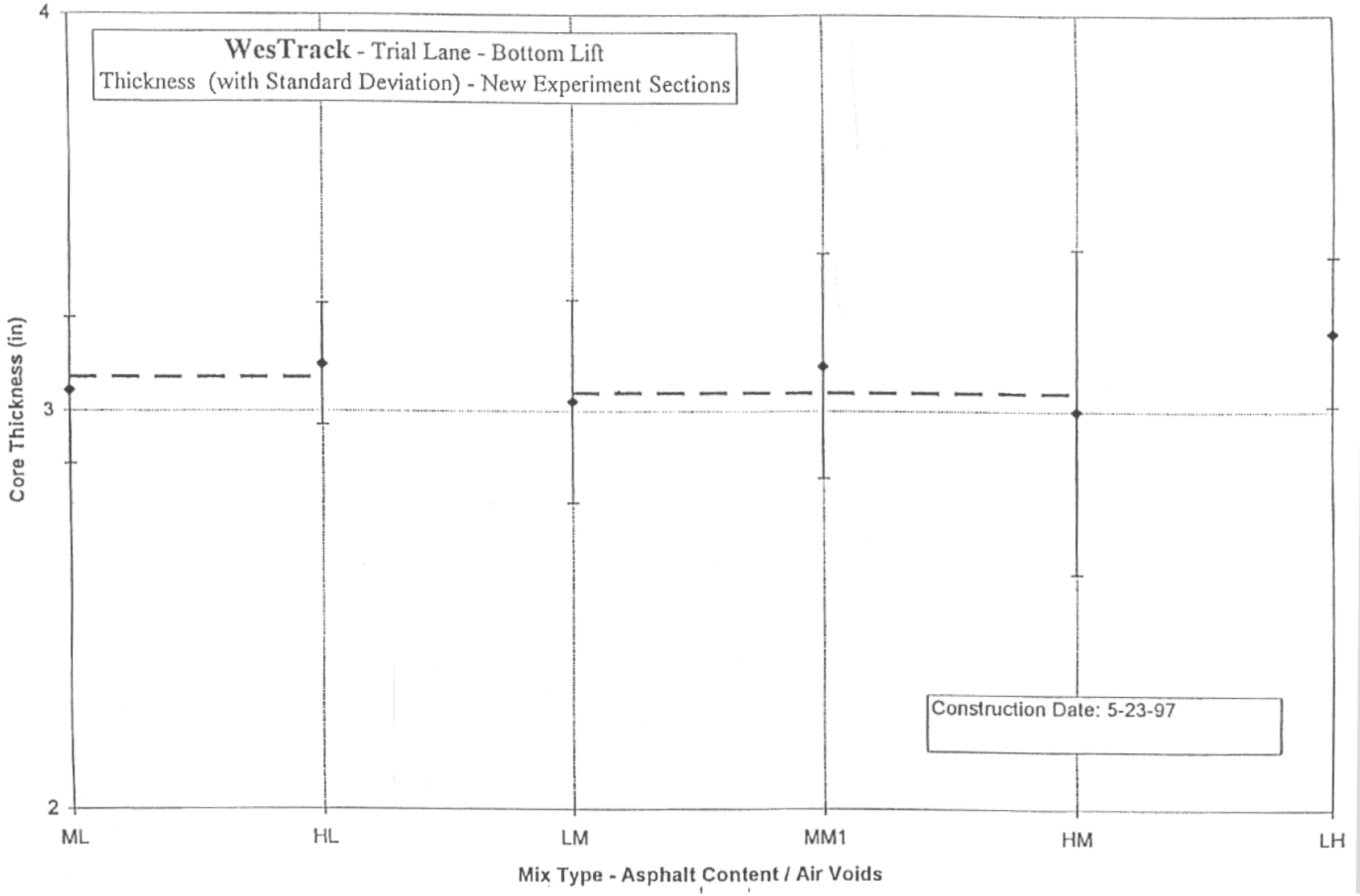
Construction Date: 5-23-97

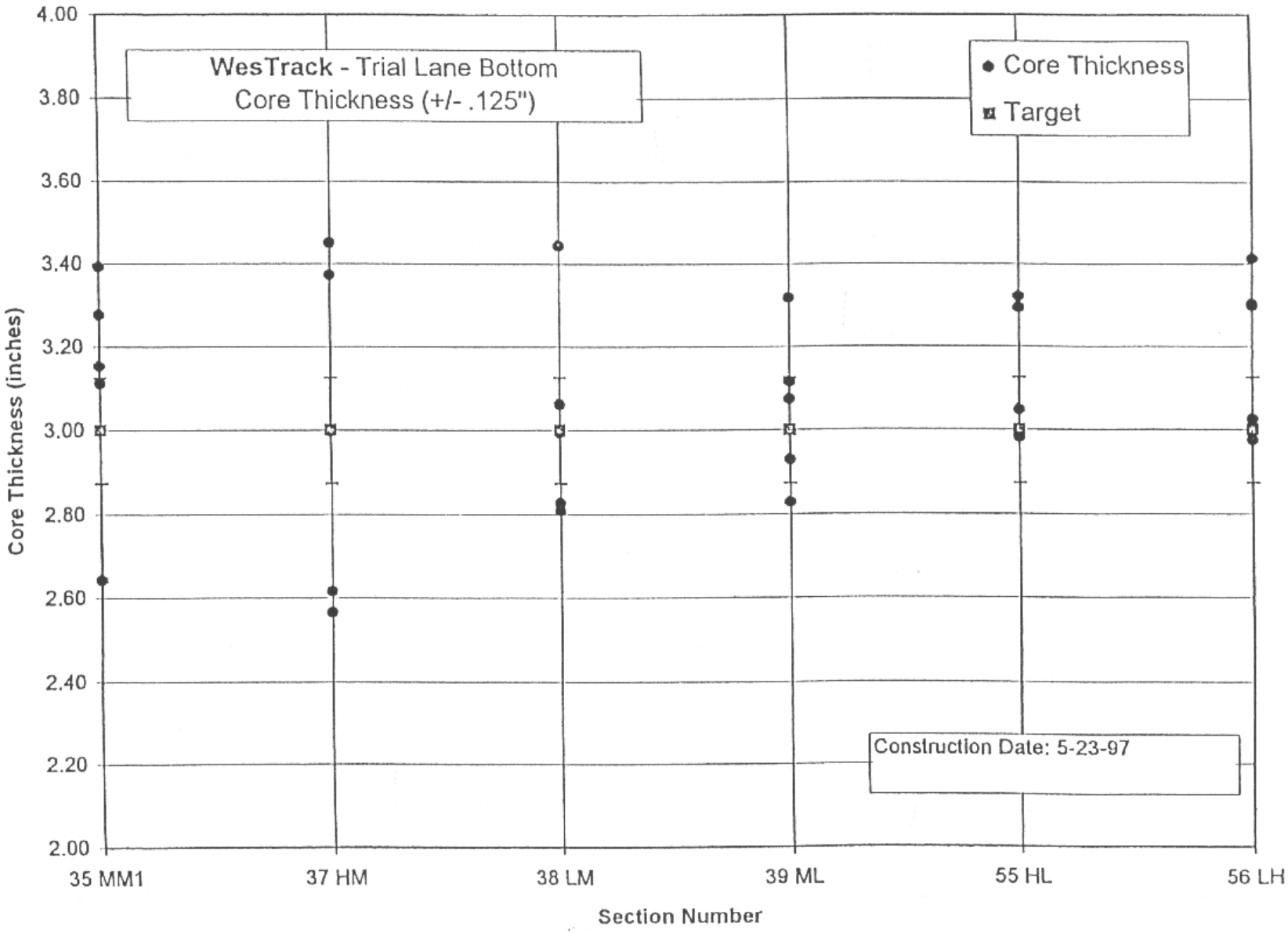
Sec	Target		Core Air Voids														
No	AC	AV	1	2	3	4	5	X	s	Range	UL	LL	QI_U	QI_L	PD_U	PD_L	PWL
35 MM1	5.8	8	8.75	6.90	7.19	7.02	7.72	7.52	0.76	1.85	9	7	1.96	0.68			100
37 HM	6.5	8	6.78	7.57	7.69	7.61	6.58	7.25	0.52	1.11	9	7	3.37	0.47			100
38 LM	5.1	8	6.72	8.40	7.79	8.57	7.05	7.70	0.81	1.84	9	7	1.60	0.87			100
39 ML	5.8	4	5.68	5.72	4.49	5.23	5.48	5.32	0.50	1.24	5	3	-0.64	4.60			100
55 HL	6.5	4	6.97	5.94	3.30	3.38	3.55	4.63	1.71	3.67	5	3	0.22	0.95			100
56 LH	5.1	12	12.66	12.66	13.31	13.07	13.52	13.05	0.38	0.86	13	11	-0.12	5.33			100

WesTrack - Core Air Voids - Trial Lane - Top Lift

Construction Date: 5-30-97

Sec	Target		Core Air Voids														
No	AC	AV	1	2	3	4	5	X	s	Range	UL	LL	QI_U	QI_L	PD_U	PD_L	PWL
35 MM1	5.8	8	12.40	9.78	9.70	11.21	10.72	10.76	1.12	2.70	9	7	-1.58	3.37			100
37 HM	6.5	8	7.48	10.48	9.29	9.00	11.13	9.47	1.42	3.66	9	7	-0.34	1.75			100
38 LM	5.1	8	11.38	11.75	11.87	11.87	10.54	11.48	0.56	1.33	9	7	-4.40	7.94			100
39 ML	5.8	4	5.63	4.36	4.93	5.34	5.18	5.09	0.48	1.26	5	3	-0.19	4.37			100
55 HL	6.5	4	5.86	4.54	11.10	5.65	5.24	6.48	2.63	6.56	5	3	-0.56	1.32			100
56 LH	5.1	12	15.51	15.67	16.08	15.18	15.96	15.68	0.36	0.89	13	11	-7.51	13.12			100


WesTrack - Trial Lane - Bottom Lift
Thickness (with Standard Deviation) - New Experiment Sections
Construction Date: 5-23-97
Core Thickness (in)
4
3
2
ML
HL
LM
MM1
HM
LH
Mix Type - Asphalt Content / Air Voids


WesTrack - Trial Lane Bottom
Core Thickness (+/- .125")
Core Thickness
Target
Construction Date: 5-23-97
Core Thickness (inches)
4.00
3.80
3.60
3.40
3.20
3.00
2.80
2.60
2.40
2.20
2.00
35 MM1
37 HM
38 LM
39 ML
55 HL
56 LH
Section Number

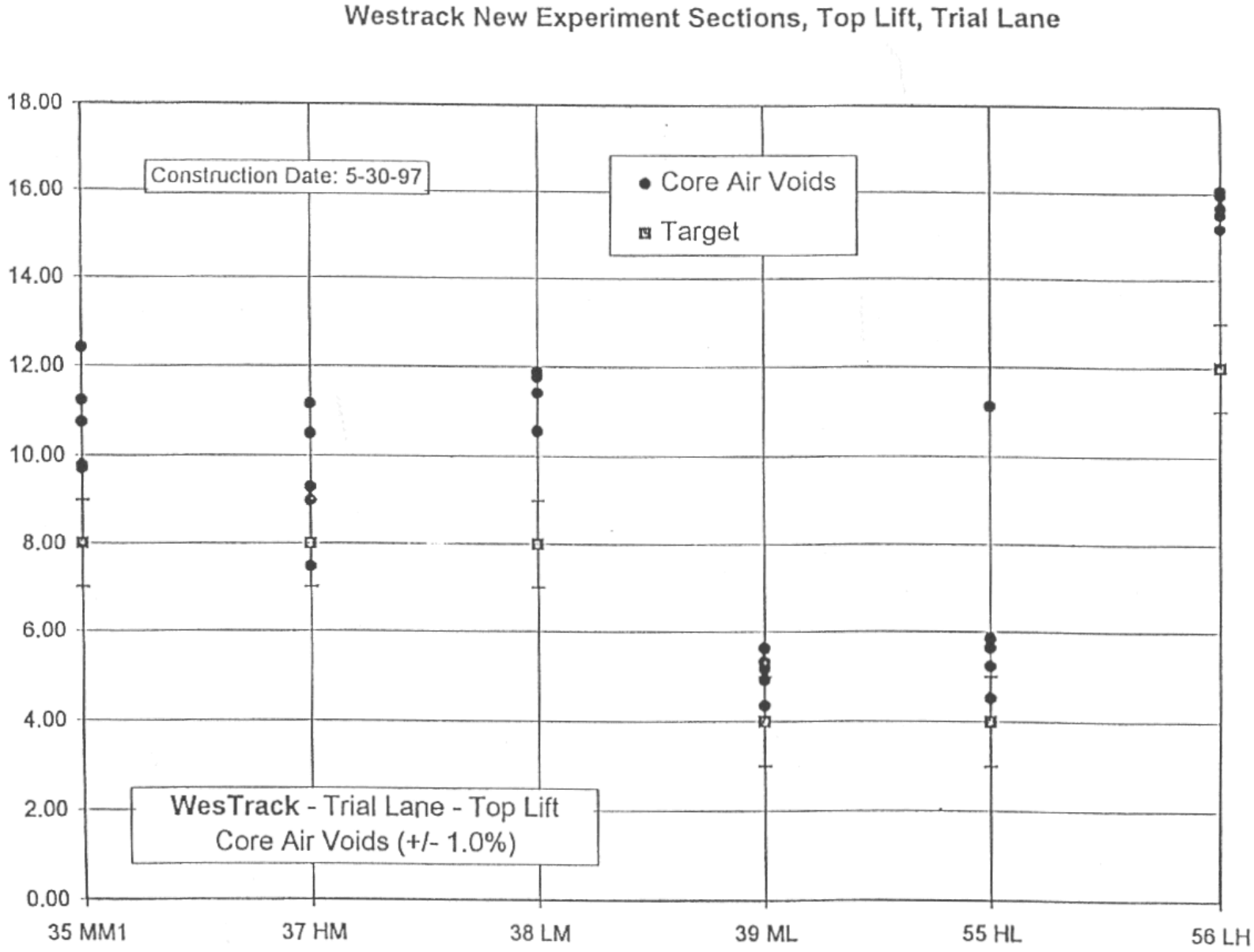
APPENDIX B

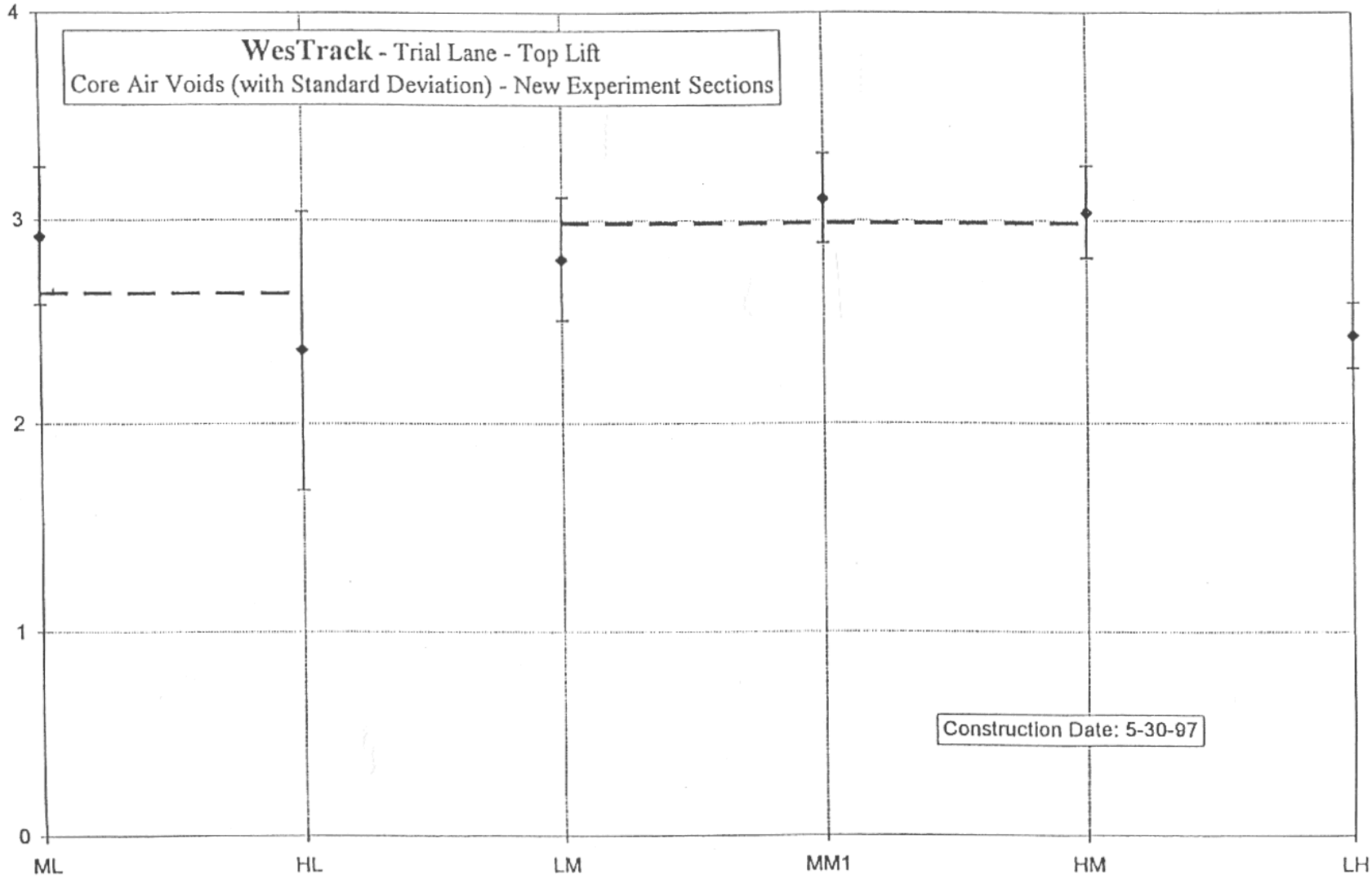
IN-PLACE AIR VOIDS AND THICKNESS – TOP LIFT, TRIAL LANE, CONSTRUCTED MAY 30, 1997

Core Air Voids for Trial Lane, Top Lift, Construction Date: 5-30-97

62.24

Section & Core No.	Core Thickness	Average Thickness	Core SG	Rice SG	Core Density	Rice Density	Air Voids				Target AC / AV
							Cores	Average	Stdev	Range	
35-1	2.9	3.1	2.141	2.444	133.3	152.1	12.4	10.8	1.1	2.7	5.8 / 8
35-2	3.1	0.12	2.205		137.2		9.8				
35-3	2.9		2.207		137.4		9.7				
35-4	3.3		2.170		135.1		11.2				
35-5	3.3		2.182		135.8		10.7				
37-1	3.4	3.0	2.252	2.434	140.2	151.5	7.5	9.5	1.4	3.7	6.5 / 8
37-2	2.9	0.12	2.179		135.6		10.5				
37-3	2.9		2.208		137.4		9.3				
37-4	2.8		2.215		137.9		9.0				
37-5	3.2		2.163		134.6		11.1				
38-1	2.3	2.8	2.195	2.477	136.6	154.2	11.4	11.5	0.6	1.3	5.1 / 8
38-2	3.0	0.11	2.186		136.1		11.7				
38-3	2.9		2.183		135.9		11.9				
38-4	2.9		2.183		135.9		11.9				
38-5	3.0		2.216		137.9		10.5				
39-1	3.2	2.9	2.314	2.452	144.0	152.6	5.6	5.1	0.5	1.3	5.8 / 4
39-2	2.4	0.11	2.345		146.0		4.4				
39-3	3.1		2.331		145.1		4.9				
39-4	3.1		2.321		144.5		5.3				
39-5	2.9		2.325		144.7		5.2				
55-1	3.4	2.4	2.282	2.424	142.0	150.9	5.9	6.5	2.6	6.6	6.5 / 4
55-2	2.4	0.09	2.314		144.0		4.5				
55-3	2.5		2.155		134.1		11.1				
55-4	1.7		2.287		142.3		5.7				
55-5	1.8		2.297		143.0		5.2				
56-1	2.3	2.4	2.081	2.463	129.5	153.3	15.5	15.7	0.4	0.9	5.1 / 12
56-2	2.4	0.10	2.077		129.3		15.7				
56-3	2.5		2.067		128.7		16.1				
56-4	2.7		2.089		130.0		15.2				
56-5	2.2		2.070		128.8		16.0				


Westrack New Experiment Sections, Top Lift, Trial Lane
Construction Date: 5-30-97
Core Air Voids
Target
WesTrack - Trial Lane - Top Lift
Core Air Voids (+/- 1.0%)
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
35 MM1
37 HM
38 LM
39 ML
55 HL
56 LH


WesTrack - Trial Lane - Top Lift
Core Air Voids (with Standard Deviation) - New Experiment Sections
Construction Date: 5-30-97
4
3
2
1
0
ML
HL
LM
MM1
HM
LH

WesTrack - Core Air Voids - Trial Lane - Bottom Lift

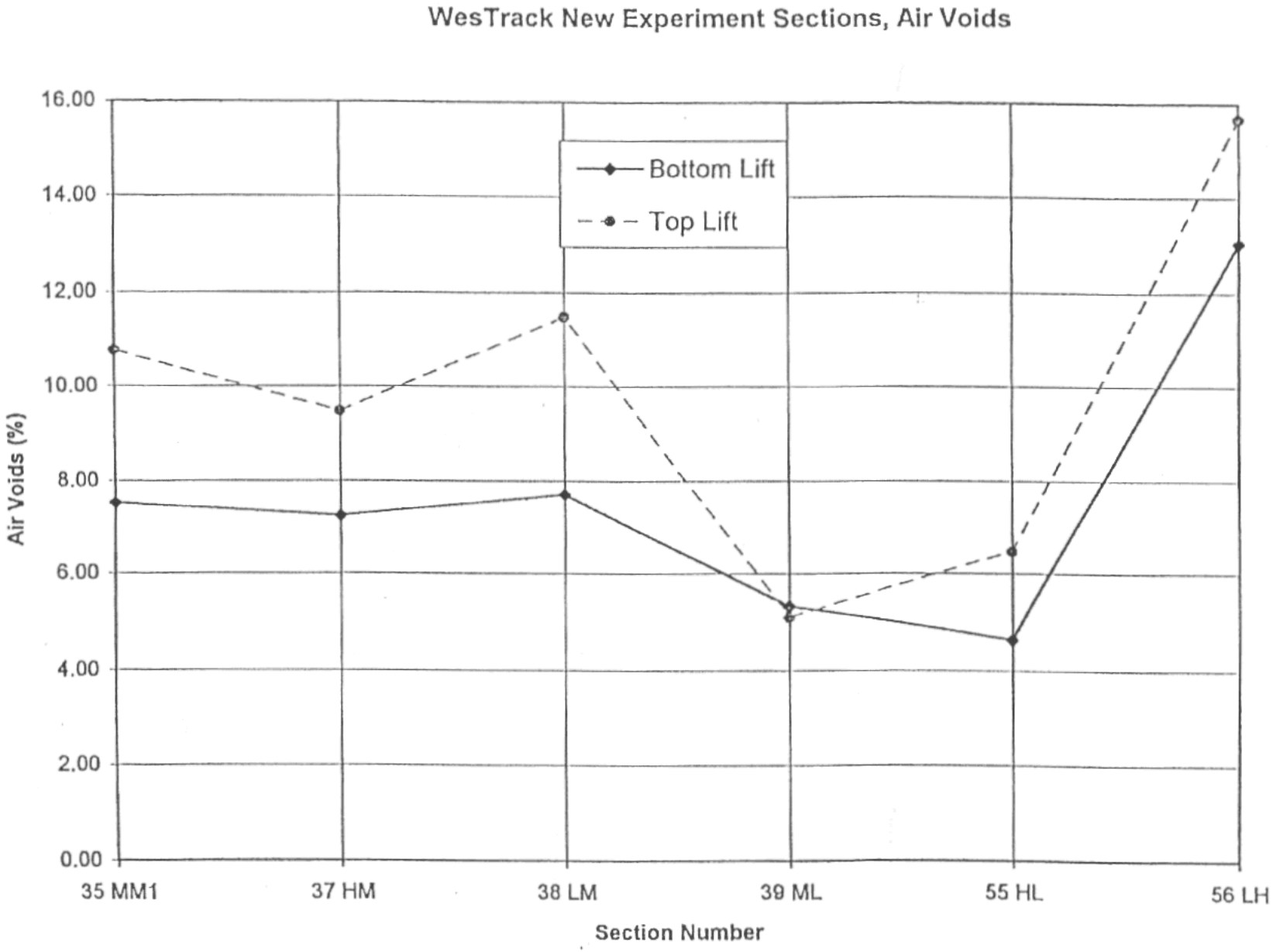
Construction Date: 5-23-97

Sec	Target		Core Air Voids														
No	AC	AV	1	2	3	4	5	X	s	Range	UL	LL	QI_U	QI_L	PD_U	PD_L	PWL
35 MM1	5.8	8	8.75	6.90	7.19	7.02	7.72	7.52	0.76	1.85	9	7	1.96	0.68			100
37 HM	6.5	8	6.78	7.57	7.69	7.61	6.58	7.25	0.52	1.11	9	7	3.37	0.47			100
38 LM	5.1	8	6.72	8.40	7.79	8.57	7.05	7.70	0.81	1.84	9	7	1.60	0.87			100
39 ML	5.8	4	5.68	5.72	4.49	5.23	5.48	5.32	0.50	1.24	5	3	-0.64	4.60			100
55 HL	6.5	4	6.97	5.94	3.30	3.38	3.55	4.63	1.71	3.67	5	3	0.22	0.95			100
56 LH	5.1	12	12.66	12.66	13.31	13.07	13.52	13.05	0.38	0.86	13	11	-0.12	5.33			100

WesTrack - Core Air Voids - Trial Lane - Top Lift

Construction Date: 5-30-97

Sec	Target		Core Air Voids														
No	AC	AV	1	2	3	4	5	X	s	Range	UL	LL	QI_U	QI_L	PD_U	PD_L	PWL
35 MM1	5.8	8	12.40	9.78	9.70	11.21	10.72	10.76	1.12	2.70	9	7	-1.58	3.37			100
37 HM	6.5	8	7.48	10.48	9.29	9.00	11.13	9.47	1.42	3.66	9	7	-0.34	1.75			100
38 LM	5.1	8	11.38	11.75	11.87	11.87	10.54	11.48	0.56	1.33	9	7	-4.40	7.94			100
39 ML	5.8	4	5.63	4.36	4.93	5.34	5.18	5.09	0.48	1.26	5	3	-0.19	4.37			100
55 HL	6.5	4	5.86	4.54	11.10	5.65	5.24	6.48	2.63	6.56	5	3	-0.56	1.32			100
56 LH	5.1	12	15.51	15.67	16.08	15.18	15.96	15.68	0.36	0.89	13	11	-7.51	13.12			100


WesTrack New Experiment Sections, Air Voids
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Air Voids (%)
Bottom Lift
Top Lift
35 MM1
37 HM
38 LM
39 ML
55 HL
56 LH
Section Number

APPENDIX C

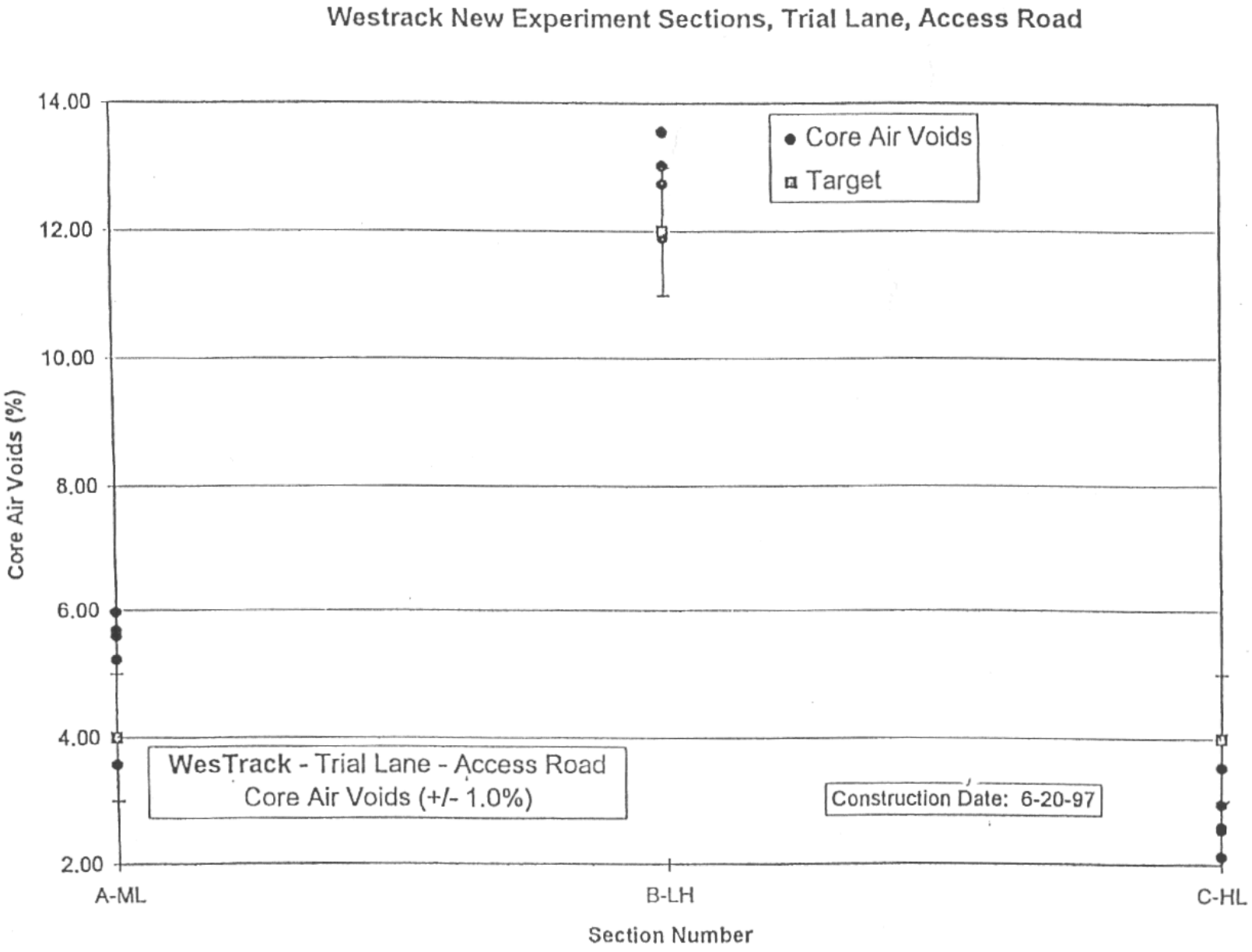
IN-PLACE AIR VOIDS AND THICKNESS –

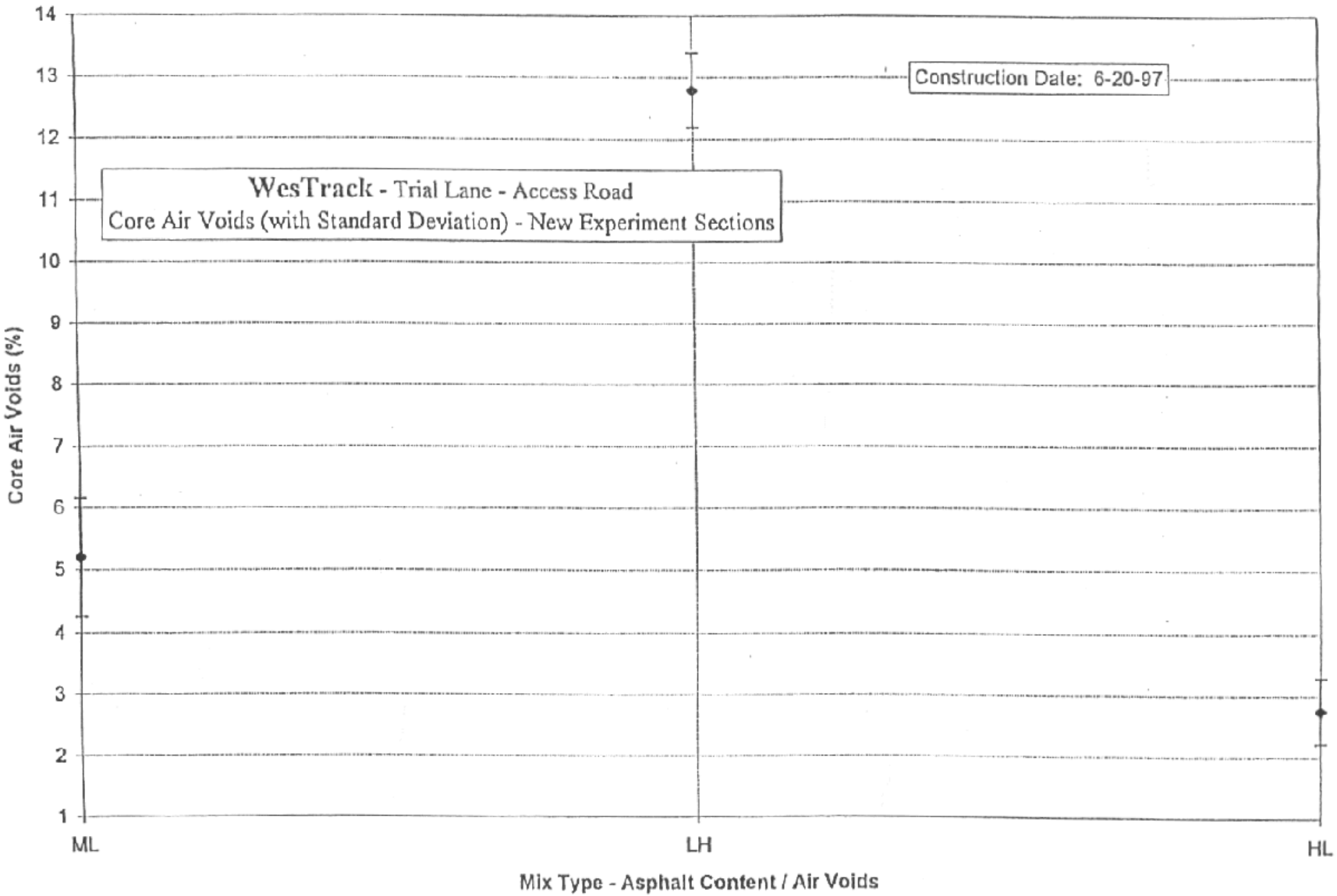
BOTTOM LIFT, ACCESS ROAD LANE, CONSTRUCTED JUNE 20, 1997

Core Air Voids for Trial Lane, Access Road
Construction Date: 6-20-97

62.24

Section & Core No.	Core Thickness	Average Thickness	Core SG	Rice SG	Core Density	Rice Density	Air Voids				Target AC / AV
							Cores	Average	Stdev	Range	
A-1	2.540	2.707	2.302	2.429	143.3	151.2	5.2	5.2	0.9	2.4	5.72 / 4
A-2	2.782	0.107	2.284		142.2		6.0				
A-3	2.792		2.291		142.6		5.7				
A-4	2.799		2.293		142.7		5.6				
A-5	2.623		2.342		145.8		3.6				
B-1	2.547	2.563	2.130	2.464	132.6	153.4	13.6	12.8	0.6	1.7	5.09 / 12
B-2	2.878	0.101	2.171		135.1		11.9				
B-3	2.793		2.143		133.4		13.0				
B-4	2.205		2.150		133.8		12.7				
B-5	2.391		2.150		133.8		12.7				
C-1	2.755	2.884	2.310	2.395	143.8	149.1	3.5	2.8	0.5	1.4	6.33 / 4
C-2	2.738	0.114	2.324		144.6		3.0				
C-3	2.711		2.334		145.3		2.5				
C-4	3.011		2.333		145.2		2.6				
C-5	3.207		2.344		145.9		2.1				


Westrack New Experiment Sections, Trial Lane, Access Road
14.00
12.00
10.00
8.00
6.00
4.00
2.00
Core Air Voids (%)
Core Air Voids
Target
WesTrack - Trial Lane - Access Road
Core Air Voids (+/- 1.0%)
Construction Date: 6-20-97
A-ML
B-LH
C-HL
Section Number


WesTrack - Trial Lane - Access Road
Core Air Voids (with Standard Deviation) - New Experiment Sections
Construction Date: 6-20-97
Core Air Voids (%)
14
13
12
11
10
9
8
7
6
5
4
3
2
1
ML
LH
HL
Mix Type - Asphalt Content / Air Voids

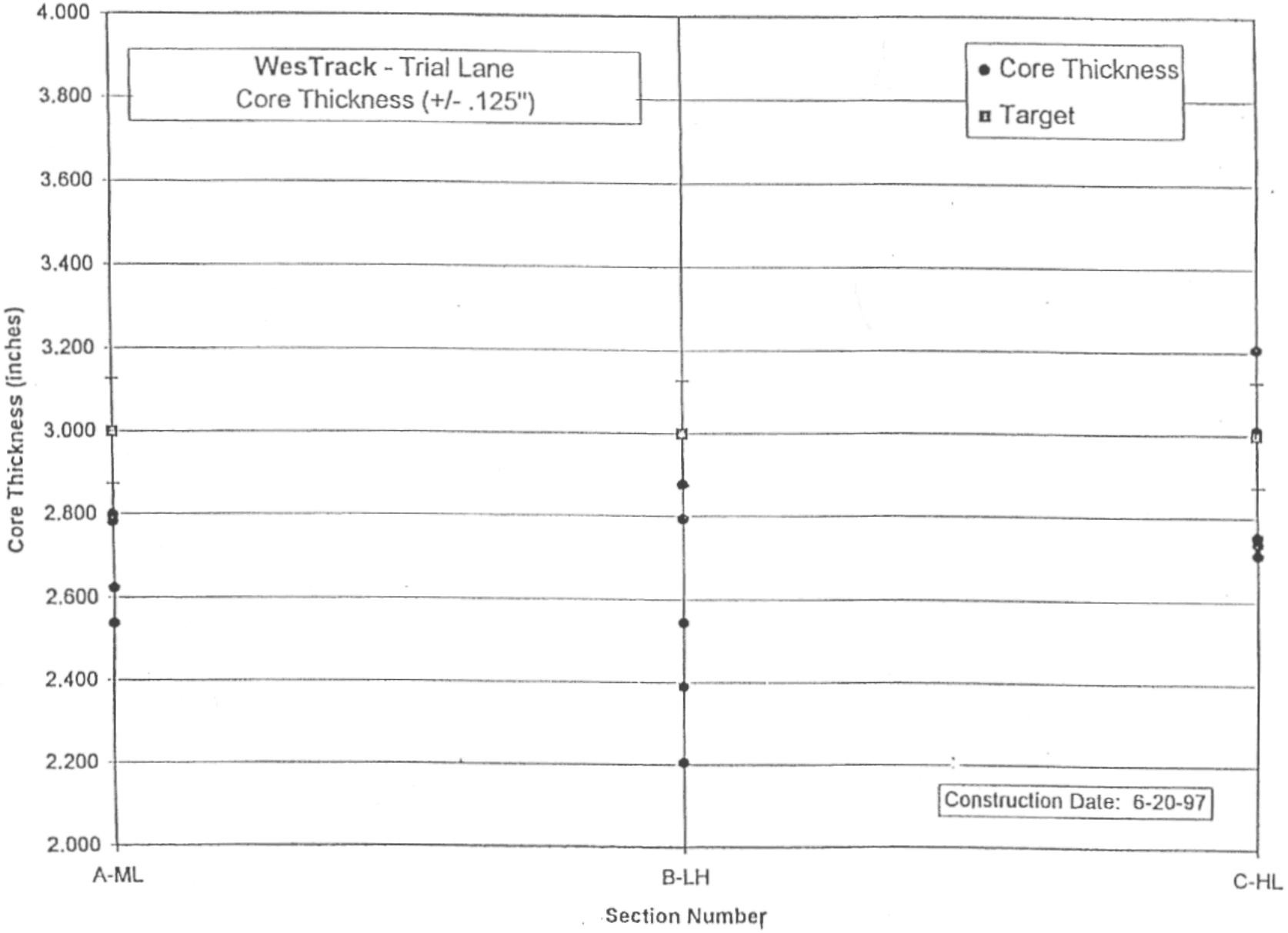
WesTrack - Core Air Voids - Trial Lane - Access Road

Construction Date: 6-20-97

Sec	Target		Core Air Voids														
No	AC	AV	1	2	3	4	5	X	s	Range	UL	LL	Ql_U	Ql_L	PD_U	PD_L	PWL
A-ML	5.8	4	5.23	5.97	5.68	5.60	3.58	5.21	0.95	2.39	5	3	-0.22	2.33	57.81	0	**42.19**
B-LH	5.1	12	13.56	11.89	13.03	12.74	12.74	12.79	0.60	1.66	13	11	0.34	2.97	37.97	0	**62.03**
C-HL	6.5	4	3.55	2.96	2.55	2.59	2.13	2.76	0.53	1.42	5	3	4.21	-0.46	0	76.19	**23.81**

WesTrack - Core Thickness - Trial Lane Built 6-20-97

Sec	Target			Core Thickness														
No	AC	AV	Ht	1	2	3	4	5	X	s	Range	UL	LL	Ql_U	Ql_L	PD_U	PD_L	PWL
A-ML	5.8	4	3	2.540	2.782	2.792	2.799	2.623	2.707	0.12	0.26	3.13	2.88	3.52	-1.41	0	94.34	5.66
B-LH	5.1	12	3	2.547	2.878	2.793	2.205	2.391	2.563	0.28	0.67	3.13	2.88	2.02	-1.12	0	87.07	12.93
C-HL	6.5	4	3	2.755	2.738	2.711	3.011	3.207	2.884	0.22	0.50	3.13	2.88	1.11	0.04	13.2	48.58	38.22


WesTrack - Trial Lane
Core Thickness (+/- .125")
Core Thickness
Target
Construction Date: 6-20-97
Core Thickness (inches)
4.000
3.800
3.600
3.400
3.200
3.000
2.800
2.600
2.400
2.200
2.000
A-ML
B-LH
C-HL
Section Number

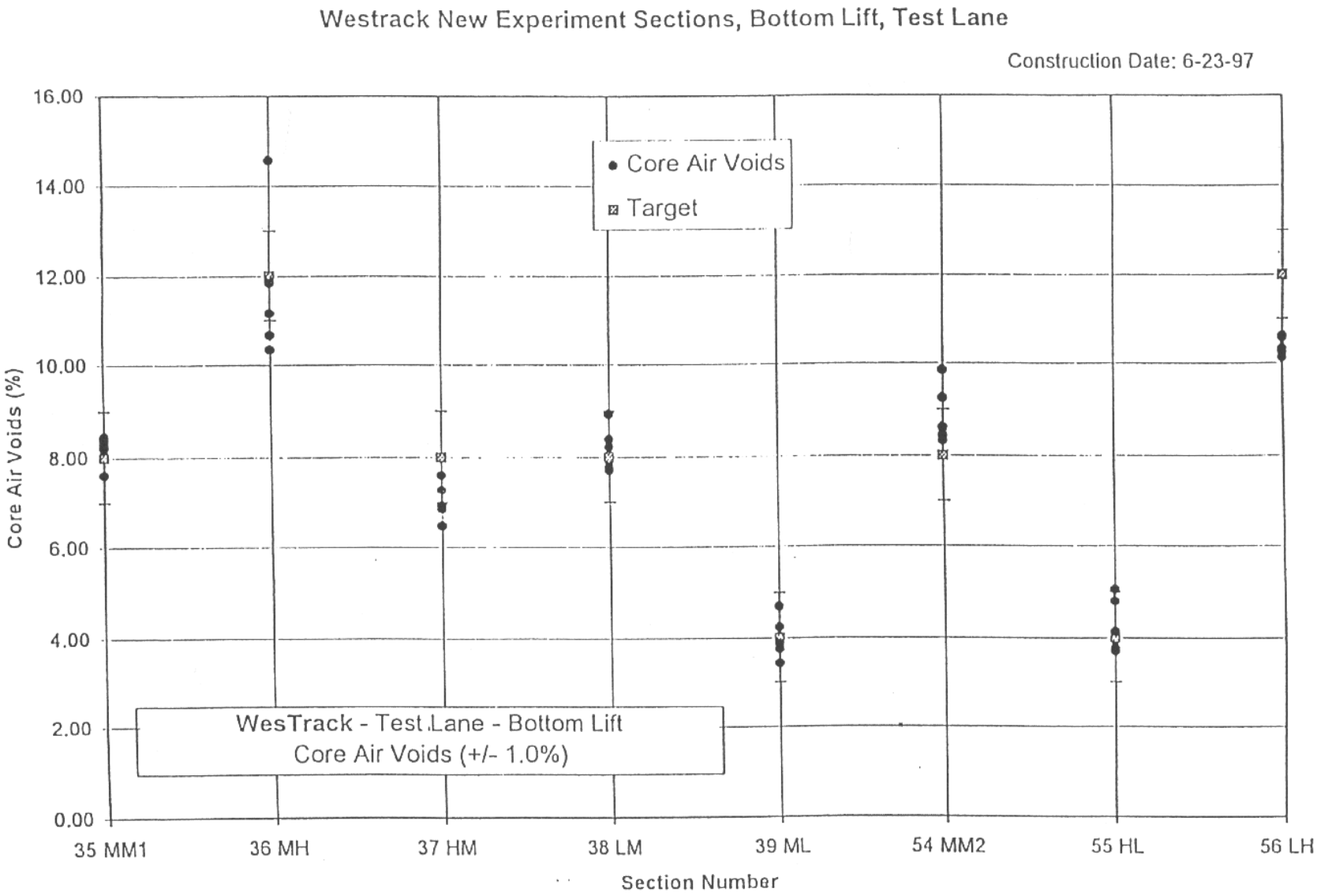
APPENDIX D

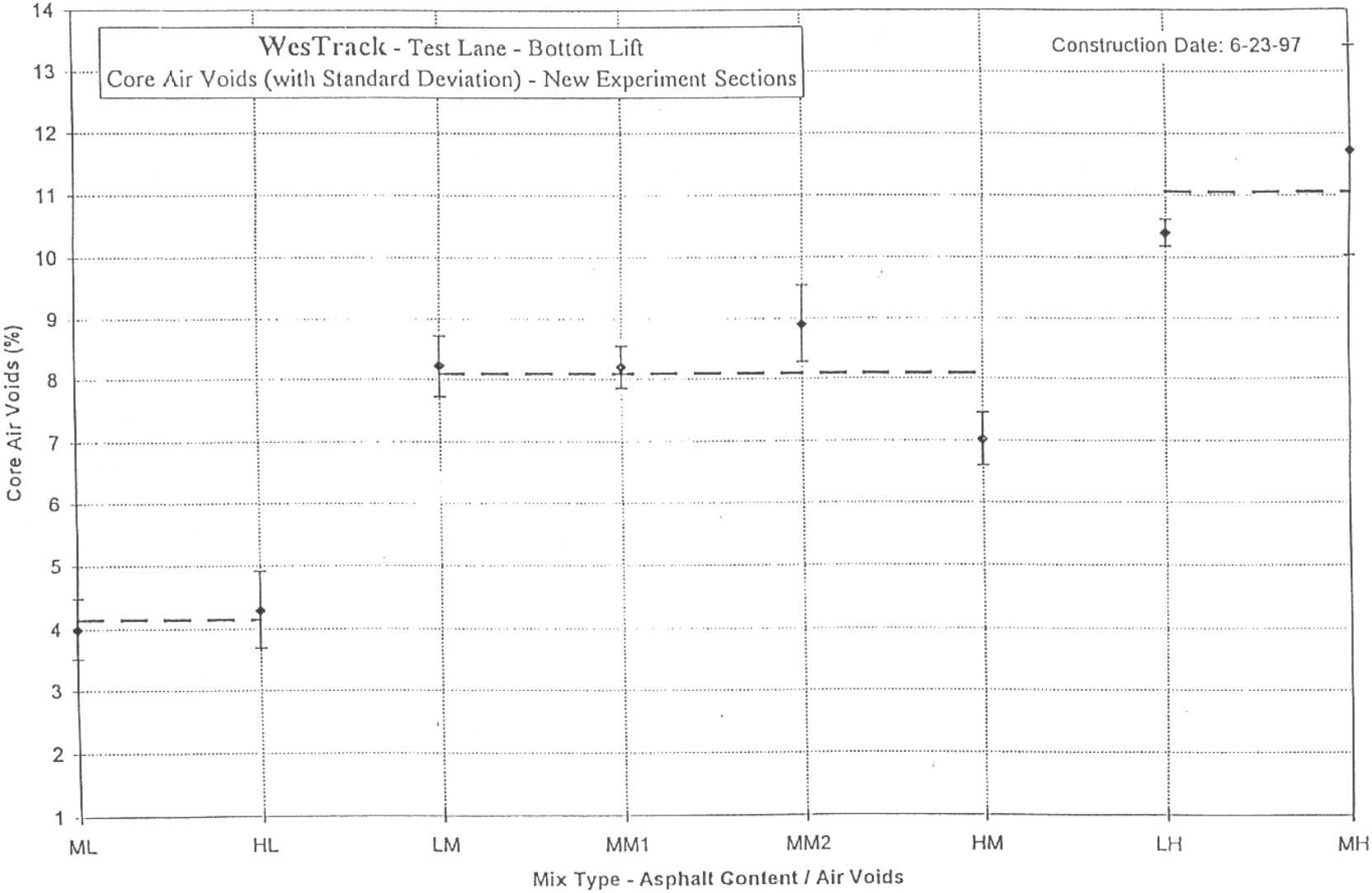
IN-PLACE AIR VOIDS AND THICKNESS – BOTTOM LIFT, TEST LANE, CONSTRUCTED JUNE 23, 1997

Core Air Voids for Test Lane, Bottom Lift, Construction Date: 6-23-97

62.24

Section & Core No.	Core Thickness	Average Thickness	Core SG	Rice SG	Core Density	Rice Density	Air Voids				Target AC / AV
							Cores	Average	Stdev	Range	
35-1	3.021	3.3	2.231	2.433	138.9	151.4	8.3	8.2	0.3	0.9	MM1
35-2	3.261	0.13	2.227		138.6		8.5				
35-3	3.162		2.233		139.0		8.2				
35-4	3.627		2.248		139.9		7.6				
35-5	3.231		2.229		138.7		8.4				
36-1	2.824	2.9	2.184	2.436	135.9	151.6	10.3	11.7	1.7	4.2	MH
36-2	2.746	0.11	2.164		134.7		11.2				
36-3	3.253		2.176		135.4		10.7				
36-4	2.895		2.147		133.6		11.9				
36-5	2.689		2.081		129.5		14.6				
37-1	3.283	3.5	2.224	2.407	138.4	149.8	7.6	7.0	0.4	1.1	HM
37-2	3.645	0.14	2.232		138.9		7.3				
37-3	3.293		2.251		140.1		6.5				
37-4	3.700		2.240		139.4		6.9				
37-5	3.436		2.242		139.5		6.9				
38-1	2.966	3.4	2.232	2.451	138.9	152.6	8.9	8.2	0.5	1.2	LM
38-2	3.293	0.13	2.260		140.7		7.8				
38-3	3.392		2.262		140.8		7.7				
38-4	3.368		2.249		140.0		8.2				
38-5	3.860		2.245		139.7		8.4				
39-1	3.249	3.3	2.321	2.424	144.5	150.9	4.2	4.0	0.5	1.3	ML
39-2	3.317	0.13	2.341		145.7		3.4				
39-3	3.323		2.333		145.2		3.8				
39-4	3.292		2.330		145.0		3.9				
39-5	3.448		2.310		143.8		4.7				
54-1	3.298	3.2	2.226	2.436	138.5	151.6	8.6	8.9	0.6	1.5	MM2
54-2	3.057	0.13	2.196		136.7		9.9				
54-3	3.406		2.230		138.8		8.5				
54-4	3.163		2.211		137.6		9.2				
54-5	3.156		2.233		139.0		8.3				
55-1	3.295	3.3	2.288	2.410	142.4	150.0	5.1	4.3	0.6	1.4	HL
55-2	3.378	0.13	2.294		142.8		4.8				
55-3	3.194		2.321		144.5		3.7				
55-4	3.290		2.310		143.8		4.1				
55-5	3.262		2.319		144.3		3.8				
56-1	3.246	3.2	2.195	2.448	136.6	152.4	10.3	10.4	0.2	0.5	LH
56-2	3.026	0.13	2.189		136.2		10.6				
56-3	3.284		2.197		136.7		10.3				
56-4	3.172		2.200		136.9		10.1				
56-5	3.502		2.188		136.2		10.6				


Westrack New Experiment Sections, Bottom Lift, Test Lane
Construction Date: 6-23-97
Core Air Voids
Target
WesTrack - Test Lane - Bottom Lift
Core Air Voids (+/- 1.0%)
Core Air Voids (%)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
35 MM1
36 MH
37 HM
38 LM
39 ML
54 MM2
55 HL
56 LH
Section Number

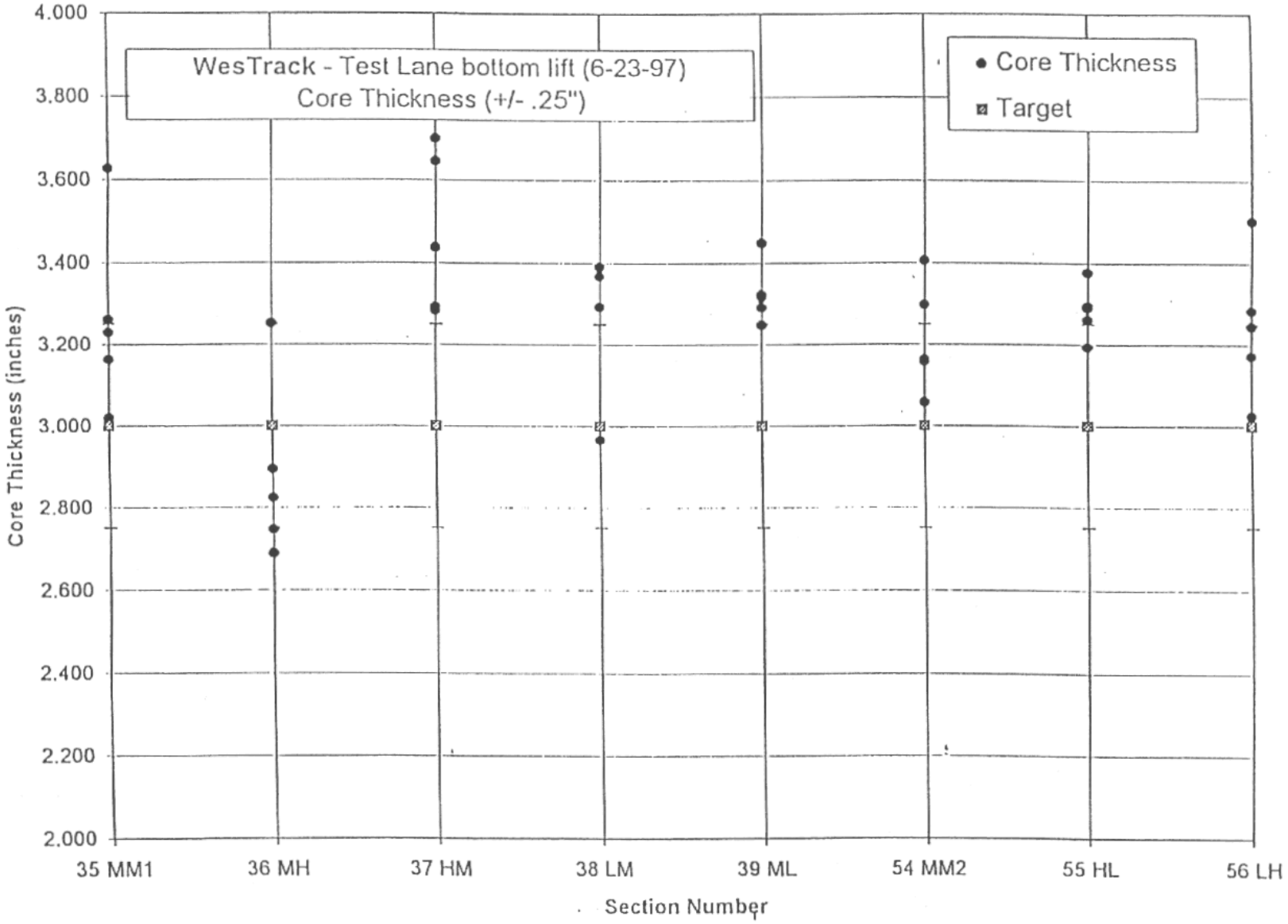

WesTrack - Test Lane - Bottom Lift
Core Air Voids (with Standard Deviation) - New Experiment Sections
Construction Date: 6-23-97
Core Air Voids (%)
14
13
12
11
10
9
8
7
6
5
4
3
2
1
ML
HL
LM
MM1
MM2
HM
LH
MH
Mix Type - Asphalt Content / Air Voids

WesTrack - Core Air Voids - Test Lane - Bottom Lift (6-23-97)

Sec	Target		Core Air Voids														
No	AC	AV	1	2	3	4	5	X	s	Range	UL	LL_1	QI_U	QI_L	PD_U	PD_L	PWL
35 MM1	5.82	8	8.30	8.47	8.22	7.60	8.38	8.20	0.34	0.86	9	7	2.34	3.48	0	0	100
36 MH	5.82	12	10.34	11.17	10.67	11.86	14.57	11.72	1.69	4.23	13	11	0.75	0.43	24.11	34.9	41
37 HM	6.43	8	7.60	7.27	6.48	6.94	6.86	7.03	0.43	1.12	9	7	4.62	0.07	0	47.5	52.5
38 LM	5.19	8	8.94	7.79	7.71	8.24	8.40	8.22	0.50	1.22	9	7	1.58	2.45	2.35	0	97.7
39 ML	5.82	4	4.25	3.42	3.75	3.88	4.70	4.00	0.49	1.28	5	3	2.03	2.04	0	0	100
54 MM2	5.82	8	8.62	9.85	8.46	9.24	8.33	8.90	0.64	1.52	9	7	0.16	2.99	44.31	0	55.7
55 HL	6.43	4	5.06	4.81	3.69	4.15	3.78	4.30	0.61	1.37	5	3	1.14	2.11	12.37	0	87.6
56 LH	5.19	12	10.33	10.58	10.25	10.13	10.62	10.38	0.21	0.49	13	11	12.4	-2.92	0	100	0

WesTrack - Core Thickness - Test Lane Bottom Lift (6-23-97)

Sec	Target			Core Thickness														
No	AC	AV	Ht	1	2	3	4	5	X	s	Range	UL	LL	QI_U	QI_L	PD_U	PD_L	PWL
35 MM1	5.82	8	3	3.021	3.261	3.162	3.627	3.231	3.260	0.22	0.61	3.25	2.75	-0.05	2.27	51.78	0	48.22
36 MH	5.82	12	3	2.824	2.746	3.253	2.895	2.689	2.881	0.22	0.56	3.25	2.75	1.66	0.59	1.15	29.4	69.46
37 HM	6.43	8	3	3.283	3.645	3.293	3.700	3.436	3.471	0.19	0.42	3.25	2.75	-1.14	3.71	87.63	0	12.37
38 LM	5.19	8	3	2.966	3.293	3.392	3.368	3.860	3.376	0.32	0.89	3.25	2.75	-0.39	1.96	63.77	0	36.23
39 ML	5.82	4	3	3.249	3.317	3.323	3.292	3.448	3.326	0.07	0.20	3.25	2.75	-1.02	7.75	84.22	0	15.78
54 MM2	5.82	8	3	3.298	3.057	3.406	3.163	3.156	3.216	0.14	0.35	3.25	2.75	0.25	3.41	41.13	0	58.87
55 HL	5.19	4	3	3.295	3.378	3.194	3.290	3.262	3.284	0.07	0.18	3.25	2.75	-0.51	8.05	67.9	0	32.1
56 LH	6.43	12	3	3.246	3.026	3.284	3.172	3.502	3.246	0.17	0.48	3.25	2.75	0.02	2.85	49.29	0	50.71


WesTrack - Test Lane bottom lift (6-23-97)
Core Thickness (+/- .25")
Core Thickness
Target
Core Thickness (inches)
4.000
3.800
3.600
3.400
3.200
3.000
2.800
2.600
2.400
2.200
2.000
35 MM1
36 MH
37 HM
38 LM
39 ML
54 MM2
55 HL
56 LH
Section Number

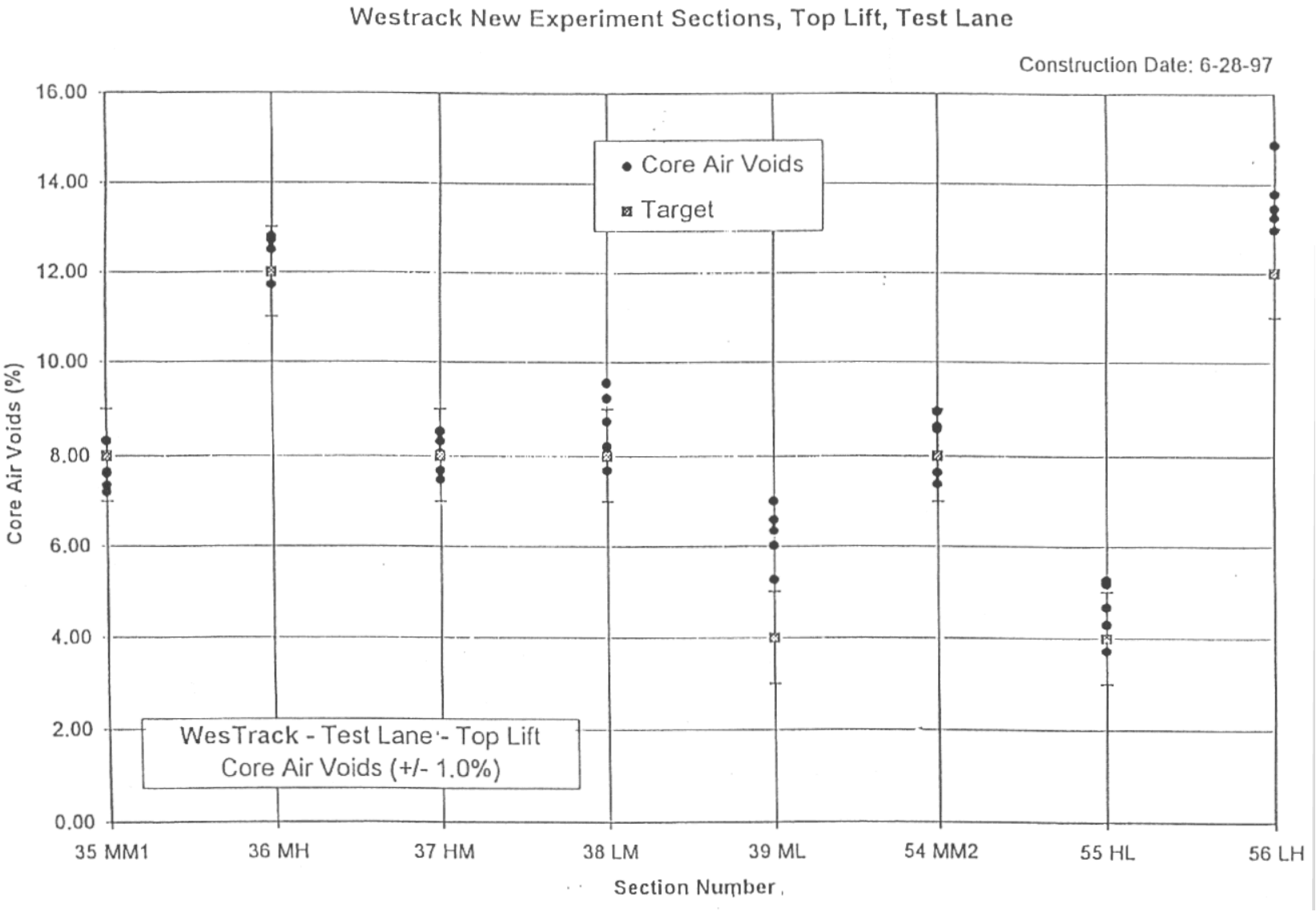
APPENDIX E

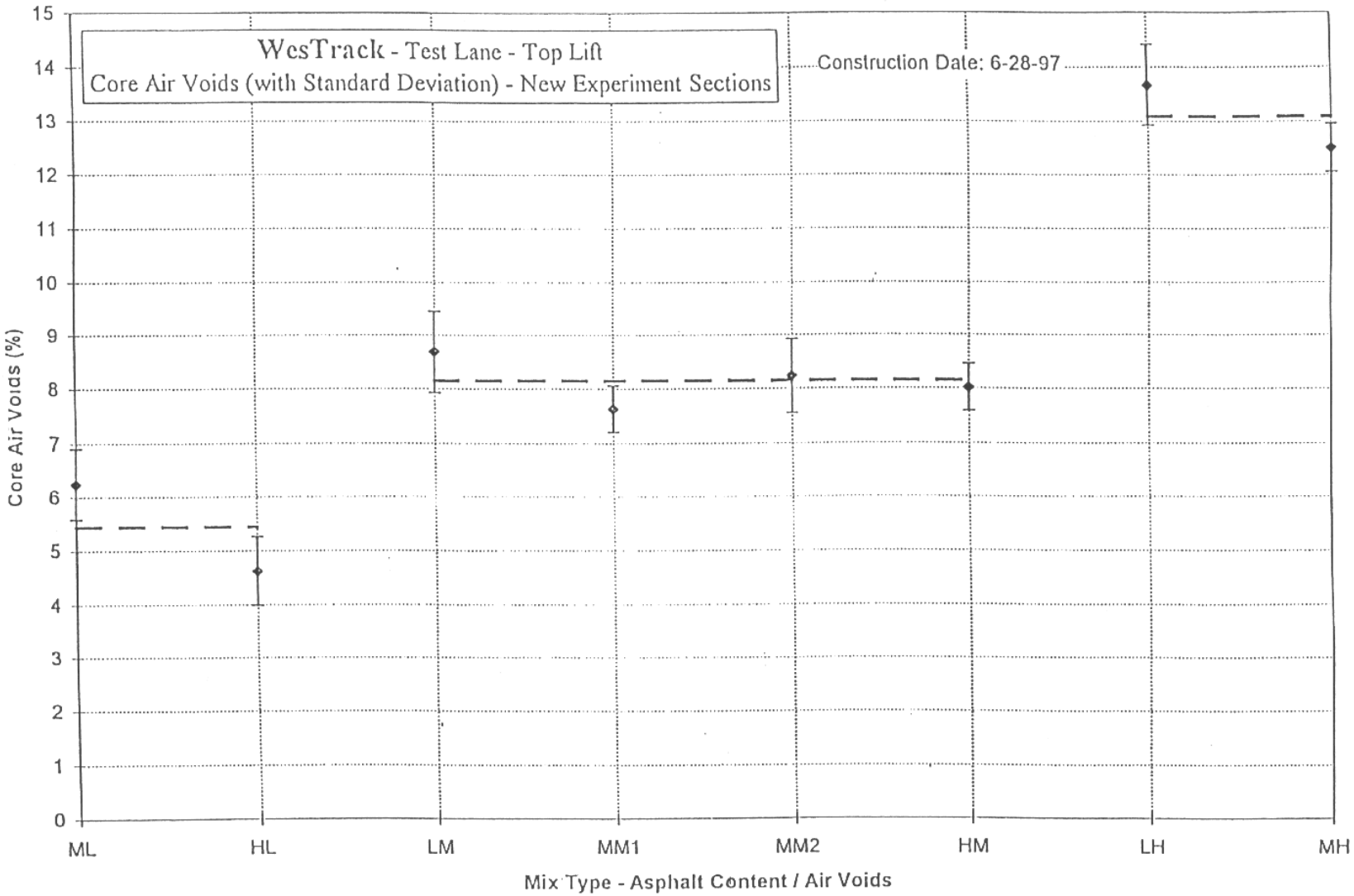
IN-PLACE AIR VOIDS AND THICKNESS – TOP LIFT, TEST LANE, CONSTRUCTED JUNE 28, 1997

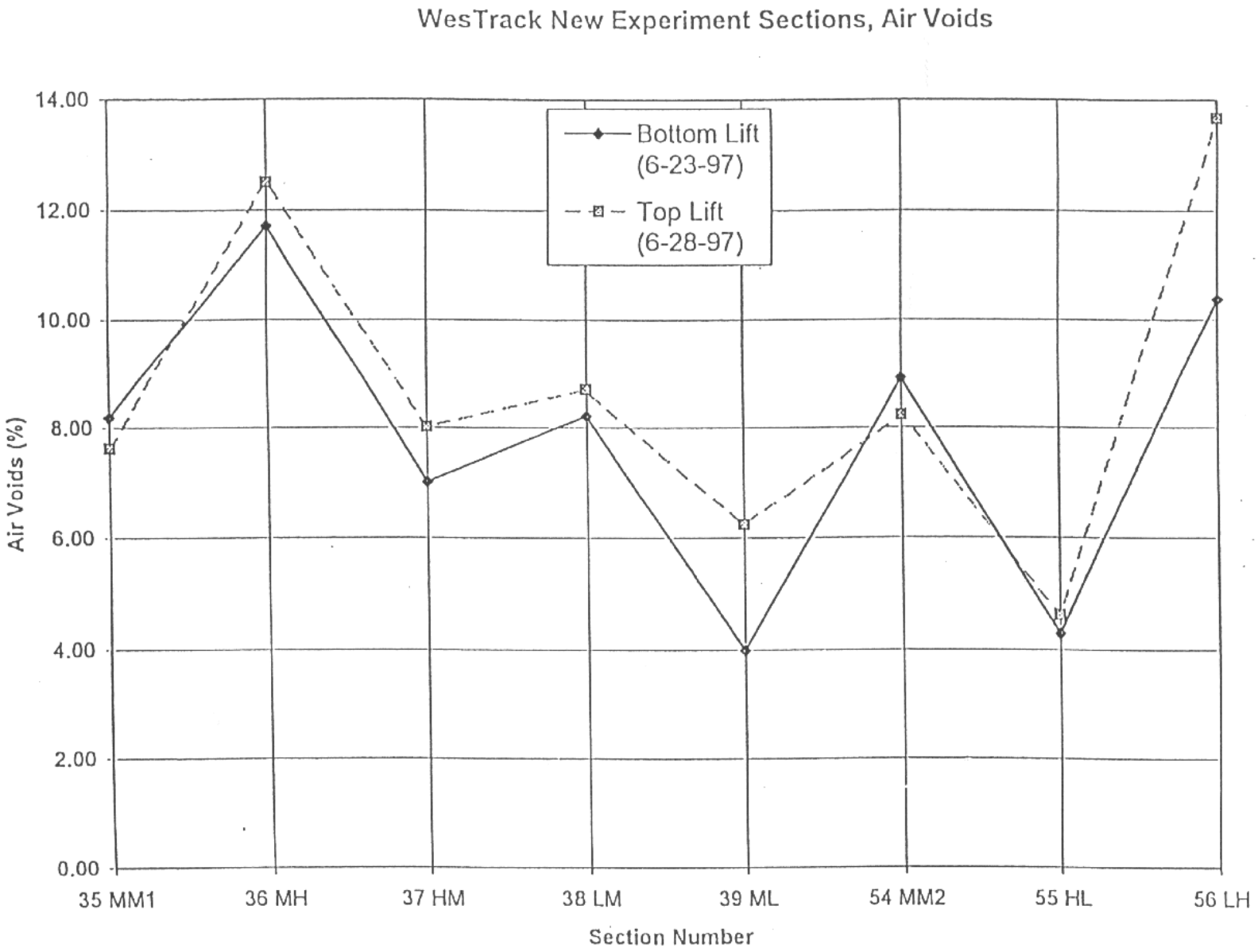
Core Air Voids for Test Lane, Top Lift, Construction Date: 6-28-97

62.24

Section & Core No.	Core Thickness	Average Thickness	Core SG	Rice SG	Core Density	Rice Density	Air Voids				Target AC / AV
							Cores	Average	Stdev	Range	
35-1	2.85	2.8	2.250	2.429	140.0	151.2	7.4	7.6	0.4	1.1	MM1
35-2	2.80	0.11	2.227		138.6		8.3				
35-3	2.70		2.243		139.6		7.7				
35-4	2.68		2.244		139.7		7.6				
35-5	2.76		2.254		140.3		7.2				
36-1	3.05	3.0	2.136	2.447	132.9	152.3	12.7	12.5	0.4	1.1	MH
36-2	2.95	0.12	2.141		133.3		12.5				
36-3	3.10		2.134		132.8		12.8				
36-4	3.15		2.134		132.8		12.8				
36-5	2.90		2.160		134.4		11.7				
37-1	3.07	2.9	2.211	2.417	137.6	150.4	8.5	8.0	0.4	1.0	HM
37-2	2.51	0.11	2.236		139.2		7.5				
37-3	3.08		2.222		138.3		8.1				
37-4	3.20		2.231		138.9		7.7				
37-5	2.64		2.216		137.9		8.3				
38-1	2.72	2.7	2.232	2.459	138.9	153.0	9.2	8.7	0.8	1.9	LM
38-2	2.76	0.11	2.270		141.3		7.7				
38-3	2.65		2.224		138.4		9.6				
38-4	2.75		2.257		140.5		8.2				
38-5	2.70		2.244		139.7		8.7				
39-1	2.83	2.7	2.280	2.441	141.9	151.9	6.6	6.2	0.7	1.8	ML
39-2	2.55	0.11	2.270		141.3		7.0				
39-3	2.78		2.313		144.0		5.2				
39-4	2.71		2.286		142.3		6.3				
39-5	2.83		2.294		142.8		6.0				
54-1	2.70	2.8	2.216	2.424	137.9	150.9	8.6	8.2	0.7	1.6	MM2
54-2	2.85	0.11	2.207		137.4		9.0				
54-3	2.40		2.245		139.7		7.4				
54-4	2.93		2.239		139.4		7.6				
54-5	2.95		2.215		137.9		8.6				
55-1	2.64	2.9	2.294	2.419	142.8	150.6	5.2	4.6	0.6	1.5	HL
55-2	3.68	0.12	2.292		142.7		5.3				
55-3	2.76		2.306		143.5		4.7				
55-4	2.90		2.329		145.0		3.7				
55-5	2.75		2.315		144.1		4.3				
56-1	2.80	2.8	2.127	2.452	132.4	152.6	13.3	13.7	0.7	1.9	LH
56-2	2.80	0.11	2.122		132.1		13.5				
56-3	2.85		2.134		132.8		13.0				
56-4	2.75		2.114		131.6		13.8				
56-5	2.55		2.087		129.9		14.9				


Westrack New Experiment Sections, Top Lift, Test Lane
Construction Date: 6-28-97
Core Air Voids
Target
WesTrack - Test Lane - Top Lift
Core Air Voids (+/- 1.0%)
Core Air Voids (%)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
35 MM1
36 MH
37 HM
38 LM
39 ML
54 MM2
55 HL
56 LH
Section Number


WesTrack - Test Lane - Top Lift
Core Air Voids (with Standard Deviation) - New Experiment Sections
Construction Date: 6-28-97
Core Air Voids (%)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
ML
HL
LM
MM1
MM2
HM
LH
MH
Mix Type - Asphalt Content / Air Voids

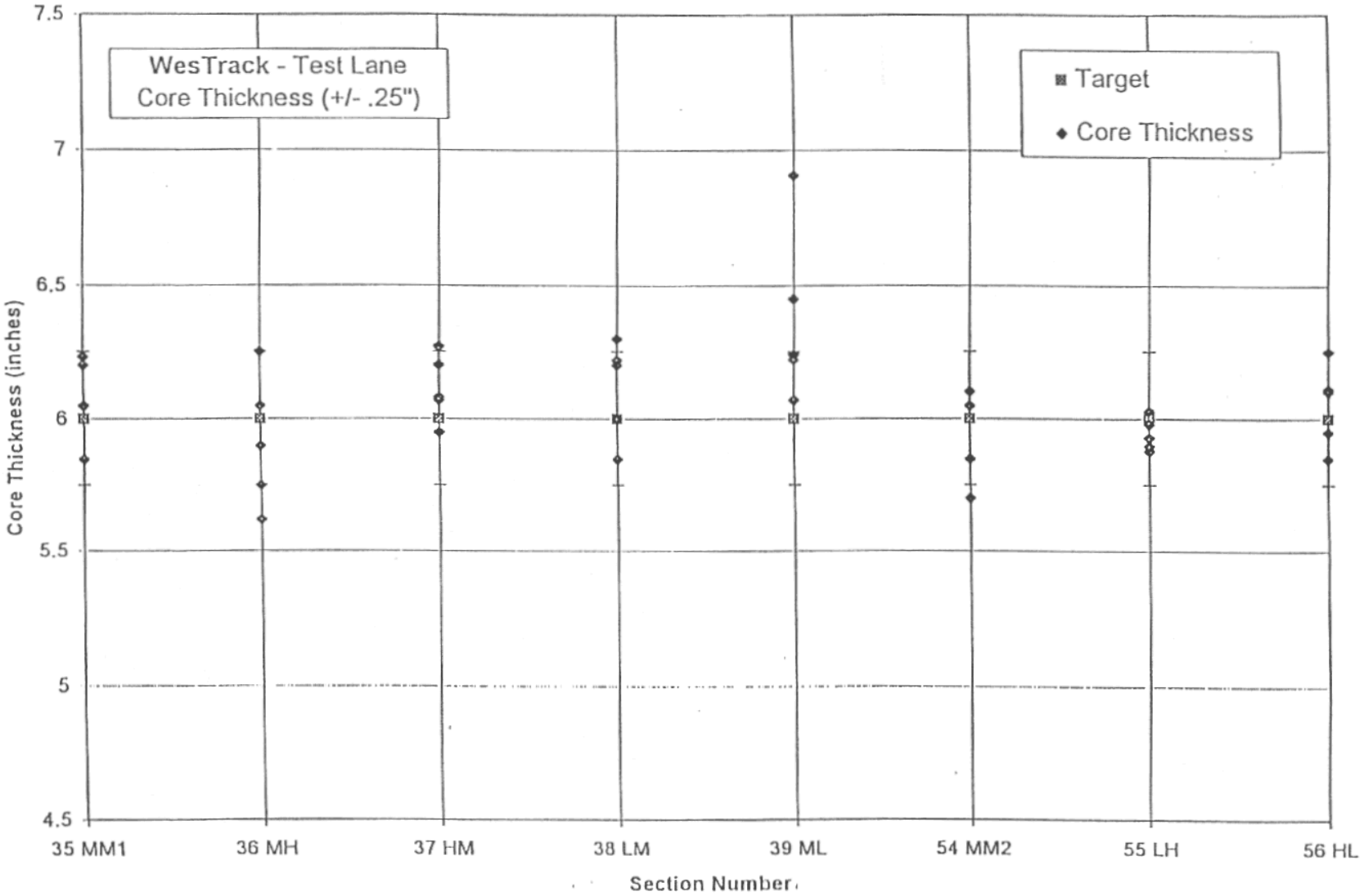

WesTrack New Experiment Sections, Air Voids
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Air Voids (%)
Bottom Lift (6-23-97)
Top Lift (6-28-97)
35 MM1
36 MH
37 HM
38 LM
39 ML
54 MM2
55 HL
56 LH
Section Number

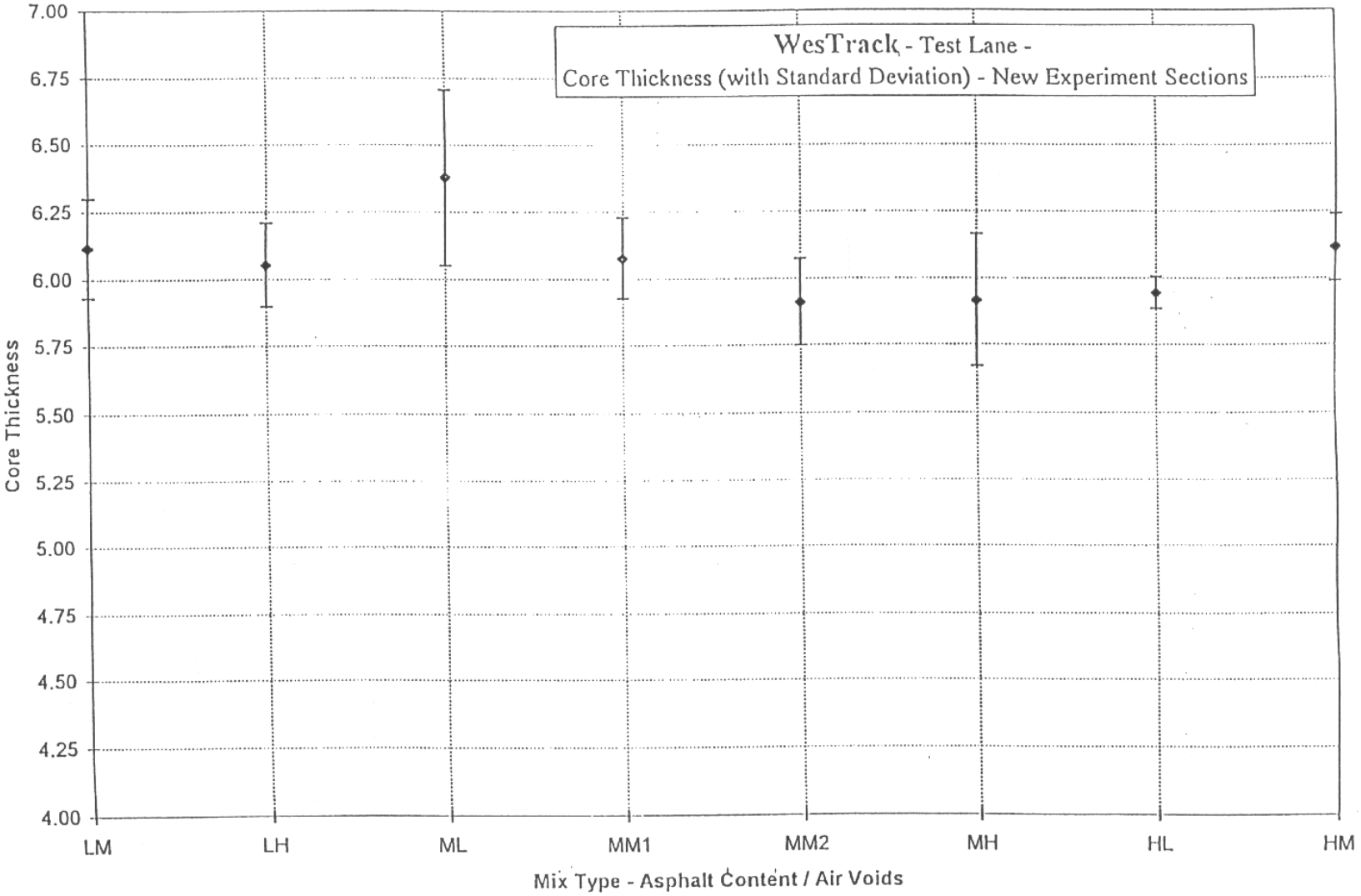
WesTrack - Core Air Voids - Test Lane - Top Lift (6-28-97)

Sec	Target		Core Air Voids														
No	AC	AV	1	2	3	4	5	X	s	Range	UL	LL	QI_U	QI_L	PD_U	PD_L	PWL
35 MM1	5.82	8	7.37	8.32	7.66	7.62	7.20	7.63	0.42	1.11	9	7	3.22	1.49	0	3.99	96
36 MH	5.82	12	12.71	12.51	12.79	12.79	11.73	12.51	0.45	1.06	13	11	1.10	3.35	13.2	0	86.8
37 HM	6.43	8	8.52	7.49	8.07	7.70	8.32	8.02	0.43	1.03	9	7	2.30	2.38	0	0	100
38 LM	5.19	8	9.23	7.69	9.56	8.21	8.74	8.69	0.76	1.87	9	7	0.42	2.23	35.19	0	64.8
39 ML	5.82	4	6.60	7.01	5.24	6.35	6.02	6.24	0.66	1.76	5	3	-1.87	4.88	100	0	0
54 MM2	5.82	8	8.58	8.95	7.38	7.63	8.62	8.23	0.68	1.57	9	7	1.12	1.80	12.93	0	87.1
55 HL	6.43	4	5.17	5.25	4.67	3.72	4.30	4.62	0.63	1.53	5	3	0.60	2.56	29.05	0	71
56 LH	5.19	12	13.25	13.46	12.97	13.78	14.89	13.67	0.74	1.92	13	11	-0.90	3.60	80.62	0	19.4

WesTrack - Core Thickness - Test Lane

Sec	Target			Core Thickness														
No	AC	AV	Ht	1	2	3	4	5	X	s	Range	UL	LL	Ql_U	Ql_L	PD_U	PD_L	PWL
35 MM1	5.82	8	6	5.85	6.05	6.20	6.05	6.23	6.08	0.15	0.38	6.25	5.75	1.15	2.16	12.10	0.00	87.9
36 MH	5.82	12	6	6.05	5.90	5.75	6.25	5.62	5.91	0.25	0.63	6.25	5.75	1.36	0.66	6.79	27.06	66.15
37 HM	6.43	8	6	6.07	6.08	6.27	6.20	5.95	6.11	0.12	0.32	6.25	5.75	1.09	2.93	13.76	0.00	86.24
38 LM	5.19	8	6	5.85	6.20	6.00	6.22	6.30	6.11	0.18	0.45	6.25	5.75	0.74	1.97	24.44	0.00	75.56
39 ML	5.82	4	6	6.45	6.07	6.24	6.91	6.22	6.38	0.33	0.84	6.25	5.75	-0.39	1.92	63.77	0.00	36.23
54 MM2	5.82	8	6	5.85	5.85	5.70	6.10	6.05	5.91	0.16	0.40	6.25	5.75	2.08	0.98	0.00	16.96	83.04
55 LH	5.19	4	6	5.88	6.03	5.98	5.90	5.93	5.94	0.06	0.15	6.25	5.75	5.01	3.18	0.00	0.00	100
56 HL	6.43	12	6	5.95	6.10	6.11	6.25	5.85	6.05	0.15	0.40	6.25	5.75	1.28	1.95	8.71	0.00	91.29


WesTrack - Test Lane
Core Thickness (+/- .25")
Target
Core Thickness
Core Thickness (inches)
7.5
7
6.5
6
5.5
5
4.5
35 MM1
36 MH
37 HM
38 LM
39 ML
54 MM2
55 LH
56 HL
Section Number


WesTrack - Test Lane -
Core Thickness (with Standard Deviation) - New Experiment Sections
Core Thickness
7.00
6.75
6.50
6.25
6.00
5.75
5.50
5.25
5.00
4.75
4.50
4.25
4.00
LM
LH
ML
MM1
MM2
MH
HL
HM
Mix Type - Asphalt Content / Air Voids

Quality Control Asphalt Binder Contents—Original Construction

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-14
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on asphalt binder contents measured during construction and referred to as "quality control asphalt binder content." The test program used for sampling and testing is contained in WesTrack Technical Report UNR-18.[4] During construction, the asphalt contents were determined by the FHWA's mobile HMA testing laboratory and by BRE Engineers.

Due to difficulties in obtaining accurate asphalt binder contents during this quality control testing, an extensive laboratory quality assurance test program was undertaken to define the asphalt content in the test sections at WesTrack. The gyratory compaction volumetric properties obtained during construction were based on the quality control asphalt binder contents contained in this report and were used to adjust the construction operation. The reported quality assurance gyratory compaction data are based on the revised asphalt binder contents obtained during the quality assurance testing.[5] The quality assurance asphalt binder contents and volumetrics are the most accurate values available and have been used to develop the performance models. (Note: In the tables in this report, letters in the section description such as LM and MH refer to target properties for the section. The first letter is the target asphalt content [Low, Medium, or High]; the second letter is the target air voids content.)

BACKGROUND

Prior to the start of production of the HMA, the HMA production facility was calibrated. This calibration included determination of individual cold-feed rates for each aggregate, calibration of the scale belt, and calibration of the asphalt binder delivery system. During the placement of the hot mixes at WesTrack, additional calibrations were performed. The initial calibration was performed on September 8, 1995. Additional calibrations were performed on September 25, 26, 28, and 29, 1995.

HMA mixtures were placed on the ramps to the test track on September 9 and 13, 1995, to determine the constructability of the HMA, as well as to determine the gradation, asphalt binder contents, and the volumetrics.

The construction of the "trial lane" and the "test lane" of the track were performed on the dates shown in table 1. The bottom lift of the trial lane was placed first, followed by placement of the bottom lift of the test lane. The top lift of the trial lane was placed prior to the top lift of the test lane. Placement of the trial lanes prior to placement of the test lanes allowed for adjustments in the binder contents and gradations, as well as adjustments in the construction operation. The test lanes were the lanes on which the traffic was placed and the WesTrack performance information obtained.

SAMPLING

Asphalt binder content determination was performed on samples of HMA obtained from trucks. These samples were split and used for both quality control and quality assurance testing. The detailed sampling and testing plan for the original construction can be found in WesTrack Technical Report UNR-18.[4]

TEST METHODS

The asphalt binder contents reported from quality control testing were obtained by the FHWA with the ignition oven (ASTM D 6307) calibrated with a WesTrack mixture placed on the ramps at the test track. This calibration factor was used for all FHWA quality control testing of mixtures placed at the track during original construction. The quality control asphalt binder content was used to determine the quality control gyratory-compacted sample volumetrics. These quality control volumetrics and asphalt binder contents were used to adjust the plant during construction.

Binder contents also were obtained with nuclear asphalt content gages during construction. The nuclear asphalt binder contents were not used for calculation of gyratory-compacted sample volumetrics. The nuclear asphalt binder contents were utilized together with other asphalt binder content data and gyratory compactor volumetrics to control the HMA plant during construction. Nuclear asphalt content determinations were performed according to AASHTO T 287 and ASTM D 4125.

ASPHALT BINDER CONTENT

FINE GRADED MIXTURES

Tables 2 and 3 contain asphalt binder content data obtained on the fine graded mixture placed at WesTrack. Ignition tests were performed on single samples of HMA for both the top and bottom lifts of each section. Test results are shown in table 2 for the trial sections and in table 3 for the test sections.

Nuclear asphalt binder contents typically were obtained on three samples per lift per section. Averages and standard deviations for the nuclear asphalt binder content data are shown in tables 2 and 3 for the fine graded mixture. The asphalt binder content reported has been corrected for moisture content of the HMA. During daily reviews of the quality control data from each day's production, it was not always possible to review data that had been corrected for moisture in the samples.

The asphalt binder contents determined by both the ignition and nuclear devices displayed a trend of increasing asphalt binder content as the asphalt binder content was increased to meet the desired target values of the low, optimum, and high binder content mixtures. The desired target value and the measured values for asphalt binder content were offset, with both the ignition and nuclear asphalt binder contents higher than expected. Mixture gyratory-compacted volumetrics suggested that the proper asphalt binder contents were being used during production. The apparent conflict in data between the measured asphalt binder content, plant setting for asphalt binder content, and field-mixed, laboratory-compacted volumetrics was a problem throughout the construction associated with the HMA for all mixtures (fine, fine plus, and coarse).

The data scatter, as measured by the standard deviation for the nuclear asphalt binder content determinations, is shown in tables 2 and 3. Over half of the standard deviations for the trial lane were greater than 0.30 (table 2). A typical standard deviation for hot-mix production is about 0.30 in the United States.[8] About one-quarter of the standard deviations for the test lane exceeded the 0.30 value (table 3). The majority of the asphalt binder contents determined by the nuclear device were larger than the values determined by the ignition device.

FINE PLUS GRADED MIXTURE

Tables 4 and 5 contain asphalt binder content data obtained on the fine plus graded mixture placed at WesTrack. Ignition tests were performed on single samples of HMA for both the top and bottom lifts of each section. Test results are shown in table 4 for the trial sections and in table 5 for the test sections.

Nuclear asphalt binder contents were obtained on fewer samples for the fine plus than for fine and coarse graded mixtures. Averages and standard deviations were reported for those lifts and sections on which three nuclear asphalt binder contents had been obtained. The asphalt binder content reported has been corrected for moisture content of the HMA. During daily reviews of the quality control data from each day's production, it was not always possible to review data that had been corrected for moisture in the samples.

The asphalt binder contents determined by both the ignition and nuclear devices displayed a trend of increasing asphalt binder content, as the asphalt binder content was increased to meet the desired target

values of the low, optimum, and high binder content mixtures. The desired target value and the measured values for asphalt binder content were offset, with both the ignition and nuclear asphalt binder contents higher than expected. Mixture gyratory-compacted volumetrics suggested that the proper asphalt binder contents were being used during production.

The data scatter, as measured by the standard deviation for the nuclear asphalt binder content determinations, is shown in table 5 where data were available. One-third of the standard deviations for the trial test lane bottom lift were greater than 0.30. The majority of the asphalt binder contents determined by the nuclear device were larger than the values determined by the ignition device.

COARSE GRADED MIXTURE

Tables 6 and 7 contain asphalt binder content data obtained on the coarse graded mixture placed at WesTrack. Ignition tests were performed on single samples of HMA for both the top and bottom lifts of each section. Test results are shown in table 6 for the trial sections and in table 7 for the test sections.

Nuclear asphalt binder contents typically were obtained on three samples per lift per section. Averages and standard deviations for the nuclear asphalt binder content data are shown in tables 6 and 7 for the fine graded mixture. The asphalt binder content reported has been corrected for moisture content of the HMA. During the daily reviews of the quality control data from each day's production, it was not always possible to review data that had been corrected for moisture in the samples.

The asphalt binder contents determined by both the ignition and nuclear devices displayed a trend of increasing asphalt binder content, as the asphalt binder content was increased to meet the desired target values of the low, optimum, and high binder content mixtures. The desired target value and the measured values for asphalt binder content were offset, with both the ignition and nuclear asphalt binder contents higher than expected. Mixture gyratory-compacted volumetrics suggested that the proper asphalt binder contents were being used during production.

The data scatter, as measured by the standard deviation for the nuclear asphalt binder content determinations, is shown in tables 6 and 7. About one-quarter of the standard deviations for the trial lane and test lane were greater than 0.30 (tables 6 and 7). A typical standard deviation for hot-mix production is about 0.30 in the United States.[8] The majority of the asphalt binder contents determined by the nuclear device were larger than the values determined by the ignition device.

MOISTURE CONTENT

Moisture content data were obtained by the FHWA during the quality control testing of the HMA. These data were utilized to correct the asphalt binder content data as well as to provide a measure of the moisture content of the HMA during construction. The HMA was sampled from the trucks which were within 30 yards of the quality control testing laboratories. Moisture content samples were obtained when the larger truck samples were split for gyratory volumetric property determination and asphalt content determinations.

Tables 8 through 11 report the moisture content data determined on the fine and coarse graded mixtures. Moisture contents were not available from the FHWA WesTrack data base for the fine plus graded

mixture. Moisture contents ranged from 0.0 to a high value of 0.23 percent. The statistical summary of the moisture contents for the fine and coarse mixtures by trial and test lane are shown in table 12. On average, moisture contents are slightly higher for the coarse graded mixtures than for the fine, but the difference is not statistically significant.

PERCENT PASSING NO. 200 SIEVE

Tables 8 through 11 contain available information obtained by the FHWA during the quality control testing program. This information defines the percentage of the aggregate that passed the No. 200 sieve. Gradations were determined on samples after asphalt content determination by the ignition method and on cold-feed samples. Differences reported were values for the percentage passing the No. 200 sieve and were due to sampling, testing, and material variability. Material variability was largely due to baghouse return system settings, degradation in the plant, and variability in the stockpiles.

SUMMARY

Tables 2 through 7 contain the asphalt binder content information obtained by the FHWA mobile laboratory during construction of WesTrack. This quality control information was used to help guide the process control during the construction operation. Typically, the ignition and nuclear asphalt binder contents were greater than the target values used to set the HMA plant. In general, the asphalt binder contents determined by the nuclear device were greater than those determined by the ignition oven.

Moisture contents are reported in tables 8 through 11 and summarized in table 12. The moisture contents were about 0.10 percent.

Tables 8 through 11 also list the percentage of aggregate that passed the No. 200 sieve. These data were obtained from aggregate remaining after the ignition oven test and from samples obtained from the cold feed. Moisture content data are also contained in these tables and represent the only HMA production moisture contents measured during the project.

The information contained in this report on asphalt binder content and gradation (percent passing No. 200 sieve) should not be used for performance modeling purposes. An extensive laboratory program was performed as part of the project's quality assurance process to determine asphalt binder contents and gradation. WesTrack Technical Reports UNR-15 and UNR-22 should be used for the representative values for asphalt binder content and aggregate gradation.

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Table 1. Schedule for original construction.

Date	Mixture	Lift	Lane	Section Numbers*
9-14-95	Fine	Bottom	Trial	1,2,3,4,14,15,16,17,18
9-15-95	Fine Plus	Bottom	Trial	19,20,21,22,9,10,11,12,13
9-16-95	Coarse	Bottom	Trial	5,6,7
9-18-95	Coarse	Bottom	Trial	8,23,24,25,26
9-20-95	Fine	Bottom	Test	1,2,3,4,14,15,16,17,18
9-21-95	Fine Plus	Bottom	Test	19,20,21,22,9,10,11,12,13
9-22-95	Fine	Top	Trial	1,2,3,4,14,15,16,17,18
9-27-95	Fine Plus	Top	Trial	19,20,21,22,9,10,11,12,13
9-27-95	Fine Plus	Bottom	Test	13
9-30-95	Coarse	Bottom	Test	5,6,7,8,23,24,25,26
10-1-95	Coarse	Top	Trial	5,6,7,8,23,24,25,26
10-2-95	Fine	Top	Test	1,2,3,4,14,15,16,17,18
10-3-95	Fine Plus	Top	Test	19,20,21,22,9,10,11,12,13
10-4-95	Coarse	Top	Test	5,6,7,8,23,24,25,26

*Section numbers follow order of placement.

Table 2. Construction quality control asphalt binder contents – fine graded mixture (trial lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Nuclear Asphalt Content, Percent				
					Split Sample	Second trailer	Second Truck	Average	Std Dev
2 LM	Fine	Top	4.7	4.94	5.55	5.81	5.33	5.56	0.20
		Bottom	4.7	5.10	5.38	5.12	5.30	5.27	0.11
3 LH	Fine	Top	4.7	5.33	5.76	5.52	4.90	5.39	0.36
		Bottom	4.7	4.73	5.12	5.05	4.86	5.01	0.11
16 LH	Fine	Top	4.7	5.14	4.77	5.45	4.75	4.99	0.33
		Bottom	4.7	4.76	5.06	4.77	4.75	4.86	0.14
1 MM	Fine	Top	5.4	6.07	6.86	6.94	6.18	6.66	0.34
		Bottom	5.4	5.72	5.36	6.01	5.96	5.78	0.30
4 ML	Fine	Top	5.4	5.83	6.13	6.86	5.66	6.22	0.49
		Bottom	5.4	5.44	5.94	6.27	5.99	6.07	0.15
15 MM	Fine	Top	5.4	6.10	6.60	7.17	6.41	6.73	0.32
		Bottom	5.4	4.85	5.60	6.48	6.01	6.03	0.36
17 MH	Fine	Top	5.4	5.74	6.06	6.68	5.18	5.97	0.62
		Bottom	5.4	5.29	5.83	6.23	5.91	5.99	0.17
14 HM	Fine	Top	6.1	6.79	7.68	8.26	7.22	7.72	0.43
		Bottom	6.1	6.25	6.52	6.47	6.33	6.44	0.08
18 HL	Fine	Top	6.1	6.83	7.51	8.58	7.37	7.82	0.54
		Bottom	6.1	6.48	7.32	6.55	6.54	6.80	0.37

Table 3. Construction quality control asphalt binder content – fine graded mixture (test lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Nuclear Asphalt Content, Percent				
					Split Sample	Second Trailer	Second Truck	Average	Std Dev
2 LM	Fine	Top	4.7	4.50	4.91	5.01	4.71	4.89	0.12
		Bottom	4.7	5.07	4.98	5.48	5.54	5.33	0.63
3 LH	Fine	Top	4.7	4.57	4.91	4.27	4.62	4.60	0.26
		Bottom	4.7	3.94	4.14	5.04	5.38	4.85	0.15
16 LH	Fine	Top	4.7	4.28	4.23	4.60	4.85	4.56	0.25
		Bottom	4.7	4.98	4.89	5.14	5.15	5.06	0.36
1 MM	Fine	Top	5.4	5.10	5.24	5.57	4.78	5.20	0.32
		Bottom	5.4	5.71	5.79	5.02		5.41	0.39
4 ML	Fine	Top	5.4	4.83	4.96	5.09	4.92	4.99	0.07
		Bottom	5.4	5.10	5.35	5.73	6.12	5.73	0.31
15 MM	Fine	Top	5.4	5.27	5.30	5.33	5.02	5.22	0.14
		Bottom	5.4	5.17	5.39	5.53	5.77	5.56	0.16
17 MH	Fine	Top	5.4	5.47	5.11	5.16	5.62	5.30	0.23
		Bottom	5.4	5.35	5.50	5.57	5.74	5.60	0.10
14 HM	Fine	Top	6.1	5.90	6.23	6.04	6.14	6.14	0.08
		Bottom	6.1	6.18	6.86	6.77	7.11	6.91	0.14
18 HL	Fine	Top	6.1	5.98	5.76	6.18	5.66	5.87	0.23
		Bottom	6.1	5.48	5.62	6.20	6.95	6.26	0.16

Table 4. Construction quality control asphalt binder content – fine plus graded mixture (trial lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Nuclear Asphalt Binder Content, Percent				
					Split Sample	Second Trailer	Second Truck	Average	Std Dev
22 LM	Fine Plus	Top	4.7	5.14					
		Bottom	4.7	4.96	4.99				
10 LH	Fine Plus	Top	4.7	5.00					
		Bottom	4.7	5.03	5.17				
19 MM	Fine Plus	Top	5.4	5.54					
		Bottom	5.4	5.81	6.03				
20 MH	Fine Plus	Top	5.4	5.91					
		Bottom	5.4	5.27	5.27				
11 MM	Fine Plus	Top	5.4	5.62					
		Bottom	5.4	5.88	5.78				
12 ML	Fine Plus	Top	5.4	5.80					
		Bottom	5.4	5.43	5.45				
21 HL	Fine Plus	Top	6.1	6.09					
		Bottom	6.1	6.34	6.41				
9 HL	Fine Plus	Top	6.1	6.22					
		Bottom	6.1	6.37	6.45				
13 HM	Fine Plus	Top	6.1	6.31					
		Bottom	6.1	6.51	6.73				

Table 5. Construction quality control asphalt binder content – fine plus graded mixture (test lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Nuclear Asphalt Binder Content, Percent				
					Split Sample	Second Trailer	Second Truck	Average	Std Dev
22 LM	Fine Plus	Top	4.7	5.12					
		Bottom	4.7	5.10	5.75	5.37	5.87	5.66	0.26
10 LH	Fine Plus	Top	4.7	5.29					
		Bottom	4.7	4.66	5.04	4.84	5.23	5.04	0.20
19 MM	Fine Plus	Top	5.4	5.93					
		Bottom	5.4	5.85	6.30	5.94	5.97	6.07	0.20
20 MH	Fine Plus	Top	5.4	6.08					
		Bottom	5.4	5.96	6.44	6.12	6.80	6.45	0.34
11 MM	Fine Plus	Top	5.4	5.94					
		Bottom	5.4	5.78	5.97	5.57	6.82	6.12	0.64
12 ML	Fine Plus	Top	5.4	6.04					
		Bottom	5.4	5.37	5.72	5.35	6.28	5.78	0.47
21 HL	Fine Plus	Top	6.1	6.82					
		Bottom	6.1	5.92	6.76	6.57	6.88	6.74	0.16
9 HL	Fine Plus	Top	6.1	6.72					
		Bottom	6.1	6.44	7.07	7.06	7.29	7.14	0.13
13 HM	Fine Plus	Top	6.1	6.60					
		Bottom	6.1	6.37					

Table 6. Construction quality control asphalt binder content – coarse graded mixture (trial lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Nuclear Asphalt Binder Content, Percent				
					Split Sample	Second Trailer	Second Truck	Average	Std Dev
8 LM	Coarse	Top	5.0	5.35	5.68	5.38	5.29	5.45	0.17
		Bottom	5.0	5.79	6.15	5.94	5.76	5.95	0.16
26 LH	Coarse	Top	5.0	5.34	5.21	5.27	5.07	5.18	0.18
		Bottom	5.0	5.45	5.60	5.48	5.91	5.66	0.18
5 MM	Coarse	Top	5.7	6.07	5.95	6.06	6.16	6.06	0.09
		Bottom	5.7	6.10	6.27	6.53	7.06	6.62	0.33
6 MH	Coarse	Top	5.7	5.95	5.82	5.84	5.16	5.61	0.32
		Bottom	5.7	6.83	6.99	6.96	6.83	6.93	0.07
23 ML	Coarse	Top	5.7	5.91	5.57	6.31	5.83	5.90	0.81
		Bottom	5.7	5.43	5.97	6.19	6.30	6.15	0.14
24 MM	Coarse	Top	5.7	6.01	5.54	5.82	5.10	5.49	0.30
		Bottom	5.7	5.82	5.98	6.41	6.28	6.22	0.18
7 HM	Coarse	Top	6.4	6.85	6.42	5.93	6.75	6.37	0.34
		Bottom	6.4	7.64	7.23	6.98	7.40	7.20	0.17
25 HL	Coarse	Top	6.4	6.24	6.45	5.42	6.07	5.98	0.43
		Bottom	6.4	6.09	6.46	6.94	6.78	6.73	0.20

Table 7. Construction quality control asphalt binder content – coarse graded mixture (test lane).

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content	Nuclear Asphalt Binder Content, Percent				
					Split Sample	Second Trailer	Second Truck	Average	Std Dev
8 LM	Coarse	Top	5.0	4.89	4.89	5.39	5.07	5.12	0.21
		Bottom	5.0	5.32	4.93	5.26	5.55	5.25	0.25
26 LH	Coarse	Top	5.0	4.98	5.61	5.56	5.22	5.46	0.17
		Bottom	5.0	5.34	5.31	5.08	5.22	5.20	0.09
5 MM	Coarse	Top	5.7	4.89	5.64	5.69	6.08	5.80	0.20
		Bottom	5.7	5.26	6.00	5.83	5.54	5.79	0.19
6 MH	Coarse	Top	5.7	5.55	5.63	5.87	5.46	5.65	0.17
		Bottom	5.7	5.05	6.02	6.21	5.50	5.91	0.30
23 ML	Coarse	Top***	5.7	5.81	6.28	6.27	6.10	6.22	0.08
		Bottom	5.7	5.05	4.63	5.56	5.60	5.26	0.45
24 MM	Coarse	Top***	5.7	6.31	6.01	6.08	5.38	5.82	0.31
		Bottom	5.7	5.11	4.85	5.28	5.92	5.35	0.44
7 HM	Coarse	Top	6.4	6.58	6.24	6.63	6.58	6.48	0.17
		Bottom	6.4	6.44	5.56	5.60	6.73	5.96	0.54
25 HL	Coarse	Top	6.4	6.06	6.60	6.43	6.19	6.41	0.17
		Bottom	6.4	6.09	5.92	6.64	6.04	6.20	0.31

***Compacted in Asphalt Institute Compactor.

Table 8. Construction quality control moisture content and percent passing No. 200 sieve – fine graded mixture (trial lane).

Section No.	Mix Designation	Lift	Target Asphalt Content, Percent	Moisture Content, Percent	Percent Passing No. 200	
					Ignition	Cold Feed
2 LM	Fine	Top	4.7	0.18		
		Bottom	4.7		3.6	3.4
3 LH	Fine	Top	4.7	0.11		
		Bottom	4.7			
16 LH	Fine	Top	4.7	0.11		
		Bottom	4.7		3.7	3.8
1 MM	Fine	Top	5.4	0.13		
		Bottom	5.4	0.18	3.8	4.2
4 ML	Fine	Top	5.4	0.06		
		Bottom	5.4	0.00		
15 MM	Fine	Top	5.4	0.18		
		Bottom	5.4	0.14	3.4	3.5
17 MH	Fine	Top	5.4	0.11		
		Bottom	5.4	0.04		
14 HM	Fine	Top	6.1	0.10		
		Bottom	6.1		3.3	3.0
18 HL	Fine	Top	6.1	0.10		
		Bottom	6.1	0.09	3.8	3.5

Table 9. Construction quality control moisture content and percent passing No. 200 sieve – coarse graded mixture (trial lane).

Section No.	Mix Designation	Lift	Target Asphalt Content, Percent	Moisture Content, Percent	Percent Passing No. 200	
					Ignition	Cold Feed
8 LM	Coarse	Top	5.0	0.10		
		Bottom	5.0		5.1	6.5
26 LH	Coarse	Top	5.0	0.16		
		Bottom	5.0		4.8	4.9
5 MM	Coarse	Top	5.7	0.10		
		Bottom	5.7	0.15	3.9	5.4
6 MH	Coarse	Top	5.7	0.17		
		Bottom	5.7	0.15	4.7	6.2
23 ML	Coarse	Top	5.7	0.04		
		Bottom	5.7	0.15	4.4	6.0
24 MM	Coarse	Top	5.7	0.13		
		Bottom	5.7	0.05	5.2	6.1
7 HM	Coarse	Top	6.24	0.10		
		Bottom	6.24		5.3	6.6
25 HL	Coarse	Top	6.4	0.20		
		Bottom	6.4	0.00		

Table 10. Construction quality control moisture content and percent passing No. 200 sieve – fine graded mixture (test lane).

Section No.	Mix Designation	Lift	Target Asphalt Content, Percent	Moisture Content, Percent	Percent Passing No. 200	
					Ignition	Cold Feed
2 LM	Fine	Top	4.7	0.15		
		Bottom	4.7	0.14		
3 LH	Fine	Top	4.7	0.12		
		Bottom	4.7	0.14		
16 LH	Fine	Top	4.7	0.17		
		Bottom	4.7	0.06		
1 MM	Fine	Top	5.4	0.18		
		Bottom	5.4	0.06		
4 ML	Fine	Top	5.4	0.14		
		Bottom	5.4	0.08		
15 MM	Fine	Top	5.4	0.07		
		Bottom	5.4	0.06		
17 MH	Fine	Top	5.4	0.04		
		Bottom	5.4	0.07		
14 HM	Fine	Top	6.1	0.13		
		Bottom	6.1	0.14		
18 HL	Fine	Top	6.1	0.07		
		Bottom	6.1	0.07		

Table 11. Construction quality control moisture content and percent passing No. 200 sieve – coarse graded mixture (test lane).

Section No.	Mix Designation	Lift	Target Asphalt Content, Percent	Moisture Content, Percent	Percent Passing No. 200	
					Ignition	Cold Feed
8 LM	Coarse	Top	5.0	0.10		
		Bottom	5.0	0.11	4.3	5.4
26 LH	Coarse	Top	5.0	0.11		
		Bottom	5.0	0.14		
5 MM	Coarse	Top	5.7	0.23		
		Bottom	5.7	0.20	3.8	5.6
6 MH	Coarse	Top	5.7	0.19		
		Bottom	5.7	0.16	4.0	5.7
23 ML	Coarse	Top	5.7	0.02		
		Bottom	5.7	0.14	3.7	4.9
24 MM	Coarse	Top	5.7	0.11		
		Bottom	5.7	0.11	3.6	4.8
7 HM	Coarse	Top	6.4	0.08		
		Bottom	6.4	0.14	3.8	4.8
25 HL	Coarse	Top	6.4	0.09		
		Bottom	6.4	0.17		

Table 12. Quality control moisture contents – original construction.

Mixture Designation	Lane	Moisture Content, Percent			
		Mean	Standard Deviation	Range	No. of Samples
Fine Graded	Trial	0.11	0.05	0.00-0.18	14
	Test	0.11	0.04	0.06-0.18	18
Coarse Graded	Trial	0.12	0.06	0.00-0.20	13
	Test	0.13	0.05	0.02-0.23	16

Original Construction—Quality Assurance Asphalt Contents

U.S. Department of Transportation
Federal Highway Administration

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the state of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 to January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the SHRP Superpave HMA volumetric design method.

This WesTrack technical report provides information on HMA quality assurance asphalt content data for the original construction mixtures. The reader is referred to WesTrack Technical Report UNR 14[4] for original construction quality control asphalt content information and WesTrack Technical Report UNR 18[5] for original construction HMA QC/QA material sampling and testing plans.

The primary purpose of this document is to summarize HMA quality assurance asphalt content data, providing an official set of original construction mixtures asphalt content data. The data also was reported in the final project report and was used for quality assurance mixture volumetric calculations, performance modeling, and specification development purposes.

A significant effort was placed on developing an understanding of appropriate correction factors for use with the ignition asphalt content test method. Solvent extraction testing was performed in addition to ignition testing. The extraction testing was used to check the results of the ignition testing and, therefore, to assist in developing the required understanding. (Note: In the figures and tables in this report letters in the section description such as LM and MH refers to target properties for the section. The first letter is the target asphalt content [Low, Medium, or High]; the second letter is the target air voids content; a number, if present, is the replicate number).

BACKGROUND

The determination of asphalt content, which had been assumed would be relatively easy, has presented significant problems for the WesTrack researchers. For the original construction of the track, it was decided that both the ignition and nuclear asphalt content determination methods would be employed in

parallel for process or quality control purposes. Ignition, nuclear, and solvent extraction (reflux) methods were all planned for use in quality acceptance. At the time, the ignition method was making the transition from a research method to a practical method used throughout the industry.

Both the ignition and nuclear devices require calibrations (See references 6, 7, 8, and 9). The purpose of the calibration processes is to account for bias introduced through the test method. In the case of the nuclear device, the environment in which the device is operated may affect measurements. This is commonly referred to as "background." The background effect is controlled by the amount of hydrogen in the surrounding environment, as the determinations made with the nuclear device are a function of the hydrogen in the material being tested.

Calibration of the nuclear device involves the laboratory preparation and testing of asphalt aggregate mixture samples over a range of "known" asphalt contents centered around the job mix formula target. Known asphalt content refers to the amount of asphalt known to have been added to a laboratory-prepared sample. "Indicated" asphalt content refers to the asphalt content indicated by the device, be it nuclear or ignition. The difference in the known and indicated asphalt contents (bias) is the basis for a correction that is applied to subsequent measurements made with the device. The device must be calibrated prior to testing field-produced samples from the same materials. It is important to note that a unique calibration must be performed for each mix design.

The ignition device may be calibrated in the exact same fashion as the nuclear device, i.e., by the known method. It also may be calibrated using what is called the "blank aggregate" method of calibration. In the ignition test, a sample of HMA is subjected to an elevated temperature of 538°C (1,000°F) in a furnace that ignites and burns the asphalt off the aggregate. However, a small amount of aggregate is lost in the process and must be accounted for. If the aggregate lost in the ignition process is not accounted for, the indicated asphalt content will exceed the actual asphalt content. The reason is that the indicated asphalt content is based on the difference in the mass of the sample (asphalt and aggregate) prior to ignition and after ignition (aggregate only). However, the mass of the aggregate after ignition is actually less than the mass of the aggregate that was in the original sample placed in the oven. The difference, the mass of the aggregate lost in the ignition process, is the reason for performing the calibration, to obtain what is called a "correction factor" to account for aggregate lost in the ignition process.

A blank aggregate correction factor is obtained by simply testing aggregate alone (no asphalt cement) in the ignition furnace, thus the terminology "blank aggregate correction method." The mass loss of the blank aggregate is then used to determine the appropriate correction factor. The calibration must take place prior to testing field-produced samples from the same materials. Just as with the nuclear device, it is important to note that a unique calibration must be performed for each mix design. An advantage to the use of the ignition method is that the gradation of the aggregate that remains after an asphalt content determination may be determined as soon as the sample cools to room temperature. This makes the method very attractive, particularly in the process control environment.

At the time of the original construction of WesTrack, the blank aggregate method of calibration was recommended for the ignition device by the developers of the method.[8] Calibration factors were established by FHWA personnel for the nuclear device and one of the two ignition ovens used in the original construction testing at WesTrack. The aggregates used to develop the ignition correction factors were not treated with hydrated lime. The calibration factor established using the one ignition oven was

assumed to be valid for the other oven. Both ovens were National Center for Asphalt Technology (NCAT) Asphalt Content Testers, manufactured by Barnstead-Thermolyne.

TESTING PLAN

The original construction daily HMA process control testing plan is summarized in table 1. The testing associated with table 1 was conducted on materials sampled from transfer trucks at the hot plant in a multitude of laboratories set up at the hot plant. The original construction quality assurance test plan is outlined in table 2. For both process control and quality assurance purposes, a section was defined as a lot.

On any given day, a single target gradation was used and three asphalt contents were employed to produce one mix type, e.g., the fine mix. On any given day, a total of eight or nine test sections were paved. Since target in-place air voids did not affect hot plant settings, the only change made in hot plant settings over the day was the adjustment of the asphalt content to the low, medium, and high levels. This meant that, on any given day, two to four replicates were generated at each asphalt content and replication of gradation was obtained with each section. With the replication, one could develop multiple lot definitions for data analysis purposes.

The WesTrack Team believed that ample process control data would be generated under such conditions. However, after multiple plant calibrations, it became evident early in the trial lane paving that additional asphalt content determinations would be required in order to properly control the construction. There was also a lack of agreement among the nuclear- and ignition- indicated asphalt contents. Additionally, visual segregation, introduced in the hot plant storage silos, was apparent in the transfer trucks from which samples were being taken at that time.

These combined observations led to three key decisions:

- Five 150-mm diameter cores would be taken, per section per lift, directly from the track the day after a section was paved for ignition asphalt content testing and gradation determinations.
- The paving operations would be stopped until baffles were installed in what is commonly referred to as the "pant chute," through which mix is diverted into individual storage silos at the plant.
- A material transfer device, commonly known as a "shuttle buggy," would be included in the paving train.

The baffles in the pant chute solved the segregation problem in the transfer trucks. A shuttle buggy was used to transfer mix from transport trucks directly into the hopper of the paver. This piece of equipment further reduced segregation problems, provided additional mixing, and made it possible to pave an entire section without stopping the paver. The process control asphalt content and gradation after ignition testing was continued, but was a second priority to asphalt content and gradation testing of the cores.

Technicians from Harding Lawson and Associates (HLA) performed the quality assurance testing outlined in table 2. As part of that effort, HLA performed new ignition oven calibrations using the known method of calibration. In addition to using a range of asphalt contents, HLA also used a range of hydrated

lime, rather than a constant 1.5 percent. The two ignition ovens used by HLA were not the same ovens used during construction, although they were the same brand. HLA also performed the five ignition asphalt content determinations per section and lift as outlined in the quality assurance test plan.

DATA ANALYSIS

While the quality assurance testing was being conducted, samples of baghouse material were sent to Chemical Lime Company (CLC) in Henderson, Nevada, for chemical analysis. CLC reported that the baghouse material did include a small percentage of lime, which suggested that some lime was lost to the baghouse during construction.[10]

A summary of asphalt content and gyratory volumetrics was compiled from the quality assurance data. The asphalt contents reported and used in the gyratory volumetrics summary calculations were those generated by HLA using the ignition method with the known method of calibration at a specific lime level. Based on the CLC analysis of baghouse material, the lime content in the mix placed at the track was estimated to be approximately 1.35 percent. Thus, the known correction factors applied in the ignition asphalt content calculations by HLA were interpolated between correction factors from data generated with 1.0 and 1.5 percent lime in the known calibration samples.

Review of the volumetric data summary suggested that there may have been a problem with asphalt content data, particularly for the coarse mix. This prompted a thorough review of the HLA ignition calibrations. Close review of the data revealed that from 15 to 40 grams of material were lost in the preparation of each of the known asphalt content samples used for the calibrations. This rendered the data useless because it was not known whether the losses were aggregate, binder, or more likely, a combination of both and there was no method of determining the actual aggregate loss in the ignition process. Considering that a known asphalt calibration sample typically weighs approximately 2,100 grams (100 grams of asphalt binder and 2,000 grams of aggregate), the loss of 40 grams represents a loss of 1.9 percent of the total, of which the percentages of aggregate and asphalt cement are unknown. When attempting to determine asphalt contents to 0.1 percent, this loss was unacceptable. The data were discarded and it was decided that a completely new asphalt content testing and analysis program would be initiated at the University of Nevada, Reno (UNR).

In the meantime, the replacement sections were constructed. HLA performed both blank aggregate and known methods of calibration using two ignition ovens. The blank aggregate samples were treated with 1.5 percent hydrated lime prior to testing. The ovens were the same two ovens used in the original construction quality assurance testing. The correction factors obtained for each oven were so similar that they were simply averaged for use. Review of the loose mix replacement ignition asphalt content data, in between trial and test lane paving determined using both the blank aggregate and known correction factors, showed a constant difference between the two of approximately 0.5 percent. The data based on the known asphalt method of correction were consistently higher, by that amount, than the data that employed the blank aggregate method of correction. It was obvious from mixture volumetrics and simple visual inspection that the known correction data could not be correct. Details regarding the replacement mixtures' asphalt contents and calibrations may be found in WesTrack Technical Report UNR 17.[11] This limited information is presented here simply to show a pattern of high asphalt contents when the known method of calibration was used with andesites in Nevada.

The new asphalt content testing and analysis program was initiated at UNR after the replacement quality assurance testing was completed because the reflux extraction equipment and one of the ignition ovens used by HLA during the replacement construction had been borrowed from UNR. Due to all of the issues experienced with the ignition method, it was decided that the reflux extraction method would play the role of referee. Two UNR graduate students performed the testing. Their data were analyzed in an effort to obtain reliable estimates of asphalt content for concurrent performance modeling efforts underway at UNR at the same time.[12]

Portions of the overall work plan used for analysis are summarized in tables 3 and 4. Table 3 represents calibration information, while table 4 represents asphalt content determination data. Additional data used in the analysis included the original construction core ignition asphalt content data reported by FHWA. None of the previously discussed data known to be erroneous was employed.

The UNR portion of the effort consisted of performing blank aggregate and known asphalt content calibrations for each of the mixtures placed at WesTrack, as outlined in table 3. Three replicate specimens were tested under each condition.

The reason for performing the calibrations with the reflux extraction method was simply to ensure that the technician was performing the test proper. There should be no bias in the method. The calibration work conducted indicated no problems were encountered. The blank aggregate calibrations, which were performed on aggregate treated with 1.5 percent hydrated lime, resulted in indicated asphalt contents ranging from 0.01 to 0.04 percent. Based on a 2,000 gram sample size, between 0.2 and of 0.8 grams of material were lost in the process. Theoretically, the loss should have been zero, but the difference is well within reason. This indicated quality data and no bias when considering that the within-lab precision of the test is greater than 0.10.

The known asphalt calibration provided excellent data also. A range of five known asphalt contents were evaluated, using aggregates treated with 1.5 percent hydrated lime. At each asphalt content, with the exception of the lowest, the measured asphalt content was the same as the known. At the lowest asphalt content, the measured was 0.10 percent less than the known. Again this indicates quality data and no bias in the method when one considers the within-lab precision of the test is greater than 0.10.

The same program was followed for the ignition calibrations with the exception that calibration factors for the blank aggregate were established with and without lime. Just as had been done in the calibration efforts prior to the replacement construction, half of the aggregate samples used for the blank aggregate calibrations were treated with 1.5 percent lime. The other half were not treated with lime. The known asphalt content samples were treated with lime. The blank aggregate ignition correction factors (C_f) obtained by UNR for the samples not treated with lime were:

Fine mix:	$C_f = 0.82$
Fine plus mix:	$C_f = 0.60$
Coarse mix:	$C_f = 0.53$

The blank aggregate ignition correction factors obtained by UNR for the samples treated with lime were:

Fine mix:	$C_f = 0.89$
Fine plus mix:	$C_f = 0.68$

Coarse mix: $C_f = 0.61$

The known asphalt calibrations with lime performed by UNR resulted in the following ignition correction factors:

Fine mix: $C_f = 0.45$
Fine plus mix: $C_f = 0.34$
Coarse mix: $C_f = 0.38$

Tables 5 and 6 represent original construction ignition asphalt content data reported by the FHWA for the top and bottom lifts, respectively. Note that a blank aggregate correction was employed in the calculation of the data. Both the process control (single test on loose mix) and the five determinations per section and lift on field cores are presented. Review of the raw data sheets and calculations revealed that the correction factor had been used improperly in the calculations. All of the reported values are actually 0.1 to 0.2 percent lower then they would have been if the calculations had been performed correctly. The blank aggregate correction factors developed by the FHWA using aggregates that were not treated with lime and used in the calculation of asphalt contents in the tables were as follows:

Fine mix: $C_f = 0.49$
Fine plus mix: $C_f = 0.40$
Coarse mix: $C_f = 0.46$

Based on a comparison of all the calibration factors for each mix type and condition, the following observations were made:

- All of the UNR blank aggregate correction factors without lime were slightly higher than those obtained by FHWA, particularly for the fine mix.
- All of the UNR blank aggregate correction factors with lime were slightly greater than those without lime.
- Under all conditions, the fine mix correction factor was greater than the fine plus mix factors as established by UNR.

Based on the data, a decision was made to provide asphalt content comparisons for each mix showing the effects of the different correction factors, but to use UNR blank aggregate with lime correction factors for ignition asphalt content comparisons beyond that point. The reasons for the use of the UNR correction factor were: low variability; UNR incorporated lime which the original FHWA factors did not; the original FHWA correction factors were very close to the UNR and HLA known correction factors, which were clearly not correct; and the quality of the data being generated in the UNR lab was excellent when compared to within-lab precision statements.

The original construction loose mix asphalt contents measured using the reflux extraction method by UNR are presented in table 7. Note that materials from both lifts of only 9 of the 26 original test sections were tested. The sections were selected such that low, medium, and high asphalt content sections for each mix type were represented. Also, note the consistency of the data. Standard deviations of less than 0.2 are very good. Recall that the material was loose mix sampled from transport trucks and that ten split samples were taken from a bulk sample with five each used for reflux and ignition determinations. The original construction ignition asphalt contents determined for each mix using the UNR blank aggregate

correction factor with lime, the blank aggregate correction factor without lime, and the known correction factor are presented in tables 8, 9, and 10, respectively. Note that the variability associated with the ignition testing is greater than observed for the reflux extraction testing on split samples.

For these same nine sections (for which the loose mix had been tested by UNR, using both the ignition and reflux extraction methods) the uncorrected ignition asphalt contents of the five cores tested per section by FHWA during the original construction were established. The data are presented in table 11 and figure 1. Uncorrected asphalt content is simply the oven-indicated asphalt content prior to applying a correction factor. Note that this addressed the incorrect calculations performed during construction. Using the raw core data along with the UNR- established correction factors, asphalt contents were recalculated. The data are presented in tables 12 through 14. The effect of the different correction factors on both the loose mix and the cores is summarized in table 15.

The fact that the reflux extraction calibrations showed no bias and extremely low variability, along with the fact that the variability associated with the loose mix testing of split samples was lower for the reflux extraction than the ignition method, suggested the use of the reflux method. A problem existed, however, in that the reflux method had only been used for materials from both lifts of nine sections. There were only two possible methods of using the reflux extraction data:

- Complement the data with actual test results from both lifts of the other 17 sections.
- Develop a relationship between the available reflux extraction data and the original construction core data.

The first option would require 170 tests, each of which would take more than one full day to perform. Project time and budgetary constraints made this option unattractive. The second option could be performed rapidly once a correction factor was selected for use with the original construction core data. The second option was selected.

The UNR-developed blank aggregate correction factor with lime was selected. It was selected because the known method had demonstrated a tendency to provide unreasonably high asphalt contents (see figure 1) and the blank without lime was not indicative of the materials actually used on the project. Additionally, the variability associated with the testing being conducted in the UNR lab was low. Note that all of the mix placed at WesTrack incorporated 1.5 percent hydrated lime.

Four simple linear regressions were performed to develop relationships between the available reflux extraction data and the original construction core ignition data using the UNR blank with lime correction factors. A scatter plot of the data is presented in figure 2. Individual relationships were developed with the available data for each mix type and a fourth relationship was developed using all data pooled together. The relationships are presented in figures 3 through 6. The developed equations, along with the degree of their fits as indicated by R^2, are presented in each figure. The fine and fine plus mix fits were very good at 0.92 and 0.94, respectively. At 0.78, the coarse mix fit was not as good. The pooled data fit was 0.85. It was decided that the individual mix models would be used to estimate the asphalt contents for each lift of each section for the simple reason that the best fits were obtained for individual mix data sets. The uncorrected core asphalt contents were determined for all 17 sections, after which they were recalculated using the UNR blank aggregate correction factor with lime. These data were then entered into the developed regression equations to obtain the original construction asphalt contents. The data are

presented for each mix type in tables 16 through 18. The data presented in tables 16 through 18 are the "official" WesTrack original construction asphalt contents.

SUMMARY

Original construction HMA quality assurance asphalt content data are summarized, providing an "official" set of original construction asphalt content data. Results of the testing conducted by FHWA during construction, HLA during postconstruction, and finally UNR during postconstruction were all presented. The testing plans employed and analysis of the data generated through the testing were detailed. A significant effort was made to develop an understanding of appropriate correction factors for use with the ignition asphalt content test method. Solvent extraction (reflux method) testing was performed in addition to ignition testing. The extraction testing was used to check the results of the ignition testing and, therefore, to assist in developing the required understanding. A lack of bias and very low variability associated with the reflux test results led to the development of relationships between reflux test results and ignition test results. The relationships were developed based on data from both lifts of each mix type (fine, fine plus, and coarse) at each of three asphalt content levels (low, medium, and high). The blank aggregate treated with lime correction factor was determined to be the most appropriate for the materials tested using the ignition test method. This was the case when the blank aggregates were treated with hydrated lime.

The data were reported in the final project report and were used for quality assurance mixture volumetric calculations. The data reported in tables 16 through 18 also were used for all performance modeling and specification development purposes.

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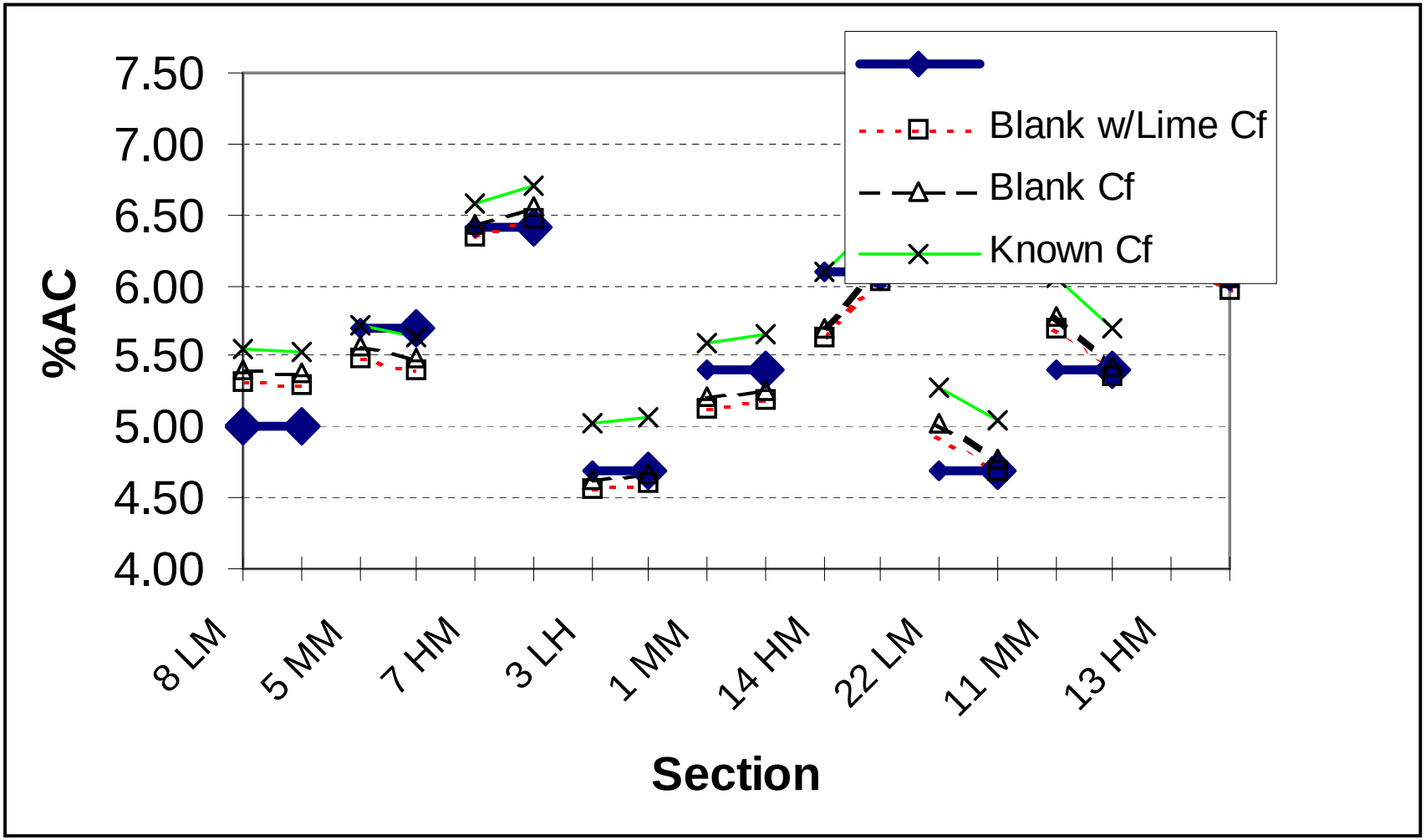

Figure 1. Original construction comparison of correction factor effects on core asphalt contents.

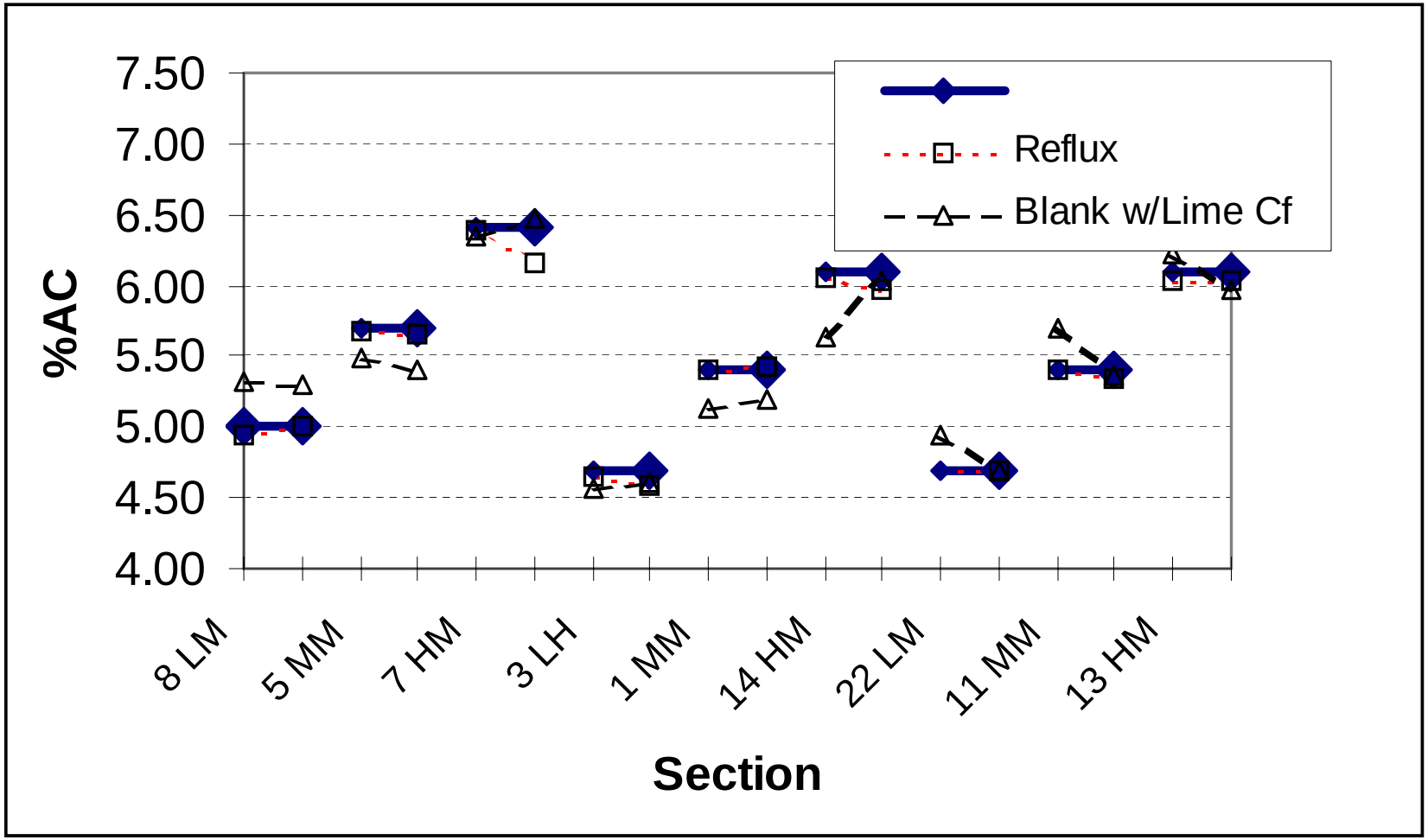

Figure 2. Original construction comparison of reflux and core ignition (using blank with lime C_f) asphalt contents (UNR).

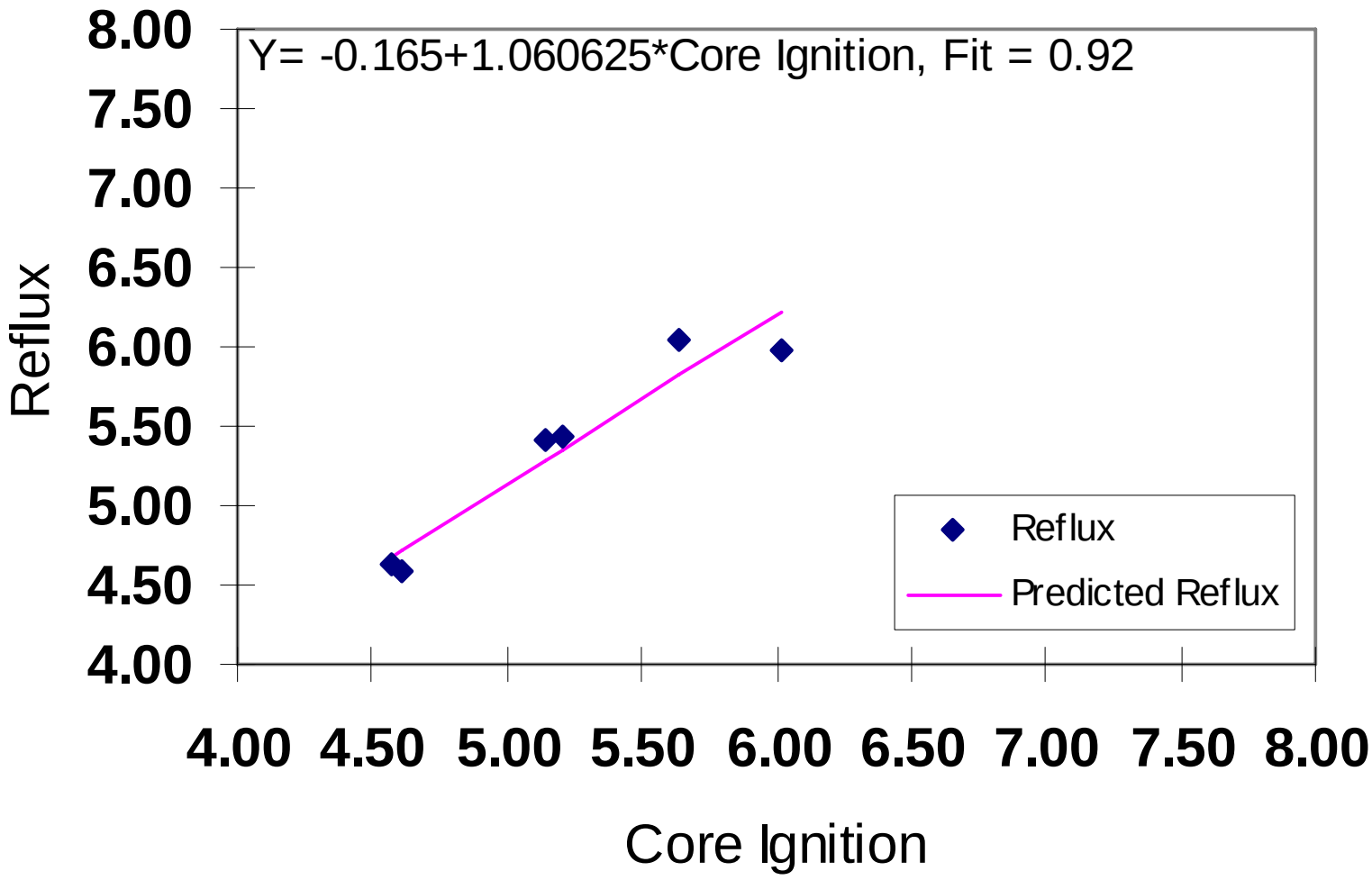

Figure 3. Original construction loose mix reflux and core ignition asphalt content correlation (fine mixes).

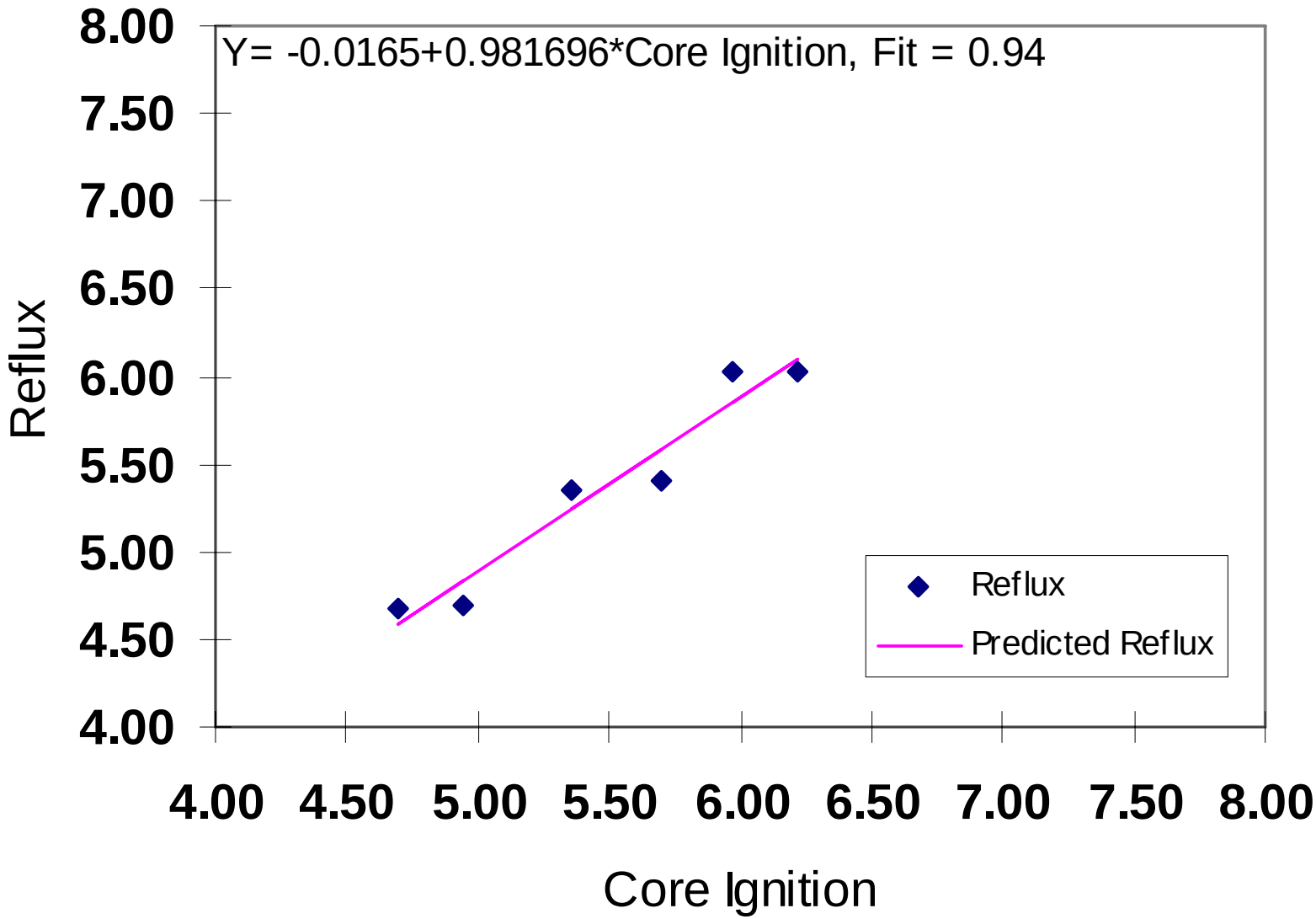

Figure 4. Original construction loose mix reflux and core ignition asphalt content correlation (fine plus mixes).

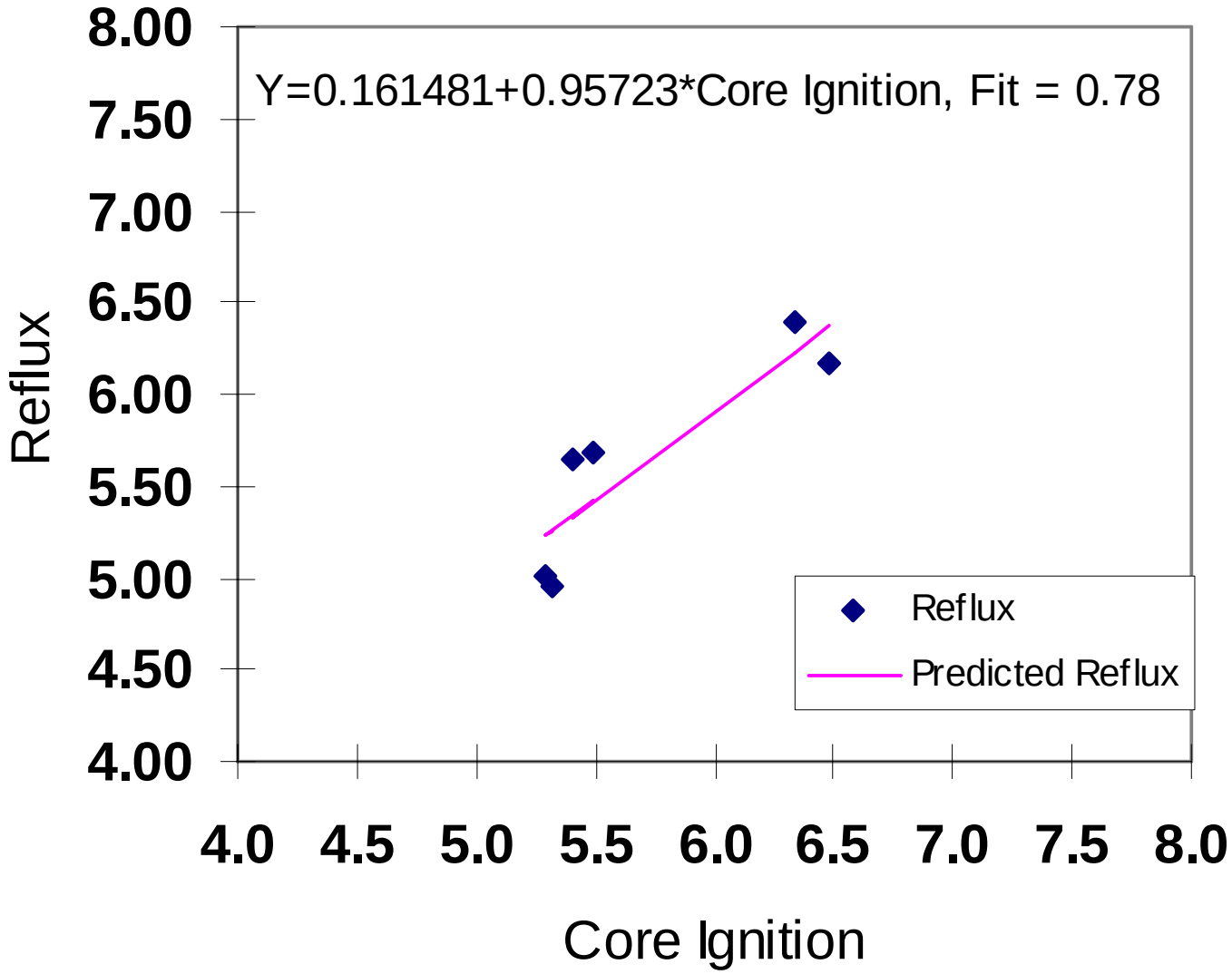

Figure 5. Original construction loose mix reflux and core ignition asphalt content correlation (coarse mixes).

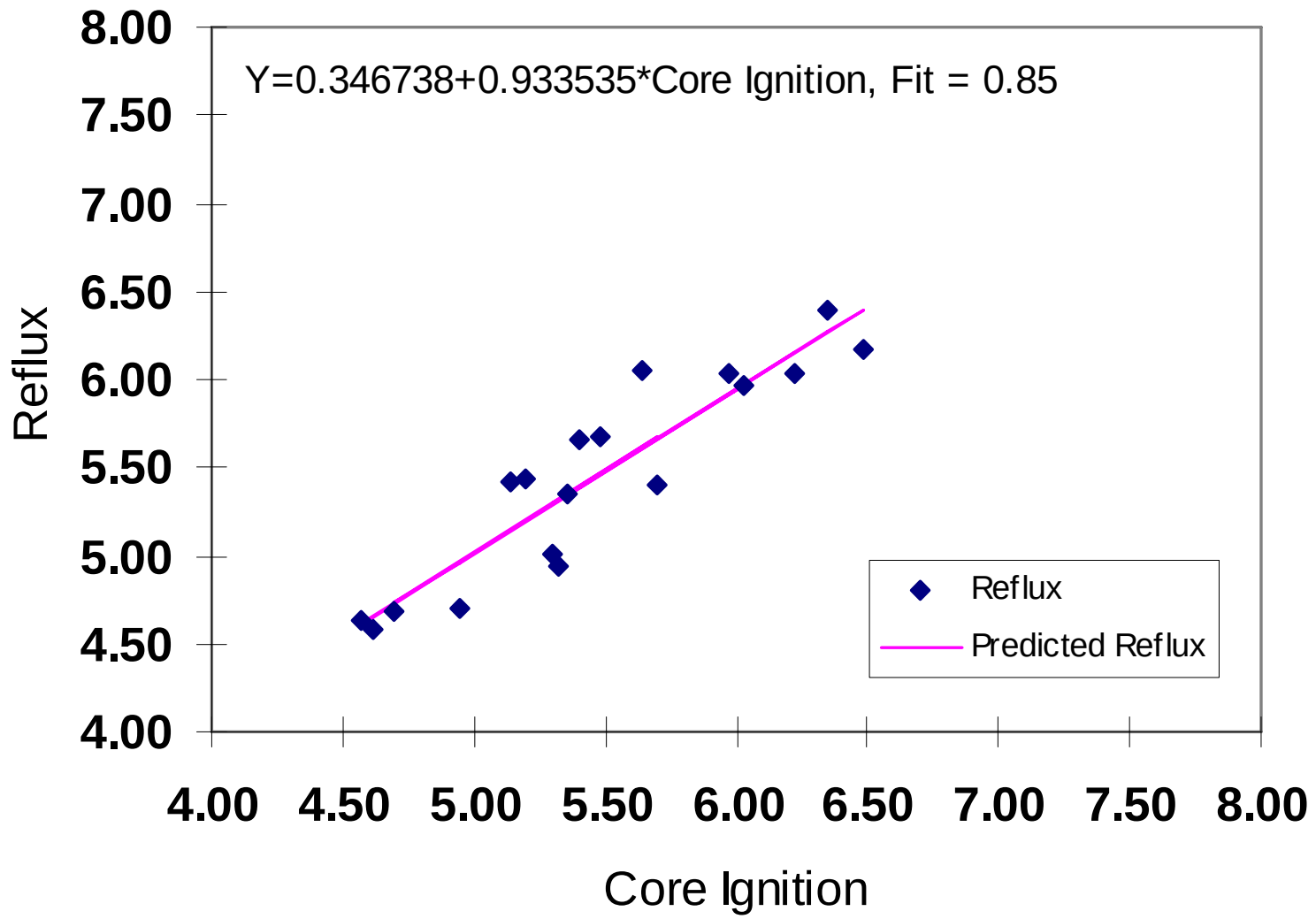

Figure 6. Original construction loose mix reflux and core ignition asphalt content correlation (all mixes).

Table 1. Daily quality control testing at the hot plant.

General Property	Test Method	Tests/Sublots	Sublots/Lot
Asphalt Content	Nuclear	1	3
	Extraction	0	0
	Ignition	1	1
Gradation	Cold feed	1	5
	Extraction	0	0
	Ignition	1	1
Superpave Gyratory Compaction	Bulk SP GR	1	2
	Volumetrics	1	2
	M_R	0	0
Marshall Compaction*	Bulk SP GR	3	1
	Volumetrics	3	1
	Stability & Flow	3	1
Hveem Compaction	Bulk SP GR	0	0
	Volumetrics	0	0
	Stability	0	0
Theo. Max. SP GR		2	1
HMA Temperature		1	5

*MM sections only.

Table 2. Quality assurance test plan.

General Property	Test Method	Tests/ Sublot	Sublots/ Lot	Number of Lots or Sections to be Tested	Number of Lifts
Asphalt Content	Nuclear	1	5	26	2
	Extraction	1	1	26	2
	Ignition	1	5	26	2
Gradation	Cold feed	1	5	26	2
	Extraction	1	1	26	2
	Ignition	1	5	26	2
Superpave Gyratory Compaction (N_{max})	Bulk SP GR	2	5	26	2
	Volumetrics	2	5	26	2
Superpave Gyratory Compaction (N_{design})	Bulk SP GR	1	5	26	2
	Volumetrics	1	5	26	2
	M_R	1	5	26	2
Marshall Compaction	Bulk SP GR	3	1	26	2
	Volumetrics	3	1	26	2
	Stability & Flow	3	1	26	2
Hveem Compaction	Bulk SP GR	3	1	26	2
	Volumetrics	3	1	26	2
	Stability	3	1	26	2
Theo. Max. SP GR		1	5	26	2
Plant HMA Temperature		1	5	26	2
Laydown HMA Temperature		1	5	26	2
In-Place Air Voids	Nuclear	2	5	26	2
	Cores	1	5	26	2

Table 3. Portion of UNR asphalt content calibration effort.

Construction	Material	Mix Type	Method			
			Reflux		Ignition	
			Blank Aggregate	Known %AC	Blank Aggregate	Known %AC
Original	Coldfeed	Fine	3*	3	3	3
		Fine Plus	3	3	3	3
		Coarse	3	3	3	3
Replacement	Coldfeed	Replacement	3	3	3	3

*Indicates number of replicates tested under each condition.

Table 4. Portion of UNR asphalt content determination effort.

Construction	Material	Mix Type	Sections	Method			
				Reflux		Ignition	
				Blank	Known	Blank	Known
Original	Bulk loose mix sampled from trucks and split between methods.	Fine	3 (LH)	n/a	5*	5	5
			1 (MM)	n/a	5	5	5
			14 (HM)	n/a	5	5	5
		Fine Plus	22 (LM)	n/a	5	5	5
			11 (MM)	n/a	5	5	5
			13 (HM)	n/a	5	5	5
		Coarse	8 (LM)	n/a	5	5	5
			5 (MM)	n/a	5	5	5
			7 (HM)	n/a	5	5	5
Replacement	Loose mix behind the paver.	Replace-ment	Raw HLA data employed.				

*Indicates number of replicates tested under each condition.

Table 5. Original construction top lift asphalt contents by ignition by FHWA.

Mix	Section	Target		**Ign Plant AC**			**Core Asphalt Content - Ignition**								
Type	No	AC	AV	1	ΔX	Δs	1	2	3	4	5	X	s	ΔX	Δs
Fine	1	5.4	8	5.10	-0.30		5.23	5.73	5.53	5.51	5.73	5.55	0.21	0.15	
	2	4.7	8	4.50	-0.20		4.97	4.93	4.83	4.91	4.94	4.92	0.05	0.22	
	3	4.7	12	4.57	-0.13		4.83	5.03	4.86	4.97	5.18	4.97	0.14	0.27	
	4	5.4	4	4.83	-0.57		5.14	5.16	5.53	4.97	4.79	5.12	0.27	-0.28	
	14	6.1	8	5.90	-0.20		4.89	5.93	6.20	6.06	5.99	5.81	0.53	-0.29	6.05
	15	5.4	8	5.27	-0.13		5.43	5.70	5.23	5.24	5.48	5.42	0.19	0.02	
	16	4.7	12	4.28	-0.42		4.69	4.90	4.66	4.84	4.64	4.75	0.12	0.05	
	17	5.4	12	5.47	0.07		5.67	5.79	5.87	5.87	5.51	5.74	0.15	0.34	
	18	6.1	4	5.98	-0.12		6.03	6.01	6.18	6.00	5.99	6.04	0.08	-0.06	
					-0.22	**0.19**							**0.19**	**0.05**	**0.23**
Fine	19	5.4	8	5.93	0.53		6.04	5.99	5.84	5.61	5.99	5.89	0.18	0.49	
Plus	20	5.4	12	6.08	0.68		6.07	5.87	5.78	5.88	5.79	5.88	0.12	0.48	
	21	6.1	4	6.82	0.72		6.83	6.91	6.58	6.74	6.70	6.75	0.13	0.65	
	22	4.7	8	5.12	0.42		5.20	5.34	5.33	5.17	5.11	5.23	0.10	0.53	
	9	6.1	4	6.72	0.62		6.35	6.27	6.45	6.83	6.92	6.56	0.29	0.46	
	10	4.7	12	5.29	0.59		5.49	4.99	5.22	5.35	5.33	5.28	0.19	0.58	
	11	5.4	8	5.94	0.54		6.04	5.92	6.01	6.17	5.79	5.99	0.14	0.59	
	12	5.4	4	6.04	0.64		5.99	5.66	5.70	6.02	5.81	5.84	0.16	0.44	
	13	6.1	8	6.60	0.50		6.20	6.56	6.38	6.65	6.74	6.51	0.22	0.41	
					0.58	**0.09**							**0.17**	**0.51**	**0.08**
Coarse	5	5.7	8	4.89	-0.81		5.40	5.70	5.95	5.51	5.60	5.63	0.21	-0.07	
	6	5.7	12	5.55	-0.15		5.72	5.6	5.93	5.58	5.74	5.71	0.14	0.01	
	7	6.4	8	6.58	0.18		6.13	6.57	6.52	6.59	6.63	6.49	0.20	0.09	
	8	5.0	8	4.89	-0.11		5.38	5.48	5.25	5.65	5.58	5.47	0.16	0.47	
	23	5.7	4	5.81	0.11		5.97	5.67	5.98	5.52	5.81	5.79	0.20	0.09	
	24	5.7	8	6.31	0.61		5.82	6.14	5.76	6.08	5.90	5.94	0.16	0.24	
	25	6.4	4	6.06	-0.34		6.40	6.62	6.59	6.56	6.57	6.55	0.09	0.15	
	26	5.0	12	4.98	-0.02		4.94	5.66	5.23	5.10	5.60	5.31	0.31	0.31	
					-0.07	**0.41**							**0.18**	**0.16**	**0.17**

Table 6. Original construction bottom lift asphalt contents by ignition by FHWA.

Mix	Section	Target		**Ign Plant AC**			**Core Asphalt Content - Ignition**								
Type	No	AC	AV	1	ΔX	Δs	1	2	3	4	5	X	s	ΔX	Δs
Fine	1	5.4	8	5.71	0.31		5.55	5.84	5.92	5.11	4.79	5.44	0.48	0.04	5.61
	2	4.7	8	5.07	0.37		5.34	4.33	4.96	4.82	4.55	4.80	0.39	0.10	4.67
	3	4.7	12	3.94	-0.76		5.06	4.78	5.15	4.78	5.31	5.02	0.23	0.32	
	4	5.4	4	5.10	-0.30		5.46	5.42	5.55	5.49	5.48	5.48	0.05	0.08	
	14	6.1	8	6.18	0.08		6.42	6.53	6.52	5.68	6.24	6.28	0.35	0.18	6.43
	15	5.4	8	5.17	-0.23		5.74	5.46	5.35	5.41	5.16	5.42	0.21	0.02	
	16	4.7	12	4.98	0.28		4.26	5.01	4.86	4.64	4.70	4.69	0.28	-0.01	
	17	5.4	12	5.35	-0.05		5.65	5.35	5.06	5.41	5.30	5.35	0.21	-0.05	
	18	6.1	4	5.48	-0.62		6.21	6.07	5.81	6.06	6.26	6.08	0.18	-0.02	
					-0.10	##							**0.27**	**0.07**	**0.11**
Fine	19	5.4	8	5.85	0.45		6.15	5.83	6.02	6.01	5.83	5.97	0.14	0.57	
Plus	20	5.4	12	5.96	0.56		6.17	5.44	5.66	5.23	5.53	5.61	0.35	0.21	
	21	6.1	4	5.92	-0.18		5.94	6.31	6.54	6.54	6.32	6.33	0.25	0.23	
	22	4.7	8	5.15	0.45		5.21	5.08	4.97	4.95	4.70	4.98	0.19	0.28	
	9	6.1	4	6.44	0.34		6.03	6.42	6.31	6.32	6.36	6.29	0.15	0.19	
	10	4.7	12	4.66	-0.04		4.98	4.82	4.67	4.72	4.03	4.64	0.36	-0.06	
	11	5.4	8	5.78	0.38		5.97	5.53	5.69	5.08	5.91	5.64	0.36	0.24	
	12	5.4	4	5.37	-0.03		6.26	5.61	5.82	5.69	5.39	5.75	0.32	0.35	
	13	6.1	8	6.37	0.27		6.27	5.94	6.28	6.09	6.69	6.25	0.28	0.15	
					0.24	##							**0.27**	**0.24**	**0.17**
Coarse	5	5.7	8	5.26	-0.44		5.39	5.53	5.60	4.78	5.66	5.39	0.36	-0.31	
	6	5.7	12	5.05	-0.65		5.93	5.60	5.80	6.16	6.18	5.93	0.25	0.23	
	7	6.4	8	6.44	0.04		6.64	6.85	6.61	6.56	6.47	6.63	0.14	0.23	
	8	5	8	5.32	0.32		5.46	5.60	5.22	5.53	5.40	5.44	0.14	0.44	
	23	5.7	4	5.05	-0.65		5.72	5.88	6.07	5.85	5.86	5.88	0.13	0.18	
	24	5.7	8	5.11	-0.59		5.76	5.55	5.98	5.69	5.87	5.77	0.17	0.07	
	25	6.4	4	6.09	-0.31		6.43	6.26	6.33	6.57	6.51	6.42	0.13	0.02	
	26	5	12	5.34	0.34		5.30	5.35	5.50	4.72	5.24	5.22	0.30	0.22	
					-0.24	##							**0.20**	**0.14**	**0.22**

Table 7. Original construction loose mix asphalt contents by reflux.

Section	Mix Type	Lift	Target	Measured					Average	Standard Deviation	COV	Max	Min	Range
				1	2	3	4	5						
5 MM	Coarse	Top	5.7	5.73	5.59	5.56	5.69	5.82	5.68	0.11	1.87	5.82	5.56	0.26
		Bottom	5.7	5.66	5.64	5.54	5.69	5.73	5.65	0.07	1.26	5.73	5.54	0.19
7 HM		Top	6.4	6.52	6.29	6.38	6.41	6.34	6.39	0.08	1.33	6.52	6.29	0.23
		Bottom	6.4	6.28	6.29	5.91	6.42	5.93	6.17	0.23	3.76	6.42	5.91	0.51
8 LM		Top	5.0	5.11	4.79	5.15	4.89	4.79	4.95	0.17	3.50	5.15	4.79	0.36
		Bottom	5.0	5.05	4.84	5.02	5.21	4.89	5.00	0.15	2.91	5.21	4.84	0.37
1 MM	Fine	Top	5.4	5.57	5.34	5.54	5.26	5.34	5.41	0.14	2.55	5.57	5.26	0.31
		Bottom	5.4	5.53	5.49	5.39	5.42	5.32	5.43	0.08	1.52	5.53	5.32	0.21
3 LH		Top	4.7	4.38	4.37	5.01	4.68	4.76	4.64	0.27	5.88	5.01	4.37	0.65
		Bottom	4.7	4.42	4.45	4.85	4.53	4.67	4.58	0.18	3.87	4.85	4.42	0.43
14 HM		Top	6.1	6.17	5.92	6.01	6.05	6.12	6.05	0.10	1.60	6.17	5.92	0.25
		Bottom	6.1	5.98	5.96	6.08	5.95	5.89	5.97	0.07	1.16	6.08	5.89	0.19
11 MM	Fine Plus	Top	5.4	5.67	5.08	5.45	5.43	5.35	5.40	0.21	3.95	5.67	5.08	0.59
		Bottom	5.4	5.35	5.38	5.49	5.31	5.22	5.35	0.10	1.85	5.49	5.22	0.27
13 HM		Top	6.1	5.98	5.93	6.12	6.03	6.09	6.03	0.08	1.29	6.12	5.93	0.19
		Bottom	6.1	6.01	6.05	6.12	5.99	6.00	6.03	0.05	0.88	6.12	5.99	0.13
22 LM		Top	4.7	4.80	4.62	4.80	4.65	4.60	4.69	0.10	2.09	4.80	4.60	0.20
		Bottom	4.7	4.75	4.92	4.60	4.55	4.60	4.68	0.15	3.25	4.92	4.55	0.37

Table 8. Original construction loose mix asphalt contents by ignition (blank with lime C_f).

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
5 MM	Coarse	Top	5.7	0.00605	5.47	4.92	5.26	5.27	5.25	5.23	0.20	3.80	5.47	4.92	0.55
		Bottom	5.7	0.00605	5.16	5.01	5.48	5.17	5.25	5.21	0.17	3.32	5.48	5.01	0.47
7 HM		Top	6.4	0.00605	6.76	6.80	6.79	6.90	6.64	6.77	0.09	1.40	6.90	6.64	0.26
		Bottom	6.4	0.00605	5.23	5.52	5.92	5.22	6.04	5.58	0.38	6.83	6.04	5.22	0.82
8 LM		Top	5.0	0.00605	4.87	4.77	5.03	4.80	4.98	4.89	0.11	2.31	5.03	4.77	0.26
		Bottom	5.0	0.00605	4.67	5.32	5.16	4.78	4.98	4.98	0.27	5.37	5.32	4.67	0.65
1 MM	Fine	Top	5.4	0.00894	4.71	4.95	4.89	5.16	5.12	4.97	0.18	3.64	5.16	4.71	0.45
		Bottom	5.4	0.00894	5.34	5.03	5.20	5.31	5.22	5.22	0.12	2.30	5.34	5.03	0.31
3 LH		Top	4.7	0.00894	4.57	4.51	4.32	4.32	4.37	4.42	0.12	2.67	4.57	4.32	0.26
		Bottom	4.7	0.00894	4.86	4.71	5.06	4.51	5.22	4.87	0.28	5.77	5.22	4.51	0.71
14 HM		Top	6.1	0.00894	5.62	5.76	5.89	5.69	5.82	5.75	0.11	1.87	5.89	5.62	0.27
		Bottom	6.1	0.00894	5.90	5.90	5.92	5.49	5.67	5.77	0.19	3.28	5.92	5.49	0.43
11 MM	Fine Plus	Top	5.4	0.00684	4.92	5.49	5.62	5.19	5.17	5.28	0.28	5.31	5.62	4.92	0.70
		Bottom	5.4	0.00684	5.66	5.51	5.42	5.33	5.51	5.49	0.12	2.21	5.66	5.33	0.33
13 HM		Top	6.1	0.00684	6.14	6.19	5.98	6.30	6.20	6.16	0.12	1.91	6.30	5.98	0.32
		Bottom	6.1	0.00684	6.11	5.61	5.68	5.44	5.56	5.68	0.26	4.53	6.11	5.44	0.68
22 LM		Top	4.7	0.00684	4.60	4.78	4.87	4.44	4.53	4.65	0.18	3.87	4.87	4.44	0.43
		Bottom	4.7	0.00684	4.49	4.36	4.55	4.78	4.63	4.56	0.16	3.41	4.78	4.36	0.42

Table 9. Original construction loose mix asphalt contents by ignition (blank C_f).

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
5 MM	Coarse	Top	5.7	0.00526	5.55	5.00	5.34	5.35	5.33	5.31	0.20	3.74	5.55	5.00	0.55
		Bottom	5.7	0.00526	5.24	5.09	5.56	5.25	5.33	5.29	0.17	3.27	5.56	5.09	0.47
7 HM		Top	6.4	0.00526	6.83	6.88	6.86	6.98	6.71	6.85	0.09	1.38	6.98	6.71	0.26
		Bottom	6.4	0.00526	5.31	5.60	6.00	5.30	6.12	5.66	0.38	6.74	6.12	5.30	0.82
8 LM		Top	5.0	0.00526	4.95	4.85	5.11	4.88	5.06	4.97	0.11	2.27	5.11	4.85	0.26
		Bottom	5.0	0.00526	4.74	5.40	5.24	4.85	5.06	5.06	0.27	5.28	5.40	4.74	0.65
1 MM	Fine	Top	5.4	0.00827	4.78	5.02	4.95	5.23	5.18	5.03	0.18	3.59	5.23	4.78	0.45
		Bottom	5.4	0.00827	5.40	5.10	5.27	5.38	5.29	5.29	0.12	2.27	5.40	5.10	0.31
3 LH		Top	4.7	0.00827	4.64	4.58	4.38	4.44	4.82	4.57	0.17	3.76	4.82	4.38	0.43
		Bottom	4.7	0.00827	4.93	4.78	5.13	4.57	5.29	4.94	0.28	5.69	5.29	4.57	0.71
14 HM		Top	6.1	0.00827	5.69	5.82	5.96	5.75	5.88	5.82	0.11	1.85	5.96	5.69	0.27
		Bottom	6.1	0.00827	5.96	5.96	5.99	5.55	5.74	5.84	0.19	3.25	5.99	5.55	0.43
11 MM	Fine Plus	Top	5.4	0.00603	5.00	5.57	5.70	5.27	5.25	5.36	0.28	5.23	5.70	5.00	0.70
		Bottom	5.4	0.00603	5.74	5.59	5.50	5.41	5.59	5.57	0.12	2.18	5.74	5.41	0.33
13 HM		Top	6.1	0.00603	6.22	6.28	6.06	6.39	6.28	6.25	0.12	1.88	6.39	6.06	0.32
		Bottom	6.1	0.00603	6.20	5.69	5.76	5.52	5.64	5.76	0.26	4.47	6.20	5.52	0.68
22 LM		Top	4.7	0.00603	4.68	4.86	4.96	4.52	4.61	4.73	0.18	3.81	4.96	4.52	0.43
		Bottom	4.7	0.00603	4.58	4.44	4.63	4.86	4.71	4.64	0.16	3.35	4.86	4.44	0.42

Table 10. Original construction loose mix asphalt contents by ignition (known C_f).

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
5 MM	Coarse	Top	5.7	0.00380	5.70	5.14	5.49	5.50	5.47	5.46	0.20	3.64	5.70	5.14	0.55
		Bottom	5.7	0.00380	5.38	5.23	5.70	5.39	5.48	5.44	0.17	3.18	5.70	5.23	0.47
7 HM		Top	6.4	0.00380	6.98	7.02	7.01	7.12	6.86	7.00	0.09	1.35	7.12	6.86	0.26
		Bottom	6.4	0.00380	5.45	5.75	6.14	5.44	6.26	5.81	0.38	6.57	6.26	5.44	0.82
8 LM		Top	5.0	0.00380	5.10	5.00	5.26	5.03	5.21	5.12	0.11	2.20	5.26	5.00	0.26
		Bottom	5.0	0.00380	4.89	5.54	5.38	5.00	5.21	5.20	0.27	5.13	5.54	4.89	0.65
1 MM	Fine	Top	5.4	0.00445	5.16	5.40	5.34	5.61	5.57	5.41	0.18	3.34	5.61	5.16	0.45
		Bottom	5.4	0.00445	5.78	5.48	5.65	5.76	5.67	5.67	0.12	2.12	5.78	5.48	0.31
3 LH		Top	4.7	0.00445	5.02	4.96	4.77	4.82	5.20	4.95	0.17	3.47	5.20	4.77	0.43
		Bottom	4.7	0.00445	5.31	5.16	5.51	4.96	5.67	5.32	0.28	5.28	5.67	4.96	0.71
14 HM		Top	6.1	0.00445	6.07	6.20	6.34	6.13	6.26	6.20	0.11	1.73	6.34	6.07	0.27
		Bottom	6.1	0.00445	6.35	6.35	6.37	5.94	6.12	6.22	0.19	3.05	6.37	5.94	0.43
11 MM	Fine Plus	Top	5.4	0.00342	5.26	5.83	5.97	5.53	5.51	5.62	0.28	4.99	5.97	5.26	0.70
		Bottom	5.4	0.00342	6.00	5.85	5.76	5.67	5.85	5.83	0.12	2.08	6.00	5.67	0.33
13 HM		Top	6.1	0.00342	6.48	6.54	6.32	6.65	6.54	6.51	0.12	1.81	6.65	6.32	0.32
		Bottom	6.1	0.00342	6.46	5.95	6.02	5.78	5.90	6.02	0.26	4.28	6.46	5.78	0.68
22 LM		Top	4.7	0.00342	4.95	5.13	5.22	4.78	4.87	4.99	0.18	3.61	5.22	4.78	0.43
		Bottom	4.7	0.00342	4.84	4.70	4.89	5.12	4.97	4.90	0.16	3.17	5.12	4.70	0.42

Table 11. Original construction uncorrected core asphalt contents by ignition (with C_f removed) by FHWA.

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
5 MM	Coarse	Top	5.7		5.86	6.16	6.41	5.97	6.06	6.09	0.21	3.44	6.41	5.86	0.55
		Bottom	5.7		5.85	5.99	6.06		6.12	6.01	0.12	1.93	6.12	5.85	0.27
7 HM		Top	6.4		6.59	7.03	6.98	7.05	7.09	6.95	0.20	2.94	7.09	6.59	0.50
		Bottom	6.4		7.10	7.31	7.07	7.02	6.93	7.09	0.14	1.99	7.31	6.93	0.38
8 LM		Top	5.0		5.84	5.94	5.71	6.11	6.04	5.93	0.16	2.68	6.11	5.71	0.40
		Bottom	5.0		5.92	6.06	5.68	5.99	5.86	5.90	0.14	2.46	6.06	5.68	0.38
1 MM	Fine	Top	5.4		5.72	6.22	6.02	6.00	6.22	6.04	0.21	3.41	6.22	5.72	0.50
		Bottom	5.4		6.04	6.33	6.41	5.60		6.10	0.37	6.01	6.41	5.60	0.81
3 LH		Top	4.7		5.32	5.52	5.35	5.46	5.67	5.46	0.14	2.58	5.67	5.32	0.35
		Bottom	4.7		5.55	5.27	5.64	5.27	5.80	5.51	0.23	4.24	5.80	5.27	0.53
14 HM		Top	6.1			6.42	6.69	6.55	6.48	6.54	0.12	1.78	6.69	6.42	0.27
		Bottom	6.1		6.91	7.02	7.01		6.73	6.92	0.13	1.94	7.02	6.73	0.29
11 MM	Fine Plus	Top	5.4		6.44	6.32	6.41	6.57	6.19	6.39	0.14	2.22	6.57	6.19	0.38
		Bottom	5.4		6.37	5.93	6.09	5.48	6.31	6.04	0.36	5.92	6.37	5.48	0.89
13 HM		Top	6.1		6.60	6.96	6.78	7.05	7.14	6.91	0.22	3.14	7.14	6.60	0.54
		Bottom	6.1		6.67	6.34	6.68	6.49	7.09	6.65	0.28	4.23	7.09	6.34	0.75
22 LM		Top	4.7		5.60	5.74	5.73	5.57	5.51	5.63	0.10	1.80	5.74	5.51	0.23
		Bottom	4.7		5.61	5.48	5.37	5.35	5.10	5.38	0.19	3.50	5.61	5.10	0.51

Table 12. Original construction core asphalt contents by ignition (UNR blank with lime C_f) by FHWA/UNR.

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
5 MM	Coarse	Top	5.7	0.00605	5.26	5.56	5.81	5.37	5.46	5.49	0.21	3.82	5.81	5.26	0.55
		Bottom	5.7	0.00605	5.25	5.39	5.46		5.52	5.40	0.12	2.15	5.52	5.25	0.27
7 HM		Top	6.4	0.00605	5.98	6.43	6.38	6.45	6.49	6.34	0.20	3.22	6.49	5.98	0.50
		Bottom	6.4	0.00605	6.50	6.71	6.46	6.42	6.33	6.48	0.14	2.17	6.71	6.33	0.38
8 LM		Top	5.0	0.00605	5.24	5.33	5.11	5.51	5.44	5.32	0.16	2.99	5.51	5.11	0.40
		Bottom	5.0	0.00605	5.32	5.46	5.08	5.39	5.26	5.30	0.14	2.74	5.46	5.08	0.38
1 MM	Fine	Top	5.4	0.00894	4.83	5.33	5.13	5.11	5.33	5.14	0.21	4.00	5.33	4.83	0.50
		Bottom	5.4	0.00894	5.15	5.44	5.52	4.71		5.20	0.37	7.04	5.52	4.71	0.81
3 LH		Top	4.7	0.00894	4.43	4.63	4.46	4.57	4.78	4.57	0.14	3.08	4.78	4.43	0.35
		Bottom	4.7	0.00894	4.66	4.38	4.75	4.38	4.91	4.61	0.23	5.06	4.91	4.38	0.53
14 HM		Top	6.1	0.00894		5.53	5.80	5.66	5.59	5.64	0.12	2.06	5.80	5.53	0.27
		Bottom	6.1	0.00894	6.02	6.13	6.12		5.84	6.02	0.13	2.23	6.13	5.84	0.29
11 MM	Fine Plus	Top	5.4	0.00684	5.76	5.64	5.73	5.89	5.51	5.70	0.14	2.48	5.89	5.51	0.38
		Bottom	5.4	0.00684	5.69	5.25	5.41	4.80	5.63	5.35	0.36	6.67	5.69	4.80	0.89
13 HM		Top	6.1	0.00684	5.92	6.28	6.10	6.37	6.46	6.22	0.22	3.48	6.46	5.92	0.54
		Bottom	6.1	0.00684	5.99	5.66	6.00	5.81	6.41	5.97	0.28	4.71	6.41	5.66	0.75
22 LM		Top	4.7	0.00684	4.92	5.06	5.05	4.89	4.83	4.95	0.10	2.05	5.06	4.83	0.23
		Bottom	4.7	0.00684	4.93	4.80	4.69	4.67	4.42	4.70	0.19	4.01	4.93	4.42	0.51

Table 13. Original construction core asphalt contents by ignition (UNR blank C_f) by FHWA/UNR.

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
5 MM	Coarse	Top	5.7	0.00526	5.33	5.63	5.88	5.44	5.53	5.57	0.21	3.76	5.88	5.33	0.55
		Bottom	5.7	0.00526	5.32	5.46	5.53		5.59	5.48	0.12	2.12	5.59	5.32	0.27
7 HM		Top	6.4	0.00526	6.06	6.50	6.45	6.52	6.56	6.42	0.20	3.18	6.56	6.06	0.50
		Bottom	6.4	0.00526	6.57	6.78	6.54	6.49	6.40	6.56	0.14	2.15	6.78	6.40	0.38
8 LM		Top	5.0	0.00526	5.31	5.41	5.18	5.58	5.51	5.40	0.16	2.94	5.58	5.18	0.40
		Bottom	5.0	0.00526	5.39	5.53	5.15	5.46	5.33	5.38	0.14	2.70	5.53	5.15	0.38
1 MM	Fine	Top	5.4	0.00827	4.89	5.39	5.19	5.17	5.39	5.21	0.21	3.95	5.39	4.89	0.50
		Bottom	5.4	0.00827	5.21	5.50	5.58	4.77		5.27	0.37	6.95	5.58	4.77	0.81
3 LH		Top	4.7	0.00827	4.49	4.69	4.52	4.63	4.84	4.64	0.14	3.04	4.84	4.49	0.35
		Bottom	4.7	0.00827	4.72	4.44	4.81	4.44	4.97	4.68	0.23	4.99	4.97	4.44	0.53
14 HM		Top	6.1	0.00827		5.59	5.86	5.72	5.65	5.71	0.12	2.04	5.86	5.59	0.27
		Bottom	6.1	0.00827	6.08	6.19	6.18		5.90	6.09	0.13	2.21	6.19	5.90	0.29
11 MM	Fine Plus	Top	5.4	0.00603	5.84	5.72	5.81	5.97	5.59	5.78	0.14	2.45	5.97	5.59	0.38
		Bottom	5.4	0.00603	5.77	5.33	5.49	4.88	5.71	5.43	0.36	6.57	5.77	4.88	0.89
13 HM		Top	6.1	0.00603	6.00	6.36	6.18	6.45	6.54	6.30	0.22	3.44	6.54	6.00	0.54
		Bottom	6.1	0.00603	6.07	5.74	6.08	5.89	6.49	6.05	0.28	4.65	6.49	5.74	0.75
22 LM		Top	4.7	0.00603	5.00	5.14	5.13	4.97	4.91	5.03	0.10	2.01	5.14	4.91	0.23
		Bottom	4.7	0.006029	5.01	4.88	4.77	4.75	4.50	4.78	0.19	3.95	5.01	4.50	0.51

Table 14. Original construction core asphalt contents by ignition (UNR known C_f) by FHWA/UNR

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
5 MM	Coarse	Top	5.7	0.00380	5.48	5.78	6.03	5.59	5.68	5.71	0.21	3.67	6.03	5.48	0.55
		Bottom	5.7	0.00380	5.47	5.61	5.68		5.74	5.62	0.12	2.07	5.74	5.47	0.27
7 HM		Top	6.4	0.00380	6.21	6.65	6.60	6.67	6.71	6.57	0.20	3.11	6.71	6.21	0.50
		Bottom	6.4	0.00380	6.72	6.93	6.69	6.64	6.55	6.71	0.14	2.10	6.93	6.55	0.38
8 LM		Top	5.0	0.00380	5.46	5.56	5.33	5.73	5.66	5.55	0.16	2.87	5.73	5.33	0.40
		Bottom	5.0	0.00380	5.54	5.68	5.30	5.61	5.48	5.52	0.14	2.63	5.68	5.30	0.38
1 MM	Fine	Top	5.4	0.00445	5.28	5.78	5.57	5.56	5.78	5.59	0.21	3.68	5.78	5.28	0.50
		Bottom	5.4	0.00445	5.60	5.89	5.97	5.16		5.65	0.37	6.48	5.97	5.16	0.81
3 LH		Top	4.7	0.00445	4.88	5.08	4.91	5.02	5.23	5.02	0.14	2.81	5.23	4.88	0.35
		Bottom	4.7	0.00445	5.11	4.83	5.20	4.83	5.36	5.06	0.23	4.61	5.36	4.83	0.53
14 HM		Top	6.1	0.00445		5.98	6.25	6.11	6.04	6.09	0.12	1.91	6.25	5.98	0.27
		Bottom	6.1	0.00445	6.47	6.58	6.57		6.29	6.47	0.13	2.08	6.58	6.29	0.29
11 MM	Fine Plus	Top	5.4	0.00342	6.10	5.98	6.07	6.23	5.85	6.04	0.14	2.34	6.23	5.85	0.38
		Bottom	5.4	0.00342	6.03	5.59	5.75	5.14	5.97	5.69	0.36	6.27	6.03	5.14	0.89
13 HM		Top	6.1	0.00342	6.26	6.62	6.44	6.71	6.80	6.56	0.22	3.30	6.80	6.26	0.54
		Bottom	6.1	0.00342	6.33	6.00	6.34	6.15	6.75	6.31	0.28	4.46	6.75	6.00	0.75
22 LM		Top	4.7	0.00342	5.26	5.40	5.39	5.23	5.17	5.29	0.10	1.91	5.40	5.17	0.23
		Bottom	4.7	0.00342	5.27	5.14	5.03	5.01	4.76	5.04	0.19	3.74	5.27	4.76	0.51

Table 15. Original construction, effect of correction factor selection on ignition asphalt contents.

Section	Mix Type	Lift	Target	Average Reflux	Loose Mix			Cores		
					Blank w/Lime C_f	Blank C_f	Known C_f	Blank w/Lime C_f	Blank C_f	Known C_f
8 LM	Coarse	Top	5.0	4.95	4.89	4.97	5.12	5.32	5.40	5.55
		Bottom	5.0	5.00	4.98	5.06	5.20	5.30	5.38	5.52
5 MM		Top	5.7	5.68	5.23	5.31	5.46	5.49	5.57	5.71
		Bottom	5.7	5.65	5.21	5.29	5.44	5.40	5.48	5.62
7 HM		Top	6.4	6.39	6.77	6.85	7.00	6.34	6.42	6.57
		Bottom	6.4	6.17	5.58	5.66	5.81	6.48	6.56	6.71
3 LH	Fine	Top	4.7	4.64	4.42	4.57	4.95	4.57	4.64	5.02
		Bottom	4.7	4.58	4.87	4.94	5.32	4.61	4.68	5.06
1 MM		Top	5.4	5.41	4.97	5.03	5.41	5.14	5.21	5.59
		Bottom	5.4	5.43	5.22	5.29	5.67	5.20	5.27	5.65
14 HM		Top	6.1	6.05	5.75	5.82	6.20	5.64	5.71	6.09
		Bottom	6.1	5.97	5.77	5.84	6.22	6.02	6.09	6.47
22 LM	Fine Plus	Top	4.7	4.69	4.65	4.73	4.99	4.95	5.03	5.29
		Bottom	4.7	4.68	4.56	4.64	4.90	4.70	4.78	5.04
11 MM		Top	5.4	5.40	5.28	5.36	5.62	5.70	5.78	6.04
		Bottom	5.4	5.35	5.49	5.57	5.83	5.35	5.43	5.69
13 HM		Top	6.1	6.03	6.16	6.25	6.51	6.22	6.30	6.56
		Bottom	6.1	6.03	5.68	5.76	6.02	5.97	6.05	6.31

Table 16. Original construction fine mix core asphalt contents from regression with reflux.

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
1 MM	Fine	Top	5.4	0.00894	5.35	5.88	5.67	5.65	5.88	5.69	0.22	3.83	5.88	5.35	0.53
		Bottom	5.4	0.00894	5.69	6.00	6.09	5.23		5.75	0.39	6.75	6.09	5.23	0.86
2 LM		Top	4.7	0.00894	5.08	5.04	4.93	5.01	5.05	5.02	0.06	1.11	5.08	4.93	0.15
		Bottom	4.7	0.00894		4.40	5.07	4.92	4.63	4.76	0.30	6.26	5.07	4.40	0.67
3 LH		Top	4.7	0.00894	4.93	5.14	4.96	5.08	5.30	5.08	0.15	2.94	5.30	4.93	0.37
		Bottom	4.7	0.00894	5.17	4.88	5.27	4.88	5.44	5.13	0.25	4.83	5.44	4.88	0.56
4 ML		Top	5.4	0.00894	5.26	5.28	5.67	5.08	4.89	5.24	0.29	5.56	5.67	4.89	0.78
		Bottom	5.4	0.00894	5.60	5.56	5.69	5.63	5.62	5.62	0.05	0.90	5.69	5.56	0.14
14 HM		Top	6.1	0.00894		6.10	6.38	6.23	6.16	6.22	0.12	1.98	6.38	6.10	0.29
		Bottom	6.1	0.00894	6.62	6.73	6.72		6.43	6.62	0.14	2.15	6.73	6.43	0.31
15 MM		Top	5.4	0.00894	5.57	5.85	5.35	5.36	5.62	5.55	0.21	3.71	5.85	5.35	0.50
		Bottom	5.4	0.00894	5.90	5.60	5.48	5.55	5.28	5.56	0.22	4.01	5.90	5.28	0.62
16 LH		Top	4.7	0.00894	4.78	5.00	4.75	4.94	4.73	4.84	0.12	2.55	5.00	4.73	0.28
		Bottom	4.7	0.00894	4.33	5.12	4.96	4.73	4.79	4.79	0.30	6.26	5.12	4.33	0.80
17 MH		Top	5.4	0.00894	5.82	5.95	6.03	6.03	5.65	5.90	0.16	2.76	6.03	5.65	0.38
		Bottom	5.4	0.00894	5.80	5.48	5.17	5.55	5.43	5.49	0.23	4.10	5.80	5.17	0.63
18 HL		Top	6.1	0.00894	6.20	6.18	6.36	6.17	6.16	6.22	0.08	1.34	6.36	6.16	0.20
		Bottom	6.1	0.00894	6.39	6.25	5.97	6.23	6.45	6.26	0.19	2.97	6.45	5.97	0.48

Table 17. Original construction fine plus mix core asphalt contents from regression with reflux.

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
19 MM	Fine Plus	Top	5.4	0.00684	5.55	5.51	5.36	5.13	5.51	5.41	0.17	3.19	5.55	5.13	0.42
		Bottom	5.4	0.00684	5.66	5.35	5.53	5.53	5.35	5.48	0.14	2.46	5.66	5.35	0.31
20 MH		Top	5.4	0.00684	5.58	5.39	5.30	5.40	5.31	5.40	0.11	2.12	5.58	5.30	0.28
		Bottom	5.4	0.00684	5.68	4.97	5.18	4.76	5.05	5.13	0.35	6.74	5.68	4.76	0.92
21 HL		Top	6.1	0.00684	6.33	6.41	6.08	6.24	6.20	6.25	0.12	1.98	6.41	6.08	0.32
		Bottom	6.1	0.00684	5.46	5.82	6.05	6.05	5.83	5.84	0.24	4.12	6.05	5.46	0.59
22 LM		Top	4.7	0.00684	4.73	4.87	4.86	4.70	4.64	4.76	0.10	2.09	4.87	4.64	0.23
		Bottom	4.7	0.00684	4.74	4.61	4.50	4.48	4.24	4.52	0.19	4.10	4.74	4.24	0.50
9 HL		Top	6.1	0.00684	5.86	5.78	5.96	6.33	6.42	6.07	0.29	4.73	6.42	5.78	0.64
		Bottom	6.1	0.00684	5.54	5.93	5.82	5.83	5.87	5.80	0.15	2.55	5.93	5.54	0.38
10 LH		Top	4.7	0.00684	5.01	4.52	4.75	4.88	4.86	4.80	0.18	3.81	5.01	4.52	0.49
		Bottom	4.7	0.00684	4.51	4.36	4.21	4.26		4.33	0.13	3.10	4.51	4.21	0.30
11 MM		Top	5.4	0.00684	5.55	5.44	5.53	5.68	5.31	5.50	0.14	2.53	5.68	5.31	0.37
		Bottom	5.4	0.00684	5.49	5.05	5.21	4.61	5.43	5.16	0.35	6.80	5.49	4.61	0.87
12 ML		Top	5.4	0.00684	5.51	5.18	5.22	5.53	5.33	5.35	0.16	3.01	5.53	5.18	0.35
		Bottom	5.4	0.00684	5.77	5.13	5.34	5.21	4.92	5.27	0.32	6.02	5.77	4.92	0.85
13 HM		Top	6.1	0.00684	5.71	6.06	5.89	6.15	6.24	6.01	0.21	3.54	6.24	5.71	0.53
		Bottom	6.1	0.00684	5.78	5.46	5.79	5.60	6.19	5.76	0.28	4.79	6.19	5.46	0.74

Table 18. Original construction coarse mix core asphalt contents from regression with reflux.

Section	Mix Type	Lift	Target	Correction Factor	Corrected %AC					Average	Standard Deviation	COV	Max	Min	Range
					1	2	3	4	5						
5	Coarse	Top	5.7	0.00605	5.50	5.72	5.90	5.58	5.64	5.67	0.15	2.66	5.90	5.50	0.40
MM		Bottom	5.7	0.00605	5.49	5.59	5.64		5.69	5.61	0.08	1.49	5.69	5.49	0.19
6		Top	5.7	0.00605	5.73	5.64	5.88	5.63	5.75	5.73	0.10	1.79	5.88	5.63	0.25
MH		Bottom	5.7	0.00605	5.88	5.64	5.79	6.05	6.06	5.89	0.18	3.01	6.06	5.64	0.42
7		Top	6.4	0.00605	6.03	6.34	6.31	6.36	6.39	6.28	0.15	2.34	6.39	6.03	0.36
HM		Bottom	6.4	0.00605	6.39	6.55	6.37	6.34	6.27	6.38	0.10	1.59	6.55	6.27	0.27
8		Top	5	0.00605	5.49	5.56	5.39	5.68	5.63	5.55	0.11	2.07	5.68	5.39	0.29
LM		Bottom	5	0.00605	5.54	5.64	5.37	5.59		5.54	0.12	2.15	5.64	5.37	0.27
23		Top	5.7	0.00605	5.91	5.70	5.92	5.59	5.80	5.78	0.14	2.46	5.92	5.59	0.33
ML		Bottom	5.7	0.00605	5.73	5.85	5.98	5.82	5.83	5.84	0.09	1.55	5.98	5.73	0.25
24		Top	5.7	0.00605		6.03	5.76	5.99	5.86	5.91	0.12	2.11	6.03	5.76	0.27
MM		Bottom	5.7	0.00605	5.76	5.61	5.92		5.84	5.78	0.13	2.29	5.92	5.61	0.31
25		Top	6.4	0.00605	6.22	6.38	6.36	6.34	6.34	6.33	0.06	0.98	6.38	6.22	0.16
HL		Bottom	6.4	0.00605	6.24	6.12	6.17	6.34	6.30	6.24	0.09	1.47	6.34	6.12	0.22
26		Top	5	0.00605	5.17	5.69	5.38	5.28	5.64	5.43	0.23	4.16	5.69	5.17	0.52
LH		Bottom	5	0.00605	5.43	5.46	5.57	5.01	5.39	5.37	0.21	3.98	5.57	5.01	0.56

Quality Control Asphalt Binder Contents—Replacement Sections

U.S. Department of Transportation
Federal Highway Administration

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WesTrack Report UNR-16
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June1997. Approximately 5 million, 80-kN (18,000-lb) equivalent single-axle loads were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on asphalt binder contents measured during construction of the replacement sections and referred to as "quality control asphalt binder contents." The test program used for sampling and testing is contained in WesTrack Technical Report UNR-19.[4] The asphalt content determinations obtained during construction were obtained by the use of the University of Nevada's ignition oven.

Since only one asphalt binder content was determined per section during the quality control testing and difficulties had been experienced with the use of ignition ovens during the original construction of WesTrack, a more extensive quality assurance testing program was utilized to determine asphalt binder contents.[5] The gyratory compaction volumetric properties obtained during construction of the replacement sections[6] were based on the quality control asphalt binder contents contained in this report (quality control testing) and were used to adjust the construction operation. The reported "quality assurance" gyratory compaction data for the replacement sections[4] are based on the revised asphalt binder contents obtained during the quality assurance testing. The quality assurance asphalt binder contents and volumetrics are the most accurate values available and were used to develop the performance models for WesTrack.

BACKGROUND

The replacement sections were placed at WesTrack to repair failed sections that were placed during the original construction of the track and to obtain additional information on the performance of coarse-graded Superpave mixtures. Mixture design information for the replacement sections is contained in WesTrack Technical Report UNR-7.[7] The replacement sections were constructed during May and June of 1997.

HMA mixtures were placed on the ramps to the test track on May 23 and 30, 1997 (table 1), to determine the constructability of the HMA, and to determine the gradations, asphalt binder contents, and the volumetrics. Additional trial sections were placed on the access road to WesTrack on June 20, 1997. Adjustments in the amount of fines returned from the baghouse, in cold feeds to obtain the desired gradation, in asphalt binder content, and in the roller pattern to obtain the desired air void content were undertaken during the time allocated for the placement of these trial sections.

The test lane of the track was constructed in two lifts that were placed on June 23 and 28, 1997. The test lanes are the lanes on which the traffic was placed and the WesTrack performance information obtained.

Prior to the start of production of the HMA, the HMA production facility was calibrated using California Department of Transportation (DOT) standard procedures for plant production. This calibration included determination of individual cold feed rates for each aggregate, calibration of the scale belt, and calibration of the asphalt binder delivery system. During the placement of the hot mixes at WesTrack, additional calibrations were performed.

SAMPLING

For quality control purposes, asphalt binder contents were determined on samples of HMA obtained from behind the paver. These samples were split and used for asphalt content determination and gyratory compactor volumetrics. The detailed sampling and testing plan for the replacement sections can be found in WesTrack Technical Report UNR-19.[4]

TEST METHODS

The asphalt binder contents reported from quality control testing were obtained by use of the National Center for Asphalt Technology (NCAT) ignition oven (ASTM D 6307) calibrated with both known asphalt binder contents in HMA and blank aggregate samples. The quality control asphalt binder content was used to determine the quality control gyratory-compacted sample volumetrics. These quality control volumetrics and asphalt binder contents were used to adjust the plant during construction.

Additional asphalt binder content calibration work was conducted and additional samples were tested for asphalt binder content after construction was complete. The latter included the testing

of core samples by the ignition oven and loose samples with solvent, reflux extraction. The revised asphalt binder contents based on additional sample testing were used in the calculations to determine the volumetrics identified as being associated with the quality assurance testing. These corrected data are shown in WesTrack Technical Report UNR-11.[8] This quality assurance information was used for development of the performance models.

ASPHALT BINDER CONTENT

Tables 2 and 3 contain the asphalt binder contents of the coarse-graded replacement section mixtures placed at WesTrack during construction (quality control testing). Ignition tests were performed on single samples of HMA obtained from behind the paver for both the top and bottom lifts of each section. Test results are shown in table 2 for the trial lane and in table 3 for the test lane. The reported asphalt binder contents display a trend of increasing asphalt binder content as the asphalt binder content was increased to meet the desired target values of the low, optimum, and high binder content mixtures. The desired target value and the ignition oven measured values for asphalt binder content were offset, with the ignition oven test results higher than expected. Mixture gyratory-compacted volumetrics suggested that the proper asphalt binder contents were being used during production.[6] The apparent conflict in data among the measured asphalt binder content, plant setting for asphalt binder content, and field-mixed, laboratory-compacted (FMLC) volumetrics was a problem throughout the construction of the replacement sections. (Note: In tables 2 and 3, letters in the section description such as LM and MH refer to target properties for the section. The first letter is the target asphalt content [Low, Medium, or High]; the second letter is the target air voids content.)

SUMMARY

Tables 2 and 3 contain the asphalt binder content information obtained during the quality control testing associated with the construction of the replacement sections. This quality control information was used to help guide the process control during the construction operation. Typically, the asphalt binder contents determined by the ignition oven were greater than the target values used to set the HMA plant.

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Table 1. Construction schedule – replacement sections.

Date	Lift	Lane	Section Numbers
5-23-97	Bottom	Trial	35,37,38,39,55,56
5-30-97	Top	Trial	35,37,38,39,55,56
6-20-97	Bottom	Trial*	A, B, C
6-23-97	Bottom	Test	35,36,37,38,39,54,55,56
6-28-97	Top	Test	35,36,37,38,39,54,55,56

*Access road.

Table 2. Construction quality control asphalt binder content:
coarse graded mixture – trial lane.

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content
38 LM	Coarse	Top	5.0	4.87
		Bottom	5.0	6.55
56 LH	Coarse	Top	5.0	4.87
		Bottom	5.0	6.99
35 MM	Coarse	Top	5.7	5.49
		Bottom	5.7	7.12
36 MH	Coarse	Top	5.7	
		Bottom	5.7	
39 ML	Coarse	Top	5.7	5.49
		Bottom	5.7	6.74
54 MM	Coarse	Top	5.7	
		Bottom	5.7	
37 HM	Coarse	Top	6.4	6.11
		Bottom	6.4	7.36
55 HL	Coarse	Top	6.4	6.11
		Bottom	6.4	8.07

Table 3. Construction quality control asphalt binder content coarse graded mixture – test lane.

Section No.	Mix Designation	Lift	Target Asphalt Content	Ignition Asphalt Content
38 LM	Coarse	Top	5.0	5.15
		Bottom	5.0	5.42
56 LH	Coarse	Top	5.0	5.26
		Bottom	5.0	5.28
35 MM	Coarse	Top	5.7	5.87
		Bottom	5.7	5.71
36 MH	Coarse	Top	5.7	5.76
		Bottom	5.7	5.61
39 ML	Coarse	Top	5.7	5.75
		Bottom	5.7	5.58
54 MM	Coarse	Top	5.7	5.89
		Bottom	5.7	5.75
37 HM	Coarse	Top	6.4	6.14
		Bottom	6.4	6.06
55 HL	Coarse	Top	6.4	6.24
		Bottom	6.4	6.11

Replacement Construction Quality Assurance Asphalt Contents

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Federal Highway Administration

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA), accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September1994 through January 2000. The research contract was awarded in September1994. The test track was designed and constructed during the period between October1994 and October1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the SHRP Superpave HMA volumetric design method.

This WesTrack technical report provides information on HMA quality assurance asphalt binder content data for the replacement section mixtures. The reader is referred to WesTrack Technical Report UNR-15[4] for original construction quality assurance asphalt binder content information and WesTrack Technical Reports UNR-18[5] and UNR-19[6] for original construction and replacement HMA quality control/quality assurance (QC/QA) materials sampling and testing plans, respectively. (Note: In the figures and tables in this report, letters in the section description such as LM and MH refer to target properties for the section. The first letter is the target asphalt content [Low, Medium, or High]; the second letter is the target air voids content; a number, if present, is the replicate number).

The primary purpose of this document is to summarize HMA quality assurance asphalt content data, providing an official set of asphalt binder content data for the replacement section mixtures. The data is reported in the final project report and was used for quality assurance mixture volumetric calculations. These data were used for all performance modeling and specification development purposes.

BACKGROUND

The determination of asphalt binder content has presented significant problems for the WesTrack Team. For the original construction of the track, it was decided that both the ignition and nuclear asphalt content determination methods would be employed in parallel for process control

purposes. Ignition, nuclear, and solvent (reflux extraction) methods were all planned for use in quality acceptance. At the time, the ignition method was making the transition from a research method to a practical method used throughout the industry.

Both the ignition and nuclear devices require calibrations (see references 7, 8, 9, and 10). The purpose of the calibration processes is to account for bias introduced through the test method. In the case of the nuclear device, the environment in which the device is operated may affect measurements also. This is commonly referred to as "background" and is largely controlled by the amount of hydrogen in the surrounding environment.

Calibration of the nuclear device involves the laboratory preparation and testing of asphalt-aggregate mixture samples over a range of "known asphalt contents" centered around the job-mix formula target. "Known asphalt content" refers to the amount of asphalt known to have been added to a laboratory-prepared sample. "Indicated asphalt content" refers to the asphalt content indicated by the device (whether nuclear or ignition). The difference between the known and indicated asphalt contents (bias) is the basis for a correction that is applied to subsequent measurements made with the device. The device must be calibrated prior to testing field-produced samples from the same materials. It is important to note that a unique calibration must be performed for each and every mix design.

The ignition device may be calibrated in the exact same fashion as the nuclear device, using the "known" method. It may also be calibrated using what is called the "blank aggregate" method of calibration. In the ignition test, a sample of HMA is subjected to an elevated temperature of 538°C (1,000°F) in a furnace that ignites and burns the asphalt off the aggregate. However, a small amount of aggregate is lost in the process and must be accounted for. If the aggregate lost in the ignition process is not accounted for, the indicated asphalt content will exceed the actual asphalt content. The reason is that the indicated asphalt content is based on the difference in the mass of the sample (asphalt and aggregate) prior to ignition and after ignition (aggregate only). However, the mass of the aggregate after ignition is actually less than the mass of the aggregate that was in the original sample placed in the oven; the difference is the mass of the aggregate lost in the ignition process. The reason for performing the calibration is to obtain a "correction factor" to account for aggregate loss in the ignition process.

A blank aggregate correction factor is obtained by simply testing aggregate alone (no asphalt cement) in the ignition furnace, thus the terminology "blank aggregate correction method." The mass loss of the blank aggregate is then used to determine the appropriate correction factor. The calibration must take place prior to testing field-produced samples from the same materials. Just as with the nuclear device, it is important to note that a unique calibration must be performed for each mix design. An advantage to the use of the ignition method is that the gradation of the aggregate that remains after an asphalt content determination may be determined as soon as the sample cools to room temperature. This makes the method very attractive, particularly in a process control environment.

At the time of the original construction of WesTrack, the blank aggregate method of calibration was recommended for the ignition device by the developers of the method.[9] Calibration factors were established by FHWA personnel for the nuclear device and for one of the two ignition ovens used in the original construction testing at WesTrack for each of the three original mix

types (fine, fine plus, and coarse). The aggregates used to develop the ignition correction factors were not treated with hydrated lime. The calibration factor established using the one ignition oven was assumed to be valid for the other oven also. Both ovens were "National Center for Asphalt Technology (NCAT) Asphalt Content Testers," manufactured by Barnstead-Thermolyne.

Based on inconsistency of asphalt content data generated using the ignition device during the original construction, it was decided that both ignition and reflux extraction methods would be employed to ensure reliable data for the replacement sections. The reflux method was ultimately selected for determination of original construction QA asphalt contents.[4] Even though it is a more time-consuming and costly procedure, no bias was introduced into the test results when this method was employed. It is recommended that the reader review references 4 and 12 if a thorough understanding of the original construction asphalt content data is desired.

TESTING PLANS

The replacement construction HMA QA testing plan, as developed prior to construction, is summarized in table 1. For both process control and quality assurance purposes, one lift of a test section was defined as a "lot ". Initially, the testing plan incorporated nuclear, ignition, and solvent (reflux) asphalt content determinations, but it was decided just prior to construction of the replacement sections that the nuclear method would not be employed. It was initially decided that ignition asphalt content testing would be performed on five 150-mm (6-in.) diameter cores, extracted as quickly as possible after paving, from each lift of each test section. It was assumed that the data generated through this process would serve as both QC and QA asphalt content data.

It became apparent during the trial lane paving process that the available time between bottom and top lift trial lane paving – and, therefore, test lane paving – was going to be inadequate to complete the testing. Additionally, ongoing research associated with the original WesTrack construction was suggesting that the solvent reflux extraction method was nearly as repeatable as the ignition method and was free of the bias associated with the ignition method. As with the original construction, the different ignition calibration methods were indicating significantly different correction factors and the question of which one was more correct remained unanswered.

This led the team to make changes in the asphalt content sampling and test plans. It was decided that bulk samples would be taken from the mat (behind the paver and prior to compaction) for asphalt content and gradation purposes. Five bulk samples were obtained from random locations within each lift of each test section. A rectangular shaped, three-sided, i.e., U-shaped, sampling device was built and used to facilitate the sampling operations. This device was shoved through the mat at each sampling location and a square point shovel was used to collect all of the material within the sides of the device. It should be noted that a material transfer device was incorporated in the paving train and the mat showed no visible signs of segregation.

Each bulk sample weighed approximately 35 kg (75 lb) and was immediately transported the short distance to the truck maintenance and control room building (where a temporary laboratory was established) and split into several individual test samples. From each bulk sample, two ignition asphalt content samples (approximately 3,000 g [7 lb] each) and two solvent asphalt content samples (approximately 3,000 g [7 lb] each) were split for QA asphalt content purposes. Additionally, two gyratory compaction, two theoretical maximum specific gravity and one moisture content sample were obtained from one of the five bulk samples for immediate determination of HMA volumetrics (QC volumetrics determinations). Therefore, a total of ten loose asphalt content samples were taken from the mat of each section.

Harding Lawson and Associates (HLA) technicians initiated the QA asphalt content testing. They tested all of the loose mix ignition samples. As part of that effort, they performed ignition oven calibrations using both the blank aggregate and known methods of calibration. In addition to using a range of asphalt contents, calibrations were performed with 1.5 percent hydrated lime added to the aggregate. The two ignition ovens used by HLA were not the same ovens used during the original WesTrack construction, although they were the same brand.

DATA ANALYSIS

HLA personnel were aware of the issues associated with the original construction ignition asphalt and gradation testing. They performed both blank aggregate and known methods of calibration for both ovens used. The blank aggregate samples were treated with 1.5 percent hydrated lime prior to testing. The correction factors obtained for each oven were so similar that they were simply averaged for use.

Review of the loose mix replacement ignition asphalt content data (between trial and test lane paving) determined using both the blank aggregate and known correction factors showed a constant difference between results with the two methods of approximately 0.5 percent. The data that employed the known asphalt method of correction were consistently higher than the data that employed the blank aggregate method of correction. It was obvious from mixture volumetrics and simple visual inspection that the known correction data could not be correct. It was also evident from the complementary reflux data that HLA was experiencing difficulties with that testing. Thus, the blank aggregate correction factor method was employed for the replacement process control. Prior to top lift paving the difficulties associated with the reflux testing were resolved. When the replacement construction was completed, an extensive investigation was conducted in an attempt to resolve some of the issues associated with asphalt content determinations on the project.

A complete new asphalt content testing and analysis program was initiated at UNR after the replacement QA testing was completed. HLA used reflux equipment and one of the ignition ovens from UNR. Due to all of the issues experienced with the ignition method, it was decided that the reflux method would play the role of "referee", i.e., serve as the ultimate standard if various test results were not in agreement. Two UNR students performed the testing, in which one was responsible for all of the reflux testing, while the other was responsible for all of the ignition testing.

The new program consisted of the following:

- Repeating the blank aggregate ignition calibrations performed by HLA, which consisted of blank aggregate calibrations with and without 1.5 percent hydrated lime added to the aggregate.
- Repeating the known asphalt ignition calibrations.
- Performing both blank aggregate and known asphalt solvent (reflux) calibrations.
- Performing solvent (reflux) extractions to supplement and/or replace solvent testing by HLA.
- Analyzing the results to obtain the best estimates of in-place asphalt contents.

CALIBRATION EFFORTS

For each reflux and ignition calibration point, a minimum of three replicate determinations was performed by UNR. It must be reiterated that the replacement loose mix ignition asphalt content testing was performed by HLA. The raw data was used by UNR, along with the calibration data generated by both HLA and UNR, in subsequent analyses.

UNR performed blank aggregate calibrations for the reflux method to ensure that the technician was performing the test properly. The calibration test results indicated that no bias was present in the data. The blank aggregate calibrations, which were performed on aggregate treated with 1.5 percent hydrated lime, resulted in a sight loss in mass and hence indicated asphalt contents ranging from 0.01 to 0.04 percent. Based on a 2,000-g (4.5-lb) sample size, between 0.2 and 0.8 g (0.007 to 0.028 oz) of material were lost in the process. Theoretically, no material should have been lost, but the slight difference is reasonable.

The UNR known asphalt reflux calibrations also provided excellent data. Using aggregates treated with 1.5 percent hydrated lime, a range of five known asphalt contents were evaluated for the replacement mix. For each asphalt content, with the exception of the lowest, the measured asphalt content was the same as the known. At the lowest asphalt content, the measured was 0.10 percent less than the known. Again, this indicates quality data and no bias in the method when one considers the within lab precision of the test is greater than 0.10.

The conclusion was that the reflux calibration data showed no bias and exhibited extremely low variability. The variability was actually lower than the variability associated with the ignition calibrations. As will be shown in this section, the variability associated with the testing of loose field mix was also lower for the reflux method than for the ignition method.

The same program was followed in the ignition calibrations, with the exception that calibration factors for the blank aggregate were established with and without lime. Just as had been done in the calibration efforts prior to replacement construction, half of the aggregate samples used for the blank aggregate calibrations were treated with 1.5 percent lime; the other half were not. The known asphalt content samples were treated with lime. The following blank aggregate ignition correction factors were obtained:

- UNR – blank aggregate – with lime: $C_f = 0.57$.
- UNR – blank aggregate – without lime: $C_f = 0.64$.
- UNR – known asphalt content – with lime: $C_f = 0.35$.

For purposes of comparison, the blank aggregate and known asphalt ignition calibration factors obtained by HLA for the replacement mix were:

- HLA – blank aggregate – with lime: $C_f = 1.05$.
- HLA – known asphalt content – with lime: $C_f = 0.35$.

Based on a comparison of both laboratories' calibration factors for each mix type and condition, the HLA replacement mix blank aggregate with lime correction factor appeared to be high. A similar analysis, which incorporated both original construction and replacement mixture calibration and test results generated by FHWA, HLA, and UNR, resulted in the same conclusion.[11]

ANALYSIS OF TEST RESULTS

Asphalt content data were available by both reflux and ignition methods. As previously mentioned, HLA performed both ignition and reflux testing, as did UNR. UNR did not perform any loose mix ignition testing, but simply applied correction factors developed by UNR to uncorrected test results generated by HLA.

HLA performed five ignition and three reflux determinations on loose mix sampled from the mat behind the paver for each lift of each replacement section. When HLA technicians reported the bottom lift reflux data, they mentioned that problems had been encountered while performing the testing. Because only three reflux determinations had been performed per lift and section, and the bottom lift data were possibly erroneous, UNR performed three reflux determinations per lift and section. The HLA and UNR reflux data are presented in tables 2 and 3. Table 2 represents top lift data, while table 3 represents bottom lift data. Summary statistics are provided for each individual laboratory's data, along with the combined results of both labs. One notes sections for which UNR performed up to six tests. The additional testing was performed in cases where the individual laboratory's data lacked general agreement. Note that for the top lift, the variability associated with each laboratory's data is fairly consistent within each section, even though it is fairly high for section 56. The standard deviations associated with the combined data are reasonable, with the exception of section 38.

This is not the case for the bottom lift data. The overall variability associated with the bottom lift HLA data is much greater than with the UNR data. As a matter of fact, it is unacceptably high when compared with the bottom lift UNR and top lift variability for both labs. Based on these observations, the fact that HLA had reported difficulties when performing the bottom lift testing, and the additional testing performed by UNR, the WesTrack Team decided to disregard all of the bottom lift HLA and the top lift HLA data for section 38. It should be noted that statistical methods other than visual inspection of standard deviations were not used to discard the data. Simple knowledge of the project, typical standard deviations associated with the test, and observation of the mix at the track were used to make this decision. The data that was

discarded is shaded in tables 4 and 5. The "outliers removed" terminology in tables 4 and 5 is not intended to be misleading – statistical methods were not used to discard data.

A decision was made to provide asphalt content comparisons for each mix showing the effects of the different ignition correction factors. Table 6 represents the uncorrected (no C_f applied) top and bottom lift replacement section ignition asphalt content data reported by HLA. Tables 7 and 8 are the top and bottom lift replacement ignition asphalt content data reported by HLA using the blank with lime correction factor, and known asphalt content ignition calibration factors generated by HLA, respectively. Tables 9 and 10 are the top and bottom lift replacement ignition asphalt content data reported by UNR using the blank with lime correction factor, and known asphalt content ignition calibration factors generated by UNR, respectively. Summary statistics are provided in each table. The effect of the different correction factors is summarized in table 11 and figure 1. The reflux data also are presented in figure 1.

As discussed, the known ignition calibration method had demonstrated a tendency to provide unreasonably high asphalt contents, while the blank aggregate without lime was not indicative of the materials actually placed at the track. The data for those correction factor methods were removed and the data were re-plotted along with the project target values in figure 2. From the plot, it is obvious that higher correction factors yield lower asphalt contents. Additionally, there does not appear to be general agreement between the reflux data and either laboratory's ignition data.

Something that is apparent from the plot provided in figure 2 is fact that the reflux data show a decrease in asphalt content from the top to the bottom lift for all sections (first to second data point at each section). The ignition data show the same trend for only six of the eight sections. This would suggest that the ignition data for sections 38 and 56 may be suspect. The reason for this statement is that, if the hot plant were producing mixtures with lower asphalt contents on a given day, the asphalt contents should be lower for all mixtures produced that day as indicated by the reflux data. The data were plotted again with the targets removed for closer review (figure 3). The discrepancy is even more obvious with the targets removed. It was also mentioned earlier that the HLA blank aggregate with lime correction factor appeared to be unreasonably high when compared with other data.

Based on the discussion above, the knowledge that no bias existed in the reflux data, and the fact that the variability associated with the reflux method was lower than the variability associated with the ignition method, it was decided that asphalt contents measured by the reflux method would constitute the official WesTrack replacement section asphalt content data. A summary of the official asphalt content data for the replacement sections is provided in table 12.

SUMMARY

The determination of in-place asphalt content was not as simple as originally anticipated on the WesTrack project. Both ignition and solvent (reflux) methods were used on the project. HLA and UNR both performed significant asphalt content calibration and loose mixture testing. It was determined that, regardless of the ignition calibration procedure (blank aggregate versus known asphalt) employed, bias existed in the ignition indicated asphalt content data. The known asphalt content method, which is currently recommended by AASHTO, showed significant bias. The same finding was observed on the original construction of WesTrack.

The reflux method showed no bias and lower variability than the ignition method. Some States have also indicated that the reflux method is more consistent with typical hot-plant operations. Therefore, the asphalt content data obtained by the reflux method were selected as the "official" WesTrack asphalt content data for the replacement sections. The data are summarized in table 12 for each section within each lift.

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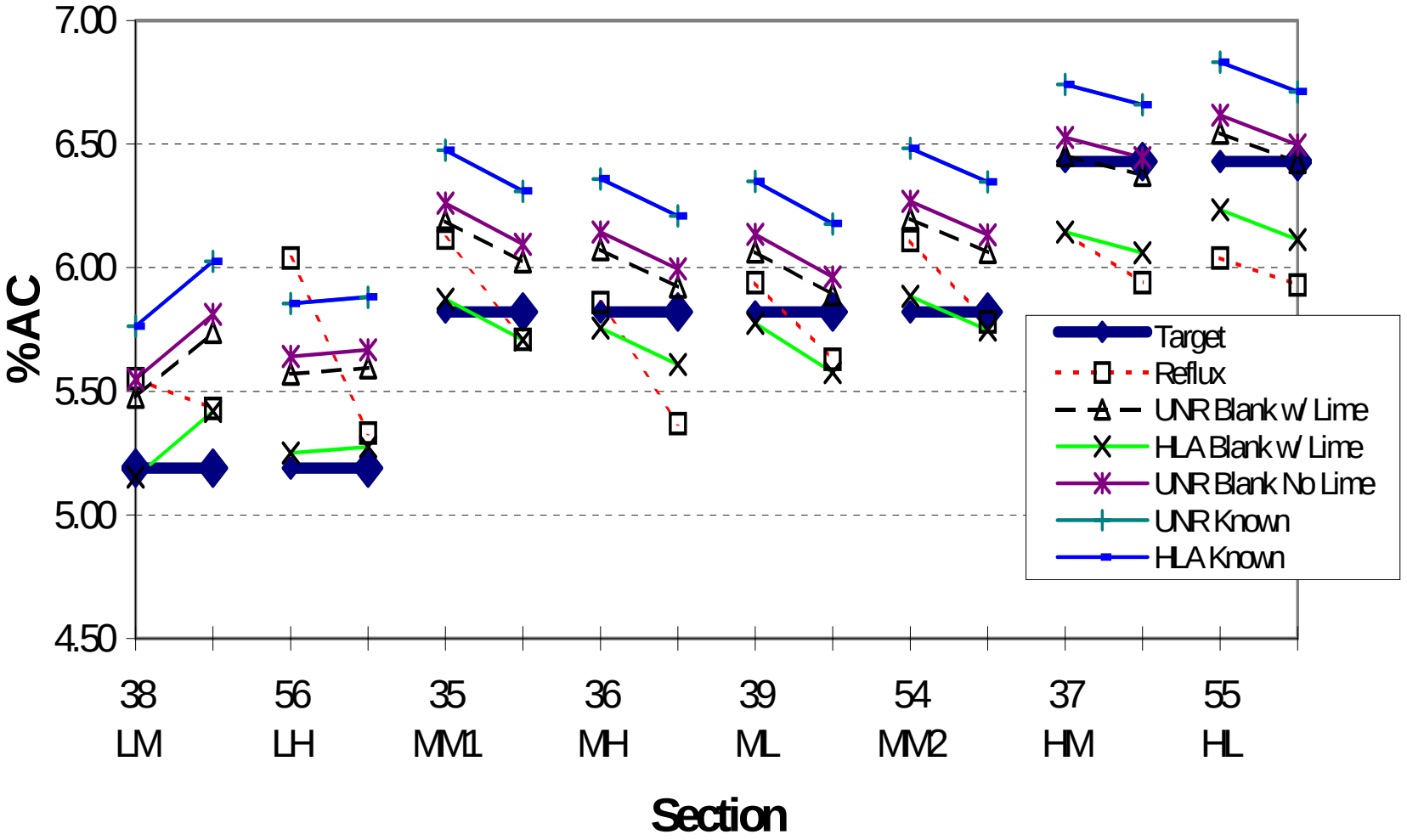

Figure 1. WesTrack replacement sections – comparison of loose mix reflux and ignition asphalt contents using multiple correction factors (C_f).

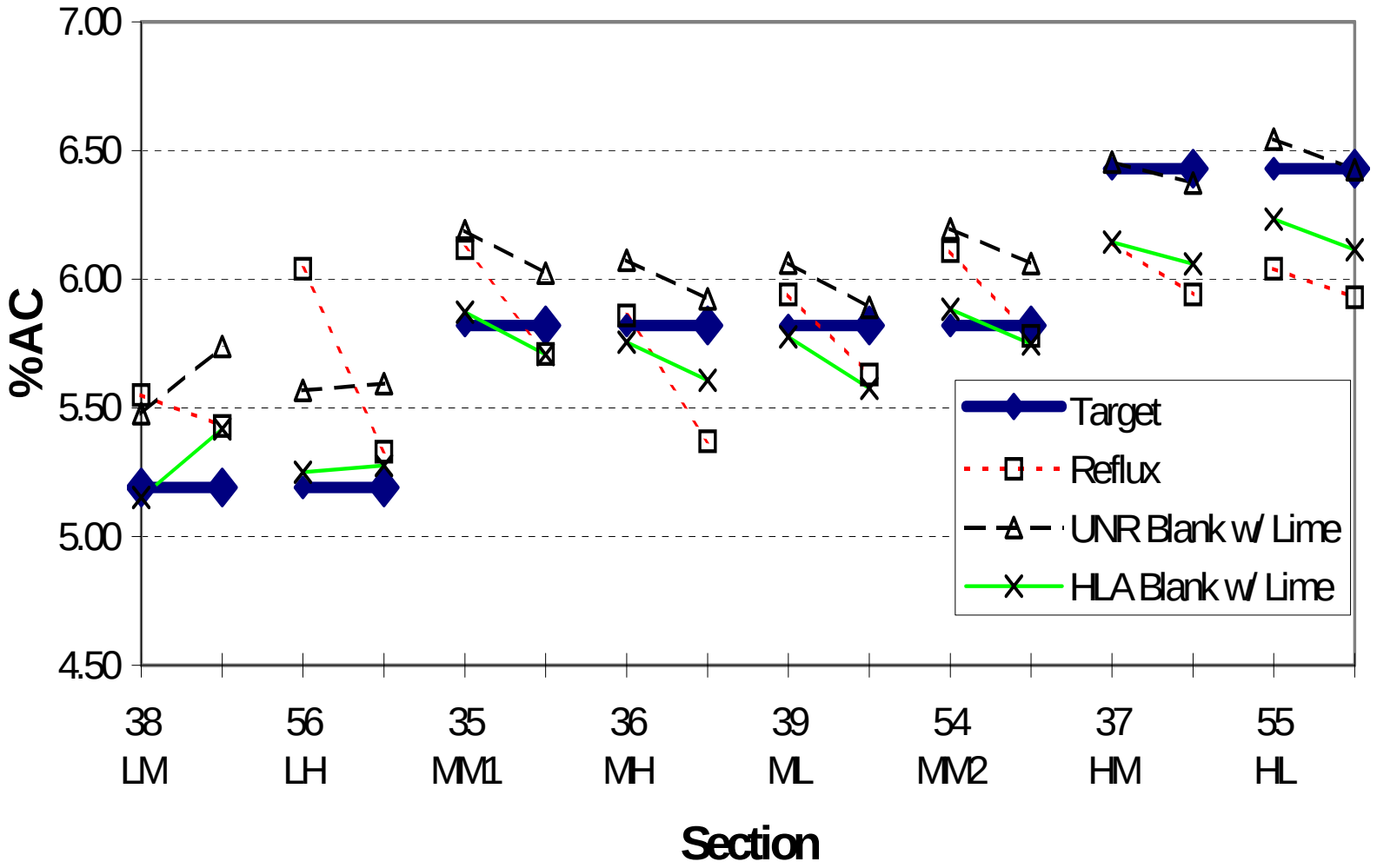

Figure 2. WesTrack replacement sections – comparison of loose mix reflux and ignition asphalt contents using only blank with lime correction factors (C_f).

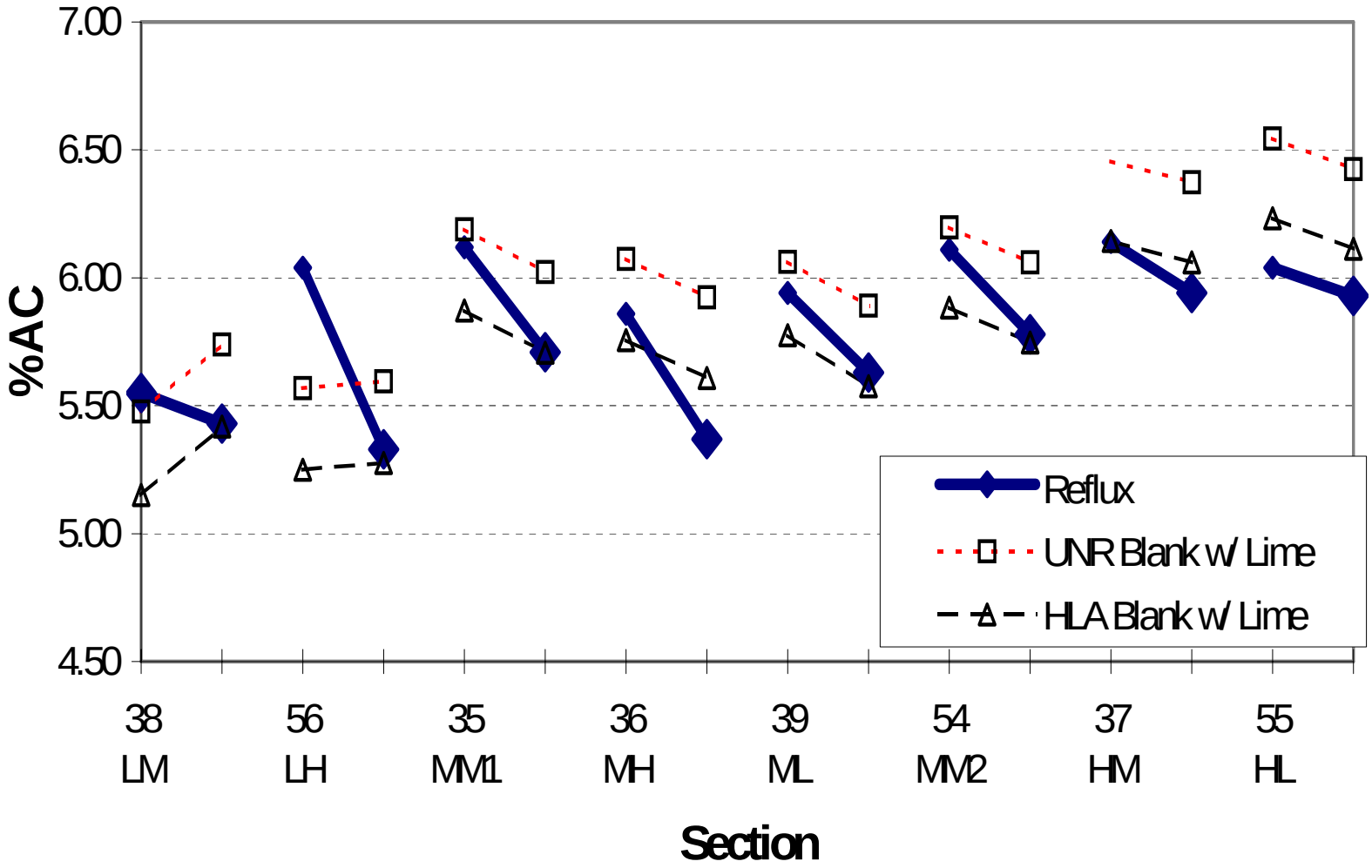

Figure 3. WesTrack replacement sections – comparison of loose mix reflux and ignition asphalt content data without targets.

Table 1. Quality assurance test plan for replacement sections.

General Property	Test Method	Tests/ Sublot	Sublots/ Lot	Number of Lots or Sections to be Tested	Number of Lifts
Asphalt Content	Nuclear*	1	5	8	2
	Extraction*	1	1	8	2
	Ignition	1	5	8	2
Gradation	Cold feed	1	5	8	2
	Extraction*	1	1	8	2
	Ignition	1	5	8	2
Superpave Gyratory Compaction (N_{max})	Bulk SP GR	2	5	8	2
	Volumetrics	2	5	8	2
Superpave Gyratory Compaction (N_{design})*	Bulk SP GR	1	5	8	2
	Volumetrics	1	5	8	2
	M_R	1	5	8	2
Marshall Compaction	Bulk SP GR	3	1	8	2
	Volumetrics	3	1	8	2
	Stability & Flow	3	1	8	2
Hveem Compaction	Bulk SP GR	3	1	8	2
	Volumetrics	3	1	8	2
	Stability	3	1	8	2
Theo. Maximum SP GR		1	5	8	2
Plant HMA Temperature		1	5	8	2
Laydown HMA Temperature		1	5	8	2
In-Place Air Voids	Nuclear	2	5	8	2
	Cores	1	5	8	2

*Indicates that changes were made in initially-planned testing associated with these items.

Table 2. WesTrack replacement mixture top lift asphalt content by reflux method prior to outlier removal.

Sec #	Target		HLA							UNR										Combined Results			
			Determinations							Determinations													
	AC	AV	1	2	3	Average	Std Dev	COV	Range	1	2	3	4	5	6	Average	Std Dev	COV	Range	Average	Std Dev	COV	Range
35 MM1	5.8	8	6.32	6.10	6.09	6.17	0.13	2.11	0.23	5.98	6.10					6.04	0.08	1.40	0.12	6.12	0.12	2.02	0.28
36 MH	5.8	12	5.90	5.93	5.88	5.90	0.03	0.43	0.05	5.69	5.92					5.81	0.16	2.80	0.24	5.86	0.10	1.69	0.24
37 HM	6.4	8	6.00	6.29	6.24	6.18	0.16	2.51	0.29	6.07	6.12					6.10	0.04	0.58	0.05	6.14	0.12	1.95	0.29
38 LM	5.2	8	4.79	4.10	4.50	4.46	0.35	7.76	0.69	5.50	5.59	5.58	5.38	5.72		5.55	0.13	2.25	0.34	5.15	0.60	11.69	1.62
39 ML	5.8	4	6.12	5.92	6.28	6.11	0.18	2.95	0.36	5.80	5.58					5.69	0.16	2.73	0.22	5.94	0.27	4.59	0.70
54 MM2	5.8	8	6.05	6.03	6.15	6.08	0.06	1.06	0.12	6.12	6.22					6.17	0.07	1.15	0.10	6.11	0.08	1.26	0.19
55 HL	6.4	4	6.05	5.99	6.53	6.19	0.30	4.78	0.54	5.59	6.06					5.83	0.33	5.71	0.47	6.04	0.33	5.52	0.94
56 LH	5.2	12	6.10	6.12	6.14	6.12	0.02	0.33	0.04	5.95	5.89					5.92	0.04	0.72	0.06	6.04	0.11	1.86	0.25

Table 3. WesTrack replacement mixture bottom lift asphalt content by reflux method prior to outlier removal.

Sec #	Target		HLA							UNR										Combined Results			
			Determinations							Determinations													
	AC	AV	1	2	3	Average	Std Dev	COV	Range	1	2	3	4	5	6	Average	Std Dev	COV	Range	Average	Std Dev	COV	Range
35 MM1	5.8	8	6.26	6.44	6.37	6.36	0.09	1.43	0.18	5.78	5.79	5.56				5.71	0.13	2.28	0.22	6.03	0.37	6.10	0.28
36 MH	5.8	12	6.58	5.05	5.63	5.75	0.77	13.43	1.53	5.52	5.39	5.21				5.37	0.16	2.90	0.31	5.56	0.54	9.71	1.53
37 HM	6.4	8	6.58	7.42	6.76	6.92	0.44	6.39	0.84	5.63	5.48	5.82	6.12	6.15	6.00	5.87	0.27	4.64	0.67	6.22	0.61	9.82	0.84
38 LM	5.2	8	6.51	6.32	6.58	6.47	0.13	2.08	0.26	5.47	5.30	5.44	5.54	5.29	5.53	5.43	0.11	2.02	0.25	5.78	0.53	9.22	0.26
39 ML	5.8	4	7.43	6.56	7.06	7.02	0.44	6.22	0.87	6.03	5.28	5.34	5.70	5.67	5.70	5.62	0.27	4.89	0.75	6.09	0.76	12.54	0.87
54 MM2	5.8	8	6.28	6.03	6.13	6.15	0.13	2.05	0.25	5.95	5.65	5.73				5.78	0.16	2.69	0.30	5.96	0.24	4.01	0.30
55 HL	6.4	12	6.73	6.43	6.51	6.56	0.16	2.37	0.30	5.87	5.79	6.14				5.93	0.18	3.09	0.35	6.25	0.37	5.98	0.35
56 LH	5.2	4	5.71	5.73	5.93	5.79	0.12	2.10	0.22	5.23	5.48	5.28				5.33	0.13	2.48	0.25	5.56	0.28	4.97	0.25

Table 4. WesTrack replacement mixture top lift asphalt content by reflux method with outliers removed.

Sec #	Target		HLA							UNR										Combined Results (Outliers Removed)			
			Determinations							Determination													
	AC	AV	1	2	3	Average	Std Dev	COV	Range	1	2	3	4	5	6	Average	Std Dev	COV	Range	Average	Std Dev	COV	Range
35 MM1	5.8	8	6.32	6.10	6.09	6.17	0.13	2.11	0.23	5.98	6.10					6.04	0.08	1.40	0.12	6.12	0.12	2.02	0.28
36 MH	5.8	12	5.90	5.93	5.88	5.90	0.03	0.43	0.05	5.69	5.92					5.81	0.16	2.80	0.24	5.86	0.10	1.69	0.24
37 HM	6.4	8	6.00	6.29	6.24	6.18	0.16	2.51	0.29	6.07	6.12					6.10	0.04	0.58	0.05	6.14	0.12	1.95	0.29
38 LM	5.2	8	4.79	4.10	4.50	4.46	0.35	7.76	0.69	5.50	5.59	5.58	5.38	5.72		5.55	0.13	2.25	0.34	5.55	0.13	2.25	0.34
39 ML	5.8	4	6.12	5.92	6.28	6.11	0.18	2.95	0.36	5.80	5.58					5.69	0.16	2.73	0.22	5.94	0.27	4.59	0.70
54 MM2	5.8	8	6.05	6.03	6.15	6.08	0.06	1.06	0.12	6.12	6.22					6.17	0.07	1.15	0.10	6.11	0.08	1.26	0.19
55 HL	6.4	4	6.05	5.99	6.53	6.19	0.30	4.78	0.54	5.59	6.06					5.83	0.33	5.71	0.47	6.04	0.33	5.52	0.94
56 LH	5.2	12	6.10	6.12	6.14	6.12	0.02	0.33	0.04	5.95	5.89					5.92	0.04	0.72	0.06	6.04	0.11	1.86	0.25

Note: Shaded cells show discarded data.

Table 5. WesTrack replacement mixture bottom lift asphalt content by reflux method with outliers removed.

Sec #	Target		HLA							UNR										Combined Results (Outliers Removed)			
			Determinations							Determination													
	AC	AV	1	2	3	Average	Std Dev	COV	Range	1	2	3	4	5	6	Average	Std Dev	COV	Range	Average	Std Dev	COV	Range
35 MM1	5.8	8	6.26	6.44	6.37	6.36	0.09	1.43	0.18	5.78	5.79	5.56				5.71	0.13	2.28	0.22	5.71	0.13	2.28	0.22
36 MH	5.8	12	6.58	5.05	5.63	5.75	0.77	13.43	1.53	5.52	5.39	5.21				5.37	0.16	2.90	0.31	5.37	0.16	2.90	0.31
37 HM	6.4	8	6.58	7.42	6.76	6.92	0.44	6.39	0.84	5.63	5.48	5.82	6.12	6.15	6.00	5.87	0.27	4.64	0.67	5.94	0.22	3.67	0.52
38 LM	5.2	8	6.51	6.32	6.58	6.47	0.13	2.08	0.26	5.47	5.30	5.44	5.54	5.29	5.53	5.43	0.11	2.02	0.25	5.43	0.11	2.02	0.25
39 ML	5.8	4	7.43	6.56	7.06	7.02	0.44	6.22	0.87	6.03	5.28	5.34	5.70	5.67	5.70	5.62	0.27	4.89	0.75	5.62	0.27	4.89	0.75
54 MM2	5.8	8	6.28	6.03	6.13	6.15	0.13	2.05	0.25	5.95	5.65	5.73				5.78	0.16	2.69	0.30	5.78	0.16	2.69	0.30
55 HL	6.4	12	6.73	6.43	6.51	6.56	0.16	2.37	0.30	5.87	5.79	6.14				5.93	0.18	3.09	0.35	5.93	0.18	3.09	0.35
56 LH	5.2	4	5.71	5.73	5.93	5.79	0.12	2.10	0.22	5.23	5.48	5.28				5.33	0.13	2.48	0.25	5.33	0.13	2.48	0.25

Note: Shaded cells show discarded data.

Table 6. WesTrack replacement mixture uncorrected (no C_f applied) loose mix asphalt contents by HLA.

Section No.	Lift	Target	Correction Factor	Loose Mix Asphalt Content - Ignition							
				1	**2**	**3**	**4**	**5**	Average	Std. Dev.	Range
35 MM1	Top	5.8	n/a	6.73	6.99	6.86	6.81	6.74	6.83	0.11	0.26
	Bottom	5.8	n/a	6.50	6.72	6.63	6.79	6.66	6.66	0.11	0.29
36 MH	Top	5.8	n/a	6.61	6.83	6.61	6.73	6.77	6.71	0.10	0.22
	Bottom	5.8	n/a	6.58	6.72	6.61	6.49	6.40	6.56	0.12	0.32
37 HM	Top	6.4	n/a	7.34	7.13	7.09	6.82	7.08	7.09	0.19	0.52
	Bottom	6.4	n/a	6.66	7.11	7.07	7.16	7.05	7.01	0.20	0.50
38 LM	Top	5.2	n/a	6.18	6.46	5.83	5.97	6.13	6.11	0.24	0.63
	Bottom	5.2	n/a	6.23	6.41	6.25	6.55	6.44	6.38	0.13	0.32
39 ML	Top	5.8	n/a	6.61	6.68	6.98	6.59	6.64	6.70	0.16	0.39
	Bottom	5.8	n/a	6.21	6.54	6.71	6.45	6.73	6.53	0.21	0.52
54 MM2	Top	5.8	n/a	6.82	7.01	6.78	6.86	6.70	6.83	0.11	0.31
	Bottom	5.8	n/a	6.73	6.78	6.72	6.67	6.59	6.70	0.07	0.19
55 HL	Top	6.4	n/a	7.10	7.28	6.92	7.25	7.36	7.18	0.17	0.44
	Bottom	6.4	n/a	6.95	7.06	7.01	7.11	7.18	7.06	0.09	0.23
56 LH	Top	5.2	n/a	6.03	6.25	6.17	6.33	6.25	6.21	0.11	0.30
	Bottom	5.2	n/a	6.08	6.15	6.28	6.23	6.42	6.23	0.13	0.34

Table 7. WesTrack replacement mixture loose mix asphalt content by ignition using HLA blank with lime C_f.

Section No.	Lift	Target	Correction Factor	Loose Mix Asphalt Content - Ignition							
				1	**2**	**3**	**4**	**5**	Average	Std. Dev.	Range
35 MM1	Top	5.8	1.05	5.74	6.05	5.91	5.87	5.79	5.87	0.12	0.31
	Bottom	5.8	1.05	5.51	5.78	5.69	5.85	5.71	5.71	0.13	0.34
36 MH	Top	5.8	1.05	5.62	5.88	5.66	5.79	5.83	5.76	0.11	0.26
	Bottom	5.8	1.05	5.59	5.78	5.66	5.55	5.46	5.61	0.12	0.32
37 HM	Top	6.4	1.05	6.36	6.19	6.15	5.88	6.14	6.14	0.17	0.48
	Bottom	6.4	1.05	5.67	6.17	6.13	6.22	6.11	6.06	0.22	0.55
38 LM	Top	5.2	1.05	5.18	5.51	4.87	5.02	5.18	5.15	0.24	0.64
	Bottom	5.2	1.05	5.23	5.46	5.30	5.61	5.49	5.42	0.15	0.38
39 ML	Top	5.8	1.05	5.62	5.74	6.04	5.65	5.70	5.78	0.18	0.42
	Bottom	5.8	1.05	5.22	5.60	5.77	5.50	5.79	5.58	0.23	0.57
54 MM2	Top	5.8	1.05	5.84	6.07	5.84	5.92	5.75	5.88	0.12	0.32
	Bottom	5.8	1.05	5.74	5.84	5.78	5.73	5.65	5.75	0.07	0.19
55 HL	Top	6.4	1.05	6.11	6.34	5.98	6.32	6.42	6.23	0.18	0.44
	Bottom	6.4	1.05	5.97	6.12	6.07	6.17	6.24	6.11	0.10	0.27
56 LH	Top	5.2	1.05	5.03	5.30	5.23	5.39	5.30	5.25	0.14	0.36
	Bottom	5.2	1.05	5.08	5.21	5.33	5.28	5.48	5.28	0.15	0.40

Table 8. WesTrack replacement mixture loose mix asphalt content by ignition using HLA known asphalt C_f.

Section No.	Lift	Target	Correction Factor	Loose Mix Asphalt Content - Ignition							
				1	**2**	**3**	**4**	**5**	Average	Std. Dev.	Range
35 MM1	Top	5.8	0.00350	6.38	6.64	6.51	6.46	6.39	6.48	0.11	0.26
	Bottom	5.8	0.00350	6.15	6.37	6.28	6.44	6.31	6.31	0.11	0.29
36 MH	Top	5.8	0.00350	6.26	6.48	6.26	6.38	6.42	6.36	0.10	0.22
	Bottom	5.8	0.00350	6.23	6.37	6.26	6.14	6.05	6.21	0.12	0.32
37 HM	Top	6.4	0.00350	6.99	6.78	6.74	6.47	6.73	6.74	0.19	0.52
	Bottom	6.4	0.00350	6.31	6.76	6.72	6.81	6.70	6.66	0.20	0.50
38 LM	Top	5.2	0.00350	5.83	6.11	5.48	5.62	5.78	5.76	0.24	0.63
	Bottom	5.2	0.00350	5.88	6.06	5.90	6.20	6.09	6.03	0.13	0.32
39 ML	Top	5.8	0.00350	6.26	6.33	6.63	6.24	6.29	6.35	0.16	0.39
	Bottom	5.8	0.00350	5.86	6.19	6.36	6.10	6.38	6.18	0.21	0.52
54 MM2	Top	5.8	0.00350	6.47	6.66	6.43	6.51	6.35	6.48	0.11	0.31
	Bottom	5.8	0.00350	6.38	6.43	6.37	6.32	6.24	6.35	0.07	0.19
55 HL	Top	6.4	0.00350	6.75	6.93	6.57	6.90	7.01	6.83	0.17	0.44
	Bottom	6.4	0.00350	6.60	6.71	6.66	6.76	6.83	6.71	0.09	0.23
56 LH	Top	5.2	0.00350	5.68	5.90	5.82	5.98	5.90	5.86	0.11	0.30
	Bottom	5.2	0.00350	5.73	5.80	5.93	5.88	6.07	5.88	0.13	0.34

Table 9. WesTrack replacement mixture loose mix asphalt content by ignition using UNR blank with lime C_f.

Section No.	Lift	Target	Correction Factor	Loose Mix Asphalt Content - Ignition							
				1	**2**	**3**	**4**	**5**	Average	Std. Dev.	Range
35 MM1	Top	5.8	0.00637	6.09	6.35	6.22	6.17	6.10	6.19	0.11	0.26
	Bottom	5.8	0.00637	5.86	6.08	5.99	6.15	6.02	6.02	0.11	0.29
36 MH	Top	5.8	0.00637	5.97	6.19	5.97	6.09	6.13	6.07	0.10	0.22
	Bottom	5.8	0.00637	5.94	6.08	5.97	5.85	5.76	5.92	0.12	0.32
37 HM	Top	6.4	0.00637	6.70	6.49	6.45	6.18	6.44	6.46	0.19	0.52
	Bottom	6.4	0.00637	6.02	6.47	6.43	6.52	6.41	6.37	0.20	0.50
38 LM	Top	5.2	0.00637	5.54	5.82	5.19	5.33	5.49	5.48	0.24	0.63
	Bottom	5.2	0.00637	5.59	5.77	5.61	5.91	5.80	5.74	0.13	0.32
39 ML	Top	5.8	0.00637	5.97	6.04	6.34	5.95	6.00	6.06	0.16	0.39
	Bottom	5.8	0.00637	5.57	5.90	6.07	5.81	6.09	5.89	0.21	0.52
54 MM2	Top	5.8	0.00637	6.18	6.37	6.14	6.22	6.06	6.20	0.11	0.31
	Bottom	5.8	0.00637	6.09	6.14	6.08	6.03	5.95	6.06	0.07	0.19
55 HL	Top	6.4	0.00637	6.46	6.64	6.28	6.61	6.72	6.55	0.17	0.44
	Bottom	6.4	0.00637	6.31	6.42	6.37	6.47	6.54	6.43	0.09	0.23
56 LH	Top	5.2	0.00637	5.39	5.61	5.53	5.69	5.61	5.57	0.11	0.30
	Bottom	5.2	0.00637	5.44	5.51	5.64	5.59	5.78	5.60	0.13	0.34

Table 10. WesTrack replacement mixture loose mix asphalt content by ignition using UNR known asphalt C_f.

Section No.	Lift	Target	Correction Factor	Loose Mix Asphalt Content - Ignition							
				1	**2**	**3**	**4**	**5**	Average	Std. Dev.	Range
35 MM1	Top	5.8	0.00351	6.38	6.64	6.51	6.46	6.39	6.48	0.11	0.26
	Bottom	5.8	0.00351	6.15	6.37	6.28	6.44	6.31	6.31	0.11	0.29
36 MH	Top	5.8	0.00351	6.26	6.48	6.26	6.38	6.42	6.36	0.10	0.22
	Bottom	5.8	0.00351	6.23	6.37	6.26	6.14	6.05	6.21	0.12	0.32
37 HM	Top	6.4	0.00351	6.99	6.78	6.74	6.47	6.73	6.74	0.19	0.52
	Bottom	6.4	0.00351	6.31	6.76	6.72	6.81	6.70	6.66	0.20	0.50
38 LM	Top	5.2	0.00351	5.83	6.11	5.48	5.62	5.78	5.76	0.24	0.63
	Bottom	5.2	0.00351	5.88	6.06	5.90	6.20	6.09	6.03	0.13	0.32
39 ML	Top	5.8	0.00351	6.26	6.33	6.63	6.24	6.29	6.35	0.16	0.39
	Bottom	5.8	0.00351	5.86	6.19	6.36	6.10	6.38	6.18	0.21	0.52
54 MM2	Top	5.8	0.00351	6.47	6.66	6.43	6.51	6.35	6.48	0.11	0.31
	Bottom	5.8	0.00351	6.38	6.43	6.37	6.32	6.24	6.35	0.07	0.19
55 HL	Top	6.4	0.00351	6.75	6.93	6.57	6.90	7.01	6.83	0.17	0.44
	Bottom	6.4	0.00351	6.60	6.71	6.66	6.76	6.83	6.71	0.09	0.23
56 LH	Top	5.2	0.00351	5.68	5.90	5.82	5.98	5.90	5.86	0.11	0.30
	Bottom	5.2	0.00351	5.73	5.80	5.93	5.88	6.07	5.88	0.13	0.34

Table 11. WesTrack replacement mix correction factor effects on loose mix ignition asphalt contents.

Section No.	Lift	Target	Reflux	UNR Blank w/Lime	HLA Blank w/Lime	UNR Blank No Lime	HLA Blank No Lime	UNR Known	HLA Known
35 MM1	Top	5.8	6.12	6.19	5.87	6.26	n/a	6.48	6.48
	Bottom	5.8	5.71	6.02	5.71	6.10	n/a	6.31	6.31
36 MH	Top	5.8	5.86	6.07	5.76	6.15	n/a	6.36	6.36
	Bottom	5.8	5.37	5.92	5.61	5.99	n/a	6.21	6.21
37 HM	Top	6.4	6.14	6.46	6.14	6.53	n/a	6.74	6.74
	Bottom	6.4	5.94	6.37	6.06	6.45	n/a	6.66	6.66
38 LM	Top	5.2	5.55	5.48	5.15	5.55	n/a	5.76	5.76
	Bottom	5.2	5.43	5.74	5.42	5.81	n/a	6.03	6.03
39 ML	Top	5.8	5.94	6.06	5.78	6.14	n/a	6.35	6.35
	Bottom	5.8	5.63	5.89	5.58	5.96	n/a	6.18	6.18
54 MM2	Top	5.8	6.11	6.20	5.88	6.27	n/a	6.48	6.48
	Bottom	5.8	5.78	6.06	5.75	6.13	n/a	6.35	6.35
55 HL	Top	6.4	6.04	6.55	6.23	6.62	n/a	6.83	6.83
	Bottom	6.4	5.93	6.43	6.11	6.50	n/a	6.71	6.71
56 LH	Top	5.2	6.04	5.57	5.25	5.64	n/a	5.86	5.86
	Bottom	5.2	5.33	5.60	5.28	5.67	n/a	5.88	5.88

Table 12. "Official" WesTrack asphalt content data summary for replacement sections.

Section	Target	Top Lift				Bottom Lift			
		Average	Std. Dev.	COV	Range	Average	Std. Dev.	COV	Range
35 MM1	5.8	6.12	0.12	2.0	0.28	5.71	0.13	2.3	0.22
36 MH	5.8	5.86	0.10	1.7	0.24	5.37	0.16	2.9	0.31
37 HM	6.4	6.14	0.12	2.0	0.29	5.94	0.22	3.7	0.52
38 LM	5.2	5.55	0.13	2.3	0.34	5.43	0.11	2.0	0.25
39 ML	5.8	5.94	0.27	4.6	0.70	5.62	0.27	4.9	0.75
54 MM2	5.8	6.11	0.08	1.3	0.19	5.78	0.16	2.7	0.30
55 HL	6.4	6.04	0.33	5.5	0.94	5.93	0.18	3.1	0.35
56 LH	5.2	6.04	0.11	1.9	0.25	5.33	0.13	2.5	0.25

Original Hot-Mix Asphalt Preconstruction, Construction, and Postconstruction Material Sampling and Testing Plan

U.S. Department of Transportation
Federal Highway Administration

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WesTrack Report UNR-18
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA), accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September1994 through January 2000. The research contract was awarded in September1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on the sampling and testing plans associated with the original construction HMA materials and mixtures. The sampling and testing plans are divided into three categories:

- Preconstruction – mix design and preconstruction quality control/quality assurance (QC/QA).
- Construction – construction QC/QA.
- Postconstruction – postconstruction mixture verification, QA, and mixture characterization.

Note this report was written as a planning document and was only partially revised, after sampling and testing were completed, to incorporate changes in the program. The reader is referred to other reports in the series, where test results are reported, for the actual sampling and testing program for the original test sections.

The primary purpose of this document is to briefly summarize each category of testing in terms of sampling and testing requirements. It also provided the personnel performing the sampling with details on sample sizes, labeling, and handling. The sampling and testing of asphalt cement, aggregate, and HMA within each of the categories is described. Details of sampling locations, numbers of samples, sample types, and the testing planned for each sample, along with the team member or institution responsible for performing the testing, are provided.

The sampling and testing plans presented in this report were developed based on a series of meetings among team members, including FHWA personnel.

PRECONSTRUCTION TESTING

Preconstruction testing involved testing of raw materials (asphalt cement and aggregate) and mixture design testing (the proportioning of raw materials). The material testing performed during the initial mix design process basically fulfilled all the preconstruction asphalt cement and aggregate test requirements. Preconstruction testing of raw materials was conducted as originally planned; however, the mix design testing was revised as noted in the following section.

MIXTURE DESIGN

The mixture design process was originally intended to be divided into three phases (A, B, and C), the first two of which would be completed prior to construction. Phase A consisted of Superpave volumetric mix designs to develop the following mixes: noncritical (coarse); critical (fine); and supercritical (fine plus). Hveem stability was used as a general indicator of the critical nature of the mix. The mix designs were to be a cooperative effort involving the FHWA Mobile Laboratory; the University of Nevada, Reno (UNR); and Oregon State University (OSU). The initial mix designs were to be performed by FHWA and UNR, with verification of the Superpave volumetric mix designs by OSU.

Phase B was originally intended to be a cooperative effort involving the University of California at Berkeley (UCB), OSU, and UNR. The phase B mix design and testing included Superpave volumetric mix design and intermediate performance testing, and conventional testing such as Marshall stability and flow and resilient modulus. The mixes developed in phase A were to be evaluated at three asphalt contents (the design optimum and ± 0.7 percent).

Phase C, a cooperative effort between UCB and OSU, extended the testing in phase B with the complete Superpave performance testing and analysis prescribed by the Nevada Automotive Test Center (NATC) Superpave Mix Analysis, May 1996. Since one of the objectives of the WesTrack project was verification of the Superpave mix design system, NATC's original planning document defined a plan to perform these tests.

Phase A testing was not completed until just prior to construction (September 1995), making it impossible to complete phase B testing before construction. As a result, the verification of the phase A mixtures, the bulk of phase B, and the phase C testing were not performed due to time constraints. In addition careful review of the Superpave Level II and III testing and analysis systems indicated that additional work was needed on those systems prior to implementation.

Phase A — Superpave Volumetric Mix Designs

In order to perform mixture designs, both asphalt cement and aggregate testing are required. Since the asphalt cement and aggregate testing performed during the mix design process fulfills both mix design and QC/QA requirements, this information is repeated in the QC/QA section. Table 1 outlines the planned mix design effort for phase A of the mix design process (in Tables 1-7, the X indicates planned activities). Table 2 summarizes the mix design methods used for each mixture, the compaction methods used for moisture sensitivity testing, and Superpave volumetric verification information. Verification of Superpave volumetric mix designs was to be performed in phase B, rather than in phase A.

Phase B — Marshall Properties, Resilient Modulus, Superpave Volumetric, and Performance Testing

Marshall properties, resilient modulus, Superpave volumetric, and performance testing were planned for each of the final mixtures (excluding the noncritical curve mix) at each of three asphalt contents (the design optimum and ± 0.7 percent) in phase B. As mentioned, the phase A testing continued through September 1995, making it impossible to complete the phase B testing prior to construction. Table 3 outlines the testing planned in phase B.

Seventy-five blow Marshall mix designs were performed in September 1995 at UNR for all mixtures, including the non-tangent mixture. Resilient modulus testing on specimens fabricated in the kneading compactor also was performed on all of the mixtures at 7 percent air voids and optimum asphalt content only. Table 4 indicates phase B testing completed to the date of this report. The remainder of the resilient modulus testing was to be completed. The plan was to perform all the resilient modulus testing at 7 percent air voids. Table 5 summarizes the testing that was planned under phase B to be performed during postconstruction testing.

Phase C — Superpave Complete Performance Testing and Analysis

Phase C plans consisted of Superpave complete (formerly known as level III) performance testing and analysis of the noncritical, critical, and supercritical mixtures at each of three asphalt contents. Tables 6 and 7 outline the testing of the mix designs planned under this phase and completed testing. As stated previously, no phase C testing was performed. All the testing required to perform one Superpave Complete Mix Design and Analysis for each of the three mixes (noncritical, critical, and supercritical) were to be performed under postconstruction testing rather than during phase C mix design. Details are given in the section on postconstruction testing.

MIX DESIGN ASPHALT CEMENT TESTING

It was decided that a non-modified PG 64-22 would be required for the project. Huntway Refining Company supplied two non-modified AC-20 binders (VZ-49 and VZ-50) that met the PG 64-22 requirements. The VZ-50 binder was used initially in the mix design process, but the crude source became unavailable and a different binder had to be used for the remainder of the mix designs. Huntway supplied two additional binders (ID 151 and ID 1512), blended in their

laboratory, which were graded. ID 151 was a PG 64-16 and ID 1512 was a PG 64-22. The ID 1512 binder was used for the remainder of the mix designs. Just prior to construction, two refinery storage tank samples of the same blend as ID 1512 (471-1 and 471-2) were sampled and graded. The samples should have had the same performance grade. The 471-1 sample was graded as a PG 64-16 and the 471-2 as a PG 64-22. The problem was the $G^*(\sin \delta) < 5000$ kPa specification on the pressure aging vessel (PAV) residue. Table 8 summarizes the binder testing conducted in the mix design process. The Superpave binder testing was performed by UNR and the traditional American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO) testing was performed by the supplier. Truck samples from construction were tested to determine the final performance grade of the binder. Note that this testing was performed under postconstruction testing.

MIX DESIGN AGGREGATE TESTING

Two aggregate sources were selected for the development of the critical and noncritical mixtures. A local source used by Granite Construction in Dayton, Nevada, was chosen for the critical mixtures and Watsonville granite, produced by Granite Rock in Watsonville, California, was chosen for the noncritical mixture. The Dayton aggregate was actually produced in 1994, and stockpiles were set aside specifically for this project. Table 9 summarizes the aggregate testing that was completed prior to performing the mix designs. Both the Dayton and Watsonville aggregates met the Superpave aggregate requirements and could be blended to meet the Superpave gradation requirements. Since it was not possible to obtain a noncritical mixture using the Watsonville granite, the Dayton aggregate was used for all of the mixtures.

ASPHALT MIXTURE

Numerous blends of both the Dayton and Watsonville aggregates, all of which met the Superpave gradation requirements, were evaluated as shown in tables 10.5 and 10.6 of the *Task G Interim Report*[3] each stockpile was dry sieved into individual fractions and recombined to produce blends. However, when batched, the blends were not adjusted for adhesion, resulting in excess fines (1.5 to 3.2 percent -0.075 mm) in the blends. Dayton aggregate blends SPD1 through SPD12 and Watsonville aggregate blends SPW1 through SPW7 were blended without checking the washed sieve analysis of the dry separated and dry blended aggregates, which resulted in excess fines in the blend. This problem was recognized and corrections for adhesion were made on all subsequent mixtures. Some of the more promising mixtures that contained the excess fines were re-run after correcting the blends for adhesion. Approximately 30 mix designs were performed.

Low voids in mineral aggregate and high dust-to-binder ratios were predominant problems in all of the mix designs, even with the excess fines removed. It was determined that obtaining mixtures that met both Hveem and Superpave volumetric requirements was not going to be possible without removing additional material passing the 0.075-mm sieve from the blends that were corrected for adhesion. This was easily achieved in the laboratory, and during construction the return on the baghouse system was utilized to remove material passing the 0.075-mm sieve.

Removal of 2.0 and 2.5 percent of the material passing the 0.075-mm sieve from blends SPD16 and SPD18, respectively resulted in critical and noncritical mixtures that met both Hveem and Superpave volumetric requirements. One percent passing the 0.075-mm sieve was added to the critical mix (SPD16) blend to produce the supercritical mixture at the same optimum percent asphalt. The mixture met Hveem requirements, but the Superpave dust-to-binder ratio recommended upper limit of 1.2 was exceeded along with the percent density at $N_{initial}$ and N_{design}. The Hveem mix designs were then verified by repeating the mix designs with three replicates per asphalt content. Subsequently, moisture sensitivity testing at the optimum asphalt content was performed on the three mixtures. All three mixtures had retained strength ratios greater than 80 percent when hydrated lime was used as an antistrip agent.

NON–TANGENT (CURVE AND RAMP) MIX DESIGN

In addition to the mix designs conducted for the test sections, mix designs were conducted for the curves and ramps using the 1995 production of aggregates.

Asphalt Cement

The same asphalt cement used for the noncritical, critical, and supercritical mixtures was used for the non-tangent mix design.

Aggregate

As previously mentioned, the Dayton aggregate for this project was stockpiled from a 1994 production run. An excess of more than two times the material required for the critical and supercritical mixtures was stockpiled for the project. However, when it was not possible to obtain a noncritical mix with the Watsonville aggregate, it was realized that the curves and ramps of the project would have to be built with a 1995 production of the Dayton aggregate. A different area of the pit was used and some additional equipment was added for the 1995 production. The same fractional stockpiles were produced and stockpile gradations were very similar. Table 10 summarizes the aggregate testing performed.

Asphalt Mixture

A mixture similar to the noncritical mixture was used for the non-tangent mix (i.e., a blend very close to the SPD18 mix). The same stockpile percentages were used, but the 1995 aggregate was cleaner (less -0.075 mm), so only 0.7 percent of the material passing the 0.075-mm sieve needed to be removed from the blend.

Hveem and Superpave volumetric mix designs were performed with the blend (SPD95). Criteria for both methods were met at the same optimum asphalt content that was used for SPD18. Moisture sensitivity testing at the optimum asphalt content was performed on the mixture; this showed a retained strength ratio greater than 80 percent when hydrated lime was used as an antistrip agent.

PRECONSTRUCTION QC/QA TESTING

Chapter 12 of the *Task G Interim Report*[3] details the entire QC/QA test plan for the project. Note that preconstruction, construction, and postconstruction QC/QA testing are all included under the single title of QC/QA testing. As mentioned, the initial mix design work included the preconstruction asphalt cement and aggregate QC/QA testing.

Preconstruction QC/QA Asphalt Cement Testing

Both conventional asphalt cement and Superpave performance grade testing were planned for the asphalt cement used on the project. Three refinery samples were to be tested, one each sampled in February, June, and July 1995. In addition to the refinery samples, approximately 17 samples were to be taken from the transport trucks during construction for postconstruction testing. Table 11 reflects the original sampling plan and table 12 indicates the actual number of samples taken.

Table 13 provides the preconstruction testing plan for the binder. Six refinery samples were taken and tested because the crude source for the binder originally used became unavailable and several others did not meet the PG 64-22 requirements. Table 14 indicates completed binder testing. The refinery samples were tested during the mix design process. The last binder tested was the only one that actually may be the same as the material used for construction, but it was prepared in the laboratory.

Preconstruction HMA Aggregate Testing

HMA QC/QA testing was planned as follows: preconstruction (stockpiles); cold-feed material during construction; aggregate remaining after solvent extraction and ignition furnace asphalt content determinations (i.e., postconstruction). Table 15 indicates the planned preconstruction aggregate testing and table 16 indicates the testing that was completed. All of the planned preconstruction aggregate testing was conducted.

CONSTRUCTION TESTING

Details of the QC/QA testing of aggregate and HMA during construction are presented in this section. Although binder testing during the construction phase was not included in the original plan, some samples were taken and tested during construction. Additionally, samples were taken for postconstruction QC/QA testing.

CONSTRUCTION ASPHALT CEMENT TESTING

The FHWA Mobile Laboratory conducted rotational viscometer and dynamic shear rheometer (DSR) testing on each tanker shipment of asphalt cement. The material was sampled and tested immediately upon arrival of the trucks so that the material did not have to be reheated. The Brookfield viscometer test was performed at 135°C and the DSR test was performed at 64°C only. Every sample tested met both the maximum viscosity specification of 3 Pa·s at 135°C and

the $G^*/(\sin\delta) \geq 1.0$kPa specification at 64°C. Early in the project, asphalt specific gravity tests also were performed.

CONSTRUCTION HMA AGGREGATE QC/QA TESTING

It is important to understand the definition of a "lot" in the remaining sections. For test lanes, each lift within one section is a lot. For trial lanes, a lot is all sections with the same asphalt content and gradation per lift (two, three, or four sections per lot).

Tables 17 and 18 show the planned QC/QA cold-feed aggregate testing for the test and trial lane construction. Similarly, tables 19 and 20 show the completed QC/QA cold-feed aggregate testing. All of the gradation testing was conducted during construction.

Table 21 outlines the QC/QA aggregate testing originally planned during construction. This QC/QA testing was for aggregate extracted from the HMA and from ignition samples for the test lanes. Table 22 indicates the testing that was completed. The gradations on extraction samples were conducted during postconstruction. Table 23 indicates the planned construction QC/QA aggregate testing for HMA-extracted and ignition samples for the trial lanes. Table 24 indicates the testing that was completed. The postconstruction extracted aggregate gradations were performed by Harding Lawson and Associates (HLA).

Control of asphalt content and gradation were critical to ensuring a statistically valid experiment. Shortly after the start of construction it became apparent that the number of planned asphalt content and gradation determinations was inadequate. Early in the project, there was significant segregation occurring in the transport trucks from which the material was sampled. To ensure that the limited testing (ignition asphalt content and gradation) would yield conclusive data, five cores were taken from each lift of each section immediately after construction for asphalt content and gradation determinations. A material transfer device was used between the trucks and paver to reduce segregation. Therefore, in addition to the previously mentioned gradations on ignition samples, five more were performed on field cores. Table 25 indicates the gradations performed on both the test and trial lane material. Note that in this special case, the definition of a lot is the same for both test and trial lanes (each lift within one section is a lot). This information is repeated in the section on HMA mixture.

CONSTRUCTION HMA MIXTURE QC/QA TESTING

Separate QC and QA plans were developed for the HMA. QC testing was conducted on materials sampled at the plant and on grade.

Hot Plant QC Testing

The lot definitions given earlier apply for this section, but for ease of illustration, mixtures are grouped by asphalt content (low, medium, and high). This is possible because only one gradation was used per day of paving (i.e., the aggregate gradation was constant throughout a day's paving). In each day of paving, three levels of asphalt content and air voids were targeted

(low, medium, and high). Thus the only mixture variable on any given day was the asphalt content (low, medium, or high).

All mixtures with the same asphalt content and gradation were grouped into lots: low, medium, and high are lots A, B, and C, respectively. This way, the daily quality control test requirements could be defined simply by lots A, B, and C. Table 26 shows the original plan for the daily quality control testing at the hot plant. Table 27 shows the testing that was actually performed. There were either two low, four medium, and three high asphalt content sections placed per day or three low, four medium, and two high asphalt content sections placed per day.

Clearly, what was planned and what was actually performed differed, most notably, the asphalt content determinations. As previously noted, five cores were taken from each lift of each section for asphalt content determination and gradation, which was not originally planned. The "Ignition 2" rows in table 27 reflect this additional testing. It is important to note that the testing was on cores, not loose mix from the transport trucks. The differences were the result of equipment and personnel constraints.

Laydown QC Testing

Typically, eight or nine sections were paved per day. Recall that aggregate gradation did not vary throughout the day. The original QC test plan at laydown is illustrated in table 28. Table 29 indicates the testing that was actually performed. All of the planned testing went as scheduled with the exception of the moisture sensitivity, which was not performed except on select sections that are identified in the postconstruction testing section.

QA Testing

QA testing of materials sampled during construction was conducted after construction.

POSTCONSTRUCTION TESTING

Both postconstruction QC/QA testing and material characterization testing were planned. Material characterization serves several purposes. First, and most importantly, material properties are needed to predict field performance based on SHRP technology, and, second, the data is needed to provide a comparison to traditional modes of laboratory testing. Additionally, mixtures were to be evaluated with several rut testing devices (torture tests) that could be used to validate mix design and possibly for crude performance predictions. This section describes the postconstruction QC/QA and material characterization testing.

POSTCONSTRUCTION QC/QA TESTING

Postconstruction QC/QA testing was planned for asphalt cement, HMA aggregates, and HMA that was sampled during construction.

Postconstruction QC/QA Binder Testing

The postconstruction QC/QA binder testing (based on truck samples taken during construction) was performed at UNR as shown in table 30. A total of 18 samples were tested rather than the original 17 planned. To get representative samples that represented the start and finish of paving, the curves/ramps, and at least two samples from each lift of the test lanes for each day of test lane paving, 18 samples were required. Although the ball indentation test is shown in table 30, this test was not conducted.

Postconstruction Aggregate Testing

Table 31 indicates the postconstruction aggregate testing plan. HLA was responsible for this testing, that was completed. All of the planned QC/QA cold-feed aggregate testing was conducted. Additionally, one gradation analysis per lot was completed on asphalt content extraction samples.

Postconstruction HMA QA Testing

The types of tests and frequency of QA testing originally planned is shown in table 32. All QA testing was performed on loose field-mixed samples or field-mixed, laboratory-compacted (FMLC) samples. Several modifications were made to the original plan after construction: water sensitivity testing was eliminated, extensive Marshall and Hveem property testing on replicate sections was reduced to be consistent for all sections, and the numbers of specimens and gyrations for Superpave gyratory compaction were changed. Two compactive efforts were scheduled (N_{max} and N_{design}), rather than just N_{max}. Ten specimens (five sublots per lot with two specimens per sublot) were compacted to N_{max} for volumetric analysis, and five specimens (five sublots per lot with one specimen per sublot) were compacted to N_{design} for resilient modulus testing. Table 33 is the revised QA test plan as of June 20, 1996, and the testing was completed.

In addition to the testing shown in tables 32 and 33, HLA conducted an extensive calibration test program for both ignition oven and nuclear gauge calibrations. Samples were prepared and tested at three asphalt cement contents and three lime contents in order to develop calibration constants for the ignition ovens and nuclear gauges. All three aggregate gradations were considered. This information was used to determine "true" field asphalt contents, which were in turn used for preparation of postconstruction laboratory-mixed, laboratory-compacted (LMLC) test specimens.

MATERIAL CHARACTERIZATION/PERFORMANCE PREDICTION TESTING

In addition to testing that was planned to characterize the change in binder properties with time, three types of materials were used to characterize the material properties of the HMA for performance prediction. They are LMLC, FMLC, and field-mixed, field-compacted (FMFC) (i.e., field cores/slabs). It should be noted that there are discrepancies in the original phase B and phase C test plans.

Postconstruction Binder Characterization

Table 34 shows the testing planned to characterize the binder over time. Both Superpave and conventional test methods were used for postconstruction binder characterization. All of the testing was performed on binder extracted and recovered from field cores.

LMLC Material Characterization

The original LMLC test plan, for use in predicting performance, is shown in the phase B and phase C mix design plans. The testing plan was modified after construction. In the revised plan, 22 mixes would be evaluated for permanent deformation and fatigue, and five sections would be evaluated for low temperature cracking and moisture sensitivity, as shown in tables A19 and A20 in appendix A. This plan is a hybrid of Superpave Intermediate and Complete Testing and Analyses, supplemented with the flexural fatigue and thermal stress restrained specimen test (TSRST). The testing summary is shown in tables A17 through A20 in appendix A. An auxiliary experiment to extend the N_{design} methodology was planned to be performed on LMLC material.

FMLC Material Characterization

The original test plan for FMLC samples is shown in table 35. Note that this test plan also has been revised. Five mixes were evaluated for permanent deformation, fatigue, low temperature cracking, and water sensitivity using the testing plan shown in tables A13 through A16 in appendix A.

FMFC Material Characterization

The original test plan for FMFC material (cores and slabs) was the same as that shown for FMLCs (table 35). Testing was planned for immediately after construction and 3, 12, and either 24 months after construction and/or postmortem. Table 36 summarizes the original testing planned. Due to budget constraints, this was revised. Testing of FMFC samples was performed at three times for performance prediction purposes: immediately after construction (t_0); 9 months after traffic (t_9); and 24 months after traffic or postmortem (t_{24}), whichever came first. Because trafficking did not begin immediately after construction, a limited number of samples were evaluated to quantify any changes in material properties that may have occurred between construction and the onset of traffic.

Immediately after construction, volumetric properties of all 26 sections were determined. Additionally, all 26 sections were evaluated in terms for permanent deformation, fatigue, and resilient modulus, and five sections were evaluated for low temperature cracking and water sensitivity. The test plan is shown in tables A1 through A12 in appendix A, which identify the mixes to be tested at the various time intervals.

ADDITIONAL TESTING

Supplemental permanent deformation testing was planned with a variety of rut testing devices as shown in table 37.

Rut Testing Devices

All 22 mixes were to be evaluated using rut testing devices. Five of the mixtures were evaluated in conjunction with TRB Committee A2D05. Table 38 provides a mixture testing summary that shows the test methods, material type, and parties responsible for the testing. As indicated by the table, LMLC, FMLC, and FMFC material for every test section were to be evaluated in the Hamburg, French, and Georgia Loaded Wheel Tester rut testing devices.

Miscellaneous Analyses

To describe the effect of the baghouse draft control on asphalt content and gradation, the baghouse fines (taken throughout the plant production) were analyzed. Knowing the quantity of lime in the baghouse fines is helpful in determining the appropriate correction factor to be used with the asphalt content devices. These, and others chemical analyses performed on hydrated lime samples taken throughout the project, were performed by CLC.

In addition, Professor James Carr at UNR performed fractal analyses and geological descriptions of the aggregates used in the HMA.

SUMMARY

This report presented the materials sampling and testing plans that were associated with the original HMA section paving in September and October 1995. Sampling and testing plans were divided into three categories:

- Preconstruction – mixture design and preconstruction QC/QA.
- Construction – construction QC/QA
- Postconstruction – postconstruction mixture verification, QA, and mixture characterization

A summary of the sampling and testing planned within each of these categories has been provided. The sampling and testing of asphalt cement, aggregate, and HMA within each of the categories is described. The postconstruction category includes sampling and testing of the pavement materials immediately after construction; at 9 months later; and at 24 months later, or at failure, whichever occurred first. The document was designed to be useful to the personnel performing the sampling and testing, and should likewise be useful to personnel planning sampling and testing programs for future accelerated pavement tests. The report was also used by the entire team to coordinate material testing, because it provided a basis for a “uniform language” or common set of materials testing terminology.

REFERENCES

1. Epps, J., Monismith, C., Seeds, S., Alavi, S., Ashmore, C., Leahy, R., and Mitchell, T., "WesTrack Performance – Interim Findings," *Journal of the Association of Asphalt Paving Technologists,* Volume 67, 1998.

2. Epps, J., Monismith, C., Seeds, S., Alavi, S., Ashmore, C., and Mitchell, T., "WesTrack Full-Scale Test Track: Interim Findings," *Proceedings,* Eighth International Conference on Asphalt Pavements, Volume III, August 10-14, 1997, Seattle, WA.

3. "Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction," *Task G Interim Report,* Final Draft, WesTrack Team, March 1996.

Table 1. Phase A mix design plan.

Mixture ID	Mix Design Methods		Moisture Sensitivity		Verification
	Superpave Volumetric	Hveem	Superpave Volumetric	Hveem	Superpave Volumetric
Noncritical	X	X	X	X	X
Critical	X	X	X	X	X
Supercritical	X	X	X	X	X

Note: "X" indicates planned testing.

Table 2. Completed phase A mix designs, moisture sensitivity, and verification.

Mixture ID	Mix Design Methods		Moisture Sensitivity		Verification
	Superpave Volumetric	Hveem	Superpave Volumetric	Hveem	Superpave Volumetric
Noncritical (SPD18 -2.5% passing 0.075-mm)	X	X	X	X	
Critical (SPD16 -2.0% passing 0.075-mm)	X	X	X	X	
Supercritical (SPD16 +1.0% passing 0.075-mm)	X	X	X	X	
Noncritical Curve (SPD95 -0.7% passing 0.075-mm)	X	X	X	X	

Note: "X" indicates completed testing.

Table 3. Phase B mix design plan.

Mixture ID	AC Levels *	Test Procedure								
		Marshall Properties	Resilient Modulus	Superpave Volumetric	Superpave Intermediate Analysis Tests					
					Simple Shear @ Constant Height	Frequency Sweep @ Constant Height	Repeated Shear @ Constant Height	Repeated Shear @ Constant Stress Ratio	Indirect Tension (IDT) Creep and Strength	IDT Strength
Non-critical	3	X	X	X	X	X	X	X	X	X
Critical	3	X	X	X	X	X	X	X	X	X
Super-critical	3	X	X	X	X	X	X	X	X	X

*See *Task G Interim Report*[3], page 10-21.

Note: "X" indicates planned testing.

Table 4. Completed phase B mix design testing.

Mixture ID	AC Levels *	Test Procedure								
					Superpave Intermediate Analysis Tests					
		Marshall Properties	Resilient Modulus	Superpave Volumetric	Simple Shear @ Constant Height	Frequency Sweep @ Constant Height	Repeated Shear @ Constant Height	Repeated Shear @ Constant Stress Ratio	IDT Creep and Strength	IDT Strength
Non-critical	3	X	X	X	X	X	X	X	X	X
Critical	3	X	X	X	X	X	X	X	X	X
Super-critical	3	X	X	X	X	X	X	X	X	X

*See *Task G Interim Report*[3], page 10-21.

Notes: (1) Resilient modulus testing has only been conducted at one of three asphalt contents per mixture.
(2) "X" indicates completed testing

Table 5. Phase B mix design testing (not yet performed).

Mixture ID	Superpave Volumetric Mix Design	Superpave Intermediate Mix Analysis and RSCH	Resilient Modulus*
Noncritical	X	X	X
Critical	X	X	X
Supercritical	X	X	X

*At two asphalt contents.

Note: "X" indicates planned testing.

Table 6. Phase C mix design plan.

Mix ID	AC Levels*	Superpave Complete Analysis Tests						
		Simple Shear @ Constant Height	Frequency Sweep @ Constant Height	Uniaxial Strain Test	Volumetric or Hydrostatic Test	Repeated Shear @ Constant Stress Ratio	IDT Creep and Strength	IDT Strength
Non-critical	3	X	X	X	X	X	X	X
Critical	3	X	X	X	X	X	X	X
Super-critical	3	X	X	X	X	X	X	X

*See *Task G Interim Report*[3], page 10-21.

Note: "X" indicates planned testing.

Table 7. Completed phase C mix design testing.

Mix ID	AC Levels*	Superpave Complete Analysis Tests						
		Simple Shear @ Constant Height	Frequency Sweep @ Constant Height	Uniaxial Strain Test	Volumetric or Hydrostatic Test	Repeated Shear @ Constant Stress Ratio	IDT Creep and Strength	IDT Strength
Non-critical	3	X	X	X	X	X	X	X
Critical	3	X	X	X	X	X	X	X
Super-critical	3	X	X	X	X	X	X	X

*See *Task G Interim Report (3)*, page 10-21.

Note: "X" indicates planned testing.

Table 8. Binder testing conducted during the mix design process.

Specification	Binder Aging	Test Method		Number of Binders Tested
Superpave	Original	Flash Point	T48	6
		Brookfield Viscosity	D4402	6
		DSR	TP5	6
	Rolling Thin Film Oven Test (RTFOT)	Mass Loss	T240	6
		DSR	TP5	6
	PAV	DSR	TP5	6
		Bending Beam Rheometer (BBR)	TP1	6
		DTT	TP3	6
ASTM and AASHTO	Original	Specific Gravity	D70	6
		Viscosity @ 60°C	D2171	6
		Viscosity @ 135°C	D2170	6
		Penetration @ 25°C	D5	6
		Flash Point	T48	6
		Solubility	D2042	6
	RTFOT	Viscosity @ 60°C	D2171	6
		Ductility @ 25°C	D113	6
		Ball Indentation		0

Table 9. Aggregate testing conducted on both Dayton and Watsonville aggregates during mix design process.

Specification	Test Method		Individual Stockpile Samples	Combined Aggregate*
ASTM and AASHTO	Gradation	C117, C136	5	1
	Apparent Specific Gravity	C127, C128	3	1
	Bulk Specific Gravity	C127, C128	3	1
	Absorption Capacity	C127, C128	3	1
	Absorption Capacity	D2041	0	0
	Plasticity Index	D4319	0	3
Superpave	C.A. Angularity	Penn DOT 621	1	0
	F.A. Angularity	TP 33	1	0
	Flat or Elongated	D4791	1	0
	Sand Equivalent	T176	1	0
	L.A. Abrasion	T96	1	5
	Sodium Soundness	T104	1	5
	Deleterious Materials	T112	1	5

*Two critical mixture gradations and one noncritical mixture gradation.

Table 10. Aggregate testing conducted during non-tangent mix design process.

Specification	Test Method		Individual Stockpile Samples	Combined Aggregate
ASTM and AASHTO	Gradation	C117, C136	5	1
	Apparent Specific Gravity	C127, C128	3	0
	Bulk Specific Gravity	C127, C128	3	0
	Absorption Capacity	C127, C128	3	0
	Absorption Capacity	D2041	0	0
	Plasticity Index	D4319	0	0
Superpave	C.A. Angularity	Penn DOT 621	1	0
	F.A. Angularity	TP 33	1	0
	Flat or Elongated	D4791	1	0
	Sand Equivalent	T176	1	0
	L.A. Abrasion	T96	0	0
	Sodium Soundness	T104	0	0
	Deleterious Materials	T112	0	0

Table 11. Original asphalt cement sampling plan.

Type	Number of Samples
Refinery	3
Transport Truck	17

Table 12. Actual number of asphalt cement samples taken.

Type	Number of Samples
Refinery	6
Transport Truck	?

Table 13. Preconstruction binder testing plan.

Specification	Binder Aging	Test Method		Refinery Samples
Superpave	Original	Flash Point	T48	3
		Brookfield Viscosity	D4402	3
		DSR	TP5	3
	RTFOT	Mass Loss	T240	3
		DSR	TP5	3
	PAV	DSR	TP5	3
		BBR	TP1	3
		DTT	TP3	3
ASTM and AASHTO	Original	Specific Gravity	D70	0
		Viscosity @ 60°C	D2171	3
		Viscosity @ 135°C	D2170	3
		Penetration @ 25°C	D5	3
		Flash Point	T48	3
		Solubility	D2042	3
	RTFOT	Viscosity @ 60°C	D2171	3
		Ductility @ 25°C	D113	3
		Ball Indentation		3

Table 14. Completed binder testing.

Specification	Binder Aging	Test Method		Refinery Samples
Superpave	Original	Flash Point	T48	6
		Brookfield Viscosity	D4402	6
		DSR	TP5	6
	RTFOT	Mass Loss	T240	6
		DSR	TP5	6
	PAV	DSR	TP5	6
		BBR	TP1	6
		DTT	TP3	6
ASTM and AASHTO	Original	Specific Gravity	D70	6
		Viscosity @ 60°C	D2171	6
		Viscosity @ 135°C	D2170	6
		Penetration @ 25°C	D5	6
		Flash Point	T48	6
		Solubility	D2042	6
	RTFOT	Viscosity @ 60°C	D2171	6
		Ductility @ 25°C	D113	6
		Ball Indentation		0

Table 15. Preconstruction aggregate testing plan.

Specification	Test Method		Individual Stockpile Samples*	Combined Aggregate**
ASTM and AASHTO	Gradation	C117, C136	5	0
	Apparent Specific Gravity	C127, C128	1	3
	Bulk Specific Gravity	C127, C128	1	3
	Absorption Capacity	C127, C128	1	3
	Absorption Capacity	D2041	0	3
	Plasticity Index	D4319	0	3
Superpave	C.A. Angularity	Penn DOT 621	1	3
	F.A. Angularity	TP 33	1	3
	Flat or Elongated	D4791	1	3
	Sand Equivalent	T176	1	3
	L.A. Abrasion	T96	1	3
	Sodium Soundness	T104	1	3
	Deleterious Materials	T112	1	3

* Samples per stockpile.
**Two critical mixture gradations, one noncritical mixture gradation — three samples each.

Table 16. Preconstruction aggregate testing conducted on both Dayton and Watsonville aggregates (during mix design process).

Specification	Test Method		Individual Stockpile Samples	Combined Aggregate*
ASTM and AASHTO	Gradation	C117, C136	5	1
	Apparent Specific Gravity	C127, C128	3	1
	Bulk Specific Gravity	C127, C128	3	1
	Absorption Capacity	C127, C128	3	1
	Absorption Capacity	D2041	0	0
	Plasticity Index	D4319	0	3
Superpave	C.A. Angularity	Penn DOT 621	1	3
	F.A. Angularity	TP 33	1	3
	Flat or Elongated	D4791	1	3
	Sand Equivalent	T176	1	3
	L.A. Abrasion	T96	1	5
	Sodium Soundness	T104	1	5
	Deleterious Materials	T112	1	5

*Two critical mixture gradations and one noncritical mixture gradation.

Table 17. Test lane material construction QC/QA cold-feed aggregate testing plan.

Specification	Test Method		Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation	C117, C136	5	1*

*Five samples per gradation (two critical mix gradations, one noncritical mix gradation) to be performed postconstruction.

Table 18. Trial lane material construction QC/QA cold-feed aggregate testing plan.

Specification	Test Method		Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation	C117, C136	5	_ or ½*

*For trial lanes, a lot is all sections with the same asphalt content and gradation per lift (two, three, or four sections per lot).

Table 19. Completed test lane material construction QC/QA cold-feed aggregate testing.

Specification	Test Method		Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation	C117, C136	5	1*

*Five samples per gradation (two critical mix gradations, one noncritical mix gradation).

Table 20. Completed trial lane material construction QC/QA cold-feed aggregate testing.

Specification	Test Method		Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation	C117, C136	5	_ or ½*

* For trial lanes, a lot is all sections with the same asphalt content and gradation per lift (two, three, or four sections per lot).

Table 21. Test lane construction QC/QA aggregate testing plan on HMA extracted and ignition samples.

Specification	Test Method	Material	Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation C117, C136	Extraction	1	1
		Ignition	5	1

Table 22. Completed test lane construction QC/QA aggregate testing on HMA extracted and ignition samples.

Specification	Test Method	Material	Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation C117, C136	Extraction	0	0
		Ignition	5	1

Table 23. Trial lane QC/QA aggregate testing plan on HMA extracted and ignition samples.

Specification	Test Method	Material	Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation C117, C136	Extraction	1	_ or ½*
		Ignition	5	1

* For trial lanes, a lot is all sections with the same asphalt content and gradation per lift (two, three, or four sections per lot).

Table 24. Completed trial lane QC/QA aggregate testing on HMA extracted and ignition samples.

Specification	Test Method	Material	Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation C117, C136	Extraction	0	0
		Ignition	5	1

Table 25. Completed test and trial lane QC/QA aggregate testing on HMA ignition samples from field cores.

Specification	Test Method	Material	Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation C117, C136	Extraction	0	0
		Ignition	5	1

Table 26. Daily quality control test plan for the hot plant.

General Property	Test Method	Asphalt Content					
		Low (Lot A)		Medium (Lot B)		High (Lot C)	
		Tests/Sublots	Sublots/Lot	Tests/Sublots	Sublots/Lot	Tests/Sublots	Sublots/Lot
Asphalt Content	Nuclear	1	3	1	3	1	4
	Extraction	0	0	0	0	0	0
	Ignition	1	5	1	5	1	5
Gradation	Cold Feed	1	2	1	2	1	1
	Extraction	0	0	0	0	0	0
	Ignition	1	2	1	2	1	2
Superpave Gyratory Compaction	Bulk SP GR	1	3	1	3	1	4
	Volumetrics	1	3	1	3	1	4
	M_R	0	0	0	0	0	0
Marshall Compaction	Bulk SP GR	0	0	3	3	0	0
	Volumetrics	0	0	3	3	0	0
	Stability and Flow	0	0	3	3	0	0
Hveem Compaction	Bulk SP GR	0	0	0	0	0	0
	Volumetrics	0	0	0	0	0	0
	Stability	0	0	0	0	0	0
Theo. Max. SP GR		2	1	2	1	2	2
HMA Temperature		1	5	1	5	1	5
Field Simple Shear		1	2	1	2	1	2

Table 27. Daily quality control testing performed at the hot plant.

General Property	Test Method	Asphalt Content					
		Low (Lot A)		Medium (Lot B)		High (Lot C)	
		Tests/Sublots	Sublots/Lot	Tests/Sublots	Sublots/Lot	Tests/Sublots	Sublots/Lot
Asphalt Content	Nuclear	3	2 or 3	3	4	3	2 or 3
	Extraction	0	0	0	0	0	0
	Ignition	1	2 or 3	1	4	1	2 or 3
	Ignition 2	5	2 or 3	5	4	5	2 or 3
Gradation	Cold Feed	1	2	1	2	1	1
	Extraction	0	0	0	0	0	0
	Ignition	1	2 or 3	1	4	1	2 or 3
	Ignition 2	5	2 or 3	5	4	5	2 or 3
Superpave Gyratory Compaction	Bulk SP GR	1	2 or 3	1	4	1	2 or 3
	Volumetrics	1	2 or 3	1	4	1	2 or 3
	M_R	0	0	0	0	0	0
Marshall Compaction	Bulk SP GR	0	0	1	4	0	0
	Volumetrics	0	0	1	4	0	0
	Stability and Flow	0	0	1	4	0	0
Hveem Compaction	Bulk SP GR	0	0	0	0	0	0
	Volumetrics	0	0	0	0	0	0
	Stability	0	0	0	0	0	0
Theo. Max. SP GR		1	2 or 3	1	4	1	2 or 3
HMA Temperature		5	2 or 3	5	4	5	2 or 3
Field Simple Shear		0	0	0	0	0	0

Table 28. Daily quality control test plan at laydown.

General Property	Test Method	Section Number								
		1	2	3	4	5	6	7	8	9
HMA Temperature		5	5	5	5	5	5	5	5	5
In-Place Air Voids	Nuclear	5	5	5	5	5	5	5	5	5
	Cores	5	5	5	5	5	5	5	5	5
Water Sensitivity	T283	1	1	1	1	1	1	1	1	1

Table 29. Daily quality control testing performed at laydown.

General Property	Test Method	Section Number								
		1	2	3	4	5	6	7	8	9
HMA Temperature		5	5	5	5	5	5	5	5	5
In-Place Air Voids	Nuclear	5	5	5	5	5	5	5	5	5
	Cores	5	5	5	5	5	5	5	5	5
Water Sensitivity	T283	0	0	0	0	0	0	0	0	0

Table 30. Postconstruction QC/QA binder test plan.

Specification	Binder Aging	Test Method		Transport Truck Samples
Superpave	Original	Flash Point	T48	8
		Brookfield Viscosity	D4402	8
		DSR	TP5	17
	RTFOT	Mass Loss	T240	17
		DSR	TP5	17
	PAV	DSR	TP5	17
		BBR	TP1	17
		DTT	TP3	3
ASTM and AASHTO	Original	Specific Gravity	D70	0
		Viscosity @ 60°C	D2171	17
		Viscosity @ 135°C	D2170	8
		Penetration @ 25°C	D5	17
		Flash Point	T48	8
		Solubility	D2042	3
	RTFOT	Viscosity @ 60°C	D2171	8
		Ductility @ 25°C	D113	8
		Ball Indentation		17

Table 31. Postconstruction test lane material QC/QA cold-feed aggregate testing plan.

Specification	Test Method		Sublots Per Lot	Lots Per Section
ASTM and AASHTO	Gradation	C117, C136	5	1
	Apparent Specific Gravity	C127, C128		*
	Bulk Specific Gravity	C127, C128		*
	Absorption Capacity	C127, C128		*
	Absorption Capacity	D2041		*
	Plasticity Index	D4319		*
Superpave	C.A. Angularity	Penn DOT 621		*
	F.A. Angularity	TP 33		*
	Flat or Elongated	D4791		*
	Sand Equivalent	T176		*
	L.A. Abrasion	T96		*
	Sodium Soundness	T104		*
	Deleterious Materials	T112		*

*Five samples per gradation (two critical mix gradations, one noncritical mix gradation).

Table 32. Quality assurance test plan.

General Property	Test Method	Tests/Sublot	Sublots/Lot	Number of Lots or Sections to be Tested	Number of Layers or Lifts
Asphalt Content	Nuclear	1	5	26	2
	Extraction	1	1	26	2
	Ignition	1	5	26	2
Gradation	Cold Feed	1	5	26	2
	Extraction	1	1	26	2
	Ignition	1	5	26	2
Superpave Gyratory Compaction	Bulk SP GR	3	5	26	2
	Volumetrics	3	5	26	2
	M_R	3	5	26	2
Marshall Compaction	Bulk SP GR	3	1	20	2
		3	5	6*	2
	Volumetrics	3	1	20	2
		3	5	6*	2
	Stability and Flow	3	1	20	2
		3	5	6*	2
Hveem Compaction	Bulk SP GR	3	1	20	2
		3	5	6*	2
	Volumetrics	3	1	20	2
		3	5	6*	2
	Stability	3	1	20	2
		3	5	6*	2
Theo. Max. SP GR		3	1	26	2
Plant HMA Temperature		1	5	26	2
Laydown HMA Temperature		1	5	26	2
In-Place Air Voids	Nuclear	2	5	26	2
	Cores	1	5	26	2
Water Sensitivity	T283	3	1	20	2
		1	5	6*	2
Field Simple Shear		1	5	26	2

*Replicate mixes only (i.e., MM1 and MM2).

Table 33. Revised quality assurance test plan.

General Property	Test Method	Tests/Sublot	Sublots/Lot	Number of Lots or Sections to be Tested	Number of Layers or Lifts
Asphalt Content	Nuclear	1	5	26	2
	Extraction	1	1	26	2
	Ignition	1	5	26	2
Gradation	Cold Feed	1	5	26	2
	Extraction	1	1	26	2
	Ignition	1	5	26	2
Superpave Gyratory Compaction (N_{max})	Bulk SP GR	2	5	26	2
	Volumetrics	2	5	26	2
Superpave Gyratory Compaction (N_{design})	Bulk SP GR	1	5	26	2
	Volumetrics	1	5	26	2
	M_R	1	5	26	2
Marshall Compaction	Bulk SP GR	3	1	26	2
	Volumetrics	3	1	26	2
	Stability and Flow	3	1	26	2
Hveem Compaction	Bulk SP GR	3	1	26	2
	Volumetrics	3	1	26	2
	Stability	3	1	26	2
Theo. Max. SP GR		1	5	26	2
Plant HMA Temperature		1	5	26	2
Laydown HMA Temperature		1	5	26	2
In-PlaceAir Voids	Nuclear	2	5	26	2
	Cores	1	5	26	2
Field Simple Shear		1	5	26	2

Table 34. Postconstruction binder test plan.

Specification	Binder Aging	Test Method		Time			
				$t = 0_{Construction}$ (pretraffic)	$t = 0_{traffic}$	$t = 9_{traffic}$	$t = 24_{traffic}$
Superpave	Original	Flash Point Brookfield Viscosity DSR	T48 D4402 TP5				
	RTFOT	Mass Loss DSR	T240 TP5	8*	8*	8*	8*
	PAV	DSR BBR DTT	TP5 TP1 TP3	8**	8**	8**	8**
ASTM and AASHTO	Original	Specific Gravity Viscosity @ 60°C Viscosity @ 135°C Penetration @ 25°C Flash Point Solubility	D70 D2171 D2170 D5 T48 D2042	8* 8*	8*	8*	8*
	RTFOT	Viscosity @ 60°C Ductility @ 25°C	D2171 D113				
		Ball Indentation		8*			

* Field-aged (construction operation), RTFOT aging will not be performed.
**Field-aged (construction operation), and in-service to RTFOT condition, PAV aging will be performed.

Table 35. Original test plan for FMLC and FMFC samples.

General Property	SHRP Level	Tests/ Sublot	Sublots/ Lot	Number of Lots or Sections to be Tested	Type of Distress
Simple Shear and Frequency Sweep	2, 3	3	1	26	Rutting Fatigue
Repeated Shear @ Constant Stress Ratio	2, 3	3	1	26	Rutting
IDT Strength	2	9	1	26	Fatigue
IDT Creep and Strength	2	9	1	6	Thermal Cracking
Uniaxial Strain and Volumetric	3	3	1	26	Rutting
Beam Fatigue	3	6	1	26	Fatigue

Table 36. Summary of original testing and testing times plan for FMFC samples.

General Property	Time from Start of Traffic (months)			
	0	3	12	24
Permanent Deformation				
Simple Shear, Frequency Sweep,	26	26	13	24
Uniaxial, and Volumetric Tests	26	8	8	24
Fatigue				
Frequency Sweep	26	26	13	24
IDT Strength	26	0	0	24
Thermal Cracking				
IDT Creep	6	0	0	6
IDT Strength	6	0	0	6

Table 37. Rut testing associated with TRB-A2D05 participating labs and testing devices.

Testing Device	Participating Lab
Hamburg Rut Tester	KOCH Materials Company
French Rut Tester	FHWA — Turner-Fairbank Highway Research Center
French Rut Tester	Colorado Department of Transportation
Georgia Loaded Wheel Tester	Georgia Department of Transportation
Aztec Rut Tester	Georgia Department of Transportation
PURWheel Rut Tester	Purdue University
Couch Rut Tester	Couch Incorporated

FMLC materials from test sections 5, 7, 15, 19, and 22 tested.

Table 38. Hot-mix asphalt test matrix, testing responsibility, and material type.

Testing	Material Type and Responsibility		
	LMLC	FMLC	FMFC
Marshall Mix Designs	UNR	FHWA (1), UNR	
Hveem Mix Designs	UNR	UNR	
Superpave Volumetric	FHWA (1)	FHWA (1), BRE	UNR (Volumetrics)
Superpave Intermediate	OSU, UCB	OSU, UCB	OSU, UCB
Superpave Complete	OSU, UCB	OSU, UCB	OSU, UCB
Georgia Loaded Wheel Tester (GLWT)	GIT	GIT	GIT
French Rut Tester	CDOT	CDOT	FHWA (2)
Hamburg Rut Tester	KOCH	KOCH	FHWA (2)
Gyratory Testing Machine		ED CO	

UNR - University of Nevada, Reno
FHWA (1) - Federal Highway Administration Mobile Laboratory B
FHWA (2) - Federal Highway Administration Turner-Fairbank Highway Research Center
BRE - Brent Rauhut Engineering Inc.
OSU - Oregon State University
UCB - University of California, Berkeley
GIT - Georgia Institute of Technology
CDOT - Colorado Department of Transportation
KOCH - KOCH Materials Company
ED CO - Engineering Developments Company Inc.

APPENDIX A

WESTRACK ORIGINAL CONSTRUCTION MATERIALS CHARACTERIZATION, PERFORMANCE TESTING, AND POSTCONSTRUCTION MATERIAL TEST PLAN

Table A1. FMFC @ time = 0 months (immediately after construction), permanent deformation (22 sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-16
		F^+-22	F^+-10
Medium	C-23	C-24	C-06
	F-04	F-01	F-17
	F^+-12	F^+-11	F^+-20
High	C-25	C-07	
	F-18	F-14	
	F^+-9, F^+-21	F^+-13	

Table A2. FMFC @ time = 0 months (immediately after construction), fatigue cracking (22 sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-16
		F^+-22	F^+-10
Medium	C-23	C-24	C-06
	F-04	F-01	F-17
	F^+-12	F^+-11	F^+-20
High	C-25	C-07	
	F-18	F-14	
	F^+-9, F^+-21	F^+-13	

Table A3. FMFC @ time = 0 months (immediately after construction), low temperature cracking (five sections).*

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
Medium		C-24	
		F-01	
		F^{+}-11	
High	C-25		

*Both Thermal Stress Restrained Specimen Test (TSRST) and Indirect Tensile Test (IDT).

Table A4. FMFC @ time = 0 months (immediately after construction), water sensitivity (five sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
Medium		C-24	
		F-01	
		F^{+}-11	
High	C-25		

Table A5. FMFC @ time = 12 months after initiation of traffic, permanent deformation (13 sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	
Medium	C-23	C-24	
	F-04	F-01	
	F^+-12	F^+-11	
High	C-25	C-07	
	F-18	F-14	
	F^+-21	F^+-13	

Table A6. FMFC @ time = 12 months after initiation of traffic, fatigue cracking (13 sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-16
		F^+-22	F^+-10
Medium		C-19, C-24	C-06
		F-01	F-17
		F^+-11	F^+-20
High			

Table A7. FMFC @ time = 12 months after initiation of traffic, low temperature cracking (0 sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			
Medium			
High			

Table A8. FMFC @ time = 12 months after initiation of traffic, water sensitivity (0 sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			
Medium			
High			

Table A9. FMFC @ time = 24 months or postmortem, permanent deformation (13 sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	
Medium	C-23	C-24	
	F-04	F-01	
	F^+-12	F^+-11	
High	C-25	C-07	
	F-18	F-14	
	F^+-21	F^+-13	

Table A10. FMFC @ time = 24 months or postmortem, fatigue cracking (13 sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-16
		F^+-22	F^+-10
Medium		C-19, C-24	C-06
		F-01	F-17
		F^+-11	F^+-20
High			

Table A11. FMFC @ time = 24 months or postmortem, low temperature cracking (five sections).*

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
Medium		C-24	
		F-01	
		F^{+}-11	
High	C-25		

*TSRST only.

Table A12. FMFC @ time = 24 months or postmortem, water sensitivity (0 sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			
Medium			
High			

Table A13. FMLC permanent deformation (four sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			
Medium		C-24	
		F-01	
		F^{+}-11	
High			
	F^{+}-21		

Table A14. FMLC fatigue cracking (five sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
Medium		C-24	
		F-01	
		F^{+}-11	
High	C-25		

Table A15. FMLC low temperature cracking (five sections).*

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
Medium		C-24	
		F-01	
		F^{+}-11	
High	C-25		

*TSRST and IDT.

Table A16. FMLC moisture sensitivity (five sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
Medium		C-24	
		F-01	
		F^{+}-11	
High	C-25		

Table A17. LMLC permanent deformation.

% Asphalt Cement	Minus 0.075mm Material	% Air Voids		
		Low	Medium	High
Low	Low			
	Medium			
	High			
Medium	Low	C, F		
	Medium	C*, F		
	High	C, F		
High	Low			
	Medium	C, F		
	High			

*Testing performed at three temperatures.

Table A18. LMLC fatigue cracking.

% Asphalt Cement	Minus 0.075mm Material	% Air Voids		
		Low	Medium	High
Low	Low			
	Medium			
	High			
Medium	Low		C, F	
	Medium		C*, F*	
	High		C, F	
High	Low			
	Medium			
	High			

*Testing performed at three temperatures.

Table A19. LMLC low temperature cracking.*

% Asphalt Cement	Minus 0.075mm Material	% Air Voids		
		Low	Medium	High
Low	Low			
	Medium			
	High			
Medium	Low			
	Medium		C, F, F^+	
	High			
High	Low			
	Medium			
	High			

* Thermal Stress Restrained Specimen Test (TSRST) only.

Table A20. LMLC moisture sensitivity.

% Asphalt Cement	Minus 0.075mm Material	% Air Voids		
		Low	Medium	High
Low	Low			
	Medium			
	High			
Medium	Low			
	Medium		C, F, F^+	
	High			
High	Low			
	Medium			
	High			

Table A21. FMFC @ time = 0 months (immediately after construction), asphalt content (ignition, nuclear, and reflux methods) and gradation (26 sections, top and bottom lifts).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-03, F-16
		F^+-22	F^+-10
Medium	C-23	C-05, C-24	C-06
	F-04	F-01, F-15	F-17
	F^+-12	F^+-11, F^+-19	F^+-20
High	C-25	C-07	
	F-18	F-14	
	F^+-9, F^+-21	F^+-13	

Table A22. FMFC @ time = 0 months (immediately after construction), recovered asphalt binder characterization (eight sections, Superpave and conventional) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
			F^+-10
Medium		C-24	
		F-01	
		F^+-11, F^+-19	
High	C-25		
	F^+-21		

Table A23. FMFC @ time = 0 months (immediately after construction), resilient modulus and volumetrics (26 sections, top, and bottom lifts) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-03, F-16
		F^+-22	F^+-10
Medium	C-23	C-05, C-24	C-06
	F-04	F-01, F-15	F-17
	F^+-12	F^+-11, F^+-19	F^+-20
High	C-25	C-07	
	F-18	F-14	
	F^+-9, F^+-21	F^+-13	

Table A24. FMFC @ time = 0 months (immediately after construction), moisture sensitivity (26 sections, bottom lift only) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-03, F-16
		F^+-22	F^+-10
Medium	C-23	C-05, C-24	C-06
	F-04	F-01, F-15	F-17
	F^+-12	F^+-11, F^+-19	F^+-20
High	C-25	C-07	
	F-18	F-14	
	F^+-9, F^+-21	F^+-13	

Table A25. FMFC @ time = 0 traffic (immediately after initiation of traffic), binder characterization (eight sections, Superpave and conventional) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
			F^+-10
Medium		C-24	
		F-01	
		F^+-11, F^+-19	
High	C-25		
	F^+-21		

Table A26. FMFC @ time = 0 traffic (immediately after initiation of traffic), resilient modulus and volumetrics (eight sections, top and bottom lifts) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
			F^+-10
Medium		C-24	
		F-01	
		F^+-11, F^+-19	
High	C-25		
	F^+-21		

Table A27. FMFC @ time = 0 traffic (immediately after initiation of traffic), moisture sensitivity (0 sections) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			
Medium			
High			

Table A28. FMFC @ time = 12 months after initiation of traffic, binder characterization (eight sections, Superpave and conventional) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
			F^{+}-10
Medium		C-24	
		F-01	
		F^{+}-11, F^{+}-19	
High	C-25		
	F^{+}-21		

Table A29. FMFC @ time = 12 months after initiation of traffic, resilient modulus and volumetrics (up to 26 sections, top and bottom lifts) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-03, F-16
		F^+-22	F^+-10
Medium	C-23	C-05, C-24	C-06
	F-04	F-01, F-15	F-17
	F^+-12	F^+-11, F^+-19	F^+-20
High	C-25	C-07	
	F-18	F-14	
	F^+-9, F^+-21	F^+-13	

Table A30. FMFC @ time = 12 months after initiation of traffic, moisture sensitivity (0 sections) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			
Medium			
High			

Table A31. FMFC @ time = 24 months after initiation of traffic, binder characterization (eight sections, Superpave and conventional) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			C-26
			F^+-10
Medium		C-24	
		F-01	
		F^+-11, F^+-19	
High	C-25		
	F^+-21		

Table A32. FMFC @ time = 24 months or postmortem, resilient modulus and volumetrics (up to 26 sections, top and bottom lifts) – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-03, F-16
		F^+-22	F^+-10
Medium	C-23	C-05, C-24	C-06
	F-04	F-01, F-15	F-17
	F^+-12	F^+-11, F^+-19	F^+-20
High	C-25	C-07	
	F-18	F-14	
	F^+-9, F^+-21	F^+-13	

Table A33. FMFC @ time = 24 months or postmortem, moisture sensitivity (0 sections) – UNR

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			
Medium			
High			

Table A34. FMLC asphalt content (ignition* and reflux**) and gradation – UNR.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		*, **	*, **
		*, **	*, **
		*, **	*, **
Medium	*, **	*, **	*, **
	*, **	*, **	*, **
	*, **	*, **	*, **
High	*, **	*, **	
	*, **	*, **	
	*, **	*, **	

* Selected sections and replicates based on review of existing data.

**Up to 26 sections, two lifts per section, and five replicates per section per lift.

Table A35. FMLC mix design properties (Superpave, Hveem, and Marshall methods), (26 sections, top and bottom lifts) – HLA.

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-08	C-26
		F-02	F-03, F-16
		F^+-22	F^+-10
Medium	C-23	C-05, C-24	C-06
	F-04	F-01, F-15	F-17
	F^+-12	F^+-11, F^+-19	F^+-20
High	C-25	C-07	
	F-18	F-14	
	F^+-9, F^+-21	F^+-13	

Table A36. Virgin binder characterization – UNR.

Material	Test Methods	
Huntway PG 64-22	Superpave	Conventional

Table A37. Aggregate characterization (Superpave and conventional) – UNR.

Material	Blends		
Dayton -1994	C	F	F^+
Dayton - 1995	C		

Table A38. LMLC asphalt content method calibrations (ignition and reflux) – UNR.

% Asphalt Cement	Mixtures		
5	C	F	F^+

Table A39. LMLC mixture sensitivity (Superpave) – UNR.

% Asphalt Cement	Minus 0.075mm Material	Mixtures		
5	Top lift measured	C	F	F^+
	Target	C	F	F^+
	Bottom lift measured	C	F	F^+

Table A40. LMLC resilient modulus and moisture sensitivity – UNR.

% Asphalt Cement	Mixtures		
1	C	F	F^+

Replacement Hot-Mix Asphalt Preconstruction, Construction, and Postconstruction Material Sampling and Testing Plan

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-19
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA), accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September1994 through January 2000. The research contract was awarded in September1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on the sampling and testing plans associated with the replacement construction HMA materials and mixtures. The sampling and testing plans are divided into three categories:

- Preconstruction — mix design and preconstruction quality control/quantity assurance (QC/QA).
- Construction — construction QC/QA.
- Postconstruction — postconstruction mixture verification, QA, and mixture characterization.

The primary purpose of this document is to briefly summarize each category of testing in terms of sampling and testing requirements. It also provides the personnel performing the sampling with details as to sample sizes, labeling, and handling. The sampling and testing of asphalt cement, aggregate, and HMA within each of the categories is described. Details of sampling locations, numbers of samples, sample types, and the testing planned for each sample, along with the team member or institution responsible for performing the testing are provided. The report also includes potential paving schedules.

The sampling and testing plans presented in this report were developed based on a series of meetings among team members, including FHWA personnel. Experience gained through the original construction also contributed significantly to the developed plans.

EXPERIMENTAL DESIGN

The replacement experimental design are identical to those of the coarse mix in the original WesTrack experiment. The seven experimental factors include:

- Aggregate type: Granite Construction's Lockwood quarry material; 1 level.
- Aggregate gradation: coarse 19-mm nominal Superpave; 1 level.
- Aggregate shape: 100 percent crushed andesite; 1 level.
- Asphalt type: Idaho Asphalt PG 64-22; 1 level.
- Asphalt content: optimum, optimum -0.7 percent, optimum +0.7 percent; 3 levels.
- Air void content: 4 percent, 8 percent, and 12 percent; 3 levels.
- Thickness: 150 mm (6 in.); 1 level.

A partial factorial, which eliminates the unrealistic and unconstructable combinations of low asphalt/low air voids and high asphalt/high air voids, and includes two replicates of optimum asphalt/8 percent air voids, results in the need for eight test sections. Table 1 summarizes the experimental design for the replacement construction.

HMA PAVING SCHEDULE

The HMA paving was scheduled to take place during five paving days. Two to four testing days between each paving day were reserved for testing. Eight sections were placed per day. Table 1 indicates the daily construction plan with details on timing, location, lift, paving block, and section identification, along with aggregate gradation, asphalt content, and air void content. In an effort to prevent confusion in original construction and replacement material handling and data, the section numbers and paving days used in the original construction have had “30" added to them for the rehabilitation efforts. Hence the new pavement in original section 5 became known as replacement section 35 and the first day of replacement paving was day 31.

Figure 1 is a plan view of the track that identifies the layout of the test sections. Note that the shaded sections were not replaced. Figure 1 also provides details of the individual asphalt content levels, air void levels, and section locations.

The bottom lift trial section paving was planned for the first paving (day 31). Two to four days of testing were to take place; then on the second paving day (32) the top lift of the trial section would be paved, followed by 2 to 4 days of testing. This process would be repeated for the placement of the test section on paving days 33 and 34. The fifth paving day (35) is in the schedule to allow for contingencies (start up, weather, patching, equipment, etc.) Figures 2 and 3 depict possible paving and testing day sequences.

Of particular interest to the sampling and testing personnel are the paving day and section number. The section number and day of paving were used extensively by the sampling and testing crews and the contractor's personnel to identify and communicate about the mixture being produced and placed. With the section number and day of paving, all other details about the mixture can be derived from table 2.

PRECONSTRUCTION SAMPLING AND TESTING

Preconstruction testing involved testing of raw materials (asphalt cement and aggregate) and mixture design testing (proportioning of the raw materials). One asphalt content, two aggregates, and three gradations were scheduled for evaluation in the mix design process.

The material testing performed during the initial mix design process fulfilled all of the preconstruction asphalt cement and aggregate test requirements. Preconstruction testing of raw materials was conducted by the University of Nevada, Reno (UNR).

It should be noted that Granite Construction changed the crushing operations at the Lockwood quarry (replacement aggregate source) in early April 1997. Sampling, raw material testing, and mix designs were performed with the newly crushed materials. At the time of construction, materials were sampled for mix design verification. Postconstruction mix design verification was performed by UNR.

PRECONSTRUCTION ASPHALT CEMENT SAMPLING AND TESTING

The binder sampled during the original construction of WesTrack was scheduled for use for preconstruction mix designs, but was not available. Instead, a neat PG 64-22 supplied by Idaho Asphalt was used. Two samples of asphalt binder were taken from the storage tank at Idaho Asphalt and shipped to UNR for preliminary acceptance testing (performance grading) prior to construction. Table 3 summarizes the preconstruction asphalt cement testing.

PRECONSTRUCTION HOT-MIX AGGREGATE SAMPLING AND TESTING

Both American Society for Testing and Materials (ASTM) and Superpave tests were performed on stockpile and combined aggregate samples of the Lockwood material. Only the target combined aggregate blend was evaluated. Table 4 indicates the preconstruction aggregate sampling requirements. The quantities in table 4 provide enough material for aggregate and mix design purposes. Table 5 summarizes the preconstruction aggregate testing requirements.

PRECONSTRUCTION HMA SAMPLING AND TESTING

The materials sampled for preconstruction aggregate testing were scheduled for mix design purposes. Due to changes in crushing operations and stockpile control, additional sampling was required.

Preconstruction HMA testing consisted of developing a coarse 19-mm nominal Superpave volumetric mixture. The gradation developed for this mixture was termed the "target" gradation. The design traffic was 10 million ESALs. This, coupled with the environment, dictated that the

design number of gyrations be 152. Five asphalt contents (Optimum-1.0 percent, Optimum-0.5 percent, Optimum, Optimum+0.5 percent, and Optimum+1.0 percent) and three replicates at each asphalt content were scheduled to be evaluated. Moisture susceptibility testing of the mixture was performed.

Once the Superpave mixture was developed, its target gradation was adjusted by adding 1.5 percent material passing the 0.075-mm sieve and by removing 1.5 percent material passing the 0.075-mm sieve to produce mixtures that were termed "target-plus" and "target-minus." The target-plus and target-minus mixtures were scheduled for evaluation at the same five asphalt contents used in the target mix design. Three replicates at each asphalt content were evaluated for both mixtures. The target-plus and target-minus mixtures were not evaluated for moisture susceptibility. Table 6 outlines the preconstruction mix design testing.

Neither SHRP-developed (Superpave) performance testing nor Hveem nor Marshall mix designs were performed during the preconstruction testing.

CONSTRUCTION SAMPLING AND TESTING

Raw materials (asphalt cement, aggregate, hydrated lime, and baghouse fines) and HMA were sampled during construction for QC on the project, future QA testing, mix design verification, and material characterization, and for bulk samples to be stored in the Materials Reference Library (MRL). Some of the raw materials and HMA were tested immediately while most were tested after construction.

CONSTRUCTION BASE COURSE SAMPLING AND TESTING

In addition to this sampling and testing, some base course testing was scheduled after the removal of the existing HMA.

When the existing pavement was removed, the base course beneath it was proof rolled. In sections where significant fatigue had occurred and resulted in punching in the wheelpaths, some base repairs were necessary. After the base had been proof rolled or repaired, density testing was performed by Harding Lawson and Associates (HLA) staff. Two sand cone and five nuclear density tests were scheduled for each section. Table 7 summarizes the base course density testing.

CONSTRUCTION ASPHALT CEMENT SAMPLING AND TESTING

It was estimated that three or four tanker trucks of asphalt cement would be required to supply the binder needed for rehabilitation. The material from only one or two of the trucks was scheduled for sampling. A total of 3,900 liters (1,030 gallons) of binder was removed from the trucks and storage tanks for samples. Table 8 details the asphalt cement sampling requirements.

No binder testing was performed during construction. All binder testing was performed afterwards on the samples taken during construction.

CONSTRUCTION HOT-MIX AGGREGATE SAMPLING AND TESTING

As previously mentioned, some materials sampled during construction were tested immediately (QC) while most were tested after construction. Hydrated lime and baghouse fines sampling requirements have been included with the aggregate sampling requirements because the same personnel sampling aggregates were sampling these materials. In order to simplify matters, the construction aggregate sampling requirements for trial and test sections, and bottom and top lifts were separated. Tables 9 and 10 indicate the trial section bottom and top lift construction aggregate sampling requirements, respectively. Tables 11 and 12 indicate the test section bottom and top lift construction aggregate sampling requirements, respectively.

Construction aggregate testing was limited to gradation analyses. Sieve analyses were performed on five cold-feed samples per section per lift during construction, as indicated in table 13.

CONSTRUCTION HMA SAMPLING AND TESTING

Both loose HMA and field cores were sampled and tested during construction. Limited loose mix was sampled from behind the paver, while the bulk of the loose mix was sampled from transport trucks. Cores were sampled from each section the day after it was placed. The bulk of the materials sampled during construction were tested after construction.

The testing scheduled immediately after placement of a section (sampled behind the paver) was limited to that associated with mixture volumetrics (gyratory compaction, theoretical maximum specific gravity, and compacted mixture bulk specific gravity testing) and asphalt content and gradation. Like the aggregate, the trial and test lane construction HMA sampling and testing data were separated by trial and test section and bottom and top lift to reduce confusion. Tables 14 and 15 indicate the trial section bottom and top lift construction HMA sampling requirements, respectively. The loose HMA was split and tested immediately to eliminate the need for reheating, and cores were taken and tested as soon as possible.

The test section bottom and top lift construction loose HMA and core sampling requirements are summarized in tables 16 and 17. It is important to note that the samples discussed below are what must be sampled behind the paver. While the material was still hot, it was split down to individual test specimen mass requirements, packaged, and labeled for postconstruction testing. Construction HMA testing was limited to asphalt content determination by the ignition method, gyratory volumetrics, in-place density, and temperature measurements. Temperature measurements were made at the hot plant and in the mat. Table 18 summarizes the construction HMA testing requirements.

DAILY MATERIAL SAMPLING SUMMARY

All of the daily sampling requirements relative to the asphalt cement, hot-mix aggregate, HMA, and cores are detailed in the tables presented in appendix A. In an attempt to simplify matters, a separate table was prepared for each section to be placed on each day. The intention was to have uniform summaries from which all field personnel could work. The tables indicate tests to be performed, sample size, number of samples required, and sampling location. The individual tables are presented in appendix A.

POSTCONSTRUCTION SAMPLING AND TESTING

Raw materials (asphalt cement, aggregate, hydrated lime, and baghouse fines) and loose HMA sampled during construction were tested after construction for mix design verification, quality assurance, and material characterization purposes. The only postconstruction sampling required was field cores and slabs (destructive sampling). Table 19 summarizes the samples to be taken immediately after construction (t=0) and at the end of loading or postmortem (t=24 or t=pm).

POSTCONSTRUCTION ASPHALT CEMENT TESTING

Postconstruction asphalt cement testing was to include both conventional and Superpave grading. The testing was to be performed by UNR.

Postconstruction Asphalt Cement Mix Design Verification and QA Testing

Three tanker truck samples taken during construction were tested as summarized in table 20. The testing in table 20 fulfills both mix design verification and QA testing requirements.

Postconstruction Asphalt Cement Material Characterization Testing

Table 21 shows the testing planned to characterize the binder over time. Both Superpave and conventional test methods were used for postconstruction binder characterization. All of the testing was performed on binder extracted and recovered from field cores.

POSTCONSTRUCTION HOT-MIX AGGREGATE TESTING

The postconstruction hot-mix aggregate testing included both conventional and Superpave testing. The testing was conducted by UNR.

Postconstruction Hot-Mix Aggregate Mix Design Verification and QA Testing

The postconstruction hot-mix aggregate testing requirements are outlined in table 22. This testing fulfilled both QA and mix design verification aggregate testing requirements.

POSTCONSTRUCTION HMA TESTING

HMA was tested for mix design verification, QA, and material characterization purposes. UNR performed the mix design verification testing, HLA performed the QA testing, and Oregon State University (OSU) and University of California, Berkeley (UCB), performed the material characterization testing.

Postconstruction HMA Mixture Design Verification Testing

Postconstruction HMA mix design verification testing consisted of verifying the original Superpave mix design with materials sampled during construction and verifying the mix design properties at the field-observed gradations, based on the results of the core ignition gradation tests performed during construction, for both top and bottom lifts. Five asphalt contents (Optimum-1.0 percent, Optimum-0.5 percent, Optimum, Optimum+0.5 percent, and Optimum+1.0 percent) and three replicates at each asphalt content were evaluated for each of the three gradations described. Moisture susceptibility testing of the target mixture was also performed. Table 23 outlines the postconstruction mix design verification testing requirements. The testing was performed by UNR.

Postconstruction HMA QA Testing

Postconstruction HMA QA testing was performed on loose mix sampled during construction. The testing was performed by HLA and is summarized in table 24.

Postconstruction HMA Material Characterization Testing

The bulk of the HMA material characterization was performed by OSU and UCB. UNR performed volumetrics and resilient modulus testing. Testing was conducted on raw materials that were laboratory-mixed, laboratory-compacted (LMLC); on field-mixed, laboratory-compacted (FMLC) materials; and on field-mixed, field-compacted (FMFC) materials. The FMFC samples (cores and slabs) were sampled two times, immediately after construction prior to loading (t=0) and at the completion of loading or postmortem (t=24 or t=pm). Table 25 summarizes the HMA material characterization testing performed by UNR. Table 26 summarizes the HMA material characterization testing performed by OSU and UCB. Tables 27 through 42 provide details of the testing outlined in table 26. The material characterization testing to be performed by OSU and UCB consisted of SHRP-developed performance testing and moisture sensitivity evaluations.

SUMMARY

This report presented thee materials sampling and testing plans associated with the replacement HMA section paving that was to be performed in June 1997. Sampling and testing plans were divided into three categories:

- Preconstruction – mix design and preconstruction QC/QA.
- Construction – construction QC/QA.
- Postconstruction – postconstruction mixture verification, QA, and mixture characterization.

A summary of the sampling and testing planned within each of these categories has been provided. The sampling and testing of asphalt cement, aggregate, and HMA within each of the categories is described. Details of sampling locations, numbers of samples, sample types, and the testing planned for each sample, along with the team member or institution responsible for performing the testing were provided. Details of sample sizes, labeling, and handling also are provided. Potential paving schedules were presented with daily sampling requirements for each individual test section. The document was designed to be particularly useful to the personnel performing the sampling and testing. Figures 1 through 3 and the tables presented in appendix A were used extensively during construction to ensure proper sampling and sample labeling. The remainder of the report was used by the entire team to coordinate material testing, because it provided a basis for a "uniform language" or common set of materials testing terminology.

REFERENCES

1. Epps, J., Monismith, C., Seeds, S., Alavi, S., Ashmore, C., Leahy, R., and Mitchell, T., "WesTrack Performance – Interim Findings," *Journal of the Association of Asphalt Paving Technologists,* Volume 67, 1998.

2. Epps, J., Monismith, C., Seeds, S., Alavi, S., Ashmore, C., and Mitchell, T., "WesTrack Full-Scale Test Track: Interim Findings," *Proceedings*, Eighth International Conference on Asphalt Pavements, Volume III, August 10-14, 1997, Seattle, WA.

3. "Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction," *Task G Interim Report*, Final Draft, WesTrack Team, March 1996.

	North Tangent												
Block #	2												
Aggregate Gradation	Target				Target				N/A				
AC/AV/Rep	LH	HL*	MM2										
Section #	56	55	54	53	52	51	50	49	48	47	46	45	44
WEST TURN													EAST TURN
Section #	31	32	33	34	35	36	37*	38	39*	40	41	42	43*
AC/AV/Rep					MM1	MH	HM	LM	ML	HM			LH
Aggregate Gradation	N/A				Target				Target				
Block #					1				2				3
	South Tangent												

Shaded sections will not be replaced.

*Indicates sections rehabilitated in November 1996.

Figure 1. Test section layout.

Days of the Week						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	Paving Day 1	Testing	Testing	Testing	Paving Day 2	Testing
Testing	Testing	Paving Day 3	Testing	Testing	Testing	Paving Day 4
Testing	Testing	Testing	Paving Day 5	Testing	Testing	Testing

Figure 2. Potential paving and testing sequence (3-week schedule).

Days of the Week						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	Paving Day 1	Testing	Testing	Testing	Paving Day 2	
	Testing	Testing	Testing	Paving Day 3	Testing	
	Testing	Testing	Paving Day 3	Testing	Testing	
	Testing	Paving Day 5	Testing	Testing	Testing	

Figure 3. Potential paving and testing sequence (4-week schedule).

Table 1. Replacement construction experimental design.

Target Air Void Content	Aggregate Gradation		
	Coarse		
	Target Asphalt Content		
	Optimum -0.7%	Optimum	Optimum +0.7%
4%		39*,**	55
8%	38	35, 54	37
12%	56	36	

* Numbers indicate test section numbers.

** Section 39 was placed in location of original section 23; all other replacement sections have section numbers 30 more than the number of the original section at that location

Table 2. Daily construction plan.

Paving Day	Morning or Afternoon	Location	Lift	Paving Block	Section Numbers	Asphalt Content Levels	Air Void Levels
31	A.M. P.M.	Trial Trial	Bottom Bottom	1 2	35, 36, 37, 38 39, 54, 55, 56	L, M, H L,M, H	M, H L, M, H
32	A.M. P.M.	Trial Trial	Top Top	1 2	35, 36, 37, 38 39, 54, 55, 56	L, M, H L,M, H	M, H L, M, H
33	A.M. P.M.	Test Test	Bottom Bottom	1 2	35, 36, 37, 38 39, 54, 55, 56	L, M, H L,M, H	M, H L, M, H
34	A.M. P.M.	Test Test	Top Top	1 2	35, 36, 37, 38 39, 54, 55, 56	L, M, H L,M, H	M, H L, M, H
35	A.M. P.M.	Contingency					

Asphalt Content Levels:

L = Optimum-0.7 percent
M = Optimum
H = Optimum+0.7 percent

Air Void Content Levels:

L = 4 percent
M = 8 percent
H = 12 percent

Table 3. Preconstruction asphalt cement testing to be conducted at UNR on refinery tank samples.

Specification	Binder Aging	Test Method		Number of Binders Tested
Superpave	Original	Flash Point	T48	2
		Brookfield Viscosity	D4402	2
		DSR	TP5	2
	RTFOT	Mass Loss	T240	2
		DSR	TP5	2
	PAV	DSR	TP5	2
		BBR	TP1	2
		DTT	TP3	2
ASTM and AASHTO	Original	Specific Gravity	D70	0
		Viscosity @ 60°C	D2171	0
		Viscosity @ 135°C	D2170	0
		Penetration @ 25°C	D5	0
		Flash Point	T48	0
		Solubility	D2042	0
	RTFOT	Viscosity @ 60°C	D2171	0
		Ductility @ 25°C	D113	0

Table 4. Preconstruction aggregate sampling requirements.

Material	Number of Samples	Sample Size (lb)
19-mm	7	100
12-mm	7	100
3/8-in.	7	100
Rock Dust	7	100

Table 5. Preconstruction aggregate test requirements.

Specification	Test Method		Individual Stockpile Samples	Combined Aggregate*
ASTM and AASHTO	Gradation	C117, C136	5	0
	Apparent Specific Gravity	C127, C128	3	3
	Bulk Specific Gravity	C127, C128	3	3
	Absorption Capacity	C127, C128	3	3
Superpave	C.A. Angularity	D5821	3	3
	F.A. Angularity	C1252	3	3
	Flat or Elongated	D4791	3	3
	Sand Equivalent	T176	3	3
	L.A. Abrasion	T96	0	0
	Sodium Soundness	T104	0	0
	Deleterious Materials	T112	0	0

*Only the "target" gradation will be tested.

Table 6. Preconstruction mix design testing requirements.

Specification	Test Method		Mixture		
			Target	Target^{+}	Target^{-}
Superpave	Anti-Strip Treatment	NDOT T320	17	17	17
	Short-Term Oven Aging	TP2	23	17	17
	Gyratory Compaction	TP4	21	15	15
	Theoretical Maximum Specific Gravity	T209	2	2	2
	Bulk Specific Gravity	T166	21	15	15
	Moisture Sensitivity	T283	1*	0	0

*Indicates one set of six specimens, three unconditioned and three conditioned.

Table 7. Base course density testing.

Specification	Test Method		Type	Number of Tests
AASHTO	Sand Cone Density	T191	Base course	2/section
AASHTO	Nuclear Density	T238	Base course	2/section

Table 8. Field asphalt cement sampling requirements.

Sampling Details	Receiving Laboratory			
	OSU	UCB	MRL	
Sample Size	5-Gallon	5-Gallon	5-Gallon	1-Gallon
Number of Tanker Trucks to be Sampled*	2	2	2	2
Number of Samples Required per Tanker Truck*	35	8	50	50
Total Samples Required	70	16	100	100

Table 9. Trial section bottom lift construction aggregate sampling requirements.

Material Type	Number of Samples Required	Individual Sample Size	Use
Cold Feeds	2/section	3,000 grams	QC

QC – Construction Quality Control.

Table 10. Trial section top lift construction aggregate sampling requirements.

Material Type	Number of Samples Required	Individual Sample Size	Use
Cold Feeds	2/section	3,000 grams	QC

QC – Construction Quality Control.

Table 11. Test section bottom lift construction aggregate sampling requirements.

Material Type	Number of Samples Required	Individual Sample Size	Use
Cold Feeds	5/section	3,000 grams	QC
	5/section	5-gallon bucket	QA
	5/section	5-gallon bucket	MRL
Stockpile	4/section (1 3/4-in., 1 1/2-in., 1 3/8-in., 1 RD)	5-gallon bucket	UNR
	7/paving day (2 3/4-in., 1 1/2-in., 2 3/8-in., 2 RD)	55-gallon drums	OSU
	27/paving day (8 3/4-in., 3 1/2-in., 8 3/8-in., 8 RD)	55-gallon drums	UCB
	17/section (5 3/4-in., 2 1/2-in., 5 3/8-in., 5 RD)	5-gallon bucket	MRL
Hydrated Lime	3/paving day	5-gallon bucket	MRL
Baghouse Fines	3/paving day	5-gallon bucket	MRL

QC - Construction Quality Control.
QA - Postconstruction Quality Assurance.
UNR (University of Nevada, Reno) - Postconstruction Mix Design Verification.
OSU (Oregon State University) - Postconstruction Material Characterization.
UCB (University of California, Berkeley) - Postconstruction Material Characterization.
MRL (Materials Reference Library) - Postconstruction Material Characterization.

Table 12. Test section top lift construction aggregate sampling requirements.

Material Type	Number of Samples Required	Individual Sample Size	Use
Cold Feeds	5/section	3,000 grams	QC
	5/section	5-gallon bucket	QA
	5/section	5-gallon bucket	MRL
Stockpile	4/section (1 3/4-in., 1 1/2-in., 1 3/8-in., 1 RD)	5-gallon bucket	UNR
	10/paving day (3 3/4-in., 1 1/2-in., 3 3/8-in., 3 RD)	55-gallon drums	OSU
	47/paving day (14 3/4-in., 5 1/2-in., 14 3/8-in., 14 RD)	55-gallon drums	UCB
	34/lift/section (10 3/4-in., 4 1/2-in., 10 3/8-in., 10 RD)	5-gallon bucket	MRL
Hydrated Lime	3/paving day	5-gallon bucket	MRL
Baghouse Fines	3/paving day	5-gallon bucket	MRL

Table 13. Construction aggregate test requirements.

Specification	Test Method		Type	Number of Tests
ASTM	Gradation	C117, C136	Cold Feeds	2/section/lift

Table 14. Trial section bottom lift construction loose HMA and core sampling requirements.

Material Type	Number of Samples Required	Individual Sample Size	Use
Cores	5/section	6-in.	QC - %AV, Ignition %AC, and Gradation
Loose HMA	1/section	5-gallon bucket	QC - Gyratory Volumetrics

QC – Construction Quality Control.

Table 15. Trial section top lift construction loose HMA and core sampling requirements.

Material Type	Number of Samples Required	Individual Sample Size	Use
Cores	5/section	150-mm (6-in.)	QC - %AV, Ignition %AC and Gradation
Loose HMA	1/section	5-gallon bucket	QC - Gyratory Volumetrics

QC – Construction Quality Control.

Table 16. Test section bottom lift construction loose HMA and core sampling requirements.

Material Type	Number of Samples Required	Individual Sample Size	Use
Cores	5/section	150-mm (6-in.)	QC - %AV, Ignition %AC and Gradation
Loose HMA	1/section	5-gallon bucket	QC - Gyratory Volumetrics
	2/section	5-gallon buckets	QA - %AC
	5/section	5-gallon buckets	QA - Gyratory Volumetrics
	1/section	1 box	QA - Marshall
	1/section	1 box	QA - Hveem
	5/section	1 box	QA - Maximum Theoretical Specific Gravity
	1/section	1 box	QA - Moisture Sensitivity
	10/section	5-gallon buckets	OSU/UCB
	10/section	5-gallon buckets	MRL

QC – Construction Quality Control.
QA – Postconstruction Quality Assurance.
OSU (Oregon State University) – Postconstruction Material Characterization.
UCB (University of California, Berkeley) – Postconstruction Material Characterization.
MRL (Materials Reference Library) – Postconstruction Material Characterization.

Table 17. Test section top lift construction loose HMA and core sampling requirements.

Material Type	Number of Samples Required	Individual Sample Size	Use
Cores	5/section	150-mm (6-in)	QC - %AV, Ignition %AC and Gradation
Loose HMA	1/section	5-gallon bucket	QC - Gyratory Volumetrics
	2/section	5-gallon buckets	QA - %AC
	5/section	5-gallon buckets	QA - Gyratory Volumetrics
	1/section	1 box	QA - Marshall
	1/section	1 box	QA - Hveem
	5/section	1 box	QA - Maximum Theoretical Specific Gravity
	1/section	1 box	QA - Moisture Sensitivity
	15/section	5-gallon buckets	OSU/UCB
	20/section	5-gallon buckets	MRL

Table 18. Construction HMA test requirements.

Specification	Test Method		Type	Number of Tests
ASTM	Mix BSG	T166	Cores	5/section/lift
	% AC by Ignition	C	Cores	5/section/lift
	Gradation	C117, C136	Cores	5/section/lift
	Nuclear Density	D2950	Mat	5/section/lift
	Mix Temperature		Truck	5/section/lift
	Mat Temperature		Mat	5/section/lift
	Maximum Theoretical Specific Gravity	T209	Loose HMA	1/section/lift
Superpave	Gyratory Compaction	TP4	Loose HMA	3/section/lift
	Mix BSG	T166	Loose HMA	3/section/lift

Table 19. Destructive sampling requirements.

Receiving Lab	Sample Type			
	Cores		Slabs	
	Sampling Time		Sampling Time	
	t=0	t=24 or post-mortem	T=0	t=24 or postmortem
OSU	20 NWP per section	9 NWP per section	1 NWP (12x12x6) per section	1 NWP (12x12x6) per section
UCB	6 LWP per section	3 NWP and 3 LWP per section	1 LWP (18x20x6) per section	1 LWP (18x20x6) per section
UNR	6 WP per section	6 NWP and 6 LWP per section		

NWP – Nonwheelpath
LWP – Left Wheelpath
WP – Wheelpath

Table 20. Postconstruction binder testing requirements (mix design verification and QA).

Specification	Binder Aging	Test Method		Transport Truck Samples
Superpave	Original	Flash Point	T48	3
		Brookfield Viscosity	D4402	3
		DSR	TP5	3
	RTFOT	Mass Loss	T240	3
		DSR	TP5	3
	PAV	DSR	TP5	3
		BBR	TP1	
		DTT	TP3	3
ASTM and AASHTO	Original	Specific Gravity	D70	0
		Viscosity @ 60°C	D2171	3
		Viscosity @ 135°C	D2170	3
		Penetration @ 25°C	D5	3
		Flash Point	T48	3
		Solubility	D2042	3
	RTFOT	Viscosity @ 60°C	D2171	3
		Ductility @ 25°C	D113	3

Table 21. Postconstruction asphalt cement material characterization testing.

Specification	Binder Aging	Test Method		Time		
				$t = 0_{Construction}$ (pretraffic)	$t = 9_{traffic}$	$t = 24_{traffic}$ or $t=pm_{traffic}$
Superpave	Original	Flash Point Brookfield Viscosity DSR	T48 D4402 TP5			
	RTFOT	Mass Loss DSR	T240 TP5	3*	3*	3*
	PAV	DSR BBR DTT	TP5 TP1 TP3	3** 3**	3** 3**	3** 3**
ASTM and AASHTO	Original	Specific Gravity Viscosity @ 60°C Viscosity @ 135°C Penetration @ 25°C Flash Point Solubility	D70 D2171 D2170 D5 T48 D2042	3* 3*	3* 3*	3* 3*
	RTFOT	Viscosity @ 60°C Ductility @ 25°C	D2171 D113			

* Field-aged (construction operation); RTFOT aging will not be performed.

**Field-aged (construction operation) and in-service to RTFOT condition; PAV aging will be performed.

Table 22. Postconstruction aggregate test requirements (mix design verification and QA).

Specification	Test Method		Individual Stockpile Samples	Combined Aggregate*
ASTM and AASHTO	Apparent Specific Gravity	C127, C128	3	3
	Bulk Specific Gravity	C127, C128	3	3
	Absorption Capacity	C127, C128	3	3
Superpave	C.A. Angularity	D5821	3	3
	F.A. Angularity	C1252	3	3
	Flat or Elongated	D4791	3	3
	Sand Equivalent	T176	3	3
	L.A. Abrasion	T96	3	3
	Sodium Soundness	T104	3	3
	Deleterious Materials	T112	3	3

*Only the "target" gradation will be tested.

Table 23. Postconstruction mix design verification testing requirements.

Specification	Test Method		Mixture		
			Target	Top Lift	Bottom Lift
Superpave	Anti-Strip Treatment	NDOT T320	17	17	17
	Short-Term Oven Aging	TP2	23	17	17
	Gyratory Compaction	TP4	21	15	15
	Theoretical Maximum Specific Gravity	T209	2	2	2
	Bulk Specific Gravity	T166	21	15	15
	Moisture Sensitivity	T283	1*	0	0

*Indicates one set of six specimens, three unconditioned and three conditioned.

Table 24. Postconstruction HMA QA test requirements.

General Property	Test Method	Tests/Sublot	Sublots/Lot	Number of Lots or Sections to be Tested	Number of Lifts
Asphalt Content	Nuclear	1	5	8	2
	Extraction	1	1	8	2
Gradation	Cold feed	1	5	8	2
	Extraction	1	1	8	2
Superpave Gyratory Compaction (N_{max})	Bulk SP GR	2	5	8	2
	Volumetrics	2	5	8	2
Superpave Gyratory Compaction (N_{design})	Bulk SP GR	1	5	8	2
	Volumetrics	1	5	8	2
	M_R	1	5	3*	2
Marshall Compaction	Bulk SP GR	3	1	8	2
	Volumetrics	3	1	8	2
	Stability and Flow	3	1	8	2
Hveem Compaction	Bulk SP GR	3	1	8	2
	Volumetrics	3	1	8	2
	Stability	3	1	8	2
Theoretical Max. Specific Gravity		1	5	8	2

*Low, medium, and high asphalt content with medium air voids only (sections 35, 37, and 38).

Table 25. HMA material characterization testing to be performed by UNR.

Material Type	Testing to be performed
FMFC	Volumetrics - all sections
	Resilient Modulus - all sections

Table 26. HMA material characterization testing to be performed by OSU and UCB.

Material Type	Testing to be Performed
LMLC	Flexural Fatigue - 1 mix (3 temperatures; 2 strain levels; triplicate specimens) – 18 specimens - 4 mixes (1 temperature; 2 strain levels; triplicate specimens) - 24 specimens
	Repeated Simple Shear Constant Height - 1 mix (3 temperatures; 3 stress levels; triplicate specimens) – 27 specimens - 4 mixes (1 temperature; 1 stress level; triplicate specimens) – 12 specimens
	Indirect Tensile Creep and Strength - 0 mixes (3 temperatures; triplicate specimens) - 0 specimens
	Thermal Stress Restrained Specimen Test - 4 mixes (1 temperature; triplicate specimens) - 12 specimens
	AASHTO T283 - 4 mixes (unconditioned and conditioned triplicate specimens) - 24 specimens
FMLC	Flexural Fatigue - 4 mixes (1 temperature; 2 strain levels; triplicate specimens) - 24 specimens
	Repeated Simple Shear Constant Height - 3 mixes (1 temperature; 1 stress level; triplicate specimens) – 9 specimens
	Indirect Tensile Creep and Strength - 0 mixes (3 temperatures; triplicate specimens) - 0 specimens
	Thermal Stress Restrained Specimen Test - 5 mixes (1 temperature; triplicate specimens) - 15 specimens
	AASHTO T283 - 4 mixes (unconditioned and conditioned triplicate specimens) - 24 specimens
FMFC (at t=0, t= post mortem)	Flexural Fatigue - 8 mixes (1 temperature; 2 strain levels; triplicate specimens) - 48 specimens
	Repeated Simple Shear Constant Height - 8 mixes (1 temperature; 1 stress level; triplicate specimens) – 24 specimens
	Indirect Tensile Creep and Strength - 0 mixes (3 temperatures; triplicate specimens) - 0 specimens
	Thermal Stress Restrained Specimen Test - 4 mixes (1 temperature; triplicate specimens) - 12 specimens
	AASHTO T283 - 4 mixes (unconditioned and conditioned triplicate specimens) - 24 specimens

Table 27. LMLC permanent deformation test plan.

% Asphalt Cement	Minus 0.075-mm Material	% Air Voids		
		Low	Medium	High
Low	Low			
	Medium			
	High			
Medium	Low	C		
	Medium	C*	C	
	High	C		
High	Low			
	Medium	C		
	High			

*Testing performed at three temperatures.

Table 28. LMLC fatigue cracking test plan.

% Asphalt Cement	Minus 0.075-mm Material	% Air Voids		
		Low	Medium	High
Low	Low			
	Medium		C	
	High			
Medium	Low		C	
	Medium		C*	
	High		C	
High	Low			
	Medium	C		
	High			

*Testing performed at three temperatures.

Table 29. LMLC low temperature cracking test plan.*

% Asphalt Cement	Minus 0.075mm Material	% Air Voids		
		Low	Medium	High
Low	Low			
	Medium		C	
	High			
Medium	Low			
	Medium	C	C	
	High			
High	Low			
	Medium		C	
	High			

*Thermal Stress Restrained Specimen Test (TSRST) only.

Table 30. LMLC moisture sensitivity test plan.

% Asphalt Cement	Minus 0.075mm Material	% Air Voids		
		Low	Medium	High
Low	Low			
	Medium		C	
	High			
Medium	Low			
	Medium		C	C
	High			
High	Low			
	Medium		C	
	High			

Table 31. FMLC permanent deformation test plan (three sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low			
Medium	C-39	C-35	
High	C-55		

Table 32. FMLC fatigue cracking test plan (four sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	C-56
Medium		C-35	
High	C-55		

Table 33. FMLC low temperature cracking test plan (five sections).*

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	
Medium	C-39	C-35	C-36
High		C-37	

*TSRST only.

Table 34. FMLC moisture sensitivity test plan (four sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	
Medium		C-35	C-36
High		C-37	

Table 35. FMFC permanent deformation test plan (time = 0, eight sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	C-56
Medium	C-39	C-35, C-54	C-36
High	C-55	C-37	

Table 36. FMFC fatigue cracking test plan (time = 0, eight sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	C-56
Medium	C-39	C-35, C-54	C-36
High	C-55	C-37	

Table 37. FMFC low temperature cracking test plan (time = 0, four sections).*

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	
Medium	C-39	C-35	
High		C-37	

*TSRST only.

Table 38. FMFC moisture sensitivity test plan (time = 0, four sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	
Medium		C-35	C-36
High		C-37	

Table 39. FMFC permanent deformation test plan (time = postmortem, eight sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	C-56
Medium	C-39	C-35, C-54	C-36
High	C-55	C-37	

Table 40. FMFC fatigue cracking test plan (time = postmortem, eight sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	C-56
Medium	C-39	C-35, C-54	C-36
High	C-55	C-37	

Table 41. FMFC low temperature cracking test plan (time = postmortem, four sections).*

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	
Medium	C-39	C-35	
High		C-37	

*TSRST only.

Table 42. FMFC moisture sensitivity test plan (time = postmortem, four sections).

% Asphalt Cement	% Air Voids		
	Low	Medium	High
Low		C-38	
Medium		C-35	C-36
High		C-37	

APPENDIX A

DAILY SAMPLING REQUIREMENTS BY SECTION

Table A1. Section 35, bottom lift trial lane sampling plan.

Date: 5/23/97 Section Number: **35**
Paving Day: 31 Lane: Trial

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A2. Section 36, bottom lift trial lane sampling plan.

Date: 5/23/97 Section Number: **36**
Paving Day: 31 Lane: Trial

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A3. Section 37, bottom lift trial lane sampling plan.

Date: 5/23/97 Section Number: **37**
Paving Day: 31 Lane: Trial

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A4. Section 38, bottom lift trial lane sampling plan.

Date: 5/23/97 Section Number: **38**
Paving Day: 31 Lane: Trial

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A5. Section 39, bottom lift trial lane sampling plan.

Date: 5/23/97 Section Number: **39**
Paving Day: 31 Lane: Trial

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A6. Section 54, bottom lift trial lane sampling plan.

Date: 5/23/97 Section Number: **54**
Paving Day: 31 Lane: Trial

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A7. Section 55, bottom lift trial lane sampling plan.

Date: 5/23/97 Section Number: **55**
Paving Day: 31 Lane: Trial

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A8. Section 56, bottom lift trial lane sampling plan.

Date: 5/23/97 Section Number: **56**
Paving Day: 31 Lane: Trial

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A9. Section 35, top lift trial lane sampling plan.

Date: 5/28/97 Section Number: **35**
Paving Day: 32 Lane: Trial

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4”, 1 1/2”, 2 3/8”, 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A10. Section 36, top lift trial lane sampling plan.

Date: 5/28/97 Section Number: **36**
Paving Day: 32 Lane: Trial

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A11. Section 37, top lift trial lane sampling plan.

Date: 5/28/97 Section Number: **37**
Paving Day: 32 Lane: Trial

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4”, 1 1/2”, 2 3/8”, 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A12. Section 38, top lift trial lane sampling plan.

Date: 5/28/97 Section Number: **38**
Paving Day: 32 Lane: Trial

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4”, 1 1/2”, 2 3/8”, 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A13. Section 39, top lift trial lane sampling plan.

Date: 5/28/97 Section Number: **39**
Paving Day: 32 Lane: Trial

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A14. Section 54, top lift trial lane sampling plan.

Date: 5/28/97 Section Number: **54**
Paving Day: 32 Lane: Trial

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A15. Section 55, top lift trial lane sampling plan.

Date: 5/28/97 Section Number: **55**
Paving Day: 32 Lane: Trial

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A16. Section 56, top lift trial lane sampling plan.

Date: 5/28/97 Section Number: **56**
Paving Day: 32 Lane: Trial

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	0			Hot Plant	
Cold Feed Agg (MRL)	0			Hot Plant	
Cold Feed Gradation	2	2,500	2	Hot Plant	
Ignition Gradation (cores)	*	*	1	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	0			Truck	
Gyratory AV & Volumetrics	0			*	
Max Theo SG (Rice) QA	0			Truck	
Marshall Properties	0			Truck	
Hveem Properties	0			Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity	0			Truck	
Bulk HMA (OSU)	0			Truck	
Bulk HMA (UCB)	0			Truck	
Bulk HMA (MRL)	0			Truck	
Baghouse Fines (MRL)	0			Return	
Lime (MRL)	0			Silo	
Stockpile Samples (OSU)	0			Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	0			Hot Plant	
Stockpile Samples (UNR)	0			Hot Plant	
Stockpile Samples (MRL)	0			Hot Plant	

*Samples obtained from previous test.

Table A17. Section 35, bottom lift test lane sampling plan.

Date: 5/30/97 Section Number: **35**
Paving Day: 33 Lane: Test

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	1	35 buckets		Tank	
Asphalt Cement (UCB)	1	8 buckets		Tank	
Asphalt Cement (UNR)	1	50 buckets		Tank	
Asphalt Cement (MRL)	1	50 buckets		Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	5 buckets	0	Truck	
Bulk HMA (UCB)	1	5 buckets	0	Truck	
Bulk HMA (MRL)	1	10 buckets	0	Truck	
Baghouse Fines (MRL)	1	3 buckets	0	Return	
Lime (MRL)	1	3 buckets	0	Silo	
Stockpile Samples (OSU)	1	7 drums	0	Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	1	27 drums	0	Hot Plant	8 3/4", 3 1/2", 8 3/8", 8 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1RD
Stockpile Samples (MRL)	1	17 buckets	0	Hot Plant	5 3/4", 2 1/2", 5 3/8", 5 RD

*Samples obtained from previous test.

Table A18. Section 36, bottom lift test lane sampling plan.

Date: 5/30/97 Section Number: **36**
Paving Day: 33 Lane: Test

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	5 buckets	0	Truck	
Bulk HMA (UCB)	1	5 buckets	0	Truck	
Bulk HMA (MRL)	1	10 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	7 drums	0	Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	1	27 drums	0	Hot Plant	8 3/4", 3 1/2", 8 3/8", 8 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	17 buckets	0	Hot Plant	5 3/4", 2 1/2", 5 3/8", 5 RD

*Samples obtained from previous test.

Table A19. Section 37, bottom lift test lane sampling plan.

Date: 5/30/97 Section Number: **37**
Paving Day: 33 Lane: Test

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	5 buckets	0	Truck	
Bulk HMA (UCB)	1	5 buckets	0	Truck	
Bulk HMA (MRL)	1	10 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	7 drums	0	Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	1	27 drums	0	Hot Plant	8 3/4", 3 1/2", 8 3/8", 8 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	17 buckets	0	Hot Plant	5 3/4", 2 1/2", 5 3/8", 5 RD

*Samples obtained from previous test.

Table A20. Section 38, bottom lift test lane sampling plan.

Date: 5/30/97 Section Number: **38**
Paving Day: 33 Lane: Test

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	5 buckets	0	Truck	
Bulk HMA (UCB)	1	5 buckets	0	Truck	
Bulk HMA (MRL)	1	10 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	7 drums	0	Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	1	27 drums	0	Hot Plant	8 3/4", 3 1/2", 8 3/8", 8 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	17 buckets	0	Hot Plant	5 3/4", 2 1/2", 5 3/8", 5 RD

*Samples obtained from previous test.

Table A21. Section 39, bottom lift test lane sampling plan.

Date: 5/30/97 Section Number: **39**
Paving Day: 33 Lane: Test

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	5 buckets	0	Truck	
Bulk HMA (UCB)	1	5 buckets	0	Truck	
Bulk HMA (MRL)	1	10 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	7 drums	0	Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	1	27 drums	0	Hot Plant	8 3/4", 3 1/2", 8 3/8", 8 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	17 buckets	0	Hot Plant	5 3/4", 2 1/2", 5 3/8", 5 RD

*Samples obtained from previous test.

Table A22. Section 54, bottom lift test lane sampling plan.

Date: 5/30/97 Section Number: **54**
Paving Day: 33 Lane: Test

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	5 buckets	0	Truck	
Bulk HMA (UCB)	1	5 buckets	0	Truck	
Bulk HMA (MRL)	1	10 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	7 drums	0	Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	1	27 drums	0	Hot Plant	8 3/4", 3 1/2", 8 3/8", 8 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	17 buckets	0	Hot Plant	5 3/4", 2 1/2", 5 3/8", 5 RD

*Samples obtained from previous test.

Table A23. Section 55, bottom lift test lane sampling plan.

Date: 5/30/97 Section Number: **55**
Paving Day: 33 Lane: Test

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	5 buckets	0	Truck	
Bulk HMA (UCB)	1	5 buckets	0	Truck	
Bulk HMA (MRL)	1	10 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	7 drums	0	Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	1	27 drums	0	Hot Plant	8 3/4", 3 1/2", 8 3/8", 8 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	17 buckets	0	Hot Plant	5 3/4", 2 1/2", 5 3/8", 5 RD

*Samples obtained from previous test.

Table A24. Section 56, bottom lift test lane sampling plan.

Date: 5/30/97 Section Number: **56**
Paving Day: 33 Lane: Test

Lift: **Bottom**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	5 buckets	0	Truck	
Bulk HMA (UCB)	1	5 buckets	0	Truck	
Bulk HMA (MRL)	1	10 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	7 drums	0	Hot Plant	2 3/4", 1 1/2", 2 3/8", 2 RD
Stockpile Samples (UCB)	1	27 drums	0	Hot Plant	8 3/4", 3 1/2", 8 3/8", 8 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	17 buckets	0	Hot Plant	5 3/4", 2 1/2", 5 3/8", 5 RD

*Samples obtained from previous test.

Table A25. Section 35, top lift test lane sampling plan.

Date: 6/3/97 Section Number: **35**
Paving Day: 34 Lane: Test

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	1	35 buckets		Tank	
Asphalt Cement (UCB)	1	8 buckets		Tank	
Asphalt Cement (UNR)	1	50 buckets		Tank	
Asphalt Cement (MRL)	1	50 buckets		Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	7 buckets	0	Truck	
Bulk HMA (UCB)	1	8 buckets	0	Truck	
Bulk HMA (MRL)	1	20 buckets	0	Truck	
Baghouse Fines (MRL)	1	3 buckets	0	Return	
Lime (MRL)	1	3 buckets	0	Silo	
Stockpile Samples (OSU)	1	10 drums	0	Hot Plant	3 3/4”, 1 1/2”, 3 3/8”, 3 RD
Stockpile Samples (UCB)	1	47 drums	0	Hot Plant	14 3/4”,5 1/2",14 3/8”,14 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4”, 1 1/2”, 1 3/8”, 1 RD
Stockpile Samples (MRL)	1	34 buckets	0	Hot Plant	10 3/4”,4 1/2”,10 3/8”,10 RD

*Samples obtained from previous test.

Table A26. Section 36, top lift test lane sampling plan.

Date: 6/3/97 Section Number: **36**
Paving Day: 34 Lane: Test

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	7 buckets	0	Truck	
Bulk HMA (UCB)	1	8 buckets	0	Truck	
Bulk HMA (MRL)	1	20 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	10 drums	0	Hot Plant	3 3/4”, 1 1/2”, 3 3/8”, 3 RD
Stockpile Samples (UCB)	1	47 drums	0	Hot Plant	14 3/4”,5 1/2”,14 3/8”,14 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4”, 1 1/2”, 1 3/8”, 1 RD
Stockpile Samples (MRL)	1	34 buckets	0	Hot Plant	10 3/4”,4 1/2”,10 3/8”,10 RD

*Samples obtained from previous test.

Table A27. Section 37, top lift test lane sampling plan.

Date: 6/3/97 Section Number: **37**
Paving Day: 34 Lane: Test

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	7 buckets	0	Truck	
Bulk HMA (UCB)	1	8 buckets	0	Truck	
Bulk HMA (MRL)	1	20 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	10 drums	0	Hot Plant	3 3/4”, 1 1/2”, 3 3/8”, 3 RD
Stockpile Samples (UCB)	1	47 drums	0	Hot Plant	14 3/4”,5 1/2",4 3/8”,14 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4”, 1 1/2”, 1 3/8”, 1 RD
Stockpile Samples (MRL)	1	34 buckets	0	Hot Plant	10 3/4”,4 1/2”,10 3/8”,10 RD

*Samples obtained from previous test.

Table A28. Section 38, top lift test lane sampling plan.

Date: 6/3/97 Section Number: **38**
Paving Day: 34 Lane: Test

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	7 buckets	0	Truck	
Bulk HMA (UCB)	1	8 buckets	0	Truck	
Bulk HMA (MRL)	1	20 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	10 drums	0	Hot Plant	3 3/4", 1 1/2", 3 3/8", 3 RD
Stockpile Samples (UCB)	1	47 drums	0	Hot Plant	14 3/4",5 1/2",14 3/8",14 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	34 buckets	0	Hot Plant	10 3/4",4 1/2",10 /8",10 RD

*Samples obtained from previous test.

Table A29. Section 39, top lift test lane sampling plan.

Date: 6/3/97 Section Number: **39**
Paving Day: 34 Lane: Test

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	7 buckets	0	Truck	
Bulk HMA (UCB)	1	8 buckets	0	Truck	
Bulk HMA (MRL)	1	20 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	10 drums	0	Hot Plant	3 3/4", 1 1/2", 3 3/8", 3 RD
Stockpile Samples (UCB)	1	47 drums	0	Hot Plant	14 3/4",5 1/2",14 3/8",14 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	34 buckets	0	Hot Plant	10 3/4",4 1/2",10 3/8",10 RD

*Samples obtained from previous test.

Table A30. Section 54, top lift test lane sampling plan.

Date: 6/3/97 Section Number: **54**
Paving Day: 34 Lane: Test

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	7 buckets	0	Truck	
Bulk HMA (UCB)	1	8 buckets	0	Truck	
Bulk HMA (MRL)	1	20 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	10 drums	0	Hot Plant	3 3/4", 1 1/2", 3 3/8", 3 RD
Stockpile Samples (UCB)	1	47 drums	0	Hot Plant	14 3/4",5 1/2",14 3/8",14 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	34 buckets	0	Hot Plant	10 3/4",4 1/2",10 3/8",10 RD

*Samples obtained from previous test.

Table A31. Section 55, top lift test lane sampling plan.

Date: 6/3/97 Section Number: **55**
Paving Day: 34 Lane: Test

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	7 buckets	0	Truck	
Bulk HMA (UCB)	1	8 buckets	0	Truck	
Bulk HMA (MRL)	1	20 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	10 drums	0	Hot Plant	3 3/4", 1 1/2", 3 3/8", 3 RD
Stockpile Samples (UCB)	1	47 drums	0	Hot Plant	14 3/4",5 1/2",14 3/8",14 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	34 buckets	0	Hot Plant	10 3/4",4 1/2",10 3/8",10 RD

*Samples obtained from previous test.

Table A32. Section 56, top lift test lane sampling plan.

Date: 6/3/97 Section Number: **56**
Paving Day: 34 Lane: Test

Lift: **Top**

Test to be Performed	Number of Samples	Sample Size (grams)	Samples to be Tested Immediately	Sample Location	Upon Completion Deliver To
Asphalt Cement (OSU)	0			Tank	
Asphalt Cement (UCB)	0			Tank	
Asphalt Cement (UNR)	0			Tank	
Asphalt Cement (MRL)	0			Tank	
BSG (cores)	5	150mm	5	Mat	
%AC by ignition	*	*	5	Mat	
Cold Feed Agg Tests (misc)	1	5 buckets	0	Hot Plant	
Cold Feed Agg (MRL)	1	5 buckets		Hot Plant	
Cold Feed Gradation	5	2,500	5	Hot Plant	
Ignition Gradation (cores)	*	*	5	*	
Gyratory BSG (QC)	3	5,500	3	Mat	
Gyratory AV & Volumetrics	*	*	3	*	
Max Theo SG (Rice) QC	1	2,500	1	Mat	
Gyratory BSG (QA)	5	1 box	0	Truck	
Gyratory AV & Volumetrics	*		0	*	
Max Theo SG (Rice) QA	5	2,000	0	Truck	
Marshall Properties	1	1 box	0	Truck	
Hveem Properties	1	1 box	0	Truck	
HMA Temperature (Truck)	5		5	Truck	
HMA Temperature (Mat)	5		5	Mat	
Water Sensitivity (QA)	1	1 box	0	Truck	
Bulk HMA (OSU)	1	7 buckets	0	Truck	
Bulk HMA (UCB)	1	8 buckets	0	Truck	
Bulk HMA (MRL)	1	20 buckets	0	Truck	
Baghouse Fines (MRL)	0		0	Return	
Lime (MRL)	0		0	Silo	
Stockpile Samples (OSU)	1	10 drums	0	Hot Plant	3 3/4", 1 1/2", 3 3/8", 3 RD
Stockpile Samples (UCB)	1	47 drums	0	Hot Plant	14 3/4",5 1/2",14 3/8",14 RD
Stockpile Samples (UNR)	1	4 buckets	0	Hot Plant	1 3/4", 1 1/2", 1 3/8", 1 RD
Stockpile Samples (MRL)	1	34 buckets	0	Hot Plant	10 3/4",4 1/2",10 3/8",10 RD

*Samples obtained from previous test.

Coarse Aggregate Angularity of the WesTrack Project Aggregates

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides detailed information on the coarse aggregate angularity (CAA) of the WesTrack Project aggregates. It has been suggested that the premature permanent deformation of the coarse mix originally placed at WesTrack may have been due to a lack of angularity of the partially crushed gravel incorporated in the mixture. Additionally, a wide range of angularity values have been reported by others for the WesTrack aggregates. In an effort to obtain CAA test results that could be reported with a high level of confidence, an experimental test program (interlaboratory study) was developed and executed. The goal of the effort was to develop a precision and bias statement, in accordance with American Society for Testing and Materials (ASTM) standards, for the coarse aggregate angularity test procedure using WesTrack materials and to obtain multiple test results on the materials, which could be used to define a "good" representative value for CAA on WesTrack aggregates.

BACKGROUND

In recent years, many States have experienced an increase in the severity and extent of permanent deformation in HMA pavements. The increased rutting has been attributed to increases in truck tire pressures, axle loads, and traffic volumes. The tire pressure and axle load increases mean that HMA near the pavement surface is under greater stresses than those assumed when structural designs are performed in accordance with the 1986 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement*

Structures, which is based on 80-kN (18,000-lb) axle loads and tire contact pressures of 75 to 80 psi (520 to 550 kPa).[4]

In 1987, concern over high truck tire pressures and rutting led to a national symposium on the subject.[5] Symposium participants concluded that increased truck weights and tire pressures had led to an increase in rutting. They also believed that rutting could be minimized by giving more attention to materials selection, mix design, and construction practices.

Several field studies have been conducted in the last 15 years in an effort to try to identify material properties and/or design parameters that relate to rutting. Many evaluated only a limited number of pavement sections. Larger evaluations, conducted by Ford [6] in Arkansas and Kandhal [7] in Pennsylvania, each evaluated over 30 sites in their respective States to determine parameters that relate to rutting.

In 1992, the National Center for Asphalt Technology (NCAT) published the results of "A National Study of Rutting in Hot-Mix Asphalt Pavements."[8] Forty-two pavements from all regions of the United States (14 States), encompassing various climatic zones, containing aggregates of different origins and angularity, and involving different specifying agencies and construction practices, were sampled and evaluated. The objectives of the study were to:

- Identify material properties, mix design parameters, and construction practices that affect rutting.
- Provide information necessary to produce HMA that would perform satisfactorily.
- Provide information to identify those mixes with a tendency to rut under today's traffic loadings.

In the study, rate of rutting was represented as the maximum rut depth at the pavement surface divided by the square root of the total applied traffic in ESALs. One of the material properties evaluated in the study was CAA. Aggregate particles were considered crushed if they had two or more fractured faces.

The NCAT researchers found a weak, but positive, relationship between CAA and rutting rate. When HMA in-place air voids were greater than 3.0 percent, rutting rates decreased as CAA increased. In cases where in-place air voids were below 2.5 percent, CAA did not contribute to rutting resistance. Figure 1, taken from Ref. 8, represents the relationship between rutting rate and CAA with 20th percentile in-place air voids greater than 2.5 percent. As previously mentioned, the fit of the linear relationship was weak (R^2=0.42), but positive. A high level of scatter existed in the data, even when the CAA was greater than 95 percent.

As an initial step in NCHRP Project 4-19, "Aggregate Tests Related to Asphalt Concrete Performance in Pavements," Kandhal et al., developed state-of-the-practice of aggregate tests for HMA used in the United States. Aggregate tests and specifications used by State transportation agencies to control quality of aggregate for HMA were summarized. In 1994, the specifications of 45 States were reviewed, summarized, submitted to respective States for review, and finally made available in a report entitled, "Aggregate Tests for Hot-Mix Asphalt: State of the Practice."[9]

At that time, coarse aggregate particle shape and surface texture were characterized by State highway departments using one or more of the following three test methods:

1. ASTM D3398, Index of Aggregate Particle Shape and Texture
2. ASTM D4791, Flat or Elongated Particles in Coarse Aggregate
3. ASTM D5821, Determining the Percentage of Fractured Particles in Coarse Aggregate

The State practices used at the time of the survey to control aggregate particle shape and surface texture are summarized in figure 2. Every State surveyed had a minimum fractured face/crushed particle requirement for coarse aggregate. Thirty-seven percent of the States surveyed had requirements for maximum percentage of flat and elongated particles , while only one State limited the maximum percentage of rounded particles. It should be noted that ASTM D3398 was only used for research purposes at the time.

As previously mentioned, ASTM D5821, or variations thereof, were used by all States surveyed for determining percentage of fractured particles. Most States had their own criteria for what constituted a fractured face. That is probably due to the vagueness associated with the definition in ASTM D5821.

Some States applied the fractured face requirements to entire aggregate blends while others specifically directed the requirements to crushed gravel components of a blend. Some States specified the minimum percentage of particles with one or more fractured faces. Others specified the minimum percentage of particles with two or more fractured faces, and some had requirements for both one or more and two or more fractured faces. Requirements also varied for base, binder, and surface courses. Figures 3 and 4, and 5 and 6, illustrate fractured face requirements for binder and surface courses, respectively. Figures 3 and 5 are histograms that represent requirements for one or more fractured faces, while figures 4 and 6 represent requirements for two or more fractured faces.

All States had requirements for one or more fractured faces for binder and surface courses. However, only 44 and 58 percent of the States surveyed had requirements for two or more faces for binder and surface courses, respectively. The figures, along with table 1, are indications that requirements were generally more stringent for the layer nearest the pavement surface. This is rational if CAA does contribute to rutting resistance, as the greatest shear stresses induced in the pavement layer are near the surface.

SUPERPAVE CAA SPECIFICATION

One of the goals of the SHRP was to develop specifications for aggregates and asphalt aggregate mixtures.[10] A modified Delphi procedure, which drew upon the combined knowledge (opinion) of a group of 14 experts (Aggregate Expert Task Group), was used to develop the aggregate specifications in the Superpave mix design system. The specifications were based entirely on expert opinion.

The Delphi method attempts to avoid the negative effects that may result from group dynamics in face-to-face meetings while retaining the strengths of group decisions. A unique aspect of the Delphi method is that group members remain anonymous to each other. This is accomplished through the use of questionnaires administered by a coordinator. Experts only deal with the coordinator, not with each other. The process is evolutionary, typically proceeding through a series of four to six rounds, beginning with general issues and converging toward specific findings. At the completion of each round, group members receive tabulated responses and statistics calculated from questionnaire results. The purpose of the initial questionnaire is to formulate issues and solicit potential options. The coordinator collects the questionnaires, summarizes the information, and disseminates the information to the participants along with a follow-up questionnaire. This process continues through a series of rounds that tend to narrow the spread of the responses, but does not necessarily guarantee consensus.

The Delphi procedure used in the development of the Superpave aggregate specifications was modified so that the experts were permitted one face-to-face meeting. The procedure involved five rounds of questionnaires. The first, fourth, and fifth rounds were conducted by mail. The second and third rounds were conducted during the one face-to-face meeting of the experts.

The initial questionnaire developed and sent to the expert task group (ETG) listed seven possible aggregate characteristics and an open-ended request for the respondents to suggest other characteristics that might be included in aggregate specifications. The experts were asked to rate their degree of disagreement or agreement with the inclusion of each characteristic as a specification. They were also asked to list suggested measurements for establishing the specification for each of the possible characteristics, to provide external factors that would have an effect on each characteristic specification limit, and to describe how the external factors would affect the specification limits. Examples of external factors would be items such as traffic level or environmental conditions. Of the seven possible characteristics, *gradation limits* received the highest degree of agreement, followed by *crushed faces* (aggregate angularity).

The second questionnaire requested that the respondents rank the seven aggregate characteristics. Additionally, a method of soliciting information about the possible effects of five external factors was included. The factors were:

1. Moisture level.
2. July mean daily high temperature.
3. Lowest expected annual temperature.
4. Traffic level (design ESALs).
5. Pavement depth (inches from the surface).

Scenarios of different highway locations defined by eight combinations of levels of the five factors were contained in the questionnaire. The experts were requested to consider the eight scenarios and to indicate their best judgment of specification limit values for each. A partial factorial design (2^{5-2}) was used to generate the scenarios that involved highway locations of differing traffic loading and weather conditions. As with the first questionnaire, *crushed faces* ranked second only to *gradation limits*. Preliminary findings indicated that *traffic level* was the external factor having the greatest effect on specification limits. *Pavement depth*, along with

July mean daily high temperature and *lowest expected annual temperature*, had statistically significant effects on the values of at least one of the specification limits also.

The third questionnaire asked for ratings of both possible characteristics and possible measurements for establishing specification limits. It included a few additional characteristics that were suggested in the responses to the first round. At that point, *crushed faces* were divided into *coarse aggregate angularity* and *fine aggregate angularity*. Another partial factorial design (2^{5-2}) was used to obtain more information about the effects of the external factors. *Coarse aggregate angularity* ranked second to *gradation limits*. *Traffic level* was the external factor that had the greatest effect on specification limits.

It was reasonably clear which characteristics should be included in the specifications after the third round; however, it was less clear which measurement (method) should be used for each characteristic. It was decided that a "forced measurement choice" would be implemented in the fourth questionnaire. In addition to ranking the characteristics, the experts were required to rank each proposed method of measurement for a characteristic, assuming the characteristic would be included as a specification. An analysis of variance of the measurement ranks was performed.

Coarse aggregate angularity ranked the highest in responses to the fourth questionnaire, but a "best" measurement technique was not identified for quantifying this characteristic.

Based on discussions during the meeting of the ETG and the results of the four Delphi rounds, SHRP decided upon the characteristics and measurements to be incorporated into specifications. The fifth and final questionnaire had two purposes:

- To determine the values of the measurements that should serve to define specification limits.
- To assess the impact of external factors on these values.

The questionnaire incorporated a set of highway scenarios based on a 2^{4-1} fractional factorial that included four of the five originally considered external factors. *Moisture level* was dropped because it had never been found statistically significant in the preliminary studies. The fractional factorial permitted an evaluation of the overall average value for any particular measurement, along with an assessment of the differences among the experts and of the possible effects of the external factors.

Analysis of the fifth questionnaire indicated that only *traffic level* and *pavement depth* had statistically significant effects on any of the measurement values specified by the experts. Although there was general agreement among the experts about the effects of the external factors, there was no overall agreement about what the measurement values should be. This was due to large variability in the responses (some experts specified high values while others specified low values for specific measurements). The data were trimmed to delete responses at the high and low end of the spectrum for each measurement and average trimmed responses were determined.

These average trimmed responses and the statistical significance associated with the external factors were then used by SHRP to develop the criteria and specification limits for aggregates in

the Superpave mix design system. *Coarse aggregate angularity* was defined by SHRP as the percentage by weight of aggregate particles larger than 4.75 mm with one or more fractured faces. A fractured face was defined as a fractured surface larger than 25 percent of the maximum aspect ratio of the aggregate particle. CAA was to be measured on the coarse (plus 4.75 mm) particles of aggregate blends.

Unfortunately, a CAA angularity measurement method was not determined in this process. However, at the completion of SHRP, the FHWA Office of Technology Applications (OTA) promoted the use of Pennsylvania Department of Transportation (DOT) Test Method 621. An ASTM standard (D5821-95), which is very similar to the Pennsylvania method, was subsequently developed and is currently the standard used for CAA measurements.[11]

The Superpave CAA requirements are a function of traffic level and position of the HMA within the pavement structure.[10] Table 2 represents the Superpave CAA requirements.[12,13] The requirements for the top lift at WesTrack (<$30x10^6$ ESALs and <100 mm depth from the surface) were 95/90, which meant that 95 percent of the coarse aggregate had to have one fractured face and 90 percent had to have two fractured faces.

CAA TEST METHOD

The current standard used for CAA measurement is ASTM D5821-95, "Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate."[11] The test method covers the determination of the percentage, by mass or count, of a coarse aggregate sample that consists of fractured particles meeting specified requirements.

Three definitions are provided in the test method. "*Fractured face* is defined as an angular, rough, or broken surface of an aggregate particle created by crushing, by other artificial means, or by nature. *Fractured particle* is defined as a particle of aggregate having at least the minimum number of fractured faces specified. *Discussion — for the standard,* a face will be considered a fractured face only if it has a projected area at least as large as one quarter of the maximum projected area (maximum cross-sectional area) of the particle and the face has sharp and well-defined edges; this excludes small nicks."

The subjective nature of the test method stems from the third definition, specifically the portion that states "the face has sharp and well-defined edges." The method does not provide a definition of sharp or well-defined edges. The interpretation of sharp and well-defined edges is left entirely to the discretion of the technician performing the test. At the time this ASTM standard was being proposed, the National Stone Association noted that "Personal judgment plays a big part in determining crushed faces."[14]

The test procedure itself is very simple. Aggregate is sampled and split to appropriate test sample size, which is a function of nominal maximum size. The sample is washed, dried, spread on a clean dry surface, and separated into one of three categories:

1. Fractured particles based on whether the particle has the required number of fractured faces.

2. Particles not meeting the specified criteria.
3. Questionable or borderline particles.

The mass or count of particles in each category is then used to calculate the percentage fractured particles, although Superpave requires the percentage be calculated on a mass basis, using the following equation:

$$P=\{(F+Q/2)/(F+Q+N)\}x100$$

where:

P = percentage of particles with the specified number of fractured faces
F = mass or count of fractured particles with at least the specified number of fractured faces
Q = mass or count of particles in the questionable or borderline category
N = mass or count of particles in uncrushed category not meeting the fractured particle criteria

The method states that if on any determination more than 15 percent of the total is placed in the questionable category, determinations will be repeated until no more than 15 percent is present in the category.

PRECISION AND BIAS

When tests are performed on presumably identical materials under presumably identical circumstances, it is not likely that identical results will be obtained. The difference in results is attributed to unavoidable random errors inherent in every test procedure. In other words, the factors that influence the outcome of a test cannot all be completely controlled. For practical interpretation of test results, this inherent variability must be accounted for. As an example, the difference between a test result and some specified value might be within that which can be expected due to unavoidable random error, in which case real deviation from the specified value has not been demonstrated. Similarly, the difference between test results from two batches of material will not indicate a fundamental quality difference if the difference is no greater than that which may be attributed to inherent variability in the test procedure.

Several factors may contribute to the variability associated with the application of a test method. They include:

- The operator.
- The equipment used.
- Equipment calibration.
- The environment.

In the case of the CAA test procedure, the primary factor of concern is the operator because only very basic equipment is employed and environmental factors such as temperature and humidity should not directly affect test results.

An ASTM precision statement normally contains elements of single-operator (within laboratory) precision and multilaboratory (between laboratory) precision. Single-operator precision is a measure of the greatest difference between two results that would be considered acceptable when properly conducted repetitive determinations are made on the same material by the same competent operator. Multilaboratory precision is a measure of the range (greatest difference between two test results) that would be considered acceptable when properly conducted determinations are made by two different operators in different laboratories on portions of a material that are intended to be identical, or at least as nearly identical as possible. Single-operator precision is sometimes referred to as "repeatability" or within-laboratory precision, while multilaboratory precision is sometimes referred to as "reproducibility" or between-laboratory precision.

Section 3.0 of ASTM C670-96 provides a description of the statistical terms actually incorporated in precision and bias statements. The fundamental statistic underlying all indexes of precision is the standard deviation of the population of measurements, termed the "one-sigma limit" and abbreviated (ls). It is an indication of the variability of a large group of individual test results obtained under similar conditions. One-sigma limits are determined for both single operator and multilaboratory conditions. In some cases, it is appropriate to use the coefficient of variation in place of the standard deviation as the fundamental statistic. Use of the coefficient of variation is further discussed in the Precision Statements section of this report. The statistic is termed the "one-sigma limit in percent" and is abbreviated (ls%). It is simply the standard deviation (ls) divided by the average of the measurements, expressed as a percent.

It is common to include an acceptable range of results section in precision statements. The "difference two-sigma limit" (d2s) or "difference two-sigma limit in percent" (d2s%) has been selected as the appropriate index of precision for establishing the acceptable difference between two results. The indexes provide a maximum acceptable difference between two results on test portions of the same material. The d2s index equals the difference between two individual test results that would be equaled or exceeded in the long run in only one case of 20 (5 percent of the time) under the normal and correct operation of the test method. The d2s% index equals the difference between two individual test results, expressed as a percentage of their average, that would be equaled or exceeded in the long run in only one case of 20 under the normal and correct operation of the test method. The d2s and d2s% indexes are determined by multiplying the d1s and d1s% indexes by a factor of $2\sqrt{2}$ or 2.828.

Bias may be defined as systematic error inherent in the test method that contributes to the difference between a population mean of the measurements or test results and an accepted reference or true value. In all test methods, tolerances are placed on the accuracy of measuring equipment. All tests performed with a given set of equipment that has an error within the permitted tolerance will produce results with a small consistent bias, but the bias is not inherent in the test method, nor is it included in the bias statement for the method.

Two conditions exist that permit the bias of a test method to be established:

- A standard reference sample of known value has been tested by the test method.

- The test method has been applied to a sample that has been compounded in a manner such that the true value of the property being measured is known.

Determining whether a potential reference sample is suitable for the purpose requires judgment. Rarely is there a reference material (value) available for most test methods, as is the case with the CAA test. When a reference is not available, that must be stated along with a statement indicating that no statement can be made on bias.

EXPERIMENTAL DESIGN

The experiment was developed around the HMA aggregate blends placed at WesTrack through June 1997. Coarse, fine, and fine plus blends developed with Dayton material produced in 1994 were placed at WesTrack in the fall of 1995. The curves that were paved in the fall of 1995 incorporated a coarse blend of the Dayton material produced in 1995. A coarse blend developed with Lockwood material produced in 1997 was placed at WesTrack in June 1997. The 1994 and 1995 Dayton materials were partially crushed gravel, mined and processed from an alluvial andesite deposit in Dayton, Nevada. The Lockwood material was an andesite mined and processed from a quarry located approximately 7 miles east of Reno, Nevada. It should be noted that the fine plus blend was not included in the experiment because the coarse fractions of the fine and fine plus blends were the same. Therefore, four materials were used in the experiment.

In order to be valid, precision indexes included in a precision statement as guides for the operator must be based on estimates of the precision of the test method obtained from a statistically designed interlaboratory series of tests. ASTM C802-96, "Conducting an Interlaboratory Test Program to Determine the Precision of Test Method for Construction Materials," recommends that at least ten participating laboratories be included, a minimum of three materials be used, and a minimum of three replicate determinations be made on each material in each laboratory.[(15)] The method also suggests that ruggedness testing be performed prior to precision and bias determination.

A total of ten laboratories participated in the experiment. The participating laboratories included the five regional Superpave Centers, both FHWA mobile laboratories, Oregon State University, Texas Transportation Institute, and the Asphalt Institute. A conscious effort was made to include as many AASHTO-accredited laboratories as possible. Three replicates of each material were tested by each laboratory. A total of 120 samples (4 materials x 10 laboratories x 3 replicates per material per laboratory) were prepared and shipped in October 1997. Table 3 provides sample identifications that were provided to participating laboratories.

The program described in table 4 fulfills all of the requirements of ASTM C802-96. As a minimum, 30 degrees of freedom are necessary to obtain reliable estimates of true precision. The experiment developed provided 54 [(10-1) x (4-1) x (3-1)] degrees of freedom. Table 4 describes the materials, blends, participating laboratories, and replicates per blend per lab in the CAA experiment.

The purpose of a ruggedness evaluation, as described by ASTM C1067-87, "Conducting a Ruggedness or Screening Program for Test Methods for Construction Materials," is the detection and control of sources of variation prior to conducting an interlaboratory study.[15] Or it may be stated, the purpose of a ruggedness evaluation is to determine how sensitive the test method is to level changes in pertinent operating factors (e.g., test temperature or applied stress or strain) that are within the limits specified in the test method.

The CAA test procedure is very simple, though extremely subjective, and there are no operating factors in the method to which levels could be assigned, with perhaps the exception of "the projected area" in the definition of a fractured face and sample size.

ASTM C670-96, "Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials," provides guidance in preparing precision and bias statements for ASTM test methods pertaining to certain construction materials.[15] The standard also provides recommended forms for precision and bias statements. ASTM C802-96 is the companion method that states minimum requirements for the interlaboratory test program that generates the data to be analyzed in accordance with ASTM C670-96.

ASTM E691-92, "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method," is an ASTM standard that provides adequate information for formulating the precision statement of a test method. A PC-based software version of the standard is available to perform the calculation of the statistical terms needed to formulate a precision statement. The statistics generated may then be incorporated into the formats specified in ASTM C670-96 and C802-96. The use of the ASTM E691-92 software not only assists in the calculation of the statistical terms, but also provides consistency statistics that are not considered in either C670-96 or C802-96.

SAMPLE PREPARATION

The materials used in the experiment were all cold-feed samples taken during original construction and rehabilitation. Multiple cold-feed samples were randomly selected from those taken while the top lift of each mixture was produced. The top lift of the test lane paved with each mixture was produced and placed in a single day. On the afternoon of the day the top lift of the coarse mix was produced, a small percentage (12 percent) of 1995 12.5-mm (½ -in.) material had to be used because the 1994 production had all been depleted. None of the cold-feed samples used in the experiment were taken from the material used that afternoon. The curve mix consisted of all 1995 aggregates and was used in the experiment to represent the 1995 aggregate production.

The multiple, randomly selected cold-feed samples from each mix were thoroughly blended among themselves to produce one large, as homogenous as possible, test unit for each given mix. The test units of each blend were then split into 30 individual test specimens of appropriate test mass for distribution and testing. A total of 120 test specimens (10 laboratories x 4 materials x 3 replicates per material per laboratory) were distributed in October 1997.

DATA ANALYSIS

All participating laboratories completed their testing and submitted their results by late December 1997. Each laboratory provided percent fractured face test results for both "one or more" and "two or more" fractured faces cases. As previously mentioned, ASTM E691-92 was used to perform a statistical analysis of the data. Separate analyses were performed for one or more fractured faces and two or more fractured faces data sets. Tables 5 and 6 provide the individual one or more and two or more fractured faces results for each laboratory and material.

The treatment and analysis of interlaboratory study test results has three purposes:

- To determine whether the data collected are adequately consistent to form the basis for a test method precision statement.
- To investigate and act on any data considered to be inconsistent.
- To obtain the precision statistics from which the precision statement may be based.

A one-way analysis of variance (within and between laboratories) (ANOVA) is conducted separately for each level (material) to obtain estimates of the precision statement. The underlying assumptions of an analysis of variance are:

- Samples taken from the population under consideration are independent of one another.
- Populations are normally distributed.
- Population standard deviations are equal (equal variance).[16]

Because severely outlying data may violate these assumptions and invalidate an analysis, it is necessary to examine variability of the data as a first step in the data analysis process.

OUTLIER DETECTION

ASTM C802-96 has provisions for outlier detection, as does E691-92. The C802-96 method uses a graphical representation of variance along with guidelines for identification of low and high variances within a material. The ratio of the largest to smallest variances from individual laboratories for a material is used to identify low variance. The ratio of largest variance from a single laboratory to the sum of all laboratories' variances for a material is used to identify high variance. If a laboratory's variance consistently exceeds recommended maximum ratios, the laboratory's data are removed from further analyses.

The ASTM E691-92 method suggests that the consistency statistics generated through the method will assist in the detection of outlying data. This is misleading in that the consistency statistics are a function of variance in the data. If outliers exist in the data, the variance used to

calculate the consistency statistics may very well lead to interpretation errors. For this reason, and to satisfy the underlying assumptions of ANOVA, outlier detection must be performed prior to the use of the consistency statistics.

Two methods of outlier detection were considered, box plot analysis outlier detection and the standard ASTM C802-96 methodologies.

Box Plot Outlier Detection

Box plots are a commonly used tool to evaluate the variability of data and identify outliers. A box plot is a graphical display of summary information contained in quartiles. If an ordered data set is divided into quarters, the resulting division points are termed, "the sample quartiles". The first quartile (Q_1) has 25 percent of the observed data below it. The second quartile (Q_2) has 50 percent of the observed data below it and is synonymous with the median. The third quartile (Q_3) has 75 percent of the observed data below it. The amount of variation in the middle half of a data set is described by the interquartile range (IQR), which is equal to the difference in the third and first quartiles ($Q_3 - Q_1$).

Inner and outer fences are defined on a box plot to identify extreme observations. An observation that lies between a pair of inner and outer lower or upper fences is considered a possible outlier and an observation that lies beyond a lower or upper outer fence is considered a probable outlier. Inner and outer fences are determined as follows:

Inner fences:	$Q_1 - 1.5(IQR)$	Lower
	$Q_3 + 1.5(IQR)$	Upper
Outer fences:	$Q_1 - 3.0(IQR)$	Lower
	$Q_3 + 3.0(IQR)$	Upper

On a box plot, the IQR is represented by a rectangle. The median is represented by a bar within the rectangle and lines extend from the first and third quartile to the minimum and maximum observations, respectively. Inner and outer fences may be represented by light and heavy bars across the lines extending to the minimum and maximum observations. Figures 7 and 8 are box plots of the one or more and two or more fractured faces test results, respectively, for each material. Observations beyond the lower outer fences are noted on the plots. Table 7 provides the descriptive statistics depicted in each figure.

It is obvious from the box plots that all 24 results (both one or more and two or more fractured faces) reported by laboratory 9 are probable outliers (below the lower outer fence). A comparison of the lower outer fence descriptive statistics highlighted in table 7 and the reported measurements in tables 5 and 6 reveals extreme values also. The values highlighted in tables 5 and 6 represent probable outliers. All three of the one or more fractured faces measurements shown in table 5 and two of the two or more fractured faces measurements shown in table 6 as reported by laboratory 1 on the Lockwood Coarse material are probable outliers, although one of the two or more fractured faces values is within 0.3 percent of the lower outer fence.

In a conservative nature, it was decided that only probable outliers would be considered for exclusion using the box plot methodology. Based on the box plot analysis, all of the laboratory 9 data were probable outliers and should be removed from further analyses. Five of the 24 measurements reported by laboratory 1 were probable outliers, but from an engineering point of view they were not unreasonable given the subjective nature of the test method. Additionally, they were all on the Lockwood material, which had much tighter fences than the other materials. Three options existed under those conditions:

1. Exclude all laboratory 1 data
2. Exclude the laboratory 1 data for the Lockwood material only
3. Do not exclude any laboratory 1 data

It was decided that all of the laboratory 1 data should be retained in further analyses.

ASTM C802-96 Outlier Detection

As previously mentioned, the ASTM C802-96 method employs a graphical representation of variance along with guidelines for identification of low and high variances within a material. Several statistics must be calculated in order to conduct the analysis. Tables 8 through 12 represent the statistics for the one or more fractured faces test results. The first step in the analysis is to plot the individual variances against the laboratories with a horizontal line across the plot at the level of the average variance. In order to check for agreement among variances, the plots are then examined for the lowest and highest variances. Figures 9 through 12 are the one or more fractured faces variance plots for each material.

It is obvious from review of table 8 and figures 9 through 12 that laboratory 9 within-laboratory variance for each material is not in agreement with the other laboratories. Additionally, the average variance of all laboratories is biased due to the presence of the laboratory 9 data.

The ratio of the largest variance from a single laboratory to the sum of all laboratories' variances within a material is used to identify high variance. For ten laboratories and three replicates per material, the maximum allowable ratio is 0.445. If a laboratory's variance consistently exceeds the recommended maximum ratio, the laboratory's data should be removed from further analyses. The maximum allowable value is obtained from table 4 of ASTM C802-96 and represents the upper 5 percent level. Table 9 summarizes the ratios for each material. The ratio exceeds the criteria for each material. The largest variance in each case is associated with laboratory 9.

The ratio of the largest to smallest laboratory variance within a material is used to identify low variance. For 10 laboratories and three replicates per material, the maximum allowable ratio is 550. If a laboratory's variance consistently exceeds the recommended maximum ratio, the laboratory's data should be removed from further analyses. The maximum allowable value is obtained from table 5 of ASTM C802-96 and represents the upper 5 percent level. Table 10 summarizes the ratios for each material. Because the minimum variance of many laboratories is zero (see table 9), the ratio is equal to infinity for each material. However, the fact that many laboratories' variances are zero indicates that zero variance is not too low.

Interactions between laboratories and materials is a common problem with test results obtained from an interlaboratory study. Interaction would mean that the pattern of change of the results obtained on a given group of materials in one laboratory would differ from the pattern obtained in another laboratory. ANOVA is the accepted statistical technique for identifying interactions. As a reasonably reliable method of checking for interactions, ASTM C802-96 recommends plotting the averages obtained on the materials by each laboratory and reviewing the plots for similar patterns of change from material to material for all laboratories (so the different laboratories fail to rate materials in the same order). If one laboratory shows a noticeably different pattern from the others, it may be eliminated. Figure 13 represents material averages for each laboratory for the one or more fractured faces determinations. None of the laboratories rank all the materials the same, but the values are so similar that data are difficult to interpret. The obvious anomaly in the plot is the low values reported by laboratory 9 in relation to the other labs. Additionally, laboratory 1 does not rank the Lockwood material the highest, which contradicts the other laboratories.

Based on the methodology of ASTM C802-96, the one or more fractured faces data for laboratory 9 should be excluded and the laboratory 1 data for the Lockwood material may or may not be excluded in further analyses.

The same analysis was conducted for the two fractured faces data and is summarized in tables 13 through 17 and figures 14 through 18. Review of table 13 and figures 14 through 17 reveal that variance is higher for two or more fractured faces determinations than one or more fractured faces determinations. As with the one or more fractured faces data, laboratory 9 shows the lowest material averages and the highest variances for all materials. Laboratories 1 and 2 also show relatively high variances for the Dayton coarse material. For the Dayton fine material, all laboratories show similar variances with the exception of laboratory 9. Laboratories 1 and 9 show similar variances for the Dayton curve material. Laboratory 1 shows high variance relative to the other labs for the Lockwood coarse material, but it is still much lower than laboratory 9. Figure 18, the interaction plot, is very similar to the same plot for the one or more fractured faces data. The obvious anomaly in the plot is the low values reported by laboratory 9 in relation to the other labs. Again, laboratory 1 does not rank the Lockwood material the highest, which contradicts the other laboratories.

Based on the methodology of ASTM C802-96, the one or more fractured faces data for laboratory 9 should be excluded and the laboratory 1 data for the Lockwood material may or may not be excluded in further analyses.

Excluded Data

Both of the outlier detection analyses suggested that all of the laboratory 9 data be removed prior to development of a precision statement. Additionally, the laboratory 1 data may or may not be removed. If one is not conservative in the outlier detection process, unrealistic tight precision statements will result, which are impractical. After consultation with a statistician, it was decided that only the laboratory 9 data would be excluded.

The ASTM procedures do not specify whether outlier analysis should be repeated after removing data, but common statistical practice does not recommend it.

ANALYSIS OF VARIANCE

As previously mentioned, the ASTM E691-92 software was used to perform the ANOVA after removing outliers. The software generates consistency statistics and provides the information necessary for formulation of precision statements. The first step in the analysis is to evaluate the consistency of the data.

Consistency Statistics

Both between- and within-laboratory consistency must be considered. The h-statistic is used to evaluate between-laboratory consistency and the k-statistic is used to evaluate within-laboratory consistency.

The h-statistic is an indicator of how one laboratory's average, for a particular material, compares with the average of all the other laboratories (similar to the common t-statistic). The critical h-value used for comparisons is actually determined with an equation derived from an unpaired t-test. The critical h-value is calculated using published values of Student's t at the 0.5 percent two-tail significance level for the selected number of laboratories. Table 12 of ASTM E691-92 provides a summary of critical h-values. The critical h-value for nine laboratories is 2.23.

The k-statistic is an indicator of how one laboratory's within-laboratory variability on a particular material, under repeatability conditions, compares with all of the laboratories combined. The k-statistic is similar to the common F ratio and is actually a function of the F-statistic. A k-value larger than one indicates greater within-laboratory variability than the average for all laboratories. The critical k-value is calculated from the upper critical value of F at the 0.5 percent significance level for the selected combination of number of test replicates and laboratories. Table 12 of ASTM E691-92 provides a summary of critical k-values. The critical k-value for three replicates per material and nine laboratories is 2.09.

The consistency statistics may be presented as a function of laboratory or material by plotting. The h-statistic comparison will show a laboratory that is consistently reporting lower (negative) values compared to the other laboratories reporting higher (positive) values or vice versa for a particular material or, more likely, for all materials. Data distributed on either side of zero is a sign of normal variability. The k-statistic comparison will show a laboratory that lacks within-laboratory precision relative to the other laboratories, as indicated by consistently high k-values. The h- and k-statistics are evaluated by reviewing the plots by laboratory and material together. In some cases, review of a plot by laboratory will show several h- or k-values near the critical value for a given laboratory. Review of the corresponding plot by material may or may not show that for a given material the laboratory is consistent with the other laboratories. There is reason for concern when both plots by laboratory and material show high values for a given laboratory.

Testing Consistency of One or More Fractured Faces

The one or more fractured faces h- and k-statistics are summarized in table 18. The highlighted cells in the table represent values that exceed the critical value, indicating significant difference at the 5 percent level, in either between- or within-laboratory consistency. Laboratory 1 exceeded the critical h-value for the Lockwood coarse material and the critical k-value for the Lockwood coarse and Dayton coarse materials. Figures 19 through 22 are the one or more fractured faces h- and k-statistic plots by laboratory and material. The heavy horizontal lines on the plots represent the critical h- and k-values.

Figure 19, the h-statistic plot by laboratory, shows both negative and positive values (11 negative and 25 positive). A positive value represents a material average for a laboratory above the average of all laboratories and a negative value represents a material average for a laboratory below the average of all laboratories. For laboratory 1, one h-statistic exceeds the critical value. It is on the Lockwood material. The k-statistic plot by laboratory (figure 20) shows that laboratory 1 may be lacking in within-laboratory precision, and within-laboratory precision is randomly distributed among the materials. Figure 21, the h-statistic plot by material is missing from the report, but would show both positive and negative values, with laboratory 1's value being the lowest for three of the four materials. The k-statistic plot by material (figure 22) again shows the greatest within-laboratory variability is associated with laboratory 1 for all materials.

Both positive and negative h-statistics were observed indicating random between-laboratory variability. Within-laboratory variability is distributed among the materials, indicating that no single material created greater within-laboratory variability than another. Laboratory 1's h- and k-statistics were typically the largest in magnitude, indicating the greatest between- and within-laboratory variability was associated with that lab. The laboratory 1 statistics were relatively consistent among materials, indicating that the variability was not associated with a single material.

Testing Consistency of Two or More Fractured Faces

The two or more fractured faces h- and k-statistics are summarized in table 19. The highlighted cells in the table represent values that exceed the critical value, indicating significant difference at the 5 percent level in either between- or within-laboratory consistency. Laboratory 1 exceeded the critical h-value for the Lockwood coarse material and the critical k-value for the Lockwood coarse and Dayton curve materials. Laboratory 2 exceeded the critical k-statistic for the Dayton fine material. Figures 23 through 26 are the two or more fractured faces h- and k-statistic plots by laboratory and material. The heavy horizontal lines on the plots represent the critical h- and k-values.

Like the one or more fractured faces data, the two or more h-statistic plot by laboratory (figure 23) shows both negative and positive values (11 negative and 25 positive). The laboratory 1 h-statistic exceeds the critical value on the Lockwood material. The k-statistic plot by laboratory (figure 24) shows that laboratories 1 and 2 had the greatest within-laboratory variability, and within-laboratory precision is randomly distributed among the materials. Figure 25, the h-statistic plot by material, shows both positive and negative values, with laboratory 1's value

being the lowest for three of the four materials. The k-statistic plot by material (figure 26) again shows the greatest within-laboratory variability is associated with laboratories 1 and 2.

Both positive and negative h-statistics were observed indicating random between-laboratory variability. Within-laboratory variability is distributed among the materials, indicating that no single material created greater within-laboratory variability than another. The h- and k-statistics from laboratories 1 and 2 were the largest in magnitude, indicating the greatest between-and within-laboratory variability was associated with those labs. The laboratory 1 statistics were relatively consistent among materials, indicating that the variability was not associated with a single material.

The intention of the consistency analysis was not to identify outliers, but rather to ensure that gross inconsistency had been controlled through the outlier detection process. As previously mentioned, outlier detection must be performed prior to ANOVA; if outliers exist in the data, the variance used to calculate the consistency statistics may lead to interpretation errors. The intention of the consistency analysis was to ensure data consistency after removal of outliers. The results of the analysis were as expected in that the box plot outlier detection identified a few potential outliers associated with laboratory 1.

PRECISION STATEMENTS

Precision statements are based on two fundamental statistics. The statistics used to form a precision statement are the repeatability (S_r) and reproducibility (S_R) standard deviations or single operator and multilaboratory one-sigma limits. The repeatability (within laboratory) standard deviation is the square root of the pooled average of within-laboratory variances. The reproducibility (between laboratory) standard deviation is the square root of the pooled average of between-laboratory variances. The reader is referred to ASTM C802-96 for formulation of the statistics.

The relationship between the average level of the measured property for different materials and the within-and between-laboratory standard deviations dictates the appropriate form of a precision statement. There are three main forms of this relationship:

- The situation where the standard deviation is relatively constant over the range of materials.

- The situation where the standard deviation has an approximately linear relationship with the average level and the coefficient of variation is relatively constant.

- The situation where the materials fall into two or more distinct groups within which form 1 or 2 approximately holds.

Coefficient of variation, expressed as a percent, is the ratio of standard deviation to average times 100. The simplest method of determining the form of the relationship is to plot the standard deviations and coefficients of variation against the average levels measured. One of the

reasons for plotting against the average levels measured is to determine whether a single statement is valid regardless of level or if statements for ranges of levels are required. In some cases, irregular or nonlinear relations will occur which do not fit any of the main forms.

In the situation where the standard deviation is relatively constant over the range of materials (form 1), the pooled within-laboratory standard deviation over all materials becomes the single-operator standard deviation or one-sigma limit (1s) and the pooled between-laboratory standard deviation becomes the multilaboratory standard deviation or one-sigma limit (1s) as described in ASTM C670-96. In the situation where the standard deviation has an approximately linear relationship with the average level and the coefficient of variation is relatively constant (form 2), the average within-laboratory coefficient of variation becomes the single-operator one-sigma limit in percent (1s%) and the average between-laboratory coefficient of variation becomes the multilaboratory one-sigma limit in percent (1s%) as described in ASTM C670-96. In the situation where the materials fall into two or more distinct groups within which form 1 or 2 approximately holds, the single-operator and multilaboratory one-sigma limits are established for each range using the appropriate form. If irregular or nonlinear relations occur that do not fit any of the main forms, the largest estimate of standard deviation or coefficient of variation is used to establish one-sigma limits.

Tables 20 and 22 summarize the average levels, within- and-between laboratory components of variance and total within- and between-laboratory variance associated with each material for the one or more and two or more fractured faces data, respectively. Tables 21 and 23 summarize the average levels, and within- and between-laboratory standard deviations and coefficients of variation associated with each material for the one or more fractured faces and two or more fractured faces data, respectively. W/L and B/L in the tables represent within- and between-laboratory. The tabulated data are plotted in figures 27 through 30.

The within-laboratory standard deviations range from 0.70 to 1.53 for the one or more fractured faces data with a pooled average of 1.05. The between-laboratory standard deviations range from 1.42 to 2.05 with a pooled average of 1.79. The within-laboratory coefficients of variation range from 0.71 to 1.57 for the one or more fractured faces data with an average of 1.07. The between- laboratory coefficients of variation range from 1.44 to 2.09 with an average of 1.82. Review of figures 27 and 28 shows the within-laboratory data suggest a possible trend in standard deviation over the range of average level, while the between-laboratory data suggest standard deviation and coefficient of variation is relatively constant for both within- and between-laboratory data. The possible trend in standard deviation could only be verified if material with a greater range of percentages of fractured faces had been included in the interlaboratory study.

The within-laboratory standard deviations range from 1.42 to 2.65 for the two or more fractured faces data with a pooled average of 1.82. The between-laboratory standard deviations range from 2.59 to 3.25 with a pooled average of 2.91. The within-laboratory coefficients of variation range from 1.46 to 2.76 for the two or more fractured faces data with an average of 1.88. The between- laboratory coefficients of variation range from 2.69 to 3.30 with an average of 3.00. The same observations are made when the two or more fractured faces plots (figures 29 and 30) are reviewed, with the exception that the possible trend in standard deviation over the range of average level is less evident.

The data indicate that the constant standard deviation form of precision statement is appropriate for both the one or more and two or more fractured faces data. Therefore, the pooled within-laboratory standard deviation over all materials becomes the single-operator standard deviation or single-operator one-sigma limit (ls) and the pooled between-laboratory standard deviation becomes the multilaboratory standard deviation or multilaboratory one-sigma limit (ls) as described in ASTM C670-96. The one-sigma limits are summarized in table 24 for the one or more and two or more fractured faces data. The single-operator one sigma limits are 1.05 and 1.82 for the one or more and two or more fractured faces conditions, respectively. The multilaboratory one-sigma limits are 1.79 and 2.91 for the one or more and two or more fractured faces conditions, respectively.

Acceptable Range of Results

Single-operator and multilaboratory acceptable range of results limits (difference two-sigma limits) are established at the 95 percent reliability level by multiplying the repeatability and reproducibility standard deviations by $2\sqrt{2}$ or 2.828. The difference two-sigma limits are summarized in table 24. The single-operator difference two-sigma limits are 2.98 and 5.15 for the one or more and two or more fractured faces conditions, respectively. The multilaboratory difference two-sigma limits are 5.07 and 8.20 for the one or more and two or more fractured faces conditions, respectively.

Interpretation of the information in table 24 for single-operator and multilaboratory acceptable range of results limits would be as follows:

- For the one or more fractured faces condition, the single-operator acceptable range of two results equals 2.98. Therefore, the difference between two individual test results that would be equaled or exceeded in the long run in only one case of 20 (five percent of the time) under the normal and correct operation of the test method is 2.98 percent.

- For the one or more fractured faces condition, the multilaboratory acceptable range of two results equals 5.07. Therefore, the difference between two individual test results that would be equaled or exceeded in the long run in only one case of 20 (five percent of the time) under the normal and correct operation of the test method is 5.07 percent.

Table 25 represents the complete precision statement developed based on the interlaboratory study.

COMPARISON OF PRECISION STATEMENTS WITH OTHER AVAILABLE DATA

An attempt to compare the precision statements developed with this analysis to AASHTO Materials Reference Laboratory (AMRL) proficiency sample test results was made. Unfortunately, as of January 1998, AMRL had not included the CAA test in its proficiency

sample testing program. AMRL did indicate that CAA was being considered for inclusion in the future.

ASTM D5821-95 states that no precision data are available, but that separate studies by Arizona (multioperator) and California (multilaboratory) DOTs using their own methods and materials that averaged approximately 80 percent crushed particles showed about 10 percent standard deviation. That level of precision suggests a difference between operators from two different laboratories would not be expected to exceed 28 percent, 95 percent of the time.

The level of variability was much greater in those studies than that measured in this study. The most obvious potential reasons for the difference are:

- The range of angularity of the materials included in this study was limited to high percentages.
- There was a large difference in the level of angularity of the materials used between this study and the highway department studies.
- It is likely that the variability associated with the method increases as angularity decreases, as indicated by this comparison.

RELATIONSHIP BETWEEN THE SUPERPAVE CAA SPECIFICATION AND WESTRACK PERFORMANCE

The four mixtures placed at WesTrack were the Dayton fine, Dayton fine plus, Dayton coarse, and Lockwood coarse. The Dayton mixtures incorporated partially crushed gravel and the Lockwood mix incorporated a quarry material. The CAA of the Dayton coarse mixture was (98/96), the Dayton fine and fine plus was (98/96), and the Lockwood coarse was (99/98). Figure 31 shows average rut depth measurements for the different mixtures placed with target optimum asphalt contents and in-place air voids of 8 percent. Note that the applied ESALs at the time of the rut depth measurements is stated on the plot. The measurements on the Dayton mixtures were conducted at 2.77×10^6 ESALs. The measurements were made on the Lockwood coarse mixture at 0.58×10^6 ESALs. The Lockwood mixture has not been in service as long as the fine Dayton mixtures, and was actually placed as a rehabilitation of the coarse Dayton mixture. The two bars for each mixture indicate replicate test sections.

It is obvious from the figure that the coarse mixtures have not performed as well as the fine mixtures, particularly the Lockwood coarse mixture, when one considers the difference in applied ESALs at the time of the rut depth measurements.

Unfortunately, there is no direct relationship between the Superpave CAA specification and the observed rutting performance at WesTrack. That statement can be made because the CAA's of both the fine and coarse Dayton mixtures were equal. The CAA of the coarse Lockwood mixture was one percent higher than the Dayton mixtures and it performed worse than all of the

Dayton mixtures. This would actually suggest that partially crushed gravels provide better rutting resistance than quarry material.

SUMMARY

An interlaboratory study was conducted to develop a precision statement for the ASTM D5821-95 coarse aggregate angularity test method. The experimental design included ten laboratories, four materials, and three replicates per material per laboratory, resulting in 54 degrees of freedom. Outlier detection was given careful consideration due to the subjective nature of the method, and resulted in exclusion of one laboratory's data; this reduced the degrees of freedom to 48. The definition of a fractured face in ASTM D5821-95 should provide a clearer description of a "sharp, well-defined edge," so that discrepancies such as those observed in this study may be avoided in the future.

The materials included three partially crushed gravel blends and one quarry stone blend, all of which were placed at the WesTrack accelerated pavement test facility. As expected, multilaboratory variability was greater than single-operator variability. There was also a greater level of variability associated with two or more fractured faces determinations than with one or more fractured faces determinations. Surprisingly, the quarry stone showed greater variability than the crushed gravels.

The results of the analysis were compared to other available data. The level of variability associated with this study was less than that observed in other studies. The likely reason for this difference is the level of fractured faces was greater for all of the materials included in this study than in the other studies.

A significant finding of the study was that the CAA's of both the fine and coarse mixtures placed at WesTrack were equal. They also met the Superpave criteria for the less than $30x10^6$ ESAL condition (95/90), with actual values of (98/96). However, the performance of the fine mixtures has been much better than coarse mixes, indicating a lack of correlation between the CAA specification and actual performance, at least for the four mixes placed at WesTrack. That in itself is a very clear indication that CAA did not have an effect on performance at WesTrack.

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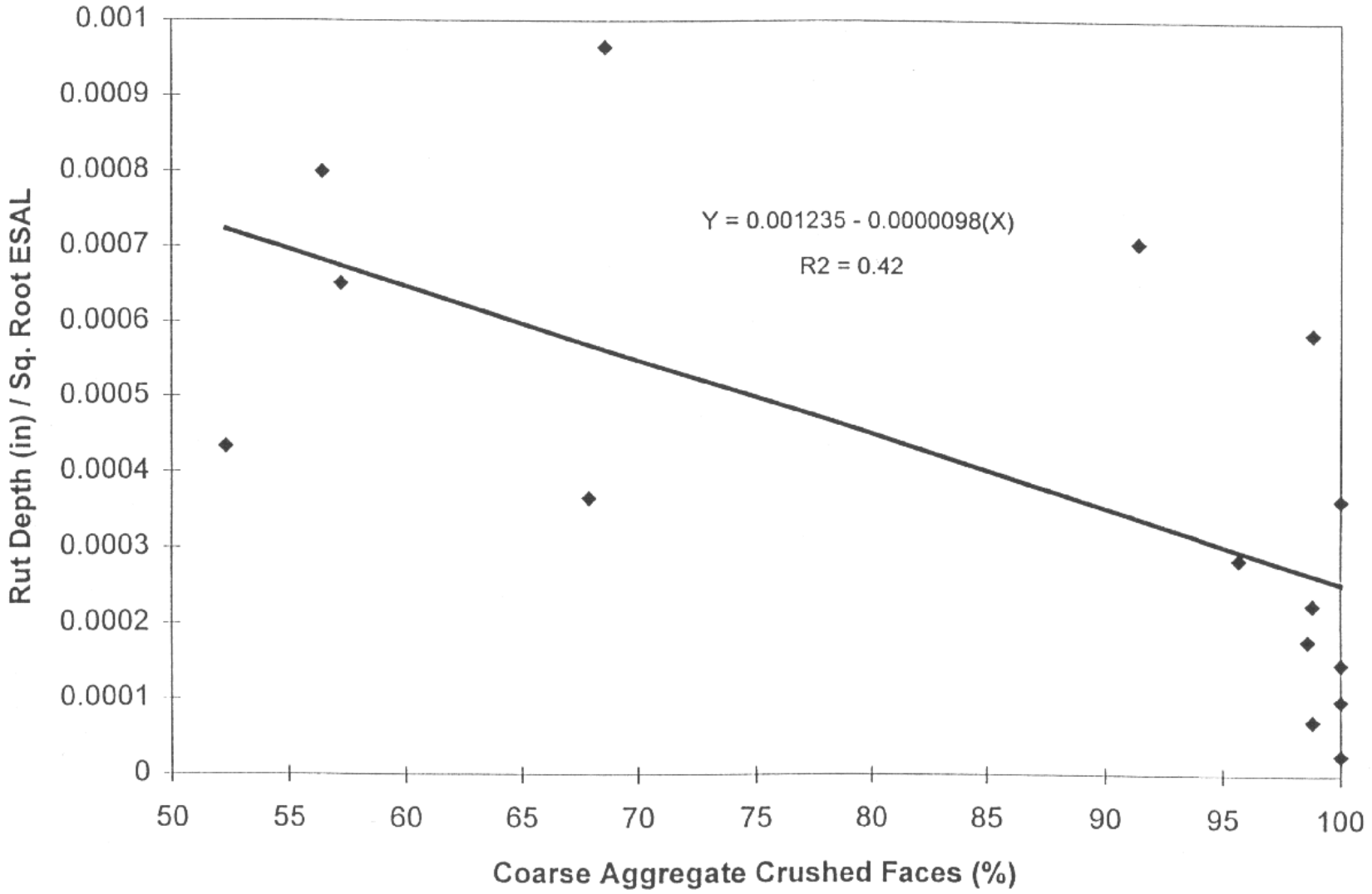

Figure 1. Relationship between rutting rate and CAA with 20th percentile in-place air voids greater than 2.5% (from Ref. 8).

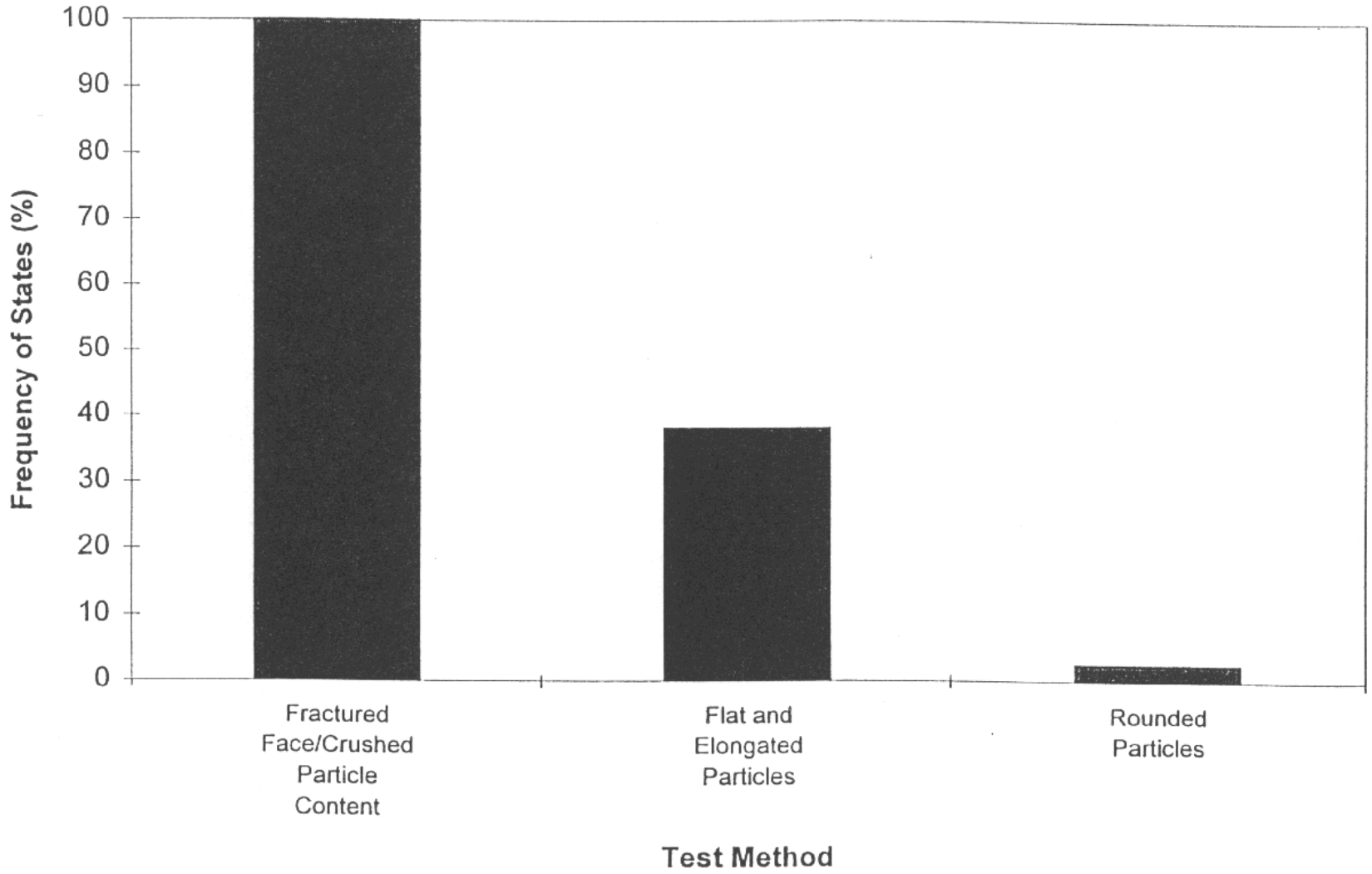

Figure 2. Test methods employed by States to control aggregate particle shape and surface texture.

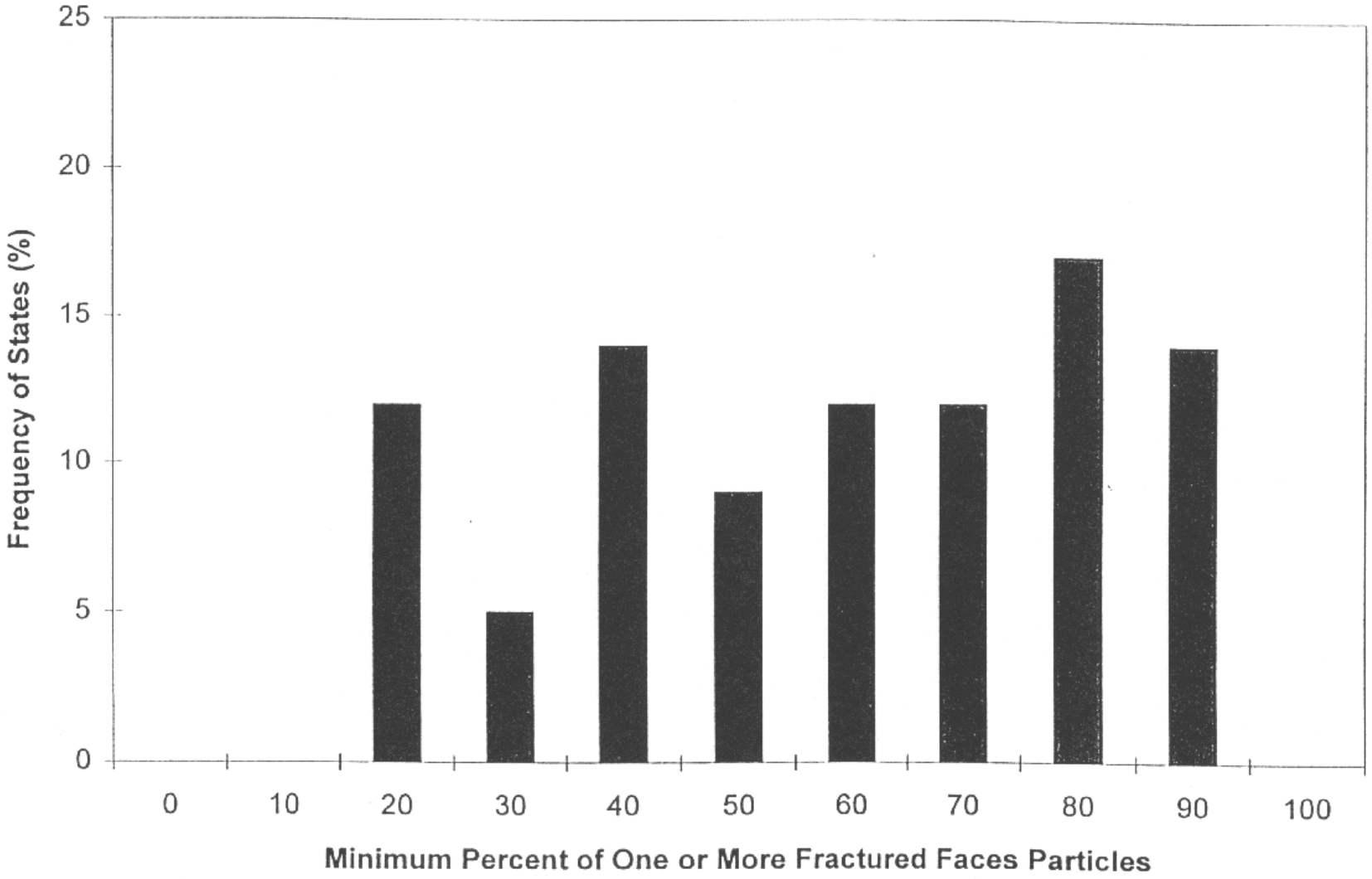

Figure 3. Binder course, one or more fractured faces requirements.

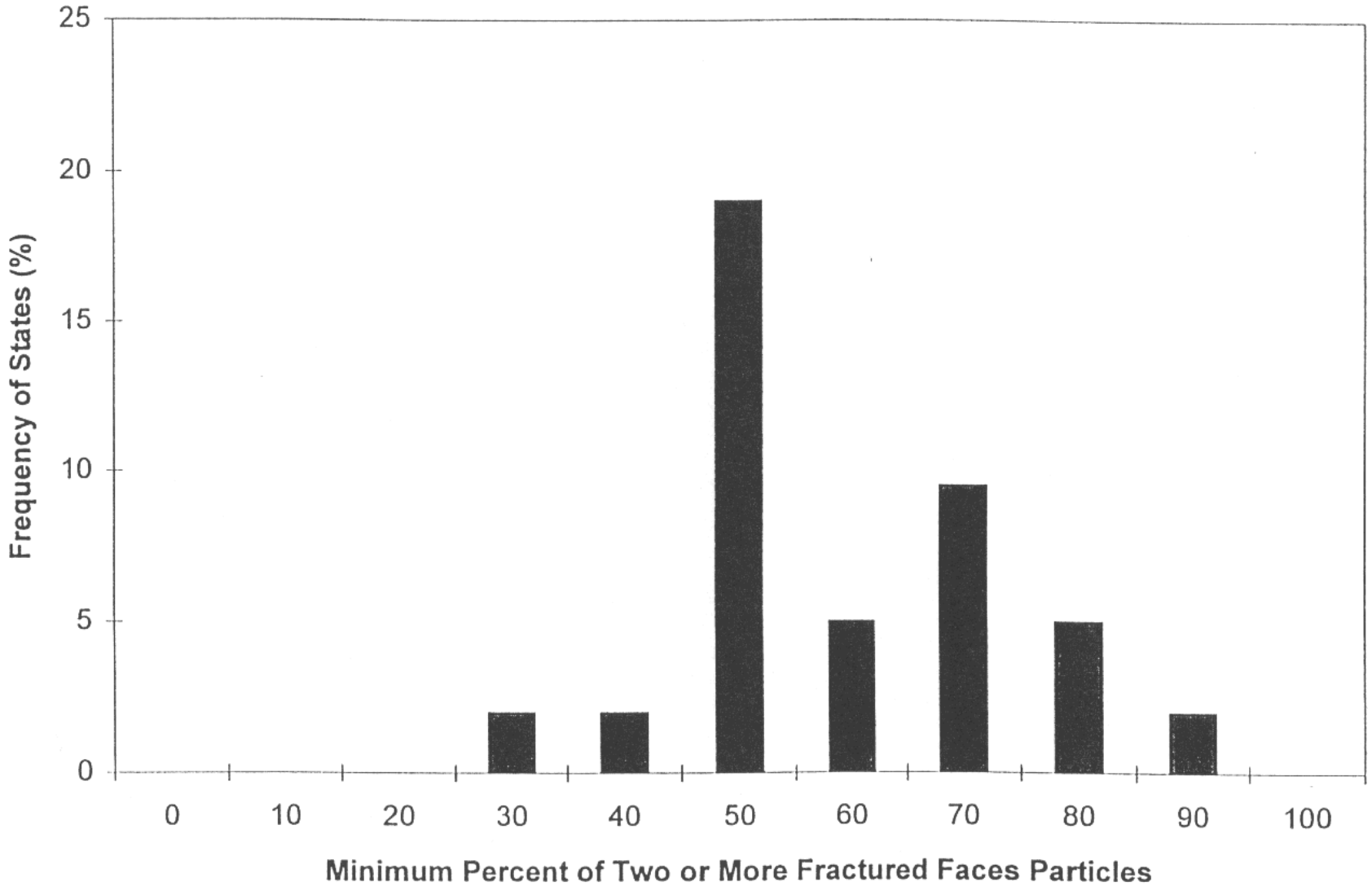

Figure 4. Binder course, two or more fractured faces requirements.

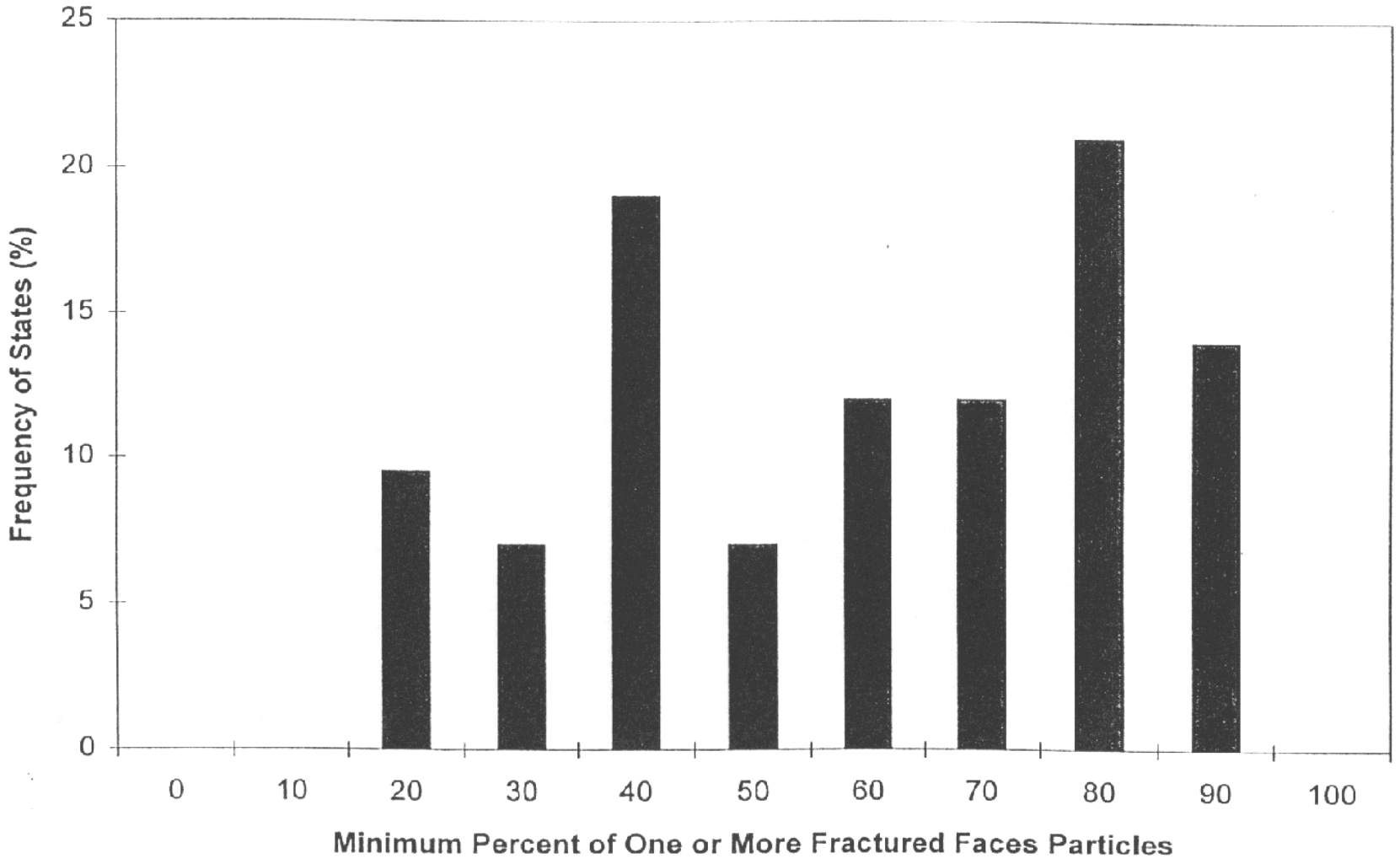

Figure 5. Surface course, one or more fractured faces requirements.

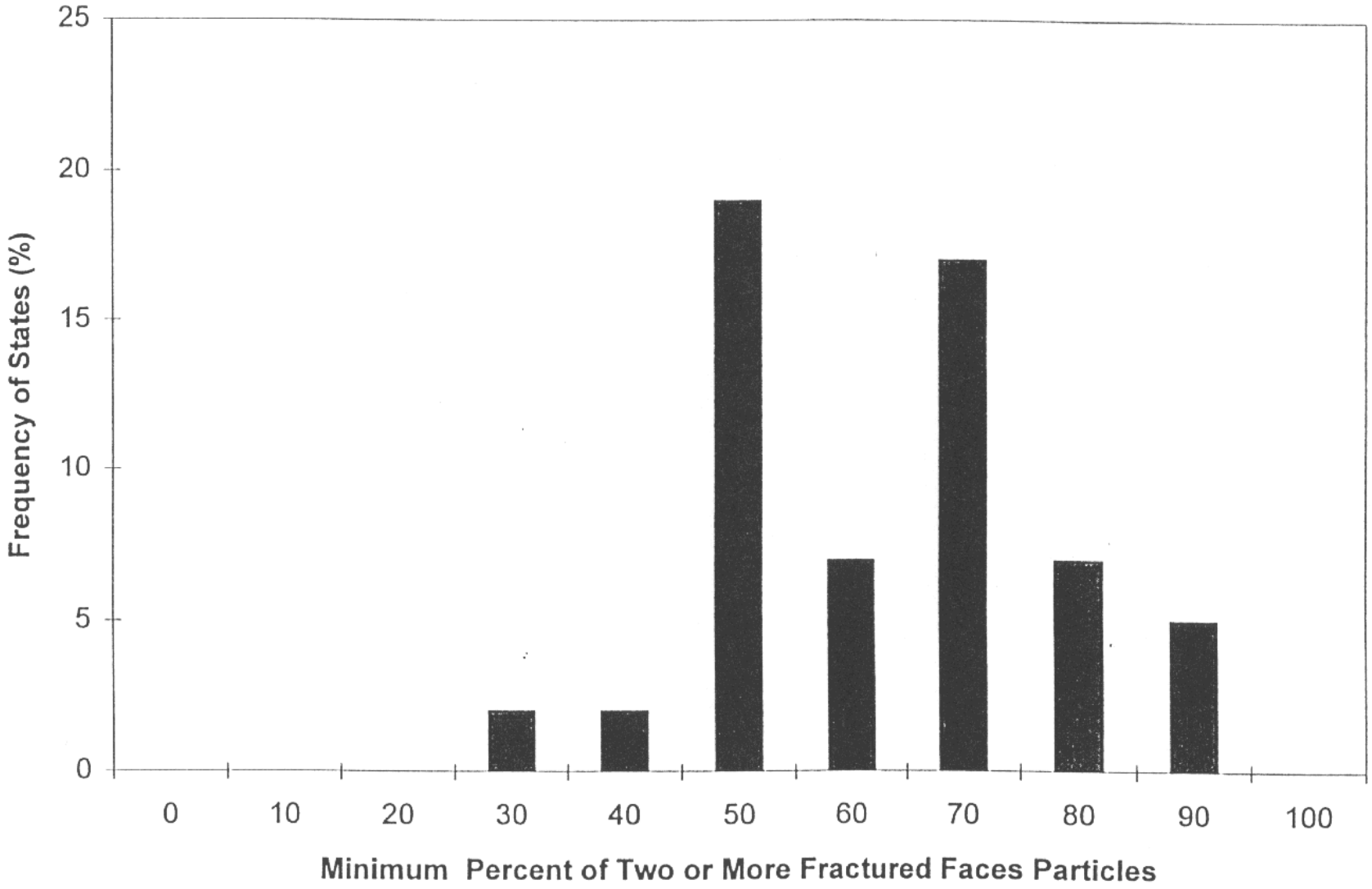

Figure 6. Surface course, two or more fractured faces requirements.

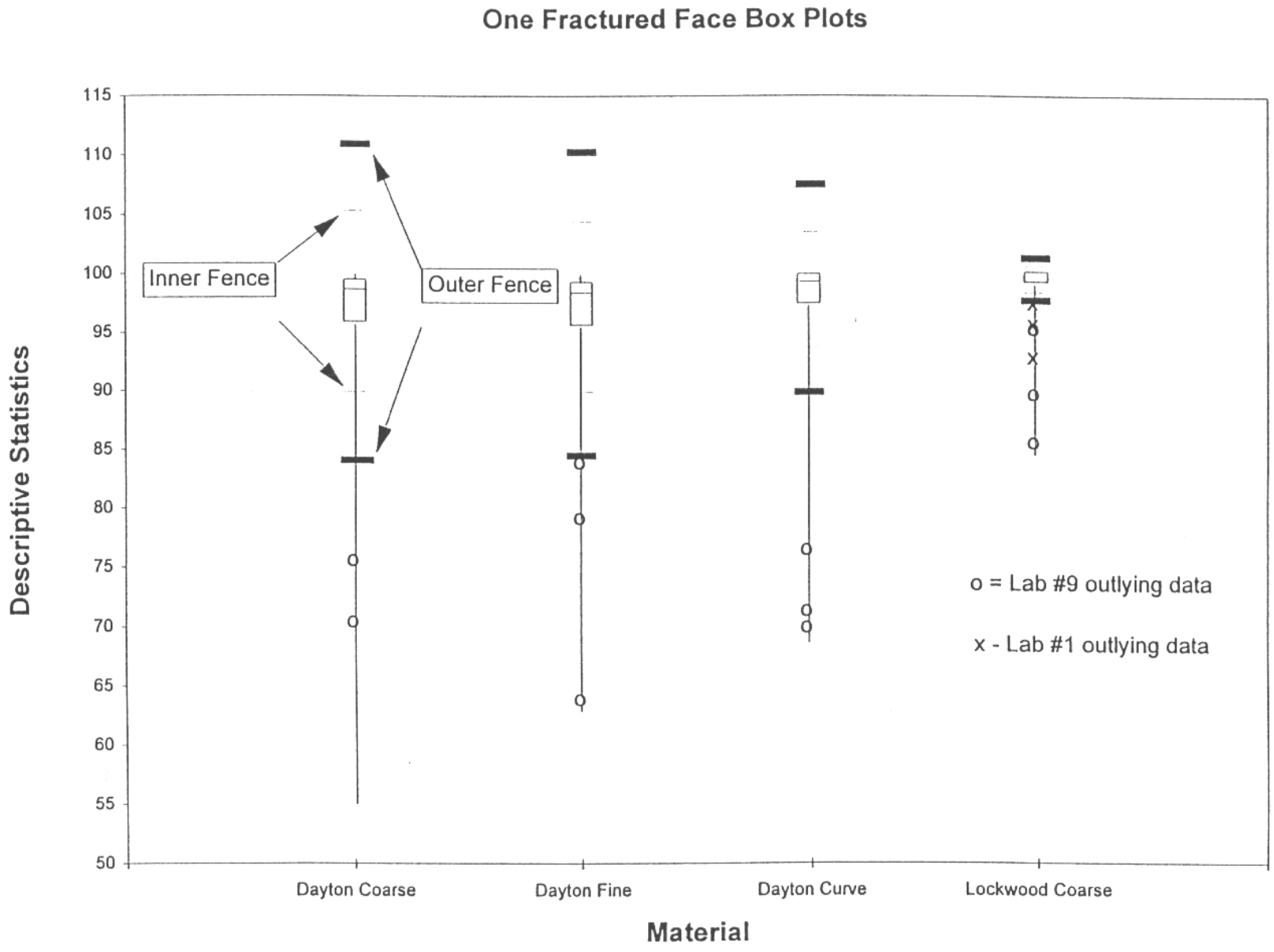

Figure 7. One or more fractured faces box plot.

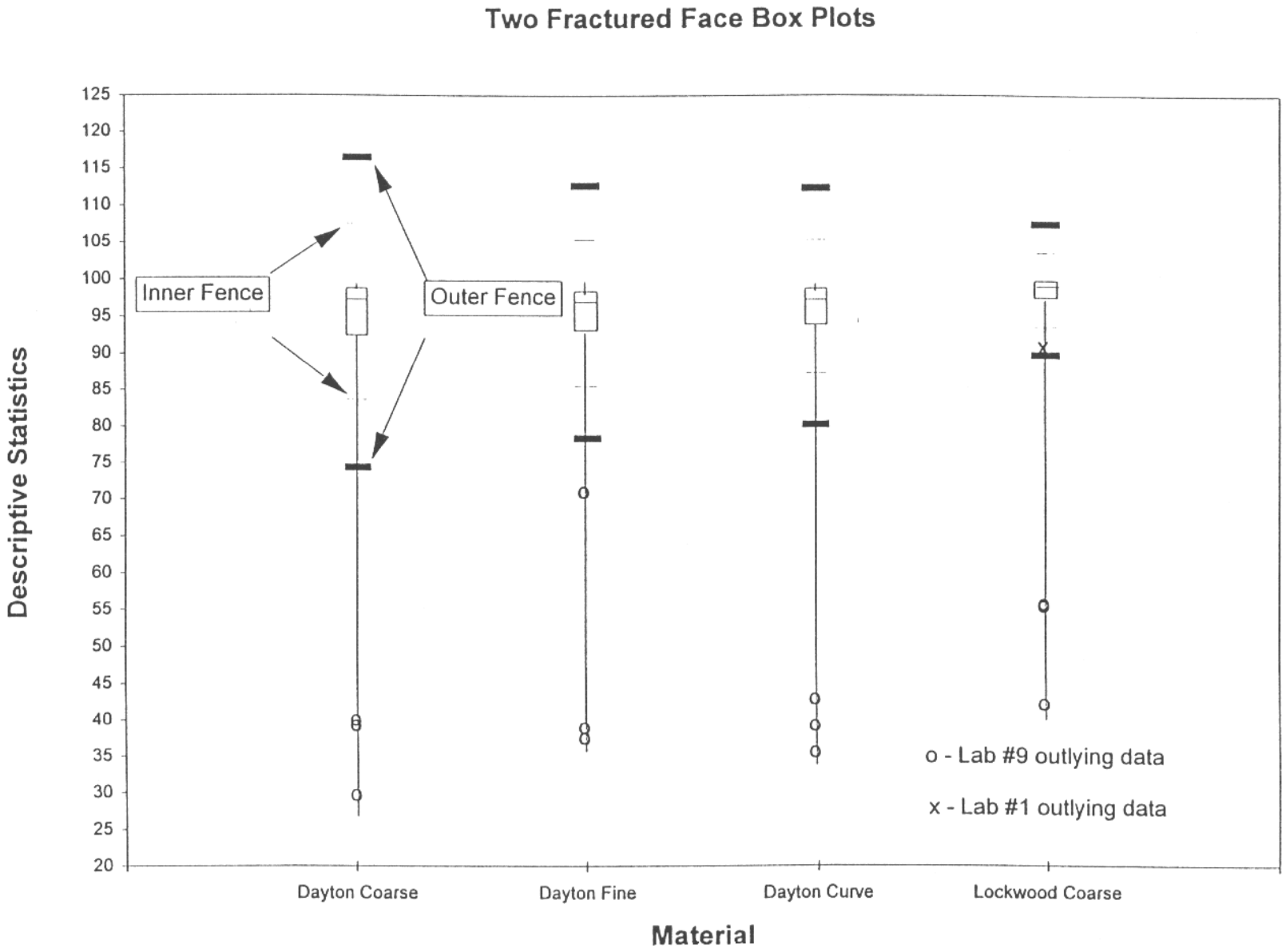

Figure 8. Two or more fractured faces box plot.

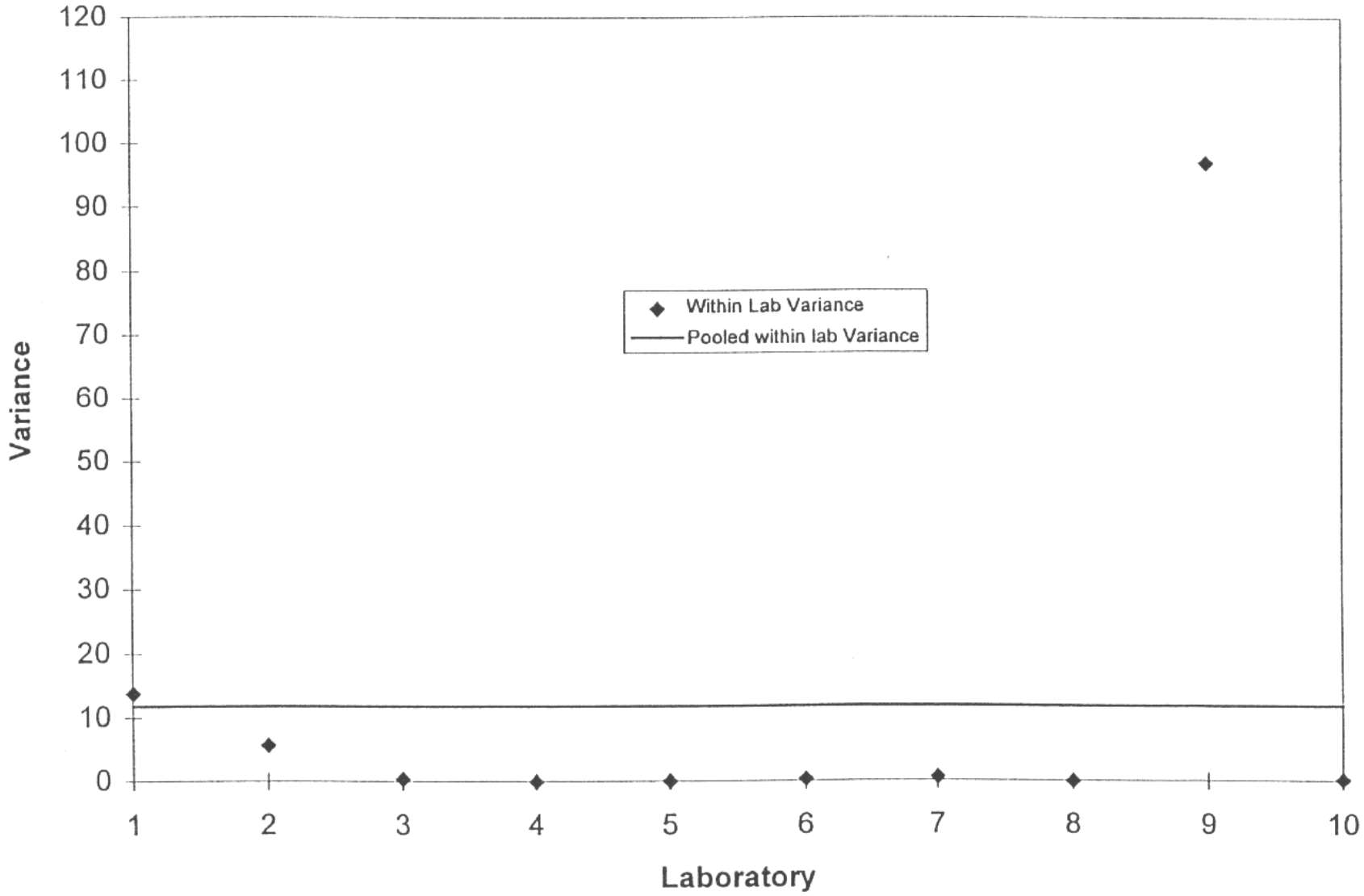

Figure 9. Dayton coarse blend one or more fractured faces variance plot by laboratory.

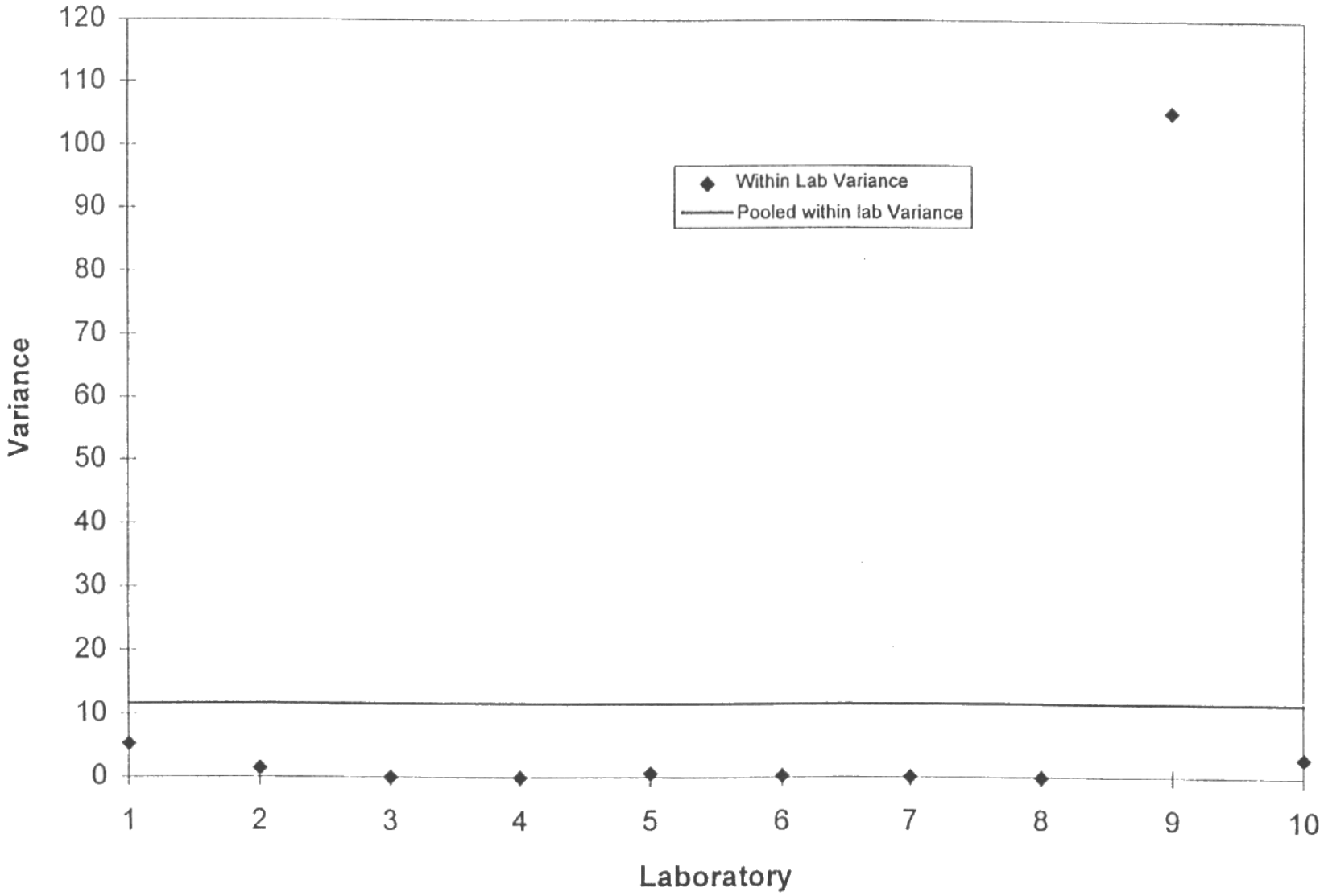

Figure 10. Dayton fine blend one or more fractured faces variance plot by laboratory.

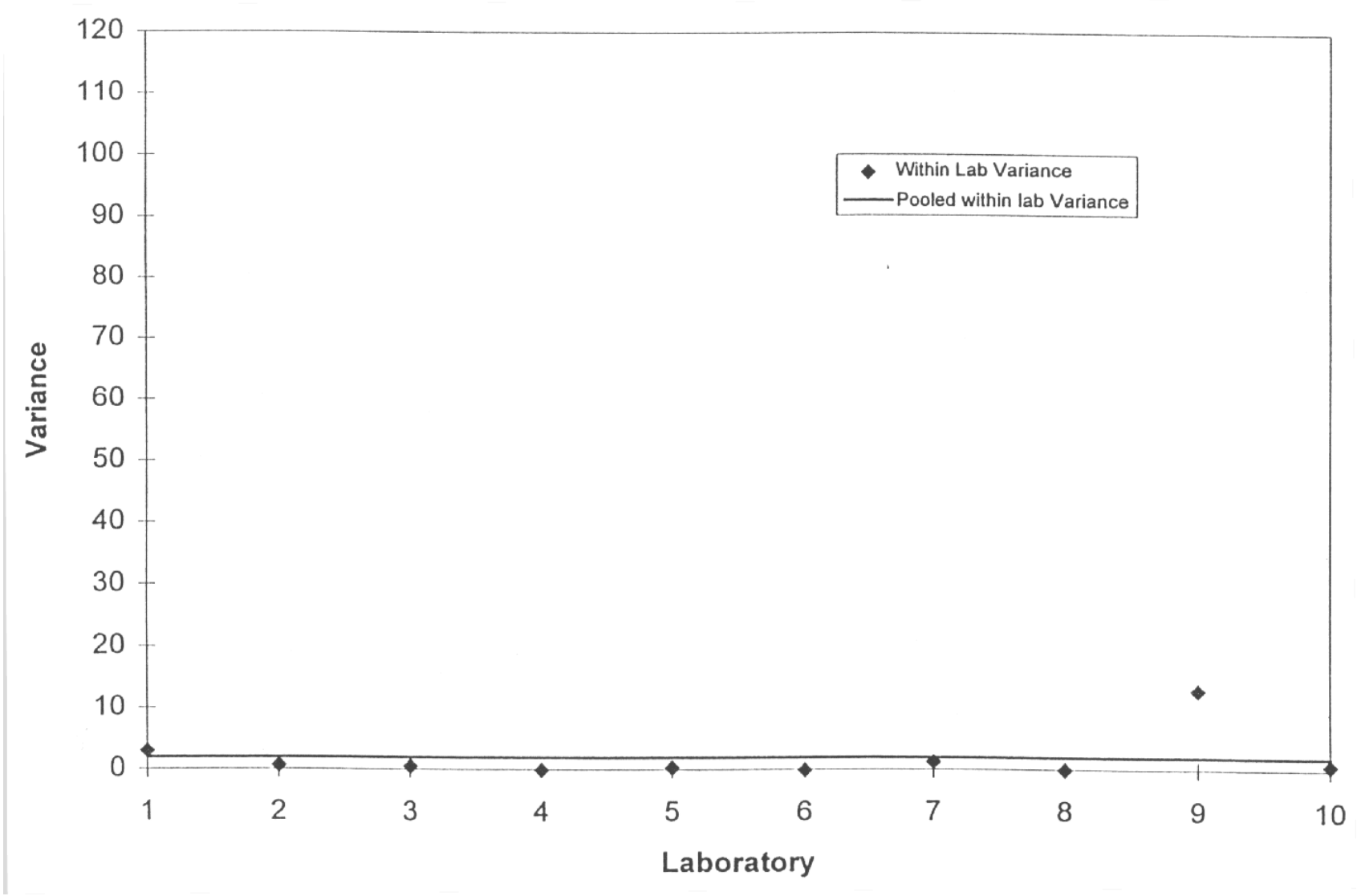

Figure 11. Dayton curve blend one or more fractured faces variance plot by laboratory.

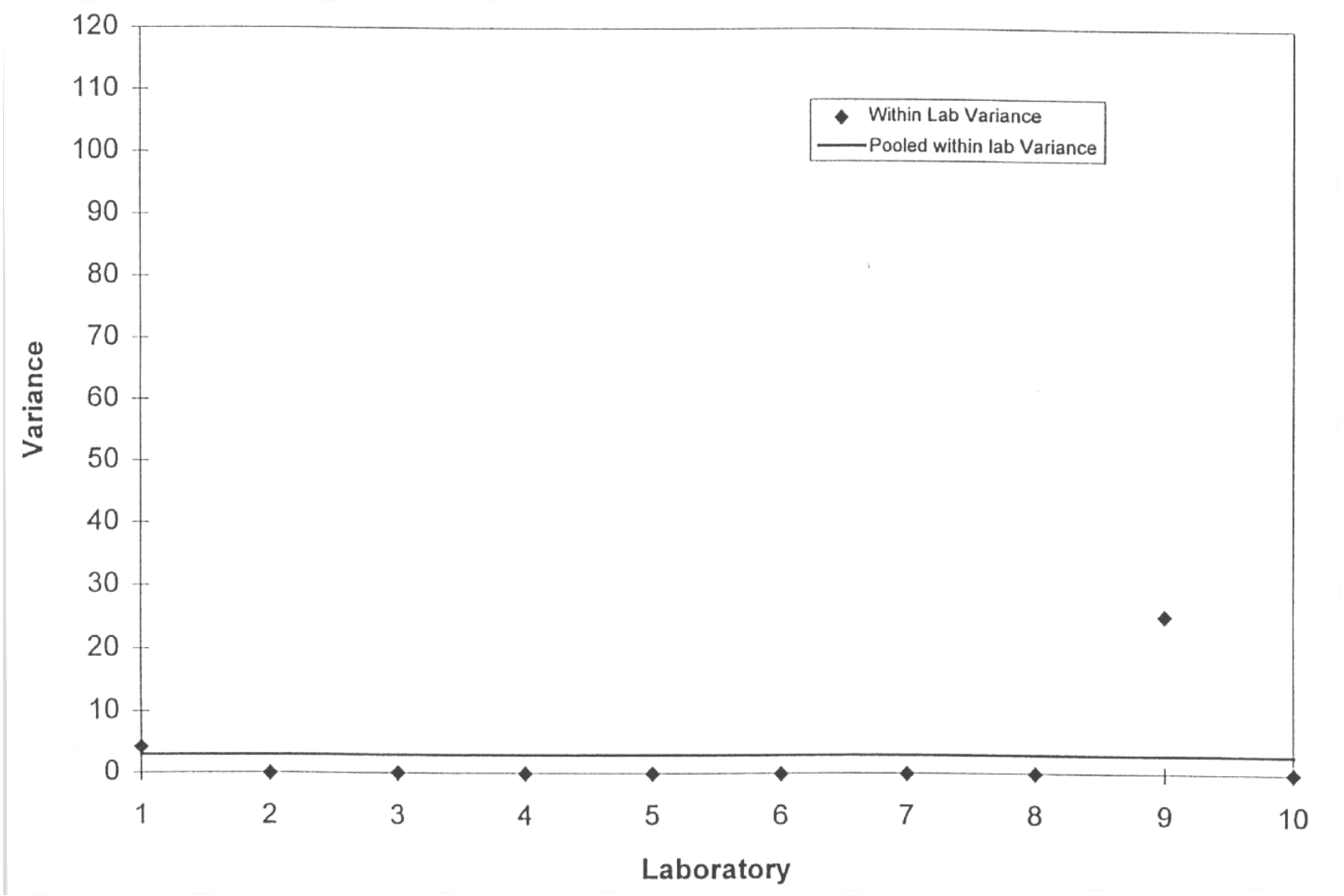

Figure 12. Lockwood coarse blend one or more fractured faces variance plot by laboratory.

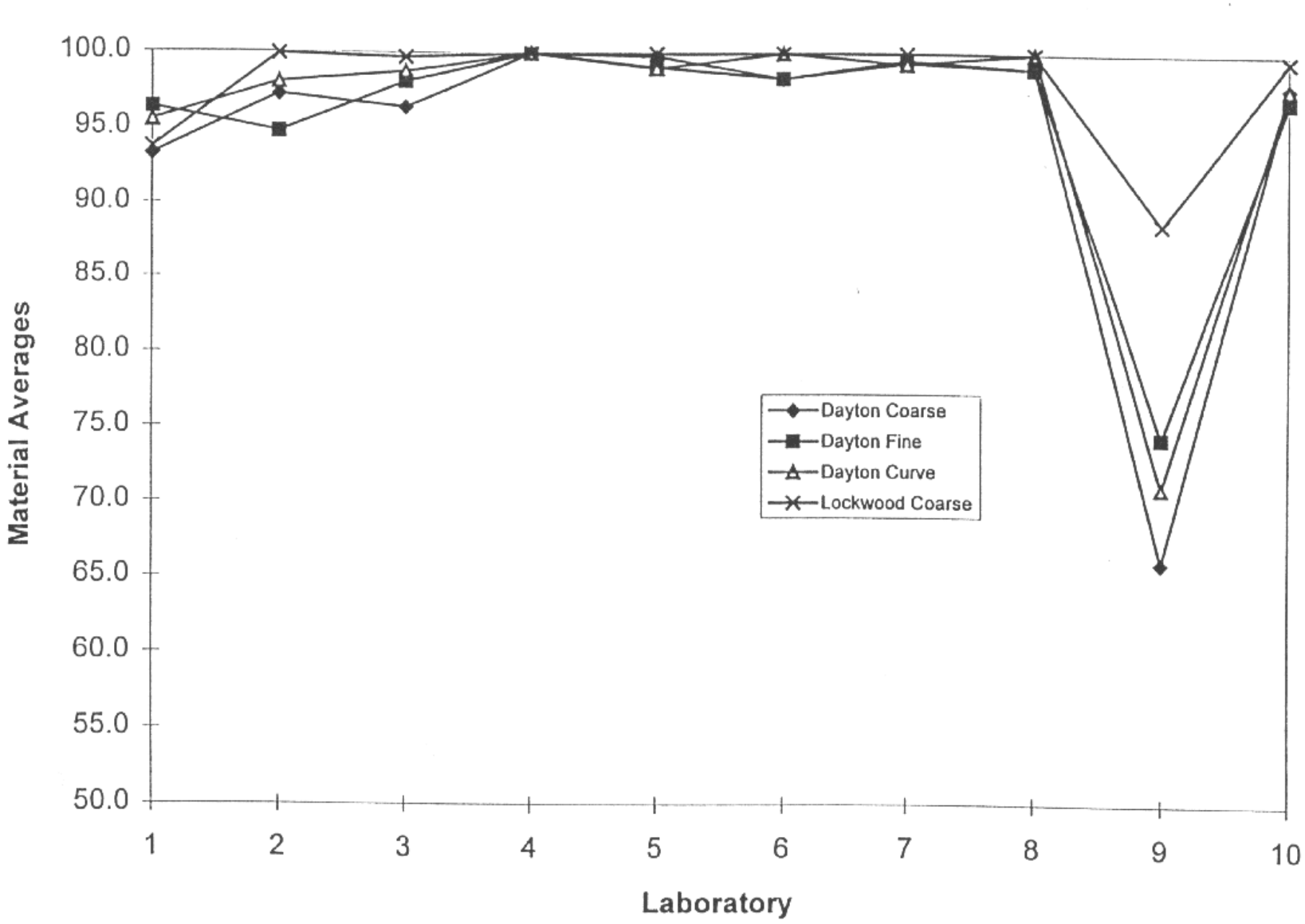

Figure 13. One or more fractured faces material averages by laboratory.

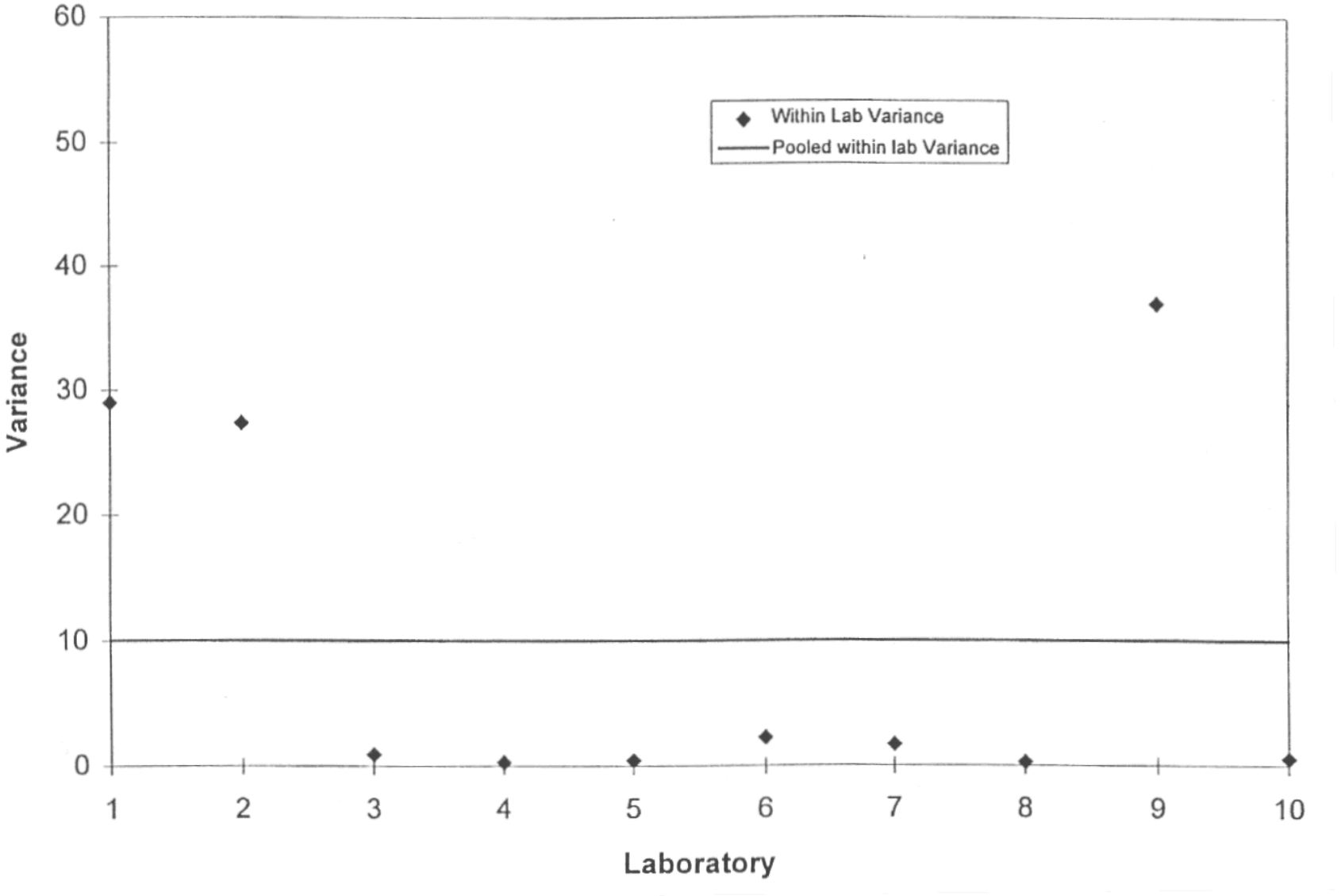

Figure 14. Dayton coarse blend two or more fractured faces variance plot by laboratory.

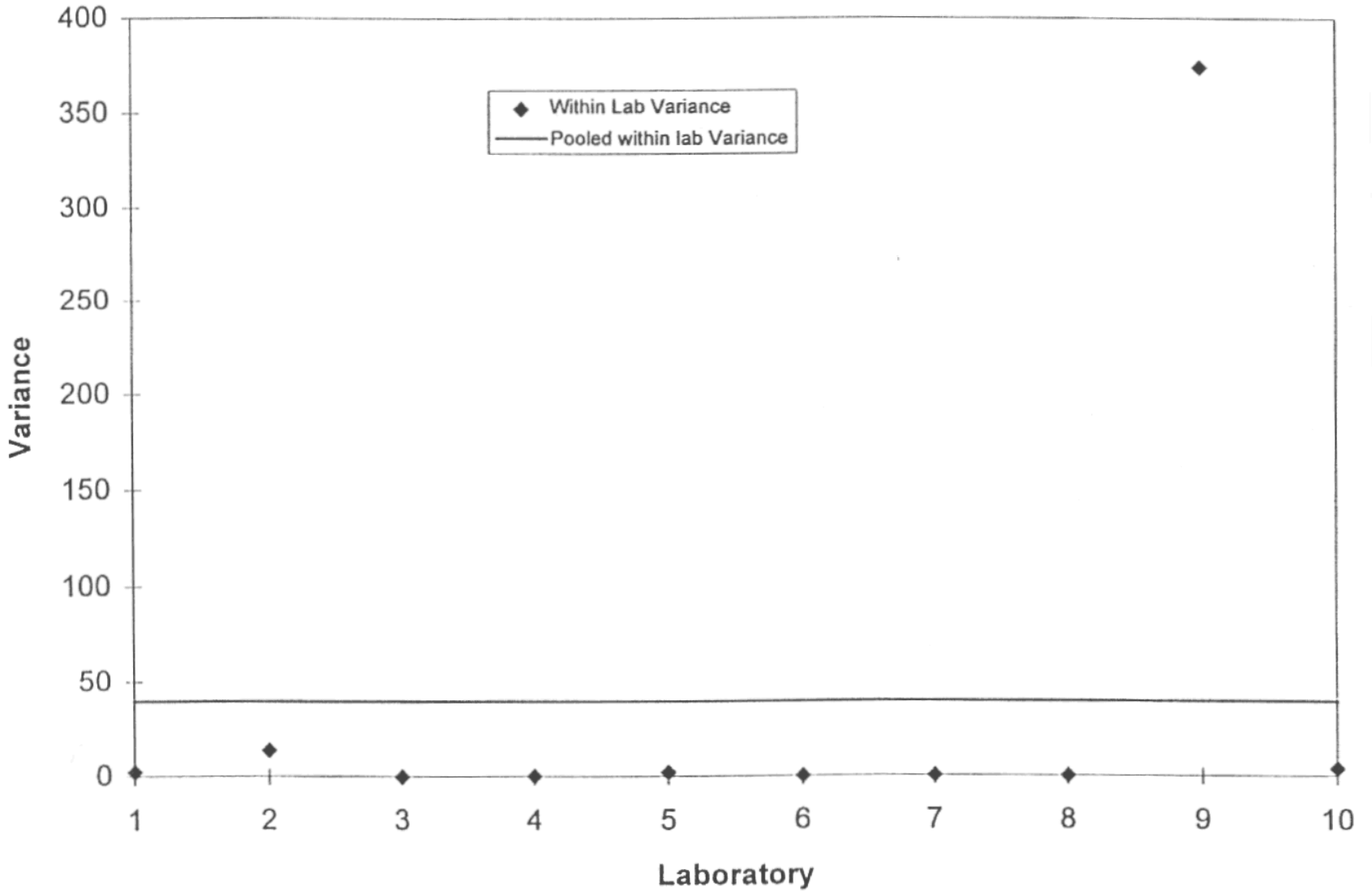

Figure 15. Dayton fine blend two or more fractured faces variance plot by laboratory.

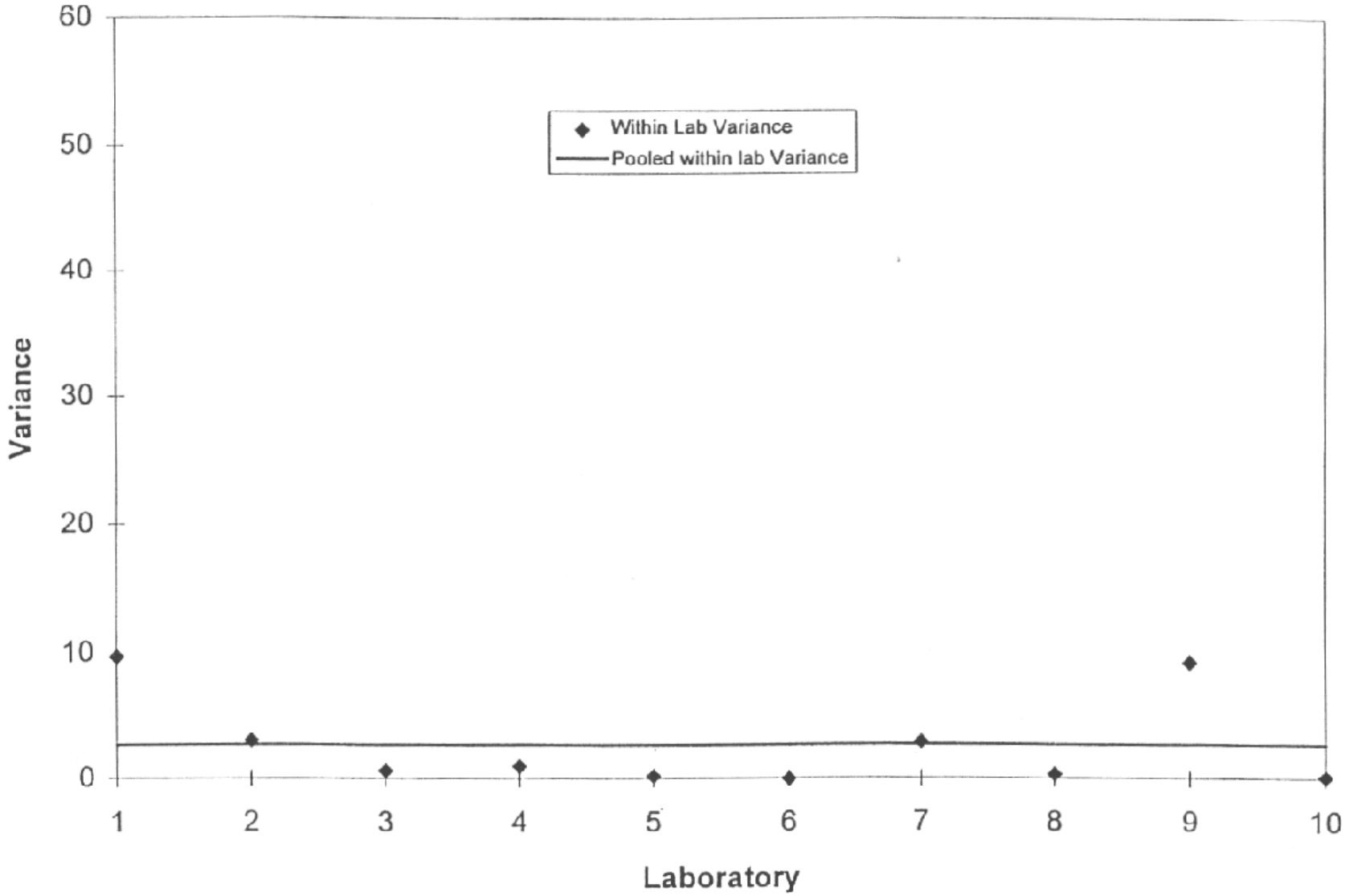

Figure 16. Dayton curve blend two or more fractured faces variance plot by laboratory.

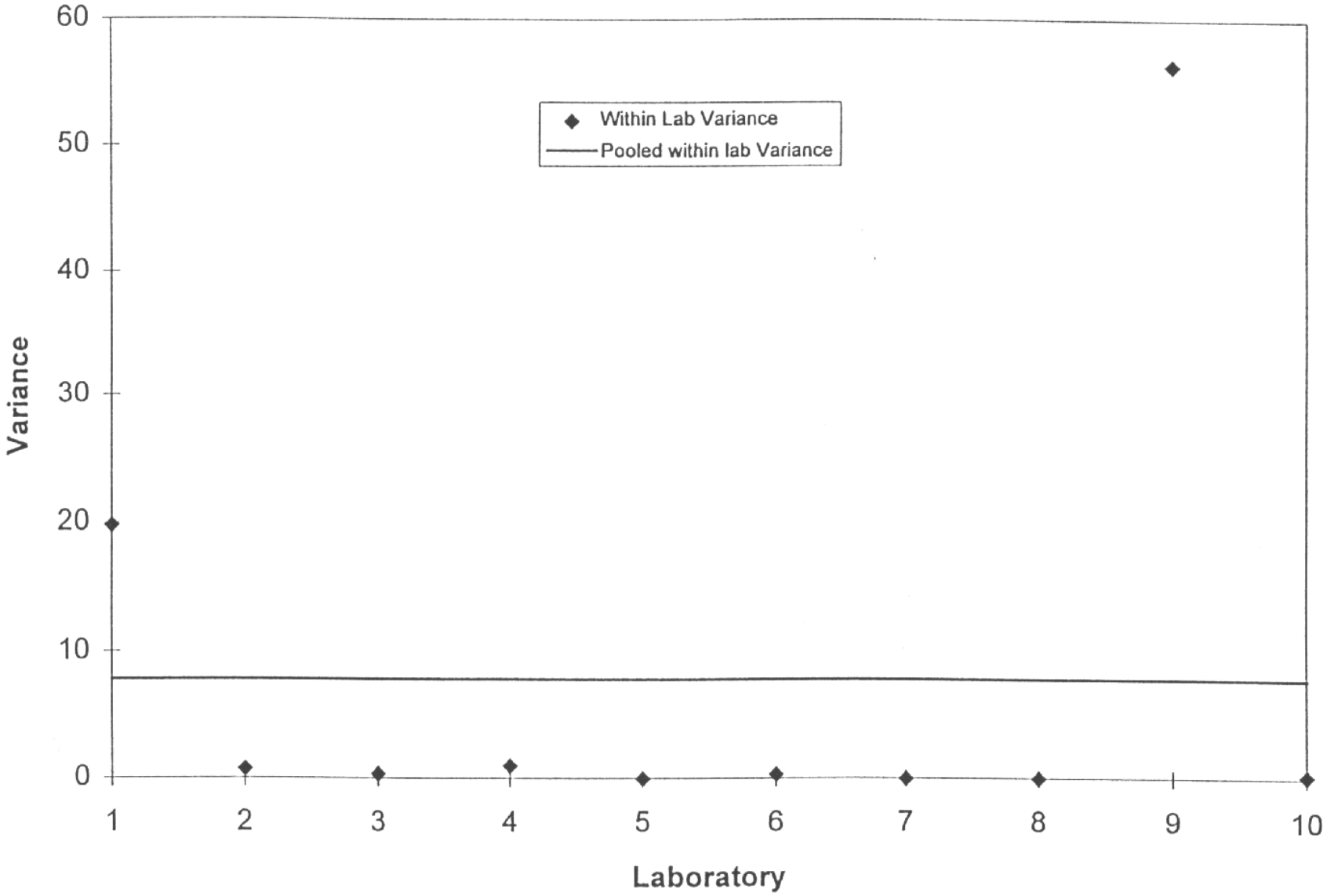

Figure 17. Lockwood coarse blend two or more fractured faces variance plot by laboratory.

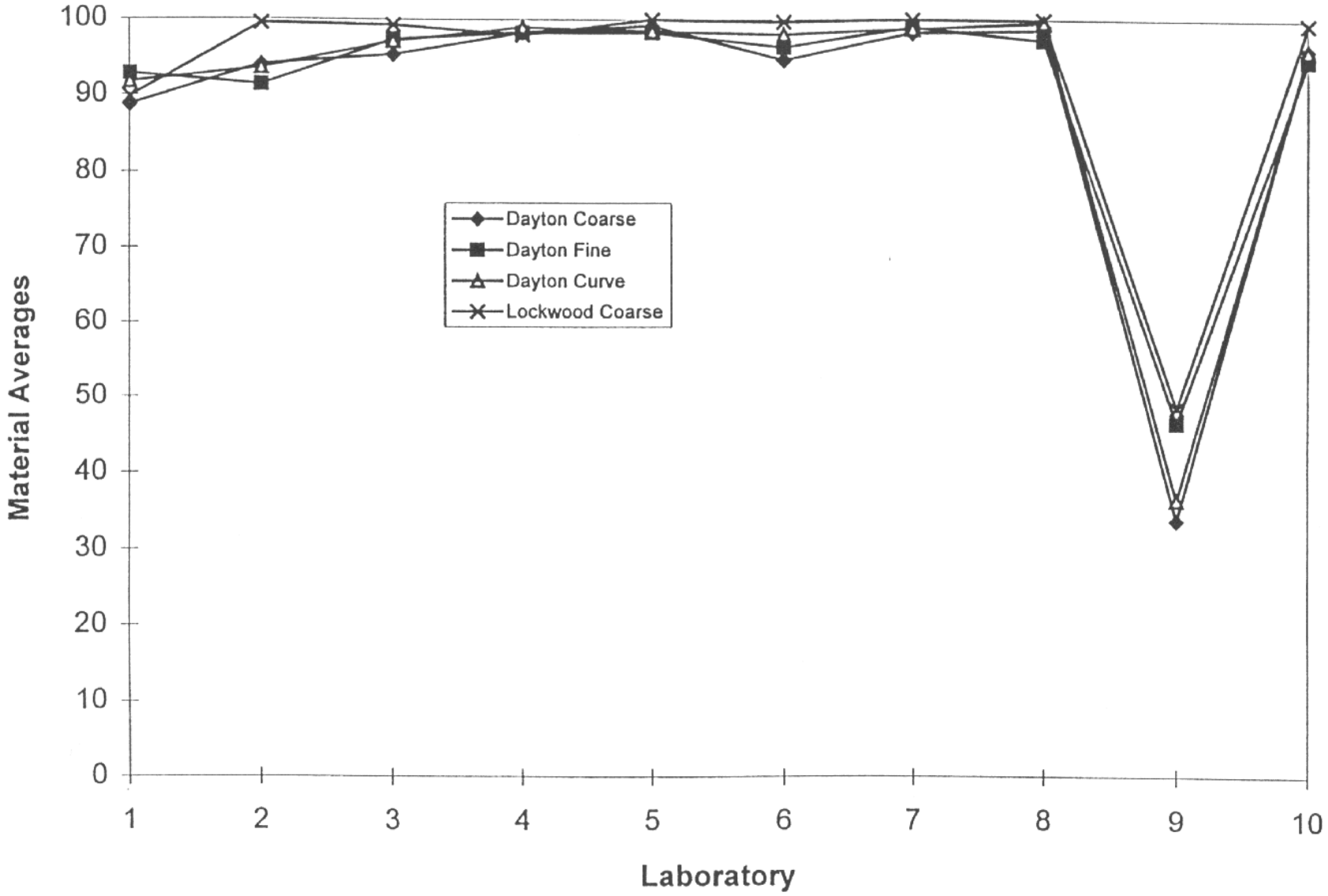

Figure 18. Two or more fractured faces material averages by laboratory.

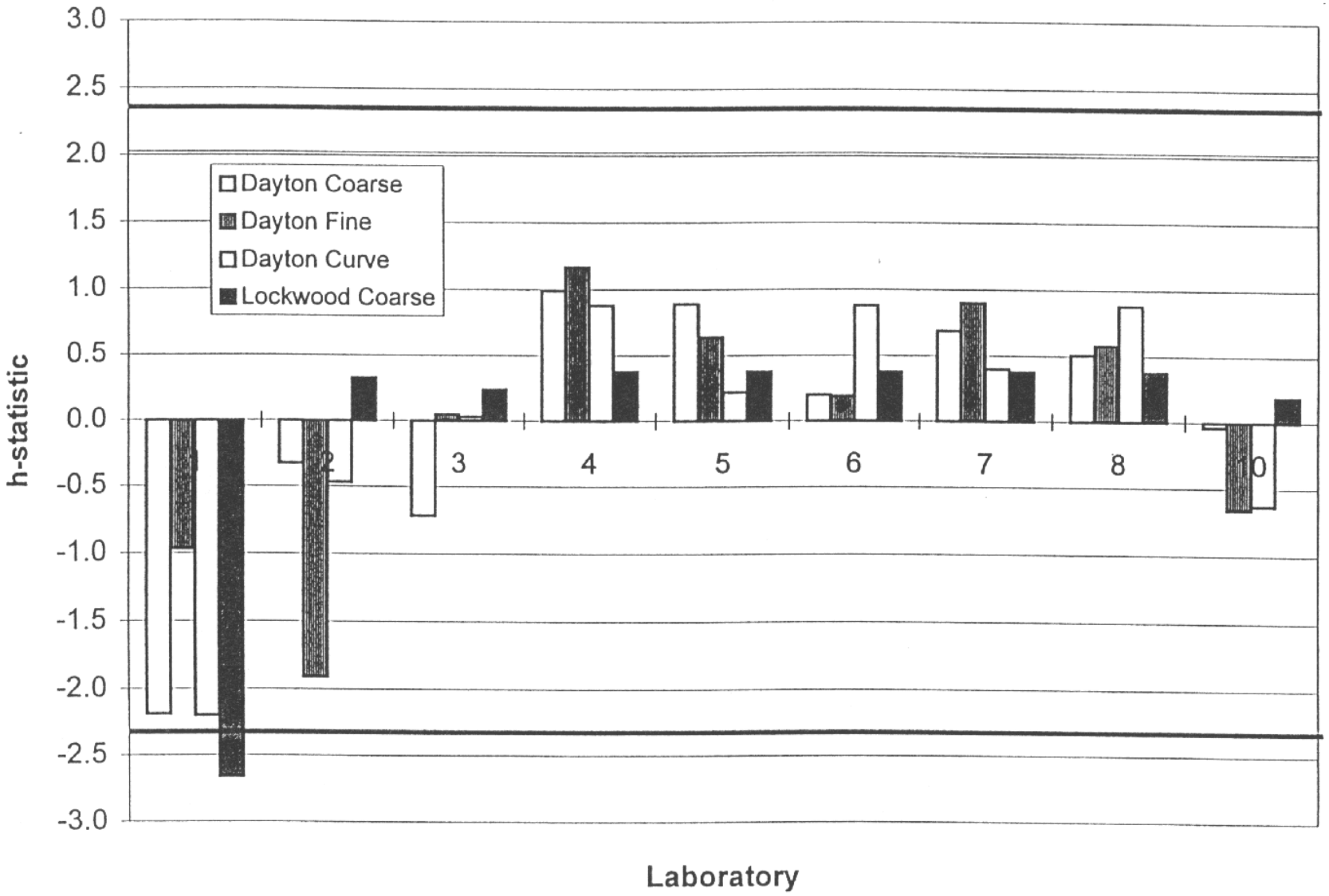

Figure 19. One or more fractured faces h-statistics by laboratory.

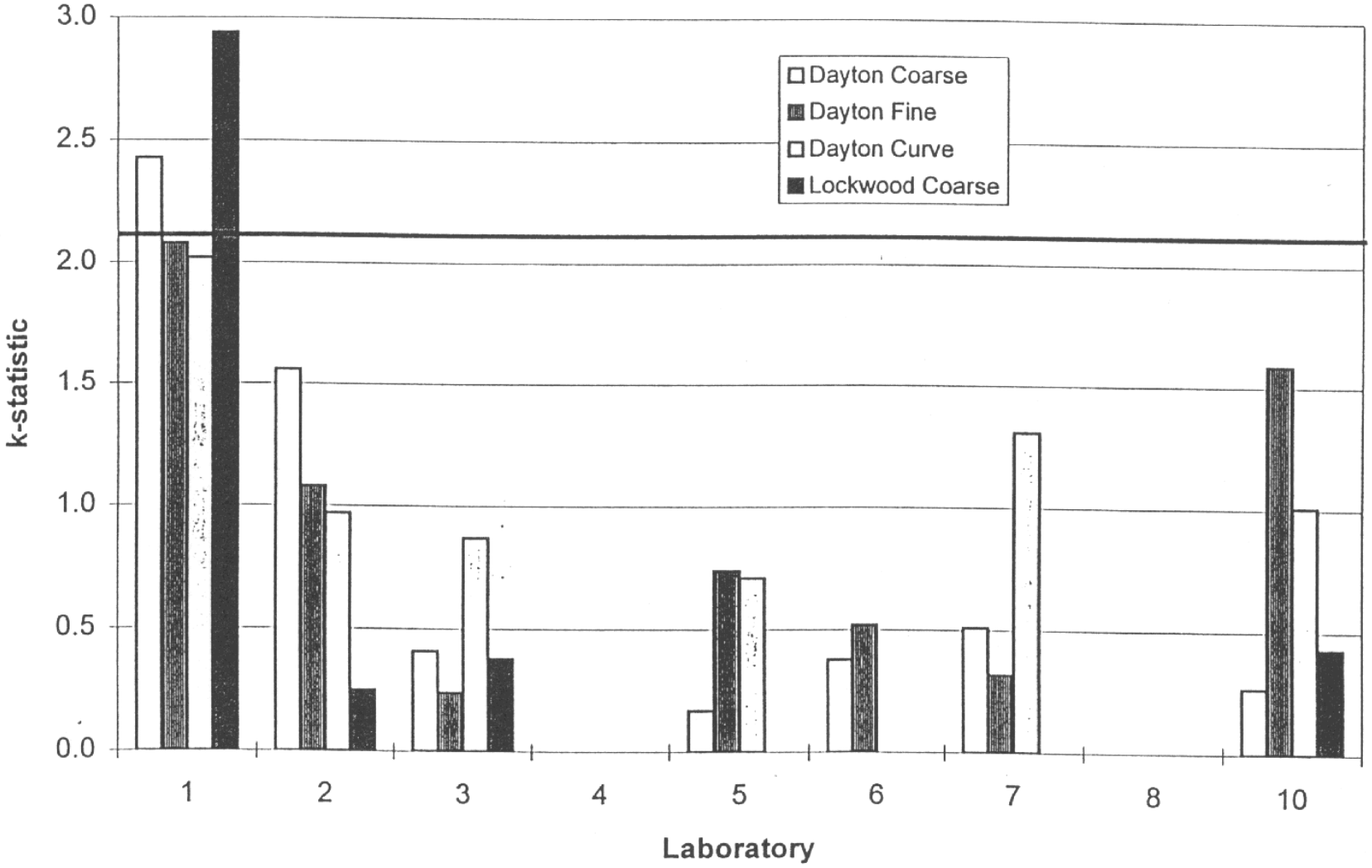

Figure 20. One or more fractured faces k-statistics by laboratory.

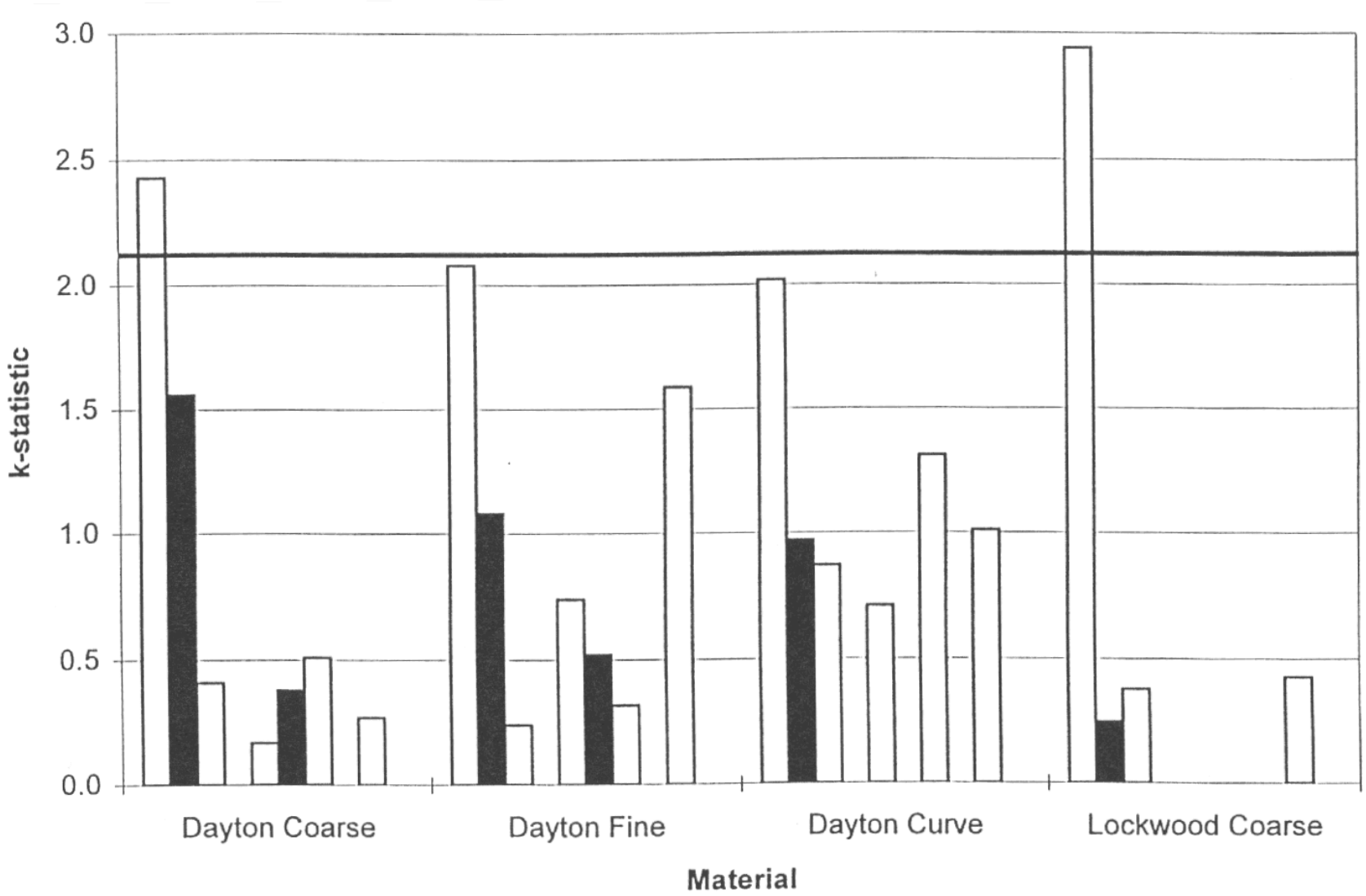

Figure 22. One or more fractured faces k-statistics by material.

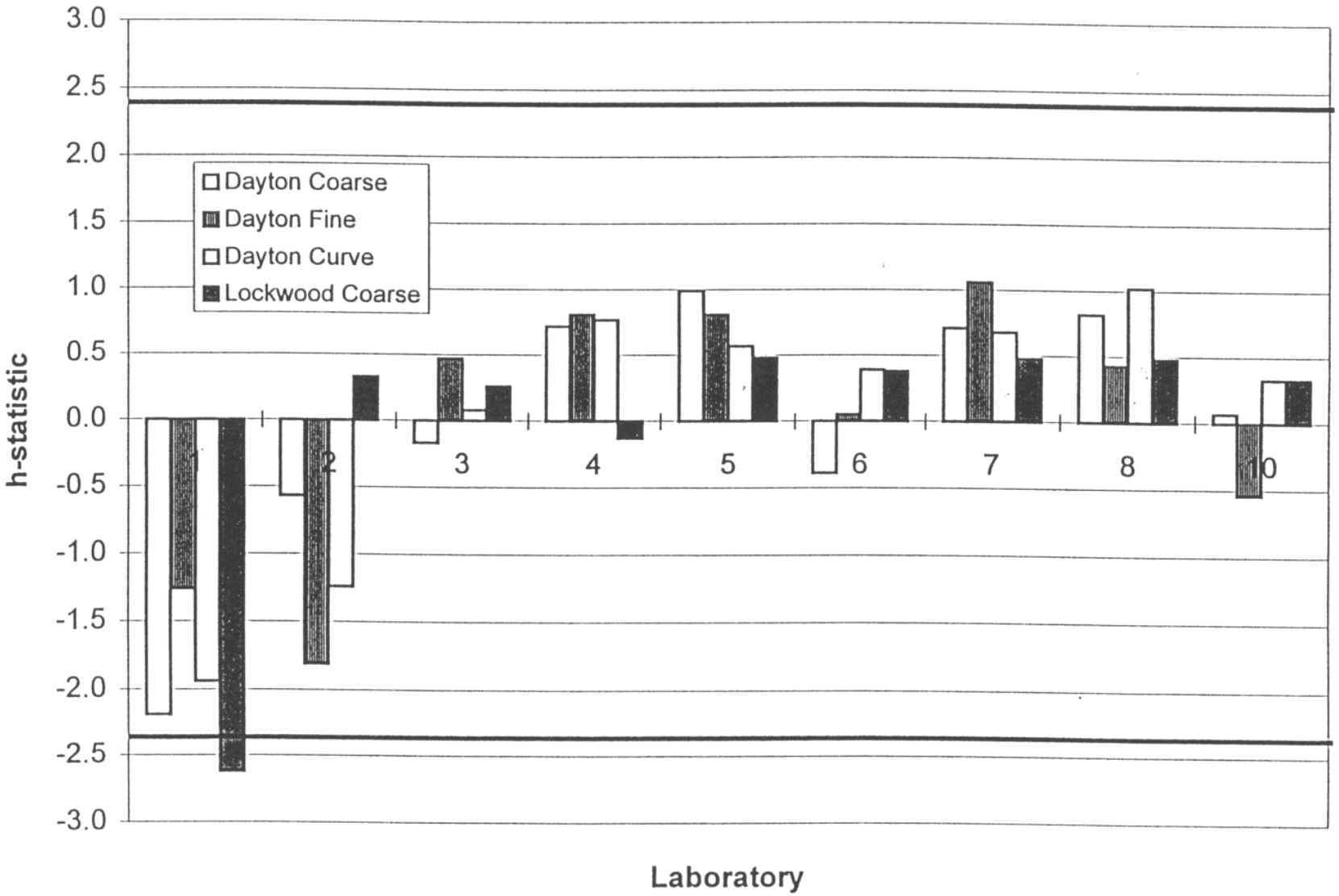

Figure 23. Two or more fractured faces h-statistics by laboratory.

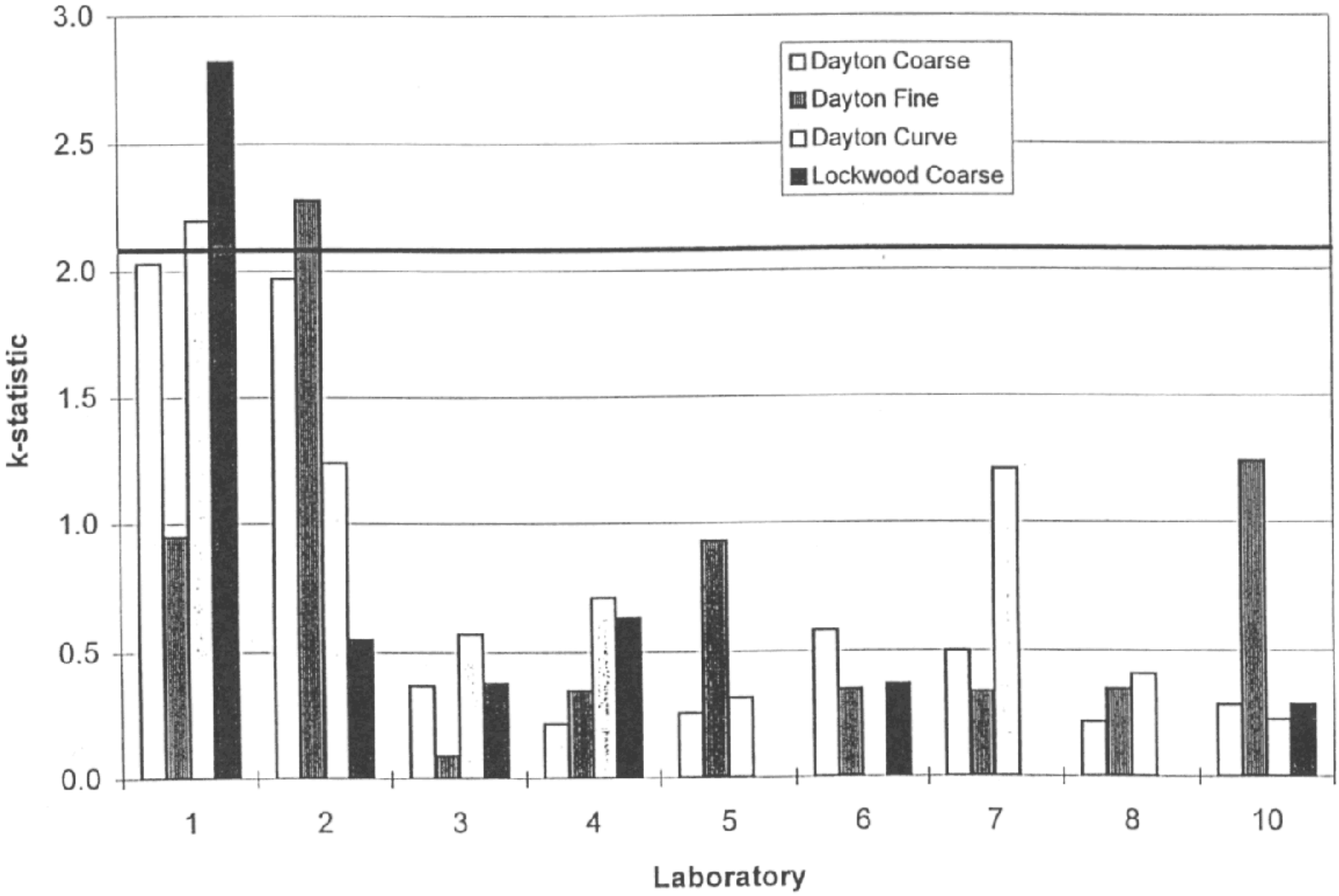

Figure 24. Two or more fractured faces k-statistics by laboratory.

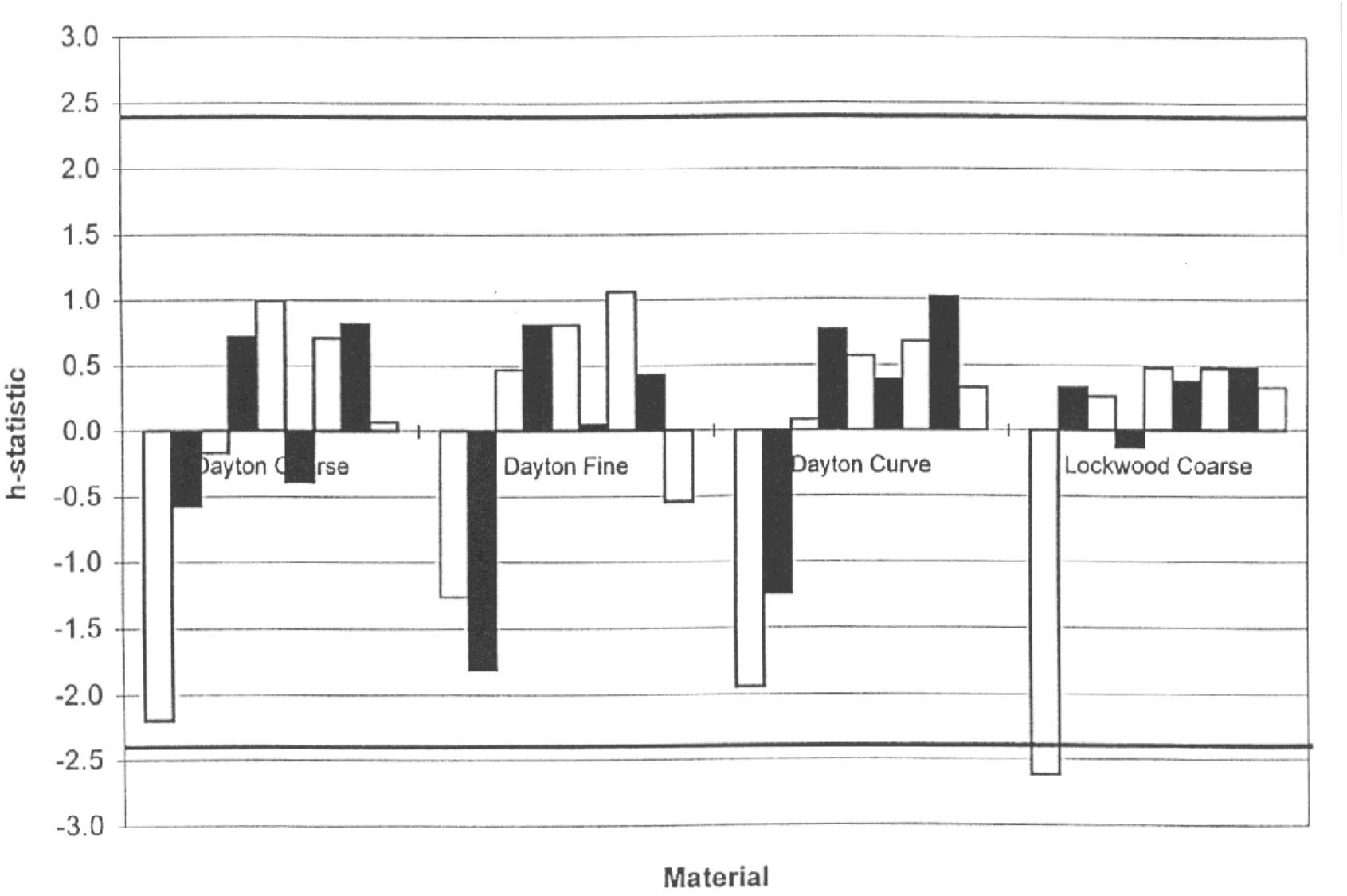

Figure 25. Two or more fractured faces h-statistics by material.

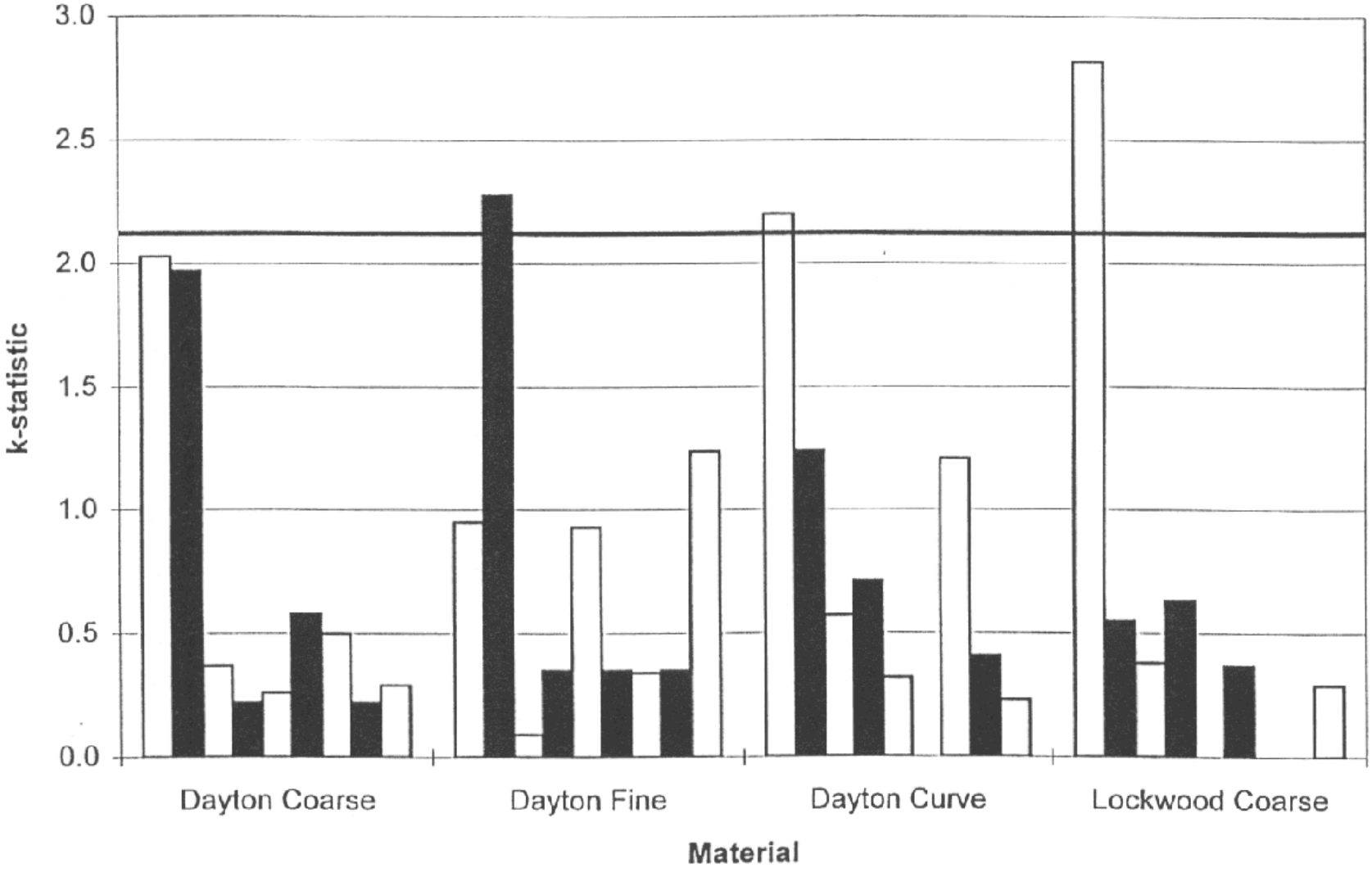

Figure 26. Two or more fractured faces k-statistics by material.

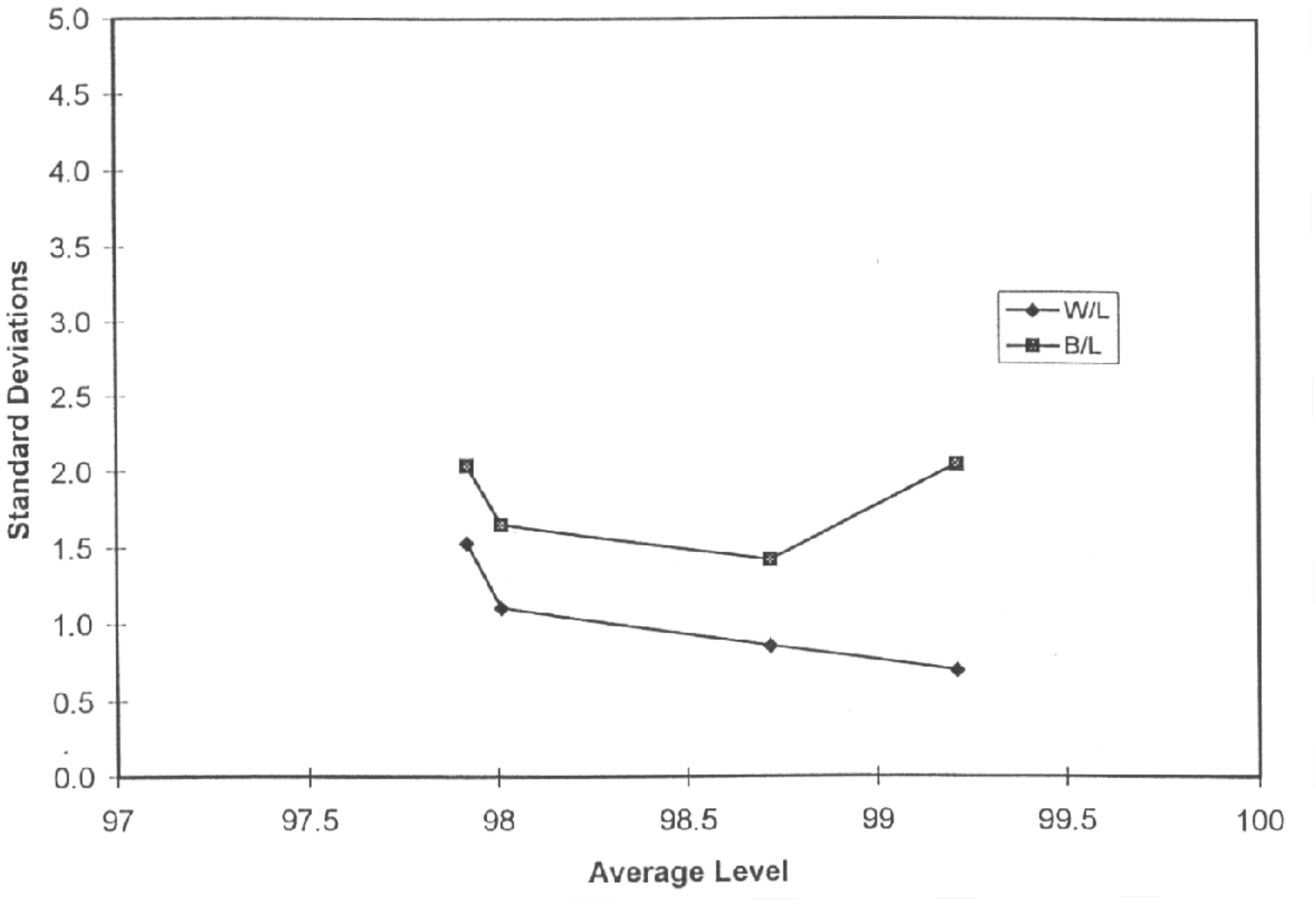

Figure 27. One or more fractured faces one-sigma limits versus material average.

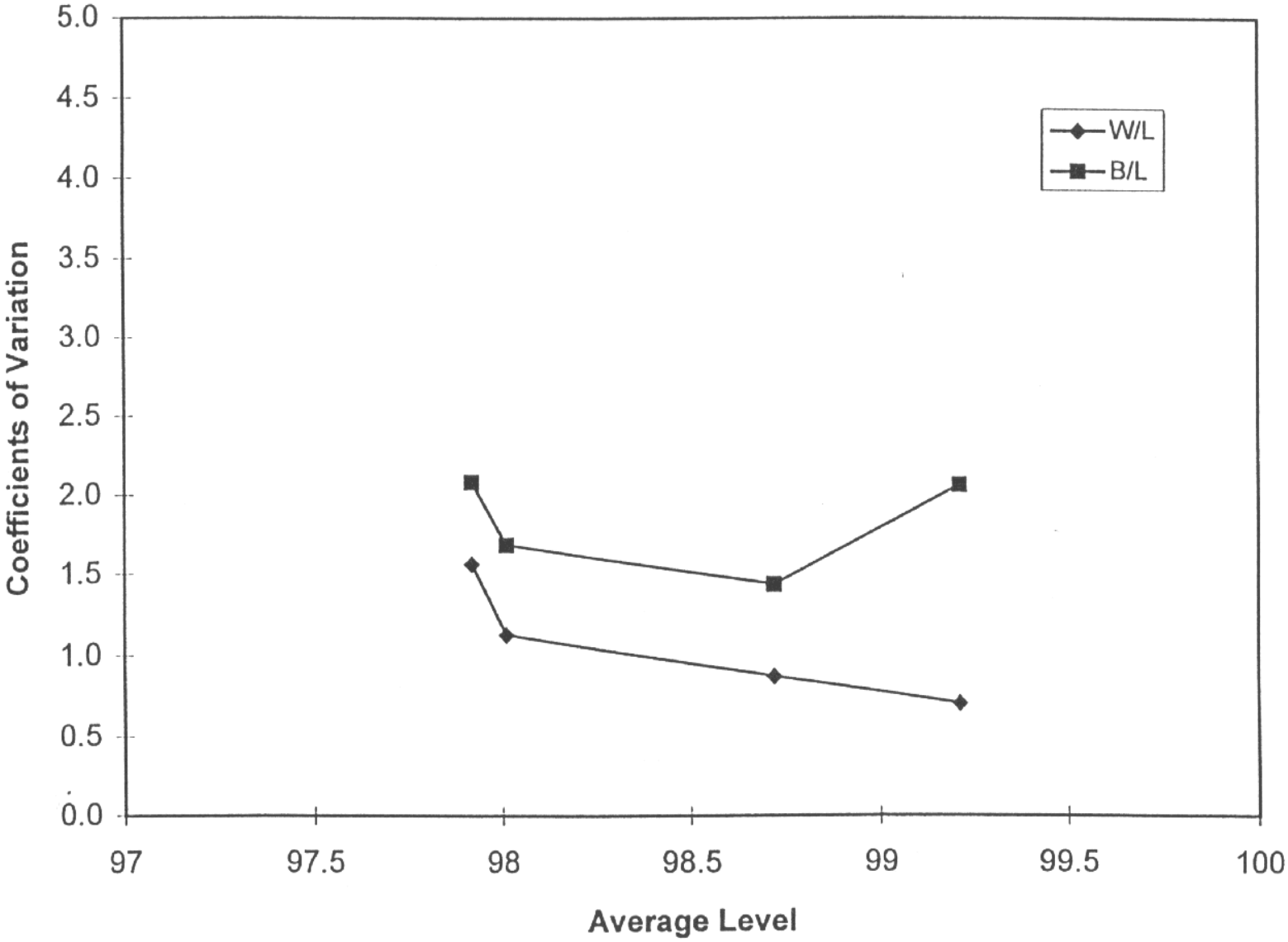

Figure 28. One or more fractured faces one-sigma limits, expressed as a percentage of the average, versus material average.

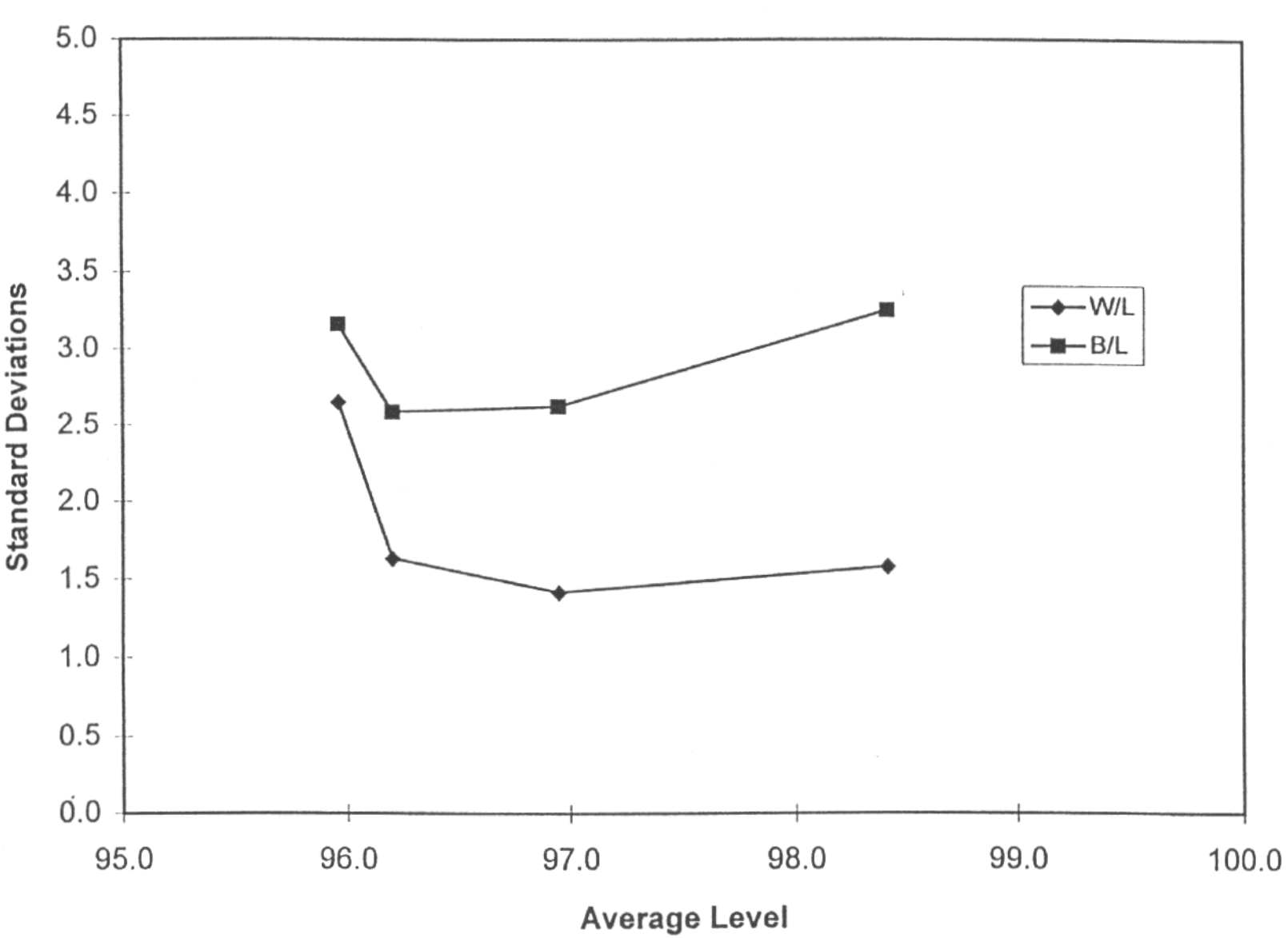

Figure 29. Two or more fractured face one-sigma limits versus material average.

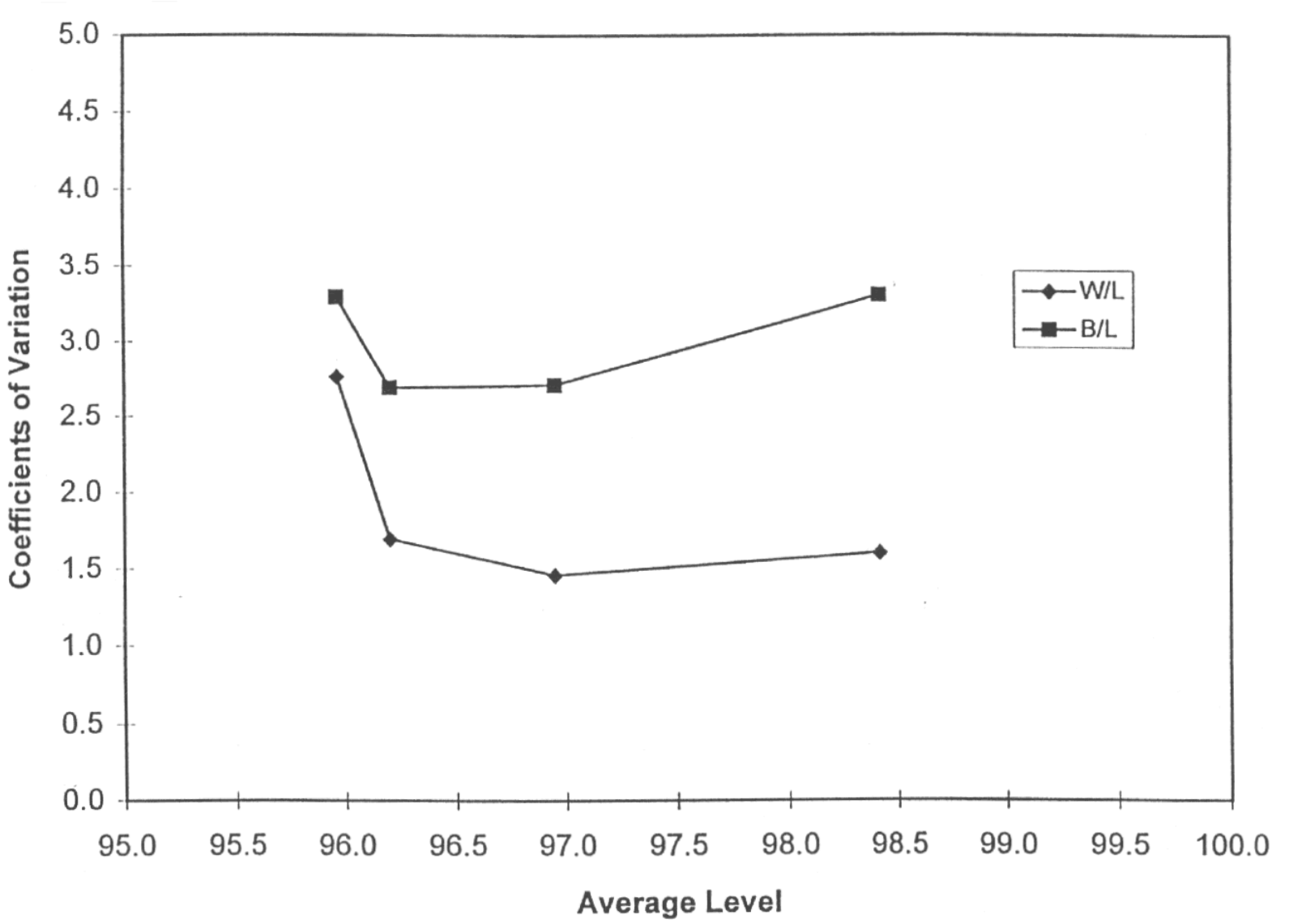

Figure 30. Two or more fractured faces one-sigma limits, expressed as a percentage of the average, versus material average.

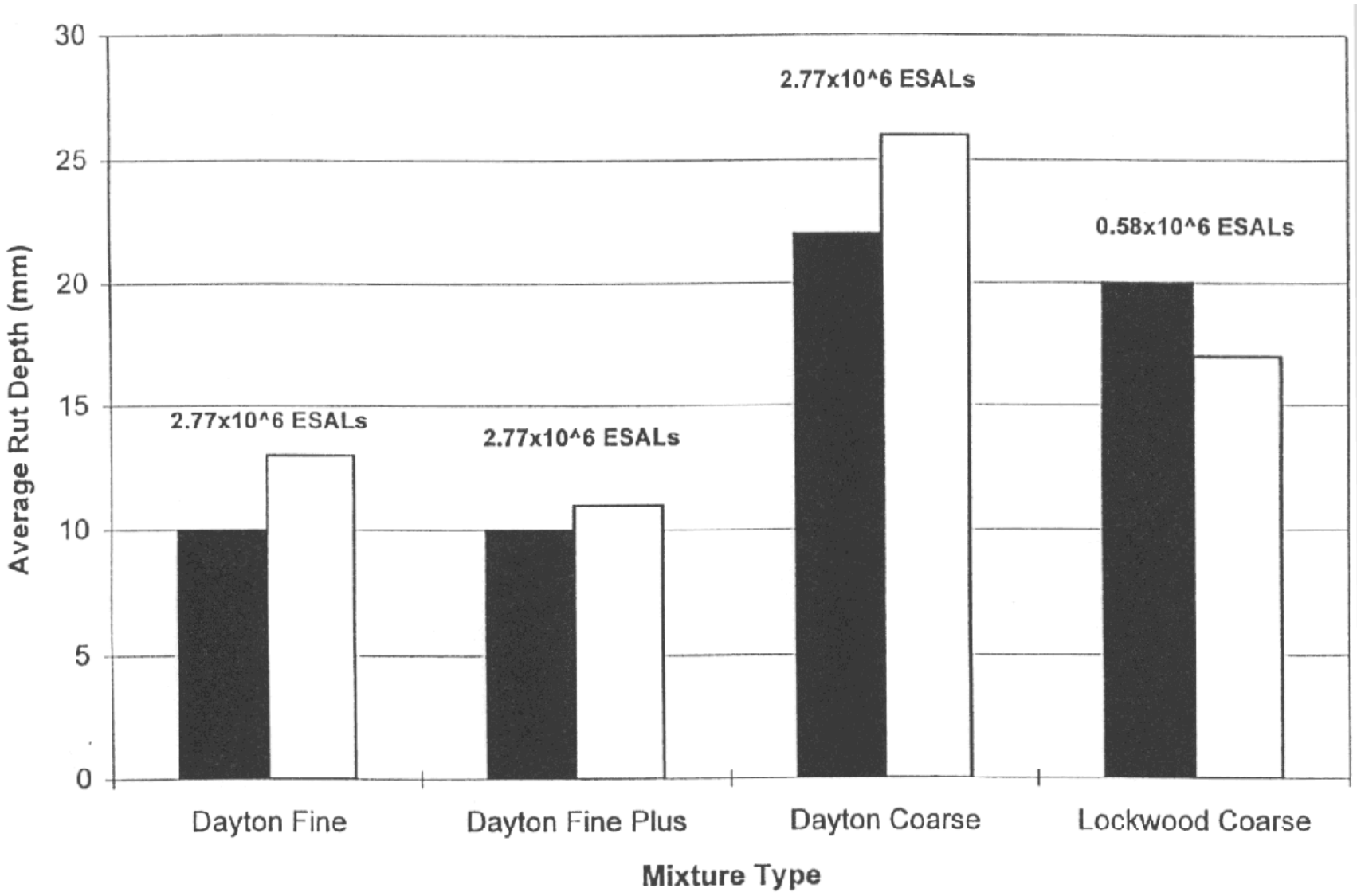

Figure 31. Average rut depth of WesTrack mixes as a function of ESALs.

Table 1. Average fractured face requirements by mix type.

Mixture Type	Average Minimum Percentage of Particles with One or More Fractured Faces	Average Minimum Percentage of Particles with Two or More Fractured Faces
Surface	61.0	63.1
Binder	56.3	59.5

Table 2. Superpave coarse aggregate angularity specifications.

Traffic Level ($x10^6$ ESALs)	Depth from Surface	
	<100 mm	>100 mm
<0.3	55 / -	- / -
<1	65 / -	- / -
<3	75 / -	50 / -
<10	85 / 80	60 / -
<30	95 / 90	80 / 75
<100	100 / 100	95 / 90
>100	100 / 100	100 / 100

Note: "85/80" means that at least 85% of the coarse aggregate has one fractured face and at least 80% has two fractured faces.

Table 3. Coarse aggregate angularity experiment

Material Source	Aggregate Blend	Participating Laboratories	Replicates per Blend per Laboratory
’94 Dayton	Coarse	Superpave Center at Reno* Superpave Center at Texas Superpave Center at Purdue Superpave Center at Auburn Superpave Center at Penn State Asphalt Institute* Texas Transportation Institute* Oregon State University FHWA Mobile Laboratories (2)	3
	Fine		3
’95 Dayton	Coarse		3
’97 Lockwood	Coarse		3

*AASHTO accredited laboratories.

Table 4. Sample identification provided to participating laboratories.

Material Source	Aggregate Blend	No. of Replicates	Identification Provided to Participating Laboratories
’94 Dayton	Coarse	3	Random Numbers
’94 Dayton	Fine	3	Random Numbers
’95 Dayton	Coarse	3	Random Numbers
’97 Lockwood	Coarse	3	Random Numbers

Table 5. One fractured face measurement by laboratory.

Lab ID	Dayton Coarse	Dayton Fine	Dayton Curve	Lockwood Coarse
1	89.0	93.7	94.2	91.8
	95.5	97.7	97.5	95.9
	95.4	97.7	94.9	93.5
2	100.0	96.0	97.6	100.0
	95.9	93.6	97.5	100.0
	95.8	94.7	99.0	99.7
3	96.9	97.8	99.2	99.6
	95.7	98.2	97.9	100.0
	96.6	98.3	99.2	99.5
4	100.0	100.0	100.0	100.0
	100.0	100.0	100.0	100.0
	100.0	100.0	100.0	100.0
5	100.0	98.2	99.7	100.0
	99.9	99.8	98.9	100.0
	99.5	99.3	98.5	100.0
6	99.0	98.0	100.0	100.0
	98.0	98.0	100.0	100.0
	98.0	99.0	100.0	100.0
7	100.0	99.5	98.0	100.0
	99.6	99.2	99.9	100.0
	98.5	99.9	100.0	100.0
8	99.0	99.0	100.0	100.0
	99.0	99.0	100.0	100.0
	99.0	99.0	100.0	100.0
9	55.0	83.0	75.0	88.0
	74.0	63.0	70.0	84.0
	69.0	77.0	68.0	94.0
10	97.7	98.2	97.2	99.3
	97.5	94.9	98.8	99.9
	98.3	97.6	97.4	99.6

Table 6. Two fractured face measurements by laboratory.

Lab ID	Dayton Coarse	Dayton Fine	Dayton Curve	Lockwood Coarse
1	82.7	91.1	91.0	85.4
	93.0	94.0	95.2	94.3
	90.6	93.5	89.1	89.7
2	100.0	89.2	93.1	100.0
	92.3	95.7	92.2	100.0
	90.0	89.3	95.6	98.5
3	96.5	97.6	98.0	98.7
	95.1	97.3	96.4	99.9
	94.6	97.4	97.1	99.2
4	99.0	98.0	100.0	99.0
	98.0	98.0	98.0	98.0
	98.0	99.0	99.0	97.0
5	99.0	96.7	98.5	100.0
	98.5	99.7	98.9	100.0
	99.2	98.6	98.0	100.0
6	95.0	96.0	98.0	99.0
	96.0	96.0	98.0	100.0
	93.0	97.0	98.0	100.0
7	98.8	99.1	96.8	100.0
	99.3	98.4	99.5	100.0
	96.8	99.5	100.0	100.0
8	98.0	97.0	100.0	100.0
	99.0	98.0	100.0	100.0
	99.0	97.0	99.0	100.0
9	27.0	69.0	40.0	53.0
	37.0	36.0	34.0	40.0
	38.0	35.0	36.0	53.0
10	96.6	95.1	95.7	99.0
	95.3	92.6	96.3	99.9
	96.7	96.6	96.2	99.6

Table 7. Box plot descriptive statistics.

Descriptive Statistics	1 or more fractured faces				2 or more fractured faces			
	Dayton Coarse	Dayton Fine	Dayton Curve	Lockwood Coarse	Dayton Coarse	Dayton Fine	Dayton Curve	Lockwood Coarse
Minimum	55.0	63.0	68.0	84.0	27.0	35.0	34.0	40.0
Lower outer fence	84.2	84.5	90.0	97.6	74.7	78.2	80.5	90.0
Lower inner fence	90.0	90.0	93.8	98.5	83.7	85.6	87.3	93.8
Q1	95.8	95.5	97.5	99.4	92.7	93.1	94.2	97.5
Q2	98.2	98.2	99.0	100.0	96.6	96.9	97.6	99.0
Q3	99.6	99.1	100.0	100.0	98.7	98.0	98.7	100.0
Upper inner fence	105.4	104.6	103.8	100.9	107.7	105.4	105.5	103.8
Upper outer fence	111.2	110.1	107.5	101.8	116.7	112.9	112.4	107.5
Maximum	100.0	100.0	100.0	100.0	100.0	99.7	100.0	100.0

Table 8. One or more fractured faces between and within analysis for all materials.

Material	Dayton Coarse			Dayton Fine			Dayton Curve			Lockwood Coarse		
Lab ID	Within Lab Average	Within Lab Std. Dev.	Within Lab Variance	Within Lab Average	Within Lab Std. Dev.	Within Lab Variance	Within Lab Average	Within Lab Std. Dev.	Within Lab Variance	Within Lab Average	Within Lab Std. Dev.	Within Lab Variance
1	93.300	3.724	13.870	96.367	2.309	5.333	95.533	1.739	3.023	93.733	2.060	4.243
2	97.233	2.397	5.743	94.767	1.201	1.443	98.033	0.839	0.703	99.900	0.173	0.030
3	96.400	0.624	0.390	98.100	0.265	0.070	98.767	0.751	0.563	99.700	0.265	0.070
4	100.000	0.000	0.000	100.000	0.000	0.000	100.000	0.000	0.000	100.000	0.000	0.000
5	99.800	0.265	0.070	99.100	0.819	0.670	99.033	0.611	0.373	100.000	0.000	0.000
6	98.333	0.577	0.333	98.333	0.577	0.333	100.000	0.000	0.000	100.000	0.000	0.000
7	99.367	0.777	0.603	99.533	0.351	0.123	99.300	1.127	1.270	100.000	0.000	0.000
8	99.000	0.000	0.000	99.000	0.000	0.000	100.000	0.000	0.000	100.000	0.000	0.000
9	66.000	9.849	97.000	74.333	10.263	105.333	71.000	3.606	13.000	88.667	5.033	25.333
10	97.833	0.416	0.173	96.900	1.758	3.090	97.800	0.872	0.760	99.600	0.300	0.090
Average of cell averages			94.727			95.643			95.947			98.160
Pooled within lab variance			11.818			11.640			1.969			2.977
Variance of lab averages			105.815			58.621			78.701			14.902
Between lab component of variance			104.633			57.457			78.504			14.605
Sum of variances			118.183			116.397			19.693			29.767

Table 9. One or more fractured faces maximum variance ratio analysis for all materials.

Material	Largest Variance	Sum of Variance	Ratio	Criteria	Pass/Fail
Dayton Coarse	97.000	118.183	0.821	0.445	Fail
Dayton Fine	105.333	116.397	0.905	0.445	Fail
Dayton Curve	13.000	19.693	0.660	0.445	Fail
Lockwood Coarse	25.333	29.767	0.851	0.445	Fail

Table 10. One or more fractured faces minimum variance ratio analysis for all materials.

Material	Largest Variance	Smallest Variance	Ratio	Criteria	Pass/Fail
Dayton Coarse	97.000	0	Undefined	550	n/a
Dayton Fine	105.333	0	Undefined	550	n/a
Dayton Curve	13.000	0	Undefined	550	n/a
Lockwood Coarse	25.333	0	Undefined	550	n/a

Table 11. One or more fractured faces averages, components of variance, and variances for all materials.

Material	Average	Components of Variance		Variances	
		W/L	B/L	W/L	B/L
Dayton Coarse	94.727	11.818	104.633	11.818	116.452
Dayton Fine	95.643	11.640	57.457	11.640	69.096
Dayton Curve	95.947	1.969	78.504	1.969	80.473
Lockwood Coarse	98.160	2.977	14.605	2.977	17.481

Table 12. One or more fractured faces averages, standard deviations, and coefficients of variations for all materials.

Material	Average	Standard Deviation		Coefficients of Variances	
		W/L	B/L	W/L	B/L
Dayton Coarse	94.727	3.438	10.229	3.629	10.798
Dayton Fine	95.643	3.412	7.580	3.567	7.925
Dayton Curve	95.947	1.403	8.860	1.463	9.235
Lockwood Coarse	98.160	1.725	3.822	1.758	3.893
Pooled		2.495	7.623		
Average				2.604	7.963

Table 13. Two or more fractured faces between and within analysis for all materials.

Material	Dayton Coarse			Dayton Fine			Dayton Curve			Lockwood Coarse		
Lab ID	Within Lab Average	Within Lab Std. Dev.	Within Lab Variance	Within Lab Average	Within Lab Std. Dev.	Within Lab Variance	Within Lab Average	Within Lab Std. Dev.	Within Lab Variance	Within Lab Average	Within Lab Std. Dev.	Within Lab Variance
1	88.767	5.389	29.043	92.867	1.550	2.403	91.767	3.121	9.743	89.800	4.451	19.810
2	94.100	5.237	27.430	91.400	3.724	13.870	93.633	1.762	3.103	99.500	0.866	0.750
3	95.400	0.985	0.970	97.433	0.153	0.023	97.167	0.802	0.643	99.267	0.603	0.363
4	98.333	0.577	0.333	98.333	0.577	0.333	99.000	1.000	1.000	98.000	1.000	1.000
5	99.200	0.700	0.490	98.333	1.518	2.303	98.467	0.451	0.203	100.000	0.000	0.000
6	94.667	1.528	2.333	96.333	0.577	0.333	98.000	0.000	0.000	99.667	0.577	0.333
7	98.300	1.323	1.750	99.000	0.557	0.310	98.767	1.721	2.963	100.000	0.000	0.000
8	98.667	0.577	0.333	97.333	0.577	0.333	99.667	0.577	0.333	100.000	0.000	0.000
9	34.000	6.083	37.000	46.667	19.348	374.333	36.667	3.055	9.333	48.667	7.506	56.333
10	96.200	0.781	0.610	94.767	2.021	4.083	96.067	0.321	0.103	99.500	0.458	0.210
Average of cell averages			89.763			91.247			90.920			93.440
Pooled within lab variance			10.029			39.833			2.743			7.880
Variance of lab averages			393.470			251.574			369.717			257.107
Between lab component of variance			392.468			247.591			369.443			256.319
Sum of variances			100.293			398.327			27.427			78.800

Table 14. Two or more fractured faces maximum variance ratio analysis for all materials.

Material	Largest Variance	Sum of Variance	Ratio	Criteria	Pass/Fail
Dayton Coarse	37.000	100.293	0.369	0.445	Pass
Dayton Fine	374.333	398.327	0.940	0.445	Fail
Dayton Curve	9.743	27.427	0.355	0.445	Fail
Lockwood Coarse	56.333	78.800	0.715	0.445	Fail

Table 15. Two or more fractured faces minimum variance ratio analysis for all materials.

Material	Largest Variance	Smallest Variance	Ratio	Criteria	Pass/Fail
Dayton Coarse	37.000	0.333	111	550.000	Pass
Dayton Fine	374.333	0.023	16043	550.000	Fail
Dayton Curve	9.743	0.000	Undefined	550.000	n/a
Lockwood Coarse	56.333	0.000	Undefined	550.000	n/a

Table 16. One or more fractured faces averages, components of variance, and variances for all materials.

Material	Average	Components of Variance		Variances	
		W/L	B/L	W/L	B/L
Dayton Coarse	89.763	10.029	392.468	10.029	402.497
Dayton Fine	91.247	39.833	247.591	39.833	287.424
Dayton Curve	90.920	2.743	369.443	2.743	372.185
Lockwood Coarse	93.440	7.880	256.319	7.880	264.199

Table 17. Two or more fractured faces averages, standard deviations, and coefficients of variations for all materials.

Material	Average	Standard Deviation		Coefficients of Variances	
		W/L	B/L	W/L	B/L
Dayton Coarse	89.763	3.167	19.811	3.528	22.070
Dayton Fine	91.247	6.311	15.735	6.917	17.244
Dayton Curve	90.920	1.656	19.221	1.821	21.140
Lockwood Coarse	93.440	2.807	16.010	3.004	17.134
Pooled		3.485	17.694		
Average				3.818	19.97

Table 18. One or more fractured faces consistency statistics.

Laboratory	1 or more fractured faces							
	Dayton Coarse		Dayton Fine		Dayton Curve		Lockwood Coarse	
	h statistic	k statistic	h statistic	k statistic	h statistic	k statistic	h statistic	k statistic
1	-2.19	2.43	-0.97	2.08	-2.20	2.02	-2.66	2.94
2	-0.33	1.56	-1.91	1.08	-0.47	0.97	0.33	0.25
3	-0.72	0.41	0.05	0.24	0.03	0.87	0.24	0.38
4	0.99	0.00	1.17	0.00	0.88	0.00	0.38	0.00
5	0.89	0.17	0.64	0.74	0.22	0.71	0.38	0.00
6	0.20	0.38	0.19	0.52	0.88	0.00	0.38	0.00
7	0.69	0.51	0.90	0.32	0.40	1.31	0.38	0.00
8	0.51	0.00	0.58	0.00	0.88	0.00	0.38	0.00
10	-0.04	0.27	-0.66	1.59	-0.63	1.01	0.19	0.43

Critical h-statistic = 2.23
Critical k-statistic = 2.09

Table 19. Two or more fractured faces consistency statistics.

Laboratory	2 or more fractured faces							
	Dayton Coarse		Dayton Fine		Dayton Curve		Lockwood Coarse	
	h statistic	k statistic	h statistic	k statistic	h statistic	k statistic	h statistic	k statistic
1	-2.19	2.03	-1.26	0.95	-1.94	2.20	-2.62	2.82
2	-0.57	1.97	-1.81	2.28	-1.24	1.24	0.33	0.55
3	-0.17	0.37	0.47	0.09	0.08	0.57	0.26	0.38
4	0.72	0.22	0.81	0.35	0.77	0.71	-0.13	0.63
5	0.99	0.26	0.81	0.93	0.57	0.32	0.48	0.00
6	-0.39	0.58	0.05	0.35	0.39	0.00	0.38	0.37
7	0.71	0.50	1.06	0.34	0.68	1.21	0.48	0.00
8	0.82	0.22	0.43	0.35	1.02	0.41	0.48	0.00
10	0.07	0.29	-0.54	1.24	0.33	0.23	0.33	0.29

Critical h-statistic = 2.23
Critical k-statistic = 2.09

Table 20. One or more fractured faces averages, components of variance, and variances for all materials.

Material	Average	Components of Variance		Variances	
		W/L	B/L	W/L	B/L
Dayton Coarse	97.919	2.354	4.167	2.354	6.520
Dayton Fine	98.011	1.229	2.740	1.229	3.969
Dayton Curve	98.719	0.744	2.020	0.744	2.764
Lockwood Coarse	99.215	0.493	4.199	0.493	4.691

Table 21. One or more fractured faces averages, standard deviations, and coefficients of variations for all materials.

Material	Average	Standard Deviation		Coefficients of Variances	
		W/L	B/L	W/L	B/L
Dayton Coarse	97.919	1.534	2.041	1.567	2.085
Dayton Fine	98.011	1.109	1.655	1.131	1.689
Dayton Curve	98.719	0.862	1.421	0.874	1.440
Lockwood Coarse	99.215	0.702	2.049	0.707	2.065
Pooled		1.052	1.792		
Average				1.070	1.820

Table 22. Two or more fractured faces averages, components of variance, and variances for all materials.

Material	Average	Components of Variance		Variances	
		W/L	B/L	W/L	B/L
Dayton Coarse	95.959	7.033	9.991	7.033	17.024
Dayton Fine	96.200	2.666	6.700	2.666	9.366
Dayton Curve	96.948	2.010	6.899	2.010	8.910
Lockwood Coarse	98.415	2.496	10.572	2.496	13.068

Table 23. Two or more fractured faces averages, standard deviations, and coefficients of variations for all materials.

Material	Average	Standard Deviation		Coefficients of Variances	
		W/L	B/L	W/L	B/L
Dayton Coarse	95.959	2.652	3.161	2.764	3.294
Dayton Fine	96.200	1.633	2.588	1.697	2.691
Dayton Curve	96.948	1.418	2.627	1.463	2.709
Lockwood Coarse	98.415	1.580	3.251	1.605	3.304
Pooled		1.821	2.907		
Average				1.882	2.999

Table 24. One and two or more fractured faces single-operator and multilaboratory sigma limit statistics.

Data/Condition	Single Operator		Multilaboratory	
	1s	d2s	1s	d2s
1 or more fractured faces	1.502	4.248	1.792	5.068
2 or more fractured faces	1.821	5.150	2.907	8.221

Table 25. Precision statement for both one and two or more fractured faces cases.

Material and Type Index	Standard Deviation	Acceptable Range of Two Results
One or more fractured faces		
Single-operator precision	1.5	4.2
Multiple-operator precision	1.8	5.1
Two or more fractured faces		
Single-operator precision	1.8	5.1
Multiple-operator precision	2.9	8.2

Quality Control Aggregate Gradations—Original Construction

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-21
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the SHRP Superpave HMA volumetric design method.

This WesTrack technical report provides information on aggregate gradation measured during construction and referred to as "quality control aggregate gradation data." The test program used for sampling and testing is contained in WesTrack Technical Report UNR-18.[4] Samples of aggregate were obtained for testing from the combined cold-feed belts and from samples used for asphalt content determination. Loose samples of hot-mix were obtained from the haul vehicles and ignition ovens were used to determine asphalt binder content. Core samples of HMA were obtained from the pavement for thickness, air void content, and asphalt binder content (which was determined by the ignition oven). Gradations were determined after the ignition oven asphalt content determinations on the loose haul-vehicle samples and the core samples.

BACKGROUND

Prior to the start of production of the HMA, the HMA production facility was calibrated. This calibration included the determination of individual cold-feed rates for each aggregate, calibration of the scale belt, and calibration of the asphalt binder delivery system. During the placement of the hot mixes at WesTrack, additional calibrations were performed. The initial calibration was performed on September 8, 1995. Additional calibrations were performed on September 25, 26, 28, and 29, 1995.

HMA mixtures were placed on the ramps to the test track on September 9 and 13, 1995, to determine the constructability of the HMA, as well as to establish the gradation, asphalt binder contents and the volumetrics.

The construction of the "trial lane" and the "test lane" of the track were performed on the dates shown in table 1. The bottom lift of the trial lane was placed first followed by placement of the bottom lift of the test lane. The top lift of the trial lane was placed prior to the top lift of the test lane. Placement of the trial lanes prior to placement of the test lanes allowed for adjustments in the binder contents and gradations, as well as in the construction operation. The test lanes were the lanes on which the traffic was placed and from which WesTrack performance information was obtained. Aggregate gradation information is presented only for the test lane's top and bottom lifts.

SAMPLING

The cold-feed aggregate samples were obtained from a "drop chute" located at the end of the cold-feed collector belt. A moveable baffle was located in the chute and was capable of diverting the entire falling aggregate stream into a sampling area.

Truck samples were obtained from various trailers in the haul vehicles used at WesTrack. Sampling was performed with shovels by sampling at random locations in the truck trailers, placing the HMA in 19-L (5-gallon) buckets and splitting the samples on a steel table top. The splitting included placing the HMA from the bucket samples on the steel table, mixing the sample, and quartering the sample.

The core samples were obtained one day after construction with a 150-mm (6-in.) inside diameter core barrel. The core samples were located at stratified random locations along the paved test sections. Samples were not obtained from the wheelpaths or within 300 mm (1 ft) of the longitudinal joints or the centerline of the paving (to avoid segregation). The detailed sampling and testing plan for the original construction can be found in WesTrack Technical Report UNR-18.[4]

TEST METHODS

During construction of the original WesTrack HMA, the FHWA determined one asphalt binder content and one aggregate gradation per section on samples obtained from the haul vehicle. The asphalt binder contents were obtained by use of the National Center for Asphalt Technology (NCAT) ignition oven (ASTM D 6307). After determination of the asphalt binder content, the remaining aggregate was used to determine the aggregate gradation (AASHTO T 11 and T 27). This gradation was used during the placement of the test sections on the ramps and on some of the test lanes to control the plant for aggregate gradation.

During the placement of the test lane, a decision was made to use core samples for determining the asphalt binder content. Core samples were already being obtained to determine lift thickness,

to determine in-place air voids, and to correlate with nuclear in-place density measurements. The core samples were obtained one day after construction of the sections. After thickness and density measurements, the cores were used to determine asphalt binder content and aggregate gradation. Five cores were obtained per section. If the fine graded mixture was placed on day 1, the fine plus mixture on day 2, the coarse mixture on day 3, the fine mixture again on day 4, etc., then it was possible to perform the ignition test on five samples per section prior to placement of the same mixture (fine mixture on day 1 and fine mixture on day 4) three days later. These test results provided reasonable control of aggregate gradations during construction. The gradations from the core samples became both the quality control (QC) gradations used for process control and the quality assurance (QA) gradations used for modeling purposes.

A third set of samples was obtained during construction but tested after construction was completed. This set of samples was obtained from the haul vehicles as described. The samples were tested to determine asphalt binder content for QA purposes and for gradation after construction was completed. Due to the problems with ignition oven calibration, these samples were not used for QA asphalt binder content purposes and were not used for QA gradation purposes. The core samples described above were used for QA purposes for both asphalt binder content and aggregate gradation.

COLD-FEED SAMPLES

Cold-feed samples were obtained in 19-L (5-gallon) buckets and split into appropriate sizes for aggregate gradation determination. The results of the wash and sieve analysis are shown in tables 2 through 5.[(5)] Tables 2 and 3 contain aggregate gradation information by mix type (fine, fine plus, and coarse) for the top lift (table 2) and the bottom lift (table 3) for each section. The sieve sizes used to determine gradation are as follows: 3/4-in., 1/2-in., 3/8-in., No. 4, No. 8, No. 16, No. 30, No. 50, No. 100, and No. 200 (19.0-mm, 12.5-mm, 9.5-mm, 4.75-mm, 2.36-mm, 1.18-mm, 600-µm, 300-µm, 150-µm, and 75-µm). Mean, standard deviation, coefficient of variation, range, and number of samples are reported for each section on an accumulated percent passing basis in tables 2 and 3 for the top and bottom lifts, respectively.

Tables 4 and 5 (top and bottom lifts) contain the same gradation information on a passing and retained basis for the following size groupings: 3/4-in. by 1/2-in., 1/2-in. by 3/8-in., 3/8-in. by No. 4, No. 4 by No. 8, No. 8 by No. 16, No. 16 by No. 30, No. 30 by No. 50, No. 50 by No. 100, No. 100 by No. 200, and passing No. 200. Representing the data on a passing and retained basis makes it is possible to easily identify the sieve size that may be causing the variation in the gradations.

LOOSE MIX FROM HAUL VEHICLES

Loose samples obtained from the haul vehicles were used for gradation determinations after ignition testing. Results from haul vehicle test samples are shown in tables 6 through 9. Tables 6 and 7 contain aggregate gradation information by mix type (fine, fine plus, and coarse) for the top lift (table 6) and the bottom lift (table 7) for each section. Standard sieve sizes, as defined

above, were used for gradation. Mean, standard deviation, coefficient of variation, range, and number of samples are reported for each section on an accumulated percent passing basis in tables 6 and 7 for the top and bottom lifts, respectively.

Tables 8 and 9 (top and bottom lifts) contain the same gradation information on a passing and retained basis for the size groupings defined above.

CORE SAMPLES

Core samples obtained from the compacted test sections were used for gradation determinations after ignition testing. Results from these core samples are shown in tables 10 through 13. Tables 10 and 11 contain aggregate gradation information by mix type (fine, fine plus, and coarse) for the top lift (table 10) and the bottom lift (table 11) for each section. Standard sieve sizes, as defined above, were utilized for gradation. Mean, standard deviation, coefficient of variation, range, and number of samples are reported for each section on an accumulated percent passing basis in tables 10 and 11.

Tables 12 and 13 (top and bottom lifts, respectively) contain the same gradation information on a passing and retained basis for the size groupings defined above.

COMPARISON OF DATA SETS

Healow[5] compared gradation data obtained from the three sample locations (cold feed, loose hot-mix, and cores). Selected comparisons from his report are summarized below (figures 1 through 18).

The standard deviations of the gradation information by sieve size for the fine, fine plus, and coarse gradations are compared for the top lift in figures 1 through 3 and for the bottom lift in figures 10 through 12. The standard deviation of the gradations obtained from the cold-feed samples was greater than the standard deviation of the gradations for the loose HMA samples and the core samples for the majority of the comparisons. This trend was particularly evident for the fine mixture in both top and bottom lifts (figures 1 and 10, respectively) and the fine plus mixture in the top lift (figure 2). A significant number of the standard deviations on the finer sieves for the cold-feed samples on the coarse mixture in the top lift (figure 3) and bottom lift (figure 12) also were greater than the corresponding loose mix and core HMA samples.

The core samples had a lower standard deviation than the loose hot-mix samples in several of the comparisons, including the fine graded mixture in the top lift (figure 1), fine plus graded mixture in the top lift (figure 2), and coarse graded mixture in the bottom lift (figure 12). This general trend was also evident for a significant number of sieves for the coarse graded mixture in the top lift (figure 3). The core samples had a higher standard deviation than loose mix samples for the fine mixture in the bottom lift (figure 10) and the fine plus mixture in the bottom lift (figure 11).

A comparison of the standard deviations associated with the loose mix sample gradations of the coarse graded mixtures (figures 3 and 12), versus the gradations of the fine and fine plus graded mixtures (figures 1, 2, 10, and 11), indicates larger standard deviation values for the coarse graded mixtures. Some of this variation was due to increased segregation and difficulty obtaining representative samples of the coarser mixture. Cold-feed sampling and core sampling reduced the difference in variability, as measured by the standard deviation, between the fine and coarse graded mixtures.

WesTrack Technical Report UNR-29 contains typical gradation construction variability information for HMA.[6] Reported standard deviations for gradation on various sieve sizes for the WesTrack project were below those typically obtained in HMA construction operations.

Figures 4, 6, 8, 13, 15, and 17 show the means and standard deviations obtained on the No. 4 (4.75-mm) sieve for the fine, fine plus, and coarse graded mixture top and bottom lifts. The percent passing the No. 4 sieve was consistently lower for the cold-feed samples than for the loose HMA and core sample gradations. The typical difference between the cold-feed samples and the loose mix or core samples was 2 to 4 percentage points on the No. 4 sieve. A consistent difference between the loose HMA samples and the core samples was not noted for the No. 4 sieve.

Figures 5, 7, 9, 14, 16, and 18 show the means and standard deviations obtained on the No. 200 (75-μm) sieve for the fine, fine plus, and coarse graded mixtures in the top and bottom lifts. The percent passing the No. 200 sieve was consistently lower for the cold-feed samples than for the loose HMA and core sample gradations, except for the coarse graded, bottom lift data (figure 18).

The cold-feed data for the No. 200 sieve for the fine and fine plus graded mixtures should be, and was nearly identical, as shown in figures 5, 7, 14, and 16. The difference between the fine and fine plus graded mixtures was the amount of material on the No. 200 sieve. The control of the percent passing the No. 200 sieve was accomplished during production by controlling the baghouse return system. The fine plus graded mixtures contained an additional 2 percent passing the No. 200 sieve.

The data for the No. 200 sieve presented in these figures do not indicate a consistent increase in the No. 200 sieve due to coring (comparison of the loose mix versus the core samples). Thus, the coring operation apparently did not increase the percent passing the No. 200 sieve. Comparisons are available for other sieve sizes in the report by Healow.[5]

SUMMARY

The variability of gradations obtained from the cold-feed samples was greater than the gradation variability for the loose HMA and core samples for the majority of the comparisons reported on the original construction of the WesTrack project. In general, the core samples had lower gradation variability than gradations obtained on the loose HMA samples obtained from the haul vehicles.

The variability of the gradations reported for the coarse graded mixtures was, in general, greater for the coarse graded mixtures than for the fine and fine plus graded mixtures. Some of this variation was due to increased segregation and difficulty obtaining representative samples of the coarse mixture. Cold-feed and core sampling reduced the difference in variability, as measured by the standard deviation, between the fine and coarse graded mixtures.

The variability of the standard deviations for the WesTrack projects was typically below the variability obtained in other HMA construction operations in the United States.

Comparison of the loose mix sampling and core sampling data indicate that coring apparently did not increase the percent passing the No. 200 sieve. The data reported on the No. 200 sieve for the fine and fine plus mixture indicate that some degradation (increase in No. 200 sieve) occurred during production and that the baghouse fines return system was effective in controlling the No. 200 quantity in the fine and fine plus mixtures.

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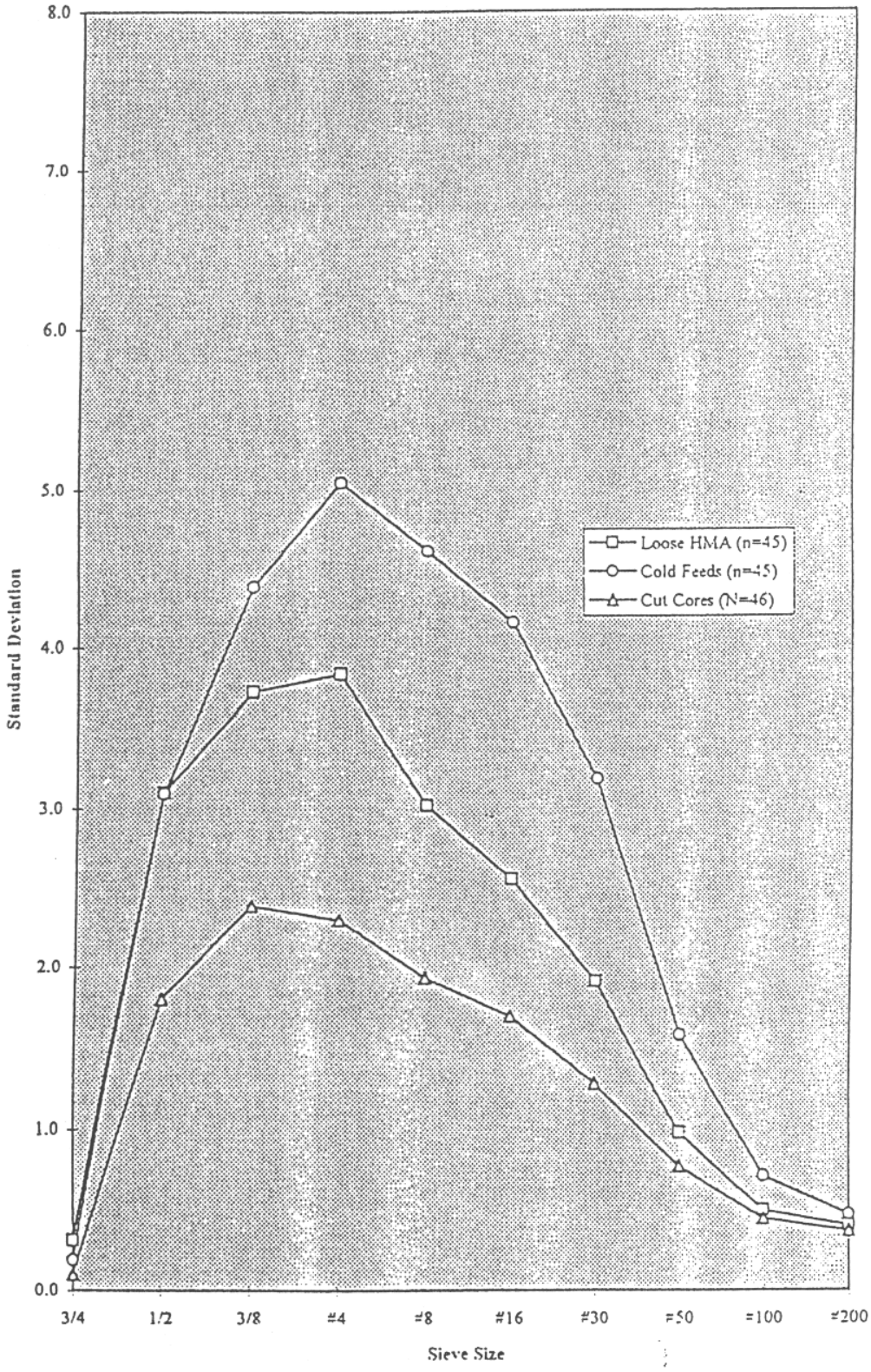

Figure 1. Comparison of standard deviations of fine graded mixture – top lift.

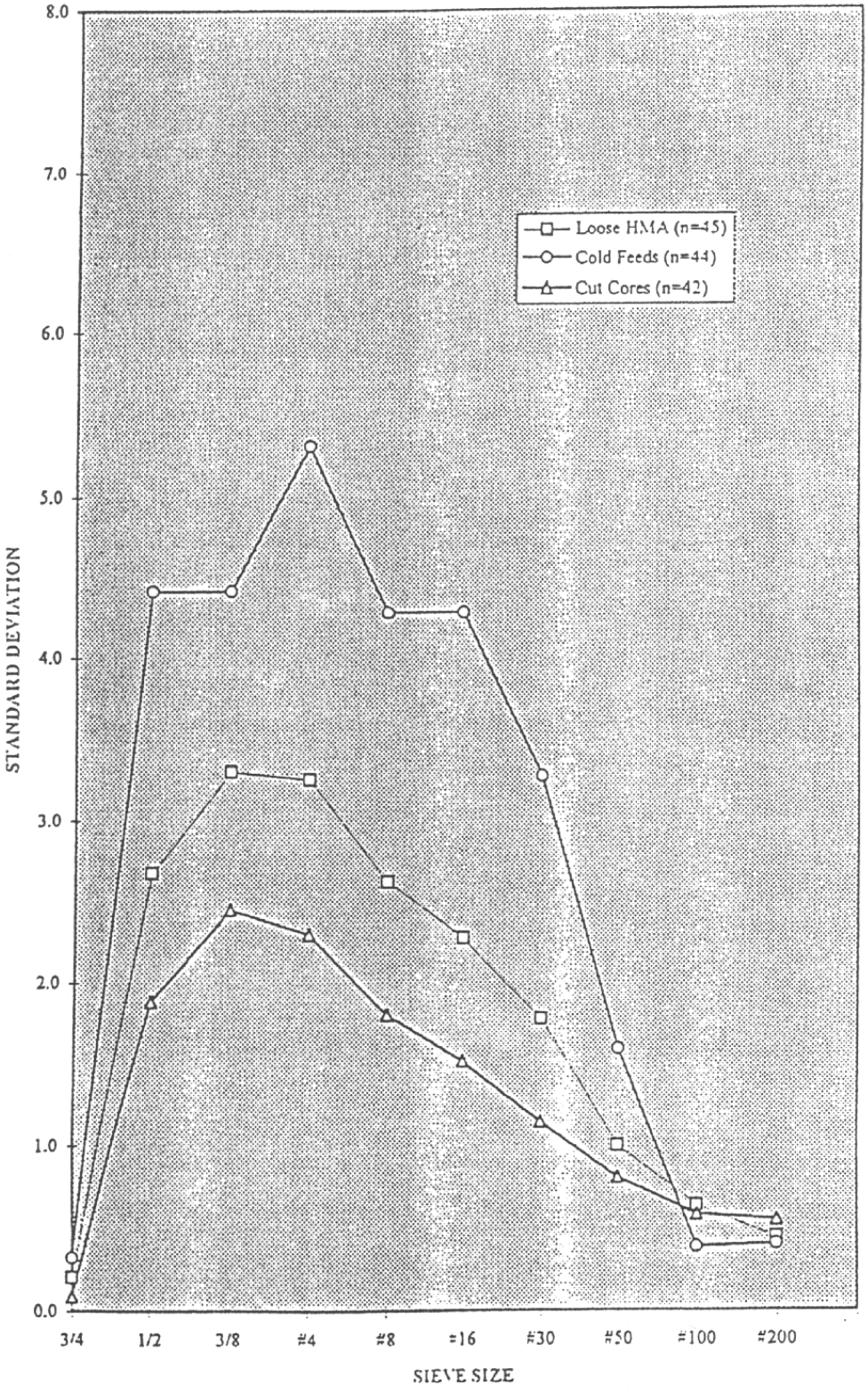

Figure 2. Comparison of standard deviations of fine plus graded mixture – top lift.

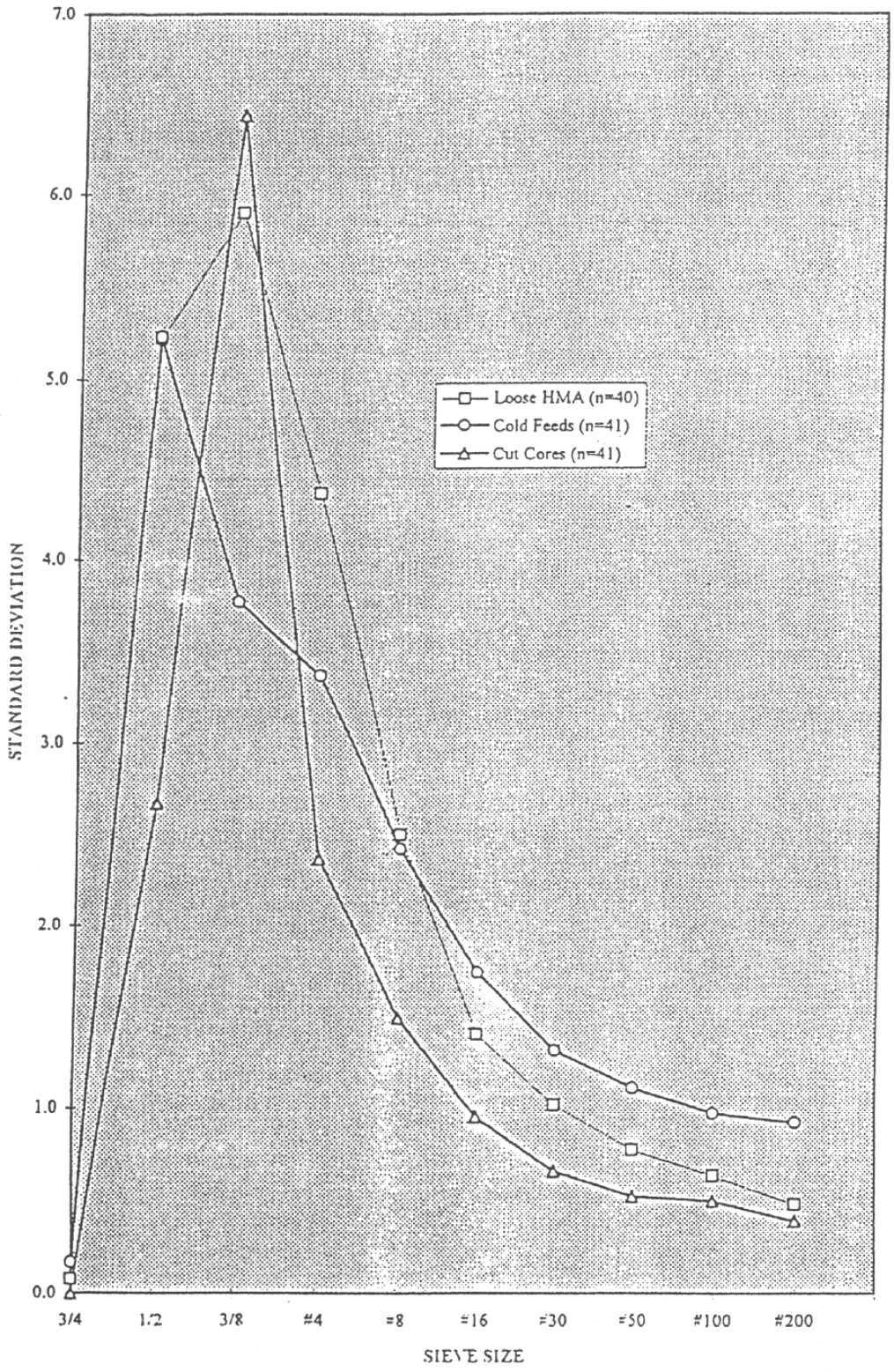

Figure 3. Comparison of standard deviations of coarse graded mixture – bottom lift.

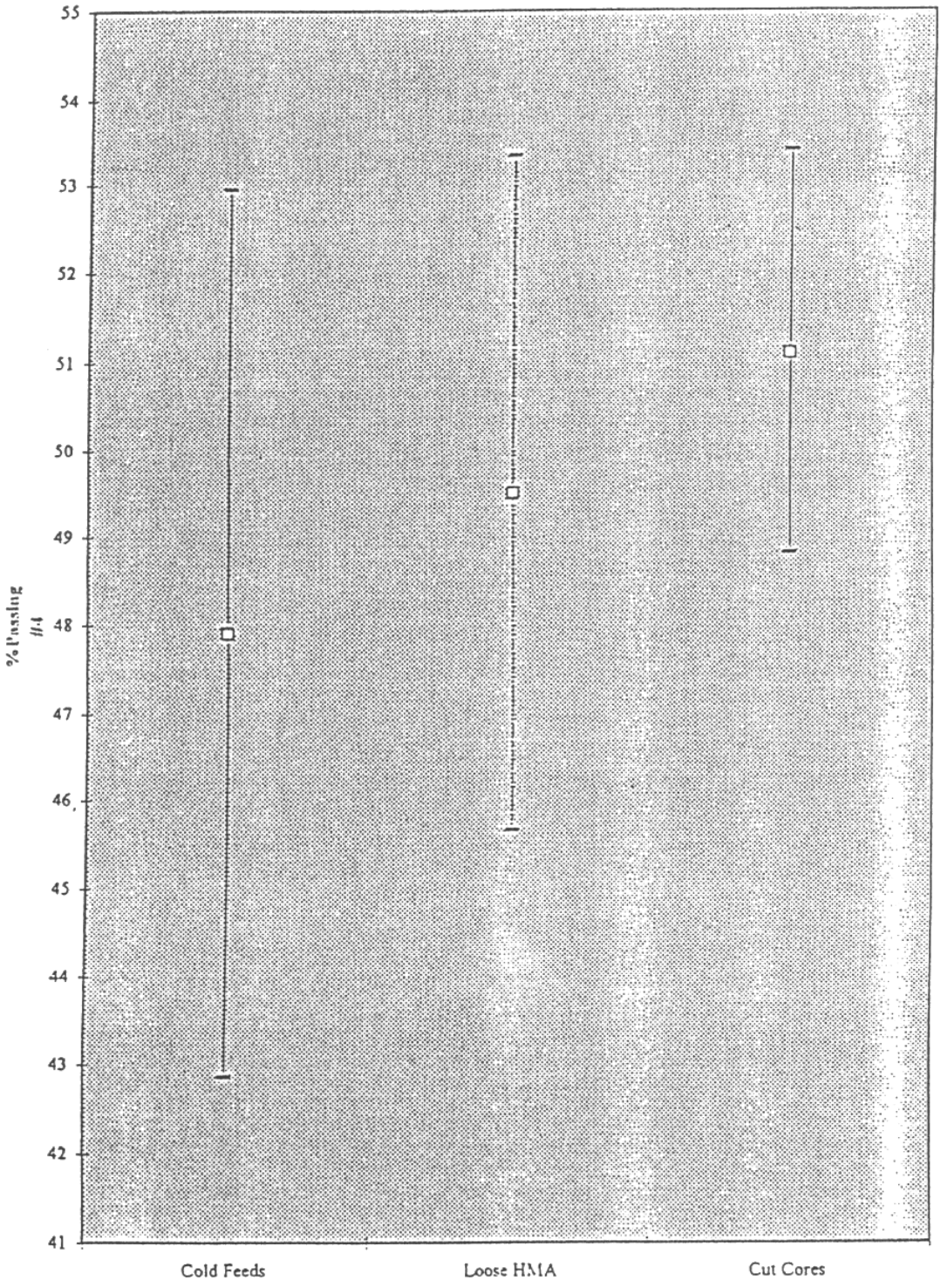

Figure 4. Comparison of sampling method using No. 4 sieve on fine graded mixture from top lift (mean values plus and minus one standard deviation).

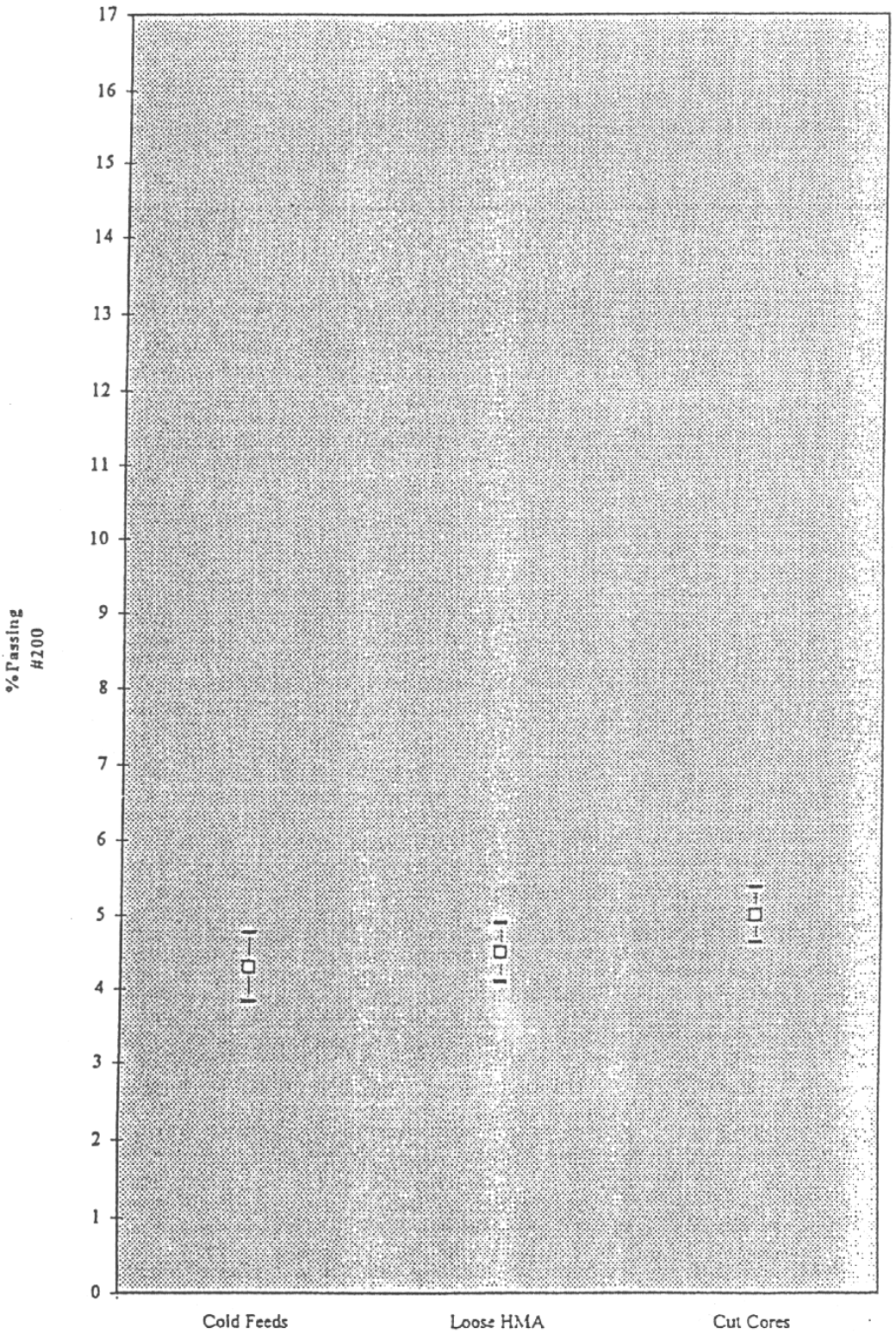

Figure 5. Comparison of sampling method using No. 200 sieve on fine graded mixture from top lift (mean values plus and minus one standard deviation).

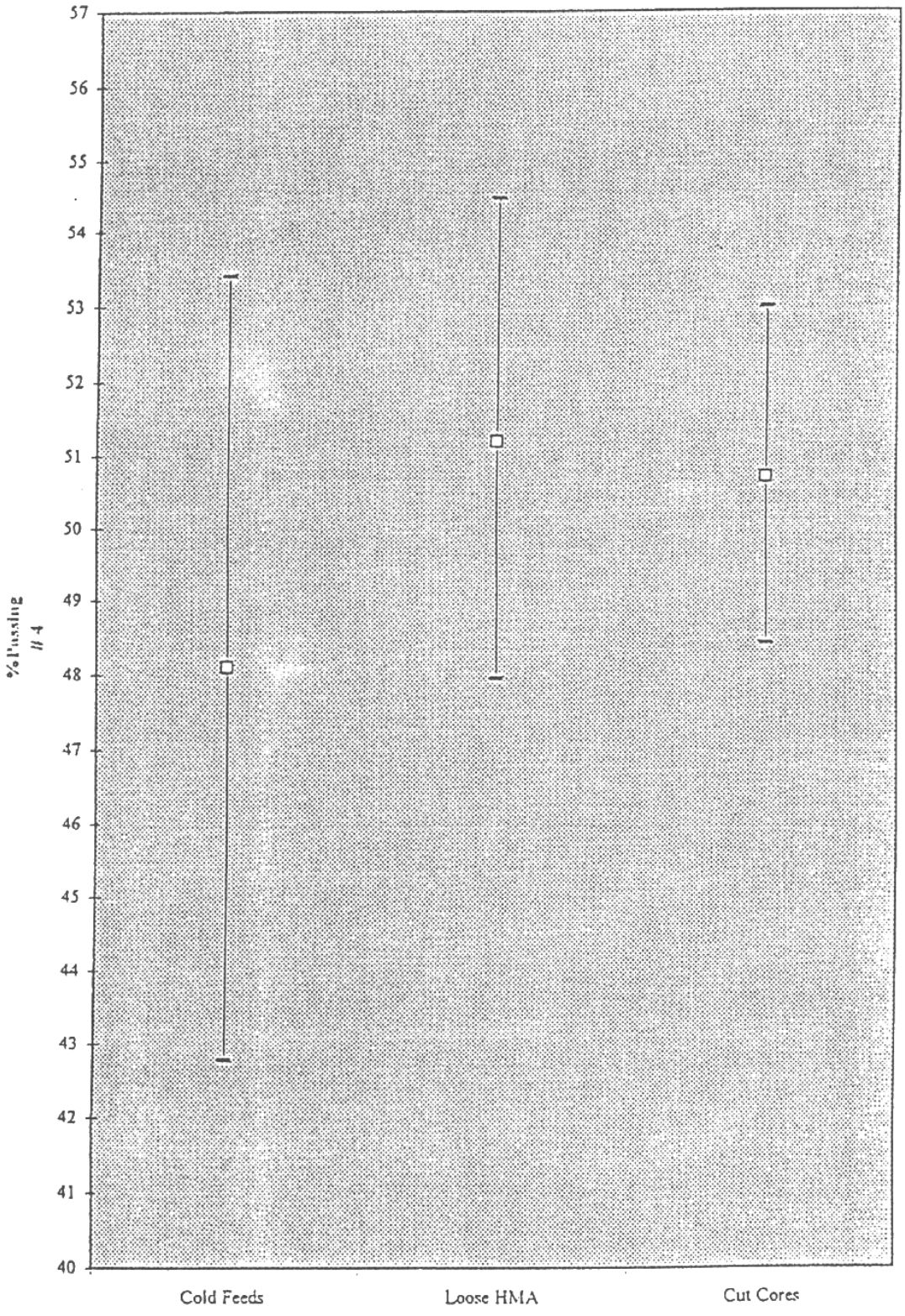

Figure 6. Comparison of sampling method using No. 4 sieve on fine plus graded mixture from top lift (mean values plus and minus one standard deviation).

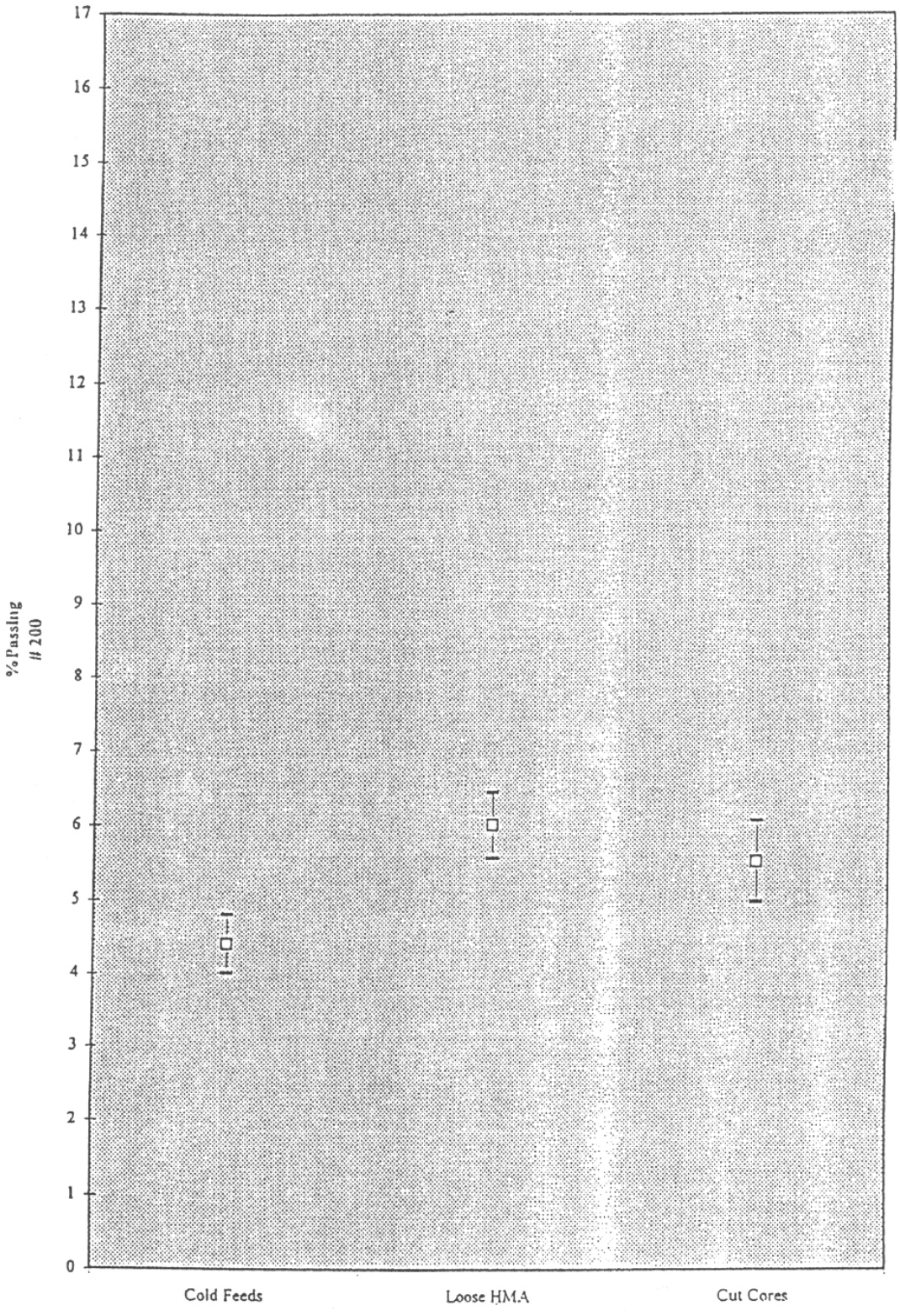

Figure 7. Comparison of sampling method using No. 200 sieve on fine plus graded mixture from top lift (mean values plus and minus one standard deviation).

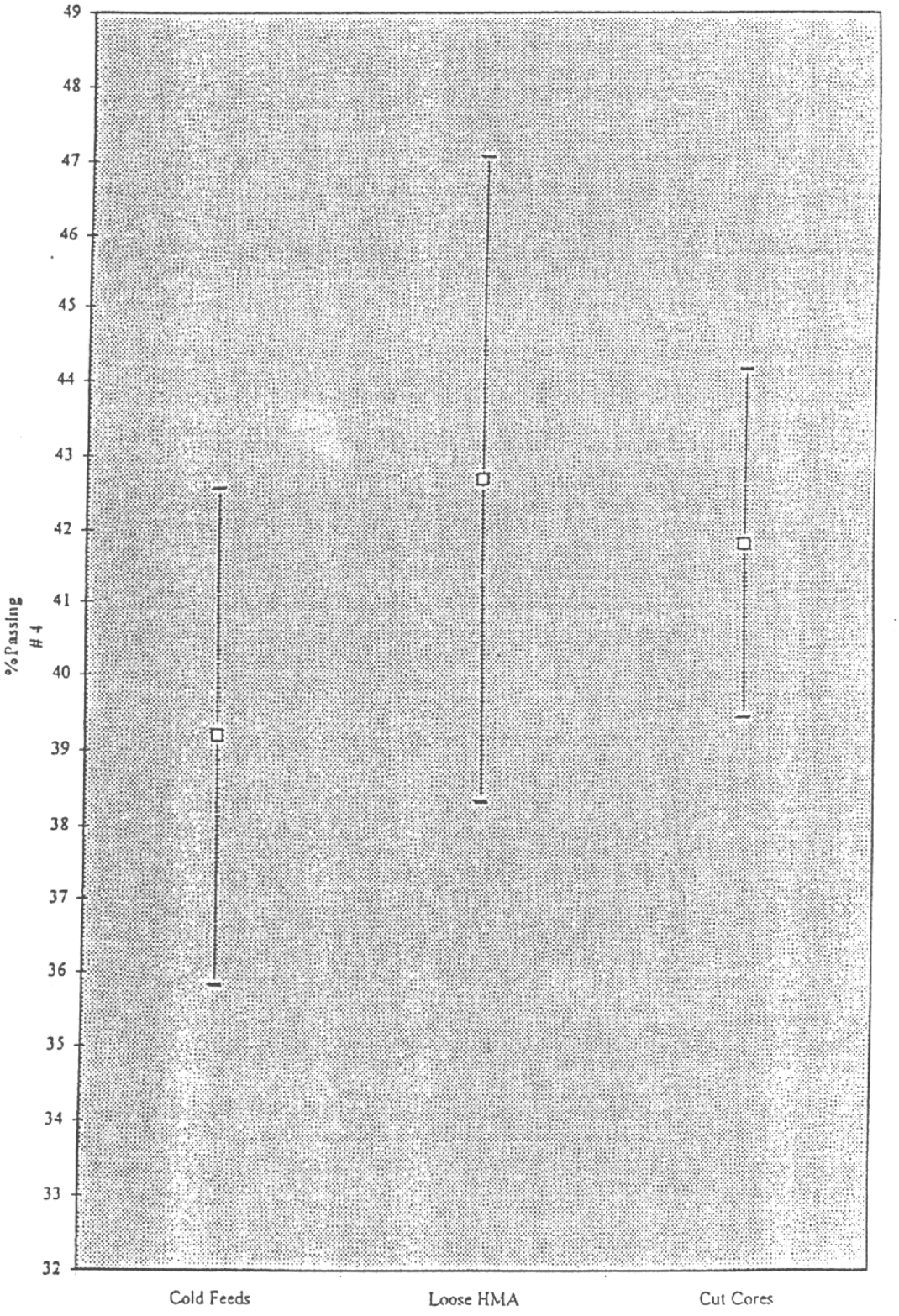

Figure 8. Comparison of sampling method using No. 4 sieve on coarse graded mixture from top lift (mean values plus and minus one standard deviation).

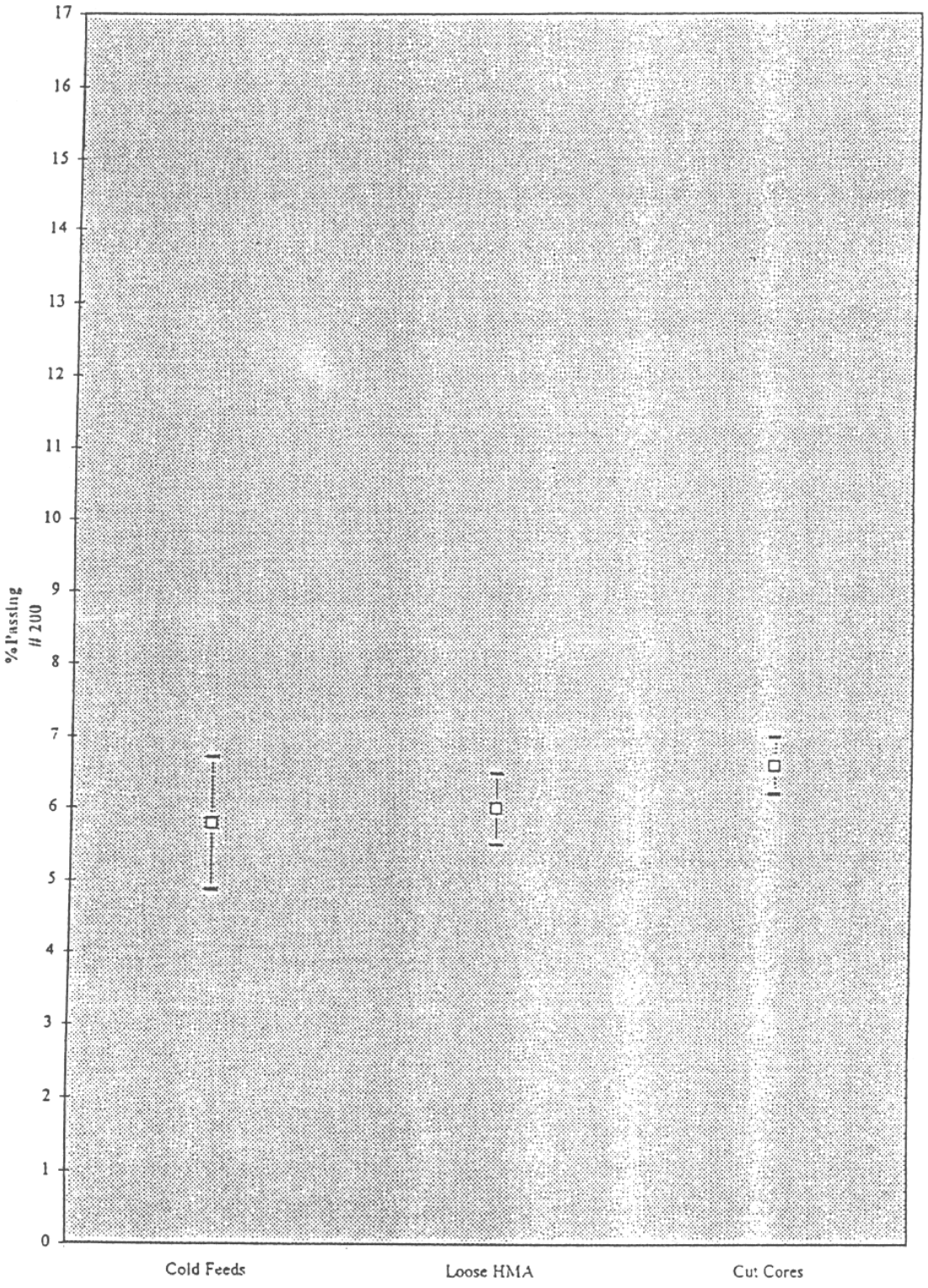

Figure 9. Comparison of sampling method using No. 200 sieve on coarse graded mixture from top lift (mean values plus and minus one standard deviation).

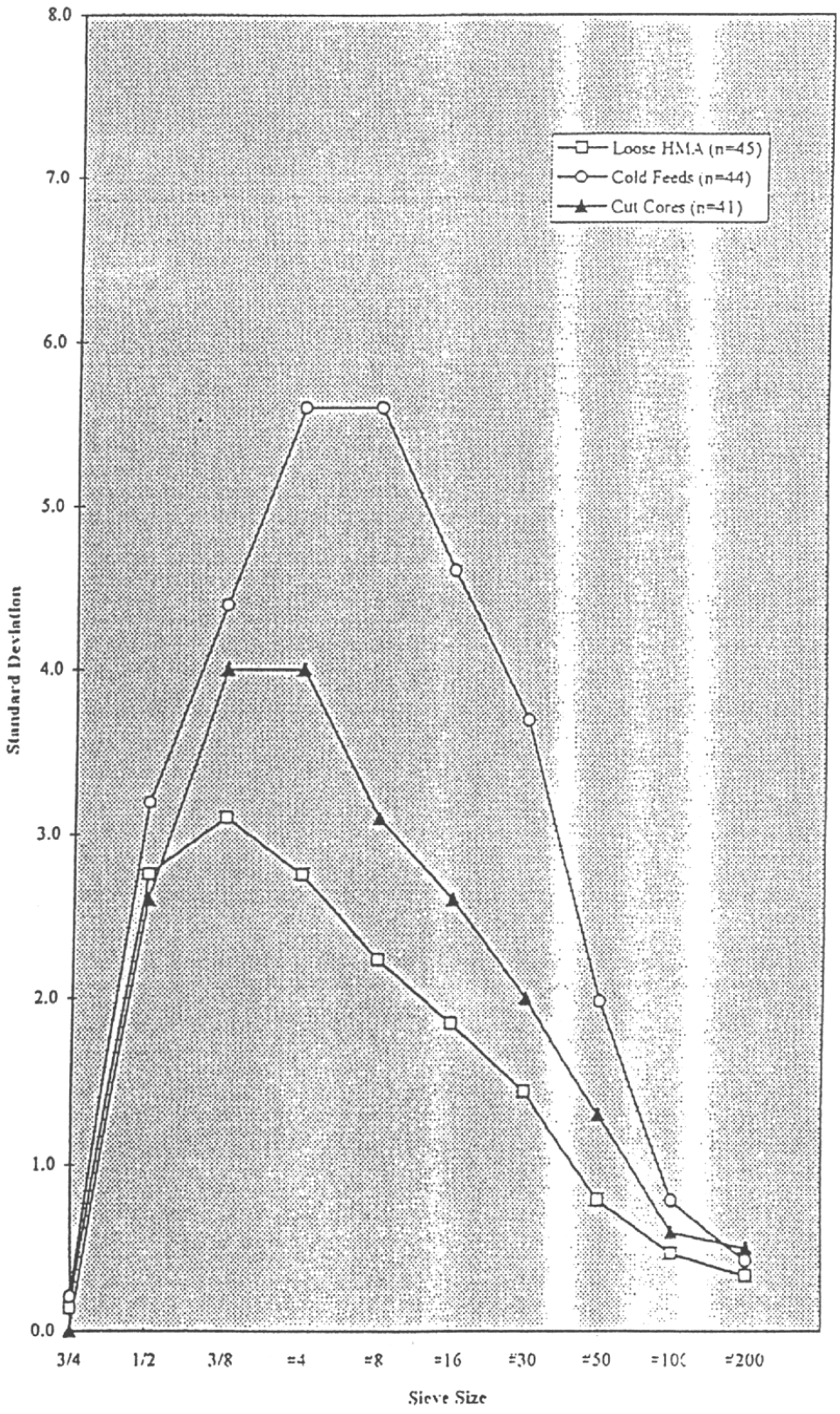

Figure 10. Comparison of standard deviations of fine graded mixture from bottom lift.

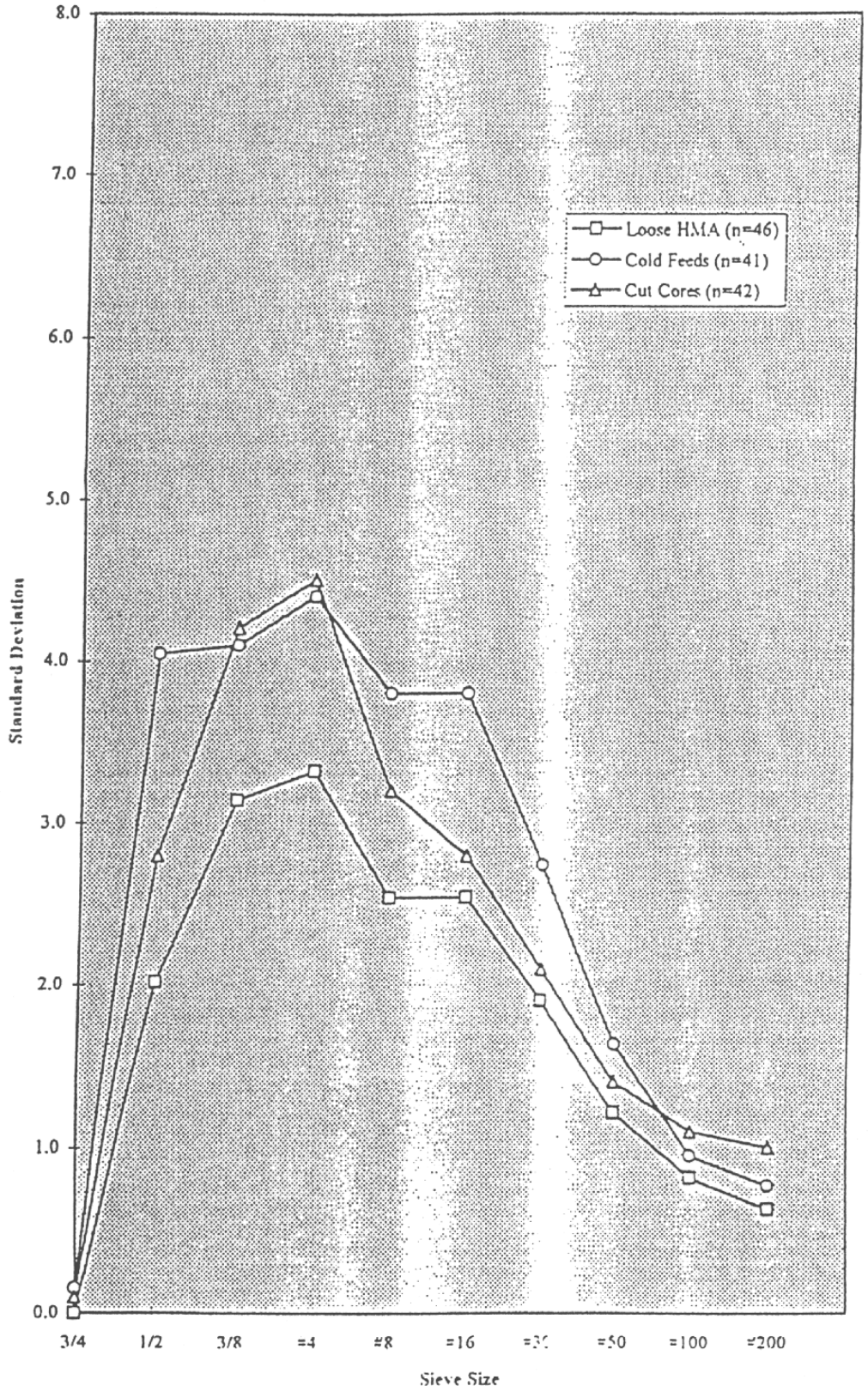

Figure 11. Comparison of standard deviations of fine plus graded mixture from top lift.

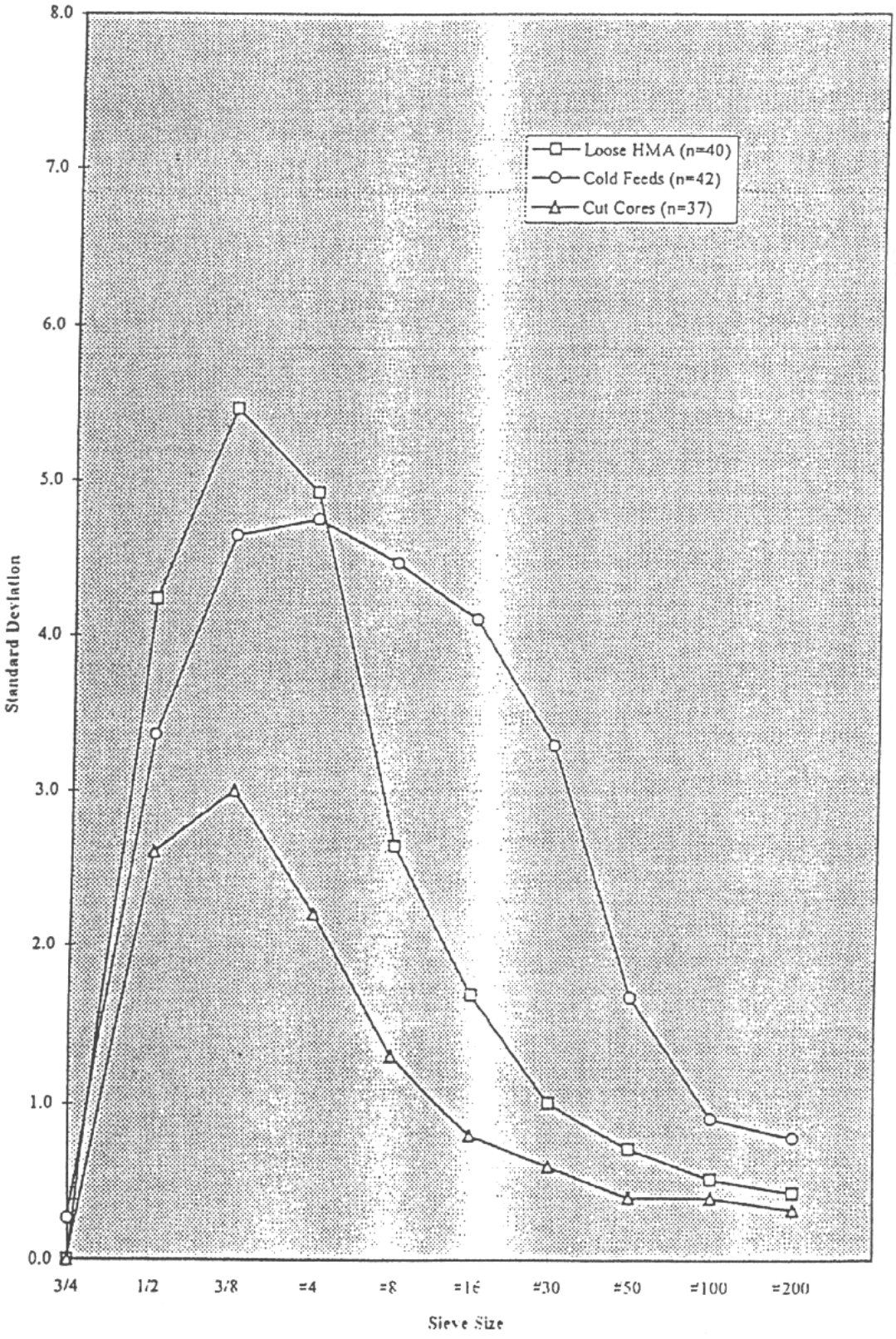

Figure 12. Comparison of standard deviations of coarse graded mixture from top lift.

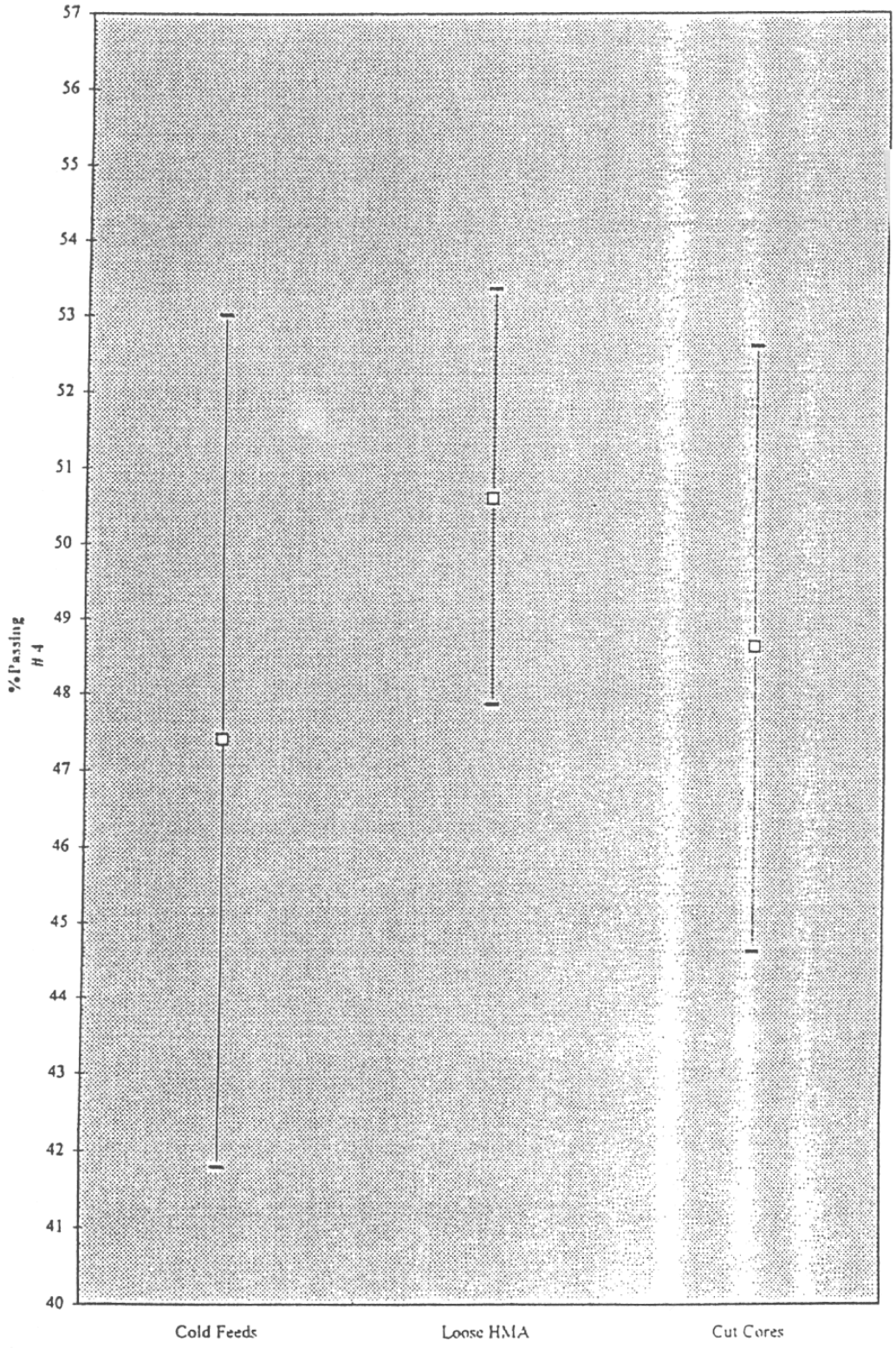

Figure 13. Comparison of sampling method using No. 4 sieve on fine graded mixture from bottom lift (mean values plus and minus one standard deviation).

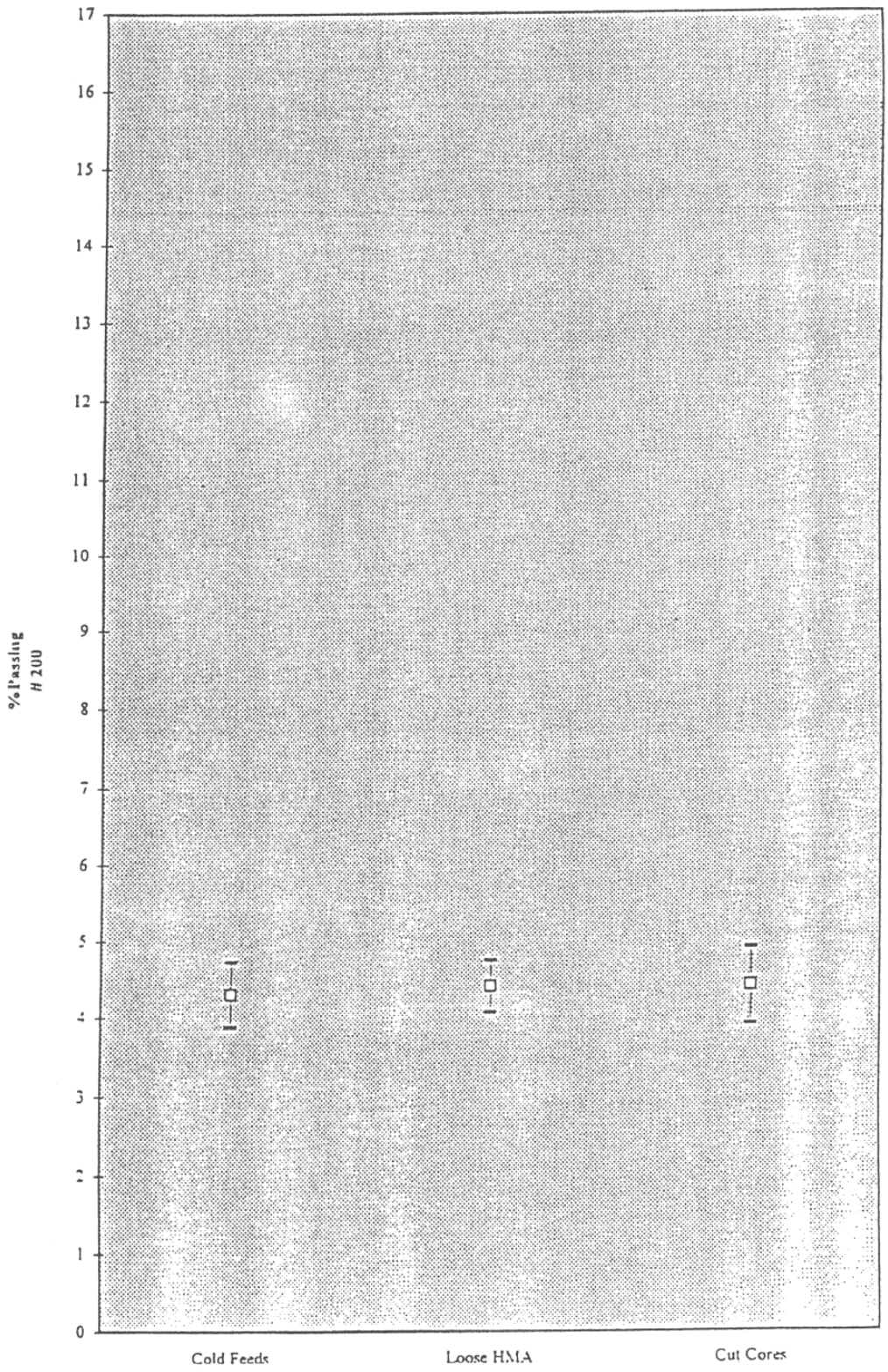

Figure 14. Comparison of sampling method using No. 200 sieve on fine graded mixture from bottom lift (mean values plus and minus one standard deviation).

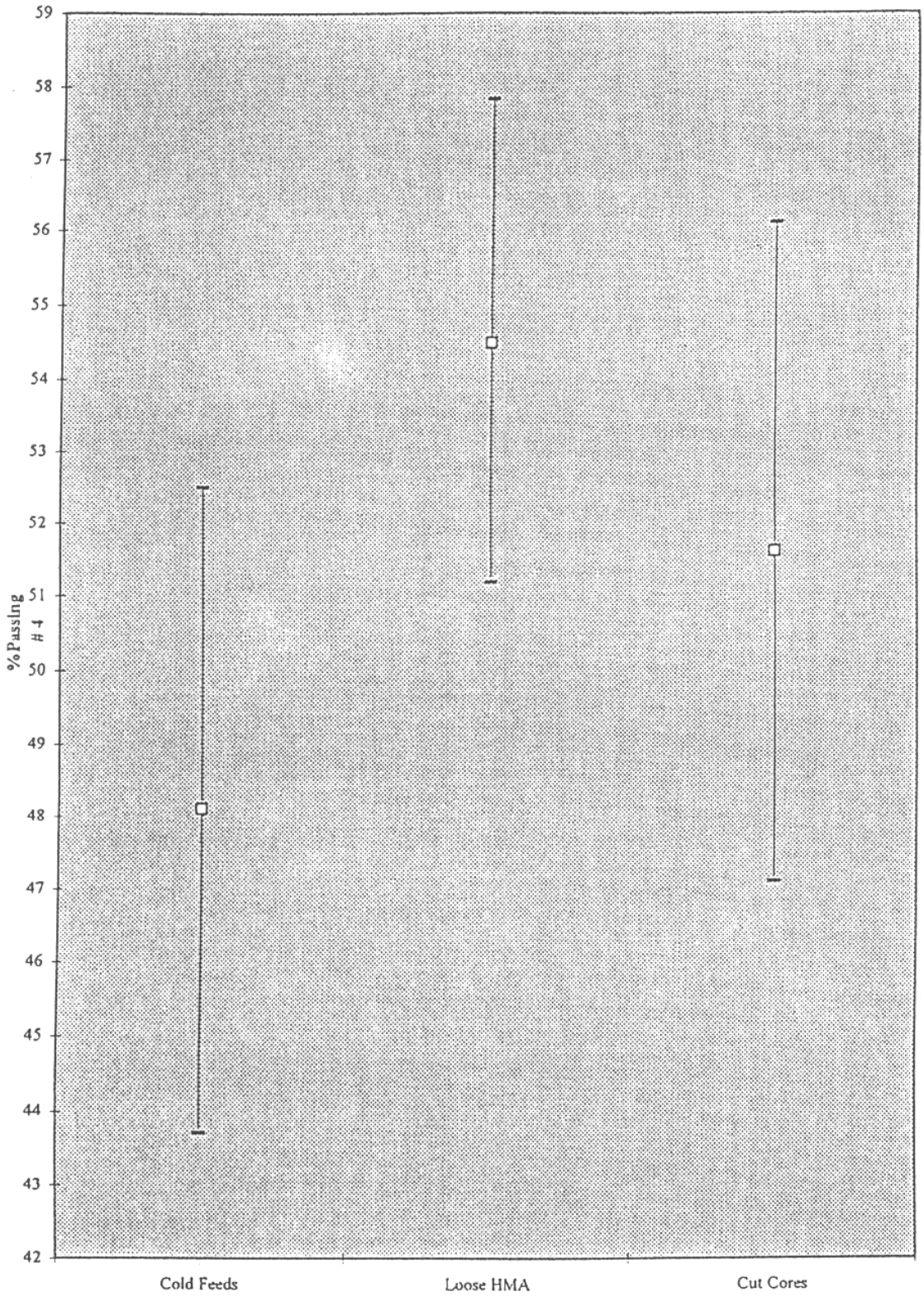

Figure 15. Comparison of sampling method using No. 4 sieve on fine plus graded mixture from bottom lift (mean values plus and minus one standard deviation).

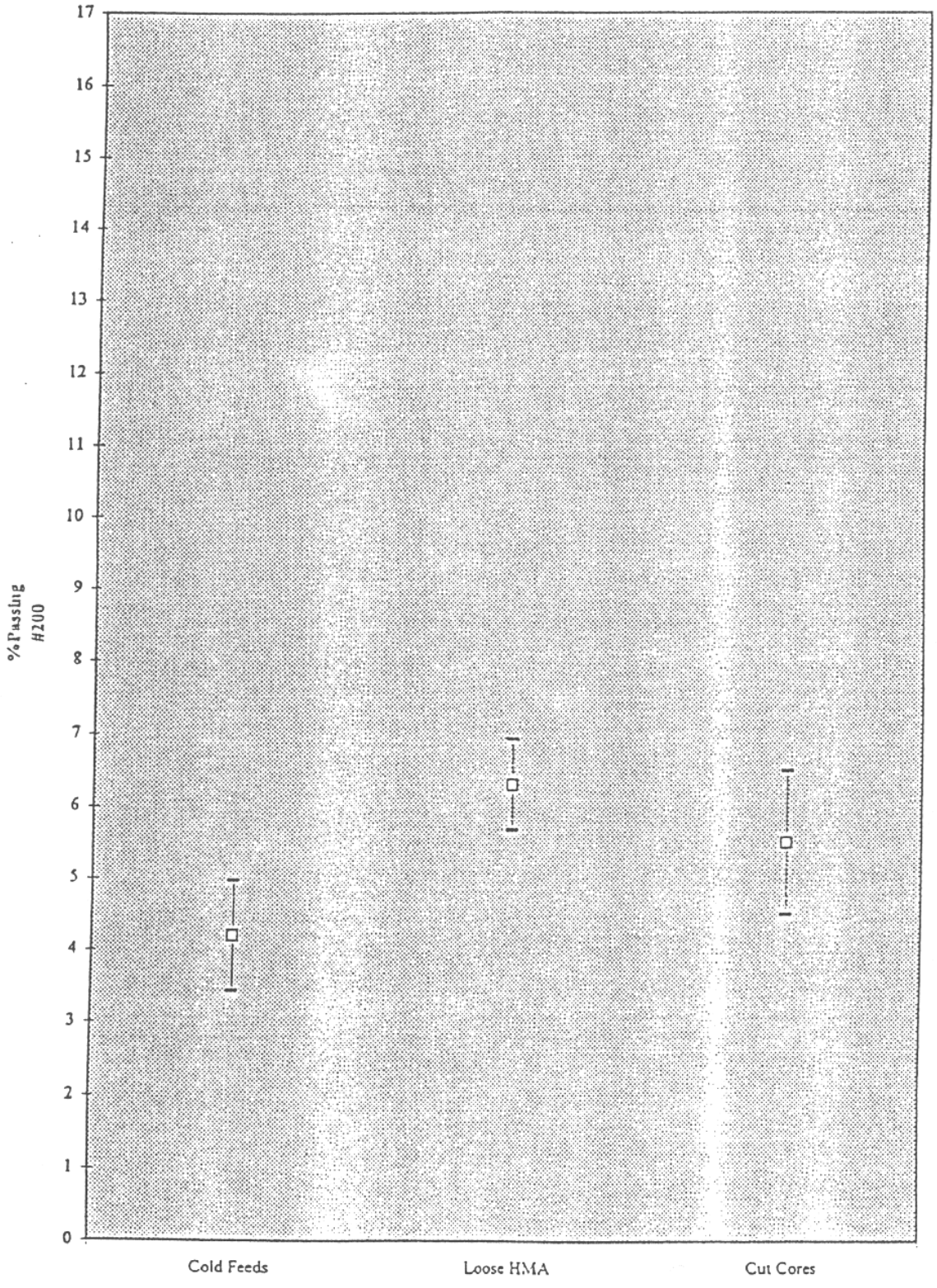

Figure 16. Comparison of sampling method using No. 200 sieve on fine plus graded mixture from bottom lift (mean values plus and minus one standard deviation).

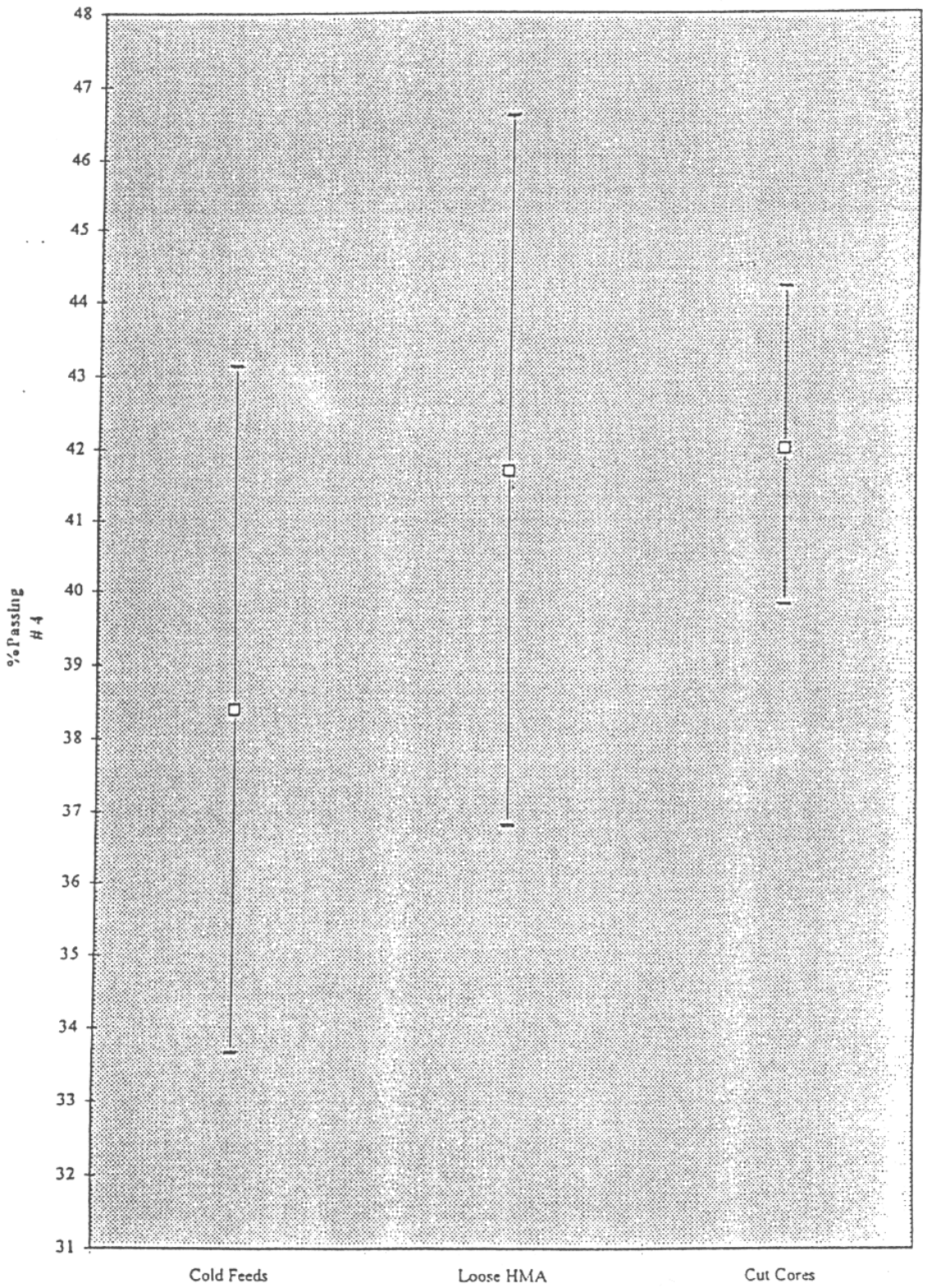

Figure 17. Comparison of sampling method using No. 4 sieve on coarse graded mixture from bottom lift (mean values plus and minus one standard deviation).

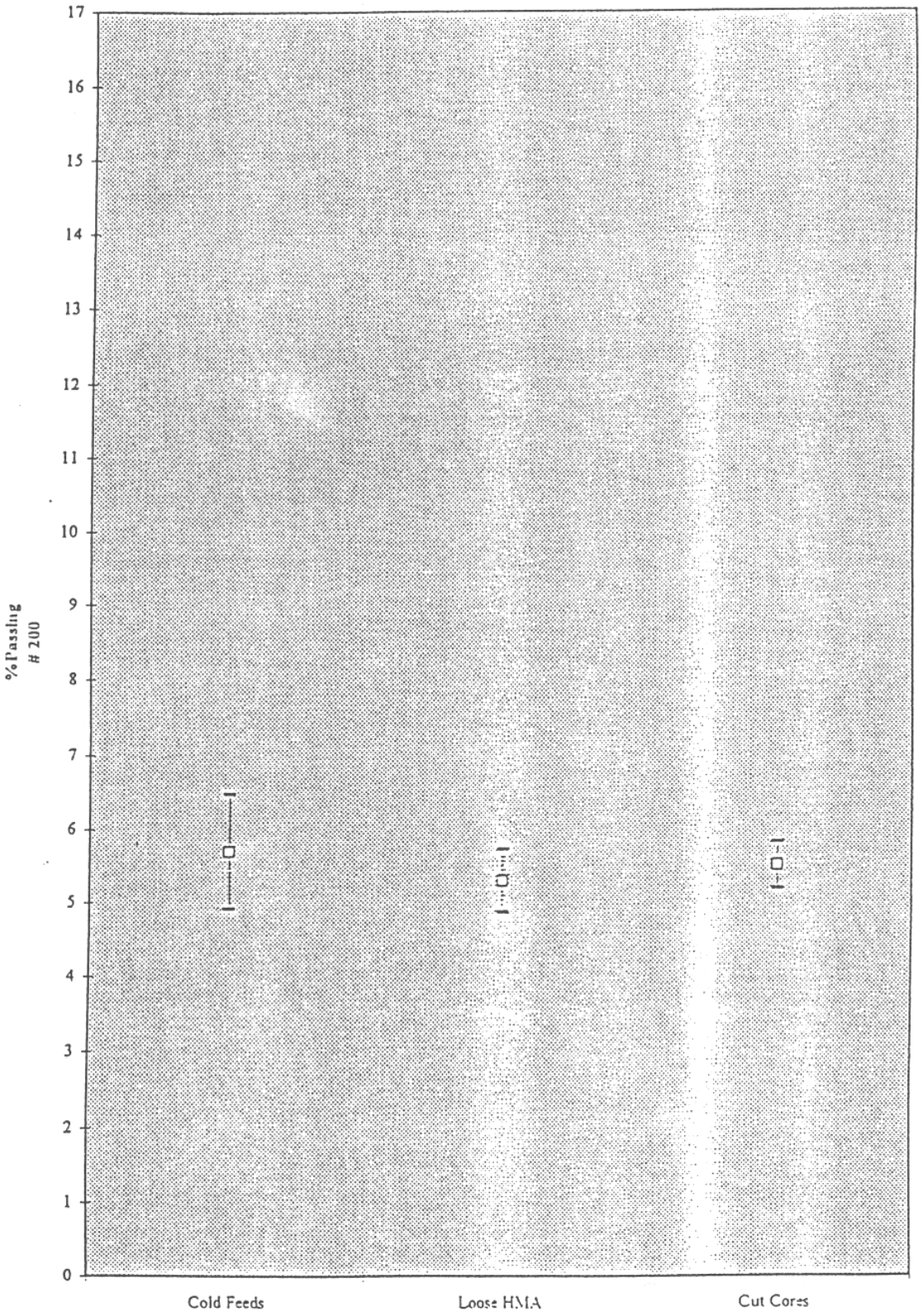

Figure 18. Comparison of sampling method using No. 200 sieve on coarse graded mixture from bottom lift (mean values plus and minus one standard deviation).

Table 1. Construction schedule for original construction.

Date	Mixture	Lift	Lane	Section Numbers*
9-14-95	Fine	Bottom	Trial	1, 2, 3, 4, 14, 15, 16,17, 18
9-15-95	Fine Plus	Bottom	Trial	19, 20, 21, 22, 9, 10, 11, 12, 13
9-16-95	Coarse	Bottom	Trial	5, 6, 7
9-18-95	Coarse	Bottom	Trial	8, 23, 24, 25, 26
9-20-95	Fine	Bottom	Test	1, 2, 3, 4, 14, 15, 16, 17, 18
9-21-95	Fine Plus	Bottom	Test	19, 20, 21, 22, 9, 10, 11, 12, 13
9-22-95	Fine	Top	Trial	1, 2, 3, 4, 14, 15, 16, 17, 18
9-27-95	Fine Plus	Top	Trial	19, 20, 21, 22, 9, 10, 11, 12, 13
9-27-95	Fine Plus	Bottom	Test	13
9-30-95	Coarse	Bottom	Test	5, 6, 7, 8, 23, 24, 25, 26
10-1-95	Coarse	Top	Trial	5, 6, 7, 8, 23, 24, 25, 26
10-2-95	Fine	Top	Test	1, 2, 3, 4, 14, 15, 16, 17, 18
10-3-95	Fine Plus	Top	Test	19, 20, 21, 22, 9, 10, 11, 12, 13
10-4-95	Coarse	Top	Test	5, 6, 7, 8, 23, 24, 25, 26

*Section numbers follow order of placement.

Table 2. Accumulated percent passing from cold-feed data for top lift.

		3/4" Sieve					1/2" Sieve					3/8" Sieve					#4 Sieve					#8 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	100.0	0.0	0.00	5	0.0	87.4	1.5	1.29	5	3.3	75.3	2.9	3.09	5	7.2	50.6	3.6	4.27	5	9.4	40.2	3.4	3.69	5	8.9
	2	99.9	0.2	0.22	5	0.5	89.9	1.2	2.39	5	3.2	79.6	2.5	2.94	5	6.2	52.0	2.2	8.42	5	5.4	40.6	1.5	10.15	5	3.8
	3	100.0	0.0	0.00	5	0.0	83.9	2.0	2.09	5	5.1	85.3	2.5	3.81	5	6.9	47.3	4.0	7.86	5	9.9	37.2	3.8	9.68	5	9.1
	4	100.0	0.0	0.00	5	0.0	86.0	1.8	2.87	5	4.1	75.5	2.9	5.10	5	6.3	52.6	4.1	9.93	5	10.4	41.9	4.1	11.59	5	10.5
	14	100.0	0.0	0.00	5	0.0	85.4	2.5	2.66	5	6.3	74.2	3.8	4.00	5	9.1	49.4	4.9	7.28	5	12.1	39.2	4.5	8.70	5	11.5
	15	100.0	0.0	0.00	5	0.0	84.4	2.3	4.07	5	5.7	71.5	2.9	7.64	5	6.9	46.3	3.4	15.38	5	8.7	36.3	3.2	17.88	5	8.1
	16	99.8	0.2	0.22	5	1.2	83.6	3.4	5.30	5	9.3	69.9	5.3	7.56	5	13.9	43.4	6.7	10.66	5	16.9	33.5	6.0	11.78	5	15.3
	17	100.0	0.0	0.00	5	0.0	85.2	4.5	3.78	5	10.8	71.5	5.4	4.41	5	13.2	44.6	4.8	7.86	5	11.9	33.9	4.0	8.63	5	9.7
	18	100.0	0.0	0.00	5	0.0	83.9	3.2	3.78	5	8.3	71.1	3.1	4.41	5	8.5	45.0	3.5	7.86	5	9.1	34.7	3.0	8.63	5	7.5
Stats for averages		100.0	0.1	0.08	9	0.2	85.5	2.0	2.38	9	6.3	74.9	4.9	6.56	9	15.4	47.9	3.4	7.05	9	9.2	37.5	3.1	8.31	9	8.5
Stats of independent		100.0	0.2	0.19	45	1.2	85.5	3.1	3.62	45	14.3	73.4	4.4	5.96	45	20.5	47.9	5.0	10.53	45	21.4	37.5	4.6	12.28	45	20.0
Samples					Max	100.0					91.5					83.0					58.8					48.2
					Min	98.8					77.2					62.5					37.4					28.2
Fine+	9	100.0	0.0	0.00	5	0.0	82.4	3.7	4.55	5	10.0	70.8	4.4	6.15	5	11.4	45.4	4.7	10.44	5	12.3	34.9	3.8	10.87	5	9.8
	10	100.0	0.0	0.00	4	0.0	83.8	2.8	3.29	4	5.4	72.4	2.5	3.48	4	5.5	49.5	2.6	5.28	4	6.4	39.4	2.1	5.30	4	5.1
	11	99.8	0.5	0.49	5	1.1	84.6	2.8	3.27	5	7.4	72.7	3.5	4.79	5	9.2	48.9	4.2	8.49	5	11.4	38.6	4.0	10.48	5	11.3
	12	100.0	0.0	0.00	5	0.0	86.4	2.1	2.45	5	5.7	74.4	3.3	4.42	5	7.9	49.4	3.8	7.67	5	9.4	38.9	3.2	8.31	5	8.0
	13	100.0	0.0	0.00	5	0.0	84.1	2.6	3.10	5	7.0	71.0	3.9	5.45	5	9.9	45.1	4.4	9.83	5	11.4	35.3	3.8	10.69	5	9.8
	19	100.0	0.0	0.00	5	0.0	85.9	2.6	3.07	5	7.0	72.6	3.9	5.43	5	9.5	46.4	6.5	14.07	5	17.1	35.8	6.3	17.59	5	16.4
	20	99.9	0.3	0.31	5	0.7	84.1	2.5	2.92	5	4.8	72.5	3.7	5.16	5	7.8	48.9	4.1	8.37	5	8.9	38.0	3.4	9.00	5	7.8
	21	100.0	0.0	0.00	5	0.0	85.3	6.0	6.98	5	15.2	75.0	8.2	10.89	5	21.8	52.0	8.4	16.14	5	22.3	41.6	7.4	17.77	5	19.5
	22	99.7	0.8	0.76	5	1.7	83.1	3.8	4.58	5	9.4	71.4	5.5	7.77	5	14.6	47.5	6.7	14.18	5	18.3	37.1	5.9	15.97	5	16.1
Stats for averages		99.9	0.1	0.13	9	0.3	84.4	1.3	1.55	9	4.0	72.5	1.4	1.97	9	4.2	48.1	2.2	4.66	9	6.9	37.7	2.2	5.79	9	6.7
Stats for independent		99.9	0.3	0.33	44	1.7	84.4	4.4	5.22	44	15.2	72.5	4.4	6.08	44	19.8	48.1	5.3	11.00	44	23.5	37.7	4.3	11.34	44	22.1
Samples						100.0					91.3					43.9					61.2					49.5
						98.3					76.1					24.1					37.7					27.4
Coarse	5	100.0	0.0	0.00	5	0.0	78.0	2.5	3.24	5	6.2	63.5	3.7	5.77	5	8.3	41.8	3.8	8.97	5	9.1	28.4	2.7	9.40	5	5.9
	6	99.8	0.5	0.49	5	1.1	78.3	2.3	2.91	5	5.9	64.2	2.2	3.48	5	5.4	41.3	1.8	4.24	5	4.4	28.0	0.9	3.03	5	1.9
	7	100.0	0.0	0.00	5	1.0	74.7	4.2	5.59	5	10.7	60.3	3.3	5.48	5	7.6	36.8	2.8	7.67	5	6.6	25.6	1.9	7.32	5	4.4
	8	100.0	0.0	0.00	5	0.0	75.2	2.7	3.59	5	6.8	62.2	3.3	5.35	5	8.4	37.4	2.5	6.58	5	5.8	28.1	1.6	5.82	5	3.6
	23	100.0	0.0	0.00	5	0.0	74.9	1.2	1.66	5	3.4	61.7	1.6	2.53	5	3.9	41.5	1.2	3.01	5	3.2	29.0	0.8	2.83	5	2.0
	24	100.0	0.0	0.00	5	0.0	72.5	2.0	2.81	5	4.8	59.0	2.7	4.66	5	7.1	38.0	2.8	7.42	5	7.5	26.1	2.4	9.08	5	6.5
	25	100.0	0.0	0.00	5	0.0	73.5	2.8	3.79	5	6.8	58.0	2.8	4.75	5	7.4	36.7	2.6	6.99	5	6.6	24.7	1.9	7.69	5	4.8
	26	100.0	0.0	0.00	6	100.0	72.7	4.9	6.80	6	11.9	57.5	4.6	8.00	6	11.2	36.4	3.6	9.77	6	8.4	24.5	2.2	9.08	6	5.3
Stats for averages		100.0	0.1	0.08	8	0.2	75.0	2.2	2.94	8	5.8	60.8	2.5	4.11	8	6.7	38.7	2.4	6.17	8	5.5	26.8	1.8	6.61	8	4.4
Stats for independent		100.0	0.2	0.17	41	1.1	85.1	5.2	6.14	41	26.5	60.7	3.8	6.20	41	15.4	39.2	3.4	8.60	41	13.5	26.7	2.4	9.07	41	9.7
Samples						100.0					93.6					67.3					46.0					31.2
						98.9					67.1					51.9					32.5					21.5

Table 2. Accumulated percent passing from cold-feed data for top lift (continued).

		#16 Sieve					#30 Sieve					#50 Sieve					#100 Sieve					#200 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	36.1	3.1	3.39	5	7.8	29.3	2.3	3.25	5	5.8	15.3	1.4	2.66	5	3.5	7.2	0.4	4.47	5	1.0	4.4	0.3	4.67	5	0.6
	2	36.2	1.2	10.46	5	3.0	29.2	1.0	9.76	5	2.4	15.4	0.4	9.41	5	1.0	7.3	0.3	6.15	5	0.7	4.4	0.2	7.21	5	0.5
	3	33.4	3.5	10.04	5	8.6	27.2	2.7	10.30	5	6.6	14.5	1.4	7.27	5	3.4	7.0	0.4	9.38	5	2.5	4.3	0.3	9.62	5	0.8
	4	37.4	3.8	11.63	5	10.0	30.3	3.1	11.75	5	8.4	16.2	1.2	17.32	5	3.0	7.6	0.7	13.03	5	1.9	4.3	0.4	7.94	5	1.1
	14	35.3	4.1	9.06	5	10.5	27.3	3.2	8.42	5	8.0	14.0	2.4	7.79	5	6.8	6.7	0.9	4.91	5	2.4	4.1	0.3	4.47	5	0.8
	15	32.5	2.9	17.92	5	7.6	26.4	2.2	16.63	5	5.9	14.3	1.1	14.12	5	2.8	6.8	0.3	21.11	5	0.9	4.1	0.2	26.09	5	0.5
	16	29.8	5.3	11.44	5	13.6	24.2	4.0	10.50	5	10.2	13.3	1.9	7.81	5	4.8	6.8	1.4	8.18	5	3.4	4.2	1.1	9.01	5	2.8
	17	30.2	3.5	7.92	5	8.1	24.6	2.6	7.49	5	6.3	13.7	1.1	6.89	5	2.5	6.9	0.6	7.96	5	1.4	4.3	0.4	11.03	5	0.9
	18	31.4	2.5	7.92	5	6.2	25.4	1.9	7.49	5	4.8	13.8	0.9	6.89	5	2.2	6.6	0.5	7.96	5	1.1	3.9	0.4	11.03	5	1.1
Stats for averages		33.6	2.8	8.36	9	7.6	27.1	2.2	7.96	9	6.1	14.5	1.0	6.55	9	2.9	7.0	0.3	4.60	9	1.0	4.2	0.2	3.90	9	0.5
Stats of independent		33.5	4.2	12.38	45	18.0	27.1	3.2	11.75	45	14.3	14.5	1.6	10.84	45	7.1	7.0	0.7	10.14	45	3.9	4.3	0.5	11.06	45	2.7
Samples						43.2					35.1					17.8					9.3					6.1
						25.2					20.8					10.7					5.4					3.4
Fine+	9	30.8	3.1	10.17	5	8.1	28.0	2.4	8.47	5	6.1	14.6	1.4	9.53	5	3.4	7.1	0.6	9.02	5	1.6	4.3	0.5	10.78	5	1.1
	10	35.0	1.7	4.92	4	4.2	28.4	1.3	4.41	4	3.0	15.7	1.0	6.09	4	22	7.8	0.3	3.96	4	0.7	4.7	0.2	4.60	4	0.5
	11	36.5	3.8	10.28	5	10.5	27.9	3.1	11.07	5	8.7	15.5	1.5	9.73	5	3.9	7.5	0.7	9.14	5	1.8	4.4	0.5	10.52	5	1.3
	12	34.4	2.9	8.32	5	7.1	27.9	2.2	7.81	5	5.5	14.5	0.8	5.85	5	2.1	7.0	0.3	4.55	5	0.9	4.1	0.3	7.37	5	0.8
	13	31.1	3.3	10.52	5	8.4	25.3	2.5	10.07	5	6.5	14.4	1.0	7.30	5	2.6	6.8	0.7	9.58	5	1.7	4.1	0.4	8.96	5	0.9
	19	31.8	5.8	18.27	5	15.0	26.1	4.6	17.48	5	11.8	14.8	1.9	12.85	5	4.1	7.4	0.6	8.33	5	1.4	4.5	0.4	7.72	5	0.9
	20	33.7	3.0	8.95	5	7.1	27.4	2.2	8.09	5	5.4	15.5	1.1	7.28	5	2.7	7.3	0.3	3.85	5	0.7	4.3	0.2	3.49	5	0.4
	21	37.1	6.4	17.38	5	17.0	29.9	4.8	16.19	5	12.9	16.2	2.5	15.52	5	6.7	7.3	0.8	10.62	5	2.0	4.4	0.4	8.96	5	1.0
	22	32.9	5.2	15.73	5	14.1	26.8	3.9	14.65	5	32.8	14.8	2.3	15.25	5	6.1	7.3	1.3	17.63	5	2.3	4.5	0.5	11.96	5	1.4
Stats for averages		33.7	2.2	6.66	9	6.3	27.5	1.3	4.86	9	4.6	15.1	0.6	4.23	9	1.8	7.3	0.3	3.97	9	1.0	4.4	0.2	4.30	9	0.6
Stats for independent		33.4	4.3	12.78	44	19.8	27.2	3.3	12.04	44	15.0	15.1	1.6	10.50	44	6.7	7.3	0.4	5.33	44	2.7	4.4	0.4	8.86	44	3.7
Samples						43.9					35.1					19.0					8.7					7.3
						24.1					20.1					12.3					6.0					3.6
Coarse	5	20.5	1.8	8.92	5	3.8	15.3	1.3	8.60	5	2.7	11.3	1.0	8.55	5	2.0	8.3	0.8	10.05	5	1.7	6.1	0.7	11.47	5	1.5
	6	20.2	0.6	3.02	5	1.3	15.2	0.6	3.72	5	1.4	11.3	0.6	5.39	5	1.5	8.2	0.5	6.17	5	1.3	5.9	0.5	9.19	5	1.4
	7	18.2	1.4	7.77	5	3.1	13.8	1.3	9.59	5	3.1	10.1	1.3	13.31	5	3.4	7.1	1.4	20.09	5	3.5	5.0	1.5	30.16	5	3.6
	8	20.5	1.1	5.50	5	2.3	15.5	0.8	5.36	5	1.6	11.8	0.8	6.49	5	1.7	8.6	0.4	4.88	5	1.0	6.3	0.4	5.64	5	0.9
	23	21.3	0.7	3.22	5	1.4	16.0	3.8	23.84	5	1.3	11.9	0.6	5.24	5	1.5	8.9	0.6	6.24	5	1.4	6.6	0.6	8.95	5	1.5
	24	19.0	1.8	9.42	5	4.9	14.4	1.3	8.84	5	3.5	10.8	0.9	8.56	5	25	8.1	0.7	8.27	5	1.7	6.0	0.6	9.34	5	1.2
	25	18.0	1.2	6.71	5	3.1	13.5	0.7	5.47	5	1.9	10.0	0.4	4.42	5	1.2	7.2	0.2	3.33	5	0.6	5.1	0.2	4.26	5	0.6
	26	17.9	1.5	8.25	6	3.5	13.5	1.1	8.17	6	2.8	9.9	0.9	9.48	6	2.7	7.2	0.9	12.71	6	2.7	5.1	0.8	16.42	6	2.5
Stats for averages		19.5	1.3	6.90	8	3.4	14.6	1.0	6.77	8	2.6	10.9	0.8	7.50	8	2.0	8.0	0.7	8.83	8	1.8	5.8	0.6	10.57	8	1.6
Stats for independent		19.5	1.7	8.96	41	6.7	14.5	1.3	9.04	41	4.9	10.9	1.1	10.21	41	4.8	7.9	1.0	12.28	41	5.0	5.8	0.9	16.06	41	5.0
Samples						22.6					16.8					12.7					9.6					7.3
						15.9					11.9					7.9					4.6					2.3

Table 3. Accumulated percent passing from cold-feed data for bottom lift.

		3/4" Sieve					1/2" Sieve					3/8" Sieve					#4 Sieve					#8 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	100.0	0.0	0.00	5	0.0	89.6	1.6	1.81	5	4.4	78.6	2.8	1.81	5	7.3	52.8	4.2	3.60	5	10.3	42.0	3.8	7.9	5	9.2
	2	100.0	0.0	0.00	4	0.0	88.6	1.7	1.92	4	3.6	76.8	3.4	1.92	4	7.1	52.7	4.3	4.49	4	9.2	37.9	3.5	8.1	4	7.7
	3	100.0	0.0	0.00	5	0.0	87.0	2.7	3.11	5	7.5	76.0	5.1	3.11	5	13.8	57.8	5.0	6.73	5	13.2	38.6	4.2	8.6	5	10.7
	4	100.0	0.0	0.00	5	0.0	85.5	4.2	4.88	5	11.2	75.8	5.7	4.88	5	15.3	47.2	6.3	7.57	5	16.0	36.6	5.2	13.4	5	12.8
	14	100.0	0.0	0.00	5	0.0	87.3	2.5	2.86	5	5.2	74.8	3.7	2.86	5	9.3	47.1	4.9	4.93	5	12.2	36.3	5.1	10.3	5	12.8
	15	100.0	0.0	0.00	5	0.0	85.8	1.2	1.37	5	2.9	72.5	1.0	1.37	5	2.7	45.6	1.4	1.44	5	3.6	34.8	1.6	3.2	5	3.8
	16	100.0	0.0	0.00	5	0.0	87.4	3.8	4.30	5	9.8	72.9	6.5	4.30	5	17.5	45.0	7.1	8.93	5	19.1	34.1	6.2	15.7	5	16.6
	17	100.0	0.0	0.00	5	0.0	84.7	2.8	3.35	5	6.8	71.1	5.4	3.35	5	13.1	44.0	7.0	7.64	5	15.6	33.9	6.8	15.9	5	14.7
	18	99.7	0.6	0.63	5	1.4	84.5	4.6	5.50	5	10.6	72.6	6.8	5.50	5	16.3	46.4	6.7	9.43	5	17.5	36.2	5.7	14.5	5	15.0
Stats for averages		100.0	0.1	0.09	9	0.3	86.7	1.7	2.00	9	5.1	74.6	2.4	3.27	9	7.5	48.7	4.6	9.48	9	13.8	36.7	2.6	7.0	9	8.1
Stats of independent		100.0	0.2	0.21	44	1.4	86.7	3.2	3.69	44	12.3	74.5	4.4	5.89	44	21.8	47.4	5.6	11.83	44	22.4	36.7	5.1	13.9	44	20.1
Samples					Max	100.0					92.0					84.3					57.8					45.8
					Min	98.6					79.7					62.5					35.4					25.7
Fine+	9	99.8	0.4	0.45	5	1.0	86.3	3.5	4.08	5	8.8	72.0	4.5	6.29	5	12.4	44.5	3.1	7.01	5	8.1	34.1	2.4	6.9	5	5.9
	10	100.0	0.0	0.00	5	0.0	89.8	1.7	1.86	5	4.4	79.2	1.7	2.16	5	4.7	52.6	2.4	4.65	5	6.8	41.1	2.0	5.0	5	5.0
	11	100.0	0.0	0.00	5	0.0	86.9	1.4	1.59	5	3.3	75.4	2.6	3.44	5	6.9	48.7	2.9	5.98	5	7.2	38.1	2.5	6.5	5	6.5
	12	100.0	0.0	0.00	5	0.0	84.1	3.3	3.89	5	7.3	71.0	5.8	8.20	5	13.5	44.7	6.4	14.31	5	14.8	34.4	5.6	16.2	5	12.3
	13	100.0	0.0	0.0	1.0	0.0	68.4	0.0	0.0	1.0	0.0	69.7	0.0	0.0	1.0	0.0	39.1	0.0	0.0	1.0	0.0	29.7	0.0	0.0	1.0	0.0
	19	100.0	0.0	0.00	5	0.0	88.2	1.7	1.98	5	4.3	75.9	2.3	2.99	5	5.3	48.8	3.9	7.96	5	9.0	37.7	3.9	10.4	5	9.4
	20	100.0	0.0	0.00	5	0.0	88.1	4.3	4.84	5	11.8	76.3	5.2	6.86	5	14.3	49.7	4.6	9.20	5	12.1	38.1	3.7	9.8	5	9.3
	21	100.0	0.0	0.00	5	0.0	86.8	1.7	1.99	5	4.5	74.9	2.3	3.05	5	5.0	49.2	2.6	5.26	5	5.8	38.1	2.2	5.8	5	4.8
	22	100.0	0.0	0.00	5	0.0	87.8	0.7	0.75	5	1.8	74.9	1.6	2.10	5	3.4	48.1	1.8	3.77	5	3.9	38.1	1.9	5.0	5	4.5
Stats for averages		100.0	0.1	0.07	9	0.2	85.2	6.5	7.60	9	21.4	74.4	3.0	3.97	9	9.5	47.3	3.9	8.34	9	13.5	36.6	3.4	9.2	9	11.4
Stats for independent		100.0	0.2	0.16	41	1.0	86.8	4.0	4.66	41	25.2	74.8	4.1	5.47	41	20.0	48.1	4.4	9.14	41	19.3	37.3	3.8	10.2	41	16.6
Samples					Max	100.0					93.6					83.3					56.1					44.0
					Min	99.0					68.4					63.3					36.8					27.4
Coarse	5	100.0	0.0	0.00	5	0.0	81.4	4.3	5.24	5	8.4	64.2	5.7	8.84	5	13.6	38.4	2.8	7.23	5	7.2	24.7	1.3	5.1	5	3.4
	6	100.0	0.0	0.00	5	0.0	78.1	2.2	2.85	5	5.7	61.3	3.4	5.48	5	8.7	37.4	3.8	10.13	5	10.2	24.7	3.7	14.8	5	9.3
	7	100.0	0.0	0.00	5	0.0	80.7	3.4	4.25	6	9.5	65.6	6.0	9.14	6	16.9	42.9	6.7	15.73	6	19.4	30.1	7.6	25.1	6	21.8
	8	100.0	0.0	0.00	5	0.0	78.4	2.5	3.16	5	6.9	61.0	3.2	5.25	5	8.5	38.1	3.0	7.99	5	8.3	25.2	1.8	7.2	5	5.0
	23	100.0	0.0	0.00	5	0.0	75.2	3.3	4.34	5	8.1	57.5	2.8	4.87	5	6.8	33.9	3.3	9.85	5	8.5	21.8	2.5	11.3	5	6.6
	24	100.0	0.0	0.00	5	0.0	77.2	3.6	4.60	5	9.0	59.9	4.2	7.01	5	11.0	35.4	2.9	8.12	5	7.6	22.5	2.1	9.5	5	5.5
	25	100.0	0.0	0.00	5	0.0	78.4	2.9	3.74	5	7.4	62.3	4.9	7.90	5	12.3	39.1	5.6	14.39	5	14.6	26.3	4.8	18.1	5	12.0
	26	99.7	0.8	0.76	6	1.7	78.8	1.9	2.41	6	4.8	63.7	2.2	3.38	6	5.4	41.4	2.4	5.69	6	5.4	28.2	1.9	6.8	6	4.9
Stats for averages		100.0	0.1	0.12	8	0.3	78.5	1.9	2.45	8	6.2	61.9	2.6	4.17	8	8.1	38.3	2.9	7.66	8	9.0	25.4	2.8	10.8	8	8.3
Stats for independent		100.0	0.3	0.27	41	1.7	78.6	3.4	4.28	42	16.6	62.0	4.6	7.47	42	24.1	38.4	4.7	12.35	42	25.1	25.5	4.5	17.5	42	25.8
Samples					Max	100.0					87.1					77.4					55.5					44.6
					Min	98.3					70.5					53.3					30.4					18.8

Table 3. Accumulated percent passing from cold- feed data for bottom lift (continued).

		#16 Sieve					#30 Sieve					#50 Sieve					#100 Sieve					#200 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	37.6	3.5	8.96	5	8.7	30.8	2.7	9.25	5	7.0	17.1	1.3	8.93	5	3.3	8.0	0.6	7.71	5	1.4	4.8	0.3	7.23	5	0.7
	2	33.7	3.1	9.37	4	6.7	27.4	2.3	9.16	4	4.9	15.6	1.3	8.24	4	2.9	7.4	0.3	8.50	4	0.8	4.3	0.3	4.68	4	0.7
	3	34.6	3.8	10.94	5	9.3	28.5	2.8	10.90	5	6.9	16.2	1.5	9.89	5	3.7	7.7	0.6	8.98	5	0.7	4.5	0.4	7.68	5	1.1
	4	32.7	4.6	14.29	5	10.9	26.3	4.2	13.93	5	9.9	13.9	3.4	15.89	5	8.0	6.7	1.2	24.12	5	2.7	4.0	0.5	18.25	5	1.2
	14	32.2	4.7	13.94	5	11.8	26.3	3.8	14.72	5	9.2	14.9	1.4	14.37	5	3.0	7.2	0.7	9.27	5	1.5	4.2	0.3	9.36	5	0.7
	15	31.0	1.6	4.73	5	3.5	25.4	1.3	5.26	5	2.9	14.4	0.8	5.16	5	1.8	6.9	0.3	5.49	5	0.7	4.1	0.2	4.01	5	0.6
	16	30.2	5.4	18.29	5	14.4	24.9	4.3	17.94	5	11.4	14.2	1.9	17.18	5	5.3	7.2	0.8	13.68	5	2.1	4.4	0.7	11.11	5	1.4
	17	30.4	6.1	19.95	5	13.3	25.0	4.9	20.23	5	10.4	14.6	2.2	19.48	5	5.0	7.1	0.8	14.80	5	1.7	4.2	0.3	11.40	5	0.7
	18	32.3	5.1	15.63	5	13.5	26.5	4.1	15.80	5	10.8	14.8	2.0	15.53	5	5.2	7.1	0.9	13.24	5	2.5	4.1	0.6	13.16	5	1.5
Stats for averages		32.7	2.3	7.16	9	7.5	26.8	1.9	7.01	9	5.9	15.1	1.0	0.95	9	3.2	7.3	0.4	5.66	9	1.4	4.3	0.2	5.40	9	0.7
Stats of independent		32.7	4.6	14.05	44	18.5	26.8	3.7	13.81	44	15.0	15.1	2.0	13.14	44	9.7	7.3	0.8	10.84	44	3.9	4.3	0.4	9.85	44	1.8
Samples						41.5					34.2					18.4					8.9					5.1
						23.0					19.2					8.7					5.0					3.3
Fine+	9	32.2	2.0	6.26	5	5.3	24.9	1.7	6.75	5	4.5	13.4	1.8	13.75	5	5.1	6.2	1.6	26.45	5	4.3	3.4	1.6	45.67	5	4.0
	10	36.8	1.8	4.99	5	4.5	30.1	1.4	4.79	5	3.6	16.8	0.9	5.57	5	4.2	7.7	0.5	6.10	5	1.2	4.7	0.4	9.48	5	1.1
	11	34.2	2.3	6.62	5	6.0	28.1	1.9	6.85	5	5.0	15.2	1.0	6.51	5	2.5	7.0	0.5	6.48	5	1.2	4.1	0.3	7.11	5	0.7
	12	30.7	4.9	16.12	5	11.0	25.2	3.8	14.94	5	8.7	13.6	1.3	9.86	5	3.4	6.4	0.5	7.74	5	1.1	3.8	0.3	8.36	5	0.9
	13	26.6	0.0	0.0	1.0	0.0	21.7	0.0	0.0	1.0	0.0	12.1	0.0	0.0	1.0	0.0	5.5	0.0	0.0	1.0	0.0	3.1	0.0	0.0	1.0	0.0
	19	33.3	3.6	10.72	5	8.7	27.2	2.8	10.42	5	6.8	15.3	1.8	11.85	5	4.4	7.2	0.7	9.66	5	1.8	4.3	0.7	15.25	5	1.8
	20	33.9	3.2	9.52	5	7.9	27.8	2.6	9.27	5	6.2	15.4	1.7	11.11	5	4.1	7.7	1.0	12.98	5	2.3	4.5	0.8	16.96	5	1.7
	21	33.7	2.0	5.89	5	4.2	27.6	1.6	5.90	5	3.4	15.0	0.7	4.18	5	1.8	7.9	0.5	6.43	5	1.4	4.7	0.3	7.22	5	0.9
	22	34.2	1.9	5.70	5	4.8	28.0	1.7	6.11	5	4.3	15.4	0.7	4.51	5	1.7	7.3	0.3	4.48	5	0.9	4.3	0.1	3.02	5	0.3
Stats for averages		32.9	2.9	8.74	9	10.2	26.7	2.4	9.16	9	8.4	14.8	1.4	9.65	9	4.7	7.0	0.8	11.38	9	2.4	4.1	0.6	13.57	9	1.6
Stats for independent		33.2	3.4	10.30	41	14.7	27.2	2.7	10.08	41	11.2	12.6	1.6	13.01	41	9.0	8.8	1.0	10.84	41	5.4	4.2	0.8	18.37	41	4.9
Samples						39.3					31.9					17.7					8.8					5.6
						24.6					20.7					8.7					3.4					0.7
Coarse	5	18.0	0.8	4.36	5	2.0	13.7	0.6	4.43	5	1.6	10.4	0.6	5.65	5	1.5	7.8	0.5	6.92	5	1.5	5.8	0.5	8.20	5	1.3
	6	18.0	2.7	14.97	5	6.6	13.6	1.9	13.82	5	4.7	10.2	1.4	13.29	5	3.6	7.6	0.8	11.01	5	2.2	5.5	0.6	10.12	5	1.5
	7	23.1	8.4	36.17	6	23.2	17.7	7.2	40.56	6	19.3	12.1	2.9	23.92	6	8.0	7.9	0.8	10.11	6	1.9	5.6	0.8	14.91	6	2.1
	8	18.4	1.1	6.24	5	3.2	13.9	0.8	5.50	5	2.1	10.4	0.5	5.19	5	1.4	7.7	0.3	4.14	5	0.8	5.6	0.3	4.61	5	0.6
	23	16.1	1.7	10.74	5	4.6	12.4	1.1	9.26	5	3.0	9.5	0.8	8.14	5	2.0	7.2	0.6	8.38	5	1.5	5.3	0.5	8.75	5	1.2
	24	16.4	1.6	9.73	5	4.2	12.5	1.1	9.16	5	3.0	9.4	0.8	8.41	5	1.9	7.0	0.6	9.20	5	1.6	5.1	0.5	10.27	5	1.2
	25	19.2	3.6	18.70	5	8.9	14.5	2.6	17.62	5	6.1	11.0	1.9	17.07	5	4.6	8.2	1.4	16.93	5	3.3	6.1	1.1	17.81	5	2.6
	26	20.7	1.4	6.86	6	3.5	15.6	1.2	7.49	6	2.7	11.7	1.1	9.03	6	2.4	8.8	0.9	10.07	6	2.2	6.7	0.9	13.95	6	2.4
Stats for averages		18.7	2.3	12.28	8	7.0	14.2	1.7	12.15	8	5.2	10.6	1.0	9.24	8	2.7	7.8	0.6	7.32	8	1.8	5.7	0.5	8.54	8	1.6
Stats for independent		23.7	4.1	17.26	42	26.1	14.3	3.3	22.98	42	21.5	10.6	1.7	15.69	42	9.6	7.8	0.9	11.65	42	4.4	5.7	0.8	13.67	42	3.6
Samples						39.7					32.0					17.6					10.6					8.1
						13.6					10.5					8.0					6.2					4.5

Table 4. Percent retained in various size ranges from cold-feed data for top lifts.

		3/4 x 1/2					1/2 x 3/8					3/8 x #4					#4 x #8					#8 x #16				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	12.6	1.5	11.79	5	3.3	12.1	1.6	12.93	5	3.9	24.7	1.4	5.70	5	3.6	10.4	0.7	6.40	5	1.6	4.1	0.5	11.57	5	1.1
	2	10.0	1.0	9.97	5	2.7	10.3	1.8	17.31	5	4.5	27.6	1.0	3.56	5	2.7	11.4	0.7	6.44	5	1.9	4.4	0.3	7.47	5	0.8
	3	16.1	2.0	12.47	5	5.1	11.9	1.4	12.17	5	4.0	24.7	1.7	6.99	5	4.4	10.1	0.6	6.34	5	1.6	3.9	0.3	8.71	5	0.9
	4	14.0	1.8	12.86	5	4.1	10.5	1.6	15.19	5	4.0	22.9	1.7	7.32	5	4.3	10.7	0.3	3.06	5	0.9	4.5	0.4	9.16	5	1.1
	14	14.6	2.5	16.82	5	6.3	11.2	1.4	12.78	5	3.4	24.8	1.4	5.84	5	3.3	10.1	0.6	5.73	5	1.6	4.0	0.5	11.65	5	1.0
	15	15.6	2.3	14.46	5	5.7	12.9	0.9	7.07	5	2.2	25.2	1.1	4.27	5	2.9	10.0	0.3	3.04	5	0.8	3.8	0.2	6.25	5	0.6
	16	16.1	3.4	21.18	5	9.3	13.7	2.2	16.17	5	5.6	26.5	1.5	5.67	5	3.8	9.9	0.9	8.62	5	1.8	3.7	0.7	17.57	5	1.7
	17	14.8	4.5	30.46	5	10.8	13.6	1.4	10.13	5	2.9	26.9	1.5	5.43	5	3.8	10.7	0.9	8.09	5	2.2	3.7	0.6	16.00	5	1.6
	18	16.1	3.2	19.71	5	8.3	12.8	1.2	9.39	5	2.8	26.1	1.0	3.66	5	2.6	10.2	0.6	5.85	5	1.6	3.7	0.5	14.53	5	1.3
Stats for averages		14.4	2.0	14.13	9	6.1	12.1	1.3	10.36	9	3.4	25.5	1.4	5.58	9	4.6	10.4	0.5	4.62	9	1.5	4.0	0.3	7.73	9	0.9
Stats of independent		14.4	3.1	21.44	45	14.3	12.1	1.8	15.17	45	8.3	25.5	1.8	7.24	45	8.5	10.4	0.7	7.15	45	3.7	4.0	0.5	12.92	45	2.0
Samples					Max	22.8					15.6					29.1					12.7					5.0
					Min	8.5					7.3					20.6					9.0					3.0
Fine+	9	17.6	3.7	21.30	5	10.0	11.6	1.1	9.33	5	3.0	25.4	1.0	3.90	5	2.5	10.5	1.0	9.94	5	2.5	4.1	0.7	17.33	5	1.7
	10	16.2	2.8	16.99	4	5.4	11.4	1.5	12.91	4	3.3	22.9	1.1	4.98	4	2.7	10.2	0.6	5.49	4	1.3	4.4	0.4	8.90	4	0.9
	11	15.1	2.7	17.53	5	7.4	12.0	1.6	12.96	5	3.9	23.8	0.9	3.69	5	2.2	10.3	0.4	3.67	5	1.0	4.2	0.4	9.52	5	1.0
	12	13.6	2.1	15.65	5	5.7	12.1	1.4	11.59	5	3.5	24.9	1.3	5.03	5	3.1	10.5	0.8	7.50	5	2.1	4.5	0.5	11.22	5	1.4
	13	15.9	2.6	16.40	5	7.0	13.1	1.5	11.09	5	3.8	25.9	1.4	5.44	5	3.5	9.8	0.7	7.35	5	1.7	4.1	0.5	12.66	5	1.4
	19	14.1	2.6	18.73	5	7.0	13.4	1.6	11.91	5	3.9	26.2	2.8	10.60	5	7.6	10.5	0.3	2.64	5	0.7	4.1	0.5	12.66	5	1.4
	20	15.8	2.6	16.53	5	5.5	11.5	2.3	19.73	5	5.4	23.6	0.7	2.77	5	1.7	11.0	0.8	7.65	5	2.2	4.3	0.4	10.18	5	1.0
	21	14.3	5.8	40.90	5	15.2	10.5	2.5	23.38	5	6.6	23.9	1.9	8.13	5	5.2	11.3	2.2	###	5	5.9	5.5	2.0	37.32	5	5.6
	22	16.6	3.6	21.40	5	9.4	11.7	2.0	17.04	5	5.4	23.9	1.7	7.29	5	3.7	10.4	0.8	7.90	5	2.2	4.2	0.8	18.04	5	2.0
Stats for averages		15.5	1.3	8.46	9	3.0	11.9	0.9	7.34	9	2.8	24.5	1.1	4.69	9	3.3	10.5	0.4	4.16	9	1.5	4.4	0.4	9.84	9	1.3
Stats for independent		15.4	3.3	21.24	44	15.2	11.9	1.8	15.04	44	8.5	24.5	1.8	7.22	44	8.8	10.5	1.0	9.51	44	6.0	4.4	0.9	20.31	44	5.6
Samples					Max	23.9					15.5					30.6					14.8					8.7
					Min	8.7					7.0					21.8					8.8					3.1
Coarse	5	22.0	2.5	11.46	5	6.2	14.4	1.2	8.55	5	2.5	21.7	0.4	1.86	5	0.8	13.5	1.2	9.02	5	3.2	7.8	0.9	11.54	5	2.3
	6	21.5	2.4	11.32	5	5.9	13.8	1.5	10.54	5	4.7	22.9	0.6	2.70	5	1.7	13.2	1.0	7.33	5	2.6	7.8	0.4	4.71	5	1.0
	7	25.3	4.2	16.55	5	10.7	14.4	2.3	15.66	5	5.6	22.9	0.7	3.03	5	1.8	11.8	1.1	8.93	5	2.7	7.1	0.8	11.62	5	2.1
	8	24.8	2.7	10.87	5	6.8	13.0	0.7	5.51	5	1.7	21.4	1.6	7.59	5	3.7	12.7	0.9	7.16	5	2.2	7.6	0.5	7.15	5	1.3
	23	25.1	1.2	4.94	5	3.4	13.1	0.8	6.25	5	1.8	20.2	0.5	2.36	5	1.2	12.5	0.6	4.43	5	1.4	7.7	0.3	3.87	5	0.8
	24	27.5	2.0	7.40	5	4.8	13.5	1.3	9.82	5	3.2	21.0	0.4	1.72	5	0.9	11.9	0.6	4.64	5	1.1	7.1	0.6	8.36	5	1.6
	25	26.5	2.8	10.48	5	6.8	15.4	1.2	7.75	5	2.9	21.4	0.9	4.03	5	2.2	12.0	0.7	5.85	5	1.8	6.7	0.7	10.54	5	1.7
	26	27.4	4.9	18.08	6	11.9	15.1	1.1	7.19	6	2.8	21.2	1.4	6.74	6	4.0	11.8	1.4	###	6	3.2	6.6	0.8	11.92	6	1.9
Stats for averages		25.0	2.3	9.00	8	6.0	14.1	0.9	6.38	8	2.4	21.6	0.9	4.34	8	2.7	12.4	0.7	5.42	8	1.7	7.3	0.5	6.69	8	1.2
Stats for independent		25.1	3.6	14.20	41	13.5	14.2	1.4	9.99	41	5.6	21.6	1.2	5.68	41	4.6	12.4	1.1	8.78	41	4.5	7.3	0.8	10.50	41	3.2
Samples					Max	32.9					17.0					23.9					14.8					8.8
					Min	19.4					11.4					19.3					10.3					5.6

Table 4. Percent retained in various size ranges from cold-feed data for top lifts (continued).

		#16 x #30					#30 x #50					#50 x #100					#100 x #200				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	6.8	0.7	10.77	5	2.0	13.9	1.2	8.50	5	2.8	8.1	1.1	13.20	5	2.7	2.9	0.2	6.68	5	0.5
	2	7.0	0.4	5.14	5	0.9	13.9	0.8	5.87	5	2.1	8.1	0.3	4.08	5	0.7	2.9	0.1	4.53	5	0.3
	3	6.2	0.8	13.69	5	2.0	12.6	1.6	12.32	5	4.2	7.6	1.1	14.16	5	2.6	2.6	0.2	8.30	5	0.6
	4	7.1	0.7	9.11	5	1.6	14.1	2.0	14.49	5	5.4	8.6	0.6	6.73	5	1.3	3.0	0.3	9.76	5	0.8
	14	7.9	3.0	38.27	5	7.6	13.4	1.7	12.61	5	4.5	7.2	1.6	21.83	5	4.4	2.6	0.6	24.78	5	1.7
	15	6.1	0.7	12.16	5	1.9	12.0	1.5	12.58	5	3.8	7.5	0.9	11.43	5	2.1	2.8	0.2	7.80	5	0.6
	16	5.6	1.3	23.61	5	3.4	10.9	2.2	20.12	5	5.4	6.5	0.6	9.39	5	1.4	2.6	0.3	13.54	5	0.8
	17	5.5	0.9	16.52	5	2.3	10.9	1.6	14.36	5	4.1	6.9	0.6	9.31	5	1.4	2.6	0.2	7.46	5	0.5
	18	5.7	0.6	10.60	5	1.4	11.6	1.4	12.45	5	3.4	7.2	0.5	6.45	5	1.1	2.6	0.2	6.88	5	0.5
Stats for averages		6.4	0.8	12.84	9	2.4	12.6	1.3	10.18	9	3.2	7.5	0.7	8.86	9	2.2	2.7	0.2	6.08	9	0.5
Stats of independent		6.4	1.4	21.62	45	8.8	12.6	1.9	15.06	45	8.8	7.5	1.0	13.55	45	4.5	2.7	0.3	11.67	45	2.0
Samples					Max	13.1					17.3					9.8					3.5
					Min	4.3					8.5					5.3					1.5
Fine+	9	5.6	0.8	14.20	5	2.0	10.5	1.0	9.76	5	2.7	7.5	0.8	10.36	5	1.8	2.8	0.2	6.68	5	0.5
	10	6.6	0.5	7.63	4	1.2	12.7	0.6	5.05	4	1.3	7.9	0.7	9.41	4	1.5	3.1	0.1	3.06	4	0.2
	11	6.5	0.7	10.81	5	1.8	12.4	1.9	15.02	5	4.8	8.0	0.9	11.69	5	2.4	3.1	0.3	9.41	5	0.8
	12	6.5	0.7	10.68	5	1.8	13.4	1.5	10.98	5	3.7	8.0	0.9	11.69	5	2.4	2.9	0.1	4.53	5	0.3
	13	5.8	0.8	13.07	5	1.9	10.9	1.5	14.10	5	3.9	7.6	0.6	8.19	5	1.7	2.7	0.4	13.10	5	0.9
	19	5.7	1.2	21.91	5	3.2	11.4	2.8	24.66	5	7.7	7.4	1.4	18.71	5	3.1	2.9	0.3	10.95	5	0.8
	20	6.4	0.8	12.90	5	1.9	11.8	1.2	9.88	5	3.1	8.3	1.0	11.54	5	2.5	2.9	0.2	5.63	5	0.4
	21	7.9	2.0	25.05	5	5.3	13.9	2.4	16.92	5	6.2	8.9	1.8	20.82	5	4.7	2.9	0.5	15.33	5	1.1
	22	6.1	1.3	20.45	5	3.4	12.0	1.8	15.22	5	4.6	7.5	1.4	18.88	5	3.8	2.8	0.3	11.85	5	0.9
Stats for averages		6.3	0.7	10.76	9	2.2	12.1	1.1	9.17	9	3.0	7.9	0.5	6.04	9	1.5	2.9	0.1	4.44	9	0.4
Stats for independent		6.3	1.2	18.46	44	6.0	12.1	1.9	15.89	44	8.7	7.8	1.1	14.23	44	5.1	2.9	0.3	9.77	44	1.2
Samples					Max	10.0					16.1					11.0					3.4
					Min	4.0					7.4					5.9					2.2
Coarse	5	5.2	0.5	10.08	5	1.2	4.0	0.4	9.52	5	0.9	3.0	0.2	6.00	5	0.4	2.3	0.2	7.85	5	0.4
	6	5.1	0.1	2.92	5	0.4	3.8	0.2	5.97	5	0.6	3.1	0.2	6.17	5	0.5	2.4	0.2	9.92	5	0.8
	7	4.7	0.5	11.02	5	1.4	3.7	0.4	9.95	5	0.9	2.9	0.4	13.30	5	1.0	2.2	0.2	7.75	5	0.4
	8	4.9	0.4	7.10	5	0.9	3.8	0.2	6.03	5	0.6	3.1	0.4	12.29	5	0.9	2.3	0.1	3.61	5	0.2
	23	5.3	0.2	3.62	5	0.5	4.1	0.3	7.56	5	0.8	3.0	0.1	3.33	5	0.2	2.3	0.1	3.07	5	0.2
	24	4.6	0.5	11.70	5	1.4	3.6	0.4	11.34	5	1.0	2.7	0.3	11.43	5	0.8	2.0	0.2	9.56	5	0.5
	25	4.4	0.5	10.75	5	1.2	3.5	0.4	10.71	5	1.0	2.8	0.2	8.09	5	0.6	2.0	0.2	7.43	5	0.4
	26	4.5	0.5	10.28	6	1.2	3.6	0.4	10.20	6	1.0	2.7	0.1	3.66	6	0.2	2.1	0.1	5.12	6	0.3
Stats for averages		4.9	0.3	6.90	8	0.9	3.8	0.2	5.70	8	0.6	2.9	0.2	5.61	8	0.4	2.2	0.1	6.30	8	0.3
Stats for independent		4.8	0.5	10.39	41	2.2	3.8	0.4	9.83	41	1.6	2.9	0.3	9.63	41	1.4	2.2	0.2	7.82	41	0.7
Samples					Max	5.8					4.5					3.6					2.5
					Min	3.6					2.9					2.2					1.8

Table 5. Percent retained in various size ranges from cold-feed data for bottom lifts.

		3/4 x 1/2					1/2 x 3/8					3/8 x #4					#4 x #8					#8 x #16				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	10.4	1.6	15.54	5	4.4	11.0	1.6	14.70	5	3.7	25.8	1.5	5.71	5	3.7	10.7	0.6	5.21	5	1.5	4.4	0.5	11.57	5	1.1
	2	11.4	1.7	14.98	4	3.6	11.9	2.4	19.89	4	7.6	27.4	1.4	5.13	4	3.3	11.5	0.8	6.56	4	1.6	4.2	0.5	11.34	4	1.0
	3	13.0	2.7	20.83	5	7.5	11.0	2.6	23.40	5	6.3	26.5	0.5	2.04	5	1.4	10.8	1.0	9.17	5	2.5	4.1	0.5	13.10	5	1.4
	4	14.5	4.2	28.78	5	11.2	11.5	1.6	13.92	5	4.1	26.8	1.0	3.84	5	2.6	10.6	1.2	11.34	5	3.2	3.9	0.7	17.98	5	1.9
	14	12.7	2.5	19.70	5	5.2	12.6	1.8	14.08	5	4.3	27.6	1.6	5.63	5	4.0	10.8	0.2	2.21	5	0.6	4.1	0.4	10.07	5	1.0
	15	14.2	1.2	8.34	5	2.9	13.4	1.5	11.46	5	3.9	26.9	0.6	2.28	5	1.6	10.7	1.0	9.01	5	2.0	3.9	0.5	12.68	5	1.1
	16	12.6	3.8	29.77	5	9.8	14.4	3.3	22.69	5	7.7	27.9	1.7	5.97	5	4.2	11.0	1.0	8.96	5	2.5	3.9	0.8	21.13	5	2.2
	17	15.3	2.8	18.59	5	6.8	13.6	2.7	19.82	5	6.3	27.1	2.2	7.98	5	5.8	10.1	0.6	6.26	5	1.6	3.5	0.6	18.18	5	1.4
	18	15.3	4.3	28.35	5	10.6	11.9	2.5	20.64	5	5.7	26.1	2.0	7.64	5	5.0	10.2	1.4	13.92	5	3.5	3.9	0.6	16.44	5	1.5
Stats for averages		13.3	1.7	12.77	9	4.9	12.4	1.2	9.85	9	3.4	26.9	0.7	2.54	9	2.1	10.7	0.4	3.69	9	1.4	4.0	0.2	6.27	9	0.9
Stats of independent		13.3	3.1	23.59	#	12.3	12.4	1.5	12.05	44	10.4	26.9	1.5	5.54	#	6.8	10.7	0.9	8.54	#	3.5	4.0	0.6	14.79	44	2.3
Samples					Max	20.3					17.4					30.5					12.5					5.0
					Min	8.0					7.0					23.7					9.0					2.7
Fine+	9	13.5	3.4	24.89	5	8.8	14.2	1.4	10.01	5	3.6	27.6	1.9	6.94	5	4.8	10.4	1.3	12.41	5	2.7	3.7	0.6	15.08	5	1.4
	10	10.2	1.7	16.31	5	4.4	10.6	1.3	12.04	5	3.2	26.6	1.0	3.74	5	2.5	11.5	0.9	7.60	5	2.2	4.3	0.4	9.11	5	1.0
	11	13.1	1.4	10.54	5	3.3	11.5	1.4	12.24	5	3.6	26.7	0.8	2.90	5	1.9	10.6	0.6	5.40	5	1.6	4.0	0.4	10.20	5	1.0
	12	15.9	3.3	20.53	5	7.3	13.1	2.6	19.96	5	6.4	26.2	0.8	3.20	5	2.2	10.4	1.0	10.11	5	2.5	3.7	0.7	18.92	5	1.7
	13																									
	19	11.8	1.7	14.80	5	4.3	12.3	0.8	6.90	5	2.2	27.1	1.7	6.42	5	4.6	11.3	1.1	9.48	5	2.8	4.4	0.4	8.45	5	0.9
	20	11.9	4.3	35.79	5	11.8	11.8	1.1	9.01	5	2.5	26.6	1.2	4.67	5	3.2	11.6	1.1	9.87	5	2.8	4.2	0.5	12.60	5	1.4
	21	13.2	1.7	13.11	5	4.5	11.9	1.2	10.07	5	3.3	25.7	0.5	2.10	5	1.4	11.1	0.5	4.33	5	1.1	4.3	0.3	6.01	5	0.6
	22	12.2	0.7	5.40	5	1.8	12.9	1.4	10.78	5	3.7	26.9	0.8	2.81	5	2.0	9.9	0.5	5.16	5	1.4	3.9	0.2	5.84	5	0.5
Stats for averages		14.8	6.5	43.69	9	21.4	10.8	4.6	43.13	9	14.4	27.1	1.4	5.19	9	4.9	10.7	0.7	6.88	9	2.2	4.0	0.4	10.32	9	1.3
Stats for independent		13.2	4.0	30.53	#	25.2	12.8	2.7	21.21	41	18.1	26.8	1.3	4.98	#	6.2	10.8	1.0	8.95	#	3.4	4.0	0.5	12.41	41	2.1
Samples					Max	31.6					16.8					30.6					12.6					4.9
					Min	6.4					-1.3					24.4					9.2					2.8
Coarse	5	18.6	4.3	22.92	5	8.4	17.2	2.5	14.48	5	6.0	25.8	3.1	11.88	5	6.7	13.7	1.6	11.71	5	3.8	6.7	0.5	7.89	5	1.4
	6	21.9	2.2	10.15	5	5.7	16.7	1.9	11.43	5	5.2	23.9	2.1	8.82	5	5.2	12.7	1.2	9.81	5	2.7	6.7	1.0	15.00	5	2.7
	7	19.3	3.4	17.72	6	9.5	15.1	2.8	18.42	6	7.4	22.8	1.5	6.49	6	3.9	12.8	1.0	7.87	6	2.9	7.0	1.2	16.83	6	3.0
	8	21.6	2.5	11.47	5	6.9	17.4	1.1	6.13	5	2.6	22.9	0.3	1.51	5	0.8	12.9	1.2	9.63	5	3.3	6.8	0.7	10.49	5	1.8
	23	24.8	3.3	13.16	5	8.1	17.7	1.1	6.26	5	2.8	23.6	2.0	8.66	5	4.6	12.1	1.0	7.91	5	2.5	5.7	0.8	13.43	5	2.0
	24	22.8	3.6	15.59	5	9.0	17.3	0.8	4.85	5	2.0	24.6	1.3	5.49	5	3.4	12.9	0.9	7.04	5	2.2	6.1	0.6	9.20	5	1.3
	25	21.6	2.9	13.53	5	7.4	16.1	3.0	18.48	5	7.9	23.2	1.0	4.41	5	2.3	12.8	1.0	7.71	5	2.6	7.1	1.2	16.96	5	3.1
	26	20.8	1.6	7.82	5	4.4	15.1	0.7	4.30	5	1.6	22.3	1.4	6.24	5	3.4	13.2	0.7	5.65	5	1.8	7.5	0.7	8.84	5	1.4
Stats for averages		21.4	1.9	9.01	8	6.2	16.6	1.0	6.29	8	2.7	23.6	1.1	4.76	8	3.5	12.9	0.4	3.48	8	1.6	6.7	0.6	8.47	8	1.8
Stats for independent		21.4	3.3	15.66	#	16.6	17.2	2.5	14.48	41	6.0	25.8	3.1	11.88	#	6.7	12.9	1.1	8.49	#	5.3	6.7	1.0	14.16	41	4.4
Samples					Max	29.5					19.4					30.1					16.2					9.1
					Min	12.9					13.4					23.4					10.9					4.7

Table 5. Percent retained in various size ranges from cold-feed data for bottom lifts. (continued).

		#16 x #30					#30 x #50					#50 x #100					#100 x #200				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	6.9	0.8	11.87	5	2.2	13.6	1.6	11.39	5	3.7	9.1	0.9	9.92	5	2.4	3.3	0.3	10.31	5	0.9
	2	6.3	0.8	13.23	4	1.8	11.8	1.0	8.50	4	2.0	8.2	1.0	12.05	4	2.1	3.1	0.1	3.11	4	0.2
	3	6.1	1.0	16.31	5	2.6	12.3	1.5	12.26	5	3.6	8.5	1.1	12.66	5	2.8	3.2	0.3	8.89	5	0.7
	4	6.4	1.2	18.67	5	2.9	12.4	1.7	13.77	5	4.5	7.2	2.2	29.99	5	5.3	2.6	0.9	32.65	5	2.1
	14	5.9	1.0	16.66	5	2.6	11.4	2.5	22.17	5	6.2	7.7	0.7	9.66	5	1.7	3.0	0.4	13.68	5	0.9
	15	5.6	0.4	7.26	5	1.0	11.0	0.8	7.15	5	1.9	7.5	0.8	11.27	5	2.1	2.8	0.1	4.62	5	0.3
	16	5.3	1.1	21.49	5	3.0	10.7	2.4	22.66	5	6.1	7.0	1.2	16.90	5	3.2	2.8	0.3	10.46	5	0.7
	17	5.3	1.3	23.89	5	2.9	10.5	2.8	26.45	5	5.9	7.5	1.4	18.32	5	3.3	2.9	0.5	18.60	5	1.1
	18	5.8	1.0	17.45	5	2.7	11.7	2.3	19.65	5	5.6	7.6	1.0	13.50	5	2.7	3.0	0.5	15.09	5	1.0
Stats for averages		5.9	0.5	8.73	9	1.6	11.7	1.0	8.38	9	3.2	7.8	0.7	8.49	9	2.1	3.0	0.2	6.88	9	0.6
Stats of independent		5.9	1.0	17.30	44	4.0	11.7	2.0	17.25	44	8.0	7.8	1.3	16.29	44	6.6	3.0	0.4	14.98	44	2.6
Samples					Max	7.8					15.8					10.3					3.8
					Min	3.8					7.8					3.7					1.2
Fine+	9	5.5	0.5	9.57	5	1.4	11.5	0.3	2.87	5	0.8	7.2	0.5	6.87	5	1.3	2.8	0.2	7.80	5	0.5
	10	6.8	0.5	6.67	5	1.2	13.3	1.1	8.58	5	2.9	9.1	0.6	7.03	5	1.6	3.0	0.1	2.94	5	0.2
	11	6.1	0.4	6.66	5	1.0	12.9	1.1	8.65	5	2.7	5.0	2.7	54.05	5	8.4	2.9	0.3	8.54	5	0.6
	12	5.5	1.3	22.75	5	3.0	11.5	2.6	22.43	5	5.3	7.2	1.0	13.51	5	2.6	2.6	0.3	11.43	5	0.7
	13																				
	19	6.2	0.8	12.24	5	1.9	11.8	1.1	9.17	5	2.4	8.2	1.3	15.68	5	3.2	2.8	0.1	4.62	5	0.3
	20	6.2	0.7	10.87	5	1.7	12.4	1.3	10.57	5	3.5	7.7	0.8	10.18	5	2.1	3.1	0.4	12.29	5	1.0
	21	6.1	0.4	6.37	5	0.8	12.0	1.2	9.60	5	2.8	7.7	0.6	7.58	5	1.5	3.2	0.2	6.82	5	0.5
	22	6.2	0.3	4.16	5	0.5	4.7	3.3	70.83	5	12.8	8.0	0.5	6.00	5	1.3	3.0	0.2	7.55	5	0.6
Stats for averages		5.9	0.6	9.27	9	1.9	11.1	2.6	23.68	9	8.6	7.4	1.2	15.52	9	4.1	2.9	0.3	8.95	9	0.8
Stats for independent		6.0	0.7	12.06	41	3.5	12.2	1.5	12.11	41	6.3	7.9	0.9	11.61	41	4.0	2.9	0.3	10.17	41	1.5
Samples						7.4					15.3					9.8					3.6
						3.9					9.0					5.8					2.1
Coarse	5	4.3	0.2	5.28	5	0.6	3.3	0.2	4.95	5	0.4	2.6	0.2	6.66	5	0.4	2.0	0.1	5.00	5	0.2
	6	4.4	0.8	18.67	5	2.1	3.4	0.6	16.90	5	1.6	2.6	0.5	20.17	5	1.4	2.0	0.3	14.12	5	0.7
	7	5.5	1.3	23.26	6	3.9	5.6	4.4	78.68	6	11.6	4.2	3.0	70.95	6	7.6	2.3	0.4	15.30	6	1.1
	8	4.5	0.4	8.84	5	1.1	3.5	0.3	8.14	5	0.7	2.7	0.2	9.07	5	0.6	2.1	0.2	8.25	5	0.4
	23	3.7	0.6	16.01	5	1.6	3.0	0.7	23.57	5	1.0	2.3	0.3	11.35	5	0.5	1.9	0.2	10.23	5	0.5
	24	3.9	0.5	12.03	5	1.2	3.1	0.4	13.59	5	1.1	2.4	0.2	8.96	5	0.5	1.9	0.1	7.44	5	0.4
	25	4.7	1.1	22.36	5	2.8	3.5	0.7	20.96	5	1.8	2.8	0.5	18.23	5	1.3	2.1	0.3	14.58	5	0.7
	26	5.1	0.4	8.77	5	1.1	3.9	0.2	6.28	5	0.6	2.9	0.3	11.95	5	0.8	2.1	0.2	9.69	5	0.5
Stats for averages		4.5	0.6	12.97	8	1.8	3.7	0.8	22.26	8	2.6	2.8	0.6	20.82	8	1.9	2.1	0.1	6.78	8	0.4
Stats for independent		4.5	0.9	19.73	41	4.7	3.7	1.8	48.31	41	11.9	2.8	1.2	43.52	41	8.4	2.1	0.3	12.44	41	1.3
Samples						7.7					14.4					10.2					2.9
						3.0					2.5					1.8					1.6

Table 6. Accumulated percent passing from loose HMA data for top lift.

		3/4" Sieve					1/2" Sieve					3/8" Sieve					#4 Sieve					#8 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	99.8	0.4	0.40	5	0.9	85.4	4.6	5.45	5	11.3	74.5	5.8	7.83	5	14.3	48.3	5.9	12.31	5	14.3	37.9	4.5	11.76	5	10.3
	2	100.0	0.0	0.00	6	0.0	88.6	2.2	2.53	6	5.8	76.9	3.0	3.94	6	8.4	50.3	3.9	7.68	6	9.6	39.2	3.0	7.69	6	7.3
	3	100.0	0.0	0.00	5	0.0	85.7	1.7	2.00	5	3.8	74.5	2.7	3.57	5	6.5	48.9	2.8	5.75	5	7.5	38.7	2.4	6.33	5	6.4
	4	100.0	0.0	0.00	4	0.0	85.7	1.8	2.10	4	4.4	74.7	2.0	2.65	4	3.8	49.3	2.4	4.95	4	5.7	38.8	2.3	5.85	4	5.2
	14	100.0	0.0	0.00	5	0.0	88.4	2.1	2.34	5	5.5	78.1	1.8	2.37	5	4.3	52.0	1.5	2.80	5	3.5	40.9	1.2	2.95	5	3.0
	15	100.0	0.8	0.76	5	1.7	86.9	4.5	5.12	5	11.6	75.6	6.4	8.51	5	15.8	49.5	5.2	10.59	5	13.0	38.9	3.9	10.01	5	9.5
	16	99.8	0.4	0.45	5	1.0	85.6	3.0	3.55	5	7.5	73.4	4.6	6.33	5	11.8	47.9	6.3	13.12	5	16.7	37.8	5.2	13.76	5	14.1
	17	100.0	0.0	0.00	5	0.0	85.8	4.3	4.99	5	11.5	74.1	4.4	6.00	5	11.7	49.3	3.5	7.05	5	8.9	38.9	2.7	7.05	5	7.1
	18	100.0	0.0	0.00	5	0.0	86.8	2.2	2.55	5	6.0	75.6	1.6	2.12	5	3.7	50.1	0.6	1.13	5	1.3	39.3	0.2	0.58	5	0.6
Stats for averages		100.0	0.1	0.08	9	0.2	86.5	1.2	1.43	9	3.2	75.3	1.5	1.93	9	4.7	49.5	1.2	2.40	9	4.1	38.9	0.9	2.31	9	3.1
Stats of independent		99.9	0.3	0.32	45	1.7	86.6	3.1	3.58	45	13.1	75.5	3.7	4.94	45	16.3	49.5	3.8	7.75	45	17.0	38.9	3.0	7.76	45	14.1
Samples					Max	100					91.7					81.1					55.3					44.3
					Min	98.3					78.6					64.8					38.3					30.2
Fine+	9	100.0	0.0	0.00	5	0.0	88.3	2.3	2.58	5	7.3	79.5	4.2	5.28	5	10.9	55.4	2.9	5.30	5	7.0	43.6	1.7	3.95	5	4.2
	10	99.9	0.3	0.31	5	0.7	84.6	1.3	1.54	5	3.2	73.7	1.3	1.79	5	3.7	48.6	0.9	1.80	5	2.3	38.2	1.1	3.00	5	2.9
	11	100.0	0.0	0.00	5	0.0	85.3	2.3	2.71	5	5.3	75.0	1.9	2.49	5	4.8	50.2	1.8	3.53	5	4.8	39.0	1.2	3.20	5	3.2
	12	100.0	0.0	0.00	5	0.0	87.8	2.4	2.77	5	5.9	75.9	2.9	3.85	5	7.6	49.8	2.1	4.31	5	5.4	38.8	1.5	3.92	5	3.6
	13	100.0	0.0	0.00	5	0.0	86.4	2.1	2.41	5	5.1	75.1	2.1	2.80	5	5.5	49.7	1.4	2.89	5	3.7	39.1	1.1	2.86	5	3.0
	19	100.0	0.0	0.00	5	0.0	85.8	1.9	2.19	5	4.6	75.9	1.6	2.15	5	4.3	52.1	2.4	4.53	5	6.4	41.2	2.0	4.84	5	5.4
	20	99.8	0.5	0.54	5	1.2	84.8	4.3	5.04	5	11.0	74.2	5.8	7.77	5	13.3	50.8	5.8	11.34	5	13.6	39.8	4.7	11.93	5	11.3
	21	100.0	0.0	0.00	5	0.0	87.0	2.7	3.15	5	6.9	77.7	3.0	3.81	5	7.3	52.9	2.6	4.85	5	5.5	41.4	2.1	5.06	5	4.5
	22	100.0	0.0	0.00	5	0.0	85.5	2.4	2.75	5	5.8	74.8	2.6	3.42	5	6.5	51.1	3.1	6.11	5	8.2	40.3	2.5	6.11	5	5.7
Stats for averages		100.0	0.2	0.20	9	0.2	86.2	0.8	0.94	9	3.7	75.8	1.4	1.85	9	5.8	51.2	1.4	2.74	9	6.9	40.1	1.1	2.80	9	5.5
Stats for independent		100.0	0.2	0.21	45	1.2	81.9	2.7	3.27	45	15.6	75.8	3.3	4.37	45	21.0	51.2	3.3	6.37	45	18.7	40.1	2.6	6.52	45	14.6
Samples					Max	100					93.3					85.8					59.5					46.1
					Min	98.8					77.7					64.8					40.8					31.5
Coarse	5	100.0	0.0	0.00	5	0.0	80.8	4.4	5.48	5	11.8	68.8	5.3	7.75	5	13.5	44.7	4.1	9.09	5	10.6	29.9	2.3	7.55	5	5.8
	6	100.0	0.0	0.00	5	0.0	78.4	4.3	5.53	5	10.1	64.4	4.9	7.58	5	12.0	40.9	3.4	8.31	5	8.0	27.7	2.0	7.27	5	4.9
	7	100.0	0.0	0.00	5	0.0	78.1	3.4	4.36	5	8.7	65.3	4.2	6.39	5	10.1	41.7	3.4	8.12	5	8.3	28.5	1.9	6.83	5	4.5
	8	99.9	0.2	0.22	5	0.5	77.7	4.7	6.05	5	12.3	65.4	5.6	8.53	5	14.1	42.9	4.6	10.78	5	11.0	29.4	2.7	9.27	5	6.5
	23	100.0	0.0	0.00	5	0.0	78.6	6.1	7.79	5	17.0	66.4	6.8	10.30	5	18.1	43.3	4.3	9.82	5	10.6	29.4	2.5	8.39	5	6.0
	24	100.0	0.0	0.00	5	0.0	74.7	7.4	9.96	5	19.0	63.2	7.9	12.58	5	20.3	41.5	5.3	12.78	5	14.1	28.3	2.8	9.78	5	7.5
	25	100.0	0.0	0.00	5	0.0	75.0	6.1	8.18	5	16.1	62.6	7.2	11.48	5	18.4	40.3	5.1	12.73	5	12.9	27.9	2.9	10.39	5	6.9
	26	100.0	0.0	0.00	5	0.0	81.2	3.9	4.79	5	10.4	69.5	4.8	6.92	5	13.4	46.6	3.7	7.86	5	9.6	31.5	2.2	7.07	5	5.8
Stats for averages		100.0	0.0	0.04	8	0.1	78.1	2.3	3.00	8	6.5	65.7	2.5	3.76	8	6.9	42.7	2.1	4.96	8	6.3	29.1	1.2	4.29	8	3.8
Stats for independent		100.0	0.1	0.08	40	0.5	78.1	5.2	6.69	40	24.7	65.7	5.9	8.98	40	25.9	42.7	4.4	10.22	40	18.2	29.1	2.5	8.61	40	10.9
Samples					Max	100.0					87.0					76.7					51.8					35.0
					Min	99.5					62.3					50.8					33.6					24.1

Table 6. Accumulated percent passing from loose HMA data for- top lift (continued).

		#16 Sieve					#30 Sieve					#50 Sieve					#100 Sieve					#200 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	33.5	3.7	11.00	5	8.6	27.4	2.6	9.42	5	6.0	15.2	0.9	6.15	5	1.9	7.7	0.2	2.97	5	0.6	4.7	0.1	2.32	5	0.2
	2	34.6	2.5	7.32	6	6.1	28.2	1.8	6.39	6	4.2	15.3	1.0	6.28	6	2.3	7.4	0.6	7.40	6	1.4	4.4	0.5	10.35	6	1.2
	3	34.3	2.2	6.42	5	5.8	28.0	1.7	6.12	5	4.3	15.1	1.1	7.51	5	2.7	7.4	0.8	10.90	5	2.1	4.4	0.7	15.87	5	1.8
	4	34.3	2.0	5.91	4	4.6	27.9	1.4	5.17	4	3.3	15.4	0.5	3.35	4	1.2	7.0	0.1	1.79	4	0.3	4.0	0.1	1.26	4	0.1
	14	36.0	0.9	2.60	5	2.3	29.1	0.8	2.83	5	2.1	15.7	0.7	4.28	5	1.8	7.5	0.3	4.14	5	0.8	4.4	0.3	5.65	5	0.5
	15	34.4	3.2	9.17	5	7.6	28.1	2.5	8.85	5	6.0	16.2	1.2	7.59	5	3.1	7.9	0.6	7.54	5	1.5	4.8	0.4	7.37	5	0.9
	16	33.4	4.5	13.40	5	12.1	27.3	3.4	###	5	9.2	15.0	1.5	9.79	5	4.1	7.1	0.3	4.81	5	0.8	4.2	0.2	4.60	5	0.5
	17	34.6	2.4	6.88	5	6.2	28.3	1.8	6.53	5	4.8	15.4	1.0	6.18	5	2.4	7.6	0.5	6.10	5	1.2	4.5	0.2	5.21	5	0.6
	18	34.9	0.3	0.75	5	0.7	28.5	0.2	0.59	5	0.4	15.9	0.6	3.75	5	1.3	7.8	0.3	4.14	5	0.9	4.6	0.4	7.78	5	1.0
Stats for averages		34.4	0.8	2.20	9	2.6	28.1	0.5	1.96	9	1.8	15.5	0.4	2.56	9	1.2	7.5	0.3	3.79	9	0.9	4.4	0.3	5.73	9	0.8
Stats of independent		34.4				12.1	28.1				9.2	15.5	1.0	6.30	45	4.5	7.5	0.5	6.64	45	2.2	4.5	0.4	8.99	45	1.9
Samples					Max	39.1					31.6					17.2					8.4					5.2
					Min	27					22.4					12.7					6.2					3.3
Fine+	9	38.7	1.4	3.67	5	3.4	31.7	1.0	3.17	5	2.4	18.4	0.4	2.41	5	1.0	10.1	0.3	3.16	5	0.9	6.5	0.2	2.95	5	0.5
	10	33.8	1.0	2.93	5	2.7	28.1	0.9	3.11	5	2.2	16.5	0.6	3.69	5	1.6	9.1	0.5	5.28	5	1.2	5.6	0.3	4.77	5	0.6
	11	34.6	1.2	3.49	5	2.7	28.7	1.2	4.13	5	2.8	16.7	0.9	5.68	5	2.3	9.1	0.7	7.56	5	1.7	5.8	0.5	8.45	5	1.2
	12	34.5	1.2	3.42	5	2.8	28.5	0.9	3.04	5	2.1	16.4	0.4	2.49	5	1.1	8.9	0.2	2.18	5	0.5	5.6	0.2	3.22	5	0.4
	13	34.6	1.0	2.79	5	2.6	28.6	0.8	2.74	5	2.1	16.8	0.5	2.99	5	1.3	9.2	0.4	4.75	5	1.2	5.9	0.4	7.10	5	1.1
	19	36.7	1.7	4.66	5	4.7	30.6	1.3	4.21	5	3.6	17.9	0.7	3.92	5	1.7	10.0	0.6	5.52	5	1.2	6.3	0.4	6.21	5	0.9
	20	35.4	4.1	11.69	5	10.0	29.6	3.3	###	5	7.9	17.5	1.7	9.81	5	4.3	9.8	0.9	9.39	5	2.3	6.2	0.6	9.74	5	1.5
	21	36.7	1.6	4.46	5	3.6	30.2	1.3	4.20	5	2.8	17.4	0.7	4.19	5	1.5	9.5	0.5	5.05	5	1.0	6.0	0.3	5.56	5	0.8
	22	35.7	2.1	5.86	5	4.8	29.5	1.5	5.17	5	3.5	17.1	0.8	4.50	5	1.8	9.3	0.4	3.86	5	0.8	5.9	0.3	4.32	5	0.7
Stats for averages		35.6	1.0	2.76	9	4.9	29.5	0.8	2.58	9	3.7	17.2	0.4	2.32	9	2.0	9.5	0.2	2.27	9	1.2	6.0	0.1	2.36	9	0.9
Stats for independent		35.6	2.3	6.38	45	12.4	29.5	1.8	6.02	45	9.2	17.2	1.0	5.80	45	4.3	9.5	0.6	6.67	45	2.3	6.0	0.4	7.40	45	1.6
Samples					Max	40.6					33.1					18.9					10.6					6.8
					Min	28.2					23.9					14.6					8.3					5.2
Coarse	5	21.0	1.3	6.25	5	3.4	15.7	0.9	5.49	5	2.2	11.8	0.7	5.87	5	1.6	8.5	0.6	6.65	5	1.3	6.1	0.5	7.52	5	1.2
	6	19.9	1.2	5.82	5	2.8	15.0	0.8	5.38	5	1.9	11.1	0.6	5.37	5	1.3	7.9	0.5	6.52	5	1.2	5.6	0.4	7.99	5	1.1
	7	20.5	1.2	5.83	5	2.9	15.5	0.9	5.84	5	2.2	11.5	0.7	6.42	5	1.7	8.3	0.6	7.32	5	1.4	6.0	0.5	8.31	5	1.2
	8	20.8	1.7	8.24	5	4.1	15.6	1.3	8.22	5	2.9	11.7	1.0	8.64	5	2.3	8.6	0.9	10.69	5	2.2	6.2	0.8	12.13	5	1.8
	23	20.8	1.5	7.42	5	3.7	15.7	1.0	6.61	5	2.5	11.5	0.9	7.91	5	1.8	8.3	0.8	9.89	5	1.8	6.1	0.4	6.77	5	0.9
	24	20.0	1.7	8.24	5	4.4	15.0	1.2	7.95	5	3.1	11.2	0.9	7.69	5	2.2	8.2	0.6	7.80	5	1.6	6.0	0.4	7.08	5	1.0
	25	20.0	1.8	9.04	5	4.2	15.0	1.4	9.06	5	3.1	11.2	1.0	8.55	5	2.1	8.2	0.7	8.62	5	1.5	6.0	0.5	8.73	5	1.1
	26	21.7	1.2	5.47	5	3.0	16.0	0.8	4.92	5	2.1	11.8	0.6	4.98	5	1.6	8.6	0.4	5.07	5	1.2	6.2	0.3	5.46	5	0.9
Stats for averages		20.6	0.6	2.90	8	1.8	15.4	0.4	2.46	8	1.0	11.5	0.3	2.42	8	0.7	8.3	0.2	2.78	8	.07	6.0	0.2	3.30	8	0.6
Stats for independent		20.6	1.4	7.01	40	6.2	15.4	1.0	6.59	40	4.2	11.5	0.8	6.78	40	2.9	8.3	0.6	7.73	40	2.4	6.0	0.5	8.09	40	2.0
Samples					Max	23.7					17.3					12.8					9.5					7.0
					Min	17.5					13.1					9.9					7.1					5.0

Table 7. Accumulated percent passing from loose HMA data for bottom lift.

		3/4" Sieve					1/2" Sieve					3/8" Sieve					#4 Sieve					#8 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	100.0	0.0	0.0	5	0.0	90.0	2.3	2.57	5	5.7	79.5	2.5	3.16	5	6.5	50.4	1.4	2.71	5	3.5	38.2	1.2	3.09	5	2.8
	2	100.0	0.0	0.0	5	0.0	89.9	2.5	2.77	5	6.0	79.0	4.2	5.26	5	11.5	50.2	4.1	8.09	5	10.8	38.3	3.2	8.31	5	8.5
	3	99.9	0.2	0.2	5	0.5	88.7	2.1	2.33	5	5.6	77.7	3.4	4.37	5	8.4	50.3	3.6	7.20	5	8.9	38.4	2.9	7.45	5	7.5
	4	100.0	0.0	0.0	5	0.0	88.9	1.1	1.20	5	2.3	78.5	1.1	1.34	5	2.8	51.7	1.0	2.03	5	2.4	39.6	1.2	3.02	5	3.2
	14	99.8	0.4	0.4	5	0.8	90.5	2.9	3.18	5	7.9	80.3	3.6	4.52	5	9.9	52.5	2.1	4.04	5	5.2	40.6	1.4	3.43	5	3.5
	15	100.0	0.0	0.0	5	0.0	88.8	2.5	2.79	5	5.2	77.0	3.6	4.66	5	8.8	48.9	3.7	7.47	5	9.6	37.4	2.5	6.69	5	6.9
	16	100.0	0.0	0.0	4	0.0	91.1	1.1	1.17	4	2.6	80.1	1.1	1.42	4	2.5	51.6	1.5	2.98	4	3.4	39.8	1.1	2.81	4	2.4
	17	100.0	0.0	0.0	6	0.0	88.9	1.6	1.78	6	4.0	77.8	2.1	2.71	6	6.4	50.4	2.2	4.29	6	6.6	38.8	1.8	4.57	6	5.3
	18	100.0	0.0	0.0	5	0.0	86.5	5.6	6.43	5	11.5	77.5	4.9	6.28	5	11.6	49.7	3.6	7.33	5	8.9	38.4	3.4	8.77	5	9.2
Stats for averages		100.0	0.1	0.1	9	0.2	89.3	1.4	1.51	9	4.7	78.6	1.2	1.50	9	3.3	50.6	1.1	2.18	9	3.6	38.9	1.0	2.55	9	3.2
Stats of independent		100.0	0.1	0.1	45	0.8	89.2	2.8	3.09	45	14.6	78.5	3.1	3.95	45	16.0	50.6	2.8	5.44	45	12.3	38.8	2.2	5.76	45	10.3
Samples					Max	100.0					93.9					85.0					55.6					43.2
					Min	99.2					79.3					69.0					43.3					32.9
Fine+	9	100.0	0.0	0.0	5	0.0	90.4	0.9	1.03	5	2.6	81.3	1.1	1.40	5	3.2	56.1	2.3	4.15	5	6.3	43.6	1.7	3.82	5	4.4
	10	100.0	0.0	0.0	6	0.0	88.4	1.4	1.62	6	2.7	78.3	2.0	2.56	6	4.9	52.8	2.2	4.17	6	6.3	41.5	2.0	4.73	6	5.1
	11	100.0	0.0	0.0	5	0.0	90.9	1.2	1.29	5	2.8	81.0	1.4	1.70	5	3.5	56.9	2.7	4.81	5	7.4	44.7	2.2	4.93	5	5.5
	12	100.0	0.0	0.0	5	0.0	89.8	1.3	1.43	5	3.4	80.0	1.7	2.08	5	4.2	54.5	1.8	3.31	5	4.9	42.5	1.3	3.17	5	3.5
	13	100.0	0.0	0.0	5	0.0	86.8	1.8	2.07	5	4.4	75.6	3.9	5.13	5	10.0	51.8	6.6	12.82	5	18.3	39.0	2.8	7.12	5	7.2
	19	100.0	0.0	0.0	5	0.0	91.8	1.6	1.73	5	3.9	82.4	2.5	3.00	5	6.5	55.4	1.8	3.19	5	3.7	42.9	1.3	3.14	5	3.2
	20	100.0	0.0	0.0	5	0.0	89.6	2.2	2.51	5	5.8	79.6	3.2	3.96	5	8.7	53.5	2.8	5.21	5	7.8	42.4	2.2	5.30	5	6.3
	21	100.0	0.0	0.0	5	0.0	89.8	1.7	1.91	5	3.9	82.6	2.9	3.56	5	7.8	54.0	3.2	5.94	5	7.8	42.3	2.7	6.44	5	6.9
	22	100.0	0.0	0.0	5	0.0	91.1	1.6	1.79	5	4.4	82.4	2.6	3.17	5	7.0	56.1	2.5	4.47	5	6.2	44.9	2.0	4.51	5	5.1
Stats for averages		100.0	0.0	0.0	9	0.0	89.8	1.5	1.68	9	5.0	80.4	2.3	2.85	9	6.9	54.5	1.7	3.11	9	5.1	42.6	1.8	4.21	9	6.0
Stats for independent		100.0	0.0	0.0	46	0.0	89.8	2.0	2.25	46	8.9	80.3	3.1	3.91	46	16.8	54.5	3.3	6.10	46	18.3	42.6	2.5	5.97	46	12.8
Samples					Max	100.0					93.8					86.8					62.0					47.2
					Min	100.0					84.9					70.0					43.7					34.4
Coarse	5	100.0	0.0	0.0	5	82.6	82.6	3.3	4.04	5	7.8	68.9	6.2	8.93	5	13.4	43.7	5.5	12.60	5	10.5	28.9	3.0	10.33	5	6.0
	6	100.0	0.0	0.0	5	80.6	80.6	3.0	3.67	5	8.2	67.1	4.1	6.16	5	10.8	42.5	4.1	9.72	5	11.5	42.5	2.7	6.43	5	7.6
	7	100.0	0.0	0.0	5	78.5	78.5	6.3	8.01	5	16.3	64.2	7.6	11.88	5	19.6	39.7	6.0	14.98	5	15.5	26.2	3.5	13.30	5	9.3
	8	100.0	0.0	0.0	5	82.7	82.7	2.1	2.53	5	5.2	69.4	3.3	4.74	5	8.3	44.4	2.9	6.62	5	7.1	28.6	1.7	5.93	5	3.9
	23	100.0	0.0	0.0	5	81.2	81.2	1.8	2.16	5	3.8	66.3	2.9	4.37	5	5.4	39.7	5.8	14.49	5	14.5	27.4	1.1	4.19	5	2.7
	24	100.0	0.0	0.0	5	80.1	80.1	3.9	4.88	5	10.9	65.8	4.2	6.45	5	11.1	40.5	3.8	9.27	5	9.6	26.5	2.4	9.14	5	6.0
	25	100.0	0.0	0.0	5	81.6	81.6	4.8	5.82	5	11.3	67.3	6.6	9.85	5	15.1	43.1	4.7	10.85	5	10.2	28.2	2.5	8.76	5	5.5
	26	100.0	0.0	0.0	5	77.6	77.6	6.3	8.18	5	16.8	62.4	7.0	11.19	5	18.2	40.1	6.6	16.40	5	16.4	26.8	3.8	14.18	5	9.8
Stats for averages		100.0	0.0	0.0	8	0.0	80.6	1.8	2.27	8	5.2	66.4	2.3	3.52	8	7.0	41.7	1.9	4.59	8	4.7	29.4	5.4	18.35	8	16.3
Stats for independent		100.0	0.0	0.0	40	0.0	80.6	4.2	5.25	40	19.7	66.4	5.5	8.22	40	25.9	41.7	4.9	11.79	40	20.5	27.6	2.6	9.57	40	12.2
Samples					Max	100					87.4					76.8					50.0					32.6
					Min	100					67.7					50.9					29.5					20.4

Table 7. Accumulated percent passing from loose HMA data for bottom lift (continued).

		#16 Sieve					#30 Sieve					#50 Sieve					#100 Sieve					#200 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	33.6	1.0	3.00	5	2.4	27.1	1.0	3.61	5	2.5	15.9	0.6	3.74	5	1.6	7.6	0.5	6.18	5	1.3	4.5	0.4	8.90	5	1.1
	2	33.6	2.6	7.85	5	7.1	27.4	2.0	7.42	5	5.4	16.0	1.0	6.52	5	2.7	7.6	0.5	6.58	5	1.2	4.5	0.3	5.94	5	0.7
	3	33.7	2.3	6.73	5	6.5	27.5	1.7	6.11	5	4.4	16.0	0.9	5.61	5	2.4	7.6	0.4	5.23	5	1.1	4.3	0.2	5.05	5	0.6
	4	34.7	1.0	3.02	5	2.9	28.4	0.8	2.87	5	2.3	16.4	0.5	3.15	5	1.3	7.9	0.5	6.14	5	1.3	4.6	0.4	8.70	5	1.1
	14	35.5	1.8	5.22	5	4.0	29.2	1.0	3.55	5	2.6	16.4	1.2	7.05	5	2.2	7.9	0.6	7.98	5	1.6	4.5	0.4	8.89	5	1.1
	15	33.1	2.1	6.21	5	5.7	26.9	1.6	5.93	5	4.2	15.6	0.9	5.62	5	2.2	7.2	0.4	6.13	5	1.2	4.0	0.3	7.13	5	0.8
	16	35.1	1.1	3.10	4	2.4	28.4	0.9	3.11	4	1.9	16.3	0.9	5.73	4	2.0	7.7	0.5	6.96	4	1.3	4.3	0.4	9.70	4	1.0
	17	34.1	1.4	4.07	6	4.1	27.5	0.9	3.32	6	2.7	16.0	0.3	1.87	6	0.8	7.6	0.1	1.54	6	0.3	4.3	0.1	2.71	6	0.3
	18	33.2	2.2	6.76	5	5.2	26.9	1.7	6.28	5	4.2	15.6	0.7	4.67	5	1.8	7.2	0.3	4.34	5	0.7	4.2	0.2	4.45	5	0.5
Stats for averages		34.1	0.8	2.48	9	2.4	27.7	0.8	2.86	9	2.3	16.0	0.3	1.95	9	0.9	7.6	0.2	3.29	9	0.7	4.4	0.2	4.34	9	0.6
Stats of independent		34.0	1.8	5.42	45	8.7	27.7	1.4	5.21	45	6.3	16.0	0.8	4.94	45	3.1	7.6	0.5	6.17	45	1.9	4.4	0.3	7.70	45	1.4
Samples						37.9					30.2					17.4					8.5					5.1
						29.2					23.9					14.3					6.6					3.7
Fine+	9	38.6	1.5	3.91	5	3.9	32.2	1.1	3.53	5	3.0	19.0	0.6	3.20	5	1.6	10.5	0.6	5.52	5	1.6	6.5	0.4	5.98	5	1.0
	10	36.7	1.7	4.54	6	4.5	30.9	2.1	6.64	6	5.7	17.9	1.1	5.88	6	2.5	10.0	1.0	10.01	6	2.9	6.3	0.8	13.41	6	2.5
	11	39.8	2.0	4.97	5	4.9	32.9	1.7	5.04	5	4.2	19.2	1.2	6.31	5	2.9	10.6	0.9	8.22	5	2.3	6.7	0.6	9.17	5	1.6
	12	37.5	1.1	3.00	5	2.8	31.0	0.9	3.01	5	2.2	17.8	0.8	4.52	5	1.9	10.0	0.6	6.04	5	1.3	6.3	0.6	9.85	5	1.4
	13	34.6	2.4	7.04	5	6.3	28.5	1.8	6.34	5	4.8	16.4	1.1	6.43	5	2.8	9.2	0.8	9.25	5	2.0	5.8	0.6	9.89	5	1.3
	19	37.7	1.1	3.03	5	2.9	30.9	0.8	2.73	5	2.1	17.9	0.6	3.29	5	1.6	10.0	0.5	5.15	5	1.4	6.3	0.4	6.47	5	1.1
	20	37.6	1.9	5.00	5	5.3	31.2	1.5	4.94	5	4.3	18.3	1.1	5.93	5	2.7	10.2	0.9	8.91	5	2.1	6.5	0.8	11.67	5	1.8
	21	39.3	4.4	11.13	5	11.6	30.7	1.8	5.89	5	4.8	17.8	1.1	6.08	5	3.0	9.9	0.6	6.44	5	1.7	6.2	0.5	7.45	5	1.1
	22	40.0	1.9	4.66	5	4.7	33.0	1.6	4.71	5	4.1	19.2	0.8	4.43	5	2.4	10.7	0.7	6.37	5	11.6	6.9	0.4	6.48	5	1.1
Stats for averages		38.0	1.7	4.43	9	5.4	31.3	1.4	4.34	9	4.5	18.2	0.9	4.93	9	2.9	10.1	0.5	4.69	9	1.6	6.4	0.3	4.97	9	1.1
Stats for independent		38.0	2.5	6.71	46	15.4	31.3	1.9	6.08	46	9.5	18.2	1.2	6.66	46	5.8	10.1	0.8	8.15	46	3.7	6.3	0.6	10.02	46	2.6
Samples						42.2					35.0					20.4					11.6					7.5
						30.6					25.5					14.6					7.9					4.9
Coarse	5	20.1	1.6	8.06	5	3.7	14.7	1.1	7.56	5	2.6	10.7	0.8	7.50	5	1.9	7.6	0.6	7.94	5	1.5	5.4	0.5	10.18	5	1.4
	6	19.6	1.7	8.75	5	4.8	14.5	1.1	7.36	5	3.0	10.7	0.7	6.33	5	1.9	7.6	0.5	6.59	5	1.4	5.5	0.4	7.18	5	1.0
	7	18.5	2.0	10.93	5	5.5	13.6	1.3	9.69	5	3.7	10.0	0.9	8.88	5	2.5	7.0	0.6	9.25	5	1.8	5.0	0.5	10.58	5	1.3
	8	19.7	1.0	5.05	5	2.3	14.5	0.6	4.44	5	1.5	10.6	0.4	4.14	5	1.1	7.6	0.3	4.35	5	0.9	5.5	0.3	5.28	5	0.8
	23	19.1	0.7	3.61	5	1.5	14.1	0.4	2.90	5	0.9	10.5	0.4	3.50	5	1.0	7.4	0.1	2.01	5	0.4	5.4	0.2	3.58	5	0.5
	24	18.8	1.4	7.43	5	3.4	14.0	0.9	6.56	5	2.2	10.3	0.6	6.29	5	1.5	7.4	0.5	6.49	5	1.2	5.3	0.4	8.13	5	1.1
	25	19.8	1.5	7.68	5	3.6	14.5	1.1	7.48	5	2.6	10.6	0.8	7.46	5	1.9	7.6	0.6	7.77	5	1.5	5.5	0.5	8.81	5	1.3
	26	19.4	3.1	16.11	5	8.5	13.8	1.3	9.73	5	3.7	10.1	1.0	9.68	5	2.7	7.2	0.7	9.47	5	1.9	5.2	0.5	10.26	5	1.5
Stats for averages		19.4	0.5	2.80	8	1.6	14.2	0.4	2.66	8	1.0	10.4	0.3	2.67	8	0.8	7.4	0.2	2.86	8	0.6	5.3	0.2	3.09	8	0.5
Stats for independent		19.4	1.7	8.71	40	9.2	14.2	1.0	7.05	40	4.8	10.4	0.7	6.79	40	3.3	7.4	0.5	6.97	40	2.4	5.3	0.4	8.05	40	1.9
Samples						24.4					16.4					12					8.6					6.3
						15.2					11.6					8.7					6.2					4.4

Table 8. Percent retained in various size ranges from loose HMA data for top lifts.

		3/4 x 1/2					1/2 x 3/8					3/8 x #4					#4 x #8				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	14.5	4.8	32.98	5	11.3	10.8	1.3	11.59	5	3.0	26.2	0.3	1.18	5	0.7	10.4	1.5	14.73	5	4.0
	2	11.4	2.2	19.63	6	5.8	11.7	1.7	14.19	6	4.5	26.6	1.3	4.81	6	3.5	11.1	0.9	8.21	6	2.3
	3	14.3	1.7	12.04	5	3.8	11.3	1.2	11.01	5	3.1	25.6	1.4	5.29	5	3.5	10.2	0.5	4.56	5	1.1
	4	14.3	1.8	12.60	4	4.4	11.1	1.3	12.13	4	3.2	25.3	1.4	5.34	4	3.5	10.6	0.2	2.26	4	0.5
	14	11.6	2.1	17.93	5	5.5	10.4	1.1	10.52	5	3.0	26.1	0.6	2.38	5	1.7	11.1	0.4	3.58	5	0.9
	15	12.7	4.8	37.58	5	11.6	11.3	2.3	20.42	5	5.8	26.2	1.2	4.77	5	3.2	10.6	1.4	12.97	5	3.5
	16	14.2	2.6	18.57	5	6.5	12.2	1.9	15.72	5	4.4	25.5	1.8	6.94	5	4.9	10.1	1.2	12.17	5	3.1
	17	14.2	4.3	30.03	5	11.5	11.6	1.1	9.78	5	3.0	24.9	1.0	4.06	5	2.8	10.4	0.8	7.42	5	1.8
	18	13.2	2.2	16.75	5	6.0	11.2	1.5	13.60	5	3.5	25.5	1.7	6.57	5	4.5	10.8	0.6	5.35	5	1.2
Stats for averages		13.4	1.3	9.59	9	3.1	11.3	0.4	3.58	9	1.8	25.8	0.5	1.83	9	1.8	10.6	0.5	4.36	9	0.9
Stats of independent		13.3	3.1	23.46	45	13.1	11.3	1.5	13.23	45	6.7	25.8	1.3	4.90	45	5.5	10.6	0.9	8.68	45	4.1
Samples					Max	21.4					15.3					28.7					12.2
					Min	8.3					8.6					23.2					8.1
Fine+	9	11.7	3.1	26.79	5	7.3	8.7	1.5	17.23	5	3.7	24.1	1.4	5.90	5	3.9	11.8	1.2	10.33	5	2.8
	10	15.3	1.3	8.53	5	3.2	10.9	1.1	10.18	5	2.8	25.2	1.8	7.33	5	4.9	10.4	0.3	3.22	5	0.8
	11	14.7	2.3	15.70	5	5.3	10.2	1.1	10.53	5	2.9	24.8	0.5	2.14	5	1.5	11.2	1.1	9.64	5	2.8
	12	12.2	2.4	19.92	5	5.9	11.9	0.9	7.97	5	2.3	26.1	1.1	4.18	5	2.9	10.9	0.7	6.01	5	1.8
	13	13.6	2.1	15.29	5	5.1	11.3	0.7	6.56	5	1.9	25.4	2.5	9.64	5	5.4	10.6	0.4	3.59	5	1.0
	19	14.2	1.9	13.28	5	4.6	9.9	1.4	14.25	5	3.1	23.8	1.3	5.66	5	3.1	10.9	0.4	3.43	5	1.0
	20	14.9	4.3	28.69	5	11.0	10.7	1.8	16.92	5	4.0	23.4	1.1	4.58	5	2.6	11.0	1.0	9.32	5	2.4
	21	13.0	2.7	21.15	5	6.9	9.3	0.8	8.96	5	2.2	24.8	1.1	4.23	5	2.5	11.5	0.6	5.52	5	1.4
	22	14.5	2.4	16.24	5	5.8	10.7	0.7	6.71	5	1.8	23.7	0.7	3.04	5	1.8	10.8	1.0	9.18	5	2.5
Stats for averages		13.8	0.8	6.12	9	3.5	10.4	0.4	3.59	9	3.2	24.6	0.6	2.37	9	2.8	11.0	0.3	3.10	9	1.4
Stats for independent		13.8	2.7	19.25	45	15.6	10.4	1.4	13.65	45	5.4	24.6	1.5	6.23	45	6.8	11.0	0.8	7.62	45	4.1
Samples					Max	22.3					12.9					28.3					13.4
					Min	6.7					7.5					21.5					9.3
Coarse	5	19.2	4.4	23.08	5	11.8	12.0	1.7	14.17	5	4.5	24.1	1.4	6.01	5	3.5	14.9	1.8	12.31	5	4.7
	6	21.6	4.3	20.05	5	10.1	14.0	0.8	5.71	5	2.0	23.5	1.5	6.57	5	4.1	13.2	1.5	11.69	5	3.1
	7	21.9	3.4	15.59	5	8.7	12.9	1.0	7.71	5	2.7	23.6	0.9	3.91	5	2.5	13.2	1.5	11.61	5	4.1
	8	22.2	4.8	21.42	5	12.3	12.3	1.4	11.38	5	3.4	22.5	1.1	4.91	5	3.1	13.5	1.9	14.24	5	4.6
	23	21.4	6.1	28.64	5	17.0	12.2	1.5	12.33	5	3.6	23.1	2.7	11.74	5	7.5	13.9	1.8	13.12	5	4.6
	24	25.3	7.4	29.41	5	19.0	11.5	1.3	11.41	5	3.3	21.7	2.8	12.78	5	6.8	13.2	2.6	19.48	5	6.6
	25	25.0	6.1	24.58	5	16.1	12.4	1.4	11.09	5	3.0	22.3	2.1	9.59	5	5.5	12.4	2.3	18.27	5	6.0
	26	18.8	3.9	20.67	5	10.4	11.7	1.4	12.11	5	3.2	22.9	1.5	6.65	5	3.8	15.2	1.5	10.14	5	3.8
Stats for averages		21.9	2.3	10.68	8	6.5	12.4	0.8	6.31	8	2.5	23.0	0.8	3.43	8	2.4	13.7	0.9	6.71	8	2.7
Stats for independent		21.9	5.2	23.84	40	24.7	12.4	1.4	11.49	40	4.7	23.0	1.9	8.12	40	9.1	13.7	1.9	14.16	40	7.3
Samples					Max	37.7					14.7					26.3					16.8
					Min	13					10					17.2					9.5

Table 8. Percent retained in various size ranges from loose HMA data for top lifts (continued).

		#8 x #16					#16 x #30					#30 x #50					#50 x #100					#100 x #200				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	4.4	0.8	17.63	5	1.7	6.1	1.1	18.29	5	2.6	12.2	1.7	13.92	5	4.3	7.5	0.8	10.47	5	1.8	3.0	0.2	5.65	5	0.4
	2	4.6	0.5	10.72	6	1.2	6.4	0.8	11.80	6	1.9	12.8	1.0	8.11	6	2.8	7.9	0.6	7.46	6	1.6	3.2	0.1	3.3	6	0.3
	3	4.3	0.3	6.52	5	0.7	6.4	0.6	8.76	5	1.5	12.9	0.9	7.31	5	2.6	7.8	0.4	5.44	5	1.0	3.0	0.2	5.12	5	0.4
	4	4.5	0.3	5.52	4	0.6	6.4	0.6	9.46	4	1.3	12.5	0.8	6.65	4	2.1	8.4	0.4	5.19	4	1.0	3.1	0.1	3.28	4	0.2
	14	4.9	0.3	6.00	5	0.7	6.9	0.3	3.66	5	0.6	13.3	0.4	3.26	5	1.1	8.2	0.6	6.69	5	1.4	3.1	0.2	6.65	5	0.4
	15	4.5	0.8	16.73	5	1.9	6.3	0.7	10.71	5	1.7	11.9	1.3	10.82	5	3.3	8.3	0.7	8.25	5	1.7	3.1	0.3	9.40	5	0.7
	16	4.4	0.7	16.81	5	2.0	6.1	1.1	17.96	5	2.9	12.3	2.0	16.28	5	5.1	7.8	1.2	15.20	5	3.3	3.0	0.3	10.02	5	0.8
	17	4.3	0.4	9.02	5	0.9	6.2	0.5	8.53	5	1.4	12.9	1.0	7.39	5	2.6	7.8	0.5	6.91	5	1.4	3.1	0.2	7.57	5	0.6
	18	4.4	0.1	3.36	5	0.4	6.3	0.1	1.73	5	0.3	12.6	0.6	4.42	5	1.2	8.2	0.4	4.52	5	0.9	3.2	0.1	2.63	5	0.2
Stats for averages		4.5	0.2	5.41	9	0.6	6.3	0.3	5.27	9	0.8	12.6	0.5	4.05	9	1.4	8.0	0.3	3.14	9	0.8	3.1	0.1	2.57	9	0.2
Stats of independent		4.5	0.5	11.16	45	2.1	6.3	0.7	10.73	45	3.0	12.6	1.2	9.19	45	5.1	8.0	0.7	8.24	45	3.3	3.1	0.2	6.36	45	0.8
Samples						5.3					7.6					14.8					9.4					3.3
						3.2					4.6					9.7					6.1					2.5
Fine+	9	5.0	0.3	6.57	5	0.8	6.9	0.4	6.08	5	1.0	13.3	0.6	4.45	5	1.4	8.3	0.4	4.26	5	0.9	3.6	0.2	4.39	5	0.4
	10	4.4	0.3	6.63	5	0.7	5.7	0.2	4.30	5	0.6	11.6	0.3	2.71	5	0.8	7.4	0.1	1.91	5	0.4	3.5	0.3	9.04	5	0.8
	11	4.4	0.3	6.63	5	0.7	5.9	0.3	4.69	5	0.7	12.0	0.3	2.68	5	0.8	7.6	0.3	3.57	5	0.6	3.3	0.2	6.87	5	3.6
	12	4.3	0.3	8.06	5	0.8	6.0	0.3	5.27	5	0.8	12.1	0.5	4.01	5	1.2	7.5	0.2	3.05	5	0.6	3.3	0.1	2.14	5	0.2
	13	4.5	0.2	5.09	5	0.6	6.0	0.3	4.83	5	0.8	11.8	0.5	3.95	5	1.1	7.6	0.2	3.13	5	0.6	3.4	0.1	1.63	5	0.1
	19	4.5	0.3	7.37	5	0.7	6.1	0.5	7.69	5	2.4	12.7	0.8	6.19	5	1.9	7.9	0.2	2.75	5	0.6	3.7	0.2	5.17	5	0.5
	20	4.3	0.6	14.07	5	1.5	5.9	0.9	15.15	5	2.1	12.0	1.6	12.99	5	3.7	7.7	0.8	10.75	5	2.0	3.6	0.3	9.03	5	0.8
	21	4.7	0.5	10.31	5	1.0	6.5	0.4	5.92	5	0.9	12.8	0.6	4.38	5	1.3	8.0	0.3	3.24	5	0.6	3.4	0.2	5.28	5	0.5
	22	4.6	0.4	8.08	5	0.9	6.3	0.6	9.22	5	1.3	12.4	0.8	6.29	5	1.7	7.8	0.6	7.85	5	1.6	3.4	0.2	5.41	5	0.5
Stats for averages		4.5	0.1	2.57	9	0.7	6.1	0.2	3.29	9	1.2	12.3	0.4	3.10	9	1.8	7.8	0.2	2.89	9	0.9	3.5	0.1	2.70	9	0.4
Stats for independent		4.5	0.4	8.86	45	2.2	6.1	0.6	9.03	45	7.5	12.3	0.9	6.96	45	4.9	7.8	0.5	5.89	45	2.5	3.5	0.2	6.88	45	1.0
Samples						5.5					7.5					14.2					8.8					4.0
						3.3					4.3					9.3					6.3					3.0
Coarse	5	8.9	1.0	10.69	5	2.5	5.2	0.5	8.70	5	1.2	3.9	0.2	6.35	5	0.6	3.3	0.2	5.98	5	0.4	2.4	0.2	9.32	5	0.6
	6	7.8	0.9	11.29	5	2.2	4.9	0.4	8.12	5	1.0	3.9	0.3	6.92	5	0.6	3.2	0.2	5.41	5	0.4	2.3	0.1	3.82	5	0.2
	7	7.9	0.8	9.49	5	1.8	5.0	0.3	6.04	5	0.7	4.0	0.2	4.83	5	0.5	3.2	0.2	4.68	5	0.4	2.3	0.1	5.32	5	0.3
	8	8.6	1.0	11.86	5	2.4	5.2	0.5	9.10	5	1.2	3.9	0.3	7.38	5	0.7	3.1	0.2	6.21	5	0.5	2.4	0.2	7.09	5	0.4
	23	8.6	0.9	10.78	5	2.3	5.1	0.5	9.98	5	1.3	4.1	0.4	10.91	5	1.2	3.3	0.2	6.61	5	0.5	2.1	0.5	22.47	5	1.1
	24	8.2	1.1	13.67	5	3.1	5.1	0.5	9.33	5	1.3	3.7	0.4	9.57	5	0.9	3.1	0.2	7.52	5	0.6	2.2	0.2	10.75	5	0.6
	25	7.9	1.1	13.95	5	2.7	5.0	0.4	9.02	5	1.1	3.8	0.4	11.01	5	1.0	3.1	0.3	8.52	5	0.6	2.1	0.2	8.49	5	0.4
	26	9.8	1.1	11.13	5	2.8	5.7	0.5	8.01	5	1.2	4.1	0.2	5.01	5	0.5	3.3	0.2	5.45	5	0.4	2.4	0.1	5.10	5	0.3
Stats for averages		8.5	0.7	7.91	8	2.0	5.1	0.2	4.74	8	0.8	3.9	0.1	3.61	8	0.4	3.2	0.1	2.98	8	0.2	2.3	0.1	4.90	8	0.3
Stats for independent		8.5	1.1	12.96	40	4.9	5.1	0.5	9.01	40	2.2	3.9	0.3	8.05	40	1.5	3.2	0.2	6.32	40	0.9	2.3	0.2	10.33	40	1.4
Samples						11.3					6.4					4.7					3.6					2.7
						6.4					4.2					3.2					2.7					1.3

Table 9. Percent retained in various size ranges from loose HMA data for bottom lifts.

		3/4 x 1/2					1/2 x 3/8					3/8 x #4					#4 x #8				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	10.0	2.3	23.25	5	5.7	10.6	1.4	13.50	5	3.9	29.1	1.7	5.86	5	3.7	12.2	0.4	3.28	5	1.0
	2	10.1	2.5	24.61	5	6.0	10.9	2.6	23.54	5	6.4	28.8	1.2	4.02	5	3.0	11.9	0.9	7.60	5	2.3
	3	11.2	2.1	18.39	5	5.6	11.0	1.6	14.51	5	4.0	27.4	1.0	3.68	5	2.5	11.8	1.2	10.40	5	3.1
	4	11.1	1.1	9.60	5	2.3	10.4	1.5	14.52	5	3.3	26.8	1.8	6.65	5	4.9	12.1	0.6	4.59	5	1.5
	14	9.4	2.9	31.04	5	7.9	10.2	1.0	9.77	5	2.5	27.7	2.2	7.83	5	5.4	11.9	0.8	6.74	5	2.1
	15	11.2	2.5	22.18	5	5.2	11.9	1.8	14.77	5	4.6	28.1	1.0	3.57	5	2.5	11.5	1.3	10.94	5	2.7
	16	8.9	1.1	12.04	4	2.6	11.1	0.7	6.46	4	1.6	28.5	0.5	1.92	4	1.3	11.8	0.7	5.82	4	1.6
	17	11.1	1.6	14.22	6	4.0	11.1	1.8	16.39	6	4.7	27.4	0.4	1.39	6	1.1	11.6	0.6	5.16	6	1.3
	18	13.5	5.6	41.94	5	11.5	8.9	4.4	49.79	5	11.4	27.8	1.4	5.18	5	3.7	11.3	1.3	11.69	5	3.2
Stats for averages		10.7	1.4	12.75	9	4.7	10.7	0.8	7.60	9	2.9	28.0	0.7	2.59	9	2.2	11.8	0.3	2.40	9	0.9
Stats of independent		10.8	2.8	25.70	45	14.6	10.7	2.1	19.65	45	13.7	27.9	1.4	5.05	45	7.0	11.8	0.9	7.41	45	3.6
Samples					Max	20.70					14.90					31.30					13.20
					Min	6.10					1.20					24.30					9.60
Fine+	9	9.6	0.9	9.65	5	2.6	9.0	0.9	10.25	5	2.5	25.3	1.7	6.83	5	4.6	12.5	0.8	6.47	5	1.9
	10	11.6	1.3	11.53	6	2.7	10.2	1.5	14.54	6	3.9	25.4	0.8	3.10	6	2.0	11.4	0.8	7.23	6	2.1
	11	9.1	1.2	12.80	5	2.8	9.8	1.8	18.02	5	3.9	24.2	1.9	8.04	5	5.3	12.1	0.7	6.15	5	1.9
	12	10.2	1.3	12.52	5	3.4	9.8	0.6	5.87	5	1.6	25.5	0.9	3.65	5	2.2	12.0	0.6	4.68	5	1.4
	13	13.2	1.8	13.63	5	4.4	11.2	2.3	20.46	5	5.6	23.8	3.4	14.26	5	8.3	12.8	4.9	38.01	5	12.1
	19	8.2	1.6	19.38	5	3.9	9.4	1.3	13.90	5	3.3	27.0	1.4	5.35	5	3.4	12.5	0.7	5.52	5	1.9
	20	10.4	2.2	21.53	5	5.8	9.9	1.6	15.91	5	3.6	26.2	0.6	2.30	5	1.7	11.1	0.6	5.14	5	1.5
	21	10.2	1.7	16.75	5	3.9	7.2	3.4	47.62	5	9.2	28.6	5.0	17.46	5	11.9	11.7	0.7	6.19	5	2.0
	22	8.9	1.6	18.32	5	4.4	8.7	1.4	16.46	5	3.8	26.3	2.0	7.73	5	51	11.2	0.6	5.19	5	1.5
Stats for averages		10.2	1.5	14.84	9	5.0	9.5	1.1	11.65	9	4.0	25.8	1.4	5.60	9	4.8	11.9	0.6	5.21	9	1.7
Stats for independent		10.2	2.0	19.77	46	8.9	9.5	1.9	20.52	46	13.4	25.8	2.5	9.83	46	19.3	11.9	1.7	14.10	46	12.1
Samples					Max	15.1					14.9					37.3					21.4
					Min	6.2					1.5					18.0					9.3
Coarse	5	17.4	3.3	19.14	5	7.8	13.7	3.0	22.06	5	6.3	25.2	1.1	4.31	5	3.0	14.8	2.6	17.25	5	5.1
	6	19.4	3.0	15.28	5	8.2	13.5	1.4	10.17	5	3.1	24.6	1.0	4.10	5	2.6	14.7	1.5	10.23	5	3.9
	7	21.5	6.3	29.32	5	16.3	14.4	1.4	9.99	5	3.4	24.4	1.8	7.34	5	4.4	13.6	2.5	18.65	5	6.2
	8	17.3	2.1	12.14	5	5.2	13.3	1.2	9.34	5	3.1	25.0	1.1	4.40	5	2.7	15.8	1.3	8.28	5	3.2
	23	18.8	1.8	9.36	5	3.8	14.9	1.2	8.26	5	2.9	26.6	4.7	17.74	5	11.7	12.3	4.9	39.63	5	11.8
	24	19.9	3.9	19.60	5	10.9	14.3	1.2	8.63	5	3.0	25.3	0.8	2.98	5	1.6	14.0	1.4	9.95	5	3.6
	25	18.4	4.8	25.76	5	11.3	14.2	2.0	14.12	5	4.5	24.2	2.2	8.88	5	5.6	14.8	2.2	14.88	5	4.7
	26	22.4	6.3	28.30	5	16.8	15.2	1.8	11.65	5	4.5	22.3	0.8	3.60	5	1.8	13.3	2.8	21.15	5	6.6
Stats for averages		19.4	1.8	9.44	8	5.2	14.2	0.7	4.69	8	1.9	24.7	1.2	4.87	8	4.2	14.2	1.1	7.70	8	3.4
Stats for independent		19.4	4.2	21.81	40	29.7	14.2	1.7	12.09	40	6.6	24.7	2.2	8.92	40	13.2	14.2	2.6	18.35	40	14.1
Samples					Max	32.3					16.9					34.5					17.8
					Min	12.6					10.3					21.3					3.7

Table 9. Percent retained in various size ranges from loose HMA data for bottom lifts (continued).

		#8 x #16					#16 x #30					#30 x #50					#50 x #100					#100 x #200				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	4.6	0.2	3.92	5	0.4	6.5	0.3	4.81	5	0.8	11.2	0.4	3.91	5	0.9	8.2	0.2	2.20	5	0.5	3.1	0.1	2.68	5	0.2
	2	4.7	0.6	12.84	5	1.4	6.2	0.7	10.64	5	1.7	11.5	1.0	8.83	5	2.7	8.3	0.6	6.81	5	1.5	3.1	0.2	7.31	5	0.5
	3	4.9	0.4	8.31	5	1.0	6.2	0.9	14.09	5	2.2	11.5	0.8	6.85	5	2.0	8.4	0.5	6.05	5	1.3	3.2	0.2	6.40	5	0.5
	4	4.9	0.2	4.41	5	0.6	6.3	0.3	4.39	5	0.7	12.0	0.4	3.69	5	1.1	8.5	0.1	1.75	5	0.4	3.2	0.1	2.76	5	0.2
	14	5.2	0.2	4.61	5	0.6	6.3	0.7	10.65	5	1.8	12.7	0.4	3.26	5	1.1	8.6	0.5	5.94	5	1.3	3.3	0.2	7.50	5	0.5
	15	4.3	0.5	10.76	5	1.2	6.2	0.6	9.25	5	1.5	11.3	0.8	7.30	5	2.0	8.4	0.5	6.07	5	1.4	3.2	0.2	6.17	5	0.4
	16	4.7	0.1	1.74	4	0.2	6.7	0.6	8.35	4	1.2	12.1	0.0	0.41	4	0.1	8.6	0.5	6.09	4	1.2	3.3	0.2	4.51	4	0.3
	17	4.7	0.4	8.62	6	1.2	6.7	0.5	8.11	6	1.4	11.4	0.6	5.66	6	1.9	8.4	0.3	3.57	6	0.9	3.3	0.1	1.58	6	0.1
	18	5.2	1.6	30.81	5	4.2	6.3	0.6	9.52	5	1.5	11.3	1.0	8.81	5	2.4	8.4	0.5	5.93	5	1.2	3.2	0.3	9.22	5	0.7
Stats for averages		4.8	0.3	5.60	9	0.8	6.4	0.2	3.01	9	0.5	11.7	0.5	4.35	9	1.5	8.4	0.1	1.41	9	0.4	3.2	0.1	2.40	9	0.2
Stats of independent		4.8	0.6	12.85	45	4.2	6.4	0.6	9.75	45	4.2	11.7	0.8	6.81	45	3.8	8.4	0.4	4.93	45	1.8	3.2	0.2	6.39	45	1.1
Samples						7.90					7.90					13.40					9.20					3.60
						3.70					3.70					9.60					7.40					2.50
Fine+	9	5.0	0.2	4.18	5	0.5	6.5	0.6	9.20	5	1.4	13.2	0.7	4.94	5	1.7	8.4	0.2	2.31	5	0.5	4.0	0.3	7.83	5	0.8
	10	4.7	0.3	6.64	6	0.8	5.8	1.2	20.37	6	3.4	13.1	1.6	12.31	6	4.3	7.9	0.3	4.34	6	0.8	3.7	0.2	5.54	6	0.4
	11	4.9	0.6	12.11	5	1.6	6.9	0.3	4.91	5	0.9	13.7	0.5	3.96	5	1.3	8.6	0.6	6.42	5	1.5	3.9	0.3	8.91	5	0.8
	12	4.9	0.3	5.83	5	0.7	6.6	0.3	4.65	5	0.7	13.2	0.5	3.53	5	1.1	7.8	0.6	8.00	5	1.6	3.7	0.4	11.14	5	1.0
	13	4.3	0.4	8.25	5	0.9	6.1	0.7	11.34	5	1.8	12.2	0.8	6.57	5	2.0	7.2	0.4	6.05	5	1.0	3.4	0.3	9.21	5	0.7
	19	5.2	0.3	5.97	5	0.8	6.7	0.4	5.30	5	0.8	13.0	0.5	4.03	5	1.2	8.0	0.3	3.48	5	0.7	3.6	0.1	3.13	5	0.3
	20	4.7	0.4	8.39	5	1.0	6.4	0.4	6.82	5	1.0	12.9	0.6	4.90	5	1.6	8.0	0.3	3.36	5	0.7	3.8	0.2	4.83	5	0.5
	21	3.0	4.7	9.06	5	10.8	8.6	4.2	49.54	5	10.1	12.9	0.8	6.28	5	1.8	8.0	0.5	6.23	5	1.3	3.7	0.2	6.77	5	0.6
	22	4.9	0.2	3.91	5	0.5	7.0	0.3	5.00	5	0.7	13.9	0.8	6.11	5	1.7	8.5	0.4	4.55	5	0.8	3.8	0.2	6.25	5	0.6
Stats for averages		4.7	0.7	14.17	9	2.2	6.7	0.8	11.59	9	2.8	13.1	0.5	3.72	9	1.7	8.1	0.4	5.36	9	1.4	3.7	0.2	4.68	9	0.6
Stats for independent		4.7	1.6	33.44	46	11.0	6.7	1.6	23.31	46	12.5	13.1	0.9	6.92	46	5.0	8.1	0.6	6.91	46	2.7	3.7	0.3	8.03	46	1.5
Samples						5.7					7.3					15.9					9.4					4.5
						3.8					3.6					10.9					6.7					3.0
Coarse	5	8.8	1.5	16.57	5	3.1	5.4	0.5	9.53	5	1.1	4.0	0.3	8.49	5	0.8	3.1	0.2	7.67	5	0.5	2.2	0.1	5.87	5	0.3
	6	8.2	1.0	12.51	5	2.8	5.1	0.6	12.79	5	1.8	3.8	0.4	10.35	5	1.1	3.1	0.2	6.78	5	0.5	2.1	0.2	8.25	5	0.4
	7	7.7	1.5	19.13	5	3.8	4.8	0.7	15.08	5	1.8	3.7	0.5	12.80	5	1.2	2.9	0.3	9.19	5	0.7	2.0	0.2	11.73	5	0.6
	8	8.9	0.7	8.21	5	1.8	5.3	0.4	7.14	5	0.8	3.9	0.2	5.59	5	0.5	3.0	0.2	6.37	5	0.5	2.1	0.1	3.37	5	0.2
	23	8.3	0.5	5.82	5	1.2	5.0	0.3	5.72	5	0.7	3.6	0.6	16.34	5	1.4	3.1	0.4	14.23	5	1.1	2.0	0.1	3.54	5	0.2
	24	7.7	1.0	13.41	5	2.6	4.8	0.5	10.08	5	1.2	3.7	0.3	7.40	5	0.7	3.0	0.2	7.01	5	0.5	2.0	0.1	2.68	5	0.1
	25	8.4	1.0	12.04	5	2.3	5.3	0.5	8.57	5	1.1	3.9	0.3	7.95	5	0.8	3.0	0.2	7.18	5	0.5	2.1	0.1	6.27	5	0.3
	26	7.4	1.2	16.32	5	2.5	5.6	1.9	33.41	5	4.8	3.7	0.4	9.93	5	1.0	2.9	0.3	10.53	5	0.8	2.0	0.2	9.35	5	0.4
Stats for averages		8.2	0.5	6.66	8	1.5	5.2	0.3	5.40	8	0.8	3.8	0.1	3.58	8	0.4	3.0	0.1	2.95	8	0.3	2.1	0.1	3.65	8	0.2
Stats for independent		8.2	1.1	13.72	40	5.5	5.2	0.8	15.28	40	5.2	3.8	0.4	9.83	40	1.8	3.0	0.3	8.35	40	1.4	2.1	0.1	7.21	40	0.8
Samples						10.7					8.8					4.4					3.9					2.4
						5.2					3.6					2.6					2.5					1.6

Table 10. Accumulated percent passing from core data for top lift.

		3/4" Sieve					1/2" Sieve					3/8" Sieve					#4 Sieve					#8 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	100.0	0.0	0.00	5	0.0	87.7	1.9	2.18	5	5.0	76.0	2.2	2.93	5	5.4	49.8	1.8	3.6	5	6.0	38.8	1.4	3.66	5	3.1
	2	100.0	0.0	0.00	6	0.0	88.5	1.6	1.85	6	3.7	76.6	1.6	2.12	6	3.6	49.9	1.3	2.5	6	6.3	83.3	1.2	3.15	6	2.8
	3	100.0	0.0	0.00	5	0.0	87.8	1.1	1.30	5	2.5	77.6	1.4	1.86	5	3.6	52.0	1.5	2.9	5	4.6	40.4	1.2	3.05	5	2.8
	4	99.9	0.2	0.22	5	0.5	87.2	3.3	3.84	5	8.2	75.0	4.5	6.02	5	11.5	50.3	4.2	8.4	5	10.7	39.2	3.4	8.78	5	4.6
	14	100.0	0.0	0.00	5	0.0	88.4	1.6	1.79	5	3.9	76.7	2.2	2.93	5	5.9	51.5	2.6	5.0	5	6.6	40.0	2.0	4.91	5	4.9
	15	100.0	0.0	0.00	5	0.0	88.7	1.4	1.60	5	3.6	77.5	2.5	3.23	5	6.1	51.7	2.2	4.2	5	6.9	40.2	1.8	4.37	5	4.1
	16	100.0	0.0	0.00	5	0.0	88.5	1.1	1.19	5	2.5	76.3	1.8	2.32	5	4.3	50.8	2.2	4.2	5	5.0	39.7	1.9	4.90	5	4.5
	17	99.9	0.2	0.22	5	0.5	89.3	2.0	2.227	5	5.2	78.3	2.1	2.70	5	5.3	53.0	2.5	4.7	5	6.2	41.5	2.0	4.76	5	5.0
	18	100.0	0.0	0.00	5	0.0	87.0	1.3	1.48	5	3.5	75.5	1.8	2.39	5	4.4	51.1	1.6	3.2	5	4.3	39.8	1.2	3.10	5	2.7
Stats for averages		100.0	0.0	0.4	9	0.1	88.1	0.7	0.84	9	2.2	76.6	1.1	1.38	9	3.3	51.1	1.1	2.1	9	3.3	39.8	1.0	2.39	9	3.2
Stats of independent		100.0	0.1	0.10	46	0.5	88.2	1.8	2.04	46	8.7	76.6	2.4	3.12	46	11.7	51.1	2.3	4.5	46	10.9	47.6	1.9	4.06	46	9.3
Samples					Max	100.0					91.8					80.4					55.2					43.4
					Min	99.5					83.1					68.7					44.3					34.1
Fine+	9	100.0	0.0	0.00	5	0.0	85.1	2.2	2.62	5	4.8	72.8	3.0	4.07	5	7.3	48.6	2.6	5.3	5	6.0	37.8	2.0	5.26	5	4.6
	10	100.0	0.0	0.00	5	0.0	86.1	2.2	2.54	5	4.8	74.7	2.3	3.02	5	5.7	50.4	2.4	4.8	5	6.3	39.7	1.8	4.46	5	4.7
	11	100.0	0.0	0.00	4	0.0	88.7	2.2	2.43	4	4.8	78.1	2.1	2.75	4	4.6	52.0	1.9	3.7	4	4.6	40.1	1.4	3.58	4	3.5
	12	100.0	0.0	0.00	5	0.0	87.9	1.5	1.66	5	3.5	76.3	1.8	2.33	5	4.3	50.3	1.9	3.7	5	4.4	38.7	1.2	3.15	5	2.9
	13	100.0	0.0	0.00	5	0.0	87.1	1.5	1.77	5	4.1	76.5	1.8	2.29	5	4.3	49.5	1.8	3.6	5	4.5	38.6	1.4	3.52	5	3.3
	19	100.0	0.0	0.00	3	0.0	86.2	1.9	2.15	3	3.7	75.1	2.5	3.38	3	4.7	51.4	2.1	4.0	3	4.0	40.3	1.4	3.47	3	2.8
	20	100.0	0.0	0.00	5	0.0	87.3	1.2	1.34	5	2.6	75.8	1.9	2.50	5	4.6	51.5	1.5	3.0	5	3.4	39.9	1.3	3.26	5	2.8
	21	99.9	0.3	0.27	5	0.6	87.0	1.0	1.18	5	2.6	76.9	1.6	2.06	5	4.1	53.0	1.8	3.4	5	5.0	41.5	1.4	3.43	5	3.8
	22	100.0	0.0	0.00	5	0.0	86.3	2.0	2.32	5	4.6	74.5	2.5	3.38	5	6.4	50.4	2.7	5.3	5	6.7	38.8	2.1	5.49	5	5.3
Stats for averages		100.0	0.0	0.04	9	0.1	86.8	1.1	1.24	9	3.6	75.6	1.5	2.04	9	5.3	50.8	1.3	2.6	9	4.4	39.5	1.1	2.82	9	3.7
Stats for independent		100.0	0.1	0.09	42	0.6	86.8	1.9	2.17	42	7.9	75.6	2.4	3.24	42	9.7	50.7	2.3	4.5	42	9.0	39.4	1.8	4.56	42	7.8
Samples					Max	100					90.3					79.7					55.5					43.7
					Min	99.4					82.4					70					40.5					35.9
Coarse	5	100.0	0.0	0.00	5	0.0	79.2	1.4	1.72	5	3.2	65.1	2.7	4.16	5	7.3	41.1	2.3	5.48	5	5.7	27.4	1.1	4.08	5	3.0
	6	100.0	0.0	0.00	5	0.0	78.0	2.7	3.47	5	5.2	63.9	2.4	3.77	5	5.6	40.0	2.1	5.14	5	5.2	27.5	1.2	4.37	5	3.0
	7	100.0	0.0	0.00	6	0.0	78.9	2.5	3.14	6	6.5	64.6	2.1	3.30	6	5.7	41.5	1.2	2.80	6	3.0	28.7	1.1	3.82	6	3.0
	8	100.0	0.0	0.00	5	0.0	82.1	1.7	2.07	5	3.7	68.6	2.3	3.38	5	5.7	44.4	1.9	4.35	5	4.7	30.2	1.1	3.62	5	2.9
	23	100.0	0.0	0.00	5	0.0	79.8	2.6	3.29	5	6.7	65.7	2.5	3.75	5	5.4	42.4	2.2	5.22	5	5.0	29.1	1.0	3.49	5	2.3
	24	100.0	0.0	0.00	5	0.0	78.5	1.8	2.32	5	4.5	64.1	1.9	2.89	5	4.5	41.7	1.8	4.20	5	3.9	28.7	1.2	4.12	5	2.8
	25	100.0	0.0	0.00	5	0.0	79.2	2.1	2.66	5	4.2	64.4	1.9	2.96	5	3.9	42.3	1.9	4.45	5	4.7	29.4	1.2	4.09	5	3.1
	26	100.0	0.0	0.00	5	0.0	78.1	4.7	6.05	5	12.2	63.5	5.7	8.92	5	14.8	40.8	3.8	9.35	5	9.8	28.0	2.2	7.76	5	5.7
Stats for averages		100.0	0.0	0.00	8	0.0	792	1.3	1.63	8	4.1	65.0	1.6	2.46	8	5.0	41.8	1.3	3.17	8	4.4	28.6	1.0	3.39	8	2.8
Stats for independent		100.0	0.0	0.00	41	0.0	79.2	2.7	3.37	41	12.2	65.0	6.4	9.92	41	14.8	41.8	2.4	5.67	41	10.4	28.6	1.5	5.21	41	6.5
Samples					Max	100.0					84.4					70.9					46.1					31.4
					Min	100.0					72.2					56.1					35.7					24.9

Table 10. Accumulated percent passing from core data for top lift (continued).

		#16 Sieve					#30 Sieve					#50 Sieve					#100 Sieve					#200 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	34.3	1.3	3.67	5	2.8	27.8	1.0	3.53	5	2.2	16.2	0.7	4.08	5	1.6	8.1	0.4	4.48	5	0.9	5.1	0.2	4.45	5	0.6
	2	33.9	0.9	2.79	6	2.3	27.6	0.5	1.77	6	1.2	15.8	0.4	2.74	6	1.2	8.1	0.3	3.56	6	0.9	5.0	0.2	4.79	6	0.7
	3	35.9	1.1	3.19	5	2.5	29.1	0.9	2.95	5	1.9	15.8	0.7	4.20	5	1.7	8.0	0.4	4.62	5	1.0	5.1	0.1	2.40	5	0.3
	4	34.8	2.8	8.19	5	6.9	28.3	1.9	6.83	5	4.9	15.4	0.9	5.61	5	2.1	7.5	0.4	4.83	5	1.0	4.4	0.4	8.36	5	1.0
	14	35.5	1.7	4.71	5	4.2	29.0	1.2	4.16	5	3.1	16.0	0.6	3.82	5	1.6	8.0	0.2	2.50	5	0.4	4.9	0.3	5.56	5	0.7
	15	35.5	1.5	4.20	5	3.6	29.0	1.1	3.86	5	2.9	16.7	0.6	3.57	5	1.5	8.5	0.4	4.99	5	1.0	5.2	0.4	7.07	5	0.9
	16	35.1	1.7	4.71	5	4.0	28.6	1.3	4.52	5	3.1	16.0	0.9	5.64	5	2.1	8.0	0.4	5.39	5	1.2	4.9	0.2	4.85	5	0.6
	17	36.8	1.7	4.57	5	4.4	29.8	1.4	4.61	5	3.7	16.8	0.8	4.86	5	1.9	8.4	0.4	4.91	5	1.0	5.1	0.3	6.24	5	0.8
	18	35.2	1.2	3.52	5	2.9	28.7	1.2	4.32	5	3.2	16.5	0.7	4.07	5	1.7	8.4	0.4	5.19	5	1.0	5.1	0.4	6.96	5	0.9
Stats for averages		35.2	0.9	2.44	9	2.9	28.7	0.7	2.36	9	2.2	16.1	0.5	2.86	9	1.4	8.1	0.3	3.55	9	0.9	5.0	0.3	5.20	9	0.8
Stats of independent		35.2	1.7	4.80	46	7.9	28.6	1.3	4.46	46	5.9	16.1	0.8	4.78	46	3.1	8.1	0.4	5.48	46	1.9	5.0	0.4	7.39	46	2.0
Samples						38.5					31.4					17.5					9.0					5.8
						30.6					25.5					14.4					7.1					3.8
Fine+	9	33.6	1.6	4.77	5	3.7	27.8	1.2	4.45	5	2.9	16.4	0.8	4.68	5	1.9	8.6	0.6	7.46	5	1.6	5.2	0.5	10.61	5	1.4
	10	35.2	1.4	4.01	5	3.7	29.0	1.0	3.33	5	2.5	17.1	0.7	4.18	5	1.7	9.1	0.4	4.40	5	1.0	5.6	0.3	6.26	5	0.8
	11	35.4	1.2	3.26	4	2.8	29.0	0.9	2.94	4	1.9	16.8	0.4	2.40	4	0.9	8.9	0.7	7.72	4	1.6	5.5	0.6	11.10	4	1.4
	12	34.3	0.9	2.75	5	2.2	28.4	0.7	2.63	5	1.8	17.2	0.5	3.13	5	1.2	9.4	0.2	.206	5	0.5	6.0	0.1	1.39	5	0.2
	13	34.1	1.1	3.26	5	2.7	28.1	0.8	2.99	5	2.1	16.9	0.7	3.95	5	1.6	9.1	0.1	0.60	5	0.1	5.7	0.1	1.99	5	0.3
	19	35.8	1.2	3.23	3	2.3	29.5	0.9	3.11	3	1.8	17.9	0.4	2.44	3	0.8	9.3	0.1	1.8	3	1.2	5.8	0.1	1.72	3	0.2
	20	35.4	1.1	3.16	5	2.5	29.1	0.8	2.78	5	1.9	17.0	0.5	3.03	5	1.1	8.8	0.4	4.88	5	1.2	5.2	0.4	7.09	5	1.0
	21	36.7	1.2	3.18	5	3.0	30.1	0.9	3.04	5	2.2	18.0	0.7	3.76	5	1.8	9.0	1.0	10.72	5	2.4	5.4	1.0	17.67	5	2.3
	22	34.3	1.8	5.30	5	4.5	28.2	1.3	4.77	5	3.3	16.6	1.1	6.80	5	2.9	8.6	0.7	8.65	5	1.8	5.3	0.7	13.62	5	1.7
Stats for averages		35.0	1.0	2.81	9	3.1	28.8	0.8	2.61	9	2.3	17.1	0.5	3.10	9	1.5	9.0	0.3	3.31	9	0.9	5.5	0.3	5.18	9	0.9
Stats for independent		34.9	1.5	4.33	42	6.4	28.8	1.1	3.97	42	4.9	17.1	0.8	4.73	42	3.5	9.0	0.6	6.48	42	2.4	5.5	0.5	9.94	42	2.4
Samples						38.6					31.6					18.8					9.7					6.2
						32.2					26.7					15.3					7.3					3.8
Coarse	5	20.0	0.6	2.95	5	1.6	15.5	0.4	2.79	5	1.1	12.0	0.5	3.84	5	1.1	9.0	0.3	3.00	5	0.7	6.5	0.2	3.20	5	0.5
	6	20.4	0.6	3.19	5	1.5	15.7	0.5	3.02	5	1.1	12.0	0.5	4.22	5	1.2	8.8	0.4	4.93	5	1.0	6.3	0.4	6.64	5	1.1
	7	21.2	1.0	4.61	6	2.8	16.1	0.8	5.24	6	2.4	12.0	0.7	5.87	6	1.9	8.7	0.9	10.15	6	2.2	6.4	0.5	8.34	6	1.6
	8	22.0	0.6	2.65	5	1.5	16.7	0.3	1.90	5	0.8	12.6	0.2	1.87	5	0.5	9.3	0.2	2.32	5	0.6	6.7	0.2	3.62	5	0.7
	23	21.4	0.3	1.61	5	0.8	16.5	0.2	1.47	5	0.6	12.6	0.3	2.63	5	0.9	9.5	0.2	2.22	5	0.5	7.0	0.2	2.82	5	0.5
	24	21.0	0.7	3.35	5	1.9	16.0	0.5	3.10	5	1.4	12.2	0.5	3.72	5	1.1	9.1	0.4	4.17	5	1.0	6.6	0.4	5.64	5	0.9
	25	21.5	0.8	3.85	5	2.3	16.4	0.6	3.43	5	1.6	12.4	0.3	2.57	5	0.9	9.2	0.5	4.95	5	1.1	6.7	0.4	6.38	5	0.9
	26	20.4	1.3	6.15	5	3.2	15.5	0.8	5.10	5	1.9	11.7	0.6	4.95	5	1.5	8.7	0.4	4.77	5	1.0	6.3	0.4	5.94	5	1.0
Stats for averages		21.0	0.7	3.22	8	2.0	16.1	0.5	2.82	8	1.2	12.2	0.3	2.64	8	0.9	9.0	0.3	3.12	8	1.4	6.6	0.2	3.38	8	0.7
Stats for independent		21.0	1.0	4.57	41	4.1	16.1	0.7	4.15	41	3.1	12.2	0.5	4.35	41	2.2	9.0	0.5	5.62	41	2.2	6.6	0.4	6.04	41	1.6
Samples						22.8					17.2					13.1					9.8					7.2
						18.6					14.1					10.9					7.5					5.5

Table 11. Accumulated percent passing from core data for bottom lift.

		3/4" Sieve					1/2" Sieve					3/8" Sieve					#4 Sieve					#8 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	100.0	0.0	0.00	4	0.0	85.1	3.9	4.56	4	8.6	70.6	6.1	8.67	4	14.0	43.0	5.3	12.44	4	12.0	32.6	3.7	11.34	4	8.4
	2	100.0	0.0	0.00	4	0.0	87.3	3.9	4.48	4	9.5	74.5	5.9	7.93	4	14.2	46.2	6.2	13.42	4	14.9	35.1	4.7	13.29	4	11.3
	3	100.0	0.0	0.00	4	0.0	88.7	3.0	3.39	4	5.8	76.2	3.6	4.70	4	6.9	48.4	3.7	7.70	4	7.1	36.5	3.1	8.45	4	5.9
	4	100.0	0.0	0.00	5	0.0	89.9	1.9	2.13	5	4.8	78.3	1.0	1.27	5	2.2	49.9	0.6	1.23	5	1.3	37.9	0.7	1.75	5	1.6
	14	100.0	0.0	0.00	5	0.0	89.0	3.5	3.91	5	88	76.9	4.7	6.06	5	10.9	49.5	4.0	8.13	5	8.9	38.0	3.0	8.00	5	6.4
	15	100.0	0.0	0.00	4	0.0	86.9	2.4	2.79	4	5.9	75.5	2.7	3.61	4	6.5	49.0	2.2	4.44	4	4.7	37.4	1.6	4.37	4	3.6
	16	100.0	0.0	0.00	5	0.0	90.2	2.2	2.44	5	6.0	77.4	4.2	5.38	5	10.2	49.0	5.1	10.40	5	12.4	36.9	4.0	10.95	5	9.8
	17	100.0	0.0	0.00	5	0.0	88.4	1.2	1.36	5	3.1	75.8	2.3	3.09	5	5.2	48.6	2.6	5.29	5	5.4	36.8	1.8	4.95	5	4.4
	18	100.0	0.0	0.00	5	0.0	88.3	1.4	1.63	5	3.6	76.6	2.1	2.77	5	5.2	49.8	2.6	5.16	5	6.4	38.0	2.1	5.46	5	5.3
Stats for averages		100.0	0.0	0.00	9	0.0	88.2	1.6	1.79	9	5.1	75.7	2.2	2.94	9	7.7	48.2	2.2	4.65	9	6.9	36.6	1.7	4.78	9	5.4
Stats of independent		100.0	0.0	0.00	41	0.0	88.3	2.6	2.97	41	12.8	75.9	4.0	5.30	41	18.3	48.6	4.0	8.27	41	15.9	36.7	3.1	8.41	41	12.0
Samples					Max	100.0					93.0					81.3					53.3					40.7
					Min	100.0					80.2					63.0					37.4					28.7
Fine+	9	100.0	0.0	0.00	5	0.0	91.2	0.6	0.67	5	1.5	81.4	1.4	1.67	5	3.5	55.0	2.3	4.19	5	5.4	42.6	1.8	4.34	5	4.3
	10	100.0	0.0	0.00	4	0.0	87.1	5.3	6.09	4	11.8	74.9	6.6	8.81	4	14.0	48.7	6.6	13.46	4	14.0	37.5	5.0	13.33	4	10.8
	11	100.0	0.0	0.00	5	0.0	89.7	1.7	1.87	5	3.6	79.6	2.3	2.87	5	5.1	53.1	2.7	5.13	5	6.2	40.8	2.5	6.04	5	6.2
	12	99.9	0.3	0.31	5	0.7	89.5	1.7	1.91	5	4.5	79.1	3.3	4.16	5	8.3	52.8	5.6	10.62	5	14.0	40.4	4.7	11.76	5	11.8
	13	100.0	0.0	0.00	3	0.0	86.9	1.4	1.62	3	2.8	75.7	1.3	1.72	3	2.3	49.5	0.4	0.73	3	0.7	38.2	0.5	1.32	3	1.0
	19	100.0	0.0	0.00	5	0.0	90.1	1.4	1.54	5	3.3	80.1	2.0	2.54	5	5.0	53.3	3.9	7.33	5	9.3	41.5	2.1	5.00	5	4.7
	20	100.0	0.0	0.00	5	0.0	87.8	3.4	3.93	5	8.8	74.9	5.7	7.65	5	14.6	48.5	5.5	11.26	5	13.5	37.7	4.0	10.57	5	9.7
	21	100	0	0.00	5	0	87.2	2.5	2.91	5	5.7	74.3	4.7	6.31	5	10.8	47.3	3.7	7.73	5	9.8	37.2	2.6	7.06	5	6.7
	22	100.0	0.0	0.00	5	0.0	90.1	1.6	1.73	5	4.3	78.7	2.5	3.21	5	6.9	52.4	2.3	4.42	5	6.1	40.5	1.8	4.34	5	4.3
Stats for averages		100.0	0.0	0.05	9	0.1	88.8	1.6	1.80	9	4.3	77.6	2.7	3.45	9	7.1	51.2	2.7	5.26	9	7.7	39.6	2.0	4.98	9	5.4
Stats for independent		100.0	0.1	0.11	42	0.7	88.8	2.8	3.19	42	13.2	77.8	4.2	5.45	42	18.5	51.6	4.5	8.76	42	22.8	39.7	3.2	8.16	42	18
Samples					Max	100.0					92.6					84.5					62.2					48.4
					Min	99.3					79.4					66.0					39.4					30.4
Coarse	5	100.0	0.0	0.00	5	0.0	82.9	2.5	3.06	5	6.1	67.3	2.9	4.35	5	7.6	42.1	1.7	4.08	5	4.1	27.3	1.3	4.60	5	3.2
	6	100.0	0.0	0.00	4	0.0	81.4	2.1	2.53	4	4.8	66.3	3.0	4.55	4	6.2	42.4	2.3	5.32	4	4.4	28.0	1.4	5.18	4	2.7
	7	100.0	0.0	0.00	3	0.0	80.5	2.5	3.12	3	4.7	64.9	2.1	3.16	3	3.7	40.3	2.0	4.98	3	3.7	26.9	1.3	4.77	3	2.4
	8	100.0	0.0	0.00	5	0.0	82.6	2.3	2.84	5	5.6	67.5	2.7	3.96	5	6.6	42.9	1.8	4.25	5	4.5	28.0	1.2	4.16	5	3.0
	23	100.0	0.0	0.00	5	0.0	83.3	2.2	2.63	5	5.2	67.9	2.6	3.84	5	6.3	43.2	1.8	4.18	5	4.0	28.2	1.0	3.67	5	2.6
	24	100.0	0.0	0.00	5	0.0	82.2	1.4	1.70	5	3.4	65.3	2.6	3.95	5	6.5	41.7	2.2	5.37	5	5.3	27.6	1.4	4.99	5	3.2
	25	100.0	0.0	0.00	5	0.0	79.8	2.3	2.86	5	5.0	65.1	1.9	2.99	5	5.3	41.8	1.7	3.97	5	4.4	27.9	1.1	3.77	5	2.7
	26	100.0	0.0	0.00	5	0.0	80.7	4.3	5.33	5	9.9	64.8	5.1	7.91	5	11.9	41.0	3.8	9.30	5	9.9	27.1	2.2	7.98	5	5.7
Stats for averages		100	0	0	8	0.0	81.7	1.3	1.54	8	6.5	66.1	1.3	1.91	8	8.2	41.9	1.0	2.27	8	6.2	27.6	0.5	1.69	8	3.3
Stats for independent		100	0	0	37	0.0	81.7	2.6	3.24	37	11	66.2	3.0	4.55	37	13.2	42.0	2.2	5.28	37	10	27.7	1.3	4.78	37	5.8
Samples					Max	100.0					86.3					71.5					45.1					29.4
					Min	100.0					75.3					58.3					35.1					23.6

Table 11. Accumulated percent passing from core data for bottom lift (continued).

		#16 Sieve					#30 Sieve					#50 Sieve					#100 Sieve					#200 Sieve				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	28.7	2.9	10.23	4	6.8	23.6	2.3	9.73	4	5.3	14.2	1.3	9.50	4	3.1	6.9	0.8	12.13	4	1.8	4.1	0.7	15.88	4	1.4
	2	30.8	3.9	12.64	4	9.5	25.3	3.0	11.69	4	7.2	14.4	1.4	9.76	4	3.4	7.2	0.8	10.64	4	1.7	4.2	0.6	13.61	4	1.3
	3	32.1	2.1	6.46	4	4.9	26.1	1.9	7.23	4	3.5	15.0	0.6	3.95	4	1.3	7.1	0.2	2.12	4	0.3	4.2	0.1	3.11	4	0.3
	4	33.3	0.6	1.82	5	1.4	27.3	0.5	1.86	5	1.3	15.5	0.3	2.01	5	0.8	7.5	0.5	6.61	5	1.2	4.3	0.4	10.24	5	1.0
	14	33.6	2.5	7.48	5	5.1	27.7	1.9	6.78	5	3.8	15.5	1.1	6.81	5	2.3	7.8	0.7	9.19	5	1.7	4.5	0.6	13.05	5	1.5
	15	33.0	1.5	4.55	4	3.3	27.0	1.2	4.30	4	2.6	15.9	1.0	6.24	4	2.3	7.8	0.5	6.67	4	1.1	4.7	0.4	9.19	4	1.0
	16	32.5	3.4	10.49	5	8.1	26.6	2.5	9.38	5	5.9	15.3	1.2	7.98	5	3.2	7.5	0.9	11.48	5	2.2	4.4	0.7	15.95	5	1.9
	17	32.5	1.5	4.54	5	3.5	26.0	1.3	5.09	5	3.3	14.3	2.4	16.69	5	6.1	7.4	0.5	7.03	5	1.3	4.6	0.3	5.57	5	0.7
	18	33.3	1.7	5.07	5	4.4	27.1	1.2	4.50	5	3.2	15.5	0.5	3.53	5	1.4	7.5	0.5	5.98	5	1.1	4.5	0.4	8.61	5	0.9
Stats for averages		32.2	1.6	4.84	9	4.9	26.3	1.3	4.80	9	4.1	15.0	0.6	4.07	9	1.7	7.4	0.3	4.21	9	0.9	4.4	0.2	4.81	9	0.6
Stats of independent		32.3	2.6	8.09	41	10.2	26.4	2.0	7.68	41	8.2	15.1	1.3	8.35	41	6.9	7.4	0.6	8.50	41	2.6	4.4	0.5	11.08	41	2.0
Samples						35.7					29.3					17.2					8.9					5.5
						25.5					21.1					10.3					6.3					3.5
Fine+	9	37.6	1.5	3.93	5	3.5	31.2	1.0	3.34	5	2.5	18.1	0.5	2.90	5	1.3	10.0	0.4	4.27	5	1.0	6.2	0.4	6.20	5	0.9
	10	33.2	4.2	12.65	4	9.1	27.5	3.3	11.89	4	7.2	16.5	1.6	9.80	4	3.6	8.5	0.9	11.16	4	2.1	5.2	0.6	12.16	4	1.4
	11	36.2	2.3	6.23	5	5.9	29.9	2.1	6.92	5	5.5	18.1	2.3	12.61	5	6.2	9.9	2.3	22.82	5	5.5	6.5	2.3	35.29	5	5.6
	12	35.5	3.9	10.89	5	9.8	29.0	2.7	9.24	5	6.9	17.1	1.2	7.28	5	2.9	8.8	0.6	6.93	5	1.6	5.4	0.5	9.78	5	1.4
	13	33.8	0.5	1.52	3	1.0	27.7	0.5	1.88	3	0.9	16.1	0.3	1.80	3	0.5	8.4	0.6	7.43	3	.12	5.5	0.7	12.98	3	1.4
	19	36.6	1.7	4.51	5	3.7	30.0	1.1	3.82	5	2.6	17.8	0.8	4.35	5	2.0	9.3	0.3	3.16	5	0.6	5.7	0.2	3.61	5	0.5
	20	33.6	3.3	9.69	5	8.0	27.7	2.3	8.30	5	6.0	16.2	1.0	6.44	5	2.5	8.3	0.2	1.82	5	0.4	5.1	0.2	4.76	5	0.5
	21	33.0	2.0	5.98	5	5.2	27.4	1.3	4.82	5	3.5	33.0	1.0	2.99	5	2.4	8.6	0.6	7.11	5	1.5	5.3	0.6	12.07	5	2
	22	35.8	1.5	4.32	5	3.9	29.3	1.2	4.05	5	3.0	16.8	0.7	4.04	5	1.7	8.3	0.6	7.78	5	1.7	4.9	0.6	12.48	5	1.7
Stats for averages		35.0	1.7	4.76	9	10.8	28.9	1.4	4.71	9	3.8	18.8	5.4	28.51	9	17.0	8.9	0.7	7.46	9	1.7	5.5	0.5	9.68	9	1.6
Stats for independent		35.1	2.8	8.02	42	14.8	29.0	2.1	7.13	42	10.7	17.1	1.4	7.95	42	7.5	8.9	1.1	11.93	42	6.4	5.5	1.0	17.85	42	6.5
Samples						42.0					33.5					21.7					13.7					10.5
						27.2					22.8					14.2					7.3					4
Coarse	5	19.8	0.9	4.51	5	2.2	15.1	0.5	3.54	5	1.5	11.0	0.5	4.99	5	1.5	8.0	0.5	5.74	5	1.2	5.7	0.4	7.13	5	1.1
	6	20.0	1.0	4.94	4	1.8	14.9	0.6	4.35	4	1.3	10.9	0.3	3.20	4	0.8	7.7	0.4	5.51	4	0.9	5.4	0.4	6.69	4	0.8
	7	19.5	0.7	3.55	3	1.2	14.6	0.6	3.78	3	1.0	10.8	0.5	4.39	3	0.9	7.7	0.3	3.44	3	0.5	5.4	0.2	3.88	3	0.4
	8	20.0	0.7	3.66	5	1.9	14.9	0.5	3.56	5	1.4	11.0	0.3	2.65	5	0.7	7.9	0.4	4.42	5	0.9	5.7	0.2	3.87	5	0.6
	23	20.1	0.7	3.52	5	1.9	15.0	0.6	3.74	5	1.5	11.1	0.4	3.45	5	1.0	7.9	0.4	5.37	5	1.1	5.6	0.3	6.18	5	0.8
	24	20.0	0.7	3.26	5	1.7	15.0	0.4	2.90	5	1.2	11.0	0.5	4.47	5	1.2	7.9	0.4	5.60	5	1.1	5.5	0.4	7.51	5	1.1
	25	20.3	0.7	3.39	5	1.7	15.2	0.5	3.35	5	1.2	11.2	0.5	4.47	5	1.4	8.0	0.4	4.53	5	1.0	5.6	0.4	6.44	5	1
	26	19.5	1.3	6.75	5	3.3	14.5	0.9	5.89	5	2.0	10.6	0.5	4.42	5	1.2	7.6	0.4	5.23	5	1.0	5.3	0.2	4.11	5	0.6
Stats for averages		19.9	0.3	1.43	8	2.1	14.9	0.2	1.64	8	1	11.0	0.2	1.80	8	0.8	7.8	0.2	.209	8	0.7	5.51	0.15	2.75	8	0.7
Stats for independent		19.9	0.8	4.12	37	3.8	14.9	0.6	3.87	37	4.0	11.0	0.4	4.05	37	2.1	7.9	0.4	5.00	37	1.6	5.51	0.32	5.85	37	1.4
Samples						21.2					15.9					1.2					8.7					6.3
						17.4					13.2					9.9					7.1					4.9

Table 12. Percent retained in various size ranges from cut core data for top lifts.

		3/4 x 1/2					1/2 x 3/8					3/8 x #4					#4 x #8				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	12.3	1.9	15.56	5	5.0	11.7	0.8	6.84	5	1.9	26.3	0.8	3.15	5	2.0	11.0	0.4	3.96	5	1.0
	2	11.5	1.6	14.29	6	3.7	11.9	0.4	3.68	6	1.2	26.7	1.7	6.49	6	4.5	11.6	0.4	3.60	6	1.1
	3	12.2	1.1	9.35	5	2.5	10.2	1.0	10.00	5	2.6	25.6	0.8	2.99	5	1.9	11.6	0.3	2.84	5	0.9
	4	12.7	3.2	25.11	5	7.7	12.1	1.3	11.06	5	3.3	24.7	0.4	1.62	5	1.0	11.2	0.9	8.15	5	2.4
	14	11.6	1.6	13.67	5	3.9	11.7	1.5	13.19	5	4.0	25.3	0.4	.169	5	0.9	11.5	0.7	6.13	5	1.7
	15	11.3	1.4	12.51	5	3.6	11.2	1.2	10.61	5	2.5	25.8	1.2	4.68	5	3.3	11.5	0.5	4.31	5	1.2
	16	11.5	1.1	9.21	5	2.5	12.2	1.0	7.84	5	2.1	25.5	0.7	2.58	5	1.8	11.1	0.4	3.67	5	1.1
	17	10.6	2.0	19.27	5	5.2	11.0	0.8	7.33	5	1.9	25.3	0.9	3.76	5	2.4	11.5	0.5	4.75	5	1.3
	18	13.0	1.3	9.95	5	3.5	11.6	0.9	7.56	5	2.3	24.4	1.1	4.65	5	2.8	11.3	0.8	7.29	5	2.0
Stats for averages		11.9	0.7	6.31	9	4.2	11.5	0.6	5.52	9	2.5	25.5	0.7	2.82	9	2.3	11.3	0.2	1.98	9	1.5
Stats of independent		11.8	1.8	15.03	46	8.2	11.5	1.1	9.66	46	5.5	25.5	1.2	4.52	46	5.6	11.4	0.6	5.08	46	2.5
Samples					Max	16.4					14.4					29.1					12.6
					Min	8.2					8.9					23.5					10.1
Fine+	9	14.9	2.2	14.91	5	4.8	12.3	1.4	11.46	5	3.5	24.2	0.8	3.28	5	1.8	10.8	0.7	6.48	5	2.3
	10	13.9	2.2	15.72	5	4.8	11.4	0.7	6.43	5	1.9	24.3	0.5	2.04	5	1.3	10.7	0.8	7.32	5	1.8
	11	11.3	2.2	19.05	4	4.8	10.6	0.6	5.55	4	1.4	26.1	0.8	2.89	4	1.6	11.9	0.5	4.50	4	1.1
	12	12.1	1.5	12.00	5	3.5	11.6	1.2	10.76	5	2.6	26.0	0.2	0.90	5	0.6	11.5	0.7	6.08	5	1.7
	13	12.9	1.5	11.95	5	4.1	10.6	0.5	5.04	5	1.3	27.0	0.6	2.25	5	1.0	10.9	0.6	5.16	5	1.4
	19	13.8	1.9	13.42	3	3.7	11.1	1.0	9.01	3	2.0	23.7	1.0	4.38	3	1.8	11.1	0.8	7.52	3	1.6
	20	12.7	1.2	9.25	5	2.6	11.5	1.3	10.87	5	3.2	24.3	0.6	2.31	5	1.5	11.6	0.4	3.61	5	1.1
	21	12.8	1.2	9.04	5	2.8	10.2	0.6	5.83	5	1.5	23.9	1.6	6.61	5	3.7	11.5	0.6	4.81	5	1.4
	22	13.7	2.0	14.59	5	4.6	11.8	0.8	6.54	5	1.9	24.1	1.0	4.17	5	2.1	11.6	0.6	4.84	5	1.4
Stats for averages		13.1	1.1	8.19	9	3.9	11.2	0.7	5.91	9	2.0	24.8	1.2	4.79	9	1.7	11.3	0.4	3.64	9	1.4
Stats for independent		13.1	2.0	15.29	42	8.8	11.2	1.2	10.45	42	5.3	24.9	1.4	5.50	42	6.1	11.3	0.7	6.23	42	2.9
Samples					Max	17.6					13.4					27.8					12.7
					Min	8.8					8.1					21.7					9.8
Coarse	5	20.8	1.4	6.53	5	3.2	14.0	1.6	11.39	5	4.2	24.1	0.6	2.63	5	1.6	13.7	1.2	8.44	5	2.7
	6	22.0	2.7	12.29	5	5.2	14.1	1.2	8.28	5	3.0	23.9	0.8	3.33	5	1.7	12.5	0.9	6.97	5	2.2
	7	21.1	2.5	11.79	6	6.5	14.3	1.7	11.76	6	4.3	23.2	4.6	19.81	6	2.8	12.7	1.1	8.55	6	3.0
	8	17.9	1.7	9.49	5	3.7	13.5	1.0	7.60	5	2.7	24.2	0.8	3.13	5	1.8	14.2	0.9	6.46	5	2.3
	23	20.2	2.6	12.98	5	6.7	14.1	1.2	8.27	5	3.3	23.3	0.4	1.80	5	1.0	13.2	1.2	9.11	5	2.6
	24	21.5	1.8	8.50	5	4.5	14.4	0.9	6.40	5	2.5	22.4	1.4	6.34	5	3.8	13.0	0.8	5.91	5	2.2
	25	20.8	2.1	10.12	5	4.2	14.8	0.6	3.89	5	1.4	22.1	0.9	3.94	5	2.4	12.9	0.8	6.02	5	2.0
	26	21.9	4.7	21.65	5	12.2	14.6	1.0	6.66	5	2.5	22.7	1.9	8.28	5	5.0	12.8	1.7	13.01	5	4.1
Stats for averages		20.8	1.3	6.21	8	4.1	14.2	0.4	2.82	8	1.3	23.2	0.8	3.39	8	2.1	13.1	0.5	4.17	8	1.7
Stats for independent		20.8	2.7	12.86	41	12.2	14.2	1.2	8.14	41	4.4	23.2	1.2	5.34	41	5.0	13.1	1.1	8.52	41	4.3
Samples					Max	27.8					16.4					25.4					15.1
					Min	15.6					12.0					20.4					10.8

Table 12. Percent retained in various size ranges from cut core data for top lifts (continued).

		#8 x #16					#16 x #30					#30 x #50					#50 x #100					#100 x #200				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	4.5	0.2	3.96	5	0.4	6.4	0.3	4.34	5	0.6	11.6	0.4	3.28	5	0.8	8.1	0.3	3.90	5	0.8	3.0	0.2	5.44	5	0.3
	2	4.5	0.3	6.59	6	0.8	6.2	0.5	7.97	6	1.3	11.9	0.6	4.77	6	1.5	7.7	0.6	7.30	6	1.2	3.1	0.1	3.44	6	0.3
	3	4.6	0.1	2.50	5	0.3	6.8	0.3	4.35	5	0.6	13.3	1.4	10.21	5	3.2	7.8	0.5	6.09	5	1.2	2.9	0.3	9.19	5	0.7
	4	4.4	0.6	13.82	5	1.6	6.4	0.9	14.55	5	2.4	12.9	1.2	9.07	5	3.2	7.9	0.9	11.60	5	2.4	3.2	0.2	4.80	5	0.3
	14	4.5	0.3	6.48	5	0.7	6.5	0.5	7.38	5	1.1	13.0	0.9	7.03	5	2.3	8.0	0.5	6.54	5	1.2	3.1	0.2	4.83	5	0.4
	15	4.7	0.3	6.48	5	0.7	6.5	0.4	6.44	5	0.9	12.3	1.0	8.08	5	2.5	8.2	0.4	5.33	5	1.2	3.3	0.2	5.98	5	0.5
	16	4.5	0.3	6.89	5	0.7	6.5	0.4	5.98	5	0.9	12.6	0.9	6.98	5	2.3	8.0	0.6	7.67	5	1.4	3.1	0.2	6.95	5	0.6
	17	4.8	2.2	46.01	5	0.8	6.9	0.3	4.73	5	0.8	13.0	1.2	9.00	5	3.0	8.4	0.5	6.47	5	1.4	3.3	0.2	4.65	5	0.4
	18	4.6	0.3	6.39	5	0.8	6.5	0.3	4.28	5	0.7	12.3	1.2	9.90	5	3.0	8.1	0.5	6.36	5	1.1	3.3	0.2	5.57	5	0.5
Stats for averages		4.6	0.1	2.57	9	0.8	6.5	0.2	3.09	9	1.1	12.5	0.6	4.55	9	2.6	8.0	0.2	2.81	9	1.4	3.1	0.1	3.68	9	0.5
Stats of independent		4.6	0.3	6.96	46	1.6	6.5	0.5	7.25	46	2.4	12.5	1.1	8.44	46	5.0	8.0	0.6	6.95	46	2.4	3.1	0.2	6.28	46	1.0
Samples						5.1					7.5					15.2					9.4					3.5
						3.5					5.1					10.2					7.0					2.5
Fine+	9	4.2	0.4	10.25	5	1.0	5.8	0.4	6.68	5	0.9	11.3	0.7	6.16	5	1.9	7.9	0.6	74.8	5	1.5	3.4	0.2	5.29	5	0.5
	10	4.5	0.4	8.89	5	1.0	6.1	0.5	7.78	5	1.2	11.9	0.4	3.66	5	1.1	8.0	0.6	7.18	5	1.3	3.5	0.1	3.11	5	0.3
	11	4.7	0.3	6.26	4	0.7	6.4	0.4	6.70	4	0.9	12.3	0.6	4.69	4	1.2	7.9	0.4	5.47	4	1.0	3.4	0.1	2.40	4	0.2
	12	4.4	0.3	6.67	5	0.7	5.9	0.2	3.88	5	0.6	11.2	0.9	8.15	5	2.1	7.7	0.5	6.57	5	1.1	3.4	0.1	4.34	5	0.4
	13	4.4	0.3	6.09	5	0.7	6.0	0.3	4.90	5	0.8	11.2	0.6	4.93	5	1.4	7.8	0.6	8.21	5	1.5	3.4	0.1	3.60	5	0.3
	19	4.5	0.3	5.88	3	0.5	6.3	0.3	3.97	3	0.5	11.6	0.6	4.80	3	1.1	8.6	0.3	4.03	3	0.6	3.5	0.2	5.71	3	0.4
	20	4.5	0.2	4.71	5	0.5	6.3	0.4	5.89	5	0.9	12.1	0.9	7.34	5	1.9	8.2	0.4	5.19	5	1.1	3.5	0.2	4.28	5	0.4
	21	4.8	0.3	6.23	5	0.8	6.6	0.3	4.48	5	0.8	12.1	1.2	9.51	5	2.8	9.0	0.4	4.60	5	1.0	3.5	0.1	3.22	5	0.3
	22	4.5	0.3	7.07	5	0.8	6.1	0.5	8.11	5	1.3	11.6	1.0	8.25	5	2.3	8.0	0.6	6.97	5	8.8	3.4	0.1	3.66	5	0.2
Stats for averages		4.5	0.2	3.48	9	0.7	6.2	0.2	3.91	9	0.9	11.7	0.4	3.56	9	1.7	8.1	0.4	5.25	9	2.1	3.5	0.1	2.11	4.6	0.3
Stats for independent		4.5	0.4	7.75	42	1.7	6.2	0.4	6.80	42	1.6	11.7	0.8	7.16	42	3.7	8.1	0.6	7.58	42	2.6	3.5	0.1	4.20	42	0.6
Samples						5.4					7.0					13.9					9.7					3.7
						3.7					5.4					10.2					7.1					3.1
Coarse	5	7.4	0.5	7.35	5	1.4	4.5	0.2	3.74	5	0.4	3.5	0.2	5.28	5	0.4	3.1	0.2	6.87	5	0.6	2.4	0.1	3.98	5	0.2
	6	7.1	0.6	7.89	5	1.4	4.7	0.2	4.08	5	0.5	3.7	0.1	2.67	5	0.2	3.2	0.1	3.34	5	0.2	2.5	0.1	4.10	5	0.3
	7	7.6	0.5	6.05	6	1.0	5.1	0.2	4.21	6	0.6	4.2	0.4	9.20	6	1.1	3.3	0.3	9.03	6	0.7	2.3	0.5	21.27	6	1.3
	8	8.2	0.5	6.67	5	1.4	5.3	0.3	5.18	5	0.7	4.1	0.2	4.93	5	0.5	3.3	0.2	6.76	5	0.5	2.6	0.1	2.59	5	0.2
	23	7.7	0.7	9.01	5	1.5	5.0	0.1	2.19	5	0.3	3.8	0.2	4.34	5	0.3	3.2	0.2	6.77	5	0.4	2.5	0.1	2.05	5	0.2
	24	7.7	0.6	7.84	5	1.4	5.0	0.2	4.38	5	0.5	3.8	0.2	6.25	5	0.6	3.1	0.2	5.50	5	0.4	2.5	0.1	3.35	5	0.2
	25	7.8	0.5	5.80	5	1.3	5.2	0.3	5.85	5	0.7	4.0	0.3	6.74	5	0.7	3.2	0.3	7.95	5	0.7	2.5	0.1	2.40	5	0.1
	26	7.6	0.9	12.14	5	2.5	4.9	0.5	9.83	5	1.3	3.8	0.4	9.70	5	1.0	3.0	0.2	8.17	5	0.6	2.4	0.1	4.74	5	0.3
Stats for averages		7.6	0.3	4.26	8	1.1	4.9	0.2	5.01	8	0.6	3.9	0.2	5.80	8	0.6	3.2	0.1	3.11	8	0.5	.25	0.1	3.34	8	0.3
Stats for independent		7.6	0.6	8.28	41	2.5	4.9	0.3	6.76	41	1.5	3.9	0.3	8.25	41	1.5	3.2	0.2	7.07	41	1.1	2.5	0.2	8.31	41	1.3
Samples						8.8					5.7					4.7					3.8					2.7
						6.3					4.1					3.2					2.7					1.4

Table 13. Percent retained in various size ranges from cut core data for bottom lifts.

		3/4 x 1/2					1/2 x 3/8					3/8 x #4					#4 x #8				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	14.9	3.9	25.99	4	8.6	14.5	2.3	15.71	4	5.4	27.6	1.4	5.12	4	3.0	10.4	1.7	15.96	4	3.6
	2	12.7	3.9	30.85	4	9.5	12.9	2.4	18.38	4	5.2	28.3	0.6	2.22	4	1.3	11.1	1.6	14.52	4	3.6
	3	11.3	3.0	26.56	4	5.8	12.5	1.0	8.16	4	2.4	27.8	0.9	3.20	4	1.9	11.9	0.6	5.45	4	1.3
	4	10.1	1.9	19.02	5	4.8	11.6	1.2	10.63	5	3.2	28.4	0.8	2.81	5	2.0	12.0	0.2	1.49	5	0.4
	14	11.0	3.5	31.47	5	8.8	12.1	1.5	12.29	5	3.6	27.4	0.8	2.93	5	2.0	11.5	1.0	8.78	5	2.5
	15	13.1	2.4	18.50	4	3.6	11.4	0.5	4.64	4	1.2	26.5	0.9	3.30	4	1.9	11.7	5.9	50.27	4	1.6
	16	9.8	2.2	22.38	5	2.5	12.8	2.5	19.86	5	6.5	28.4	9.3	32.58	5	3.1	12.0	1.1	8.80	5	2.6
	17	11.6	1.2	10.33	5	3.1	12.6	1.7	13.23	5	4.1	27.2	0.6	2.14	5	1.3	11.8	0.9	7.30	5	2.2
	18	11.7	1.4	12.31	5	3.6	11.7	1.0	8.29	5	2.4	26.7	1.3	4.73	5	3.4	11.9	0.6	5.32	5	1.4
Stats for averages		11.8	1.6	13.35	9	5.1	12.4	0.9	7.49	9	3.1	27.6	0.7	2.55	9	1.9	11.6	0.5	4.72	9	1.7
Stats of independent		11.7	2.8	24.14	41	12.8	12.4	1.7	14.02	41	7.7	27.6	1.1	4.01	41	4.9	11.6	1.0	8.82	41	4.1
Samples					Max	19.8					17.2					29.9					12.8
					Min	7.0					9.5					25.0					8.7
Fine+	9	8.8	0.6	6.86	5	1.5	9.7	1.0	10.58	5	2.3	26.4	1.5	5.64	5	3.6	12.4	0.5	3.92	5	1.2
	10	13.0	5.3	40.93	4	11.8	12.2	1.8	15.06	4	3.9	26.2	0.8	3.05	4	1.6	11.2	1.6	14.00	4	3.4
	11	10.3	1.7	16.21	5	3.6	10.1	1.0	9.75	5	2.5	26.5	0.9	3.47	5	2.4	12.2	0.5	4.15	5	1.3
	12	10.4	1.7	16.05	5	4.5	10.4	1.9	17.90	5	4.9	26.3	2.3	8.93	5	5.7	12.4	0.9	6.94	5	2.2
	13	13.1	1.4	10.70	3	2.8	11.2	0.6	4.93	3	1.1	26.2	1.1	4.13	3	2.1	11.3	0.3	2.84	3	0.6
	19	9.9	1.4	13.98	5	3.3	10.0	0.7	6.55	5	1.7	26.7	2.1	7.73	5	5.2	11.8	1.9	16.45	5	5.0
	20	12.2	3.4	28.36	5	8.8	12.9	2.4	18.56	5	5.8	26.4	0.8	3.20	5	2.3	10.8	1.5	14.09	5	3.8
	21	12.8	2.5	19.81	5	5.7	12.9	2.3	18.13	5	5.3	27.0	1.7	6.31	5	4.1	10.2	1.3	12.62	5	3.1
	22	9.9	1.6	15.80	5	4.3	11.4	0.6	5.63	5	4.0	26.3	0.8	2.92	5	2.0	11.9	0.8	6.53	5	1.8
Stats for averages		11.2	1.6	14.43	9	5.1	11.2	1.2	11.06	9	3.2	26.5	0.3	1.01	9	0.8	11.6	0.8	6.75	9	2.3
Stats for independent		11.0	2.7	24.33	42	13.2	11.2	1.9	17.19	42	8.7	26.5	1.4	5.12	42	7.9	11.6	1.3	11.26	42	5.5
Samples					Max	20.6					16.4					30.2					13.8
					Min	7.4					7.7					22.3					8.3
Coarse	5	17.1	2.5	14.89	5	6.1	15.7	0.6	3.90	5	1.5	25.1	1.3	5.24	5	3.5	14.8	0.5	3.54	5	1.2
	6	18.7	2.1	11.05	4	4.8	15.1	1.2	8.02	4	2.6	23.9	1.1	4.67	4	2.7	14.4	0.8	5.69	4	1.7
	7	19.5	2.5	12.92	3	4.7	15.6	0.7	4.49	3	1.3	24.6	0.1	0.47	3	0.2	13.4	0.7	5.41	3	1.3
	8	17.4	2.3	13.43	5	5.6	15.1	1.5	10.08	5	3.3	24.6	1.0	4.07	5	2.5	14.9	0.7	4.93	5	2.0
	23	16.7	2.2	13.09	5	5.2	15.4	1.3	8.45	5	3.3	24.7	1.3	5.25	5	3.2	15.0	0.9	6.10	5	2.3
	24	17.8	1.4	7.85	5	3.4	16.9	1.8	10.81	5	5.0	23.6	0.8	3.57	5	2.2	14.1	0.9	6.37	5	2.1
	25	20.2	2.3	11.29	5	5.0	14.7	1.7	11.30	5	3.5	23.3	0.9	4.04	5	2.6	13.8	0.7	4.81	5	1.7
	26	19.3	4.3	22.28	5	9.9	15.9	1.5	9.5	5	3.9	23.8	1.9	7.86	5	4.8	13.9	1.7	12.21	5	4.2
Stats for averages		18.3	1.3	6.88	8	3.48	15.5	0.7	4.35	8	2.22	24.2	0.6	2.65	8	1.8	14.3	0.6	4.08	8	1.6
Stats for independent		18.3	2.6	14.37	37	11	15.6	1.4	9.11	37	6.6	24.2	1.2	5.14	37	5.6	14.3	1.0	7.01	37	4.6
Samples					Max	24.7					19.2					26.7					16.1
					Min	13.7					12.6					21.1					11.5

Table 13.Percent retained in various size ranges from cut core data for bottom lifts (continued).

		#8 x #16					#16 x #30					#30 x #50					#50 x #100					#100 x #200				
Grada-tion	Sec-tion	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range	Mean	Std	COV	n	Range
Fine	1	3.9	0.8	19.97	4	1.6	5.2	0.6	12.53	4	1.5	9.4	1.0	10.39	4	2.2	7.3	0.6	8.52	4	1.4	2.8	0.2	8.96	4	0.4
	2	4.3	0.8	18.94	4	1.8	5.5	1.0	17.50	4	2.3	10.9	1.6	14.96	4	3.8	7.2	0.8	10.82	4	1.7	3.0	0.2	8.40	4	0.6
	3	4.4	0.5	11.88	4	1.0	6.0	0.7	11.37	4	1.4	11.1	1.4	12.59	4	2.7	7.9	0.5	6.03	4	1.0	2.9	0.2	7.05	4	0.5
	4	4.5	0.1	1.97	5	0.2	6.1	0.2	3.00	5	0.5	11.8	0.7	5.75	5	1.9	8,0	0.6	8.00	5	1.4	3.2	0.1	4.10	5	0.3
	14	4.4	0.5	12.34	5	1.3	5.9	2.8	46.72	5	1.4	12.2	0.9	7.03	5	1.9	7.6	0.4	5.52	5	1.0	3.3	0.2	6.21	5	0.5
	15	4.4	0.1	3.21	4	0.3	6.0	0.4	5.90	4	0.7	11.3	0.9	8.16	4	2.0	8.1	0.5	6.10	4	1.2	3.1	0.1	4.09	4	0.3
	16	4.4	0.6	14.74	5	1.7	5.9	1.0	16.17	5	2.5	11.3	1.4	12.16	5	3.4	7.8	0.9	11.03	5	2.1	3.0	0.2	7.21	5	0.5
	17	4.3	0.4	8.08	5	0.9	6.4	1.4	21.87	5	3.5	11.7	1.6	13.52	5	4.3	6.9	1.7	24.65	5	4.9	2.7	0.7	27.44	5	1.8
	18	4.6	0.4	8.96	5	1.0	6.2	0.5	7.74	5	1.2	11.6	1.1	9.40	5	2.9	8,0	7.2	90.98	5	1.0	3.0	0.1	2.94	5	0.2
Stats for averages		4.4	0.2	4.69	9	0.7	5.9	0.4	6.42	9	1.3	11.3	0.8	7.21	9	2.8	7.7	0.4	5.31	9	1.1	3.0	0.2	6.48	9	0.6
Stats of independent		4.4	0.5	11.53	41	2.0	5.9	0.8	13.34	41	4.7	11.3	1.3	11.62	41	6.1	7.7	0.9	11.42	41	5.1	3.0	0.3	11.26	41	2.1
Samples						5.1					8.9					14.3					8.9					3.5
						3.1					4.2					8.2					3.8					1.4
Fine+	9	5.0	0.4	8.01	5	1.0	6.4	0.5	7.25	5	1.2	13.1	0.7	5.56	5	1.3	8.1	0.2	1.86	5	0.4	3.8	0.1	2.63	5	0.2
	10	4.3	0.8	18.53	4	1.7	5.8	0.9	16.47	4	2.1	11.0	1.7	15.50	4	4.0	8.0	0.8	9.55	4	1.8	3.3	0.4	11.34	4	0.9
	11	4.6	0.4	7.56	5	0.9	6.3	0.4	6.98	5	1.2	11.8	0.7	5.65	5	1.6	8.2	0.7	8.22	5	1.8	3.3	0.1	3.93	5	0.3
	12	4.9	0.9	18.50	5	2.2	6.5	1.2	18.40	5	2.9	12.0	1.7	13.92	5	4.1	8.3	0.9	10.61	5	2.4	3.4	0.2	5.69	5	0.5
	13	4.3	0.1	1.33	3	0.1	6.1	0.2	2.49	3	4.4	11.6	0.7	6.10	3	1.4	7.7	0.5	6.16	3	0.9	2.9	0.1	3.94	3	0.2
	19	4.9	0.4	8.86	5	1.0	6.6	0.5	7.85	5	1.2	12.2	0.8	6.80	5	2.3	8.5	0.7	7.78	5	1.7	3.6	0.2	4.59	5	0.4
	20	4.1	0.7	17.96	5	1.9	5.8	1.0	17.36	5	2.7	11.6	1.4	12.45	5	3.9	7.8	1.0	12.15	5	2.4	3.3	0.2	6.61	5	0.6
	21	4.1	0.7	16.52	5	1.5	5.6	0.7	12.16	5	1.7	11.0	1.1	9.96	5	2.9	7.8	0.6	7.42	5	1.2	3.3	0.2	6.17	5	0.5
	22	4.7	0.3	6.02	5	0.8	6.5	0.4	6.62	5	1.1	12.5	1.2	9.23	5	2.6	8.6	0.6	6.61	5	1.4	3.3	0.2	4.54	5	0.4
Stats for averages		4.6	0.3	7.11	9	0.8	6.2	0.4	5.76	9	1.0	11.9	1.1	9.36	9	2.1	8.1	0.3	3.83	9	8.6	3.4	0.2	6.96	9	0.9
Stats for independent		4.6	0.6	13.44	42	3.5	6.2	0.7	12.02	42	4.2	11.9	1.2	10.35	42	6.2	8.1	0.7	8.28	42	3.3	3.4	0.3	8.07	42	1.1
Samples						6.4					8.5					14.8					9.7					3.9
						2.9					4.3					8.6					6.4					2.8
Coarse	5	7.6	0.4	5.09	5	1.0	4.7	0.5	11.45	5	1.4	4.1	0.4	10.88	5	1.2	3.0	0.1	4.71	5	0.3	2.3	0.1	3.61	5	0.2
	6	8.1	0.5	5.96	4	1.0	5.1	0.4	6.98	4	0.7	3.9	0.3	8.16	4	0.6	3.2	0.1	2.97	4	0.2	2.3	0.1	5.41	4	0.3
	7	7.4	0.6	8.22	3	1.2	4.9	0.2	3.10	3	0.3	3.8	0.2	4.56	3	0.3	3.1	0.3	8.21	3	0.5	2.3	0.1	2.47	3	0.1
	8	8.0	0.5	6.65	5	1.4	5.1	0.2	4.10	5	0.5	3.9	0.3	6.62	5	0.7	3.1	0.1	3.73	5	0.3	2.3	0.2	8.44	5	0.5
	23	8.1	0.4	4.72	5	1.0	5.1	0.2	3.10	5	0.4	3.9	0.2	4.96	5	0.5	3.3	0.1	1.68	5	0.1	2.3	0.1	5.32	5	0.3
	24	7.7	0.8	10.30	5	1.6	5.0	0.3	5.83	5	0.8	3.9	0.3	7.08	5	0.7	3.1	0.2	5.27	5	0.4	2.4	0.1	3.52	5	0.2
	25	7.7	0.4	5.11	5	1.0	5.1	0.2	3.79	5	0.5	4.0	0.2	6.00	5	0.6	3.2	0.2	5.41	5	0.4	2.4	0.1	4.53	5	0.3
	26	7.7	0.9	11.66	5	2.4	5.0	0.5	9.63	5	1.3	3.9	0.4	10.26	5	1.0	3.0	0.1	4.32	5	0.3	2.3	0.2	8.70	5	0.4
Stats for averages		7.8	0.3	3.22	8	0.7	5.0	0.1	2.81	8	0.42	3.9	0.1	2.05	8	0.3	3.1	0.1	3.16	8	0.3	2.3	0.0	1.98	8	0.1
Stats for independent		7.8	0.6	7.40	37	2.4	5.0	0.3	6.61	37	1.7	3.9	0.3	7.27	37	1.5	3.1	0.2	5.12	37	0.7	2.3	0.1	5.54	37	0.6
Samples						8.6					5.5					4.8					3.5					2.6
						6.2					3.8					3.3					2.8					2

Quality Assurance Aggregate Gradations—Original Construction

U.S. Department of Transportation
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WesTrack Report UNR-22
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on aggregate gradation determined after construction as part of the quality assurance testing program and referred to as "quality assurance aggregate gradation data." Samples of aggregate were obtained for quality control (QC) and quality assurance (QA) testing as shown in WesTrack Technical Report UNR-18.[4] WesTrack Technical Report UNR-21[5] contains the results from the QC testing program. QC testing was performed on combined cold-feed belt samples and on samples used for asphalt content determination. Loose samples of HMA were obtained from the haul vehicles and ignition ovens were used to determine asphalt binder content. Core samples of HMA were obtained from the pavement and tested for thickness, air void content, and asphalt binder content (by using the ignition oven). Gradations were determined after the ignition oven asphalt content determinations on the loose haul-vehicle samples and the core samples. As discussed below, the gradations obtained from core samples of HMA have been reported as the QA gradations.

BACKGROUND

Prior to the start of production of the HMA, the HMA production facility was calibrated. This calibration included determination of individual cold-feed rates for each aggregate, calibration of the scale belt, and calibration of the asphalt binder delivery system. During the placement of the hot mixes at WesTrack, additional calibrations were performed. The initial calibration was performed on September 8, 1995. Additional calibrations were performed on September 25, 26, 28, and 29, 1995.

HMA mixtures were placed on the ramps to the test track on September 9 and 13, 1995, to determine the constructability of the HMA, as well as to determine the gradations, asphalt binder contents, and volumetrics.

The construction of the "trial lane" and the "test lane" of the track were performed on the dates shown in table 1. The bottom lift of the trial lane was placed first, followed by placement of the bottom lift of the test lane. The top lift of the trial lane was placed prior to the top lift of the test lane. Placement of the trial lanes prior to placement of the test lanes allowed for adjustments in the binder contents and gradations and in the construction operation. The test lanes are the lanes on which the traffic was placed and from which the WesTrack performance information was obtained. Aggregate gradation information is presented only for the test lane top and bottom lifts.

SAMPLING

The core samples used for QA testing were obtained one day after construction with a 150-mm (6-in.) inside diameter core barrel. The core samples were taken at stratified random locations along the paved test sections. Samples were not obtained from the wheel paths or within 300 mm (1 ft) of the longitudinal joints or the centerline of the paving (to avoid segregation). The detailed sampling and testing plan for the original construction can be found in WesTrack Technical Report UNR-18.[4]

TEST METHODS

The asphalt binder contents were obtained on core samples by using the National Center for Asphalt Technology (NCAT) ignition oven (ASTM D 6307) and the reflux solvent extraction device (AASHTO T 164 and ASTM D 2172). After determination of the asphalt binder content, the remaining aggregate was used to determine the aggregate gradation (AASHTO T 11 and T 27).

GRADATION AND IGNITION TEST

The literature[6,7,8] suggests that the aggregate gradation can change when HMA samples are subjected to the ignition test to determine asphalt binder content. NCAT studies[6,7] indicate that the ignition oven did not affect the amount of material passing the No. 4 (4.75-mm) sieve, but the amount of material passing the No. 200 (75-μm) sieve could be affected by the ignition oven. NCAT observed changes in the amount of material passing the No. 200 (75-μm) sieve ranged from minus 0.75 to plus 2.0 percentage points for the four materials evaluated.

A similar study conducted by the Florida Department of Transportation[8] showed changes in the amount of material passing the No. 4 sieve to range from minus 0.6 to plus 0.5 percentage points. Changes in the No. 200 sieve were reported to range from plus 0.6 to 1.0 percentage points. The

NCAT researchers suggested that caution be exercised in interpreting any results from aggregate recovered after the ignition test.

Studies[9, 10, 11] were performed at the University of Nevada to investigate the effect of ignition oven calibration procedures on asphalt binder content determinations as part of the WesTrack project. As part of these studies, aggregate gradations were determined prior to and after ignition testing. These results are presented below.

IGNITION OVEN CALIBRATION STUDY

A portion of the University of Nevada ignition oven calibration study is shown in table 2. Ignition oven asphalt binder calibrations were performed on mixtures prepared with all three gradations (fine, fine plus, and coarse) used at WesTrack. Both blank (aggregate without asphalt binder) and known asphalt binder content samples were subjected to ignition oven testing and solvent (reflux) extraction testing. The aggregate was obtained from the combined cold feed samples and, therefore, represents the aggregate actually entering the plant during the production of the fine, fine plus, and coarse graded mixtures.

Aggregates were separated on individual sieve sizes (3/4-in. x 1/2-in., 1/2 x 3/8, 3/8 x No. 4, No. 4 x No. 8, No. 8 x No. 16, No. 16 x No. 30, No. 30 x No. 50, No. 50 x No. 100, No. 100 x No. 200 and percent passing the No. 200 sieve) (19.0-mm x 12.5-mm, 12.5 x 9.5, 9.5 x 4.75, 4.75 x 2.36, 2.36 x 1.18, 1.18 x 0.60, 0.60 x 0.30, 0.30 x 0.15, 0.15 x 0.075, and percent passing the 0.075-mm sieve) and combined to meet the target gradations. The gradations for the individual samples were fabricated as close to the target gradations as possible. Some slight variability in the individual sample gradations fabricated to the same target was expected.

BLANK AGGREGATE CALIBRATIONS

Samples were fabricated without asphalt binder (blank aggregate samples) and subjected to the ignition oven and reflux extraction processes for determining asphalt binder content. Gradation information obtained from this series of tests is shown in tables 3 through 18 and figures 1 through 9.

Gradations (expressed as cumulative percent passing a particular sieve size) of the blank aggregate samples after reflux extraction are shown in tables 3, 5, and 7 for the fine, fine plus, and coarse gradation, respectively. These same results are shown on a passing and retained basis in tables 9, 11, and 13. Gradations (expressed as cumulative percent passing a particular sieve size) of the blank aggregates subjected to ignition oven testing is shown in tables 4, 6, and 8 for the fine, fine plus, and coarse gradations, respectively. These same results are shown on a passing and retained basis in tables 10, 12, and 14.

Comparisons between aggregate gradation results obtained from ignition oven and reflux extraction are shown on a number of tables and figures. Figures 1 through 3 are bar charts showing the cumulative percent passing for target gradation values as well as the gradations obtained after ignition and reflux testing. Figures 4 through 6 show the gradations on a percent

passing/retained basis for the target values as well as the gradations after ignition and reflux testing for the three gradations (fine, fine plus, and coarse).

Deviations from target values for gradations obtained after the ignition oven and reflux extraction are shown in tables 15 through 17 and figures 7 through 9. The information presented for the fine graded mixture (table 15 and figure 7) indicates that the cumulative percent passing the No. 4 sieve ranged from plus 0.3 to minus 0.8 percent points relative to the target value. A trend was not evident to suggest that the ignition oven gradations were always lower or higher than the target value or that the reflux test gradations were always lower or higher than the target value for the No. 4 (4.75-mm) sieve or any other of the coarse aggregate size sieves. For the No. 200 (0.075-mm) sieve the fine graded test results suggest that the ignition oven increased the percent passing by 0.1 to 0.2 percentage points. This indicates that the ignition oven produced some minus No. 200 material. The reflux extraction results indicate that the percent passing the No. 200 sieve decreased (figure 7).

The information presented for the fine plus graded mixture (table 16 and figure 8) indicates that the cumulative percent passing the No. 4 sieve ranged from plus 0.2 to minus 0.7 percentage points relative to the target value. In general, the results from the reflux extraction suggested that the cumulative percent passing a given coarse aggregate sieve size slightly decreased (figure 8). For the No. 200 sieve, the fine plus graded test results suggest that the reflux and ignition oven decreased the percent passing the No. 200 sieve (figure 8).

The information presented for the coarse graded mixture (table 17 and figure 9) indicates that the cumulative percent passing the No. 4 sieve ranged from about plus 0.2 to minus 0.7 percentage points relative to the target value. In general, both the ignition and reflux test results indicated a decrease in cumulative percent passing on the coarse aggregate size sieves (figure 9). For the No. 200 sieve, the coarse graded test results suggest that the reflux and ignition oven decreased the percent passing the No. 200 sieve (figure 9).

KNOWN ASPHALT BINDER CONTENT CALIBRATIONS

Calibrations for asphalt binder contents were determined for the fine, fine plus, and coarse graded mixtures. Table 18 contains information obtained using the ignition test on the fine graded mixtures with various known asphalt binder contents. Differences between determined gradations after the ignition test and the target values that were used to prepare the samples ranged from minus 0.8 to plus 1.0 percentage points. For the No. 4 sieve, the difference between the determined and target values ranged from minus 0.4 to plus 0.1 percentage points. For the No. 200 sieve, the differences were minus 0.4 to plus 0.3.

Observed standard deviations for both the “blank” aggregate and “known” asphalt binder content samples were typically very low, indicating good consistency of the data. Three possible explanations exist for the relatively small differences in the observed gradations after ignition oven and reflux testing, as compared to the batched samples. First, it is likely that the batched gradations did not exactly match the target gradations due to imprecise sieving techniques and/or batching scale problems. A second reason could be the effect of the ignition oven or solvent

extraction process on aggregate gradation. A third possible reason is test method variability associated with determining aggregate gradation.

The ASTM precision and bias statement for the sieve analysis test method states that the single-operator precision (1s) for coarse sieves (with the percent of the size fraction between consecutive sieves being 20 to 50) is equal to 1.38 percent. Thus, the acceptable range of test results (d2s) for a single operator is 3.9 percent.[12] For fine sieves, the single operator precision (1s) (with the percent of the size fraction between consecutive sieves being 3 to 10) is equal to 0.43 and the acceptable range of test results from a single operator (d2s) is equal to 1.2 percent. These precision statements indicate that the variability obtained in this calibration study is most likely due to the precision of the sieve analysis test method.

REFLUX EXTRACTION — TEST SECTIONS

As part of the asphalt content calibration study effort to determine field binder contents, a series of solvent (reflux) extraction tests were performed on loose HMA samples obtained from the trucks during construction. Tables 19 through 21 contain these data. Five random samples were tested from the fine graded mixtures placed in sections 1, 3, and 14 (both top and bottom lifts); the fine plus graded mixtures placed in sections 11, 13, and 22 (both top and bottom lifts); and the coarse graded mixtures placed in sections 5, 7, and 8 (both top and bottom lifts).

TEST SECTION GRADATIONS

The gradations for each individual test section used for performance modeling are those identified as the quality assurance (QA) gradations in this report. Based on the calibration study described above, the decision was made to use the aggregate gradations obtained from the core samples after ignition testing. This decision was based on several factors including those provided below.

An attempt was made to establish an aggregate gradation correction factor for the ignition oven for the fine, fine plus, and coarse graded mixtures. This investigation included defining the difference between the target gradation and the ignition oven gradation and the difference between the reflux extraction gradation and the ignition oven gradation. Obtaining a correction factor was not possible by performing regression analyses on these differences because the differences were not consistent in magnitude or direction from the target.

The calibration study indicated that the aggregate gradation was not significantly affected by the ignition oven used to determine the asphalt binder contents of these mixtures. The differences between the target values and the ignition oven gradations and between the reflux gradations and the ignition oven gradations were small in comparison to the test method variability.

Due to the high temperature of operation the ignition oven will alter the aggregate gradation somewhat (See references 6, 7, 8, and 9.) This thermal breakdown and the loss of No. 200 material during testing with the ignition oven can be avoided with the use of the reflux extraction

device for asphalt content determination and aggregate gradation determination. Thus, using the reflux test for determination of aggregate gradation may be preferable. Environmental, health, and safety problems with solvent and the time required to perform the test have greatly reduced the use of the reflux test for asphalt binder content and aggregate gradation determination in recent years.

Since only a limited number of reflux extraction tests were performed on samples obtained from the test sections, only a limited number of gradations were available after reflux extraction. Ignition asphalt content determinations were determined on four-to-five samples per test section. Thus, gradation information after the ignition oven was available and used for QA purposes.

Tables 22 and 23 contain aggregate gradation information obtained on the core samples taken during construction and tested with the NCAT ignition test for asphalt binder content and gradation. The data are available for both the top (table 22) and bottom (table 23) lift by section number for each individual sieve. Statistical information including mean, standard deviation, coefficient of variation, and number of samples is shown in the tables. Tables 24 through 29 contain a summary of the aggregate gradation information by section. Average values are shown for both the top and bottom lift.

The construction sequence (table 1) indicates that multiple sections of fine, fine plus, and coarse gradations were placed on a single day (either top or bottom lift). Thus, the aggregate gradation information for a given construction day was summarized and is shown in tables 30 through 35. Tables 30 through 32 compare the top and bottom lift average gradation values to the target gradation values. Differences between targets and actual gradations are also shown, as well as the difference between the top and bottom lift for each individual sieve size. Statistical information for the combined fine, fine plus, and coarse graded sections (top and bottom lifts) is shown in tables 33 through 35.

SUMMARY

The QA aggregate gradation information used for performance model development is shown in tables 22 through 29 by section and in tables 30 through 35 for combined fine, fine plus, and coarse graded mixture sections. Statistical comparisons were made between top and bottom lift gradations and between gradations determined after ignition oven and reflux extraction testing as part of the calibration study. These statistical comparisons can be found in reference 10.

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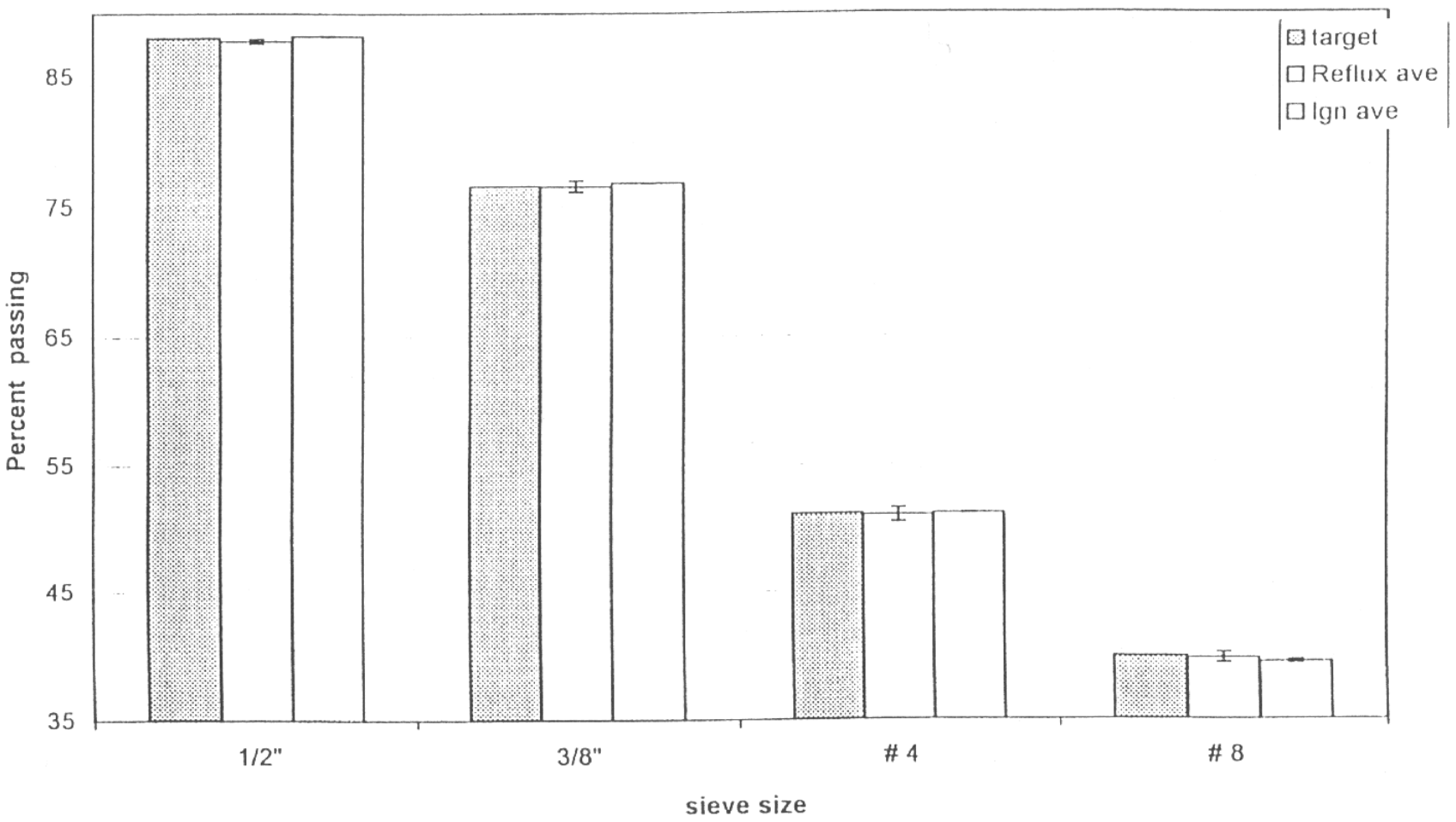

Figure 1a. Gradation data for unwashed with lime blank aggregate for fine mix (reflux and ignition).

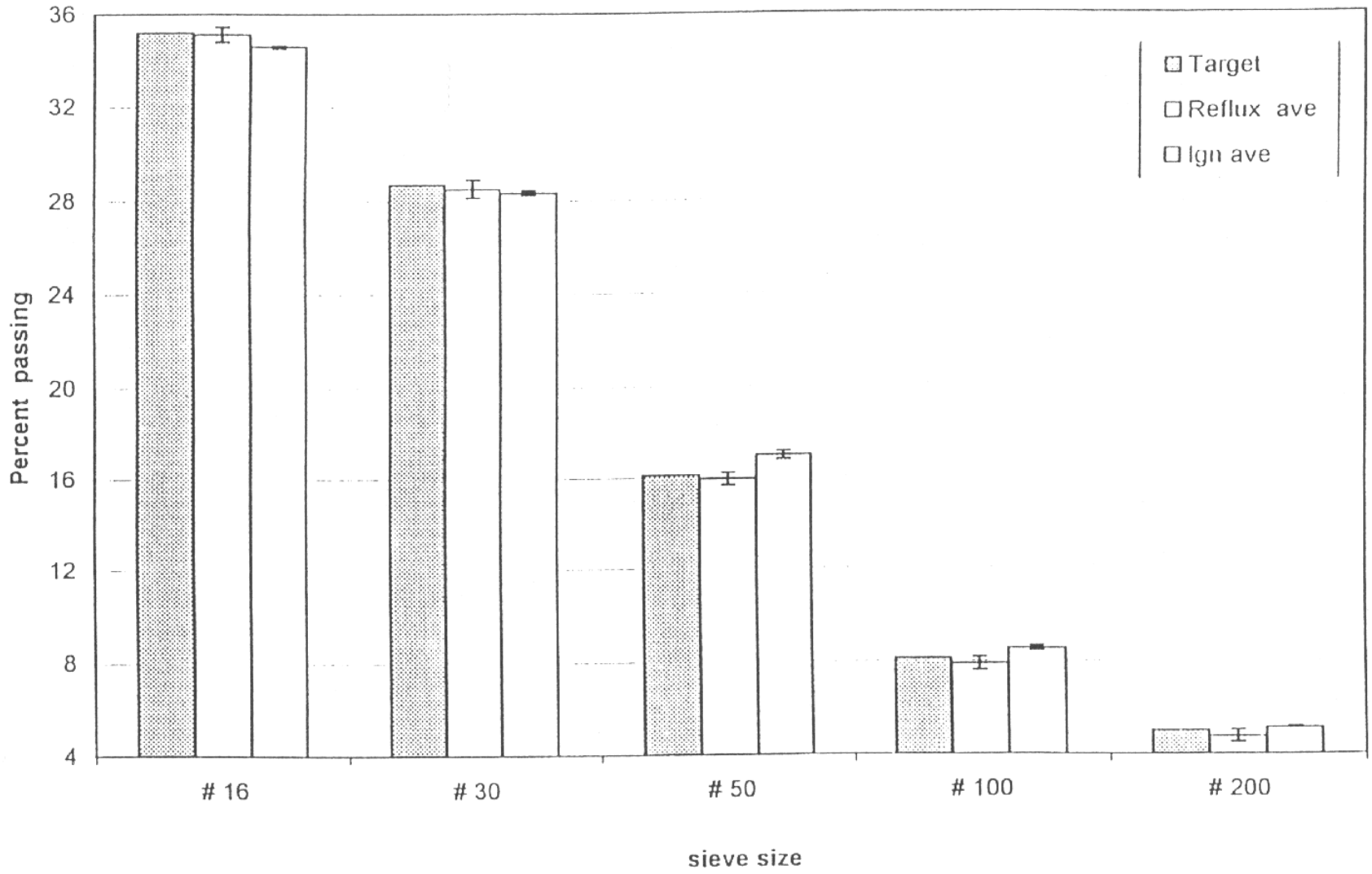

Figure 1b. Gradation data for unwashed with lime blank aggregate for fine mix (reflux and ignition).

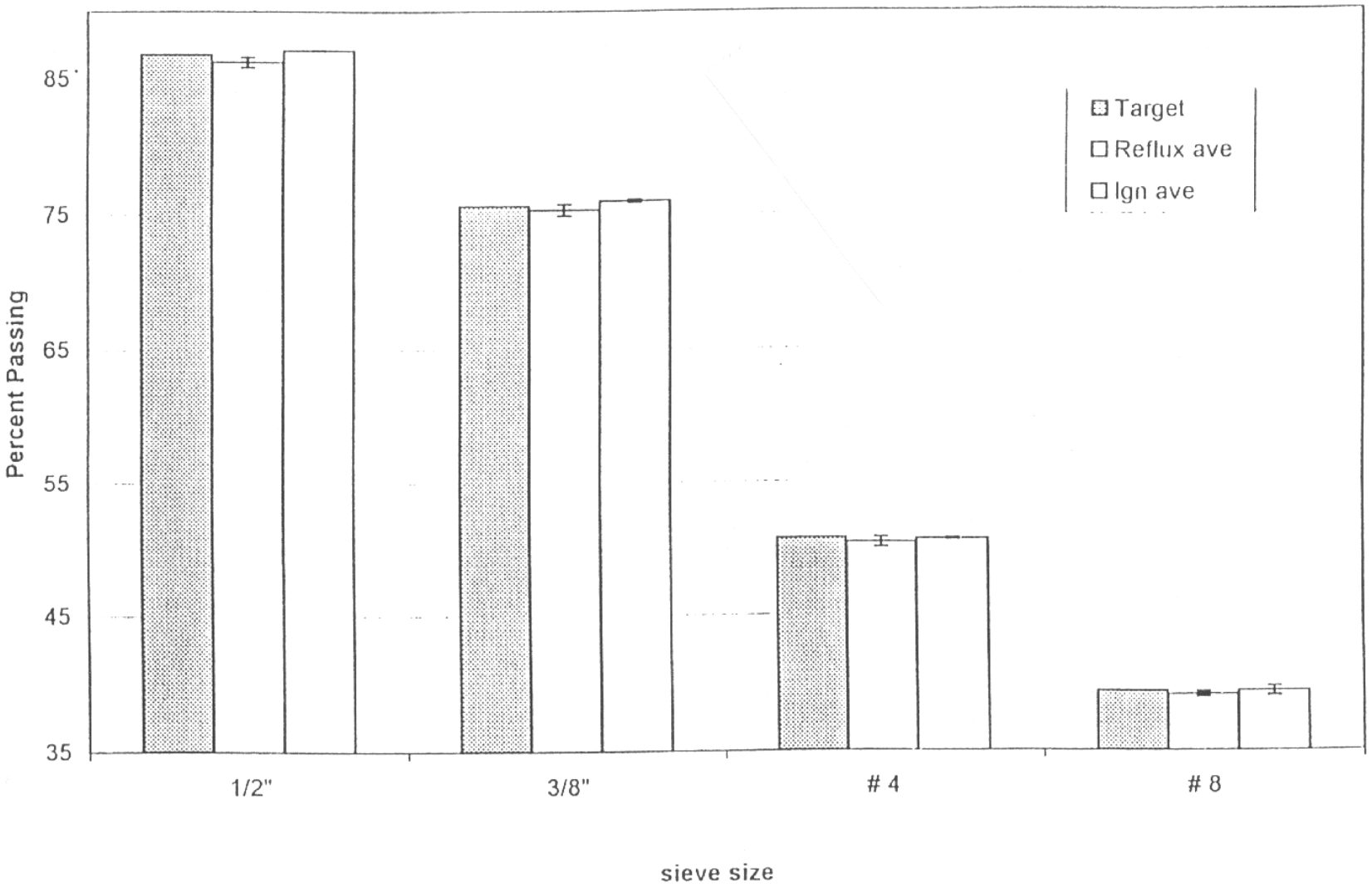

Figure 2a. Gradation data for unwashed with lime blank aggregate for fine plus mix (reflux and ignition).

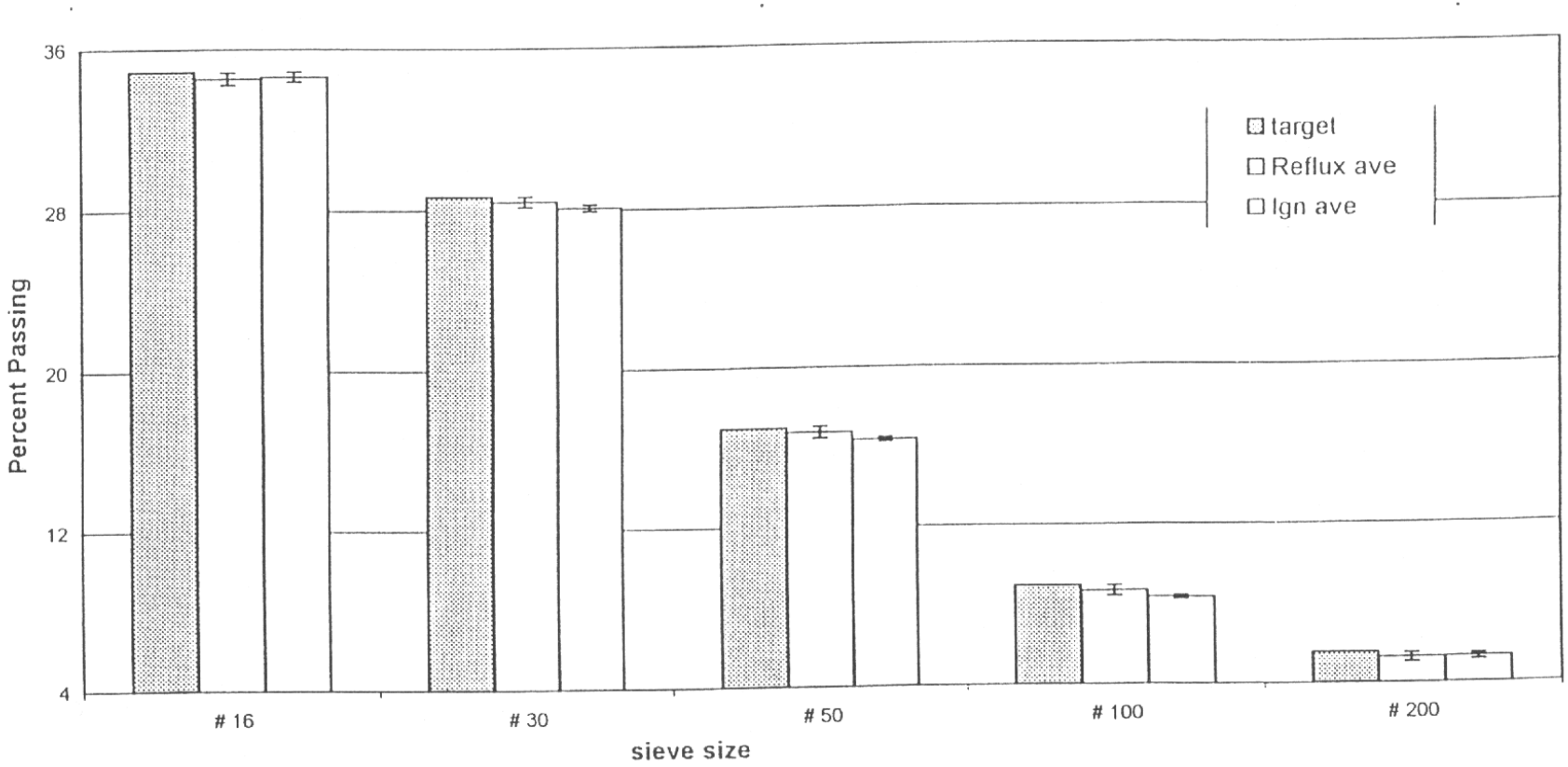

Figure 2b. Gradation data for unwashed with lime blank aggregate for fine plus mix (reflux and ignition).

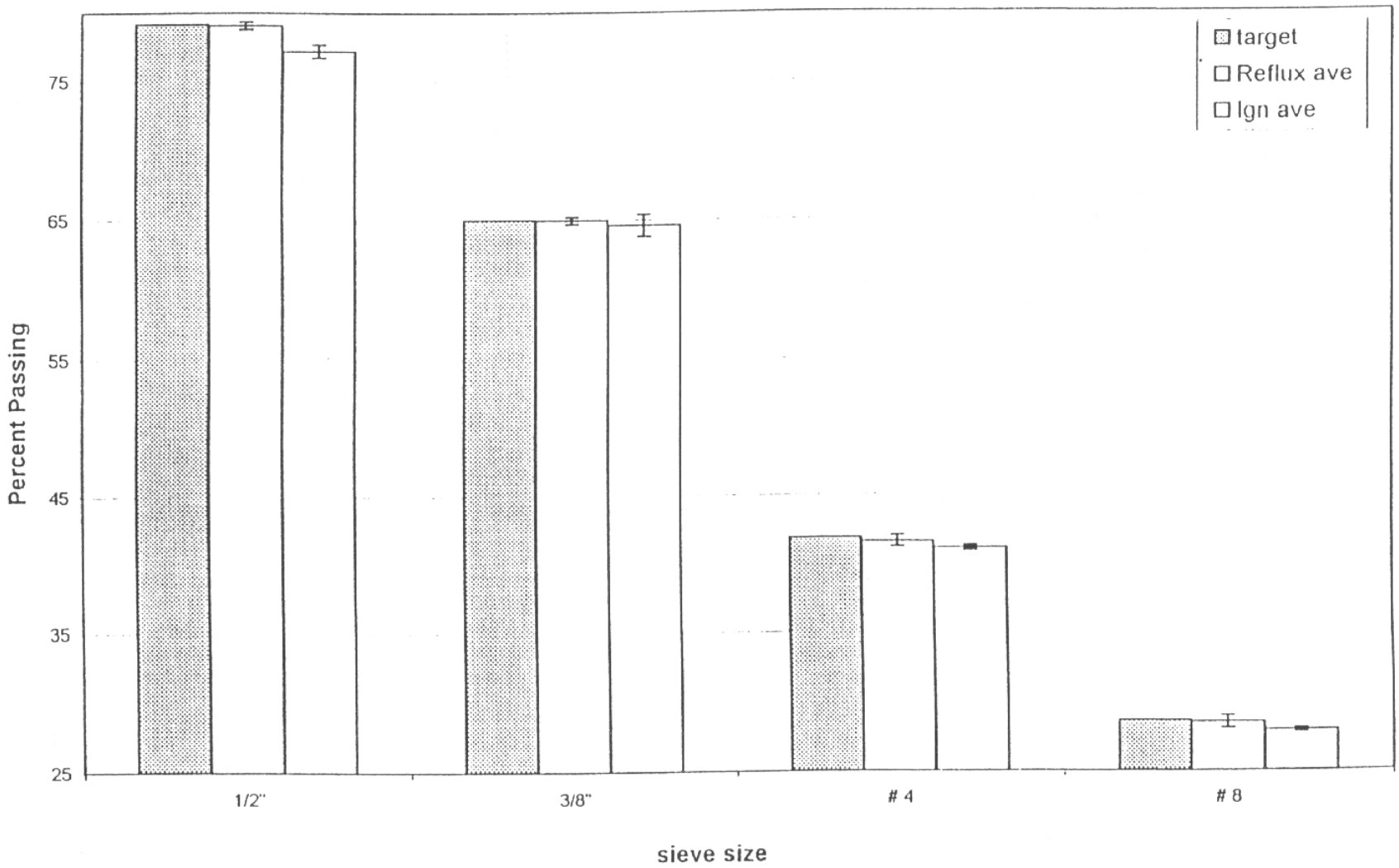

Figure 3a. Gradation data for unwashed with lime blank aggregate for coarse mix (reflux and ignition).

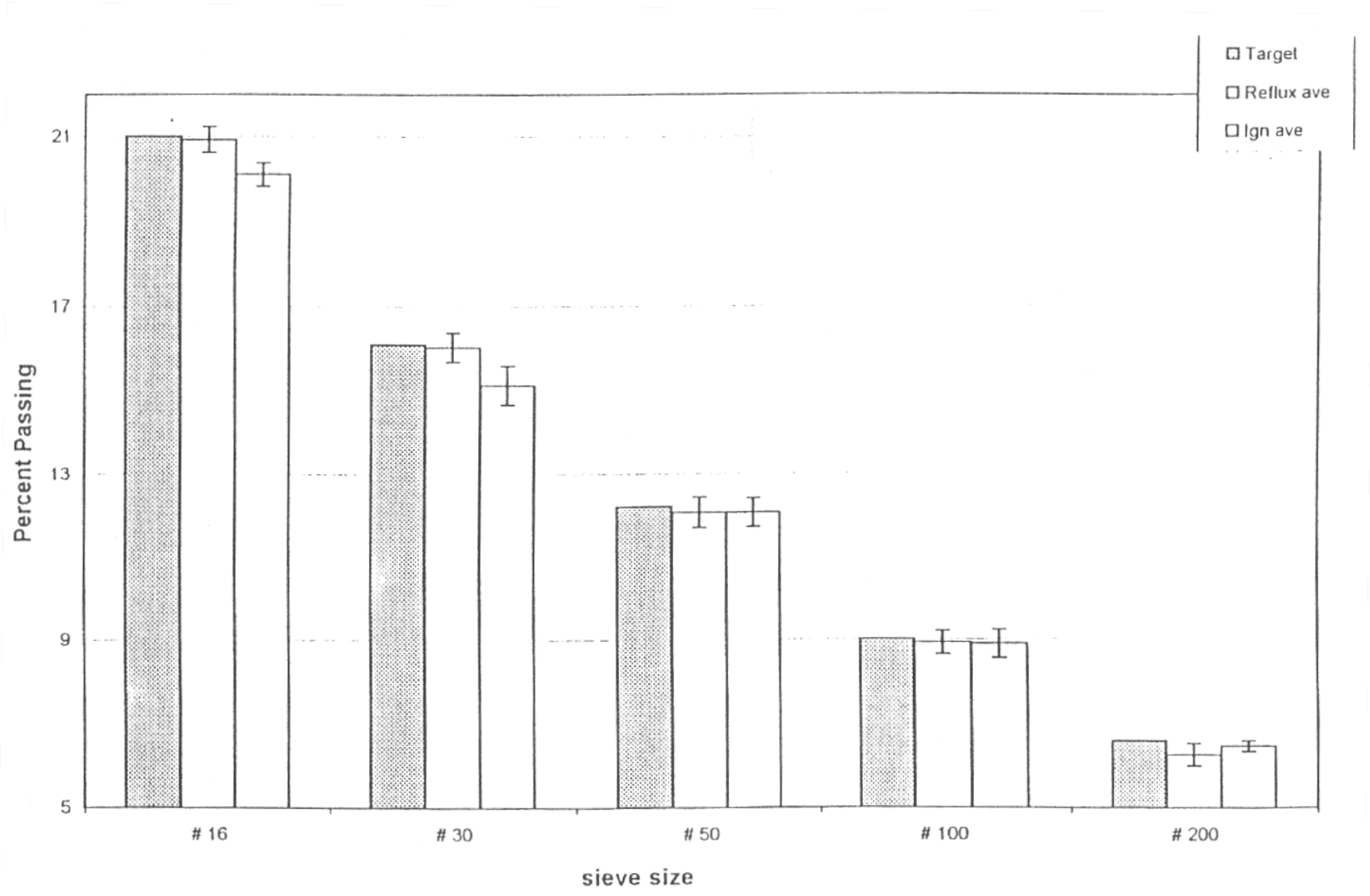

Figure 3b. Gradation data for unwashed with lime blank aggregate coarse mix (reflux and ignition).

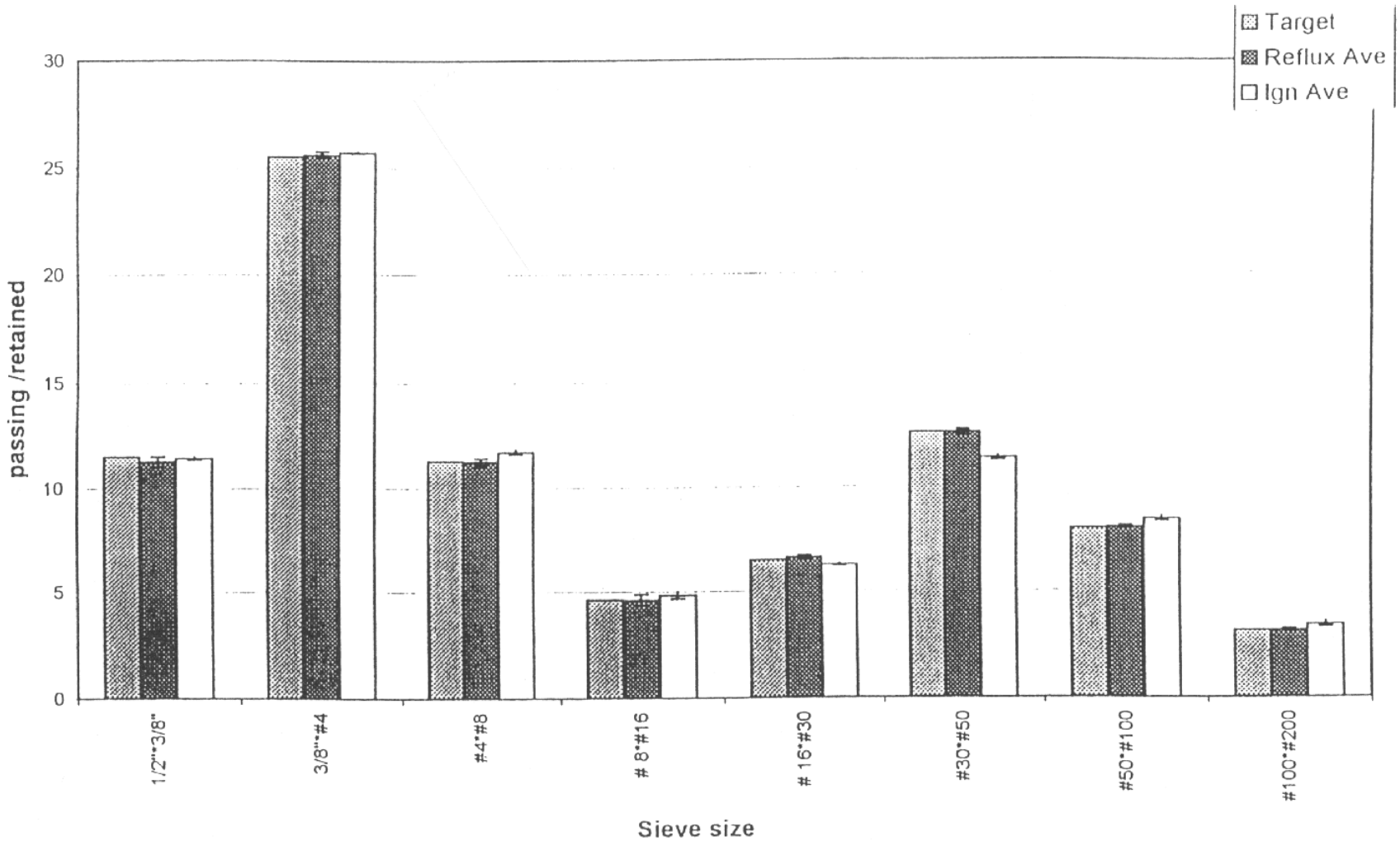

Figure 4. Gradation (passing/retained) data for unwashed with lime blank aggregate for fine mix (reflux and ignition).

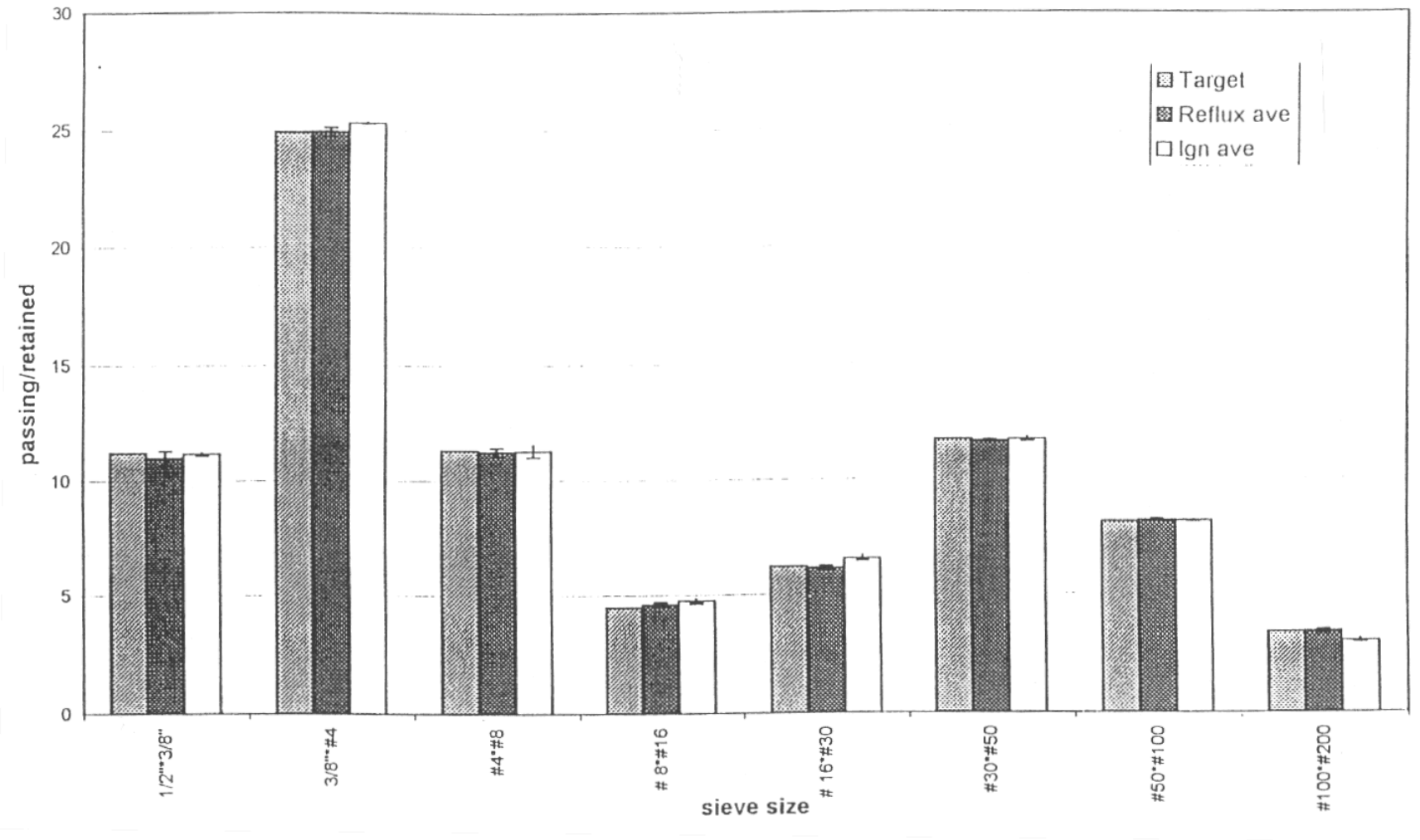

Figure 5. Gradation (passing/retained) data for unwashed with lime blank aggregate for fine plus mix (reflux and ignition).

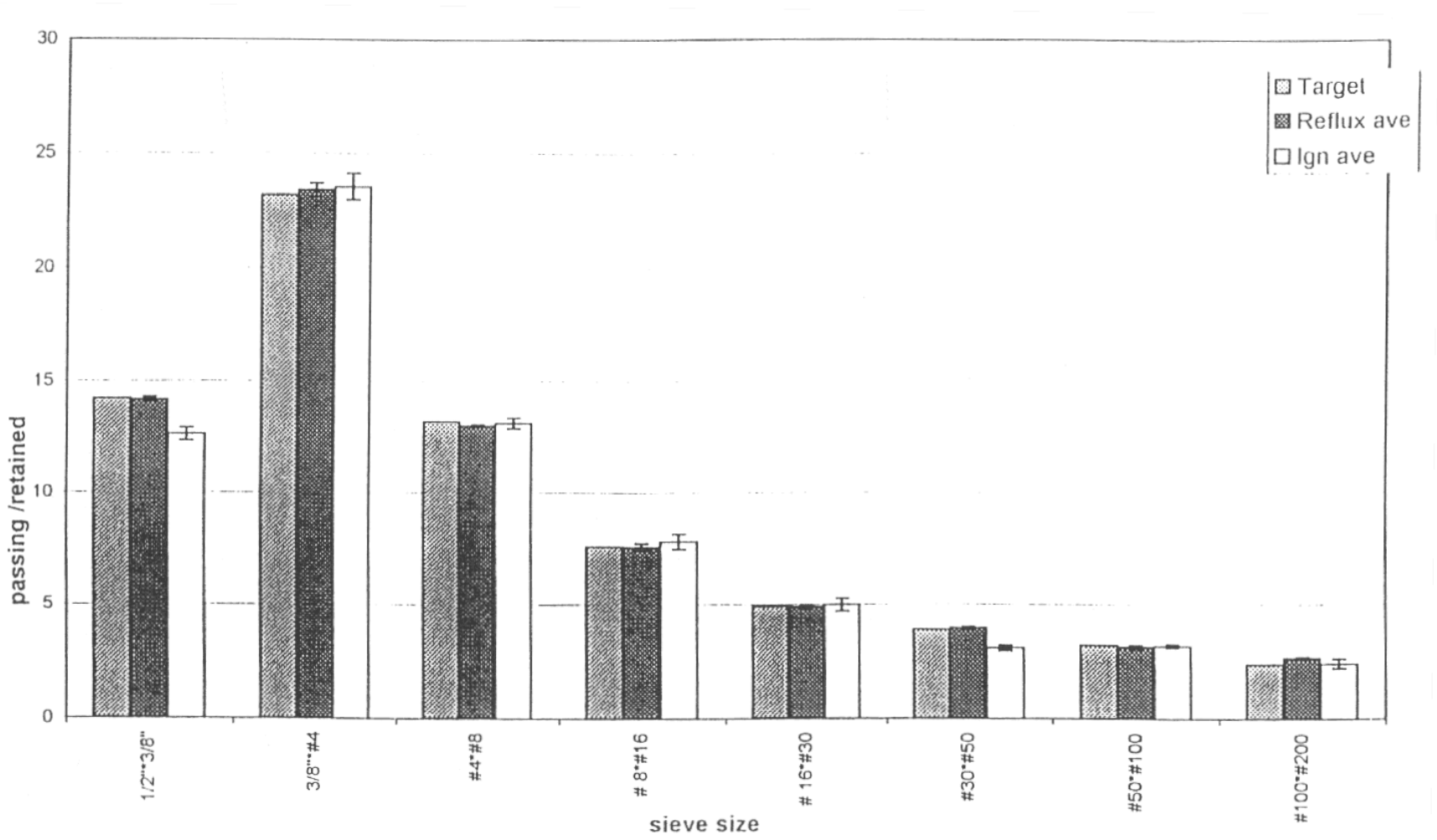

Figure 6. Gradation (passing/retained) data for unwashed with lime blank aggregate for coarse mix (reflux and ignition).

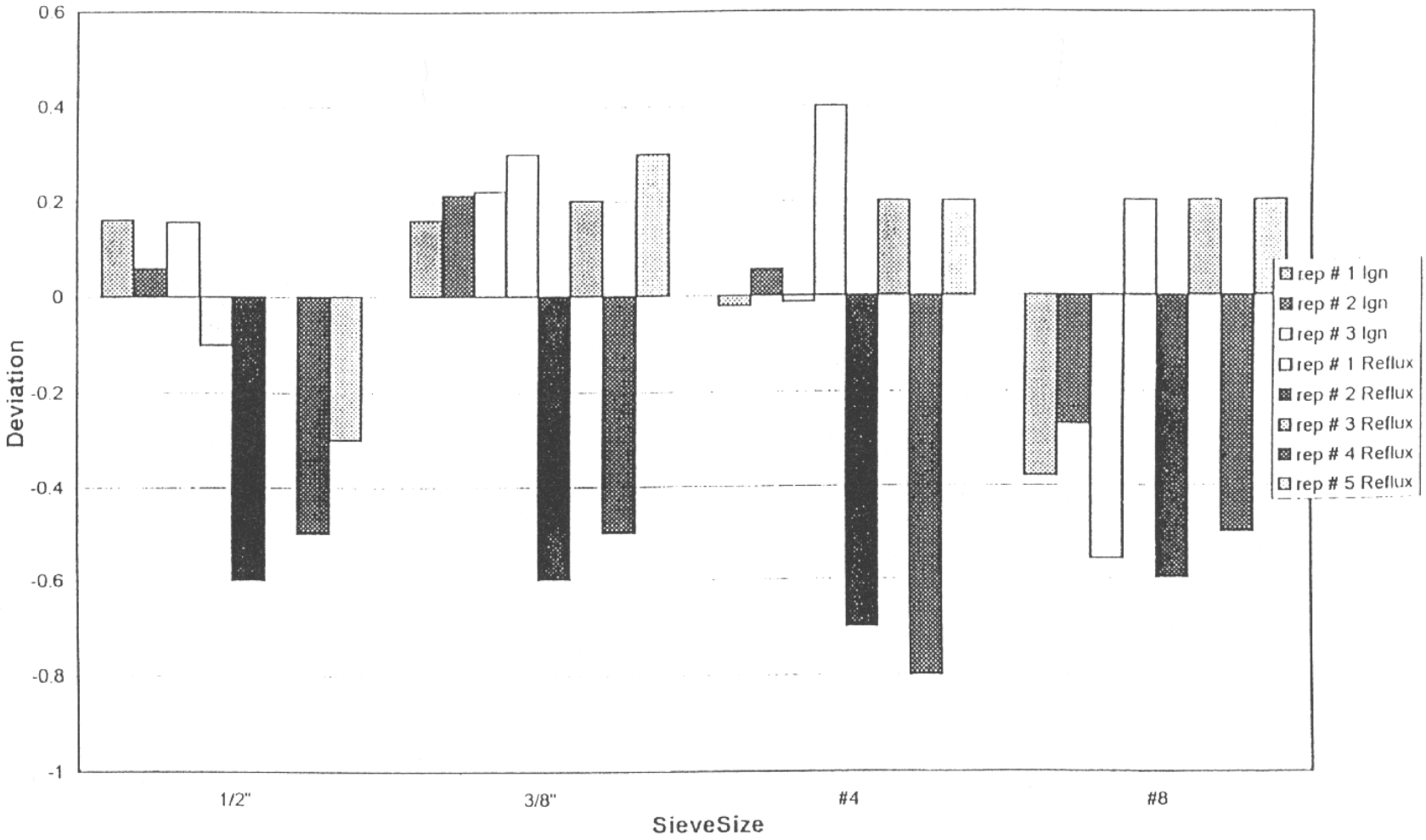

Figure 7a. Bar chart showing the deviation from the target gradation for unwashed with lime blank aggregate for fine mix (reflux and ignition).

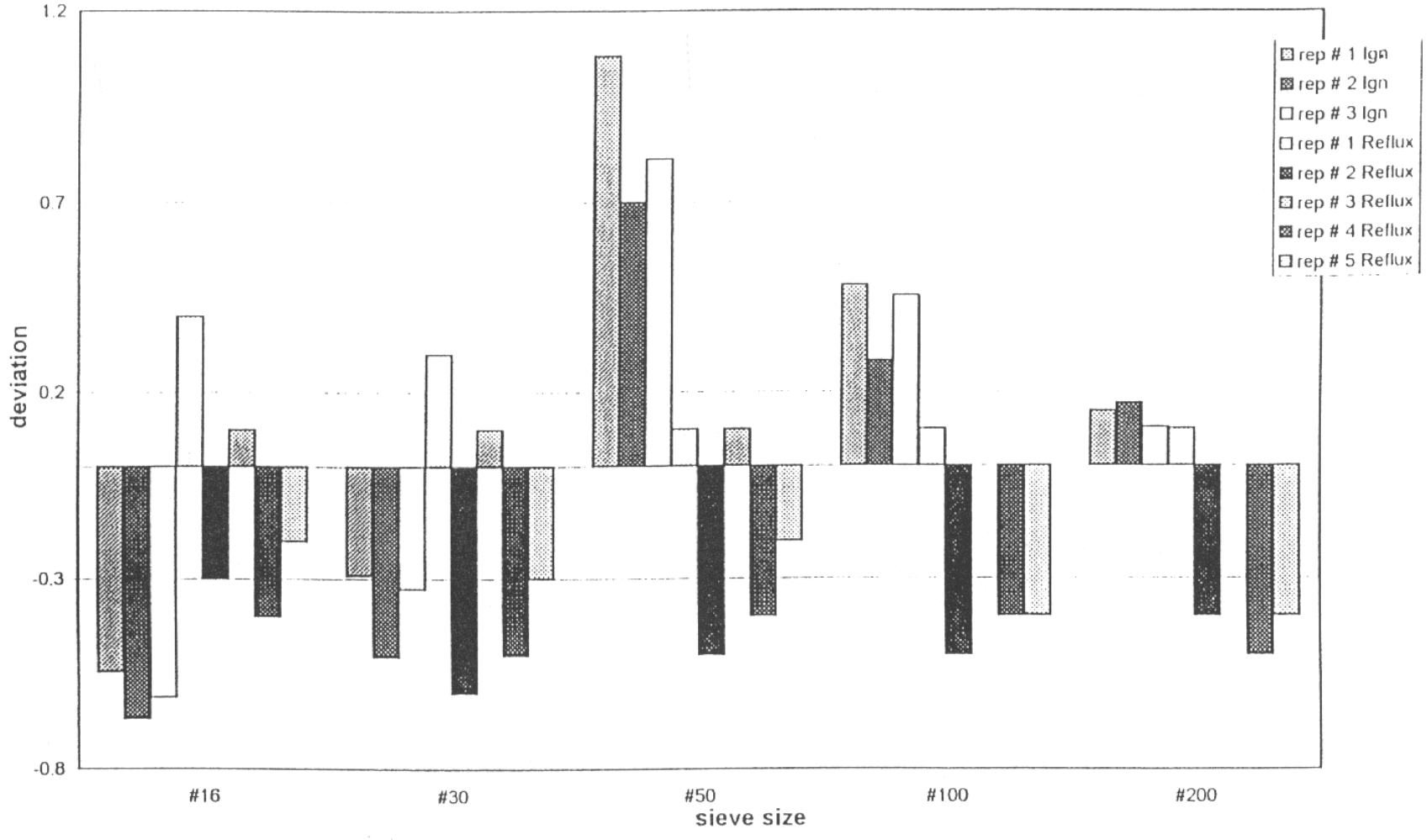

Figure 7b. Bar chart showing the deviation from the target gradation for unwashed with lime blank aggregate for fine mix (reflux and ignition).

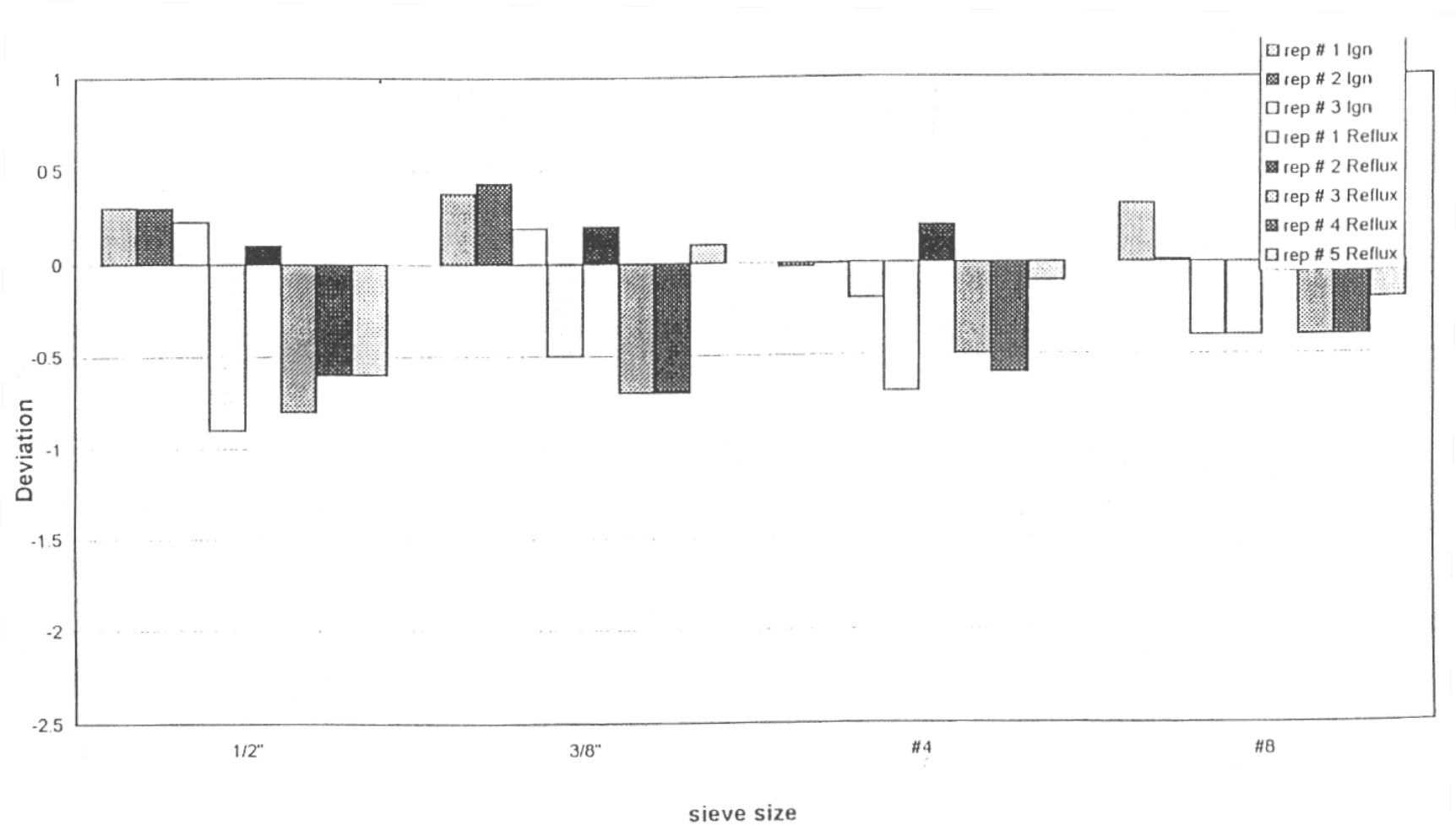

Figure 8a. Bar chart showing the deviation from the target gradation for unwashed with lime blank aggregate for fine plus mix (reflux and ignition).

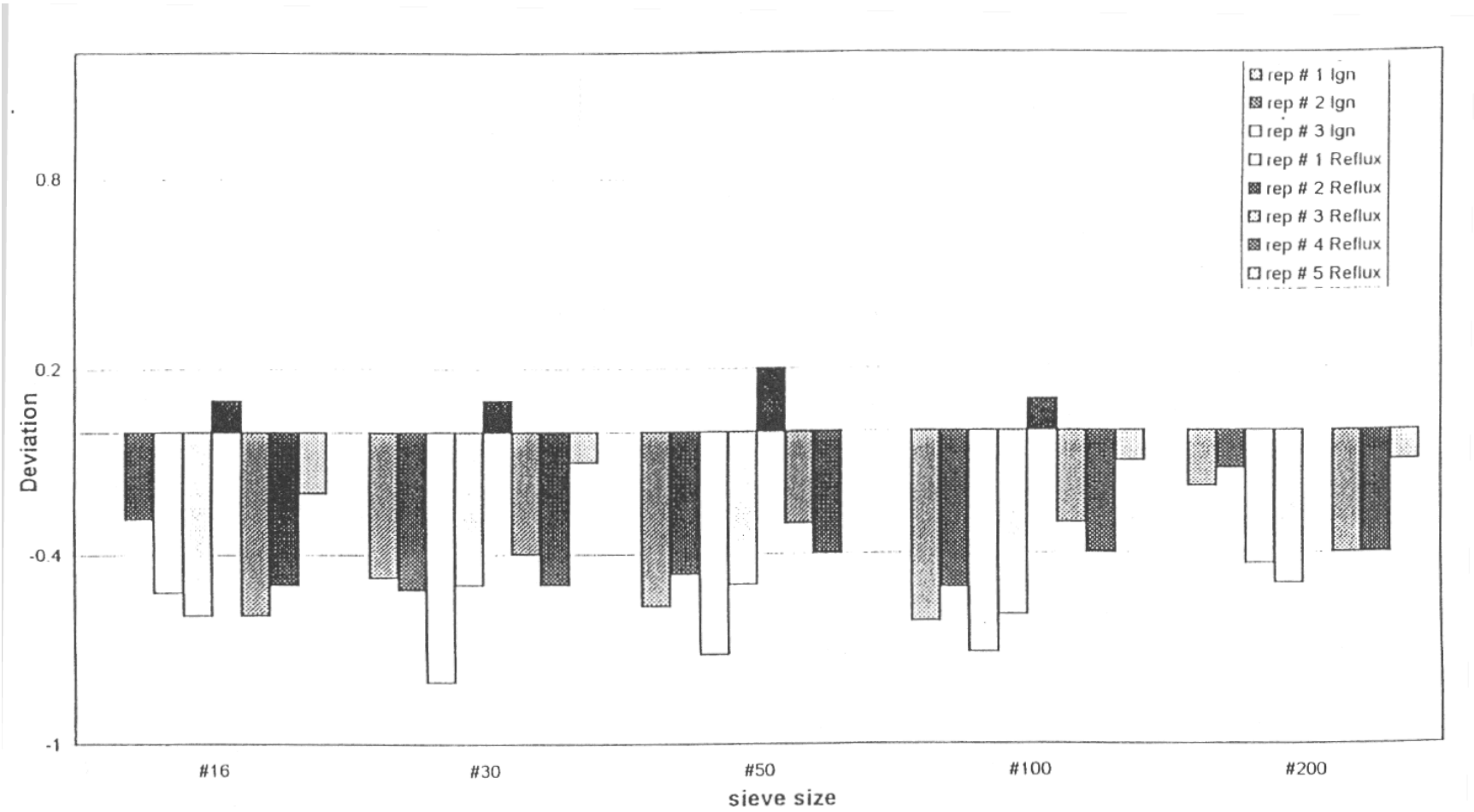

Figure 8b. Bar chart showing the deviation from the target gradation for unwashed with lime blank aggregate for fine plus mix (reflux and ignition).

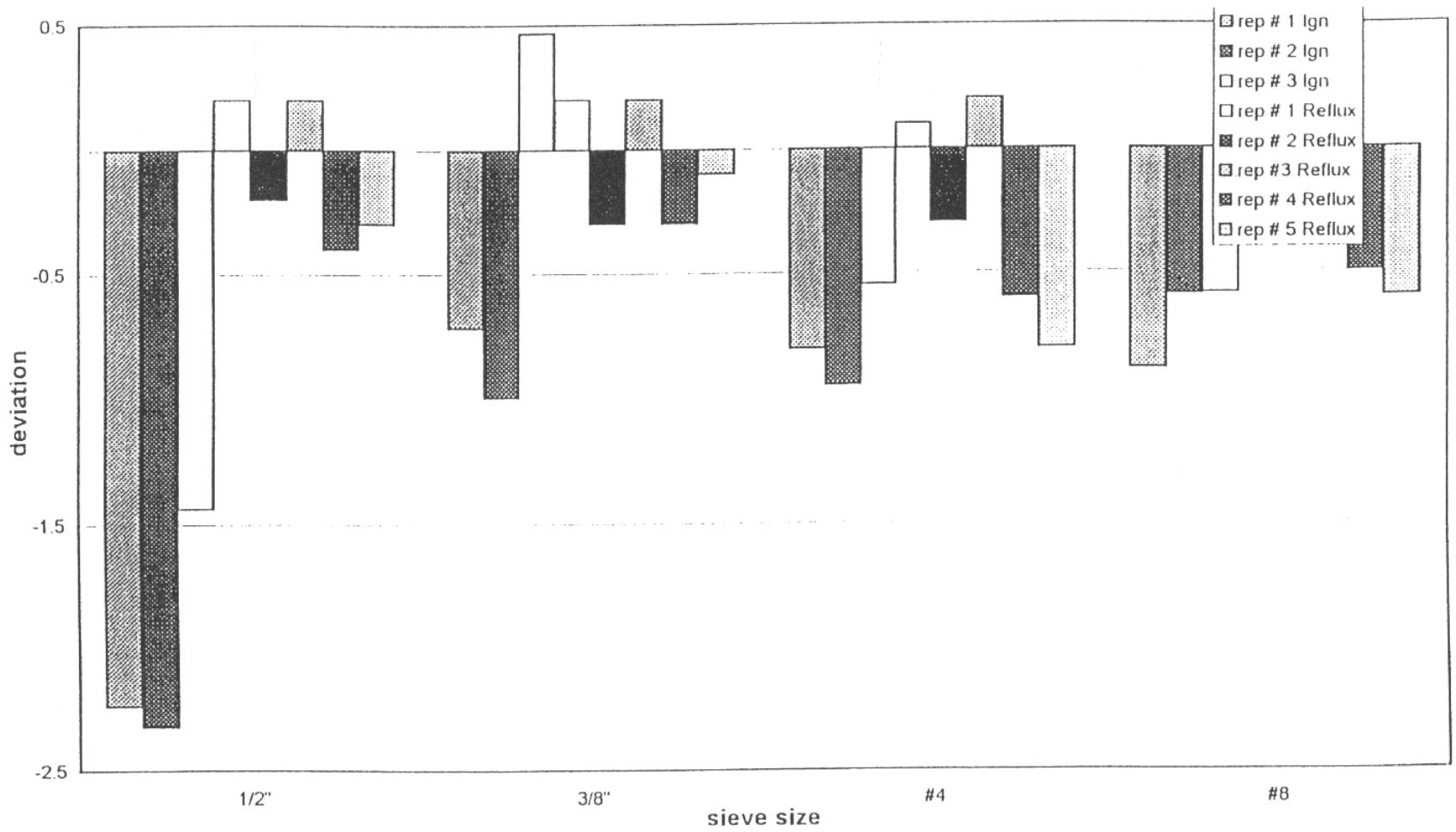

Figure 9a. Bar chart showing the deviation from the target gradation for unwashed with lime blank aggregate for coarse mix (reflux and ignition).

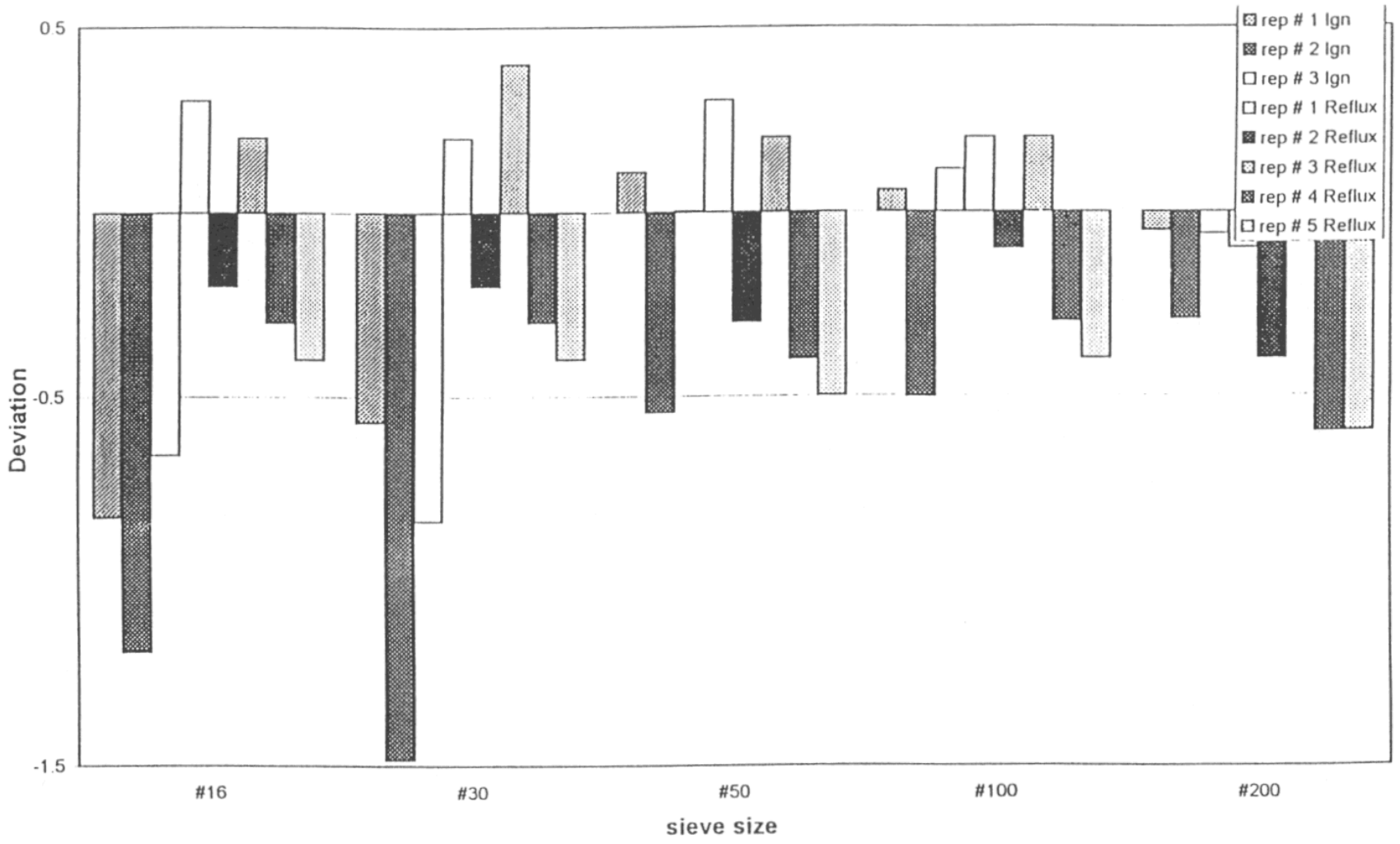

Figure 9b. Bar chart showing the deviation from the target gradation for unwashed with lime blank aggregate for coarse mix (reflux and ignition).

Table 1. Construction schedule for original construction.

Date	Mixture	Lift	Lane	Section Numbers*
9-14-95	Fine	Bottom	Trial	1,2,3,4,14,15,16,17,18
9-15-95	Fine Plus	Bottom	Trial	19,20,21,22,9,10,11,12,13
9-16-95	Coarse	Bottom	Trial	5,6,7
9-18-95	Coarse	Bottom	Trial	8,23,24,25,26
9-20-95	Fine	Bottom	Test	1,2,3,4,14,15,16,17,18
9-21-95	Fine Plus	Bottom	Test	19,20,21,22,9,10,11,12,13
9-22-95	Fine	Top	Trial	1,2,3,4,14,15,16,17,18
9-27-95	Fine Plus	Top	Trial	19,20,21,22,9,10,11,12,13
9-27-95	Fine Plus	Bottom	Test	13
9-30-95	Coarse	Bottom	Test	5,6,7,8,23,24,25,26
10-1-95	Coarse	Top	Trial	5,6,7,8,23,24,25,26
10-2-95	Fine	Top	Test	1,2,3,4,14,15,16,17,18
10-3-95	Fine Plus	Top	Test	19,20,21,22,9,10,11,12,13
10-4-95	Coarse	Top	Test	5,6,7,8,23,24,25,26

*Section numbers follow order of placement.

Table 2. Portion of UNR asphalt content calibration effort.

Construction	Material	Mix Type	Method			
			Reflux		Ignition	
			Blank Aggregate	Known % AC	Blank Aggregate	Known % AC
Original	Cold Feed	Fine	3*	3	3	3
			3	3	3	3
			3	3	3	3
Replacement	Cold Feed	Replacement	3	3	3	3

*Indicates number of replicates tested under each condition.

Table 3. Gradation after reflux for unwashed with lime blank aggregate for fine mixes.

Sieve Size	Percent Passing											
	Target	Replicate					Ave	Std	Cov	Max	Min	Range
		1	2	3	4	5						
1/2”	88.1	88	87.5	88.1	87.6	87.8	87.8	0.25	0.3	88.1	87.5	0.6
3/8”	76.6	76.9	76	76.8	76.1	76.9	76.5	0.45	0.6	76.9	76	0.9
#4	51.1	51.5	50.4	51.3	50.3	51.3	51.0	0.56	1.1	51.5	50.3	1.2
#8	39.8	40	39.2	40	39.3	40	39.7	0.41	1.0	40.0	39.2	0.8
#16	35.2	35.6	34.9	35.3	34.8	35	35.1	0.33	0.9	35.6	34.8	0.8
#30	28.7	29	28.1	28.8	28.2	28.4	28.5	0.39	1.4	29.0	28.1	0.9
#50	16.1	16.2	15.6	16.2	15.7	15.9	15.9	0.28	1.7	16.2	15.6	0.6
#100	8.1	8.2	7.6	8.1	7.7	7.7	7.9	0.27	3.4	8.2	7.6	0.6
#200	5	5.1	4.6	5	4.5	4.6	4.8	0.27	5.7	5.1	4.5	0.6

Table 4. Gradation after ignition oven for unwashed with lime blank aggregate for fine mixes.

Sieve Size	Percent Passing				Ave	Std	Cov	Max	Min	Range
	Target	Rep 1	Rep 2	Rep 3						
1/2”	88.1	88.3	88.2	88.3	88.2	0.06	0.07	88.3	88.2	0.1
3/8”	76.6	76.8	76.8	76.8	76.8	0.03	0.04	76.8	76.8	0.1
#4	51.1	51.1	51.2	51.1	51.1	0.04	0.08	51.2	51.1	0.1
#8	39.8	39.4	39.5	39.2	39.4	0.15	0.37	39.5	39.2	0.3
#16	35.2	34.7	34.5	34.6	34.6	0.06	0.18	34.7	34.5	0.1
#30	28.7	28.4	28.2	28.4	28.3	0.11	0.40	28.4	28.2	0.2
#50	16.1	17.2	16.8	16.9	17.0	0.20	1.16	17.2	16.8	0.4
#100	8.1	8.6	8.4	8.6	8.5	0.11	1.28	8.6	8.4	0.2
#200	5	5.1	5.2	5.1	5.1	0.03	0.66	5.2	5.1	0.1

Table 5. Gradation after reflux for unwashed with lime blank aggregate for fine plus mixes.

Sieve Size	Percent Passing											
	Target	Replicate					Ave	Std	Cov	Max	Min	Range
		1	2	3	4	5						
1/2”	86.8	85.9	96.9	86	86.2	86.2	86.24	0.39	0.45	86.9	85.9	1
3/8”	75.6	75.1	75.8	74.9	74.9	75.7	75.28	0.44	0.58	75.8	74.9	0.9
#4	50.7	50	50.9	50.2	50.1	50.6	50.36	0.38	0.75	50.9	50	0.9
#8	39.4	39	39.5	39	39	39.2	39.14	0.22	0.56	39.5	39	0.5
#16	34.9	34.3	35	34.3	34.4	34.7	34.54	0.30	0.88	35	34.3	0.7
#30	28.7	28.2	28.8	28.3	28.2	28.6	28.42	0.27	0.94	28.8	28.2	0.6
#50	17	16.5	17.2	16.7	16.6	17	16.8	0.29	1.74	17.2	16.5	0.7
#100	8.9	8.3	9	8.6	8.5	8.8	8.64	0.27	3.13	9	8.3	0.7
#200	5.5	5	5.5	5.1	5.1	5.4	5.22	0.22	4.15	5.5	5	0.5

Table 6. Gradation after ignition oven for unwashed with lime blank aggregate for fine plus mixes.

Sieve Size	Percent Passing				Ave	Std	Cov	Max	Min	Range
	Target	Rep 1	Rep 2	Rep 3						
1/2”	88.1	87.1	87.1	87.0	87.1	0.04	0.05	87.1	87.0	0.1
3/8”	76.6	76.0	76.0	75.8	75.9	0.13	0.17	76.0	75.8	0.2
#4	51.1	50.7	50.7	50.5	50.6	0.10	0.20	50.7	50.5	0.2
#8	39.8	39.7	39.4	39.0	39.4	0.36	0.91	39.7	39.0	0.7
#16	35.2	34.9	34.6	34.4	34.6	0.26	0.76	34.9	34.4	0.5
#30	28.7	28.2	28.2	27.9	28.1	0.18	0.64	28.2	27.9	0.3
#50	16.1	16.4	16.5	16.3	16.4	0.13	0.78	16.5	16.3	0.3
#100	8.1	8.3	8.4	8.2	8.3	0.10	1.23	8.4	8.2	0.2
#200	5.0	5.3	5.4	5.1	5.3	0.16	3.14	5.4	5.1	0.3

Table 7. Gradation after reflux for unwashed with lime blank aggregate for coarse mixes.

Sieve Size	Percent Passing											
	Target	Replicate					Ave	Std	Cov	Max	Min	Range
		1	2	3	4	5						
1/2”	79.2	79.4	79	79.4	78.8	78.9	79.1	0.28	0.36	79.4	78.8	0.6
3/8”	65	65.2	64.7	65.2	64.7	64.9	64.94	0.25	0.39	65.2	64.7	0.5
#4	41.8	41.9	41.5	42	41.2	41	41.52	0.43	1.04	42	41	1
#8	28.6	29	28.5	28.9	28.1	28	28.5	0.45	1.59	29	28	1
#16	21	21.3	20.8	21.2	20.7	20.6	20.92	0.31	1.49	21.3	20.6	0.7
#30	16.1	16.3	15.9	16.5	15.8	15.7	16.04	0.34	2.14	16.5	15.7	0.8
#50	12.2	12.5	11.9	12.4	11.8	11.7	12.06	0.36	3.02	12.5	11.7	0.8
#100	9	9.2	8.9	9.2	8.7	8.6	8.92	0.28	3.11	9.2	8.6	0.6
#200	6.6	6.5	6.2	6.6	6	6	6.26	0.28	4.46	6.6	6	0.6

Table 8. Gradation after ignition oven for unwashed with lime blank aggregate for coarse mixes.

Sieve Size	Percent Passing				Ave	Std	Cov	Max	Min	Range
	Target	Rep 1	Rep 2	Rep 3						
1/2”	79.2	77.0	76.9	77.8	77.2	0.5	0.6	77.8	76.9	0.9
3/8”	65.0	64.3	64.0	65.5	64.6	0.8	1.2	65.5	64.0	1.5
#4	41.8	41.0	40.9	41.3	41.0	0.2	0.5	41.3	40.9	0.4
#8	28.6	27.7	28.0	28.0	27.9	0.2	0.6	28.0	27.7	0.3
#16	21.0	20.2	19.8	20.3	20.1	0.3	1.4	20.3	19.8	0.5
#30	16.1	15.5	14.6	15.3	15.1	0.5	3.1	15.5	14.6	0.9
#50	12.2	12.3	11.7	12.2	12.1	0.4	2.9	12.3	11.7	0.7
#100	9.0	9.1	8.5	9.1	8.9	0.3	3.8	9.1	8.5	0.6
#200	6.6	6.5	6.3	6.5	6.5	0.1	2.1	6.5	6.3	0.2

Table 9. Gradation after reflux for unwashed with lime blank aggregate for fine mixes.

Sieve Size	Percent Passing											
	Target	Replicate					Ave	Std	Cov	Max	Min	Range
		1	2	3	4	5						
1/2”*3/8”	11.5	11.1	11.5	11.3	11.5	10.9	11.3	0.26	2.3	11.5	10.9	0.6
3/8”*#4	25.5	25.4	25.6	25.5	25.8	25.6	25.6	0.15	0.6	25.8	25.4	0.4
#4*#8	11.3	11.5	11.2	11.3	11	11.3	11.3	0.18	1.6	11.5	11	0.5
#8*#16	4.6	4.4	4.3	4.7	4.5	5	4.6	0.28	6.1	5.0	4.3	0.7
#16*#30	6.5	6.6	6.8	6.5	6.6	6.6	6.6	0.11	1.7	6.8	6.5	0.3
#30*#50	12.6	12.8	12.5	12.6	12.5	12.5	12.6	0.13	1.0	12.8	12.5	0.3
#50*#100	8	8	8	8.1	8	8.2	8.1	0.09	1.1	8.2	8	0.2
#100*#200	3.1	3.1	3	3.1	3.2	3.1	3.1	0.07	2.3	3.2	3	0.2

Table 10. Gradation (passing/retained) after ignition oven for unwashed with lime blank aggregate for fine mixes.

Sieve Size	Percent Passing				Ave	Std	Cov	Max	Min	Range
	Target	Rep 1	Rep 2	Rep 3						
1/2”*3/8”	11.5	11.5	11.3	11.4	11.4	0.08	0.68	11.5	11.3	0.2
3/8”*#4	25.5	25.7	25.7	25.7	25.7	0.04	0.15	25.7	25.7	0.1
#4*#8	11.3	11.7	11.6	11.8	11.7	0.12	1.09	11.8	11.6	0.2
#8*#16	4.6	4.8	5.0	4.7	4.8	0.18	3.67	5.0	4.7	0.3
#16*#30	6.5	6.2	6.3	6.2	6.3	0.06	1.01	6.3	6.2	0.1
#30*#50	12.6	11.2	11.4	11.5	11.4	0.12	1.06	11.5	11.2	0.2
#50*#100	8.0	8.6	8.4	8.4	8.5	0.13	1.48	8.6	8.4	0.2
#100*#200	3.1	3.4	3.2	3.4	3.4	0.13	3.98	3.4	3.2	0.2

Table 11. Gradation (passing/retained) after reflux for unwashed with lime blank aggregate for fine plus mixes.

Sieve Size	Percent Passing											
	Target	Replicate					Ave	Std	Cov	Max	Min	Range
		1	2	3	4	5						
1/2”*3/8”	11.2	10.8	11.1	11.1	11.3	10.5	11.0	0.3	2.9	11.0	10.5	0.5
3/8”*#4	24.9	25.1	24.9	24.7	24.8	25.1	24.9	0.2	0.7	24.9	24.7	0.2
#4*#8	11.3	11	11.4	11.2	11.1	11.4	11.2	0.2	1.6	11.2	11.0	0.2
#8*#16	4.5	4.7	4.5	4.7	4.6	4.5	4.6	0.1	2.2	4.6	4.5	0.1
#16*#30	6.2	6.1	6.2	6	6.2	6.1	6.1	0.1	1.4	6.1	6.0	0.1
#30*#50	11.7	11.7	11.6	11.6	11.6	11.6	11.6	0.0	0.4	11.6	11.6	0.0
#50*#100	8.1	8.2	8.2	8.1	8.1	8.2	8.2	0.1	0.7	8.2	8.1	0.1
#100*#200	3.4	3.3	3.5	3.5	3.4	3.4	3.4	0.1	2.4	3.4	3.3	0.1

Table 12. Gradation (passing/retained) after ignition oven for unwashed with lime blank aggregate for fine plus mixes.

Sieve Size	Percent Passing				Ave	Std	Cov	Max	Min	Range
	Target	Rep 1	Rep 2	Rep 3						
1/2”*3/8”	11.5	11.1	11.1	11.2	11.1	0.09	0.78	11.2	11.1	0.2
3/8”*#4	25.5	25.3	25.3	25.3	25.3	0.03	0.12	25.3	25.3	0.1
#4*#8	11.3	11.0	11.3	11.5	11.2	0.27	2.43	11.5	11.0	0.5
#8*#16	4.6	4.8	4.8	4.6	4.7	0.11	2.24	4.8	4.6	0.2
#16*#30	6.5	6.7	6.4	6.5	6.5	0.13	1.96	6.7	6.4	0.2
#30*#50	12.6	11.8	11.6	11.6	11.7	0.09	0.81	11.8	11.6	0.2
#50*#100	8.0	8.1	8.1	8.1	8.1	0.03	0.38	8.1	8.1	0.1
#100*#200	3.1	3.0	3.0	3.1	3.0	0.08	2.64	3.1	3.0	0.2

Table 13. Gradation (passing/retained) after reflux for unwashed with lime blank aggregate for coarse mixes.

Sieve Size	Percent Passing											
	Target	Replicate					Ave	Std	Cov	Max	Min	Range
		1	2	3	4	5						
1/2”*3/8”	14.2	14.2	14.3	14.2	14.1	14	14.2	0.1	11.3	10.7	10.1	9.3
3/8”*#4	23.2	23.2	23.2	23.2	23.5	23.9	23.4	0.3	18.9	18.0	16.9	15.5
#4*#8	13.2	12.9	13	13.1	13.1	13	13.0	0.1	10.5	9.9	9.3	8.5
#8*#16	7.6	7.7	7.7	7.7	7.4	7.4	7.6	0.2	6.0	5.7	5.4	5.0
#16*#30	4.9	5	4.9	4.7	4.9	4.9	4.9	0.1	3.9	3.7	3.5	3.2
#30*#50	3.9	3.8	4	4.1	4	4	4.0	0.0	3.2	3.1	2.9	2.6
#50*#100	3.2	3.3	3	3.2	3.1	3.1	3.1	0.1	2.5	2.4	2.2	2.1
#100*#200	2.4	2.7	2.7	2.6	2.7	2.6	2.7	0.1	2.1	2.0	1.9	1.8

Table 14. Gradation (passing/retained) after ignition oven for unwashed with lime blank aggregate for coarse mixes.

Sieve Size	Percent Passing				Ave	Std	Cov	Max	Min	Range
	Target	Rep 1	Rep 2	Rep 3						
1/2”*3/8”	14.2	12.7	12.9	12.3	12.6	0.3	2.3	12.9	12.3	0.6
3/8”*#4	23.2	23.3	23.2	24.2	23.6	0.6	2.5	24.2	23.2	1.1
#4*#8	13.2	13.3	12.8	13.2	13.1	0.2	1.8	13.3	12.8	0.4
#8*#16	7.6	7.5	8.2	7.7	7.8	0.3	4.5	8.2	7.5	0.7
#16*#30	4.9	4.6	5.2	5.1	5.0	0.3	5.8	5.2	4.6	0.5
#30*#50	3.9	3.2	3.0	3.1	3.1	0.1	4.2	3.2	3.0	0.3
#50*#100	3.2	3.3	3.2	3.1	3.2	0.1	2.6	3.3	3.1	0.2
#100*#200	2.4	2.5	2.2	2.6	2.4	0.2	8.5	2.6	2.2	0.4

Table 15. Deviation from target gradation for unwashed with lime blank aggregate for fine mix.

Sieve Size	Percent Passing								
	Ignition				Reflux				
	Target	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
1/2”	88.1	0.2	0.1	0.2	-0.1	-0.6	0.0	-0.5	-0.3
3/8”	76.6	0.2	0.2	0.2	0.3	-0.6	0.2	-0.5	0.3
#4	51.1	0.0	0.1	0.0	0.4	-0.7	0.2	-0.8	0.2
#8	39.8	-0.4	-0.3	-0.6	0.2	-0.6	0.2	-0.5	0.2
#16	35.2	-0.5	-0.7	-0.6	0.4	-0.3	0.1	-0.4	-0.2
#30	28.7	-0.3	-0.5	-0.3	0.3	-0.6	0.1	-0.5	-0.3
#50	16.1	1.1	0.7	0.8	0.1	-0.5	0.1	-0.4	-0.2
#100	8.1	0.5	0.3	0.5	0.1	-0.5	0.0	-0.4	-0.4
#200	5	0.1	0.2	0.1	0.1	-0.4	0.0	-0.5	-0.4

Table 16. Deviation from target gradation for unwashed with lime blank aggregate for fine plus mix.

Sieve Size	Percent Passing								
	Ignition				Reflux				
	Target	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
1/2”	86.8	0.3	0.3	0.2	-0.9	0.1	-0.8	-0.6	-0.6
3/8”	75.6	0.4	0.4	0.2	-0.5	0.2	-0.7	-0.7	0.1
#4	50.7	0.0	0.0	-0.2	-0.7	0.2	-0.5	-0.6	-0.1
#8	39.4	0.3	0.0	-0.4	-0.4	0.1	-0.4	-0.4	-0.2
#16	34.9	0.0	-0.3	-0.5	-0.6	0.1	-0.6	-0.5	-0.2
#30	28.7	-0.5	-0.5	-0.8	-0.5	0.1	-0.4	-0.5	-0.1
#50	17.0	-0.6	-0.5	-0.7	-0.5	0.2	-0.3	-0.4	0.0
#100	8.9	-0.6	-0.5	-0.7	-0.6	0.1	-0.3	-0.4	-0.1
#200	5.5	-0.2	-0.1	-0.4	-0.5	0.0	-0.4	-0.4	-0.1

Table 17. Deviation from target gradation for unwashed with lime blank aggregate for coarse mix.

Sieve Size	Percent Passing								
	Ignition				Reflux				
	Target	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
1/2”	79.2	-2.2	-2.3	-1.4	0.2	-0.2	0.2	-0.4	-0.3
3/8”	65.0	-0.7	-1.0	0.5	0.2	-0.3	0.2	-0.3	-0.1
#4	41.8	-0.8	-0.9	-0.5	0.1	-0.3	0.2	-0.6	-0.8
#8	28.6	-0.9	-0.6	-0.6	0.4	-0.1	0.3	-0.5	-0.6
#16	21.0	-0.8	-1.2	-0.7	0.3	-0.2	0.2	-0.3	-0.4
#30	16.1	-0.6	-1.5	-0.8	0.2	-0.2	0.4	-0.3	-0.4
#50	12.2	0.1	-0.5	0.0	0.3	-0.3	0.2	-0.4	-0.5
#100	9.0	0.1	-0.5	0.1	0.2	-0.1	0.2	-0.3	-0.4
#200	6.6	-0.1	-0.3	-0.1	-0.1	-0.4	0.0	-0.6	-0.6

Table 18. Comparison of gradation after ignition to target for the fine mix known asphalt content calibration (UNR).

Sieve Size	Target or Batched	Known Asphalt Content																			
		4.2			4.7			5.2			5.7			6.2			6.7			Overall	Overall
		Avg	Std Dev	Differ-ence	Avg	Std Dev	Differ-ence	Avg	Std Dev	Differ-ence	Avg	Std Dev	Differ-ence	Avg	Std Dev	Differ-ence	Avg	Std Dev	Differ-ence	Average	Average Difference
19	100.0	100	0.0	0.0	100	0.0	0.0	100	0.0	0.0	100	0.0	0.0	100	0.0	0.0	100	0.0	0.0	100	0.0
12.5	88.1	88.7	0.1	-0.6	88.6	0.2	-0.5	88.7	0.2	-0.6	88.6	0.2	-0.5	88.5	0.1	-0.4	88.5	0.3	-0.4	88.6	-0.5
9.50	76.6	77.0	0.3	-0.4	77.1	0.3	-0.5	77.1	0.3	-0.5	76.9	0.3	-0.3	76.7	0.3	-0.1	76.8	0.6	-0.2	76.9	-0.3
4.75	51.1	51.5	0.1	-0.4	51.4	0.1	-0.3	51.5	0.4	-0.4	51.0	0.3	0.1	51.1	0.9	0.0	51.2	0.7	-0.1	51.3	-0.2
2.36	39.8	39.7	0.1	0.1	39.4	0.2	0.4	39.8	0.2	0.0	39.5	0.2	0.3	39.0	0.3	0.8	39.1	0.4	0.7	39.4	0.4
1.18	35.2	35.0	0.1	0.2	34.7	0.2	0.5	35.0	0.2	0.2	34.9	0.1	0.3	34.5	0.2	0.7	34.5	0.3	0.7	34.7	0.5
0.60	28.7	28.0	0.3	0.7	28.0	0.0	0.7	28.3	0.2	0.4	28.2	0.2	0.5	27.8	0.1	0.9	27.7	0.5	1.0	28.0	0.7
0.30	16.1	16.5	0.6	-0.4	16.6	0.3	-0.5	16.9	0.3	-0.8	16.7	0.4	-0.6	16.6	0.1	-0.5	16.4	0.4	-0.3	16.6	-0.5
0.15	8.1	7.7	0.3	0.4	8.3	0.3	-0.2	8.5	0.3	-0.4	8.5	0.3	-0.4	8.1	0.2	0.0	8.1	0.2	0.0	8.2	-0.1
0.075	5.0	4.7	0.1	0.3	5.1	0.1	-0.1	5.2	0.1	-0.2	5.4	0.2	-0.4	4.9	0.3	0.1	5.0	0.1	0.0	5.1	-0.1

Table 19. Original construction fine mix gradation of loose mix after reflux (n=5/section).

Sieve Size	Target	Fine Mix - Average Percent Passing					
		Top Lift			Bottom Lift		
		Section #3	Section #1	Section #14	Section #3	Section #1	Section #14
12.5	88.5	89.3	88.9	89.1	89.1	87.4	86.7
9.50	75.4	79.1	76.6	78.1	78.2	75.9	76.8
4.75	48.9	53.8	51.5	52.1	50.3	48.0	48.2
2.36	38.4	42.0	40.2	40.8	38.8	36.4	37.5
1.18	33.9	36.7	35.5	36.0	34.4	32.1	34.2
0.60	27.6	29.8	28.4	28.4	27.6	25.5	27.2
0.30	15.7	15.9	15.8	16.0	15.4	15.1	14.9
0.15	6.8	7.9	7.4	7.4	7.0	7.3	7.0
0.075	3.6	5.0	4.1	4.1	3.8	4.2	4.0

Table 20. Original construction fine plus mix gradation of loose mix after reflux (n=5/section).

Sieve Size	Target	Fine Mix - Average Percent Passing					
		Top Lift			Bottom Lift		
		Section #22	Section #11	Section #13	Section #22	Section #11	Section #13
12.5	88.8	79.5	82.2	83.4	88.8	88.9	87.3
9.50	76.1	66.4	89.9	71.1	78.8	78.1	78.0
4.75	50.4	44.1	45.7	46.5	52.6	52.5	52.7
2.36	40.2	34.6	36.4	36.6	40.4	40.4	40.0
1.18	35.8	32.1	32.1	31.2	35.7	35.2	35.4
0.60	29.7	25.5	26.3	26.4	29.0	28.9	29.2
0.30	18.2	15.2	16.0	15.5	17.3	17.4	16.5
0.15	9.6	7.8	8.0	7.9	8.5	8.5	8.7
0.075	6.4	4.5	4.6	4.7	4.8	5.0	4.9

Table 21. Original construction coarse mix gradation of loose mix after reflux (n=5/section).

Sieve Size	Target	Fine Mix - Average Percent Passing					
		Top Lift			Bottom Lift		
		Section #8	Section #5	Section #7	Section #8	Section #5	Section #7
12.5	82.4	77.3	76.5	76.1	79.2	75.4	73.9
9.50	64.6	63.6	62.4	63.4	62.9	61.7	55.2
4.75	41.2	40.7	38.5	40.7	39.0	42.3	31.9
2.36	27.8	27.9	25.9	27.6	25.7	27.7	21.8
1.18	19.7	20.1	18.5	19.8	18.4	18.6	16.2
0.60	14.6	15.0	14.0	14.9	13.4	14.3	12.0
0.30	10.8	11.2	10.7	11.1	10.2	10.0	8.9
0.15	7.7	7.9	7.7	7.9	7.2	7.5	6.4
0.075	5.1	5.5	5.2	5.4	4.7	4.8	4.2

Table 22a. Accumulated percent passing from core data - top lift.

	Section	3/4" Sieve					1/2" Sieve					3/8" Sieve					#4 Sieve					#8 Sieve				
		MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE
Fine	1	100.0	0.0	0.00	5	0.0	87.7	1.9	2.18	5	5.0	76.0	2.2	2.93	5	5.4	49.8	1.8	3.6	5	6.0	38.8	1.4	3.66	5	3.1
	2	100.0	0.0	0.00	6	0.0	88.5	1.6	1.85	6	3.7	76.6	1.6	2.12	6	3.6	49.9	1.3	2.5	6	6.3	38.3	1.2	3.15	6	2.8
	3	100.0	0.0	0.00	5	0.0	87.8	1.1	1.30	5	2.5	77.6	1.4	1.86	5	3.6	52.0	1.5	2.9	5	4.6	40.4	1.2	3.05	5	2.8
	4	99.9	0.2	0.22	5	0.5	87.2	3.3	3.84	5	8.2	75.0	4.5	6.02	5	11.5	50.3	4.2	8.4	5	10.7	39.2	3.4	8.78	5	4.6
	14	100.0	0.0	0.00	5	0.0	88.4	1.6	1.79	5	3.9	76.7	2.2	2.93	5	5.9	51.5	2.6	5.0	5	6.6	40.0	2.0	4.91	5	4.9
	15	100.0	0.0	0.00	5	0.0	88.7	1.4	1.60	5	3.6	77.5	2.5	3.23	5	6.1	51.7	2.2	4.2	5	6.9	40.2	1.8	4.37	5	4.1
	16	100.0	0.0	0.00	5	0.0	88.5	1.1	1.19	5	2.5	76.3	1.8	2.32	5	4.3	50.8	2.2	4.2	5	5.0	39.7	1.9	4.90	5	4.5
	17	99.9	0.2	0.22	5	0.5	89.5	2.0	2.27	5	5.2	78.3	2.1	2.70	5	5.3	53.0	2.5	4.7	5	6.2	41.5	2.0	4.76	5	5.0
	18	100.0	0.0	0.00	5	0.0	87.0	1.3	1.48	5	3.5	75.5	1.8	2.39	5	4.4	51.1	1.6	3.2	5	4.3	39.8	1.2	3.10	5	2.7
Stats for averages		100.0	0.0	0.04	9	0.1	88.1	0.7	0.84	9	2.2	76.6	1.1	1.38	9	3.3	51.1	1.1	2.1	9	3.3	39.8	1.0	2.39	9	3.2
Stats for independent samples		100.0	0.1	0.10	46	0.1	88.2	1.8	2.04	46	8.7	76.6	2.4	3.12	46	11.7	51.1	2.3	4.5	46	10.9	39.8	1.9	4.06	46	9.3
					MAX	100.0					91.8					80.4					55.2					43.4
					MIN	99.5					83.1					68.7					44.3					34.1
Fine +	9	100.0	0.0	0.00	5	0.0	85.1	2.2	2.62	5	4.8	72.8	3.0	4.07	5	7.3	48.6	2.6	5.3	5	6.0	37.8	2.0	5.26	5	4.6
	10	100.0	0.0	0.00	5	0.0	86.1	2.2	2.54	5	4.8	74.7	2.3	3.02	5	5.7	50.4	2.4	4.8	5	6.3	39.7	1.8	4.46	5	4.7
	11	100.0	0.0	0.00	4	0.0	88.7	2.2	2.43	4	4.8	78.1	2.1	2.75	4	4.6	52.0	1.9	3.7	4	4.6	40.1	1.4	3.58	4	3.5
	12	100.0	0.0	0.00	5	0.0	87.9	1.5	1.66	5	3.5	76.3	1.8	2.33	5	4.3	50.3	1.9	3.7	5	4.4	38.7	1.2	3.15	5	2.9
	13	100.0	0.0	0.00	5	0.0	87.1	1.5	1.77	5	4.1	76.5	1.8	2.29	5	4.3	49.5	1.8	3.6	5	4.5	38.6	1.4	3.52	5	3.3
	19	100.0	0.0	0.00	3	0.0	86.2	1.9	2.15	3	3.7	75.1	2.5	3.38	3	4.7	51.4	2.1	4.0	3	4.0	40.3	1.4	3.47	3	2.8
	20	100.0	0.0	0.00	5	0.0	87.3	1.2	1.34	5	2.6	75.8	1.9	2.50	5	4.6	51.5	1.5	3.0	5	3.4	39.9	1.3	3.26	5	2.8
	21	99.9	0.3	0.27	5	0.6	87.0	1.0	1.18	5	2.6	76.9	1.6	2.06	5	4.1	53.0	1.8	3.4	5	5.0	41.5	1.4	3.43	5	3.8
	22	100.0	0.0	0.00	5	0.0	86.3	2.0	2.32	5	4.6	74.5	2.5	3.38	5	6.4	50.4	2.7	5.3	5	6.7	38.8	2.1	5.49	5	5.3
Stats for averages		100.0	0.0	0.04	9	0.1	86.8	1.1	1.24	9	3.6	75.6	1.5	2.04	9	5.3	50.8	1.3	2.6	9	4.4	39.5	1.1	2.82	9	3.7
Stats for independent samples		100.0	0.1	0.09	4.2	0.6	86.8	1.9	2.17	42	7.9	75.6	2.4	3.24	42	9.7	50.7	2.3	4.5	42	9.0	39.4	1.8	4.56	42	7.8
					MAX	100.0					90.3					79.7					55.5					43.7
					MIN	99.4					82.4					70.0					40.5					35.9
Coarse	5	100.0	0.0	0.00	5	0.0	79.2	1.4	1.72	5	3.2	54.1	2.7	4.16	5	7.3	41.1	2.3	5.5	5	5.7	27.4	1.1	4.08	5	3.0
	6	100.0	0.0	0.00	5	0.0	78.0	2.7	3.47	5	5.2	63.9	2.4	3.77	5	5.6	40.0	2.1	5.1	5	5.2	27.5	1.2	4.37	5	3.0
	7	100.0	0.0	0.00	6	0.0	78.9	2.5	3.14	6	6.5	64.6	2.1	3.30	6	5.7	41.5	1.2	2.8	6	3.0	28.7	1.1	3.82	6	3.0
	8	100.0	0.0	0.00	5	0.0	82.1	1.7	2.07	5	3.7	68.6	2.3	3.38	5	5.7	44.4	1.9	4.4	5	4.7	30.2	1.1	3.62	5	2.9
	23	100.0	0.0	0.00	5	0.0	79.8	2.6	3.29	5	6.7	65.7	2.5	3.75	5	5.4	42.4	2.2	5.2	5	5.0	29.1	1.0	3.49	5	2.3
	24	100.0	0.0	0.00	5	0.0	78.5	1.8	2.32	5	4.5	64.1	1.9	2.89	5	4.5	41.7	1.8	4.2	5	3.9	28.7	1.2	4.12	5	2.8
	25	100.0	0.0	0.00	5	0.0	79.2	2.1	2.66	5	4.2	64.4	1.9	2.96	5	3.9	42.3	1.9	4.5	5	4.7	29.4	1.2	4.09	5	3.1
	26	100.0	0.0	0.00	5	0.0	78.1	4.7	6.05	5	12.2	63.5	5.7	8.92	5	14.8	40.8	3.8	5.4	5	9.8	28.0	2.2	7.76	5	5.7
Stats for averages		100.0	0.0	0.00	8	0.0	79.2	1.3	1.63	8	4.1	65.0	1.6	2.46	8	5.0	41.8	1.3	3.2	8	4.4	28.6	1.0	3.39	8	2.8
Stats for independent samples		100.0	0.0	0.00	41	0.0	79.2	2.7	3.37	41	12.2	65.0	6.4	9.92	41	14.8	41.8	2.4	5.7	41	10.4	28.6	1.5	5.21	41	6.5
					MAX	100.0					84.4					70.9					46.1					31.4
					MIN	100.0					72.2					56.1					35.7					24.9

Table 22b. Accumulated percent passing from core data - top lift.

	Section	#16 Sieve					#30 Sieve					#50 Sieve					#100 Sieve					#200 Sieve				
		MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE
Fine	1	34.3	1.3	3.67	5	2.8	27.8	1.0	3.53	5	2.2	16.2	0.7	4.08	5	1.6	8.1	0.4	4.48	5	0.9	5.1	0.2	4.45	5	0.6
	2	33.9	0.9	2.79	6	2.3	27.6	0.5	1.77	6	1.2	15.8	0.4	2.74	6	1.2	8.1	0.3	3.56	6	0.9	5.0	0.2	4.79	6	0.7
	3	35.9	1.1	3.19	5	2.5	29.1	0.9	2.95	5	1.9	15.8	0.7	4.20	5	1.7	8.0	0.4	4.62	5	1.0	5.1	0.1	2.40	5	0.3
	4	34.8	2.8	8.19	5	6.9	28.3	1.9	6.83	5	4.9	15.4	0.9	5.61	5	2.1	7.5	0.4	4.83	5	1.0	4.4	0.4	8.36	5	1.0
	14	35.5	1.7	4.71	5	4.2	29	1.2	4.16	5	3.1	16.0	0.6	3.82	5	1.6	8.0	0.2	2.50	5	0.4	4.9	0.3	5.56	5	0.7
	15	35.5	1.5	4.20	5	3.6	29	1.1	3.86	5	2.9	16.7	0.6	3.57	5	1.5	8.5	0.4	4.99	5	1.0	5.2	0.4	7.07	5	0.9
	16	35.1	1.7	4.71	5	4.0	28.6	1.3	4.52	5	3.1	16.0	0.9	5.64	5	2.1	8.0	0.4	5.39	5	1.2	4.9	0.2	4.85	5	0.6
	17	36.8	1.7	4.57	5	4.4	29.8	1.4	4.61	5	3.7	16.8	0.8	4.86	5	1.9	8.4	0.4	4.91	5	1.0	5.1	0.3	6.24	5	0.8
	18	35.2	1.2	3.52	5	2.9	28.7	1.2	4.32	5	3.2	16.5	0.7	4.07	5	1.7	8.4	0.4	5.19	5	1.0	5.1	0.4	6.96	5	0.9
Stats for averages		35.2	0.9	2.44	9	2.9	28.7	0.7	2.36	9	2.2	16.1	0.5	2.86	9	1.4	8.1	0.3	3.55	9	0.9	5.0	0.3	5.20	9	0.8
Stats for independent samples		35.2	1.7	4.80	46	7.9	28.6	1.3	4.46	46	5.9	16.1	0.8	4.78	46	3.1	8.1	0.4	5.48	46	1.9	5.0	0.4	7.39	46	2.0
					MAX	38.5					31.4					17.5					9.0					5.8
					MIN	30.6					25.5					14.4					7.1					3.8
Fine +	9	33.6	1.6	4.77	5	3.7	27.8	1.2	4.45	5	2.9	16.4	0.8	4.68	5	1.9	8.6	0.6	7.46	5	1.6	5.2	0.5	10.61	5	1.4
	10	35.2	1.4	4.01	5	3.7	29.0	1.0	3.33	5	2.5	17.1	0.7	4.18	5	1.7	9.1	0.4	4.40	5	1.0	5.6	0.3	6.26	5	0.8
	11	35.4	1.2	3.26	4	2.8	29.0	0.9	2.94	4	1.9	16.8	0.4	2.40	4	0.9	8.9	0.7	7.72	4	1.6	5.5	0.6	11.10	4	1.4
	12	34.3	0.9	2.75	5	2.2	28.4	0.7	2.63	5	1.8	17.2	0.5	3.13	5	1.2	9.4	0.2	2.06	5	0.5	6.0	0.1	1.39	5	0.2
	13	34.1	1.1	3.26	5	2.7	28.1	0.8	2.99	5	2.1	16.9	0.7	3.95	5	1.6	9.1	0.1	0.60	5	0.1	5.7	0.1	1.99	5	0.3
	19	35.8	1.2	3.23	3	2.3	29.5	0.9	3.11	3	1.8	17.9	0.4	2.44	3	0.8	9.3	0.1	1.08	3	1.2	5.8	0.1	1.72	3	0.2
	20	35.4	1.1	3.16	5	2.5	29.1	0.8	2.78	5	1.9	17.0	0.5	3.03	5	1.1	8.8	0.4	4.88	5	1.2	5.2	0.4	7.09	5	1.0
	21	36.7	1.2	3.18	5	3.0	30.1	0.9	3.04	5	2.2	18.0	0.7	3.76	5	1.8	9.0	1.0	10.72	5	2.4	5.4	1.0	17.67	5	2.3
	22	34.3	1.8	5.30	5	4.5	28.2	1.3	4.77	5	3.3	16.6	1.1	6.80	5	2.9	8.6	0.7	8.65	5	1.8	5.3	0.7	13.62	5	1.7
Stats for averages		35.0	1.0	2.81	9	3.1	28.8	0.8	2.61	9	2.3	17.1	0.5	3.10	9	1.5	9.0	0.3	3.31	9	0.9	5.5	0.3	5.18	9	0.9
Stats for independent samples		34.9	1.5	4.33	42	6.4	28.8	1.1	3.97	42	4.9	17.1	0.8	4.73	42	3.5	9.0	0.6	6.48	42	2.4	5.5	0.5	9.94	42	2.4
					MAX	38.6					31.6					18.8					9.7					6.2
					MIN	32.2					26.7					15.3					7.3					3.8
Coarse	5	20.0	0.6	2.95	5	1.6	15.5	0.4	2.79	5	1.1	12.0	0.5	3.84	5	1.1	9.0	0.3	3.00	5	0.7	6.5	0.2	3.20	5	0.5
	6	20.4	0.6	3.19	5	1.5	15.7	0.5	3.02	5	1.1	12.0	0.5	4.22	5	1.2	8.8	0.4	4.93	5	1.0	6.3	0.4	6.64	5	1.1
	7	21.2	1.0	4.61	6	2.8	16.1	0.8	5.24	6	2.4	12.0	0.7	5.87	6	1.9	8.7	0.9	10.15	6	2.2	6.4	0.5	8.34	6	1.6
	8	22.0	0.6	2.65	5	1.5	16.7	0.3	1.90	5	0.8	12.6	0.2	1.87	5	0.5	9.3	0.2	2.32	5	0.6	6.7	0.2	3.62	5	0.7
	23	21.4	0.3	1.61	5	0.8	16.5	0.2	1.47	5	0.6	12.6	0.3	2.63	5	0.9	9.5	0.2	2.22	5	0.5	7.0	0.2	2.82	5	0.5
	24	21.0	0.7	3.35	5	1.9	16.0	0.5	3.10	5	1.4	12.2	0.5	3.72	5	1.1	9.1	0.4	4.17	5	1.0	6.6	0.4	5.64	5	0.9
	25	21.5	0.8	3.85	5	2.3	16.4	0.6	3.43	5	1.6	12.4	0.3	2.57	5	0.9	9.2	0.5	4.95	5	1.1	6.7	0.4	6.38	5	0.9
	26	20.4	1.3	6.15	5	3.2	15.5	0.8	5.10	5	1.9	11.7	0.6	4.95	5	1.5	8.7	0.4	4.77	5	1.0	6.3	0.4	5.94	5	1.0
Stats for averages		21.0	0.7	3.22	8	2.0	16.1	0.5	2.82	8	1.2	12.2	0.3	2.64	8	0.9	9.0	0.3	3.12	8	1.4	6.6	0.2	3.38	8	0.7
Stats for independent samples		21.0	1.0	4.57	41	4.1	16.1	0.7	4.15	41	3.1	12.2	0.5	4.35	41	2.2	9.0	0.5	5.62	41	2.2	6.6	0.4	6.04	41	1.6
					MAX	22.8					17.2					13.1					9.8					7.2
					MIN	18.6					14.1					10.9					7.5					5.5

Table 23a. Accumulated percent passing from core data - bottom lift.

	Section	3/4" Sieve					1/2" Sieve					3/8" Sieve					#4 Sieve					#8 Sieve				
		MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE
Fine	1	100.0	0.0	0.00	4	0.0	85.1	3.9	4.56	4	8.6	70.6	6.1	8.67	4	14.0	43.0	5.3	12.44	4	12.0	32.6	3.7	11.34	4	8.4
	2	100.0	0.0	0.00	4	0.0	87.3	3.9	4.48	4	9.5	74.5	5.9	7.93	4	14.2	46.2	6.2	13.42	4	14.9	35.1	4.7	13.29	4	11.3
	3	100.0	0.0	0.00	4	0.0	88.7	3.0	3.39	4	5.8	76.2	3.6	4.70	4	6.9	48.4	3.7	7.70	4	7.1	36.5	3.1	8.45	4	5.9
	4	100.0	0.0	0.00	5	0.0	89.9	1.9	2.13	5	4.8	78.3	1.0	1.27	5	2.2	49.9	0.6	1.23	5	1.3	37.9	0.7	1.75	5	1.6
	14	100.0	0.0	0.00	5	0.0	89.0	3.5	3.91	5	8.8	76.9	4.7	6.06	5	10.9	49.5	4.0	8.13	5	8.9	38.0	3.0	8.00	5	6.4
	15	100.0	0.0	0.00	4	0.0	86.9	2.4	2.79	4	5.9	75.5	2.7	3.61	4	6.5	49.0	2.2	4.44	4	4.7	37.4	1.6	4.37	4	3.6
	16	100.0	0.0	0.00	5	0.0	90.2	2.2	2.44	5	6.0	77.4	4.2	5.38	5	10.2	49.0	5.1	10.40	5	12.4	36.9	4.0	10.95	5	9.8
	17	100.0	0.0	0.00	5	0.0	88.4	1.2	1.36	5	3.1	75.8	2.3	3.09	5	5.2	48.6	2.6	5.29	5	5.4	36.8	1.8	4.95	5	4.4
	18	100.0	0.0	0.00	5	0.0	88.3	1.4	1.63	5	3.6	76.6	2.1	2.77	5	5.2	49.8	2.6	5.16	5	6.4	38.0	2.1	5.46	5	5.3
Stats for averages		100.0	0.0	0.00	9	0.0	88.2	1.6	1.79	9	5.1	75.7	2.2	2.94	9	7.7	48.2	2.2	4.65	9	6.9	36.6	1.7	4.78	9	5.4
Stats for independent samples		100.0	0.0	0.00	41	0.0	88.3	2.6	2.97	41	12.8	75.9	4.0	5.30	41	18.3	48.6	4.0	8.27	41	15.9	36.7	3.1	8.41	41	12.0
					MAX	100.0					93.0					81.3					53.3					40.7
					MIN	100.0					80.2					63.0					37.4					28.7
Fine +	9	100.0	0.0	0.00	5	0.0	91.2	0.6	0.67	5	1.5	81.4	1.4	1.67	5	3.5	55.0	2.3	4.19	5	5.4	42.6	1.8	4.34	5	4.3
	10	100.0	0.0	0.00	4	0.0	87.1	5.3	6.09	4	11.8	74.9	6.6	8.81	4	14.0	48.7	6.6	13.46	4	14.0	37.5	5.0	13.33	4	10.8
	11	100.0	0.0	0.00	5	0.0	89.7	1.7	1.87	5	3.6	79.6	2.3	2.87	5	5.1	53.1	2.7	5.13	5	6.2	40.8	2.5	6.04	5	6.2
	12	99.9	0.3	0.31	5	0.7	89.5	1.7	1.91	5	4.5	79.1	3.3	4.16	5	8.3	52.8	5.6	10.62	5	14.0	40.4	4.7	11.76	5	11.8
	13	100.0	0.0	0.00	3	0.0	86.9	1.4	1.62	3	2.8	75.7	1.3	1.72	3	2.3	49.5	0.4	0.73	3	0.7	38.2	0.5	1.32	3	1.0
	19	100.0	0.0	0.00	5	0.0	90.1	1.4	1.54	5	3.3	80.1	2.0	2.54	5	5.0	53.3	3.9	7.33	5	9.3	41.5	2.1	5.00	5	4.7
	20	100.0	0.0	0.00	5	0.0	87.8	3.4	3.93	5	8.8	74.9	5.7	7.65	5	14.6	48.5	5.5	11.26	5	13.5	37.7	4.0	10.57	5	9.7
	21	100.0	0.0	0.00	5	0.0	87.2	2.5	2.91	5	5.7	74.3	4.7	0.31	5	10.8	47.3	3.7	7.73	5	9.8	37.2	2.6	7.06	5	6.7
	22	100.0	0.0	0.00	5	0.0	90.1	1.6	1.73	5	4.3	78.7	2.5	3.21	5	6.9	52.4	2.3	4.42	5	6.1	40.5	1.8	4.34	5	4.3
Stats for averages		100.0	0.0	0.05	9	0.1	88.8	1.6	1.80	9	4.3	77.6	2.7	3.45	9	7.1	51.2	2.7	5.26	9	7.7	39.6	2.0	4.98	9	5.4
Stats for independent samples		100.0	0.1	0.11	42	0.7	88.8	2.8	3.19	42	13.2	77.8	4.2	5.45	42	18.5	51.6	4.5	8.76	42	22.0	39.7	3.2	8.16	42	18.0
					MAX	100.0					92.6					84.5					62.2					48.4
					MIN	99.3					79.4					66.0					39.4					30.4
Coarse	5	100.0	0.0	0.00	5	0.0	82.9	2.5	3.06	5	6.1	67.3	2.9	4.35	5	7.6	42.1	1.7	4.08	5	4.1	27.3	1.3	4.60	5	3.2
	6	100.0	0.0	0.00	4	0.0	81.4	2.1	2.53	4	4.8	66.3	3.0	4.55	4	6.2	42.4	2.3	5.32	4	4.4	28.0	1.4	5.18	4	2.7
	7	100.0	0.0	0.00	3	0.0	80.5	2.5	3.12	3	4.7	64.9	2.1	3.16	3	3.7	40.3	2.0	4.98	3	3.7	26.9	1.3	4.77	3	2.4
	8	100.0	0.0	0.00	5	0.0	82.6	2.3	2.84	5	5.6	67.5	2.7	3.96	5	6.6	42.9	1.8	4.25	5	4.5	28.0	1.2	4.16	5	3.0
	23	100.0	0.0	0.00	5	0.0	83.3	2.2	2.63	5	5.2	67.9	2.6	3.84	5	6.3	43.2	1.8	4.18	5	4.0	28.2	1.0	3.67	5	2.6
	24	100.0	0.0	0.00	5	0.0	82.2	1.4	1.70	5	3.4	65.3	2.6	3.95	5	6.5	41.7	2.2	5.37	5	5.3	27.6	1.4	4.99	5	3.2
	25	100.0	0.0	0.00	5	0.0	79.8	2.3	2.86	5	5.0	65.1	1.9	2.99	5	5.3	41.8	1.7	3.97	5	4.4	27.9	1.1	3.77	5	2.7
	26	100.0	0.0	0.00	5	0.0	80.7	4.3	5.33	5	9.9	64.8	5.1	7.91	5	11.9	41.0	3.8	9.30	5	9.9	27.1	2.2	7.98	5	5.7
Stats for averages		100.0	0.0	0.00	8	0.0	81.7	1.3	1.54	8	6.5	66.1	1.3	1.91	8	8.2	41.9	1.0	2.27	8	6.2	27.6	0.5	1.69	8	3.3
Stats for independent samples		100.0	0.0	0.00	37	0.0	81.7	2.6	3.24	37	11.0	66.2	3.0	4.55	37	13.2	42.0	2.2	5.28	37	10.0	27.7	1.3	4.78	37	5.8
					MAX	100.0					86.3					71.5					45.1					29.4
					MIN	100.0					75.3					58.3					35.1					23.6

Table 23b. Accumulated percent passing from core data - bottom lift.

	Section	#16 Sieve					#30 Sieve					#50 Sieve					#100 Sieve					#200 Sieve				
		MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE	MEAN	STD	COV	n	RANGE
Fine	1	28.7	2.9	10.23	4	6.8	23.6	2.3	9.73	4	5.3	14.2	1.3	9.50	4	3.1	6.9	0.8	12.13	4	1.8	4.1	0.7	15.88	4	1.4
	2	30.8	3.9	12.64	4	9.5	25.3	3.0	11.69	4	7.2	14.4	1.4	9.76	4	3.4	7.2	0.8	10.64	4	1.7	4.2	0.6	13.61	4	1.3
	3	32.1	2.1	6.46	4	4.9	26.1	1.9	7.23	4	3.5	15.0	0.6	3.95	4	1.3	7.1	0.2	2.12	4	0.3	4.2	0.1	3.11	4	0.3
	4	33.3	0.6	1.82	5	1.4	27.3	0.5	1.86	5	1.3	15.5	0.3	2.01	5	0.8	7.5	0.5	6.61	5	1.2	4.3	0.4	10.24	5	1.0
	14	33.6	2.5	7.48	5	5.1	27.7	1.9	6.78	5	3.8	15.5	1.1	6.81	5	2.3	7.8	0.7	9.19	5	1.7	4.5	0.6	13.05	5	1.5
	15	33.0	1.5	4.55	4	3.3	27.0	1.2	4.30	4	2.6	15.9	1.0	6.24	4	2.3	7.8	0.5	6.67	4	1.1	4.7	0.4	9.19	4	1.0
	16	32.5	3.4	10.49	5	8.1	26.6	2.5	9.38	5	5.9	15.3	1.2	7.98	5	3.2	7.5	0.9	11.48	5	2.2	4.4	0.7	15.95	5	1.9
	17	32.5	1.5	4.54	5	3.5	26.0	1.3	5.09	5	3.3	14.3	2.4	16.69	5	6.1	7.4	0.5	7.03	5	1.3	4.6	0.3	5.57	5	0.7
	18	33.3	1.7	5.07	5	4.4	27.1	1.2	4.50	5	3.2	15.5	0.5	3.53	5	1.4	7.5	0.5	5.98	5	1.1	4.5	0.4	8.61	5	0.9
Stats for averages		32.2	1.6	4.84	9	4.9	26.3	1.3	4.80	9	4.1	15.0	0.6	4.07	9	1.7	7.4	0.3	4.21	9	0.9	4.4	0.2	4.81	9	0.6
Stats for independent samples		32.3	2.6	8.09	41	10.2	26.4	2.0	7.68	41	8.2	15.1	1.3	8.35	41	6.9	7.4	0.6	8.50	41	2.6	4.4	0.5	11.08	41	2.0
					MAX	35.7					29.3					17.2					8.9					5.5
					MIN	25.5					21.1					10.3					6.3					3.5
Fine +	9	37.6	1.5	3.93	5	3.5	31.2	1.0	3.34	5	2.5	18.1	0.5	2.90	5	1.3	10.0	0.4	4.27	5	1.0	6.2	0.4	6.20	5	0.9
	10	33.2	4.2	12.65	4	9.1	27.5	3.3	11.89	4	7.2	16.5	1.6	9.80	4	3.6	8.5	0.9	11.16	4	2.1	5.2	0.6	12.16	4	1.4
	11	36.2	2.3	6.23	5	5.9	29.9	2.1	6.92	5	5.5	18.1	2.3	12.61	5	6.2	9.9	2.3	22.82	5	5.5	8.5	2.3	35.29	5	5.6
	12	35.5	3.9	10.89	5	9.8	29.0	2.7	9.24	5	6.9	17.1	1.2	7.28	5	2.9	8.8	0.6	6.93	5	1.6	5.4	0.5	9.78	5	1.4
	13	33.8	0.5	1.52	3	1.0	27.7	0.5	1.88	3	0.9	16.1	0.3	1.80	3	0.5	8.4	0.6	7.43	3	1.2	5.5	0.7	12.98	3	1.4
	19	36.6	1.7	4.51	5	3.7	30.0	1.1	3.82	5	2.6	17.8	0.8	4.35	5	2.0	9.3	0.3	3.16	5	0.6	5.7	0.2	3.61	5	0.5
	20	33.6	3.3	9.69	5	8.0	27.7	2.3	8.30	5	6.0	16.2	1.0	6.44	5	2.5	8.3	0.2	1.82	5	0.4	5.1	0.2	4.76	5	0.5
	21	33.0	2.0	5.98	5	5.2	27.4	1.3	4.82	5	3.5	33.0	1.0	2.99	5	2.4	8.6	0.6	7.11	5	1.5	5.3	0.6	12.07	5	2.0
	22	35.8	1.5	4.32	5	3.9	29.3	1.2	4.05	5	3.0	16.8	0.7	4.04	5	1.7	8.3	0.6	7.78	5	1.7	4.9	0.6	12.48	5	1.7
Stats for averages		35.0	1.7	4.76	9	10.8	28.9	1.4	4.71	9	3.8	18.8	5.4	28.51	9	17.0	8.9	0.7	7.46	9	1.7	5.5	0.5	9.68	9	1.6
Stats for independent samples		35.1	2.8	8.02	42	14.8	29.0	2.1	7.13	42	10.7	17.1	1.4	7.95	42	7.5	8.9	1.1	11.93	42	6.4	5.5	1.0	17.85	42	6.5
					MAX	42.0					33.5					21.7					13.7					10.5
					MIN	27.2					22.8					14.2					7.3					4.0
Coarse	5	19.8	0.9	4.51	5	2.2	15.1	0.5	3.54	5	1.5	11.0	0.5	4.99	5	1.5	8.0	0.5	5.74	5	1.2	5.7	0.4	7.13	5	1.1
	6	20.0	1.0	4.94	4	1.8	14.9	0.6	4.35	4	1.3	10.9	0.3	3.20	4	0.8	7.7	0.4	5.51	4	0.9	5.4	0.4	6.69	4	0.8
	7	19.5	0.7	3.55	3	1.2	14.6	0.6	3.78	3	1.0	10.8	0.5	4.39	3	0.9	7.7	0.3	3.44	3	0.5	5.4	0.2	3.88	3	0.4
	8	20.0	0.7	3.66	5	1.9	14.9	0.5	3.56	5	1.4	11.0	0.3	2.65	5	0.7	7.9	0.4	4.42	5	0.9	5.7	0.2	3.87	5	0.6
	23	20.1	0.7	3.52	5	1.9	15.0	0.6	3.74	5	1.5	11.1	0.4	3.45	5	1.0	7.9	0.4	5.37	5	1.1	5.6	0.3	6.18	5	0.8
	24	20.0	0.7	3.26	5	1.7	15.0	0.4	2.90	5	1.2	11.0	0.5	4.47	5	1.2	7.9	0.4	5.60	5	1.1	5.5	0.4	7.51	5	1.1
	25	20.3	0.7	3.39	5	1.7	15.2	0.5	3.35	5	1.2	11.2	0.5	4.47	5	1.4	8.0	0.4	4.53	5	1.0	5.6	0.4	6.44	5	1.0
	26	19.5	1.3	6.75	5	3.3	14.5	0.9	5.89	5	2.0	10.6	0.5	4.42	5	1.2	7.6	0.4	5.23	5	1.0	5.3	0.2	4.11	5	0.6
Stats for averages		19.9	0.3	1.43	8	2.1	14.9	0.2	1.64	8	1.0	11.0	0.2	1.80	8	0.8	7.8	0.2	2.09	8	0.7	5.5	0.2	2.75	8	0.7
Stats for independent samples		19.9	0.8	4.12	37	3.8	14.9	0.6	3.87	37	4.0	11.0	0.4	4.05	37	2.1	7.9	0.4	5.00	37	1.6	5.5	0.3	5.85	37	1.4
					MAX	21.2					15.9					12.0					8.7					6.8
					MIN	17.4					13.2					9.9					7.1					4.9

Table 24. Original construction fine mix top lift gradation of cores after ignition (n=5/section).

Sieve Size (mm)	Target	Fine Mix Top Lift - Average Percent Passing								
		Section Number								
		1	2	3	4	14	15	16	17	18
19	99.9	100.0	100.0	100.0	99.9	100.0	100.0	100.0	99.9	100.0
12.5	88.5	87.7	88.5	87.8	87.2	88.4	88.7	88.5	89.3	87.0
9.50	75.4	76.0	76.6	77.6	75.0	76.7	77.5	76.3	78.3	75.5
4.75	48.9	49.8	49.9	52.0	50.3	51.5	51.7	50.8	53.0	51.1
2.36	38.4	38.8	38.3	40.4	39.2	40.0	40.2	39.7	41.5	39.8
1.18	33.9	34.3	33.9	35.9	34.8	35.5	35.5	35.1	36.8	35.2
0.60	27.6	27.8	27.6	29.1	28.3	29.0	29.0	28.6	29.8	28.7
0.30	15.7	16.2	15.8	15.8	15.4	16.0	16.7	16.0	16.8	16.5
0.15	6.8	8.1	8.1	8.0	7.5	8.0	8.5	8.0	8.4	8.4
0.075	3.6	5.1	5.0	5.1	4.4	4.9	5.2	4.9	5.1	5.1
Surface Area (ft^2/lb)		29.1	28.7	29.3	27.5	29.0	30.0	28.9	30.1	29.6
Surface Area (m^2/kg)		5.95	5.88	6.00	5.63	5.93	6.14	5.91	6.16	6.06
Ratio #4 to #50		3.07	3.16	3.29	3.27	3.22	3.10	3.18	3.15	3.10

Table 25. Original construction fine mix bottom lift gradation of cores after ignition (n=5/section).

Sieve Size (mm)	Target	Fine Mix Bottom Lift - Average Percent Passing								
		Section Number								
		1	2	3	4	14	15	16	17	18
19	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	88.5	85.1	87.3	88.7	89.9	89.0	86.9	90.2	88.4	88.3
9.50	75.4	70.6	74.5	76.2	78.3	76.9	75.5	77.4	75.8	76.6
4.75	48.9	43.0	46.2	48.4	49.9	49.5	49.0	49.0	48.6	49.8
2.36	38.4	32.6	35.1	36.5	37.9	38.0	37.4	36.9	36.8	38.0
1.18	33.9	28.7	30.8	32.1	33.3	33.6	33.0	32.5	32.5	33.3
0.60	27.6	23.6	25.3	26.1	27.3	27.7	27.0	26.6	26.0	27.1
0.30	15.7	14.2	14.4	15.0	15.5	15.5	15.9	15.3	14.3	15.5
0.15	6.8	6.9	7.2	7.1	7.5	7.8	7.8	7.5	7.4	7.5
0.075	3.6	4.1	4.2	4.2	4.3	4.5	4.7	4.4	4.6	4.5
Surface Area (ft^2/lb)		24.7	25.7	26.1	27.0	27.6	27.9	26.9	26.8	27.3
Surface Area (m^2/kg)		5.06	5.26	5.35	5.54	5.65	5.71	5.51	5.48	5.60
Ratio #4 to #50		3.03	3.21	3.23	3.22	3.19	3.08	3.20	3.40	3.21

Table 26. Original construction fine plus mix top lift gradation of cores after ignition (n=5/section).

Sieve Size (mm)	Target	Fine Plus Mix Top Lift - Average Percent Passing								
		Section Number								
		9	**10**	**11**	**12**	**13**	**19**	**20**	**21**	**22**
19	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0
12.5	88.8	85.1	86.1	88.7	87.9	87.1	86.2	87.3	87.0	86.3
9.50	76.1	72.8	74.7	78.1	76.3	76.5	7.5	75.8	76.9	74.5
4.75	50.4	48.6	50.4	52.0	50.3	49.5	51.4	51.5	53.0	50.4
2.36	40.1	37.8	39.7	40.1	38.7	38.6	40.3	39.9	41.5	38.8
1.18	35.8	33.6	35.2	35.4	34.3	34.1	35.8	35.4	36.7	34.3
0.60	29.7	27.8	29.0	29.0	28.4	28.1	29.5	29.1	30.1	28.2
0.30	18.2	16.4	17.1	16.8	17.2	16.9	17.9	17.0	18.0	16.6
0.15	9.6	8.6	9.1	8.9	9.4	9.1	9.3	8.8	9.0	8.6
0.075	6.4	5.2	5.6	5.5	6.0	5.7	5.8	5.2	5.4	5.3
Surface Area (ft^2/lb)		29.5	31.0	30.7	31.7	30.8	31.9	30.2	31.3	29.9
Surface Area (m^2/kg)		6.03	6.35	6.29	6.49	6.32	6.53	6.19	6.41	6.12
Ratio #4 to #50		2.96	2.95	3.10	2.92	2.93	2.87	3.03	2.94	3.04

Table 27. Original construction fine plus mix bottom lift gradation of cores after ignition (n=5/section).

Sieve Size (mm)	Target	Fine Plus Mix Bottom Lift - Average Percent Passing								
		Section Number								
		9	10	11	12	13	19	20	21	22
19	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	88.8	91.2	87.1	89.7	89.5	86.9	90.1	87.8	87.2	90.1
9.50	76.1	81.4	74.9	79.6	79.1	75.7	80.1	74.9	74.3	78.7
4.75	50.4	55.0	48.7	53.1	52.8	49.5	53.5	48.5	47.3	52.4
2.36	40.1	42.6	37.5	40.8	40.4	38.2	41.5	37.7	37.2	40.5
1.18	35.8	37.6	33.2	36.2	35.5	33.8	36.6	33.6	33.0	35.8
0.60	29.7	31.2	27.5	29.9	29.0	27.7	30.0	27.7	27.4	29.3
0.30	18.2	18.1	16.5	18.1	17.1	16.1	17.8	16.2	17.2	16.8
0.15	9.6	10.0	8.5	9.9	8.8	8.4	9.3	8.3	8.6	8.3
0.075	6.4	6.2	5.2	6.5	5.4	5.5	5.7	5.1	5.3	4.9
Surface Area (ft^2/lb)		33.5	29.4	33.5	30.6	29.8	31.9	29.0	29.7	29.5
Surface Area (m^2/kg)		6.87	6.01	6.87	6.27	6.10	6.53	5.95	6.09	6.04
Ratio #4 to #50		3.04	2.95	2.93	3.09	3.07	3.01	2.99	2.75	3.12

Table 28. Original construction coarse mix top lift gradation of cores after ignition (n=5/section).

Sieve Size (mm)	Target	Coarse Mix Top Lift - Average Percent Passing							
		Section Number							
		5	6	7	8	23	24	25	26
19	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	82.4	79.0	78.0	78.9	82.1	79.8	78.5	79.2	78.1
9.5	64.6	65.1	63.9	64.6	68.6	65.7	64.1	64.4	63.5
4.75	41.2	41.1	40.0	41.5	44.4	42.4	41.7	42.3	40.8
2.36	27.8	27.4	27.5	28.7	30.2	29.1	28.7	29.4	28.0
1.18	19.7	20.0	20.4	21.2	22.0	21.4	21.0	21.5	20.4
0.6	14.6	15.5	15.7	16.1	16.7	16.5	16.0	16.4	15.5
0.3	10.8	12.0	12.0	12.0	12.6	12.6	12.2	12.4	11.7
0.15	7.7	9.0	8.8	8.7	9.3	9.5	9.1	9.2	8.7
0.075	5.1	6.5	6.3	6.4	6.7	7.0	6.6	6.7	6.3
Surface Area (ft^2/lb)		27.1	26.7	27.0	28.3	28.7	27.6	28.0	26.5
Surface Area (m^2/kg)		5.55	5.47	5.53	5.79	5.88	5.65	5.73	5.44
Ratio #4 to #50		3.43	3.33	3.46	3.52	3.37	3.42	3.41	3.49

Table 29. Original construction coarse mix bottom lift gradation of cores after ignition (n=5/section).

Sieve Size (mm)	Target	Coarse Mix Top Lift - Average Percent Passing							
		Section Number							
		5	6	7	8	23	24	25	26
19	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	82.4	82.9	81.4	80.5	82.6	83.3	82.2	79.8	80.7
9.50	64.6	67.3	66.3	64.9	67.5	67.9	65.3	65.1	64.8
4.75	41.2	42.1	42.4	40.3	42.9	43.2	41.7	41.8	41.0
2.36	27.8	27.3	28.0	26.9	28.0	28.2	27.6	27.9	27.1
1.18	19.7	19.8	20.0	19.5	20.0	20.1	20.0	20.3	19.5
0.6	14.6	15.1	14.9	14.6	14.9	15.0	15.0	15.2	14.5
0.3	10.8	11.0	10.9	10.8	11.0	11.1	11.0	11.2	10.6
0.15	7.7	8.0	7.7	7.7	7.9	7.9	7.9	8.0	7.6
0.075	5.1	5.7	5.4	5.4	5.7	5.6	5.5	5.6	5.3
Surface Area (ft^2/lb)		24.9	24.2	24.0	24.8	24.7	24.5	24.8	23.7
Surface Area (m^2/kg)		5.09	4.95	4.91	5.08	5.07	5.01	5.08	4.86
Ratio #4 to #50		3.83	3.89	3.73	3.90	3.89	3.79	3.73	3.87

Table 30. WesTrack original construction fine plus mix gradations.

Sieve Size		Fine Mix Target	Top Lift Field Observed*	Difference in Target & Field Observed	Bottom Lift Field Observed*	Difference in Target & Field Observed	Difference in Top & Bottom
(US)	(mm)						
1”	25	100.0	100.0	0.0	100.0	0.0	0.0
3/4”	19	100.0	100.0	0.0	100.0	0.0	0.0
½”	12.5	88.5	88.1	-0.4	88.3	-0.2	0.2
3/8”	9.5	75.4	76.6	1.2	75.9	0.5	0.7
#4	4.75	48.9	51.1	2.2	48.3	-0.6	2.8
#8	2.36	38.4	39.8	1.4	36.7	-1.7	3.1
#16	1.18	33.9	35.2	1.3	32.3	-1.6	2.9
#30	0.6	27.6	28.7	1.1	26.4	-1.2	2.3
#50	0.3	15.7	16.1	0.4	15.1	-0.6	1.0
#100	0.15	6.8	8.1	1.3	7.4	0.6	0.7
#200	0.075	3.6	5.0	1.5	4.4	0.9	0.6

*Based on mean of core ignition gradations (45 tests/lift).

Table 31. WesTrack original construction fine mix gradations.

Sieve Size		Fine Plus Mix Target	Top Lift Field Observed*	Difference in Target & Field Observed	Bottom Lift Field Observed*	Difference in Target & Field Observed	Difference in Top & Bottom
(US)	(mm)						
1”	25	100.0	100.0	0.0	100.0	0.0	0.0
3/4”	19	100.0	100.0	0.0	100.0	0.0	0.0
½”	12.5	88.8	86.8	-2.0	89.0	0.2	2.2
3/8”	9.5	76.1	75.6	-0.5	77.8	1.7	2.2
#4	4.75	50.4	50.7	0.3	51.3	0.9	0.6
#8	2.36	40.2	39.4	-0.8	39.7	-0.5	0.3
#16	1.18	35.8	34.9	-0.9	35.1	-0.7	0.2
#30	0.6	29.7	28.7	-1.0	29.0	-0.7	0.3
#50	0.3	18.2	17.0	-1.2	17.1	-1.1	0.1
#100	0.15	9.6	8.9	-0.7	8.9	-0.7	0.0
#200	0.075	6.4	5.5	-0.9	5.5	-0.9	0.0

*Based on mean of core ignition gradations (45 tests/lift).

Table 32. WesTrack original construction coarse mix gradations.

Sieve Size		Coarse Mix Target	Top Lift Field Observed*	Difference in Target & Field Observed	Bottom Lift Field Observed*	Difference in Target & Field Observed	Difference in Top & Bottom
(US)	(mm)						
1”	25	100.0	100.0	0.0	100.0	0.0	0.0
3/4”	19	100.0	100.0	0.0	100.0	0.0	0.0
½”	12.5	82.4	79.2	-3.2	81.8	-0.6	2.6
3/8”	9.5	64.6	65.0	0.4	66.3	1.7	1.3
#4	4.75	41.2	41.8	0.6	42.1	0.9	0.3
#8	2.36	27.8	28.6	0.8	27.7	-0.1	0.9
#16	1.18	19.7	21.0	1.3	19.9	0.2	1.1
#30	0.6	14.6	16.1	1.5	14.9	0.3	1.2
#50	0.3	10.8	12.2	1.4	11.0	0.2	1.2
#100	0.15	7.7	9.0	1.3	7.9	0.2	1.1
#200	0.075	5.1	6.6	1.5	5.5	0.4	1.1

*Based on mean of core ignition gradations (40 tests/lift).

Table 33. Aggregate gradation summary for fine graded mixture – original construction.

Sieve Size		Target	Top Layer				Bottom Layer			
(US)	(mm)		Mean	Std Dev	Cov	n	Mean	Std Dev	Cov	n
3/4"	19.0	100	100	0.1	0.1	46	100	0.0	0.0	41
1/2"	12.5	88.5	88.2	1.8	2.0	46	88.3	2.6	3.0	41
3/8"	9.50	75.4	76.6	2.4	3.1	46	75.9	4.0	5.3	41
No. 4	4.75	48.9	51.1	2.3	4.5	46	48.6	4.0	8.3	41
No. 8	2.36	38.4	39.8	1.9	4.1	46	36.7	3.1	8.4	41
No. 16	1.18	33.9	35.2	1.7	4.8	46	32.3	2.6	8.1	41
No. 30	0.60	27.6	28.6	1.3	4.5	46	26.4	2.0	7.7	41
No. 50	0.30	15.7	16.1	0.8	4.7	46	15.1	1.3	8.4	41
No. 100	0.15	6.8	8.1	0.4	5.5	46	7.4	0.6	8.5	41
No. 200	0.075	3.6	5.0	0.4	7.4	46	4.4	0.5	11.0	41

Table 34. Aggregate gradation summary for fine plus graded mixture – original construction.

Sieve Size		Target	Top Layer				Bottom Layer			
(US)	(mm)		Mean	Std Dev	Cov	n	Mean	Std Dev	Cov	n
3/4"	19.0	100	100	0.1	0.1	42	100	0.1	0.1	42
1/2"	12.5	88.8	86.8	1.9	2.2	42	88.8	2.8	3.2	42
3/8"	9.50	76.1	75.6	2.4	3.2	42	77.8	4.2	5.5	42
No. 4	4.75	50.4	50.7	2.3	4.5	42	51.6	4.5	8.8	42
No. 8	2.36	40.2	39.4	1.8	4.6	42	39.7	3.2	8.2	42
No. 16	1.18	35.8	34.9	1.5	4.3	42	35.1	2.8	8.0	42
No. 30	0.60	29.7	28.8	1.1	4.0	42	29.0	2.1	7.1	42
No. 50	0.30	18.2	17.1	0.8	4.7	42	17.1	1.4	8.0	42
No. 100	0.15	9.6	9.0	0.6	6.5	42	8.9	1.1	11.9	42
No. 200	0.075	6.4	5.5	0.5	9.9	42	5.5	1.0	17.9	42

Table 35. Aggregate gradation summary for coarse graded mixture – original construction.

Sieve Size		Target	Top Layer				Bottom Lift			
(US)	(mm)		Mean	Std Dev	Cov	n	Mean	Std Dev	Cov	n
3/4"	19.0	100	100	0.0	0.0	41	100	0	0	37
1/2"	12.5	82.4	79.2	2.7	3.4	41	81.7	2.6	3.2	37
3/8"	9.50	64.6	65.0	6.4	9.9	41	66.2	3.0	4.6	37
No. 4	4.75	41.2	41.8	2.4	5.7	41	42.0	2.2	5.2	37
No. 8	2.36	27.8	28.6	1.5	5.2	41	27.7	1.3	4.8	37
No. 16	1.18	19.7	21.0	1.0	4.6	41	19.9	0.8	4.1	37
No. 30	0.60	14.6	16.1	0.7	4.2	41	14.9	0.6	3.9	37
No. 50	0.30	10.8	12.2	0.5	4.4	41	11.0	0.4	4.1	37
No. 100	0.15	7.7	9.0	0.5	5.6	41	7.9	0.4	5.0	37
No. 200	0.075	5.1	6.6	0.4	6.0	41	5.5	0.3	5.1	37

Quality Control Aggregate Gradations—Replacement Sections

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-23
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the SHRP Superpave HMA volumetric design method.

This WesTrack technical report provides information on aggregate gradation measured during construction of the replacement sections and referred to as "quality control aggregate gradation." The test program used for sampling and testing is contained in WesTrack Technical Report UNR-19.[4] Gradations were obtained during construction on samples obtained from the cold feed and from samples obtained behind the paving machine. Gradations on the HMA samples were obtained after ignition oven testing.

The aggregate gradation, asphalt binder content, and gyratory compactor information obtained during construction was used to control the HMA process. Problems with calibration of ignition ovens was evident during construction. WesTrack Technical Report UNR-16[5] provides information on the quality control testing associated with asphalt binder content determination during construction.

BACKGROUND

The replacement sections were placed at WesTrack to repair failed sections that were placed during the original construction of the track and to obtain additional information on the performance of coarse-graded Superpave mixtures. Mixture design information for the replacement sections is contained in WesTrack Technical Report UNR-7.[6] Construction of the replacement sections was performed during May and June 1997.

HMA mixtures were placed on the ramps to the test track on May 23 and 30, 1997 (table 1), to determine the constructability of the HMA and to determine the gradation, asphalt binder contents, and the volumetrics. Additional trial sections were placed on the access road to WesTrack on June 20, 1997. Adjustments in the amount of fines returned from the baghouse, in the cold feeds to obtain the desired gradation, in the asphalt binder content, and in the roller pattern to obtain the desired air void content were undertaken during the time allocated for the placement of these trial sections.

The construction of the test lane of the track was performed in two lifts that were placed on June 23 and 28, 1997. The test lanes were the lanes on which the traffic was placed and from which WesTrack performance information was obtained.

Prior to the start of production of the HMA, the HMA production facility was calibrated using California Department of Transportation standard procedures for plant production. This calibration included determination of individual cold-feed rates for each aggregate, calibration of the scale belt, and calibration of the asphalt binder delivery system. Additional calibrations were performed during the placement of the hot mixes at WesTrack.

SAMPLING

Aggregate gradations determined for quality control purposes were performed on combined cold-feed samples and on samples of HMA. Combined belt cold-feed samples were obtained prior to the addition of lime to the aggregate. A diversion plate was used to re-direct the falling aggregate stream as it fell from the cold-feed collector belt to the pugmill mixer used for the addition of lime to the aggregate. The samples of HMA were obtained from randomly located cores for the trial sections and from loose mixture obtained from behind the paver prior to compaction for the test sections. The loose hot-mix samples obtained from behind the paver were used for asphalt content determination and gyratory compactor volumetrics. The detailed sampling and testing plan for the replacement sections can be found in WesTrack Technical Report UNR-19.[4]

TEST METHODS

The aggregate gradations were determined by use of AASHTO T 11 and T 27. The gradations were performed after the samples of HMA had been tested to determine asphalt binder content by use of the National Center for Asphalt Technology (NCAT) ignition oven (ASTM D6307).

TRIAL SECTIONS

BOTTOM LIFT

The bottom lift of the trial sections was placed on May 23, 1997. Sections 35, 37, and 38 and sections 39, 55, and 56 were placed at different asphalt binder contents with the same cold-feed

settings, but with different baghouse return settings. Both cold-feed samples and core samples were used to determine the aggregate gradations.

Cold-Feed Gradations

Individual sample gradations for the cold-feed samples are shown in appendix A. Summary information for sections 35, 37, and 38 and sections 39, 55, and 56 are shown in tables 2 and 3, respectively. The setting on the baghouse return system was changed between these groups of sections.

Core Sample Gradations

Individual sample gradations obtained from core samples after the asphalt binder content was determined by the ignition oven are shown in appendix B. Summary information for sections 35, 37, and 38 and sections 39, 55, and 56 are shown in tables 4 and 5, respectively. As expected, the gradations of the cold-feed samples (tables 2 and 3) did not change with a change in the baghouse settings; however, a slight change was noted in the gradations obtained from the core samples (tables 4 and 5).

TOP LIFT

The top lift of the trial sections was placed on May 30, 1997. Sections 35, 37, and 38 and sections 39, 55, and 56 were placed at different asphalt binder contents with the same cold-feed settings, but with different baghouse return settings. Both cold-feed samples and core samples were used to determine the aggregate gradations.

Cold-Feed Gradations

Individual sample gradations for the cold-feed samples are shown in appendix C. Summary information for sections 35, 37, and 39 and sections 39, 55, and 56 are shown in tables 6 and 7, respectively. The setting on the baghouse was changed between these groups of sections.

Core Sample Gradations

Individual sample gradations obtained from core samples taken after the asphalt binder content was determined by the ignition oven are shown in appendix D. Summary information for sections 35, 37, and 38 and sections 39, 55, and 56 are shown in tables 8 and 9, respectively. As expected, the gradations of the cold-feed samples (tables 6 and 7) did not change with a change in the baghouse settings; however, a slight change was noted in the gradations obtained from the core samples (tables 8 and 9).

ACCESS ROAD

The access road to WesTrack was paved on June 20, 1997, to provide additional trial section locations for the replacement sections. Three additional sections (sections 39, 55, and 56) were

placed at different asphalt contents with the same gradation. Both cold-feed and core samples were used to determine the aggregate gradations.

Cold-Feed Gradations

Individual sample gradations for the cold-feed samples are shown in appendix E. Summary information for the three trial sections is shown in table 10.

Core Sample Gradations

Individual sample gradations obtained from core samples taken after the asphalt binder content was determined by the ignition oven are shown in appendix F. Summary information for the three sections is shown in table 3.

TEST SECTIONS

BOTTOM LIFT

The bottom lift of the test section was placed on June 23, 1997. Gradations were determined from cold-feed samples and from samples obtained behind the paver after asphalt binder content determination.

Cold-Feed Gradations

Individual sample gradations for the cold-feed samples from each section are shown in appendix G. Summary statistics for the gradations for all of the sections placed on the bottom lift are shown in table 12. Table 13 shows the average gradation for each section.

Loose Mix Sample Gradations

Individual sample gradations for loose mix samples from each section, obtained behind the paver and after ignition oven testing, are shown in appendix H. Summary statistics for the gradations for all of the sections placed on the bottom lift are shown in table 14. Table 15 shows the average gradation for each section.

TOP LIFT

The top lift of the test section was placed on June 28, 1997. Gradations were determined from cold-feed samples and from samples obtained behind the paver after asphalt binder content determination.

Cold-Feed Gradations

Individual sample gradations for the cold-feed samples from each section are shown in appendix I. Summary statistics for the gradations for all of the sections placed on the top lift are shown in table 16. Table 17 shows the average gradation for each section.

Loose Mix Sample Gradations

Individual sample gradations for loose mix samples from each section, obtained from behind the paver after ignition oven testing, are shown in appendix J. Summary statistics for the gradations for all of the sections placed on the top lift are shown on table 18. Table 19 shows the average gradation for each section.

SUMMARY

The gradation information presented in this report was used for quality control purposes. Aggregate gradation "quality assurance" data is reported in WesTrack Technical Report UNR-24.[7] Quality assurance data should be used for performance modeling and is considered the most accurate information available that defines the gradation of the aggregate on the replacement sections.

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Table 1. Construction schedule – replacement sections.

Date	Lift	Lane	Section Numbers
5-23-97	Bottom	Trial	35, 37, 38, 39, 55, 56
5-30-97	Top	Trial	35, 37, 38, 39, 55, 56
6-20-97	Bottom	Trial*	A, B, C
6-23-97	Bottom	Test	35, 36, 37, 38, 39, 54, 55, 56
6-28-97	Top	Test	35, 36, 37, 38, 39, 54, 55, 56

*Access road.

Table 2. Cold-feed gradation statistics (sections 35, 37, and 38) – trial sections – bottom lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R
3/4-in.	99.6	97.1	102.1	99.6	0.4	0.9
1/2-in.	81.2	78.7	83.7	85.5	2.0	5.2
3/8-in.	66.7	64.2	69.2	69.6	1.7	4.1
#4	37.3	34.8	39.8	35.0	1.2	3.1
#8	22.5	20.5	24.5	21.8	0.9	2.3
#16	14.5	12.5	16.5	14.4	0.6	1.4
#30	10.5	8.5	12.5	10.4	0.4	1.2
#50	7.8	6.3	9.3	8.0	0.4	1.1
#100	6.2	5.2	7.2	6.5	0.4	1.1
#200	4.9	4.4	5.4	5.4	0.4	1.1

Construction date: May 23, 1997.

Table 3. Cold-feed gradation statistics (sections 39, 55, and 56) – trial sections – bottom lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R	UL	LL	QI_U	QI_L
3/4-in.	99.6	97.1	102.1	99.7	0.3	0.8	102.1	97.1	6.905747	7.462522
1/2-in.	81.2	78.7	83.7	85.7	3.8	10.2	83.7	78.7	-0.51987	1.832556
3/8-in.	66.7	64.2	69.2	70.5	5.7	15.7	69.2	64.2	-0.2244	1.106157
#4	37.3	34.8	39.8	36.8	3.3	9.1	39.8	34.8	0.921483	0.600241
#8	22.5	20.5	24.5	22.6	2.0	5.7	24.5	20.5	0.939794	1.03374
#16	14.5	12.5	16.5	14.9	1.5	3.9	16.5	12.5	1.117479	1.628617
#30	10.5	8.5	12.5	10.5	0.9	2.3	12.5	8.5	2.23113	2.18384
#50	7.8	6.3	9.3	8.0	0.7	1.9	9.3	6.3	1.875974	2.353287
#100	6.2	5.2	7.2	6.4	0.7	1.9	7.2	5.2	1.138096	1.786316
#200	4.9	4.4	5.4	5.3	0.7	1.8	5.4	4.4	0.226297	1.309092

Construction date: May 23, 1997.

Table 4. Core ignition gradation statistics (sections 35, 37, and 38) – trial sections – bottom lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R
3/4-in.	99.6	97.1	102.1	99.9	0.3	1.0
1/2-in.	81.5	79.0	84.0	86.8	2.1	8.1
3/8-in.	67.2	64.7	69.7	71.9	2.5	10.4
#4	38.2	35.7	40.7	39.1	2.2	7.5
#8	23.7	21.7	25.7	26.0	1.2	5.2
#16	15.8	13.8	17.8	17.8	1.0	4.8
#30	11.8	9.8	13.8	13.2	1.0	4.8
#50	9.1	7.6	10.6	10.3	1.0	4.7
#100	7.5	6.5	8.5	8.4	1.0	4.6
#200	6.0	5.5	6.5	6.8	1.0	4.4

Construction date: May 23, 1997.

Table 5. Core ignition gradation statistics (sections 39, 55, and 56) – trial sections – bottom lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R
3/4-in.	99.6	97.1	102.1	99.9	0.3	1.3
1/2-in.	81.3	78.8	83.8	87.4	1.5	4.4
3/8-in.	66.9	64.4	69.4	73.7	3.9	15.1
#4	37.5	35.0	40.0	40.8	2.4	8.6
#8	22.9	20.9	24.9	27.0	3.9	15.9
#16	15.0	13.0	17.0	17.4	1.4	4.7
#30	10.9	8.9	12.9	12.6	1.0	3.0
#50	8.2	6.7	9.7	9.6	0.7	1.9
#100	6.5	5.5	7.5	7.7	0.5	1.4
#200	5.1	4.6	10.1	6.2	0.4	1.1

Construction date: May 23, 1997.

Table 6. Cold-feed gradation statistics (sections 35, 37, and 38) – trial sections – top lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R
3/4-in.	99.5	97	102	99.7	0.5	1.3
1/2-in.	82.7	80.2	85.2	83.0	3.5	9.9
3/8-in.	65.8	63.3	68.3	66.2	4.5	12.8
#4	38.8	36.3	41.3	34.8	3.3	9.7
#8	24.2	22.2	26.2	21.1	2.3	5.6
#16	15.9	13.9	17.9	14.5	1.5	3.9
#30	11.5	9.5	13.5	10.3	1.0	2.7
#50	8.7	7.2	10.2	7.9	0.7	2.1
#100	6.8	5.8	7.8	6.2	0.6	1.7
#200	5.7	5.2	6.2	5.0	0.5	1.4

Construction date: May 30, 1997.

Table 7. Cold-feed gradation statistics (sections 39, 55, and 56) – trial sections – top lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R
3/4-in.	99.5	97	102	99.6	0.9	2.2
1/2-in.	82.7	80.2	85.2	85.2	2.4	6.7
3/8-in.	65.8	63.3	68.3	69.1	2.7	7.1
#4	38.8	36.3	41.3	37.8	2.4	6.4
#8	24.2	22.2	26.2	22.7	1.5	4.1
#16	15.9	13.9	17.9	14.9	0.9	2.5
#30	11.5	9.5	13.5	10.4	0.5	1.3
#50	8.7	7.2	10.2	7.9	0.4	0.9
#100	6.8	5.8	7.8	6.2	0.3	0.7
#200	5.7	5.2	6.2	4.9	0.3	0.6

Construction date: May 30, 1997.

Table 8. Core ignition gradation statistics (sections 35, 57, and 38) – trial sections – top lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R	UL	LL
3/4-in.	99.6	97.1	102.1	99.9	0.2	0.5	102.1	97.1
1/2-in.	83.4	80.9	85.9	86.7	1.7	5.8	85.9	80.9
3/8-in.	68.2	65.7	70.7	71.7	2.3	8.0	70.7	65.7
#4	38.5	36.0	41.0	39.6	2.1	8.3	41	36
#8	24.2	22.2	26.2	23.9	1.4	5.8	26.2	22.2
#16	16.5	14.5	18.5	15.9	0.7	2.6	18.5	14.5
#30	11.9	9.9	13.9	11.4	0.5	1.9	13.9	9.9
#50	9.0	7.5	10.5	8.7	0.4	1.6	10.5	7.5
#100	7.3	6.3	8.3	6.8	0.4	1.4	8.3	6.3
#200	5.9	5.4	6.4	5.4	0.4	1.2	6.4	5.4

Construction date: May 30, 1997.

Table 9. Core ignition gradation statistics (sections 39, 55, and 56) – trial sections – top lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R	UL	LL
3/4-in.	99.6	97.1	102.1	99.9	0.2	0.4	102.1	97.1
1/2-in.	83.3	80.8	85.8	88.1	1.7	5.7	85.8	80.8
3/8-in.	68.1	65.6	70.6	74.3	2.2	7.9	70.6	65.6
#4	38.2	35.7	40.7	42.0	2.5	8.2	40.7	35.7
#8	23.8	21.8	25.8	25.6	1.5	5.2	25.8	21.8
#16	16.1	14.1	18.1	16.3	0.8	2.9	18.1	14.1
#30	11.5	9.5	13.5	11.3	0.6	2.0	13.5	9.5
#50	8.6	7.1	10.1	8.4	0.5	2.0	10.1	7.1
#100	6.8	5.8	7.8	6.5	0.5	2.0	7.8	5.8
#200	5.5	5.0	10.5	5.1	0.6	2.0	10.5	5.0

Construction date: May 30, 1997.

Table 10. Cold-feed gradation statistics, sections A (39), B (55), C (56) – access road.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R	UL	LL	QI_U	QI_L	PD_U	PD_L	PWL (n=6)
3/4-in.	99.2	96.7	102	99.9	0.3	0.8	101.7	96.7	5.55	9.56	0.00	0.00	100
1/2-in.	82.6	80.1	85.1	86.6	3.3	8.4	85.1	80.1	-0.44	1.97	69.38	0.00	30.62
3/8-in.	69.4	66.9	71.9	72.9	5.1	14.2	71.9	66.9	-0.21	1.19	60.58	6.82	32.6
#4	41.3	38.8	43.8	43.5	6.7	19.6	43.8	38.8	0.05	0.70	50.73	18.78	30.49
#8	25.4	23.4	27.4	26.8	4.4	13.0	27.4	23.4	0.14	0.78	48.90	10.28	40.82
#16	16.6	14.6	18.6	17.4	2.5	7.3	18.6	14.6	0.47	1.13	33.38	0.00	66.62
#30	11.8	9.8	13.8	12.4	1.5	4.3	13.8	9.8	0.94	1.73	10.51	0.00	89.49
#50	8.9	7.4	10.4	9.3	1.1	3.0	10.4	7.4	1.05	1.71	26.92	0.00	73.08
#100	7.1	6.1	8.1	7.3	0.9	2.4	8.1	6.1	0.84	1.35	44.50	0.15	55.35
#200	5.8	5.3	6.3	6.1	0.8	2.1	6.3	5.3	0.28	1.04	65.92	4.98	29.1

Construction date: June 20, 1997.

Table 11. Core ignition gradation statistics, sections A (39), B (55), C (56) – access road.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R	UL	LL	QI_U	QI_L	PD_U	PD_L	PWL (n=15)
3/4-in.	99.2	96.7	101.7	99.6	0.4	1.1	101.7	96.7	4.84	6.55	0	0	100
1/2-in.	82.8	80.3	85.3	85.6	4.1	13.7	85.3	80.3	-0.06	1.28	52.44	9.77	37.79
3/8-in.	69.5	67.0	72.0	70.4	4.7	15.4	72.0	67.0	0.35	0.72	36.57	23.83	39.6
#4	41.4	38.9	43.9	40.8	4.1	12.4	43.9	38.9	0.76	0.46	22.6	32.57	44.83
#8	25.6	23.6	27.6	25.1	2.6	8.1	27.6	23.6	0.96	0.55	16.94	29.41	53.65
#16	16.8	14.8	18.8	16.1	1.5	5.0	18.8	14.8	1.78	0.82	3.11	20.81	76.08
#30	12.1	10.1	14.1	11.3	1.0	3.1	14.1	10.1	2.76	1.22	0.05	10.93	89.02
#50	9.1	7.6	10.6	8.4	0.8	2.1	10.6	7.6	2.91	1.09	0.01	13.74	86.25
#100	7.2	6.2	8.2	6.6	0.6	1.6	8.2	6.2	2.67	0.58	0.08	28.39	71.53
#200	5.8	5.3	10.8	5.3	0.5	1.3	10.8	5.3	10.70	-0.06	0	52.44	47.56

Construction date: June 20, 1997.

Table 12. Cold-feed gradation statistics – test lane – bottom lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R
3/4-in.	99.2	96.7	101.7	99.7	0.4	1.2
1/2-in.	82.6	80.1	85.1	86.1	2.7	13.0
3/8-in.	69.4	66.9	71.9	71.3	3.9	19.3
#4	41.3	38.8	43.8	42.2	3.9	18.8
#8	25.4	23.4	27.4	25.8	2.7	12.8
#16	16.6	14.6	18.6	16.8	1.7	7.9
#30	11.8	9.8	13.8	12.0	1.1	5.2
#50	8.9	7.4	10.4	9.1	0.9	4.0
#100	7.1	6.1	8.1	7.2	0.8	3.6
#200	5.8	5.3	6.3	5.9	0.8	3.4

Construction date: June 23, 1997.

Table 13. Cold-feed gradation – average values by section – test lane – bottom lift.

Average Percent Passing									
		Section Number							
Sieve Size	**Target**	**35**	**36**	**37**	**38**	**39**	**54**	**55**	**56**
3/4-in.	99.2	100.0	99.9	99.6	99.4	99.4	99.8	99.4	99.7
1/2-in.	82.6	86.1	86.2	83.4	85.9	84.9	87.5	88.0	87.0
3/8-in.	69.4	71.6	70.6	67.8	70.6	69.7	73.1	74.2	72.6
#4	41.3	43.5	40.9	39.8	41.0	39.9	45.1	43.7	43.7
#8	25.4	27.2	25.1	24.7	25.1	24.0	27.3	26.5	26.4
#16	16.6	18.0	16.5	16.3	16.4	15.7	17.5	17.1	17.0
#30	11.8	12.9	11.9	11.7	11.8	11.2	12.3	12.1	12.2
#50	8.9	9.7	9.1	8.9	9.0	8.5	9.2	9.1	9.2
#100	7.1	7.8	7.3	7.1	7.1	6.8	7.3	7.2	7.2
#200	5.8	6.3	5.9	5.8	5.8	5.6	6.0	6.0	5.9

Construction date: June 23, 1997.

Table 14. Gradation statistics from loose mix samples – test lane – bottom lift.*

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R
3/4-in.	99.2	96.7	101.7	99.6	0.6	2.7
1/2-in.	82.8	80.3	85.3	85.1	1.9	10.0
3/8-in.	69.5	67	72	70.5	2.0	10.0
#4	41.4	38.9	43.9	40.7	1.7	8.1
#8	25.6	23.6	27.6	24.9	1.1	5.4
#16	16.8	14.8	18.8	16.2	0.6	2.7
#30	12.1	10.1	14.1	11.4	0.7	3.8
#50	9.1	7.6	10.6	8.4	0.6	2.5
#100	7.2	6.2	8.2	6.6	0.5	2.1
#200	5.8	5.3	6.3	5.2	0.5	2.1

*After ignition oven.
Construction date: June 23, 1997.

Table 15. Gradation by section from loose mix samples – test lane – bottom lift.*

Average Percent Passing									
		Section Number							
Sieve Size	**Target**	**35**	**36**	**37**	**38**	**39**	**54**	**55**	**56**
3/4-in.	99.2	99.8	99.2	99.8	99.5	99.6	99.8	99.6	99.8
1/2-in.	82.8	85.3	84.3	85.1	87.0	84.2	84.9	84.3	85.3
3/8-in.	69.5	70.3	69.9	70.1	72.4	69.1	71.3	69.3	71.6
#4	41.4	41.3	39.4	40.3	42.4	39.3	41.5	39.8	41.8
#8	25.6	25.4	24.2	24.3	25.9	24.2	25.3	24.2	25.7
#16	16.8	16.4	15.9	15.9	16.9	15.7	16.7	16.0	17.0
#30	12.1	11.6	11.3	11.3	11.9	11.0	11.9	10.6	12.0
#50	9.1	8.6	8.0	8.5	8.9	8.2	8.9	8.0	9.0
#100	7.2	6.6	6.6	6.7	7.0	6.2	6.9	6.2	7.1
#200	5.8	5.1	5.3	5.4	5.5	4.8	5.6	5.1	5.7

*After ignition oven.
Construction date: June 23, 1997.

Table 16. Cold-feed gradation statistics – test lane – top lift.

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R
3/4-in.	99.2	96.7	101.7	99.8	0.4	1.6
1/2-in.	82.6	80.1	85.1	86.3	3.4	15.7
3/8-in.	69.4	66.9	71.9	72.9	4.8	19.5
#4	41.3	38.8	43.8	43.5	5.5	26.9
#8	25.4	23.4	27.4	26.9	4.0	21.2
#16	16.6	14.6	18.6	17.4	2.3	12.4
#30	11.8	9.8	13.8	12.1	1.1	5.2
#50	8.9	7.4	10.4	9.2	0.9	4.7
#100	7.1	6.1	8.1	7.3	0.8	3.9
#200	5.8	5.3	6.3	6.0	0.7	3.2

Construction date: June 28, 1997.

Table 17. Cold-feed gradation – average values by section – test lane – top lift.

Average Percent Passing									
		Section Number							
Sieve Size	**Target**	**35**	**36**	**37**	**38**	**39**	**54**	**55**	**56**
3/4-in.	99.2	99.8	99.6	99.9	99.8	99.6	99.9	99.7	99.9
1/2-in.	82.6	91.3	86.3	85.4	85.9	84.8	82.4	86.3	87.9
3/8-in.	69.4	80.3	73.3	72.3	72.3	69.5	67.1	72.4	75.5
#4	41.3	52.8	45.2	43.6	42.3	41.6	37.4	40.6	44.5
#8	25.4	34.0	28.1	27.1	25.8	25.9	22.9	24.1	27.1
#16	16.6	21.5	18.1	17.5	16.8	17.1	15.1	15.7	17.6
#30	11.8	13.6	12.5	12.3	12.0	12.1	10.7	11.1	12.2
#50	8.9	10.8	9.4	9.3	9.1	9.3	8.2	8.5	9.2
#100	7.1	8.6	7.4	7.4	7.2	7.4	6.3	6.6	7.3
#200	5.8	7.1	6.0	6.3	5.9	6.0	5.2	5.5	5.9

Construction date: June 28, 1997.

Table 18. Gradation statistics from loose mix samples – test lane – top lift.*

Sieve Size	Target	Spec Minus	Spec Plus	X	S	R
3/4-in.	99.2	96.7	101.7	99.90	0.22	0.89
1/2-in.	82.8	80.3	85.3	84.30	2.30	11.02
3/8-in.	69.5	67	72	69.80	2.44	10.32
#4	41.4	38.9	43.9	40.02	1.70	9.63
#8	25.6	23.6	27.6	25.01	1.03	4.85
#16	16.8	14.8	18.8	16.64	0.61	2.94
#30	12.1	10.1	14.1	11.94	0.46	2.32
#50	9.1	7.6	10.6	9.13	0.38	1.92
#100	7.2	6.2	8.2	7.28	0.35	1.59
#200	5.8	5.3	6.3	5.87	0.31	1.33

*After ignition oven.
Construction date: June 28, 1997.

Table 19. Gradation by section from loose mix samples – test lane – top lift.*

Average Percent Passing									
		Section Number							
Sieve Size	**Target**	**35**	**36**	**37**	**38**	**39**	**54**	**55**	**56**
3/4-in.	99.2	100.0	99.8	100.0	99.9	100.0	99.8	99.9	99.8
1/2-in.	82.8	84.0	84.1	83.3	83.8	83.4	84.9	86.3	84.6
3/8-in.	69.5	69.5	68.7	68.7	69.9	69.3	71.0	71.5	69.8
#4	41.4	39.1	40.0	39.1	40.6	39.6	41.3	40.5	40.0
#8	25.6	24.0	25.4	24.6	25.6	24.3	25.7	25.1	25.3
#16	16.8	16.0	16.7	16.5	17.4	16.1	16.8	16.6	17.0
#30	12.1	11.5	12.0	11.8	12.6	11.6	11.9	12.0	12.2
#50	9.1	8.8	9.1	9.0	9.7	8.9	9.0	9.2	9.4
#100	7.2	7.0	7.2	7.1	7.7	7.1	7.2	7.4	7.5
#200	5.8	5.6	5.8	5.7	6.2	5.7	5.8	6.0	6.1

*After ignition oven.
Construction date: June 28, 1997.

APPENDIX A

COLD-FEED AGGREGATE GRADATIONS FOR BOTTOM LIFT OF TRIAL LANE

coldfeed summary

Section 35					Construction Date:	5-23-97
Sieve Size	Target	35-1	35-2	X	S	R
3/4"	99.6	99.1	99.5	99.3	0.3	0.5
1/2"	81.2	87.1	87.5	87.3	0.3	0.4
3/8"	66.7	71.5	70.4	71.0	0.8	1.2
#4	37.3	33.9	35.8	34.9	1.4	1.9
#8	22.5	21.0	22.1	21.6	0.7	1.1
#16	14.5	13.9	14.9	14.4	0.7	0.9
#30	10.5	10.1	10.6	10.4	0.3	0.5
#50	7.8	7.9	8.3	8.1	0.3	0.4
#100	6.2	6.4	6.7	6.6	0.2	0.3
#200	4.9	5.7	5.6	5.6	0.1	0.1

coldfeed summary

Section 37				Construction Date: 5-23-97		
Sieve Size	Target	37-1	37-2	X	S	R
3/4"	99.6	100.0	99.5	99.7	0.4	0.5
1/2"	81.2	84.1	85.6	84.8	1.0	1.5
3/8"	66.7	67.8	70.8	69.3	2.2	3.1
#4	37.3	33.8	36.9	35.4	2.2	3.1
#8	22.5	21.2	23.2	22.2	1.4	2.0
#16	14.5	14.2	15.3	14.7	0.8	1.1
#30	10.5	10.6	10.9	10.7	0.2	0.3
#50	7.8	8.4	8.3	8.4	0.1	0.1
#100	6.2	6.9	6.6	6.8	0.2	0.3
#200	4.9	5.8	5.3	5.6	0.3	0.4

coldfeed summary

Section 38						Construction Date: 5-23-97
Sieve Size	Target	38-1	38-2	X	S	R
3/4"	99.6	100.0	99.5	99.8	0.3	0.5
1/2"	81.2	86.4	82.3	84.3	2.9	4.1
3/8"	66.7	69.7	67.5	68.6	1.6	2.2
#4	37.3	34.9	34.3	34.6	0.4	0.6
#8	22.5	22.1	21.0	21.5	0.8	1.1
#16	14.5	14.4	13.9	14.2	0.4	0.5
#30	10.5	10.4	9.7	10.0	0.5	0.7
#50	7.8	8.1	7.3	7.7	0.5	0.8
#100	6.2	6.5	5.8	6.1	0.5	0.7
#200	4.9	5.4	4.7	5.0	0.5	0.7

coldfeed summary

Section 39				Construction Date:		5-23-97
Sieve Size	Target	39-1	39-2	X	S	R
3/4"	99.6	100.0	99.4	99.7	0.4	0.6
1/2"	81.2	87.6	83.1	85.3	3.2	4.5
3/8"	66.7	71.4	64.9	68.2	4.6	6.5
#4	37.3	36.3	34.6	35.4	1.2	1.8
#8	22.5	21.7	22.2	22.0	0.3	0.4
#16	14.5	14.0	14.9	14.4	0.6	0.8
#30	10.5	9.8	10.4	10.1	0.4	0.6
#50	7.8	7.4	7.9	7.6	0.3	0.5
#100	6.2	5.8	6.3	6.1	0.4	0.5
#200	4.9	4.6	5.2	4.9	0.4	0.6

coldfeed summary

Section 55				Construction Date: 5-23-97		
Sieve Size	Target	55-1	55-2	X	S	R
3/4"	99.6	100.0	99.2	99.6	0.6	0.8
1/2"	81.2	92.5	83.9	88.2	6.1	8.6
3/8"	66.7	80.6	67.5	74.1	9.3	13.2
#4	37.3	42.9	35.3	39.1	5.3	7.5
#8	22.5	26.3	21.4	23.9	3.5	4.9
#16	14.5	17.5	13.8	15.7	2.6	3.7
#30	10.5	12.2	9.8	11.0	1.6	2.3
#50	7.8	9.3	7.5	8.4	1.3	1.8
#100	6.2	7.7	6.0	6.8	1.2	1.7
#200	4.9	6.4	4.8	5.6	1.1	1.6

coldfeed summary

Section 56				Construction Date:		5-23-97
Sieve Size	Target	56-1	56-2	X	S	R
3/4"	99.6	99.5	100.0	99.8	0.3	0.5
1/2"	81.2	84.6	82.4	83.5	1.6	2.3
3/8"	66.7	71.8	66.6	69.2	3.7	5.2
#4	37.3	37.7	33.8	35.8	2.8	3.9
#8	22.5	23.3	20.6	22.0	1.9	2.7
#16	14.5	15.4	13.6	14.5	1.3	1.8
#30	10.5	10.8	9.9	10.3	0.7	0.9
#50	7.8	8.2	7.6	7.9	0.4	0.6
#100	6.2	6.7	6.1	6.4	0.4	0.6
#200	4.9	5.5	5.0	5.2	0.4	0.5

APPENDIX B

AGGREGATE GRADATIONS OBTAINED FROM BOTTOM LIFT OF TRIAL LANE

core summary

Sieve Size	Target	Section 35					Construction Date: 5-23-97		
		35-1	35-2	35-3	35-4	35-5	X	S	R
3/4"	99.6	100.0	99.5	100.0	100.0	100.0	99.9	0.2	0.5
1/2"	81.5	84.3	86.6	87.6	85.1	88.0	86.3	1.6	3.7
3/8"	67.2	68.7	71.3	72.8	72.0	72.6	71.5	1.7	4.1
#4	38.2	35.8	39.7	39.2	39.0	39.1	38.5	1.6	3.9
#8	23.7	23.1	26.3	25.9	25.8	26.0	25.4	1.3	3.1
#16	15.8	15.1	17.9	17.9	17.4	17.8	17.2	1.2	2.8
#30	11.8	10.5	13.2	13.4	12.8	13.2	12.6	1.2	2.9
#50	9.1	7.5	10.3	10.5	9.9	10.2	9.7	1.2	3.0
#100	7.5	5.5	8.3	8.5	8.1	8.2	7.7	1.2	3.0
#200	6.0	4.0	6.8	6.9	6.7	6.6	6.2	1.2	2.9

core summary

Sieve Size	Target	Section 37					Construction Date:		5-23-97
		37-1	37-2	37-3	37-4	37-5	X	S	R
3/4"	99.6	100.0	99.6	99.0	100.0	100.0	99.7	0.5	1.0
1/2"	81.5	88.0	86.8	81.6	88.5	86.3	86.2	2.8	6.9
3/8"	67.2	73.3	71.5	65.2	73.2	71.0	70.9	3.3	8.1
#4	38.2	39.9	39.0	35.7	39.6	40.3	38.9	1.9	4.6
#8	23.7	26.5	25.6	24.2	25.4	27.1	25.8	1.1	2.8
#16	15.8	18.4	17.8	17.0	17.4	19.0	17.9	0.8	1.9
#30	11.8	13.8	13.3	12.8	13.1	14.3	13.5	0.6	1.5
#50	9.1	10.9	10.5	10.1	10.4	11.4	10.7	0.5	1.3
#100	7.5	9.0	8.7	8.2	8.5	9.4	8.8	0.4	1.1
#200	6.0	7.5	7.2	6.7	7.0	7.7	7.2	0.4	1.0

core summary

Sieve Size	Target	Section 38					Construction Date:		5-23-97
		38-1	38-2	38-3	38-4	38-5	X	S	R
3/4"	99.6	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	81.5	88.0	89.0	87.1	89.6	85.3	87.8	1.7	4.3
3/8"	67.2	74.0	74.6	72.6	75.7	70.3	73.4	2.1	5.4
#4	38.2	41.5	41.9	39.7	41.4	34.4	39.8	3.1	7.5
#8	23.7	27.5	28.3	26.4	26.5	25.7	26.9	1.0	2.6
#16	15.8	18.5	19.9	17.9	17.6	18.0	18.4	0.9	2.3
#30	11.8	13.5	15.3	13.1	12.7	13.5	13.6	1.0	2.6
#50	9.1	10.5	12.2	10.1	9.7	10.6	10.6	0.9	2.5
#100	7.5	8.5	10.1	8.2	7.8	8.7	8.6	0.9	2.3
#200	6.0	6.9	8.4	6.6	6.2	7.1	7.0	0.8	2.2

core summary

Sieve Size	Target	Section 39							Construction Date: 5-23-97
		39-1	39-2	39-3	39-4	39-5	X	S	R
3/4"	99.6	98.7	100.0	100.0	100.0	100.0	99.7	0.6	1.3
1/2"	81.3	87.8	85.3	85.5	85.8	86.4	86.2	1.0	2.5
3/8"	66.9	74.2	68.9	70.4	69.5	73.4	71.3	2.4	5.3
#4	37.5	41.1	37.8	38.4	37.5	38.6	38.7	1.4	3.5
#8	22.9	25.7	24.2	24.9	23.6	23.8	24.4	0.9	2.1
#16	15.0	17.2	16.1	16.7	15.5	15.8	16.2	0.7	1.7
#30	10.9	12.7	11.7	12.2	11.4	11.5	11.9	0.5	1.3
#50	8.2	9.8	9.1	9.4	8.8	8.9	9.2	0.4	1.0
#100	6.5	7.9	7.4	7.6	7.1	7.1	7.4	0.3	0.8
#200	5.1	6.4	6.2	6.2	5.8	5.8	6.1	0.3	0.6

core summary

Sieve Size	Target	Section 55							Construction Date: 5-23-97
		55-1	55-2	55-3	55-4	55-5	X	S	R
3/4"	99.6	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	81.3	89.7	87.2	89.5	88.0	89.2	88.7	1.1	2.6
3/8"	66.9	84.0	72.9	78.6	73.7	76.5	77.1	4.4	11.0
#4	37.5	41.0	40.9	46.1	42.9	42.8	42.8	2.1	5.2
#8	22.9	25.0	26.1	30.5	28.3	27.6	27.5	2.1	5.6
#16	15.0	16.2	17.0	20.1	18.7	17.9	18.0	1.5	3.9
#30	10.9	11.6	12.0	14.2	13.4	13.0	12.8	1.0	2.6
#50	8.2	8.8	9.0	10.5	10.2	10.1	9.7	0.8	1.7
#100	6.5	7.0	7.1	8.3	8.0	8.1	7.7	0.6	1.3
#200	5.1	5.6	5.7	6.7	6.5	6.6	6.2	0.5	1.1

core summary

Sieve Size	Target	Section 56							Construction Date: 5-23-97
		56-1	56-2	56-3	56-4	56-5	X	S	R
3/4"	99.6	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	81.3	87.8	88.8	86.7	86.4	86.6	87.3	1.0	2.4
3/8"	66.9	74.0	76.0	71.8	70.9	70.6	72.7	2.3	5.5
#4	37.5	42.5	42.8	41.4	39.7	39.1	41.1	1.6	3.6
#8	22.9	27.8	39.5	26.8	25.7	25.4	29.0	5.9	14.1
#16	15.0	19.0	19.6	17.8	17.1	16.8	18.1	1.2	2.8
#30	10.9	13.9	14.4	12.8	12.3	12.2	13.1	1.0	2.2
#50	8.2	10.5	10.7	9.8	9.3	9.4	9.9	0.6	1.4
#100	6.5	8.3	8.4	7.8	7.4	7.5	7.9	0.5	1.0
#200	5.1	6.8	6.8	6.3	5.9	6.1	6.4	0.4	0.9

APPENDIX C

COLD-FEED AGGREGATE GRADATIONS FOR TOP LIFT OF TRIAL LANE

coldfeed summary

Section 35				Construction Date: 5-30-97		
Sieve Size	Target	35-1	35-2	X	S	R
3/4"	99.5	99.5	100.0	99.7	0.4	0.5
1/2"	82.7	84.5	85.2	84.9	0.5	0.7
3/8"	65.8	67.6	69.3	68.4	1.2	1.7
#4	38.8	36.6	35.4	36.0	0.8	1.1
#8	24.2	23.2	20.4	21.8	2.0	2.8
#16	15.9	16.2	13.9	15.0	1.6	2.3
#30	11.5	11.5	10.1	10.8	1.0	1.4
#50	8.7	8.8	7.9	8.4	0.7	0.9
#100	6.8	7.0	6.3	6.7	0.5	0.7
#200	5.7	5.6	5.1	5.4	0.3	0.5

coldfeed summary

Section 37					Construction Date:	5-30-97
Sieve Size	Target	37-1	37-2	X	S	R
3/4"	99.5	100.0	100.0	100.0	0.0	0.0
1/2"	82.7	87.1	81.9	84.5	3.7	5.2
3/8"	65.8	70.5	65.3	67.9	3.7	5.2
#4	38.8	38.7	35.7	37.2	2.1	3.0
#8	24.2	23.2	22.6	22.9	0.4	0.5
#16	15.9	15.5	15.4	15.5	0.1	0.1
#30	11.5	10.9	10.7	10.8	0.1	0.1
#50	8.7	8.2	8.2	8.2	0.0	0.0
#100	6.8	6.4	6.5	6.5	0.1	0.1
#200	5.7	5.0	5.3	5.2	0.2	0.3

coldfeed summary

Section 38					Construction Date:	5-30-97
Sieve Size	Target	38-1	38-2	X	S	R
3/4"	99.5	100.0	98.7	99.3	0.9	1.3
1/2"	82.7	82.4	77.1	79.8	3.7	5.3
3/8"	65.8	66.5	57.7	62.1	6.2	8.7
#4	38.8	33.6	29.0	31.3	3.2	4.5
#8	24.2	19.9	17.6	18.7	1.7	2.3
#16	15.9	13.6	12.2	12.9	0.9	1.3
#30	11.5	9.7	8.8	9.3	0.6	0.9
#50	8.7	7.4	6.7	7.1	0.5	0.7
#100	6.8	5.8	5.3	5.6	0.4	0.5
#200	5.7	4.6	4.2	4.4	0.3	0.4

coldfeed summary

Section 39					Construction Date:	5-30-97
Sieve Size	Target	39-1	39-2	X	S	R
3/4"	99.5	100.0	100.0	100.0	0.0	0.0
1/2"	82.7	85.6	84.0	84.8	1.1	1.6
3/8"	65.8	69.1	70.1	69.6	0.7	1.0
#4	38.8	36.3	40.2	38.3	2.7	3.9
#8	24.2	22.0	24.6	23.3	1.8	2.5
#16	15.9	14.6	16.2	15.4	1.1	1.6
#30	11.5	10.2	11.2	10.7	0.7	1.0
#50	8.7	7.7	8.4	8.1	0.5	0.8
#100	6.8	6.0	6.6	6.3	0.4	0.6
#200	5.7	4.8	5.2	5.0	0.3	0.4

coldfeed summary

Section 55					Construction Date:	5-30-97
Sieve Size	Target	55-1	55-2	X	S	R
3/4"	99.5	100.0	97.8	98.9	1.6	2.2
1/2"	82.7	85.4	84.0	84.7	1.0	1.4
3/8"	65.8	69.8	66.2	68.0	2.6	3.6
#4	38.8	37.2	34.7	35.9	1.8	2.5
#8	24.2	22.2	20.5	21.3	1.2	1.7
#16	15.9	14.5	13.6	14.1	0.6	0.9
#30	11.5	10.1	9.9	10.0	0.2	0.2
#50	8.7	7.7	7.5	7.6	0.1	0.1
#100	6.8	6.0	5.9	6.0	0.1	0.1
#200	5.7	4.7	4.7	4.7	0.0	0.0

coldfeed summary

Section 56					Construction Date:	5-30-97
Sieve Size	Target	56-1	56-2	X	S	R
3/4"	99.5	100.0	100.0	100.0	0.0	0.0
1/2"	82.7	82.8	89.6	86.2	4.8	6.7
3/8"	65.8	66.2	73.2	69.7	5.0	7.1
#4	38.8	37.4	41.1	39.3	2.7	3.8
#8	24.2	22.9	24.1	23.5	0.9	1.2
#16	15.9	15.0	15.5	15.3	0.4	0.5
#30	11.5	10.5	10.8	10.6	0.2	0.3
#50	8.7	7.9	8.3	8.1	0.2	0.3
#100	6.8	6.2	6.6	6.4	0.2	0.3
#200	5.7	5.0	5.2	5.1	0.2	0.2

APPENDIX D

AGGREGATE GRADATIONS OBTAINED FROM CORE SAMPLES FOR TOP LIFT OF TRIAL LANE

core summary

Sieve Size	Target	Section 35 35-1	35-2	35-3	35-4	35-5	X	S	R
							Construction Date:		5-30-97
3/4"	99.6	100.0	100.0	99.5	99.6	99.6	99.7	0.2	0.5
1/2"	83.4	88.2	84.5	86.6	88.0	86.5	86.8	1.5	3.8
3/8"	68.2	72.7	69.2	71.6	71.2	70.1	71.0	1.3	3.5
#4	38.5	40.7	37.9	39.4	39.2	38.0	39.0	1.2	2.9
#8	24.2	24.5	23.2	23.8	24.0	23.6	23.8	0.5	1.3
#16	16.5	16.1	15.4	15.8	15.9	15.7	15.8	0.3	0.7
#30	11.9	11.5	11.1	11.5	11.6	11.4	11.4	0.2	0.5
#50	9.0	8.6	8.4	8.7	8.8	8.6	8.6	0.1	0.4
#100	7.3	6.8	6.6	6.9	6.9	6.8	6.8	0.1	0.3
#200	5.9	5.4	5.2	5.6	5.6	5.4	5.4	0.1	0.3

core summary

Sieve Size	Target	Section 37							Construction Date: 5-30-97
		37-1	37-2	37-3	37-4	37-5	X	S	R
3/4"	99.6	100.0		100.0	100.0	100.0	100.0	0.0	0.0
1/2"	83.4	83.8		85.8	86.5	88.1	86.1	1.8	4.3
3/8"	68.2	68.1		69.8	71.4	76.1	71.3	3.4	8.0
#4	38.5	36.6		37.8	40.7	44.9	40.0	3.7	8.3
#8	24.2	21.7		22.9	24.7	27.5	24.2	2.5	5.8
#16	16.5	14.9		14.9	16.7	17.5	16.0	1.3	2.6
#30	11.9	11.0		10.5	11.9	12.4	11.5	0.9	1.9
#50	9.0	8.6		7.7	9.1	9.3	8.7	0.7	1.6
#100	7.3	7.0		5.9	7.2	7.3	6.9	0.6	1.4
#200	5.9	5.5		4.6	5.6	5.8	5.4	0.5	1.2

core summary

Sieve Size	Target	Section 38 38-1	38-2	38-3	38-4	38-5	X	S	R
							Construction Date:		5-30-97
3/4"	99.6	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	83.4	85.7	86.4	89.6	85.1	89.1	87.2	2.1	4.5
3/8"	68.2	70.9	73.5	74.7	70.2	74.2	72.7	2.0	4.5
#4	38.5	38.3	39.9	40.8	37.9	41.3	39.6	1.5	3.4
#8	24.2	22.6	23.9	24.3	22.8	24.8	23.7	0.9	2.1
#16	16.5	15.3	16.2	16.5	15.4	16.6	16.0	0.6	1.3
#30	11.9	10.9	11.6	12.0	11.0	11.9	11.5	0.5	1.1
#50	9.0	8.2	8.9	9.2	8.3	9.2	8.8	0.5	1.0
#100	7.3	6.4	7.0	7.3	6.4	7.2	6.9	0.4	0.9
#200	5.9	4.9	5.3	5.7	4.8	5.6	5.3	0.4	0.9

core summary

Sieve Size	Target	Section 39							Construction Date: 5-30-97
		39-1	39-2	39-3	39-4	39-5	X	S	R
3/4"	99.6	100.0	99.6	100.0	100.0		99.9	0.2	0.4
1/2"	83.3	88.1	85.3	89.4	88.1		87.7	1.7	4.1
3/8"	68.1	74.0	71.6	72.2	74.2		73.0	1.3	2.6
#4	38.2	42.5	40.0	40.5	41.3		41.0	1.1	2.5
#8	23.8	25.8	24.5	24.6	25.4		25.1	0.6	1.3
#16	16.1	16.2	15.8	15.7	16.6		16.1	0.4	0.9
#30	11.5	11.3	11.1	11.1	10.5		11.0	0.3	0.8
#50	8.6	8.3	8.1	8.2	9.2		8.5	0.5	1.1
#100	6.8	6.5	6.3	6.4	7.3		6.6	0.5	1.0
#200	5.5	5.2	4.9	5.1	6.0		5.3	0.5	1.0

core summary

Sieve Size	Target	Section 55							Construction Date: 5-30-97
		55-1	55-2	55-3	55-4	55-5	X	S	R
3/4"	99.6	100.0	99.7	100.0	99.6	99.6	99.8	0.2	0.4
1/2"	83.3	89.0	87.1	88.8	91.0	85.5	88.3	2.1	5.4
3/8"	68.1	76.8	74.3	74.5	78.9	71.1	75.1	2.9	7.9
#4	38.2	45.6	44.6	42.6	46.9	39.1	43.7	3.0	7.8
#8	23.8	28.4	27.3	26.1	27.7	24.2	26.7	1.7	4.2
#16	16.1	17.8	17.1	16.4	17.0	15.6	16.8	0.8	2.2
#30	11.5	12.2	11.8	11.2	11.5	11.0	11.6	0.5	1.2
#50	8.6	8.9	8.7	8.1	8.3	8.1	8.4	0.4	0.8
#100	6.8	6.8	6.6	6.1	6.2	6.2	6.4	0.3	0.7
#200	5.5	5.4	5.0	4.6	4.8	4.8	4.9	0.3	0.8

core summary

Sieve Size	Target	Section 56							Construction Date: 5-30-97
		56-1	56-2	56-3	56-4	56-5	X	S	R
3/4"	99.6	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	83.3	87.1	90.1	89.6	85.9	88.0	88.1	1.7	4.2
3/8"	68.1	72.5	76.7	74.7	73.0	75.5	74.5	1.8	4.3
#4	38.2	38.7	43.5	39.5	40.7	43.0	41.1	2.1	4.8
#8	23.8	23.1	26.6	24.0	25.1	25.3	24.8	1.3	3.5
#16	16.1	14.9	17.0	15.5	16.4	16.4	16.1	0.8	2.1
#30	11.5	10.2	12.1	10.8	11.7	11.5	11.3	0.8	2.0
#50	8.6	7.2	9.2	7.7	8.8	8.5	8.3	0.8	1.9
#100	6.8	5.4	7.4	5.8	7.0	6.6	6.4	0.8	2.0
#200	5.5	4.1	6.1	4.5	5.7	5.2	5.1	0.8	2.0

APPENDIX E

COLD-FEED AGGREGATE GRADATIONS FOR ACCESS ROAD

coldfeed summary

Section A				Construction Date: 6-20-97		
Sieve Size	Target	39-1	39-2	X	S	R
3/4"	99.2	100.0	99.2	99.6	0.6	0.8
1/2"	82.6	80.0	88.4	84.2	5.9	8.4
3/8"	69.4	63.2	74.0	68.6	7.6	10.7
#4	41.3	30.6	45.6	38.1	10.6	14.9
#8	25.4	18.6	27.8	23.2	6.5	9.2
#16	16.6	12.7	17.8	15.3	3.6	5.1
#30	11.8	9.6	12.6	11.1	2.1	2.9
#50	8.9	7.4	9.3	8.3	1.4	2.0
#100	7.1	5.8	7.3	6.6	1.1	1.5
#200	5.8	4.7	5.9	5.3	0.8	1.2

coldfeed summary

Section B				Construction Date: 6-20-97		
Sieve Size	Target	55-1	55-2	X	S	R
3/4"	99.2	100.0	100.0	100.0	0.0	0.0
1/2"	82.6	88.4	87.4	87.9	0.7	1.0
3/8"	69.4	77.4	75.0	76.2	1.7	2.5
#4	41.3	50.2	45.8	48.0	3.1	4.4
#8	25.4	31.6	28.6	30.1	2.1	3.0
#16	16.6	20.1	18.9	19.5	0.9	1.2
#30	11.8	13.9	13.5	13.7	0.3	0.4
#50	8.9	10.4	10.2	10.3	0.1	0.2
#100	7.1	8.2	8.2	8.2	0.0	0.0
#200	5.8	6.8	6.8	6.8	0.0	0.1

coldfeed summary

Section C					Construction Date:	6-20-97
Sieve Size	Target	56-1	56-2	X	S	R
3/4"	99.2	100.0	100.0	100.0	0.0	0.0
1/2"	82.6	88.3	86.8	87.6	1.0	1.4
3/8"	69.4	76.0	72.1	74.0	2.7	3.8
#4	41.3	45.3	43.3	44.3	1.4	2.0
#8	25.4	27.4	26.6	27.0	0.6	0.8
#16	16.6	17.7	17.3	17.5	0.3	0.5
#30	11.8	12.7	12.1	12.4	0.4	0.6
#50	8.9	9.5	8.8	9.2	0.5	0.7
#100	7.1	7.6	6.8	7.2	0.6	0.8
#200	5.8	6.2	6.1	6.2	0.1	0.2

APPENDIX F

AGGREGATE GRADATIONS OBTAINED FROM CORE SAMPLES FOR ACCESS ROAD

core summary

Sieve Size	Target	Section A							Construction Date: 6-20-97
		39-1	39-2	39-3	39-4	39-5	X	S	R
3/4"	99.2	99.6	99.0	100.0	100.0	99.6	99.6	0.4	1.0
1/2"	82.8	84.8	85.2	90.6	86.9	87.4	87.0	2.3	5.8
3/8"	69.5	66.2	68.9	74.8	74.3	72.0	71.2	3.7	8.6
#4	41.4	35.4	40.2	44.7	45.0	42.4	41.5	3.9	9.6
#8	25.6	20.7	24.5	27.5	27.9	26.4	25.4	2.9	7.2
#16	16.8	13.5	15.6	17.3	17.7	16.8	16.2	1.7	4.2
#30	12.1	9.8	11.1	12.3	12.5	11.9	11.5	1.1	2.6
#50	9.1	7.5	8.3	9.3	9.3	9.0	8.7	0.8	1.8
#100	7.2	5.9	6.4	7.4	7.3	7.1	6.8	0.6	1.4
#200	5.8	4.8	5.1	6.0	5.9	5.8	5.5	0.5	1.2

core summary

Sieve Size	Target	Section B 55-1	55-2	55-3	55-4	55-5	X	S	R
							Construction Date:		6-20-97
3/4"	99.2	98.9	98.9	99.0	99.4	100.0	99.2	0.5	1.1
1/2"	82.8	77.7	77.7	85.8	88.1	86.8	83.2	5.1	10.4
3/8"	69.5	61.8	61.8	71.7	73.3	71.5	68.0	5.7	11.5
#4	41.4	34.0	34.0	40.9	42.9	41.7	38.7	4.3	8.9
#8	25.6	20.8	20.8	24.8	25.0	24.9	23.3	2.2	4.1
#16	16.8	13.8	13.8	15.6	15.4	15.7	14.9	1.0	1.9
#30	12.1	10.0	10.0	10.7	10.8	11.1	10.5	0.5	1.1
#50	9.1	7.5	7.5	7.8	7.9	8.3	7.8	0.3	0.8
#100	7.2	5.8	5.8	6.0	6.1	6.5	6.0	0.3	0.6
#200	5.8	4.7	4.7	4.8	4.9	5.2	4.9	0.2	0.5

core summary

Sieve Size	Target	Section C							Construction Date: 6-20-97
		56-1	56-2	56-3	56-4	56-5	X	S	R
3/4"	99.2	99.5	100.0	100.0	99.7	100.0	99.8	0.2	0.5
1/2"	82.8	86.7	91.4	87.2	87.3	80.0	86.5	4.1	11.4
3/8"	69.5	71.3	77.2	73.5	72.4	64.8	71.8	4.5	12.4
#4	41.4	39.9	45.6	46.4	42.0	36.8	42.1	4.0	9.7
#8	25.6	24.8	28.2	28.9	26.3	24.4	26.5	2.0	4.5
#16	16.8	16.3	18.1	18.5	16.8	15.9	17.1	1.1	2.6
#30	12.1	11.7	12.7	12.9	11.6	11.0	12.0	0.8	1.9
#50	9.1	8.7	9.4	9.6	8.5	8.0	8.8	0.7	1.6
#100	7.2	6.7	7.4	7.5	6.5	6.1	6.8	0.6	1.4
#200	5.8	5.4	5.9	6.0	5.1	4.7	5.4	0.5	1.3

APPENDIX G

COLD-FEED AGGREGATE GRADATIONS FOR BOTTOM LIFT OF TEST LANE

coldfeed summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 35							
				35-1	35-2	35-3	35-4	35-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	82.6	80.1	85.1	89.5	84.4	87.9	87.2	81.5	86.1	3.2	8.0
3/8"	69.4	66.9	71.9	76.7	66.8	76.0	73.3	65.3	71.6	5.3	11.4
#4	41.3	38.8	43.8	48.6	37.0	49.5	45.4	36.8	43.5	6.2	12.7
#8	25.4	23.4	27.4	30.8	22.9	31.3	28.4	22.6	27.2	4.2	8.8
#16	16.6	14.6	18.6	20.3	15.6	20.4	18.8	14.9	18.0	2.6	5.4
#30	11.8	9.8	13.8	14.3	11.6	14.3	13.4	10.8	12.9	1.6	3.6
#50	8.9	7.4	10.4	10.7	9.2	10.6	10.1	8.1	9.7	1.1	2.5
#100	7.1	6.1	8.1	8.5	7.5	8.5	7.9	6.5	7.8	0.8	2.0
#200	5.8	5.3	6.3	6.9	6.3	6.9	6.2	5.3	6.3	0.7	1.6

coldfeed summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 36							
				36-1	36-2	36-3	36-4	36-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	99.5	100.0	99.9	0.2	0.5
1/2"	82.6	80.1	85.1	88.9	84.8	89.1	85.1	83.1	86.2	2.7	6.0
3/8"	69.4	66.9	71.9	76.0	68.7	72.9	68.0	67.6	70.6	3.7	8.5
#4	41.3	38.8	43.8	44.5	39.7	43.0	39.2	38.0	40.9	2.7	6.5
#8	25.4	23.4	27.4	27.4	23.9	26.8	24.3	22.9	25.1	1.9	4.5
#16	16.6	14.6	18.6	17.8	15.7	17.6	16.1	15.2	16.5	1.2	2.6
#30	11.8	9.8	13.8	12.9	11.5	12.6	11.7	11.0	11.9	0.8	1.9
#50	8.9	7.4	10.4	9.9	8.8	9.5	8.9	8.3	9.1	0.6	1.5
#100	7.1	6.1	8.1	8.0	7.1	7.5	7.1	6.6	7.3	0.5	1.4
#200	5.8	5.3	6.3	6.6	5.8	6.1	5.8	5.2	5.9	0.5	1.4

coldfeed summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 37							
				37-1	37-2	37-3	37-4	37-5	X	S	R
3/4"	99.2	96.7	101.7	99.1	100.0	99.3	100.0	99.5	99.6	0.4	0.9
1/2"	82.6	80.1	85.1	83.9	83.7	84.5	85.7	79.2	83.4	2.5	6.5
3/8"	69.4	66.9	71.9	68.7	67.4	68.5	71.9	62.5	67.8	3.4	9.5
#4	41.3	38.8	43.8	39.2	38.8	40.7	44.4	35.7	39.8	3.1	8.7
#8	25.4	23.4	27.4	24.2	23.8	25.0	28.2	22.2	24.7	2.2	6.0
#16	16.6	14.6	18.6	16.1	15.4	16.6	18.3	15.0	16.3	1.3	3.3
#30	11.8	9.8	13.8	11.8	10.9	12.1	12.9	11.0	11.7	0.8	2.0
#50	8.9	7.4	10.4	9.2	8.1	9.2	9.6	8.5	8.9	0.6	1.5
#100	7.1	6.1	8.1	7.4	6.3	7.3	7.6	6.8	7.1	0.5	1.4
#200	5.8	5.3	6.3	6.2	5.0	5.9	6.3	5.6	5.8	0.5	1.3

coldfeed summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 38							
				38-1	38-2	38-3	38-4	38-5	X	S	R
3/4"	99.2	96.7	101.7	99.6	99.4	100.0	98.9	99.2	99.4	0.4	1.1
1/2"	82.6	80.1	85.1	81.8	86.8	86.5	85.5	89.0	85.9	2.6	7.2
3/8"	69.4	66.9	71.9	65.7	71.9	71.1	71.5	73.0	70.6	2.9	7.3
#4	41.3	38.8	43.8	35.2	42.6	42.0	42.0	43.4	41.0	3.3	8.2
#8	25.4	23.4	27.4	21.2	26.0	26.0	25.6	26.8	25.1	2.2	5.6
#16	16.6	14.6	18.6	13.9	16.7	17.5	16.6	17.4	16.4	1.5	3.7
#30	11.8	9.8	13.8	10.1	12.0	13.0	11.8	12.4	11.8	1.1	2.8
#50	8.9	7.4	10.4	7.7	9.0	10.1	8.7	9.4	9.0	0.9	2.3
#100	7.1	6.1	8.1	6.1	7.1	8.3	6.7	7.5	7.1	0.8	2.2
#200	5.8	5.3	6.3	5.0	5.8	7.0	5.3	6.2	5.8	0.8	2.0

coldfeed summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 39							
				39-1	39-2	39-3	39-4	39-5	X	S	R
3/4"	99.2	96.7	101.7	99.2	99.2	100.0	100.0	98.8	99.4	0.5	1.2
1/2"	82.6	80.1	85.1	86.6	85.8	83.5	86.6	82.0	84.9	2.1	4.7
3/8"	69.4	66.9	71.9	70.0	71.0	68.0	71.4	68.2	69.7	1.6	3.4
#4	41.3	38.8	43.8	39.6	39.9	36.8	40.0	43.4	39.9	2.4	6.6
#8	25.4	23.4	27.4	23.2	23.8	22.1	23.6	27.1	24.0	1.9	5.0
#16	16.6	14.6	18.6	14.9	16.0	14.6	14.9	17.9	15.7	1.4	3.3
#30	11.8	9.8	13.8	10.7	11.3	10.6	10.4	12.9	11.2	1.0	2.5
#50	8.9	7.4	10.4	8.2	8.7	8.1	7.7	10.0	8.5	0.9	2.3
#100	7.1	6.1	8.1	6.5	7.0	6.4	5.9	8.2	6.8	0.9	2.3
#200	5.8	5.3	6.3	5.2	5.8	5.2	4.7	7.0	5.6	0.9	2.4

coldfeed summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 54							
				54-1	54-2	54-3	54-4	54-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	99.4	99.7	100.0	99.8	0.3	0.6
1/2"	82.6	80.1	85.1	85.6	85.6	85.1	88.8	92.2	87.5	3.0	7.1
3/8"	69.4	66.9	71.9	69.6	69.6	70.3	74.1	81.8	73.1	5.2	12.2
#4	41.3	38.8	43.8	41.8	41.8	44.6	43.4	54.0	45.1	5.1	12.1
#8	25.4	23.4	27.4	24.7	24.7	27.7	25.2	34.0	27.3	4.0	9.3
#16	16.6	14.6	18.6	15.8	15.8	18.1	16.0	21.8	17.5	2.6	6.0
#30	11.8	9.8	13.8	11.0	11.0	13.0	11.2	15.4	12.3	1.9	4.4
#50	8.9	7.4	10.4	8.1	8.1	9.8	8.3	11.6	9.2	1.5	3.5
#100	7.1	6.1	8.1	6.3	6.3	8.0	6.5	9.5	7.3	1.4	3.2
#200	5.8	5.3	6.3	5.0	5.0	6.7	5.1	8.1	6.0	1.4	3.0

coldfeed summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 55							
				55-1	55-2	55-3	55-4	55-5	X	S	R
3/4"	99.2	96.7	101.7	99.3	99.0	99.2	100.0	99.3	99.4	0.4	1.0
1/2"	82.6	80.1	85.1	86.1	86.4	86.9	90.2	90.4	88.0	2.1	4.4
3/8"	69.4	66.9	71.9	70.2	72.3	73.4	77.3	78.0	74.2	3.3	7.8
#4	41.3	38.8	43.8	41.0	42.1	42.3	46.5	46.6	43.7	2.6	5.6
#8	25.4	23.4	27.4	25.0	25.9	25.7	27.1	28.9	26.5	1.5	3.9
#16	16.6	14.6	18.6	16.0	16.9	16.7	17.4	18.6	17.1	1.0	2.6
#30	11.8	9.8	13.8	11.3	12.2	12.0	11.6	13.4	12.1	0.8	2.1
#50	8.9	7.4	10.4	8.4	9.4	9.1	8.5	10.3	9.1	0.8	1.9
#100	7.1	6.1	8.1	6.5	7.7	7.2	6.3	8.4	7.2	0.9	2.1
#200	5.8	5.3	6.3	5.1	6.5	6.0	5.3	7.1	6.0	0.8	2.1

coldfeed summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 56							
				56-1	56-2	56-3	56-4	56-5	X	S	R
3/4"	99.2	96.7	101.7	99.0	100.0	99.6	100.0	100.0	99.7	0.4	1.0
1/2"	82.6	80.1	85.1	86.1	88.6	84.2	90.2	86.1	87.0	2.4	6.0
3/8"	69.4	66.9	71.9	72.4	73.8	68.3	77.0	71.3	72.6	3.2	8.7
#4	41.3	38.8	43.8	42.4	45.6	40.8	47.0	42.9	43.7	2.5	6.2
#8	25.4	23.4	27.4	25.6	28.4	24.1	27.9	26.0	26.4	1.8	4.3
#16	16.6	14.6	18.6	16.6	18.2	15.6	17.9	16.8	17.0	1.1	2.6
#30	11.8	9.8	13.8	12.5	12.7	11.2	12.7	12.1	12.2	0.7	1.6
#50	8.9	7.4	10.4	9.5	9.4	8.4	9.5	9.1	9.2	0.5	1.2
#100	7.1	6.1	8.1	7.6	7.3	6.6	7.5	7.3	7.2	0.4	1.0
#200	5.8	5.3	6.3	6.2	5.7	5.3	6.1	6.0	5.9	0.4	1.0

APPENDIX H

AGGREGATE GRADATIONS OBTAINED FROM LOOSE MIX BEHIND THE PAVER – SAMPLES FROM BOTTOM LIFT OF TEST LANE

ignition summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 35							
				35-1	35-2	35-3	35-4	35-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	99.2	99.6	99.8	0.4	0.8
1/2"	82.8	80.3	85.3	84.0	85.1	86.6	87.3	83.5	85.3	1.6	3.7
3/8"	69.5	67	72	69.6	69.5	71.1	73.4	67.7	70.3	2.1	5.7
#4	41.4	38.9	43.9	39.7	41.3	41.6	43.1	41.0	41.3	1.2	3.4
#8	25.6	23.6	27.6	24.6	25.9	25.8	25.4	25.3	25.4	0.5	1.3
#16	16.8	14.8	18.8	16.1	16.6	16.4	16.7	16.2	16.4	0.2	0.5
#30	12.1	10.1	14.1	11.6	11.6	11.5	11.9	11.4	11.6	0.2	0.5
#50	9.1	7.6	10.6	8.5	8.5	8.5	8.9	8.3	8.6	0.2	0.6
#100	7.2	6.2	8.2	6.6	6.5	6.4	6.9	6.3	6.6	0.2	0.6
#200	5.8	5.3	6.3	5.2	5.1	5.1	5.4	4.9	5.1	0.2	0.5

ignition summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 36							
				36-1	36-2	36-3	36-4	36-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	99.5	100.0	97.3	99.3	99.2	1.1	2.7
1/2"	82.8	80.3	85.3	85.3	86.2	83.9	82.4	83.6	84.3	1.5	3.8
3/8"	69.5	67	72	72.1	71.6	69.5	68.0	68.4	69.9	1.9	4.1
#4	41.4	38.9	43.9	40.5	40.0	39.6	39.5	37.6	39.4	1.1	2.9
#8	25.6	23.6	27.6	24.2	25.0	24.4	24.2	23.4	24.2	0.6	1.6
#16	16.8	14.8	18.8	15.8	16.3	16.3	15.6	15.5	15.9	0.4	0.8
#30	12.1	10.1	14.1	11.4	11.5	11.7	11.2	10.6	11.3	0.4	1.0
#50	9.1	7.6	10.6	6.8	8.6	8.7	8.4	7.7	8.0	0.8	1.8
#100	7.2	6.2	8.2	6.6	6.6	7.0	6.7	5.8	6.6	0.4	1.2
#200	5.8	5.3	6.3	5.5	5.2	5.7	5.3	4.5	5.3	0.5	1.2

ignition summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 37							
				37-1	37-2	37-3	37-4	37-5	X	S	R
3/4"	99.2	96.7	101.7	99.4	100.0	100.0	99.6	100.0	99.8	0.3	0.6
1/2"	82.8	80.3	85.3	82.9	82.4	86.4	86.5	87.2	85.1	2.3	4.8
3/8"	69.5	67	72	68.9	68.3	70.9	71.7	70.7	70.1	1.4	3.4
#4	41.4	38.9	43.9	38.3	39.0	41.1	41.9	41.2	40.3	1.5	3.6
#8	25.6	23.6	27.6	22.7	23.6	25.0	25.2	25.1	24.3	1.1	2.5
#16	16.8	14.8	18.8	14.9	15.5	15.9	16.2	16.8	15.9	0.7	1.9
#30	12.1	10.1	14.1	10.4	11.1	11.2	11.4	12.2	11.3	0.7	1.8
#50	9.1	7.6	10.6	7.7	8.4	8.3	8.5	9.3	8.5	0.6	1.6
#100	7.2	6.2	8.2	6.0	6.5	6.5	6.7	7.7	6.7	0.6	1.7
#200	5.8	5.3	6.3	4.7	5.2	5.2	5.4	6.4	5.4	0.6	1.7

ignition summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 38							
				38-1	38-2	38-3	38-4	38-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	98.9	99.4	100.0	99.4	99.5	0.5	1.1
1/2"	82.8	80.3	85.3	87.0	87.0	86.0	89.9	85.2	87.0	1.8	4.7
3/8"	69.5	67	72	72.3	74.3	71.1	75.1	69.1	72.4	2.4	6.0
#4	41.4	38.9	43.9	41.3	42.6	41.9	45.6	40.6	42.4	1.9	5.0
#8	25.6	23.6	27.6	24.8	25.7	26.4	28.2	24.7	25.9	1.4	3.4
#16	16.8	14.8	18.8	16.3	16.8	17.1	17.6	16.4	16.9	0.5	1.3
#30	12.1	10.1	14.1	11.6	11.9	12.1	12.2	11.8	11.9	0.3	0.6
#50	9.1	7.6	10.6	8.7	8.9	9.1	8.9	9.1	8.9	0.1	0.4
#100	7.2	6.2	8.2	6.7	7.0	7.2	6.8	7.2	7.0	0.2	0.5
#200	5.8	5.3	6.3	5.2	5.5	5.9	5.2	5.8	5.5	0.3	0.7

ignition summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 39							
				39-1	39-2	39-3	39-4	39-5	X	S	R
3/4"	99.2	96.7	101.7	98.6	100.0	100.0	100.0	99.6	99.6	0.6	1.4
1/2"	82.8	80.3	85.3	79.9	85.5	86.6	83.3	85.8	84.2	2.7	6.7
3/8"	69.5	67	72	65.1	69.2	69.6	69.9	71.8	69.1	2.5	6.7
#4	41.4	38.9	43.9	37.6	39.8	40.2	39.0	40.2	39.3	1.1	2.7
#8	25.6	23.6	27.6	22.7	24.9	25.1	24.1	24.2	24.2	0.9	2.4
#16	16.8	14.8	18.8	15.1	16.2	16.2	15.5	15.2	15.7	0.5	1.1
#30	12.1	10.1	14.1	10.8	11.5	11.4	11.0	10.5	11.0	0.4	1.0
#50	9.1	7.6	10.6	8.1	8.6	8.5	8.0	7.6	8.2	0.4	1.0
#100	7.2	6.2	8.2	6.1	6.6	6.6	6.1	5.7	6.2	0.4	1.0
#200	5.8	5.3	6.3	4.8	5.2	5.2	4.7	4.3	4.8	0.4	0.9

ignition summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 54						
				54-1	54-2	54-3*	54-4	X	S	R
3/4"	99.2	96.7	101.7	100.0	99.2	100.0	100.0	99.8	0.4	0.8
1/2"	82.8	80.3	85.3	86.1	85.2	82.6	85.6	84.9	1.6	3.5
3/8"	69.5	67	72	71.3	70.4	72.0	71.5	71.3	0.7	1.6
#4	41.4	38.9	43.9	41.6	40.9	43.1	40.3	41.5	1.2	2.8
#8	25.6	23.6	27.6	25.1	24.9	27.2	24.0	25.3	1.3	3.1
#16	16.8	14.8	18.8	16.0	16.2	18.9	15.6	16.7	1.5	3.3
#30	12.1	10.1	14.1	11.1	11.5	14.1	10.8	11.9	1.5	3.3
#50	9.1	7.6	10.6	8.1	8.6	11.0	7.8	8.9	1.5	3.2
#100	7.2	6.2	8.2	5.9	6.5	9.1	6.1	6.9	1.5	3.2
#200	5.8	5.3	6.3	4.4	5.3	7.7	4.8	5.6	1.5	3.3

*This test may be bad.
It will be left out of
the n=37 PWL calculations.

ignition summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 55						
				55-1	55-2	55-3	55-5	X	S	R
3/4"	99.2	96.7	101.7	99.5	100.0	98.9	100.0	99.6	0.5	1.1
1/2"	82.8	80.3	85.3	83.0	83.7	84.2	86.1	84.3	1.3	3.1
3/8"	69.5	67	72	69.0	68.6	69.6	70.0	69.3	0.6	1.4
#4	41.4	38.9	43.9	39.4	39.1	40.2	40.7	39.8	0.8	1.6
#8	25.6	23.6	27.6	23.6	23.8	24.4	25.0	24.2	0.7	1.4
#16	16.8	14.8	18.8	15.6	15.7	16.1	16.4	16.0	0.4	0.8
#30	12.1	10.1	14.1	11.1	11.1	8.7	11.5	10.6	1.3	2.8
#50	9.1	7.6	10.6	8.3	8.3	6.9	8.4	8.0	0.7	1.5
#100	7.2	6.2	8.2	6.3	6.5	5.5	6.6	6.2	0.5	1.1
#200	5.8	5.3	6.3	4.7	5.1	5.1	5.2	5.1	0.2	0.5

ignition summary

Construction Date: 6-23-97

Sieve Size	Target	Spec Minus	Spec Plus	Section 56							
				56-1	56-2	56-3	56-4	56-5	X	S	R
3/4"	99.2	96.7	101.7	99.1	100.0	100.0	100.0	100.0	99.8	0.4	0.9
1/2"	82.8	80.3	85.3	84.1	83.3	86.4	86.5	85.9	85.3	1.5	3.2
3/8"	69.5	67	72	68.7	71.8	74.1	70.9	72.4	71.6	2.0	5.4
#4	41.4	38.9	43.9	38.4	42.3	43.6	42.4	42.5	41.8	2.0	5.3
#8	25.6	23.6	27.6	23.9	26.0	26.1	26.5	25.9	25.7	1.0	2.6
#16	16.8	14.8	18.8	16.2	17.5	17.0	17.1	17.2	17.0	0.5	1.3
#30	12.1	10.1	14.1	11.6	12.5	11.8	12.2	12.1	12.0	0.4	0.9
#50	9.1	7.6	10.6	8.7	9.3	8.6	9.3	9.1	9.0	0.3	0.7
#100	7.2	6.2	8.2	6.9	7.4	6.5	7.4	7.2	7.1	0.4	0.9
#200	5.8	5.3	6.3	5.6	6.0	4.9	6.1	5.8	5.7	0.5	1.2

APPENDIX I

COLD-FEED AGGREGATE GRADATIONS FOR TOP LIFT OF TEST LANE

coldfeed summary

				Section 35							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	35-1	35-2	35-3	35-4	35-5	X	S	R
3/4"	99.2	96.7	101.7	99.6	99.6	100.0	100.0	100.0	99.8	0.2	0.4
1/2"	82.6	80.1	85.1	91.4	90.0	90.4	92.6	92.4	91.3	1.2	2.7
3/8"	69.4	66.9	71.9	82.7	77.9	77.8	82.4	80.8	80.3	2.4	4.9
#4	41.3	38.8	43.8	60.3	47.3	50.2	54.3	52.0	52.8	4.9	13.0
#8	25.4	23.4	27.4	40.7	29.5	32.3	34.5	32.9	34.0	4.2	11.3
#16	16.6	14.6	18.6	25.5	18.7	20.4	21.6	21.3	21.5	2.5	6.8
#30	11.8	9.8	13.8	12.1	13.1	13.8	14.7	14.6	13.6	1.1	2.6
#50	8.9	7.4	10.4	12.1	9.9	10.1	10.9	10.9	10.8	0.8	2.2
#100	7.1	6.1	8.1	9.5	8.0	8.0	8.7	8.7	8.6	0.6	1.5
#200	5.8	5.3	6.3	7.9	7.0	6.5	7.2	7.1	7.1	0.5	1.3

coldfeed summary

Sieve Size	Target	Spec Minus	Spec Plus	Section 36							Construction Date: 6-28-97
				36-1	36-2	36-3	36-4	36-5	X	S	R
3/4"	99.2	96.7	101.7	99.2	100.0	100.0	99.1	99.5	99.6	0.4	0.9
1/2"	82.6	80.1	85.1	85.3	88.1	86.2	82.8	89.0	86.3	2.5	6.2
3/8"	69.4	66.9	71.9	72.6	76.8	73.2	68.3	75.7	73.3	3.3	8.5
#4	41.3	38.8	43.8	45.7	45.8	45.3	40.1	49.0	45.2	3.2	8.8
#8	25.4	23.4	27.4	29.2	27.4	28.1	25.1	30.9	28.1	2.2	5.8
#16	16.6	14.6	18.6	18.8	17.5	18.2	16.4	19.4	18.1	1.2	3.0
#30	11.8	9.8	13.8	13.2	11.7	12.9	11.6	13.4	12.5	0.8	1.7
#50	8.9	7.4	10.4	9.8	8.6	9.7	8.8	9.9	9.4	0.6	1.3
#100	7.1	6.1	8.1	7.7	6.7	7.7	7.0	7.9	7.4	0.5	1.2
#200	5.8	5.3	6.3	6.3	5.3	6.3	5.6	6.4	6.0	0.5	1.2

coldfeed summary

Sieve Size	Target	Spec Minus	Spec Plus	Section 37							Construction Date: 6-28-97
				37-1	37-2	37-3	37-4	37-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	99.6	100.0	100.0	100.0	99.9	0.2	0.4
1/2"	82.6	80.1	85.1	84.5	84.9	89.8	83.7	83.9	85.4	2.5	6.1
3/8"	69.4	66.9	71.9	70.8	71.6	78.5	72.0	68.4	72.3	3.8	10.1
#4	41.3	38.8	43.8	43.0	44.5	51.1	40.6	38.8	43.6	4.7	12.3
#8	25.4	23.4	27.4	27.2	27.6	32.0	24.9	23.9	27.1	3.1	8.1
#16	16.6	14.6	18.6	17.5	18.2	19.8	16.0	15.9	17.5	1.6	3.9
#30	11.8	9.8	13.8	12.3	13.0	13.3	11.3	11.6	12.3	0.9	2.1
#50	8.9	7.4	10.4	9.3	10.0	9.7	8.4	8.9	9.3	0.6	1.6
#100	7.1	6.1	8.1	7.5	8.1	7.6	6.6	7.2	7.4	0.5	1.5
#200	5.8	5.3	6.3	6.3	6.6	6.7	5.7	6.0	6.3	0.4	1.0

coldfeed summary

Sieve Size	Target	Spec Minus	Spec Plus	Section 38							Construction Date: 6-28-97
				38-1	38-2	38-3	38-4	38-5	X	S	R
3/4"	99.2	96.7	101.7	99.5	100.0	100.0	100.0	99.6	99.8	0.3	0.5
1/2"	82.6	80.1	85.1	87.2	88.0	87.0	87.1	80.0	85.9	3.3	8.0
3/8"	69.4	66.9	71.9	74.3	75.8	74.5	73.6	63.5	72.3	5.0	12.3
#4	41.3	38.8	43.8	44.0	45.5	43.9	43.9	34.3	42.3	4.6	11.2
#8	25.4	23.4	27.4	26.2	27.3	27.0	27.2	21.1	25.8	2.6	6.2
#16	16.6	14.6	18.6	17.1	17.8	17.8	17.4	14.1	16.8	1.6	3.8
#30	11.8	9.8	13.8	12.1	12.6	12.7	12.3	10.3	12.0	1.0	2.3
#50	8.9	7.4	10.4	9.2	9.6	9.6	9.1	7.9	9.1	0.7	1.7
#100	7.1	6.1	8.1	7.2	7.6	7.6	7.2	6.3	7.2	0.5	1.3
#200	5.8	5.3	6.3	5.8	6.1	6.2	5.9	5.2	5.9	0.4	1.0

coldfeed summary

				Section 39							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	39-1	39-2	39-3	39-4	39-5	X	S	R
3/4"	99.2	96.7	101.7	98.8	100.0	99.2	100.0	100.0	99.6	0.6	1.2
1/2"	82.6	80.1	85.1	80.2	84.9	85.3	85.9	88.0	84.8	2.9	7.8
3/8"	69.4	66.9	71.9	66.1	67.1	69.7	70.8	73.9	69.5	3.1	7.8
#4	41.3	38.8	43.8	37.1	39.4	41.3	42.9	47.0	41.6	3.8	9.9
#8	25.4	23.4	27.4	23.2	24.9	25.8	26.6	29.2	25.9	2.2	6.1
#16	16.6	14.6	18.6	15.4	16.4	16.7	17.6	19.3	17.1	1.5	3.9
#30	11.8	9.8	13.8	11.1	11.6	11.9	12.3	13.8	12.1	1.0	2.7
#50	8.9	7.4	10.4	8.6	8.8	9.0	9.4	10.5	9.3	0.7	1.9
#100	7.1	6.1	8.1	6.9	7.0	7.2	7.4	8.3	7.4	0.6	1.5
#200	5.8	5.3	6.3	5.6	5.7	5.9	6.0	6.8	6.0	0.5	1.2

coldfeed summary

Sieve Size	Target	Spec Minus	Spec Plus	Section 54							Construction Date: 6-28-97
				54-1	54-2	54-3	54-4	54-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	99.6	100.0	100.0	99.9	0.2	0.4
1/2"	82.6	80.1	85.1	76.9	86.4	81.5	84.4	82.6	82.4	3.6	9.5
3/8"	69.4	66.9	71.9	64.8	74.5	63.3	66.3	66.7	67.1	4.3	11.2
#4	41.3	38.8	43.8	37.1	45.0	35.9	35.7	33.5	37.4	4.4	11.5
#8	25.4	23.4	27.4	23.0	27.5	22.7	21.6	19.5	22.9	2.9	8.0
#16	16.6	14.6	18.6	15.4	17.9	14.8	14.4	13.1	15.1	1.8	4.8
#30	11.8	9.8	13.8	10.8	12.4	10.6	10.4	9.5	10.7	1.1	2.9
#50	8.9	7.4	10.4	8.2	9.4	7.9	8.0	7.4	8.2	0.7	2.0
#100	7.1	6.1	8.1	6.4	7.4	6.2	5.8	5.8	6.3	0.7	1.6
#200	5.8	5.3	6.3	5.1	6.1	5.1	5.1	4.7	5.2	0.5	1.4

coldfeed summary

Sieve Size	Target	Spec Minus	Spec Plus	Section 55							Construction Date: 6-28-97
				55-1	55-2	55-3	55-4	55-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	100.0	98.4	99.7	0.7	1.6
1/2"	82.6	80.1	85.1	89.5	85.3	86.8	87.0	83.2	86.3	2.3	6.3
3/8"	69.4	66.9	71.9	73.9	73.6	72.8	73.6	68.3	72.4	2.4	5.6
#4	41.3	38.8	43.8	41.0	40.4	41.4	42.8	37.5	40.6	1.9	5.3
#8	25.4	23.4	27.4	24.3	23.5	25.0	25.4	22.3	24.1	1.2	3.1
#16	16.6	14.6	18.6	15.6	15.3	16.4	16.4	14.7	15.7	0.7	1.7
#30	11.8	9.8	13.8	11.1	10.9	11.4	11.5	10.6	11.1	0.4	0.9
#50	8.9	7.4	10.4	8.4	8.4	8.7	8.8	8.2	8.5	0.2	0.6
#100	7.1	6.1	8.1	5.6	6.6	6.9	7.0	6.6	6.6	0.5	1.4
#200	5.8	5.3	6.3	5.4	5.3	5.6	5.7	5.3	5.5	0.2	0.4

coldfeed summary

				Section 56							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	56-1	56-2	56-3	56-4	56-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	99.6	100.0	100.0	100.0	99.9	0.2	0.4
1/2"	82.6	80.1	85.1	88.6	88.2	87.7	88.5	86.7	87.9	0.8	1.9
3/8"	69.4	66.9	71.9	75.9	76.1	75.9	74.1	75.6	75.5	0.8	2.0
#4	41.3	38.8	43.8	45.6	43.5	44.8	42.5	46.0	44.5	1.5	3.5
#8	25.4	23.4	27.4	28.0	26.9	27.0	25.5	27.8	27.1	1.0	2.5
#16	16.6	14.6	18.6	18.4	17.2	17.6	16.9	18.0	17.6	0.6	1.5
#30	11.8	9.8	13.8	12.6	12.0	12.2	11.8	12.4	12.2	0.3	0.7
#50	8.9	7.4	10.4	9.5	8.9	9.3	9.0	9.3	9.2	0.3	0.7
#100	7.1	6.1	8.1	7.6	7.0	7.4	7.1	7.3	7.3	0.2	0.6
#200	5.8	5.3	6.3	6.2	5.8	6.0	5.7	5.9	5.9	0.2	0.5

APPENDIX J

AGGREGATE GRADATIONS OBTAINED FROM LOOSE MIX BEHIND THE PAVER – SAMPLES FROM TOP LIFT OF TEST LANE

Ignition Summary

				Section 35							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	35-1	35-2	35-3	35-4	35-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	82.8	80.3	85.3	84.2	85.6	83.6	84.1	82.5	84.0	1.1	3.1
3/8"	69.5	67	72	68.2	71.5	70.0	70.3	67.7	69.5	1.6	3.8
#4	41.4	38.9	43.9	38.2	40.3	39.5	39.6	38.0	39.1	1.0	2.2
#8	25.6	23.6	27.6	23.4	24.7	24.4	24.6	23.2	24.0	0.7	1.5
#16	16.8	14.8	18.8	15.5	16.3	16.3	16.5	15.4	16.0	0.5	1.1
#30	12.1	10.1	14.1	11.3	11.7	11.6	11.9	11.0	11.5	0.3	0.9
#50	9.1	7.6	10.6	8.7	9.0	8.9	9.1	8.3	8.8	0.3	0.7
#100	7.2	6.2	8.2	6.9	7.1	7.1	7.3	6.6	7.0	0.3	0.7
#200	5.8	5.3	6.3	5.5	5.7	5.7	5.8	5.2	5.6	0.2	0.6

Ignition Summary

				Section 36							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	36-1	36-2	36-3	36-4	36-5	X	S	R
3/4"	99.2	96.7	101.7	99.6	100.0	99.4	100.0	100.0	99.8	0.3	0.6
1/2"	82.8	80.3	85.3	85.7	86.6	80.6	83.4	84.2	84.1	2.3	6.0
3/8"	69.5	67	72	69.4	71.1	64.5	68.9	69.8	68.7	2.5	6.6
#4	41.4	38.9	43.9	39.8	40.8	38.1	40.1	40.9	40.0	1.1	2.8
#8	25.6	23.6	27.6	25.5	25.2	24.5	25.9	25.6	25.4	0.6	1.5
#16	16.8	14.8	18.8	16.6	16.6	16.1	17.4	17.0	16.7	0.5	1.2
#30	12.1	10.1	14.1	11.9	11.6	11.6	12.5	12.2	12.0	0.4	0.8
#50	9.1	7.6	10.6	9.0	8.7	8.9	9.6	9.3	9.1	0.4	0.9
#100	7.2	6.2	8.2	7.2	6.7	7.1	7.7	7.4	7.2	0.4	1.0
#200	5.8	5.3	6.3	5.9	5.3	5.8	6.2	5.9	5.8	0.3	0.9

Ignition Summary

				Section 37							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	37-1	37-2	37-3	37-4	37-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	82.8	80.3	85.3	84.5	81.9	84.6	80.9	84.5	83.3	1.8	3.7
3/8"	69.5	67	72	73.4	68.1	69.5	64.7	67.8	68.7	3.2	8.8
#4	41.4	38.9	43.9	40.5	39.8	39.7	36.5	39.2	39.1	1.6	4.1
#8	25.6	23.6	27.6	25.8	24.8	24.3	22.9	25.4	24.6	1.1	2.8
#16	16.8	14.8	18.8	17.4	16.6	16.2	15.6	16.7	16.5	0.7	1.8
#30	12.1	10.1	14.1	12.3	11.8	11.6	11.3	11.9	11.8	0.3	0.9
#50	9.1	7.6	10.6	9.4	8.9	8.8	8.8	9.0	9.0	0.2	0.6
#100	7.2	6.2	8.2	7.4	7.0	7.0	7.1	7.1	7.1	0.2	0.5
#200	5.8	5.3	6.3	6.0	5.5	5.6	5.6	5.7	5.7	0.2	0.5

Ignition Summary

				Section 38							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	38-1	38-2	38-3	38-4	38-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	100.0	99.4	99.9	0.3	0.6
1/2"	82.8	80.3	85.3	86.1	87.3	81.5	78.2	86.0	83.8	3.8	9.1
3/8"	69.5	67	72	71.2	74.8	67.3	64.5	71.8	69.9	4.0	10.2
#4	41.4	38.9	43.9	42.5	45.4	38.2	35.7	41.3	40.6	3.7	9.6
#8	25.6	23.6	27.6	26.5	27.8	24.2	23.5	26.2	25.6	1.8	4.3
#16	16.8	14.8	18.8	17.8	18.3	16.7	16.5	17.4	17.4	0.7	1.8
#30	12.1	10.1	14.1	13.0	13.3	12.1	11.9	12.8	12.6	0.6	1.4
#50	9.1	7.6	10.6	10.1	10.3	9.3	9.1	9.8	9.7	0.5	1.2
#100	7.2	6.2	8.2	8.1	8.2	7.4	7.1	7.9	7.7	0.4	1.0
#200	5.8	5.3	6.3	6.5	6.5	5.9	5.6	6.4	6.2	0.4	0.9

Ignition Summary

				Section 39							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	39-1	39-2	39-3	39-4	39-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	82.8	80.3	85.3	85.1	79.0	85.6	82.6	84.6	83.4	2.7	6.6
3/8"	69.5	67	72	71.5	66.6	69.2	69.0	70.0	69.3	1.8	4.9
#4	41.4	38.9	43.9	40.8	38.8	40.1	38.5	39.6	39.6	0.9	2.2
#8	25.6	23.6	27.6	24.6	24.0	24.4	24.1	24.4	24.3	0.3	0.6
#16	16.8	14.8	18.8	16.2	15.9	16.1	16.0	16.2	16.1	0.1	0.3
#30	12.1	10.1	14.1	11.8	11.5	11.6	11.4	11.5	11.6	0.1	0.4
#50	9.1	7.6	10.6	9.1	8.9	9.0	8.6	8.8	8.9	0.2	0.5
#100	7.2	6.2	8.2	7.4	7.1	7.3	6.8	7.0	7.1	0.2	0.6
#200	5.8	5.3	6.3	5.9	5.8	5.8	5.5	5.6	5.7	0.2	0.4

Ignition Summary

				Section 54							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	54-1	54-2	54-3	54-4	54-5	X	S	R
3/4"	99.2	96.7	101.7	100.0	99.4	100.0	99.5	100.0	99.8	0.3	0.6
1/2"	82.8	80.3	85.3	83.9	84.3	87.1	85.5	83.7	84.9	1.4	3.4
3/8"	69.5	67	72	69.9	70.8	73.9	71.4	68.8	71.0	1.9	5.1
#4	41.4	38.9	43.9	40.6	41.9	41.4	41.8	40.5	41.3	0.6	1.4
#8	25.6	23.6	27.6	25.1	26.6	25.3	26.5	24.9	25.7	0.8	1.8
#16	16.8	14.8	18.8	16.7	17.1	16.5	17.2	16.6	16.8	0.3	0.6
#30	12.1	10.1	14.1	11.6	12.2	11.9	12.1	11.9	11.9	0.2	0.6
#50	9.1	7.6	10.6	8.6	9.2	9.1	9.0	9.1	9.0	0.2	0.6
#100	7.2	6.2	8.2	6.7	7.4	7.3	7.1	7.3	7.2	0.3	0.6
#200	5.8	5.3	6.3	5.4	6.0	5.9	5.7	5.9	5.8	0.3	0.6

Ignition Summary

				Section 55							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	55-1	55-2	55-3	55-4	55-5	X	s	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	99.6	100.0	99.9	0.2	0.4
1/2"	82.8	80.3	85.3	86.0	87.8	85.2	84.9	87.9	86.3	1.4	3.0
3/8"	69.5	67	72	70.9	73.0	71.2	69.3	73.3	71.5	1.6	4.0
#4	41.4	38.9	43.9	39.8	40.9	40.3	40.4	41.3	40.5	0.6	1.5
#8	25.6	23.6	27.6	24.4	25.4	24.8	25.7	25.1	25.1	0.5	1.3
#16	16.8	14.8	18.8	16.4	16.7	16.3	17.0	16.5	16.6	0.3	0.7
#30	12.1	10.1	14.1	11.6	12.2	11.8	12.3	11.9	12.0	0.3	0.7
#50	9.1	7.6	10.6	8.9	9.4	9.1	9.4	9.2	9.2	0.2	0.5
#100	7.2	6.2	8.2	7.2	7.6	7.3	7.6	7.3	7.4	0.2	0.4
#200	5.8	5.3	6.3	5.8	6.2	6.0	6.2	5.8	6.0	0.2	0.4

Ignition Summary

				Section 56							Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	56-1	56-2	56-3	56-4	56-5	X	S	R
3/4"	99.2	96.7	101.7	99.1	100.0	100.0	100.0	100.0	99.8	0.4	0.9
1/2"	82.8	80.3	85.3	83.4	84.5	89.2	82.8	83.1	84.6	2.7	6.4
3/8"	69.5	67	72	68.2	70.8	73.2	68.9	68.1	69.8	2.1	5.0
#4	41.4	38.9	43.9	38.8	41.2	42.3	38.8	38.6	40.0	1.7	3.8
#8	25.6	23.6	27.6	24.7	25.7	26.9	25.0	24.4	25.3	1.0	2.5
#16	16.8	14.8	18.8	16.6	17.2	17.5	17.1	16.7	17.0	0.4	0.9
#30	12.1	10.1	14.1	12.1	12.2	12.5	12.3	12.1	12.2	0.2	0.4
#50	9.1	7.6	10.6	9.2	9.4	9.5	9.4	9.4	9.4	0.1	0.3
#100	7.2	6.2	8.2	7.5	7.5	7.6	7.5	7.6	7.5	0.0	0.1
#200	5.8	5.3	6.3	6.1	6.2	6.2	6.1	6.1	6.1	0.0	0.1

Quality Assurance Aggregate Gradations—Replacement Sections

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-24
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials, and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on aggregate gradation measured after construction of the replacement sections and referred to as "quality assurance aggregate gradations." The test program used for sampling and testing is contained in WesTrack Technical Report UNR-19.[4] Samples used to determine aggregate gradations for quality assurance (QA) purposes were obtained during construction from loose HMA taken from behind the paving machine. Gradations of the HMA samples were obtained after ignition oven testing.

Problems with calibration of ignition ovens for asphalt binder content testing were evident during construction. Thus, a significant amount of QA testing involving additional ignition oven testing and reflux extraction testing was performed. WesTrack Technical Report UNR-23[5] provides information on the quality control (QC) testing associated with aggregate gradation determination.

BACKGROUND

The replacement sections were placed at WesTrack to repair failed sections that were placed during the original construction of the track and to obtain additional information on the performance of coarse-graded Superpave mixtures. Mixture design information for the replacement sections is contained in WesTrack Technical Report UNR-7.[6] Construction of the replacement sections was performed during May and June 1997.

HMA mixtures were placed on the ramps to the test track on May 23 and 30, 1997 (table 1), to determine the constructability of the HMA, as well as to determine the gradation, asphalt binder contents, and the volumetrics. Additional trial sections were placed on the access road to WesTrack on June 20, 1997. Adjustments in the amount of fines returned from the baghouse, in cold feeds to obtain the desired gradation in asphalt binder content, and in the roller pattern to obtain the desired air void content were undertaken during the time allocated for the placement of these trial sections.

The construction of the "test lane" of the track was performed in two lifts that were placed on June 23 and 28, 1997. The test lanes are the lanes on which the traffic was placed and the WesTrack performance information obtained.

Prior to the start of production of the HMA, the HMA production facility was calibrated using California Department of Transportation (DOT) standard procedures for plant production. This calibration included determination of individual cold-feed rates for each aggregate, calibration of the scale belt, and calibration of the asphalt binder delivery system. Additional calibrations were performed during the placement of the hot mixes at WesTrack.

SAMPLING

Aggregate gradations were determined for QA purposes on HMA sampled from behind the paver prior to compaction. The samples of HMA were obtained from random locations in the mat. The loose hot-mix samples obtained from behind the laydown machine were used for asphalt content determination, gyratory compactor volumetrics, and aggregate gradation. The detailed sampling and testing plan for the replacement sections can be found in WesTrack Technical Report UNR-19.[4]

TEST METHODS

The aggregate gradations were determined by using AASHTO T 11 and T 27. The gradations were performed after the samples of HMA were tested to determine asphalt binder content by use of the National Center for Asphalt Technology (NCAT) ignition oven (ASTM D6307).

GRADATION AND IGNITION TEST

The literature [7,8,9] suggests that the aggregate gradation can change when the HMA sample is subjected to the ignition test to determine asphalt binder content. NCAT studies[7,8] indicate that the ignition oven did not affect the amount of material passing the No. 4 sieve, but could affect the amount of material passing the No. 200 sieve. NCAT observed that changes in the amount of material passing the No. 200 sieve ranged from minus 0.75 to plus 2.0 percentage points for the four materials evaluated.

A similar study conducted by Florida DOT[9] showed changes in the amount of material passing the No. 4 sieve to range from minus 0.6 to plus 0.5 percentage points. Changes in the No. 200 sieve were reported to range from plus 0.6 to 1.0 percentage points. The NCAT researchers suggested that caution be exercised in interpreting any results from aggregate recovered after the ignition test.

A study was performed at the University of Nevada to investigate ignition oven calibration procedures on asphalt binder content determination as part of the WesTrack Project for HMA placed during original construction and during construction of the replacement sections. These results are reported in references 10, 11, and 12. As part of this study, aggregate gradations were determined prior to and after ignition testing. These results are presented below.

IGNITION OVEN CALIBRATION STUDY

A portion of the University of Nevada ignition oven calibration study is shown in table 2. Ignition oven asphalt binder calibrations were performed on replacement sections. Both blank (aggregate without asphalt binder) and known asphalt binder content samples were subjected to ignition oven testing as well as reflux solvent extraction testing. The aggregate was obtained from the combined cold-feed samples and, therefore, represents the aggregate actually entering the plant during the production of the HMA.

Aggregates were separated on individual sieve sizes (3/4 in. x 1/2 in., 1/2 in. x 3/8 in., 3/8 in. x No. 4, No. 4 x No. 8, No. 8 x No. 16, No. 16 x No. 30, No. 30 x No. 50, No. 50 x No. 100, No. 100 x No. 200, and percent passing the No. 200 sieve) and combined to meet the target gradations. The gradations for the individual samples were fabricated as close to the target gradations as possible. Some variability in the individual sample gradations fabricated to the same target is expected but is likely to be small.

BLANK AGGREGATE CALIBRATIONS

Samples were fabricated without asphalt binder (blank aggregate samples) and subjected to the ignition oven and reflux solvent extraction processes for determining asphalt binder content. Gradation information obtained from this series of tests is shown in tables 3 through 7 and figures 1 through 3.

Gradation expressed as cumulative percent passing a particular sieve size of the blank aggregate samples after reflux solvent extraction are shown in table 3. These same results are shown on a passing and retained basis in table 5. Gradation expressed as cumulative percent passing a particular sieve size for the blank aggregates subjected to ignition oven testing are shown in table 4. These same results are shown on a passing and retained basis in table 6.

Comparisons between aggregate gradation results obtained from ignition oven and reflux solvent extraction are shown in several different ways in table 7 and figures 1 through 3. Figure 1 is a bar chart showing the cumulative percent passing for target gradation values, as well as the gradations obtained after ignition and reflux testing. Figure 2 shows the gradations on a percent

passing/retained basis for the target values, as well as the gradations after ignition and reflux testing.

Deviations from target values for gradations obtained after the ignition and reflux solvent extraction are shown in table 7 and figure 3. The information presented for the replacement section mixtures indicates that the cumulative percent passing the No. 4 sieve ranged from plus 0.8 to minus 0.5 percentage points relative to the target value. A trend was not evident to suggest that the ignition oven gradations were always lower or higher than the target value or that the reflux test gradations were always lower or higher than the target value for the coarse aggregate size sieves.

The information in figure 3 indicates that both the ignition oven and the reflux solvent extraction gradations are somewhat lower than the target value gradations for most of the fine aggregate sieve sizes. However, there was no clear trend in the data reported for the No. 200 sieve. The ignition oven altered the percent passing No. 200 sieve from minus 0.4 to plus 0.1 percentage points while the reflux extraction gradations varied from the target by minus 0.8 to plus 0.3 percentage points.

The ASTM precision and bias statement for the sieve analysis test method states that the single-operator precision (1s) for coarse sieves (with the percent of the size fraction between consecutive sieves being 20 to 50) is equal to 1.38 percent. Thus, the acceptable range of test results (d2s) for a single operator is 3.9 percent.[13] For fine sieves, the single-operator precision (1s) (with the percent of the size fraction between consecutive sieves being 3 to 10) is equal to 0.43 and the acceptable range of test results from a single operator (d2s) is equal to 1.2 percent. These precision statements indicate that the variability obtained in this calibration study is likely largely due to the precision of the sieve analysis test method.

REFLUX EXTRACTION GRADATIONS

As part of the asphalt content calibration study effort to determine field binder contents, a series of reflux solvent extraction tests were performed on loose HMA samples obtained from behind the paver during construction. Tables 8 and 9 and appendix A contain these data. Statistical summaries of the gradation information are shown in table 8 for the top lift and table 9 for the bottom lift of the test sections.

IGNITION OVEN GRADATIONS

The gradations for each individual test section used for performance modeling are those identified as the “quality assurance gradations” in this report. Based on the calibration study described above, the decision was made to use the aggregate gradations obtained from the loose mix samples taken from behind the paving machine and determined after ignition oven testing (tables 10 and 11). This decision was based on several factors including those provided below.

An attempt was made to establish an aggregate gradation correction factor for the ignition oven replacement section mixtures. This investigation included defining the difference between the target gradation and the ignition oven gradation and the difference between the reflux extraction gradation and the ignition oven gradation. A correction factor could not be obtained by performing regression analyses on these differences because these differences were not consistent in magnitude or direction from the target. This same result was obtained with the original construction samples and is documented in WesTrack Technical Report UNR-22.[14]

The calibration study indicated that the aggregate gradation was not significantly affected by the ignition oven used to determine the asphalt binder contents on these mixtures. The differences between the target values and the ignition oven calibrations and the reflux gradations and the ignition oven gradations were small in comparison to the test method variability.

Due to the high temperature of operation, the ignition oven will alter the aggregate gradation somewhat.[7,8,9] This thermal breakdown and the loss of No. 200 material during testing with the ignition oven can be avoided with the use of the reflux extraction device for asphalt content and aggregate gradation determinations. Thus, it may be preferable to use the reflux test for determining aggregate gradation. However, environmental, health, and safety problems with solvent, and the time required to perform the test have greatly reduced the use of the reflux test for asphalt binder content and aggregate gradation determination.

For the replacement sections, a total of five samples from each section were tested with the reflux solvent extractor and thus a large database was available to determine aggregate gradation. An equal number of samples were tested for each section for gradation after the ignition asphalt content determinations. Thus, gradation information after either the reflux or the ignition oven could be used with approximately equal confidence. The decision was made to use the gradation information after ignition oven testing to be consistent with the test methods used for the HMA mixtures placed during original construction of WesTrack.

Tables 10 and 11 contain aggregate gradation information obtained on the loose mix samples taken from behind the laydown machine during construction and tested with the NCAT ignition test for asphalt binder content and gradation. The data are available for both the top (table 10) and the bottom (table 11) lifts by section number for each individual sieve. Statistical information including mean, standard deviation, coefficient of variation, and number of samples is shown in the tables for the combined gradations from all of the sections. Table 12 presents summary statistics for the top and bottom lifts. Reference 11 contains individual sample test results for each section and individual section gradation statistics for both the top and the bottom lifts.

SUMMARY

The QA aggregate gradation information used for performance model development is shown by section in tables 10 and 11. Statistical comparisons were made between top and bottom lift gradations and between gradations determined after ignition oven and reflux extraction testing as part of the calibration study. These statistical comparisons can be found in reference 11.

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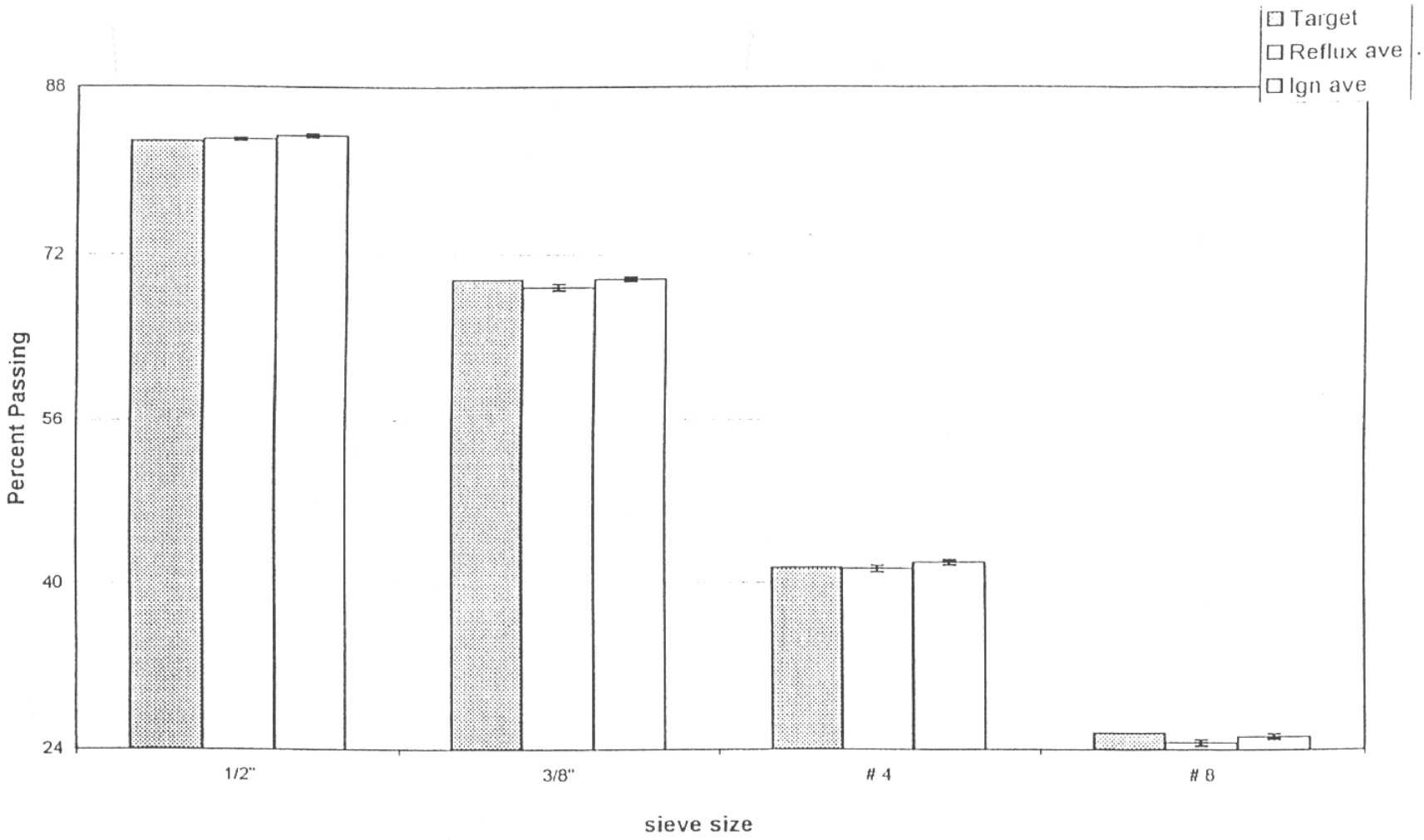

Figure 1a. Gradation data for unwashed blank aggregate for replacement mix (reflux and ignition).

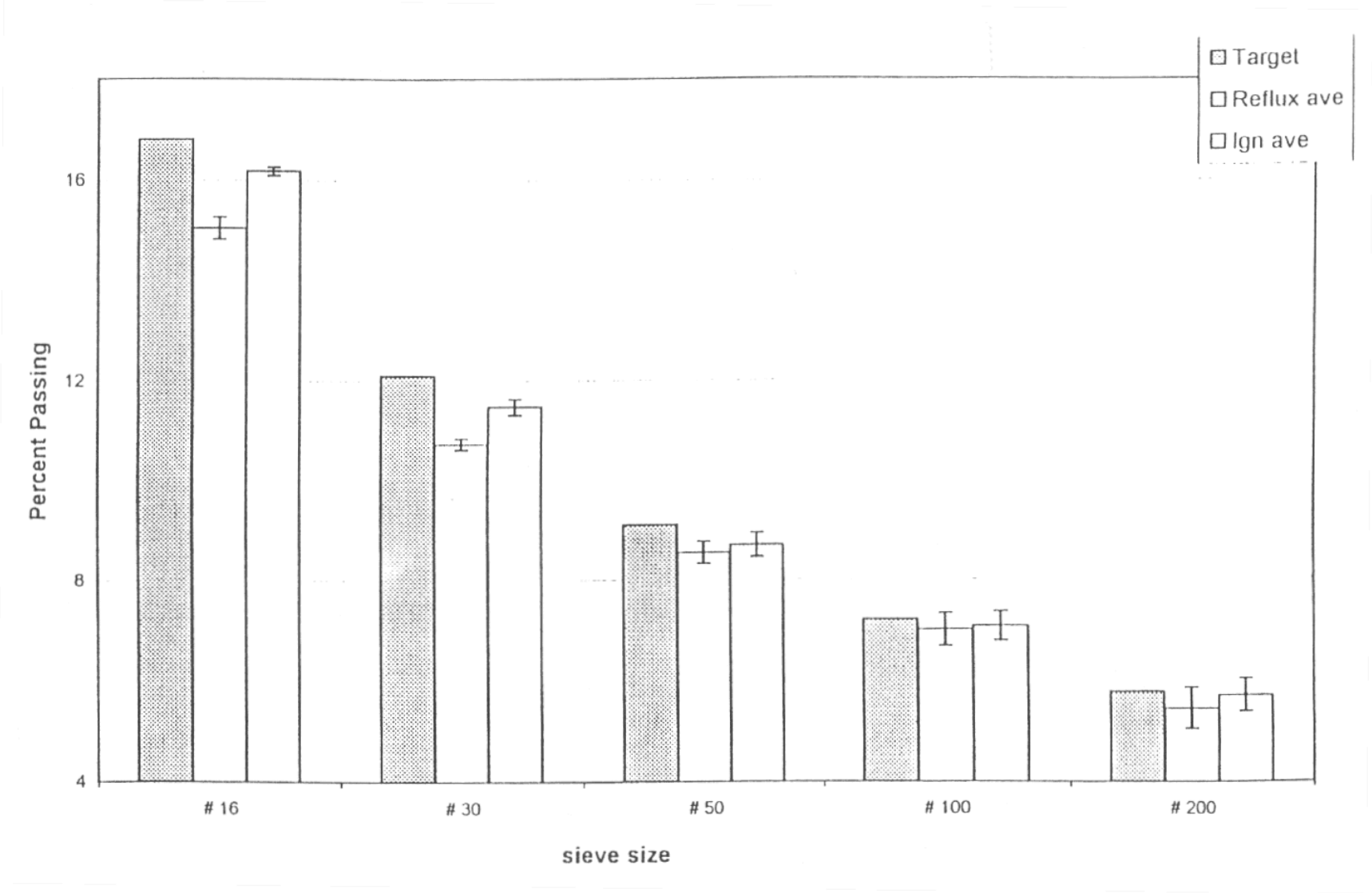

Figure 1b. Gradation data for unwashed lime blank aggregate for replacement mix (reflux and ignition).

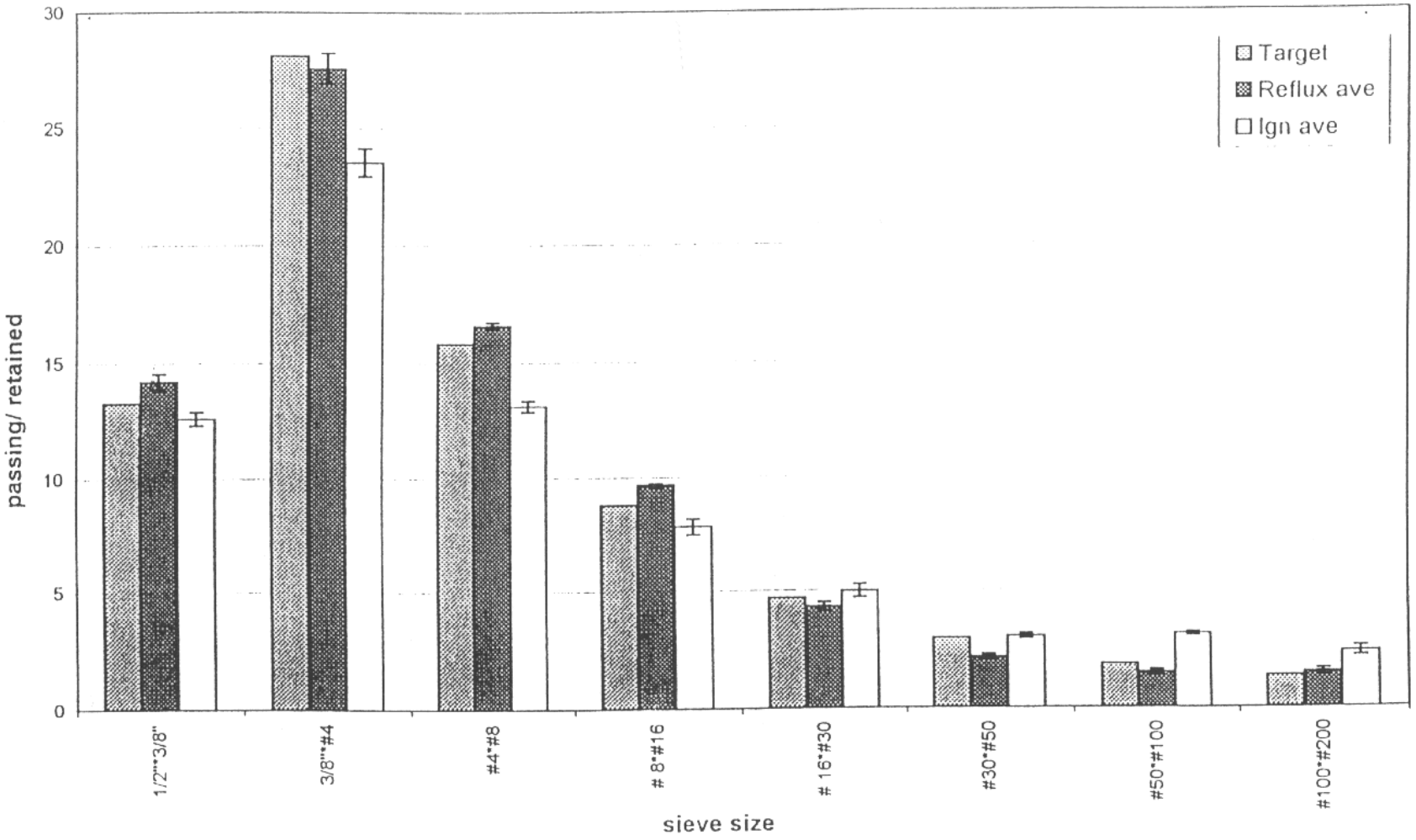

Figure 2. Gradation (passing/retained) data for unwashed with lime blank aggregate for replacement mix (reflux and ignition).

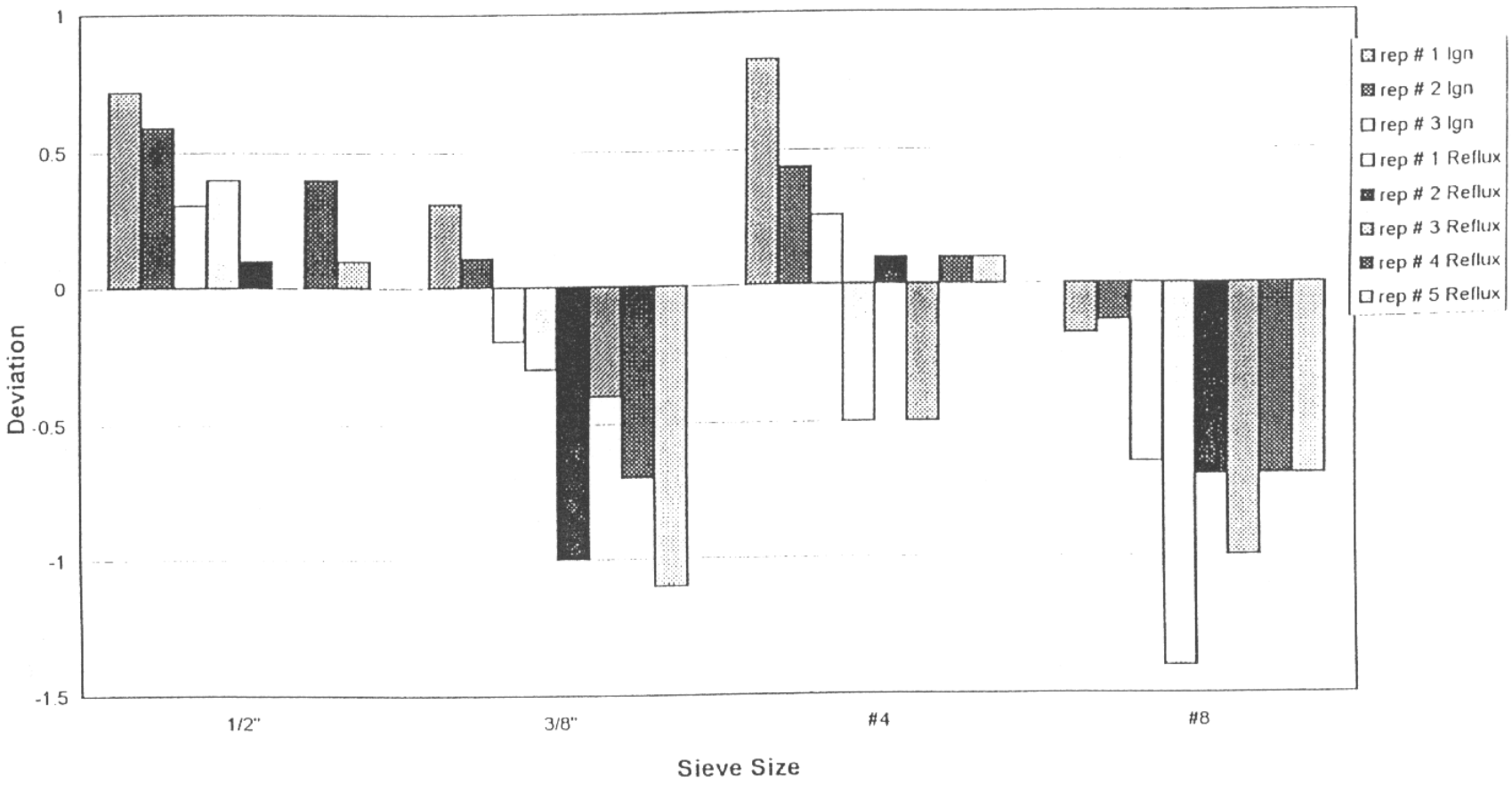

Figure 3a. Bar chart showing the deviation from the target gradation for unwashed with lime blank aggregate for replacement mix (reflux and ignition).

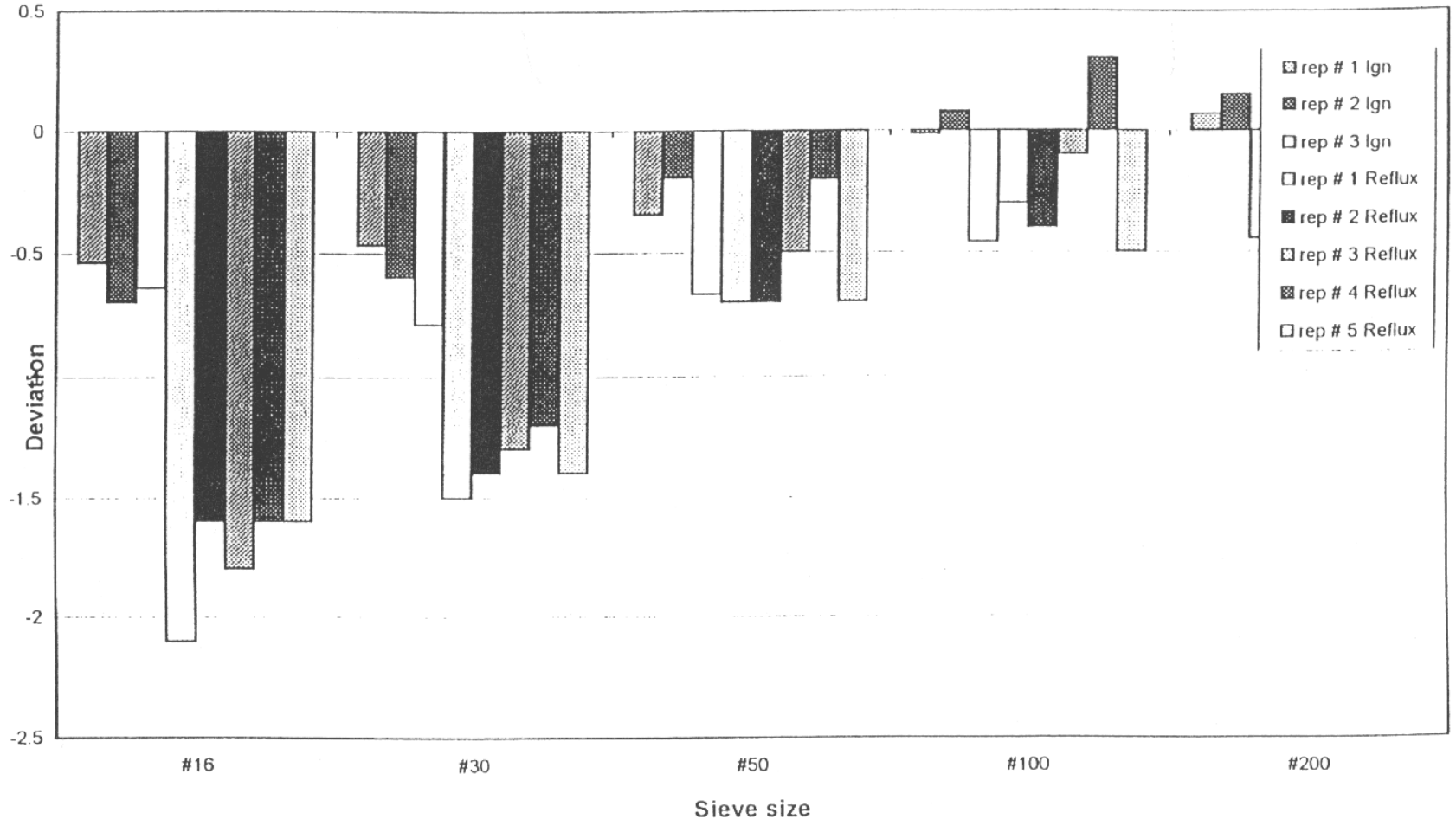

Figure 3b. Bar chart showing the deviation from the target gradation for unwashed with lime blank aggregate for replacement mix (reflux and ignition).

Table 1. Construction schedule – replacement sections.

Date	Lift	Lane	Section Numbers
5-23-97	Bottom	Trial	35, 37, 38, 39, 55, 56
5-30-97	Top	Trial	35, 37, 38, 39, 55, 56
6-20-97	Bottom	Trial*	A, B, C
6-23-97	Bottom	Test	35, 36, 37, 38, 39, 54, 55, 56
6-28-97	Top	Test	35, 36, 37, 38, 39, 54, 55, 56

*Access road.

Table 2. Portion of UNR asphalt content calibration effort.

Construction	Material	Mix Type	Method			
			Reflux		Ignition	
			Blank Aggregate	Known % AC	Blank Aggregate	Known % AC
Original	Original	Fine	3*	3	3	3
		Fine Plus	3	3	3	3
		Coarse	3	3	3	3
Replacement	Cold-feed	Replacement	3	3	3	3

*Indicates number of replicates tested under each condition.

Table 3. Gradation after reflux for unwashed with lime blank aggregate for replacement mixes.

Sieve Size	Percent Passing											
	Target	Replicate					Ave	Std	Cov	Max	Min	Range
		1	2	3	4	5						
1/2 in.	82.8	83.2	82.9	82.8	83.2	82.9	83	0.19	0.23	83.2	82.8	0.4
3/8 in.	69.5	69.2	68.5	69.1	68.8	68.4	68.8	0.35	0.51	69.2	68.4	0.8
#4	41.4	40.9	41.5	40.9	41.5	41.5	41.26	0.33	0.80	41.5	40.9	0.6
#8	25.6	24.2	24.9	24.6	24.9	24.9	24.7	0.31	1.25	24.9	24.2	0.7
#16	16.8	14.7	15.2	15	15.2	15.2	15.06	0.22	1.45	15.2	14.7	0.5
#30	12.1	10.6	10.7	10.8	10.9	10.7	10.74	0.11	1.06	10.9	10.6	0.3
#50	9.1	8.4	8.4	8.6	8.9	8.4	8.54	0.22	2.57	8.9	8.4	0.5
#100	7.2	6.9	6.8	7.1	7.5	6.7	7	0.32	4.52	7.5	6.7	0.8
#200	5.8	5.5	5.2	5.5	6.1	5	5.46	0.42	7.62	6.1	5	1.1

Table 4. Gradation after ignition oven for unwashed with lime blank aggregate for replacement mixes.

Sieve Size	Percent Passing				Ave	Std	Cov	Max	Min	Range
	Target	Rep 1	Rep 2	Rep 3						
1/2 in.	82.8	83.5	83.4	83.1	83.3	0.21	0.25	83.5	83.1	0.4
3/8 in.	69.5	69.8	69.6	69.3	69.6	0.26	0.37	69.8	69.3	0.5
#4	41.4	42.2	41.8	41.7	41.9	0.29	0.70	42.2	41.7	0.6
#8	25.6	25.4	25.5	24.9	25.3	0.28	1.12	25.5	24.9	0.5
#16	16.8	16.3	16.1	16.2	16.2	0.08	0.50	16.3	16.1	0.2
#30	12.1	11.6	11.5	11.3	11.5	0.16	1.41	11.6	11.3	0.3
#50	9.1	8.8	8.9	8.4	8.7	0.24	2.79	8.9	8.4	0.5
#100	7.2	7.2	7.3	6.7	7.1	0.29	4.04	7.3	6.7	0.5
#200	5.8	5.9	5.9	5.4	5.7	0.32	5.64	5.9	5.4	0.6

Table 5. Gradation (passing/retained) after reflux for unwashed with lime blank aggregate for replacement mixes.

Sieve Size	Percent Passing											
	Target	Replicate					Ave	Std	Cov	Max	Min	Range
		1	2	3	4	5						
1/2 in.* 3/8 in.	13.3	14	14.4	13.7	14.4	14.5	14.2	0.3	2.4	14.5	13.7	0.8
3/8 in.*#4	28.1	28.3	27	28.2	27.3	26.9	27.5	0.7	2.4	28.3	26.9	1.4
#4*#8	15.8	16.7	16.6	16.3	16.6	16.6	16.6	0.2	0.9	16.7	16.3	0.4
#8*#16	8.8	9.5	9.7	9.6	9.7	9.7	9.6	0.1	0.9	9.7	9.5	0.2
#16*#30	4.7	4.1	4.5	4.2	4.3	4.5	4.3	0.2	4.1	4.5	4.1	0.4
#30*#50	3	2.2	2.3	2.2	2	2.3	2.2	0.1	5.6	2.3	2.0	0.3
#50*#100	1.9	1.5	1.6	1.5	1.4	1.7	1.5	0.1	7.4	1.7	1.4	0.3
#100*#200	1.4	1.4	1.6	1.6	1.4	1.7	1.5	0.1	8.7	1.7	1.4	0.3

Table 6. Gradation (passing/retained) after ignition oven for unwashed with lime blank aggregate for replacement mixes.

Sieve Size	Percent Passing				Ave	Std	Cov	Max	Min	Range
	Target	Rep 1	Rep 2	Rep 3						
1/2 in.*3/8 in.	13.3	13.7	13.8	13.8	13.8	0.05	0.37	13.8	13.7	0.1
3/8 in.*#4	28.1	27.6	27.8	27.6	27.7	0.10	0.35	27.8	27.6	0.2
#4*#8	15.8	16.8	16.4	16.7	16.6	0.23	1.37	16.8	16.4	0.4
#8*#16	8.8	9.2	9.4	8.8	9.1	0.29	3.19	9.4	8.8	0.6
#16*#30	4.7	4.6	4.6	4.9	4.7	0.14	2.93	4.9	4.6	0.3
#30*#50	3.0	2.9	2.6	2.9	2.8	0.16	5.87	2.9	2.6	0.3
#50*#100	1.9	1.6	1.6	1.7	1.6	0.06	3.55	1.7	1.6	0.1
#100*#200	1.4	1.3	1.3	1.4	1.3	0.04	2.94	1.4	1.3	0.1

Table 7. Deviation from target gradation for unwashed with lime blank aggregate for replacement mix.

Sieve Size	Percent Passing								
	Target	Ignition			Reflux				
		Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
1/2 in.	82.8	0.7	0.6	0.3	0.4	0.1	0.0	0.4	0.1
3/8 in.	69.5	0.3	0.1	-0.2	-0.3	-1.0	-0.4	-0.7	-1.1
#4	41.4	0.8	0.4	0.3	-0.5	0.1	-0.5	0.1	0.1
#8	25.6	-0.2	-0.1	-0.7	-1.4	-0.7	-1.0	-0.7	-0.7
#16	16.8	-0.5	-0.7	-0.6	-2.1	-1.6	-1.8	-1.6	-1.6
#30	12.1	-0.5	-0.6	-0.8	-1.5	-1.4	-1.3	-1.2	-1.4
#50	9.1	-0.3	-0.2	-0.7	-0.7	-0.7	-0.5	-0.2	-0.7
#100	7.2	0.0	0.1	-0.5	-0.3	-0.4	-0.1	0.3	-0.5
#200	5.8	0.1	0.1	-0.4	-0.3	-0.6	-0.3	0.3	-0.8

Table 8. Replacement section top lift loose mix gradations summary after reflux asphalt content determinations.

Top Lift Data																
Sieve (mm)	Section #	35	36	37	38	39	54	55	56	Top Lift						
	Target	Percent Passing Data								Average	Std Dev	COV	Max	Min	Range	Average
25	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0	100.0	0.0	-0.1
19	99.2	99.8	99.7	98.6	99.3	99.7	99.8	99.8	99.1	99.5	0.4	0.4	99.8	98.6	1.2	-0.3
12.5	82.8	81.6	84.2	85.2	85.2	85.5	85.3	86.4	85.4	84.9	1.4	1.7	86.4	81.6	4.8	-2.1
9.5	69.5	66.8	69.3	68.7	69.9	70.5	69.5	70.5	70.2	69.4	1.2	1.8	70.5	66.8	3.7	0.1
4.75	41.4	38.2	39.8	39.7	40.7	40.6	40.1	39.8	40.9	40.0	0.9	2.1	40.9	38.2	2.7	1.4
2.36	25.6	24.0	25.0	24.7	25.6	25.5	25.0	24.4	26.1	25.0	0.7	2.7	26.1	24.0	2.1	0.6
1.18	16.8	15.8	16.5	16.2	17.2	16.8	16.6	16.4	17.2	16.6	0.5	2.9	17.2	15.8	1.4	0.2
0.60	12.1	11.2	12.2	11.8	12.4	11.7	11.9	11.8	12.4	11.9	0.4	3.4	12.4	11.2	1.2	0.2
0.30	9.1	8.3	8.9	9.0	9.5	9.3	9.1	9.0	9.4	9.1	0.4	4.1	9.5	8.3	1.2	0.0
0.15	7.2	6.4	7.0	7.1	7.6	7.4	7.0	7.2	7.4	7.1	0.4	5.1	7.6	6.4	1.2	0.1
0.075	5.8	5.0	5.7	5.7	6.0	5.9	5.4	5.8	5.5	5.6	0.3	5.7	6.0	5.0	1.0	0.2

Table 9. Replacement section bottom lift loose mix gradations summary after reflux asphalt content determinations.

Bottom Lift Data																
Sieve (mm)	Section #	35	36	37	38	39	54	55	56	Bottom Lift						
	Target	Percent Passing Data								Average	Std Dev	COV	Max	Min	Range	Average
25	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0	100.0	0.0	-0.1
19	99.2	99.5	98.5	99.1	99.4	99.5	99.3	99.9	99.3	99.3	0.4	0.4	99.9	98.5	1.4	-0.1
12.5	82.8	85.5	86.6	86.2	86.6	87.0	86.2	86.7	85.6	86.3	0.5	0.6	87.0	85.5	1.6	-3.5
9.5	69.5	69.7	68.9	70.1	70.6	71.7	70.6	70.9	70.7	70.4	0.9	1.2	71.7	68.9	2.9	-0.9
4.75	41.4	39.6	39.5	40.2	40.6	42.0	40.3	39.6	41.5	40.4	0.9	2.3	42.0	39.5	2.5	1.0
2.36	25.6	24.4	24.2	25.0	24.9	25.8	24.9	24.3	26.5	25.0	0.8	3.1	26.5	24.2	2.3	0.6
1.18	16.8	15.9	15.9	16.5	16.4	16.9	16.2	16.0	17.7	16.4	0.6	3.8	17.7	15.9	1.8	0.4
0.60	12.1	11.4	11.5	12.2	11.7	11.9	11.5	11.4	12.9	11.8	0.5	4.3	12.9	11.4	1.5	0.3
0.30	9.1	8.4	8.7	9.3	8.7	9.3	8.7	8.7	9.8	8.9	0.5	5.3	9.8	8.4	1.4	0.2
0.15	7.2	6.6	6.9	7.5	6.7	7.2	6.8	7.0	7.6	7.0	0.4	5.1	7.6	6.6	1.0	0.2
0.075	5.8	5.2	5.6	6.1	5.3	5.7	5.4	5.6	6.0	5.6	0.3	6.0	6.1	5.2	0.9	0.2

Table 10. Replacement top lift gradation of loose mix after ignition (n=5/section).

Sieve Size (mm)	Target	Replacement Mix Top Lift — Average Percent Passing								Average	Std Dev
		Section Number									
		35	36	37	38	39	54	55	56		
19	99.2	100.0	99.8	100.0	99.9	100.0	99.8	99.9	99.8	99.9	0.22
12.5	82.8	84.0	84.1	83.3	83.8	83.4	84.9	86.3	84.6	84.3	2.30
9.5	69.5	69.5	68.7	68.7	69.9	69.3	71.0	71.5	69.8	69.8	2.44
4.75	41.4	39.1	40.0	39.1	40.6	39.6	41.3	40.5	40.0	40.0	1.70
2.36	25.6	24.0	25.4	24.6	25.6	24.3	25.7	25.1	25.3	25.0	1.03
1.18	16.8	16.0	16.7	16.5	17.4	16.1	16.8	16.6	17.0	16.6	0.61
0.6	12.1	11.5	12.0	11.8	12.6	11.6	11.9	12.0	12.2	11.9	0.46
0.3	9.1	8.8	9.1	9.0	9.7	8.9	9.0	9.2	9.4	9.3	0.38
0.15	7.2	7.0	7.2	7.1	7.7	7.1	7.2	7.4	7.5	7.3	0.35
0.075	5.8	5.6	5.8	5.7	6.2	5.7	5.8	6.0	6.1	5.9	0.31
Surface Area (ft^2/lb)		22.4	23.2	22.8	24.5	22.7	23.1	23.6	24.1		
Surface Area (m^2/kg)		4.59	4.75	4.67	5.01	4.65	4.73	4.84	4.93		
Ratio #4 to #50 (4.75 to 0.3)		4.45	4.40	4.36	4.19	4.46	4.58	4.41	4.26		

Table 11. Replacement bottom lift gradation of loose mix after ignition (n=5/section).

Sieve Size (mm)	Target	Replacement Mix Top Lift — Average Percent Passing								Average	Std Dev
		Section Number									
		35	36	37	38	39	54	55	56		
19	99.2	99.8	99.2	99.8	99.5	99.6	99.8	99.6	99.8	99.5	0.60
12.5	82.8	85.3	84.3	85.1	87.0	84.2	84.9	84.3	85.3	85.1	1.90
9.5	69.5	70.3	69.9	70.1	72.4	69.1	71.3	69.3	71.6	70.5	2.00
4.75	41.4	41.3	39.4	40.3	42.4	39.3	41.5	39.8	41.8	40.7	1.70
2.36	25.6	25.4	24.2	24.3	25.9	24.2	25.3	24.2	25.7	24.9	1.10
1.18	16.8	16.4	15.9	15.9	16.9	15.7	16.7	16.0	17.0	16.2	0.60
0.6	12.1	11.6	11.3	11.3	11.9	11.0	11.9	10.6	12.0	11.4	0.70
0.3	9.1	8.6	8.0	8.5	8.9	8.2	8.9	8.0	9.0	8.4	0.60
0.15	7.2	6.6	6.6	6.7	7.0	6.2	6.9	6.2	7.1	6.6	0.50
0.075	5.8	5.1	5.3	5.4	5.5	4.8	5.6	5.1	5.7	5.2	0.50
Surface Area (ft^2/lb)		21.5	21.3	21.8	22.6	20.5	22.5	20.7	23.0		
Surface Area (m^2/kg)		4.40	4.37	4.46	4.63	4.19	4.62	4.24	4.70		
Ratio #4 to #50 (4.75 to 0.3)		4.83	4.90	4.77	4.74	4.82	4.68	5.0	4.66		

Table 12. Aggregate gradation summary for coarse graded mixture – replacement sections.

Sieve Size		Target	Top Layer				Bottom Layer			
U.S. (in.)	Metric (mm)		Mean	Std Dev	Cov	n	Mean	Std Dev	Cov	n
3/4	19.0	99.2	99.9	0.22	0.2	40	99.5	0.60	0.6	40
1/2	12.5	82.8	84.3	2.30	2.7	40	85.1	1.90	2.2	40
3/8	9.50	69.5	69.8	2.44	3.5	40	70.5	2.00	2.8	40
No. 4	4.75	41.4	40.0	1.70	4.3	40	40.7	1.70	4.2	40
No. 8	2.36	25.6	25.0	1.03	4.1	40	24.9	1.10	4.4	40
No. 16	1.18	16.8	16.6	0.61	3.7	40	16.2	0.60	3.7	40
No. 30	0.60	12.1	11.9	0.46	3.9	40	11.4	0.70	6.1	40
No. 50	0.30	9.1	9.3	0.38	4.1	40	8.4	0.60	7.1	40
No. 100	0.15	7.2	7.3	0.35	4.8	40	6.6	0.50	7.6	40
No. 200	0.075	5.8	5.9	0.31	5.3	40	5.2	0.50	9.6	40

APPENDIX A

AGGREGATE GRADATIONS AFTER REFLUX EXTRACTION FOR REPLACEMENT SECTIONS
TEST SECTION TOP LIFT

Reflux Summary

				Section 35					Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	35-1	35-2	35-3	x	s	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	82.8	80.3	85.3	81.4	82.2	81.0	81.5	0.6	1.2
3/8"	69.5	67	72	67.3	66.9	67.4	67.2	0.2	0.5
#4	41.4	38.9	43.9	39.0	38.4	39.0	38.8	s.3	0.6
#8	25.6	23.6	27.6	24.7	24.6	24.7	24.7	0.1	0.2
#16	16.8	14.8	18.8	16.2	16.1	16.4	16.2	0.1	0.3
#30	12.1	10.1	14.1	12.0	11.6	11.8	11.8	0.2	0.4
#50	9.1	7.6	10.6	9.1	8.8	9.0	9.0	0.1	0.3
#100	7.2	6.2	8.2	7.3	7.0	7.1	7.1	0.2	0.4
#200	5.8	5.3	6.3	6.1	5.7	5.7	5.8	0.3	0.5

Reflux Summary

				Section 36					Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	36-1	36-2	36-3	x	s	R
3/4"	99.2	96.7	101.7	100.0	99.6	100.0	99.9	0.2	0.4
1/2"	82.8	80.3	85.3	83.3	87.1	81.4	83.9	2.9	5.7
3/8"	69.5	67	72	71.3	69.2	68.5	69.7	1.4	2.8
#4	41.4	38.9	43.9	40.2	40.3	39.8	40.1	0.3	0.6
#8	25.6	23.6	27.6	25.0	25.9	25.6	25.5	0.5	0.9
#16	16.8	14.8	18.8	16.6	17.0	16.9	16.9	0.2	0.4
#30	12.1	10.1	14.1	12.1	12.3	12.1	12.2	0.1	0.2
#50	9.1	7.6	10.6	9.4	9.4	9.2	9.3	0.1	0.2
#100	7.2	6.2	8.2	7.5	7.5	7.3	7.4	0.1	0.3
#200	5.8	5.3	6.3	6.0	6.0	5.9	6.0	0.1	0.2

Reflux Summary

				Section 37					Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	37-1	37-2	37-3	x	s	R
3/4"	99.2	96.7	101.7	99.2	99.4	99.4	99.3	0.1	0.2
1/2"	82.8	80.3	85.3	84.4	87.6	79.4	83.8	4.1	8.2
3/8"	69.5	67	72	67.3	72.6	64.8	68.2	4.0	7.9
#4	41.4	38.9	43.9	39.5	42.0	38.6	40.0	1.8	3.4
#8	25.6	23.6	27.6	25.4	25.8	25.6	25.6	0.2	0.4
#16	16.8	14.8	18.8	16.8	16.8	17.2	17.0	0.2	0.4
#30	12.1	10.1	14.1	12.3	12.2	12.5	12.3	0.2	0.3
#50	9.1	7.6	10.6	9.4	9.3	9.6	9.4	0.2	0.3
#100	7.2	6.2	8.2	7.4	7.4	7.8	7.6	0.2	0.4
#200	5.8	5.3	6.3	6.0	6.0	6.5	6.1	0.3	0.5

Reflux Summary

				Section 38					Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	38-1	38-2	38-3	x	s	R
3/4"	99.2	96.7	101.7	99.5	98.1	99.5	99.0	0.8	1.4
1/2"	82.8	80.3	85.3	86.1	87.5	81.3	85.0	3.2	6.1
3/8"	69.5	67	72	71.4	74.0	65.2	70.2	4.5	8.9
#4	41.4	38.9	43.9	42.4	45.2	38.5	42.0	3.4	6.8
#8	25.6	23.6	27.6	28.3	29.4	25.8	27.8	1.8	3.6
#16	16.8	14.8	18.8	19.4	20.0	17.9	19.1	1.1	2.1
#30	12.1	10.1	14.1	14.6	15.0	13.4	14.4	0.8	1.6
#50	9.1	7.6	10.6	11.5	11.8	10.6	11.3	0.6	1.2
#100	7.2	6.2	8.2	9.5	9.7	8.7	9.3	0.5	1.0
#200	5.8	5.3	6.3	8.0	8.0	7.3	7.8	0.4	0.7

Reflux Summary

				Section 39				Construction Date: 6-28-97	
Sieve Size	Target	Spec Minus	Spec Plus	39-1	39-2	39-3	x	s	R
3/4"	99.2	96.7	101.7	100.0	99.5	100.0	99.8	0.3	0.5
1/2"	82.8	80.3	85.3	83.3	84.1	86.4	84.6	1.6	3.1
3/8"	69.5	67	72	68.2	69.4	71.0	69.5	1.4	2.8
#4	41.4	38.9	43.9	40.4	40.9	41.4	40.9	0.5	1.0
#8	25.6	23.6	27.6	25.3	25.9	25.9	25.7	0.4	0.6
#16	16.8	14.8	18.8	16.4	17.2	16.8	16.8	0.4	0.8
#30	12.1	10.1	14.1	11.8	10.4	12.1	11.4	1.0	1.8
#50	9.1	7.6	10.6	9.0	9.5	9.8	9.4	0.4	0.7
#100	7.2	6.2	8.2	7.2	7.6	7.5	7.4	0.2	0.3
#200	5.8	5.3	6.3	5.9	6.1	6.2	6.1	0.1	0.3

Reflux Summary

				Section 54					Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	54-1	54-2	54-3	x	s	R
3/4"	99.2	96.7	101.7	100.0	100.0	100.0	100.0	0.0	0.0
1/2"	82.8	80.3	85.3	85.3	86.7	82.0	84.6	2.4	4.7
3/8"	69.5	67	72	68.0	70.7	66.2	68.3	2.3	4.6
#4	41.4	38.9	43.9	38.6	39.8	37.9	38.8	1.0	1.9
#8	25.6	23.6	27.6	23.9	24.6	24.3	24.3	0.4	0.8
#16	16.8	14.8	18.8	15.7	16.1	16.1	16.0	0.2	0.4
#30	12.1	10.1	14.1	11.4	11.7	11.6	11.6	0.1	0.3
#50	9.1	7.6	10.6	8.7	8.9	8.8	8.8	0.1	0.2
#100	7.2	6.2	8.2	7.0	7.1	7.0	7.0	0.1	0.1
#200	5.8	5.3	6.3	5.7	5.7	5.6	5.7	0.0	0.1

Reflux Summary

				Section 55					Construction Date: 6-28-97
Sieve Size	Target	Spec Minus	Spec Plus	55-1	55-2	55-3	x	s	R
3/4"	99.2	96.7	101.7	99.5	99.3	100.0	99.6	0.4	0.7
1/2"	82.8	80.3	85.3	81.6	84.5	87.8	84.6	3.1	6.3
3/8"	69.5	67	72	66.0	68.4	73.3	69.2	3.7	7.3
#4	41.4	38.9	43.9	37.6	37.9	42.3	39.3	2.6	4.7
#8	25.6	23.6	27.6	22.6	23.8	25.8	24.1	1.6	3.2
#16	16.8	14.8	18.8	15.9	15.7	16.5	16.0	0.4	0.7
#30	12.1	10.1	14.1	11.5	11.4	11.6	11.5	0.1	0.2
#50	9.1	7.6	10.6	8.8	8.8	8.7	8.8	0.1	0.1
#100	7.2	6.2	8.2	7.1	7.1	6.8	7.0	0.2	0.3
#200	5.8	5.3	6.3	5.7	5.8	5.4	5.6	0.2	0.5

Reflux Summary

				Section 56				Construction Date: 6-28-97	
Sieve Size	Target	Spec Minus	Spec Plus	56-1	56-2	56-3	x	s	R
3/4"	99.2	96.7	101.7	100.0	99.0	98.8	99.3	0.6	1.2
1/2"	82.8	80.3	85.3	83.6	85.8	84.7	84.7	1.1	2.2
3/8"	69.5	67	72	67.1	70.0	71.7	69.6	2.3	4.6
#4	41.4	38.9	43.9	38.1	40.6	42.9	40.5	2.4	4.8
#8	25.6	23.6	27.6	24.6	25.8	27.0	25.8	1.2	2.4
#16	16.8	14.8	18.8	16.4	16.9	17.4	16.9	0.5	1.0
#30	12.1	10.1	14.1	11.9	12.1	12.3	12.1	0.2	0.4
#50	9.1	7.6	10.6	8.9	9.1	9.0	9.0	0.1	0.2
#100	7.2	6.2	8.2	6.9	7.2	7.0	7.0	0.2	0.3
#200	5.8	5.3	6.3	5.5	5.9	5.6	5.6	0.1	0.2

Effect of Aging Conditions on Hot-Mix Asphalt Theoretical Maximum Specific Gravities—Replacement Sections

U.S. Department of Transportation
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA), accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 to January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3 km (1.8 mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the SHRP Superpave HMA volumetric design method.

This WesTrack technical report provides information on the need for "short-term" oven aging (STOA) for samples of HMA obtained for quality control/quality assurance (QC/QA) purposes. These samples are typically field-mixed, laboratory-compacted samples. Laboratory-mixed, laboratory-compacted samples are subjected to a STOA procedure to simulate construction hardening.

BACKGROUND

The Superpave volumetric mix design procedure stipulates that laboratory-prepared samples be short-term oven-aged prior to compaction and testing.[4,5,6] STOA in the laboratory is intended to simulate the aging that occurs during the construction process.[7] The aging that occurs during construction is primarily due to the loss of volatiles and oxidation while the mix is at elevated temperatures.

The WesTrack process control team felt it was important to determine whether the mixture aging occurring during construction was similar to that induced by the STOA procedure used in the mix design process. The idea was to determine whether differences in mix design and process control volumetric properties could be due to differences in laboratory and field aging. A question that needed to be answered was whether or not the mix samples behind the paver

needed to be further aged prior to compaction in order to obtain a fair comparison of mix design and process control volumetric properties.

During construction of the WesTrack replacement sections, the mix typically sat at elevated temperatures for 2 to 3 hours. The 2- to 3-hour time period included storage after production, haul, and placement times. After placement, the mixture had a tendency to cool rapidly. The materials sampled for process control purposes were taken from the mat behind the paver and tested immediately. Asphalt content, gradation, theoretical maximum specific gravity, and volumetric properties were determined on the materials.

The WesTrack Team decided that theoretical maximum specific gravity determinations would be performed on laboratory-prepared, laboratory-aged and field-produced, field-aged materials in an effort to assess the effects of the different aging processes. Changes in theoretical maximum specific gravities, levels of absorption, and calculated effective specific gravities could be evaluated along with their effects on other volumetric properties such as air voids. It may have been more appropriate to perform stiffness measurements on materials, but a lack of time and possible confounding issues associated with compaction precluded this alternative.

The test plan associated with the study is outlined in table 1. Loose field-mix was sampled during trial section paving and tested immediately. Laboratory samples were prepared using the trial section job mix formula and aged under the range of temperatures and times specified in table 1. The aging times were selected so that they bracketed the actual time the mix was at elevated temperatures in the field and included the 4-hour period in the STOA protocol. The selected aging temperatures included 60°C, 135°C, 149°C, and 163°C (140°F, 275°F, 300°F, and 325°F). Thus, the selections included the standard STOA temperature of 135°C. The 149°C and 163°C temperatures were selected because they surrounded the range of mix temperatures measured immediately after discharge at the hot plant into transport trucks.

BACKGROUND OF SUPERPAVE STOA SPECIFICATIONS

The Superpave STOA procedure was selected based on an extensive study conducted at Oregon State University (OSU) during the Strategic Highway Research Program (SHRP).[7,8] The study considered both short- and long-term aging and was conducted in three phases:

- Preliminary test program.
- Expanded test program.
- Field validation.

The preliminary test program evaluated a limited number of materials and variables in an attempt to identify the most appropriate methods to be developed further under the expanded test program and field validation tasks. The following discussion is limited to the short-term aging portion of the study.

In the preliminary program, forced-draft oven aging and extended mixing procedures were applied to loose mix. The forced-draft oven aging simply amounted to aging loose mix in flat

pans in ovens. The extended mixing procedure employed a rolling thin film oven modified with a drum attachment to the rotating carousel that allowed for extended mixing times.

Table 2 outlines the variables and levels of each evaluated in the preliminary study. The study was limited to two aggregate and two asphalt cement sources for a total of four mixtures. For the short-term oven aging procedure, the time periods used were 0, 6, and 15 hours. For the extended mixing procedure 0-, 10-, 120-, and 360-minute time periods were used. A single replicate was used under each of the conditions indicated in table 2.

The mixture tests used to evaluate the effects of each aging method included resilient modulus and tensile strength. All specimens were compacted using the California kneading method after aging. A resilient modulus ratio (resilient modulus after aging to the resilient modulus before aging) was used as a measure of degree of aging. Figure 1 is a typical example of the preliminary results.

Because resilient modulus is a nondestructive test, tensile strengths were performed on the same specimens after the modulus testing. Tensile test results provided an indication of mixture brittleness. Load and deformation were monitored during the testing so that strength and strain could be determined at yield. Von Quintus et al.[9] suggested that strain at yield was an indication of aging during the Asphalt-Aggregate Mixture Analysis System (AAMAS) program.

The resilient modulus and tensile strength data indicated similar results. Both showed that significant aging took place with time and both ranked aging similarly. Because both methods provided similar results, the WesTrack Team decided that only the forced-draft oven aging technique would be evaluated further in the expanded test and field-aging phases. The decision was very practical because multiple pans of mix could be aged in a single oven. Multiple rolling thin film oven tests (RTFOTs) would have been required in production laboratories had the extended mixing method been selected. The WesTrack Team also decided that oven aging would be conducted at a single temperature of 135°C for up to a maximum of 4 hours in the future research efforts based on this study and literature review.

Validation of the aging methods was accomplished by comparing the stiffness (moduli) of field cores to laboratory-prepared and -aged specimens using materials from the field projects. These validation efforts are detailed in SHRP Report A-390.[8] Validation of the short- and long-term aging methods developed at OSU were performed in three phases:

- Preliminary short-term validation.
- Expanded validation.
- Supplemental validation.

The preliminary short-term validation was aimed at identifying a common time period to short-term age mixtures to a state representative of that which occurs during construction operations. Four projects were selected for the preliminary validation. They were all located in Oregon and two each were in wet/no-freeze and dry/freeze environments. They encompassed two grades of asphalt cement; two of the mixtures incorporated antistrip admixtures. The admixtures were lime and Pavebond Special.

Cores were taken from each project and diametral resilient modulus testing was performed. The air void levels, asphalt contents, and gradations of the cores were determined and the laboratory-prepared specimens were fabricated as closely to the field core properties as possible. The laboratory-prepared specimens were aged in forced-draft ovens at 135°C (275°F) for 0, 4, and 8 hours prior to California kneading compaction. For the projects that incorporated admixtures, specimens were prepared with and without the admixtures under the same conditions; an additional set of specimens was also oven-aged 12 hours.

The preliminary validation data are presented in figures 2 through 5. The figures show that the range of STOA times needed to age the laboratory specimens to produce moduli equal to those measured in the field cores was from 4.5 to 12 hours. The earlier proposed 4-hour period did make a reasonable contribution to the aging observed for the four projects, particularly those that did not incorporate admixtures. The admixtures in two of the mixtures retarded aging, as noted in figures 4 and 5. This finding was consistent with the literature as Edler et al.[10] found that lime had a considerable effect on retarding the aging of asphalt-aggregate mixtures.

The expanded validation study approach is presented in figure 6. The same methodology followed in the preliminary validation was followed with the addition of long-term aging. The number of sites and climate zones were both increased. The projects encompassed SHRP general pavement studies (GPS) and specific pavement studies (SPS) sites, AAMAS sites, and a French Laboratoire Central des Ponts et Chaussées (LCPC) site. A minimum of two sites and one backup, in case virgin materials were unavailable, were selected for study in each of the four general environmental regions (wet/no-freeze, dry/no- freeze, wet/freeze, and dry/freeze). Six grades of asphalt cement and three admixtures (lime, portland cement, and flyash) were represented. Ultimately, a total of 12 sites were obtained. Site selection was driven almost entirely by availability of virgin materials for construction. The only drawback to the validation was that most of the projects were only 3 years old. The laboratory aging and testing program followed is detailed in figures 7 and 8. It should be noted that both diametral and triaxial resilient modulus testing was conducted.

The supplemental validation effort included sites that ranged in age from 3 to 18 years. The sites were all located in Washington State in dry/freeze or wet/no-freeze environments. The sites were limited to Washington State because they were the only old sites for which virgin materials were available. The same study plan and laboratory aging and testing plans followed in the expanded validation were followed in the supplemental validation.

STATISTICAL ANALYSIS

Thorough statistical analyses were performed on the expanded and supplemental validation data. Both Tukey honest significant difference (HSD) and least significant difference (LSD) comparisons were performed. The analyses compared the effects of the different aging conditions within each specific site and modulus test method. Figure 9 is an example of Tukey intervals for factor (aging condition) means for a site in Michigan.

The "honest" in Tukey HSD indicates that the analysis protects against false claims that there are significant differences by constructing confidence intervals large enough to account for the expected difference between the largest and smallest averages. Tukey is commonly employed when there are no plans prior to the study to compare specific means. With the Tukey method, all means are compared against all others. This is sometimes conservative and may result in true differences going undetected. The Tukey confidence intervals have a larger spread than LSD intervals in order to capture any similar means from a large group. The reason LSD was used was because it is a common method employed when planned comparisons are made between various treatments and a control (the field cores in this case). The smaller intervals associated with LSD allow true differences to be detected, particularly in the case of preplanned comparisons.

Only two sites in the expanded validation were 2 years old or less. The moduli of cores from these sites were similar to the moduli of laboratory-prepared and STOA samples produced with the project materials. Based on the preliminary study data and the limited expanded study data, the WesTrack Team recommended that the STOA procedure be implemented. This recommendation took into account three climate zones and was somewhat conservative. The reader is referred to SHRP Report A-390[8] for details on long-term aging.

THEORETICAL MAXIMUM SPECIFIC GRAVITY TEST METHOD

Theoretical maximum specific gravity is the ratio of the dry mass of loose mixture sample to the volume of the sample under the zero air voids condition at 25°C (77°F). The zero air voids condition is achieved by placing loose mix in a pycnometer, covering it with water, and applying vacuum to evacuate entrapped air. ASTM D 2041-95 and AASHTO T 209 are the standard test methods followed in conducting the determination.[11,12]

If aggregate pores are not thoroughly sealed by a film of bitumen, they may become saturated with water during the evacuation process. If this occurs, the volume of the mixture will be underestimated, resulting in an overestimation of the maximum specific gravity. Both the ASTM and AASHTO test methods incorporate a supplemental procedure for determination of the surface dry condition after vacuuming for mixtures containing porous aggregate to account for this. This procedure is commonly referred to as the "dryback" procedure. All determinations performed on WesTrack materials incorporated the dryback procedure. The single-operator levels of precision (within laboratory), i.e., the acceptable ranges of two test results, are 0.018 and 0.011 with and without the dryback procedure, respectively.

Like aggregate bulk specific gravity, theoretical maximum specific gravity (Gmm or Rice) plays a very important role in the determination of mixture volumetrics. Gmm represents the zero air void state against which other densities are compared and calculated. Additionally, the effective specific gravity of a mixture is a function of Gmm. With a measured Gmm at a given asphalt content, effective specific gravity may be calculated. Asphalt absorption is determined and accounted for in determining effective specific gravities. Rice specific gravity, at asphalt contents other than the one at which the Gmm test was performed, may then be calculated with the effective specific gravity because it is assumed to be constant for a given mix. Effective

asphalt content is a function of asphalt absorption, which is a function of the effective specific gravity of a mix (see figure 10 for a component diagram of compacted HMA).

SAMPLE PREPARATION

All of the laboratory-prepared samples were composed of 2 kg (4.5 lb) of aggregate treated with 1.5 percent hydrated lime by dry weight of aggregate, mixed with 5.5 percent asphalt cement by total weight of mixture. The aggregate blend was Lockwood "Blend F," which was the replacement job mix formula blend. The asphalt cement used was Idaho Asphalt performance grade 64-22. Mechanical mixing was used, although not required, to achieve thorough coating. All attributes of the STOA protocol, AASHTO PP 2-94, were followed with the exception of the varying aging times and temperatures.[13] In other words, the thickness of the mix was controlled while aging (21 - 22 kg/m^2 [4.3 - 4.5 lbs/ft $^{(2)}$]), and the loose mix stirred every hour.

Field-mixed samples were taken from the mat behind the paver, and tested immediately on each day that trial mix was placed. One bulk sample (5-gallon [19-L] bucket) was taken per section, and then was split into three gyratory compaction, two theoretical maximum specific gravity, and one moisture content sample. The same technicians performed all of the testing (on laboratory- and field-mixed samples), and the bulk of the laboratory equipment used was the same. The field-mix sampling was conducted on June 23 and 28, 1997, during replacement section bottom and top lift paving.

LABORATORY-MIX TEST RESULTS

The results of the testing on the laboratory-prepared samples are summarized in table 3. In addition to the measured Rice specific gravity, calculated aggregate effective specific gravities, percent binder absorbed, and effective asphalt contents are presented. Figures 11 through 14 are plots of the same properties as a function of aging temperature. Figures 15 through 18 represent the data as a function of both aging time and temperature. The long-time, low-temperature aging (16 hours at 60°C [140°F) appears to have aged the mix the least. Since there is very little difference in the measured Rice specific gravities between the 2- and 4- hour aging at the higher temperatures, this aging is more likely to be related to the temperature than to the time.

The figures suggest that the Rice specific gravity of the material was insensitive to aging time and temperature. That statement may be made because the Rice specific gravities only range from 2.432 to 2.443, a difference of 0.011, which is well within the single-operator precision (acceptable range of two results) for the test method with the dryback procedure (0.018). It is actually within the precision without the dryback process (0.011). This means that either the material is insensitive to the aging conditions placed on it or the variability associated with the test method is greater than differences created by the conditioning. Unfortunately, statistical comparisons could not be performed since a decision was made earlier not to conduct replicate testing, because of time and personnel constraints.

The calculated aggregate effective specific gravities should theoretically all be equal, as long as the asphalt content was great enough to at least satisfy the aggregate absorption. The effective

specific gravities ranged from 2.640 to 2.654 with a difference of 0.014. Figure 19 shows the relationship between mixture theoretical maximum and aggregate effective specific gravities over a range of asphalt contents, assuming an asphalt specific gravity of 1.032. One may assess the sensitivity of the relationship through such curves. At the single-operator level of precision for the Rice test with the dryback procedure (0.018), effective specific gravities could have a range up to 0.023; without the dryback procedure, they could have a range up to 0.014. The effective specific gravities for the tests conducted had a range of 0.014, which is well within the precision of the test even though the aging conditions were varied.

The percent absorbed asphalt had values from 0.62 to 0.83; this range, 0.21, appears high initially, but if the relationship between effective specific gravity and percent asphalt absorption is evaluated within the precision of the Rice test procedure, as above, absorption may range from 0.21 to 0.33 without and with the dryback procedure, respectively. Again, the absorptions measured were within the stated precision limits without the dryback procedure. The relationship between effective specific gravity and percent asphalt absorption is presented in figure 20 over a range of aggregate bulk specific gravities, assuming constant asphalt specific gravity of 1.032 and asphalt content of 5.5 percent.

Table 3 shows effective asphalt contents took values from 4.72 to 4.91, a range of 0.19 percent. At the asphalt content used in the laboratory-prepared samples (5.5 percent), the effective asphalt content range could be expected not to exceed 0.19 or 0.32 percent without and with dry back, respectively. This percentage is based on the allowed ranges of effective specific gravities (0.14 and 0.18) and thus asphalt absorption ranges (0.21 and 0.33) under the single-operator precision conditions of the Rice test without and with the dryback, respectively. The observed effective asphalt content range of 0.19 percent is within the single-operator precision without the dryback procedure over all aging conditions.

In the Superpave mix design method, there is a dust proportion specification. Dust proportion is defined as the ratio of the percent materials passing the 0.075-mm (No. 200) sieve in the blend to the effective asphalt content.[14] The specification limits are 0.6 to 1.2. Figure 21 depicts the relationship between theoretical maximum specific gravity and dust proportion assuming constant asphalt content of 5.5 percent, asphalt specific gravity of 1.032, and aggregate bulk specific gravity of 2.599. Two acceptable single-operator Rice test results could produce dust proportions differing by as much as 0.05 or 0.08, without and with the dryback procedure, respectively (at the 5.8 percent passing the 0.075-mm sieve level). The dust proportions determined from the laboratory testing had values from 1.18 to 1.23; the 0.05 difference is within the allowed range cited here.

Because the level of air voids in compacted mix is the controlling volumetric property in a Superpave volumetric mix design, the relationship between theoretical maximum specific gravity and air voids will be discussed briefly. The relationship is presented in figure 22 over a range of mixture bulk specific gravities. Figure 23 provides the relationship between mixture bulk specific gravities and air voids over a range of theoretical maximum specific gravities. The relationship shows that for a given mixture bulk specific gravity, e.g., 2.300 in figure 22, air voids may have a range up to 0.42 or 0.68 for two acceptable single-operator Rice test results without and with the dryback procedure, respectively.

The single-operator precision (acceptable range of two results) associated with the mixture bulk specific gravity test procedure is 0.035 according to ASTM D 2726-96.[11] The precision statement in T 166, its AASHTO counterpart, simply states that "duplicate specific gravity results by the same operator should not be considered suspect unless they differ more than 0.020."[12] Figure 23 shows that for a given Rice, two acceptable single-operator air void determinations on the same material may differ as much as 1.44 or 0.82 percent in accordance with ASTM and AASHTO specifications, respectively. Assuming a Rice of 2.440 and applying the ranges around a mixture bulk specific gravity of 2.342 (4.0 percent air void level) results in air voids from 3.3 to 4.7 percent and 3.6 to 4.4 percent for ASTM and AASHTO precision statements at the single-operator level, respectively.

FIELD-MIX TEST RESULTS

The results of the testing on the field mixes are summarized in table 4. Both top and bottom lift process control data are presented. In addition to the measured Rice specific gravities, calculated aggregate effective specific gravities, percent binder absorbed, and effective asphalt contents are provided. It is important to note that laboratory-prepared samples all contained 5.5 percent binder, while the field samples represent a range of binder contents. As previously mentioned, the Rice at any given asphalt content may be calculated from a Rice at another asphalt content. The last column in table 4 represents Rices calculated at 5.5 percent asphalt from the process control or field-measured Rices. The reason for calculating them at 5.5 percent binder is that they may then be compared with the laboratory data at the same asphalt content. Rice specific gravities calculated at asphalt contents, other than the content at which they are measured, are a function of the effective specific gravity of the aggregate, which is a function of asphalt content. The asphalt contents in table 4 represent the average of five determinations performed on loose mix sampled from the mat behind the paver. One of the five samples per section was split from the same bulk sample used to obtain the Rice specific gravity sample. The version of the ignition asphalt content method which uses the blank aggregate correction factor was the method selected for determining the asphalt contents. The determinations were performed by Harding Lawson and Associates (HLA).

The data in the table suggest that the aggregate effective specific gravity and absorbed asphalt were slightly higher on the top lift than on the bottom lift. Figures 24 and 29 appear to be reasonable in that as asphalt content increases, Rice specific gravity decreases. At each asphalt content level (low, medium, and high), the measured Rices are within the single-operator precision range for the test, with one exception (top lift medium asphalt), even though the actual asphalt contents at each level fluctuated somewhat and most likely account for the exception. When viewing the figures, note the actual measured asphalt contents are shown below the section numbers on the charts.

As noted in the previous section, effective specific gravity values may differ as much as 0.23 when two test results are within the precision of the Rice test. Figures 25 and 30 illustrate the top and bottom lift data, respectively. The top lift effective specific gravities ranged 0.23 and the bottom lift ranged 0.27. On average, the top lift was 0.010 greater than the bottom lift. The average top lift absorbed asphalt was 0.14 percent greater than the average for the bottom lift

(compare figures 26 and 31). Some of the differences may have been due to the fact that effective specific gravity is a function of asphalt content and there was variability associated with the asphalt content determinations. Figures 27 and 32 represent the effective asphalt contents.

The Rice specific gravities calculated at 5.5 percent asphalt from the measured Rice specific gravities at other asphalt contents are presented in figures 28 and 33 for the top and bottom lift, respectively. The top and bottom lift data are plotted together in figure 34. The top lift data met the single-operator acceptable difference of two test results of up to 0.018, while the bottom lift results exceeded that limit by 0.004. The top lift average for the Rice specific gravity was 2.445, while the average for the bottom lift was 2.437. The average of the top and bottom lift calculated Rice specific gravities was 2.441.

A comparison of the means of the calculated top and bottom lift Rice specific gravities was performed. Before performing mean comparisons, one must determine whether equal variance exists within each sample of data to be compared.[(15)] An F-test is used to test for equality of two variances. The central hypothesis of this type of test is that the variances of the two data sets are equal. An F-value is calculated from the variances associated with each data set to be compared. The calculated F-statistic is compared to a critical F-value. If the observed F-statistic is greater than the critical F-value, the variances of the data sets are considered to be significantly different, and the central hypothesis is rejected. If the calculated F-statistic is less than the critical F-value, the central hypothesis is accepted.

The maximum probability of wrongly rejecting the central hypothesis is termed alpha (α). For small data sets, alpha should not be greater than 5 percent ($\alpha = 0.05$). With alpha equal to 5 percent, the chance that two variances may not be equal when the F-value is less than the critical F-value is 5 percent. Critical F-values may be obtained from look-up tables of the F-distribution for given alpha levels and degrees of freedom.

A t-test is used to test for equality of means with small sample sizes. The central hypothesis of the t-test is that the means or averages of the two data sets are equal. A t-statistic is calculated from the means of each data set, the variances associated with each data set to be compared, and the number of observations in each data set. The formula used to calculate the t-statistic is dependent on whether or not equal variance exists in the samples to be compared. The calculated t-statistic is compared to a critical t-value. If the observed t-statistic is greater than the critical t-value, the means of the data sets are considered to be significantly different, and the central hypothesis is rejected. If the calculated t-statistic is less than the critical t-value, the central hypothesis is accepted. The alpha concepts associated with the F-test hold true for the t-test. Critical t-values may be obtained from look-up tables of the t-distribution for given alpha levels and degrees of freedom.

A conservative alpha level of 0.01 was selected for both F- and t-testing for several reasons, including the nature of the samples tested and the fact that the property compared was a function of several other properties. The calculated F-statistic was 0.54 and the critical F-value was 0.26, indicating significance and forcing the rejection of the central hypothesis that the variances were equal. The calculated t-statistic (unequal variance) was 2.16 and the critical two-tail t-value was

3.01. Thus, the comparison was not significant and the central hypothesis that the means were equal was accepted.

COMPARISON OF LABORATORY AND FIELD TEST RESULTS

Figures 35 through 37 are comparisons of laboratory- and field-mix theoretical maximum specific gravities, effective specific gravities, and asphalt absorption under the aging conditions imposed. Note that the top and bottom lift data in the plots each represent the average of eight determinations (eight sections). In figure 35, in addition to the individual Rices at 5.5 percent asphalt, the top and bottom lift field average (2.441) is indicated with a heavy horizontal line. The single-operator precision, the range of two results with dryback (0.018), is plotted around (±0.009) the field average. The plot suggests that the field aging produced results similar to all of the laboratory aging conditions with the possible exception of the 16-hour at 60°C (140°F) condition.

The Rice specific gravity under the 2-hours at 135°C (275°F) condition and the STOA (4 hours at 135°C) conditions actually bracket the top and bottom lift field average. This is very interesting considering that the field-mix typically sat at elevated temperatures for approximately 3 hours. Field-mix, plant-discharged temperatures were typically between 149°C and 157°C (300°F and 315°F), with mat temperatures immediately after laydown ranging from 121 to 143°C (250 to 290°F). Assuming linear dissipation of temperature over the 3-hour period, the average temperatures during field aging would have been approximately 142°C (288°F), which is very reasonable considering the data. These data show that the laboratory STOA procedure induced aging very similar to the aging that occurred during construction.

The comparison of effective specific gravities, under all conditions presented in figure 36, shows that the values are all well within the single-operator precision range of 0.23 established previously (see figure 19). The percent asphalt absorption data presented in figure 37 is also well within the single-operator precision range of 0.33 percent under all of the aging conditions (see figure 20).

From the comparison of laboratory and field data, it is clear that the STOA procedure associated with the Superpave mix design method induced aging very similar to the aging that occurred during construction, when measured in terms of theoretical maximum specific gravity and other related volumetric properties. Thus, it was appropriate to perform tests on field-mix immediately after sampling (i.e., it would have been inappropriate to further age field samples prior to testing). Additionally, differences in mix design and process control volumetric properties should be independent of the different aging conditions actually associated with each material type. That answers the question of whether or not the mix sampled behind the paver needed to be further aged prior to compaction in order to obtain a fair comparison of mix design and process control volumetric properties.

The facts that the measured Rice specific gravities under all aging conditions were within the precision of the test method, and replication was not conducted on the laboratory portion of the experiment, make it impossible to perform sound statistical comparisons. The reality is that in

situations where all test results, under the range of conditions imposed, are randomly distributed within the precision of a test method, statistical comparisons may not effectively deduce the differences due specifically to the imposed conditions. In other words, if the differences are less than the variability typically associated with the test method, it is difficult to discern whether the differences are due to the conditions imposed or simply reveal the variability associated with the test.

With the knowledge that the STOA and field aging processes induced similar aging, a powerful conclusion may be drawn relative to measured field asphalt contents. As noted earlier, theoretical maximum specific gravity is a function of asphalt content and aggregate effective specific gravity is constant, assuming absorption is satisfied. Rice specific gravity at asphalt contents, other than the content at which the Rice is measured, may be calculated from the effective aggregate specific gravity obtained at the measured asphalt content. Thus, Rice specific gravities calculated at a given asphalt content, from Rice specific gravities measured over a range of asphalt contents, should be equal to Rice specific gravities measured at the given asphalt content. The conclusion that may be drawn is that the field asphalt contents measured using the ignition method should be accurate within the precision of the Rice test method. The average top and bottom lift effective specific gravities of 2.657 and 2.647, respectively, are indicated in figure 38 around the 5.5 percent asphalt content line at the combined top and bottom lift average Rice value of 2.441. The data suggest that the asphalt contents measured on the field samples should be accurate within 0.24 percent or ± 0.12 percent on average. This finding is in line with typical construction variability associated with asphalt content (0.15 - 0.45) and single-operator range of precision (acceptable range of two results) statements of 0.11 and 0.13 found in the literature for the ignition method.[3,16,17]

SUMMARY AND CONCLUSIONS

The Superpave volumetric mix design procedure stipulates that laboratory-prepared samples be short-term oven aged prior to compaction and testing. STOA in the laboratory is intended to simulate the aging that occurs during the construction process. The WesTrack Team felt it was important to determine whether the mixture aging occurring during construction was similar to that induced by the STOA procedure used in the mix design process. The idea was to determine whether differences in mix design and process control volumetric properties could be due to differences in laboratory and field aging. The question that needed to be answered was whether or not the mix sample behind the paver needed to be further aged prior to compaction in order to obtain a fair comparison of mix design and process control volumetric properties. A testing program was conducted to address this question.

Theoretical maximum specific gravity determinations were performed on laboratory-prepared laboratory-aged and field-produced, field-aged (construction only) materials in an effort to assess the effects of the different aging processes. In addition to Rice specific gravity, other volumetric properties were evaluated. Multiple aging conditions (times and temperatures) were applied to the laboratory-prepared samples.

The differences in volumetric properties due to the different laboratory aging conditions were within the single-operator precision of the Rice test method. In cases where the differences induced are less than the variability typically associated with the test method, it is difficult to discern whether the differences are due to the conditions imposed or simply reveal the variability associated with the test. However, properties of the laboratory-aged samples correlated very well with those of the field-aged samples. Comparison of laboratory and field data showed that the STOA procedure associated with the Superpave mix design method induced aging that was very similar to the aging that occurred during construction, when measured in terms of theoretical maximum specific gravity and other related volumetric properties. Thus, it was appropriate to perform process control tests on field-mix immediately after sampling for comparison to mix design properties. The fact that the mix was somewhat insensitive to aging conditions may have been confounded by the fact that the mix contained 1.5 percent hydrated lime, which was found to retard aging during the STOA development. This finding was supported by the literature.

A conservative statistical comparison ($\alpha = 0.01$) of Rice specific gravities calculated at 5.5 percent asphalt on the top and bottom lift field samples (eight per lift) indicated no significant difference. This, coupled with the knowledge that STOA and field aging resulted in similar Rice specific gravities, led to an indirect assessment of the accuracy of field asphalt contents determined using the ignition method. The data suggest that the asphalt contents measured on the field samples should be accurate to within 0.24 percent or ± 0.12 percent on average. This finding is in agreement with typical construction variability associated with asphalt content (0.15 - 0.45) and single-operator precision (acceptable range of two results) statements of 0.11 and 0.13 found in the literature for the ignition method.

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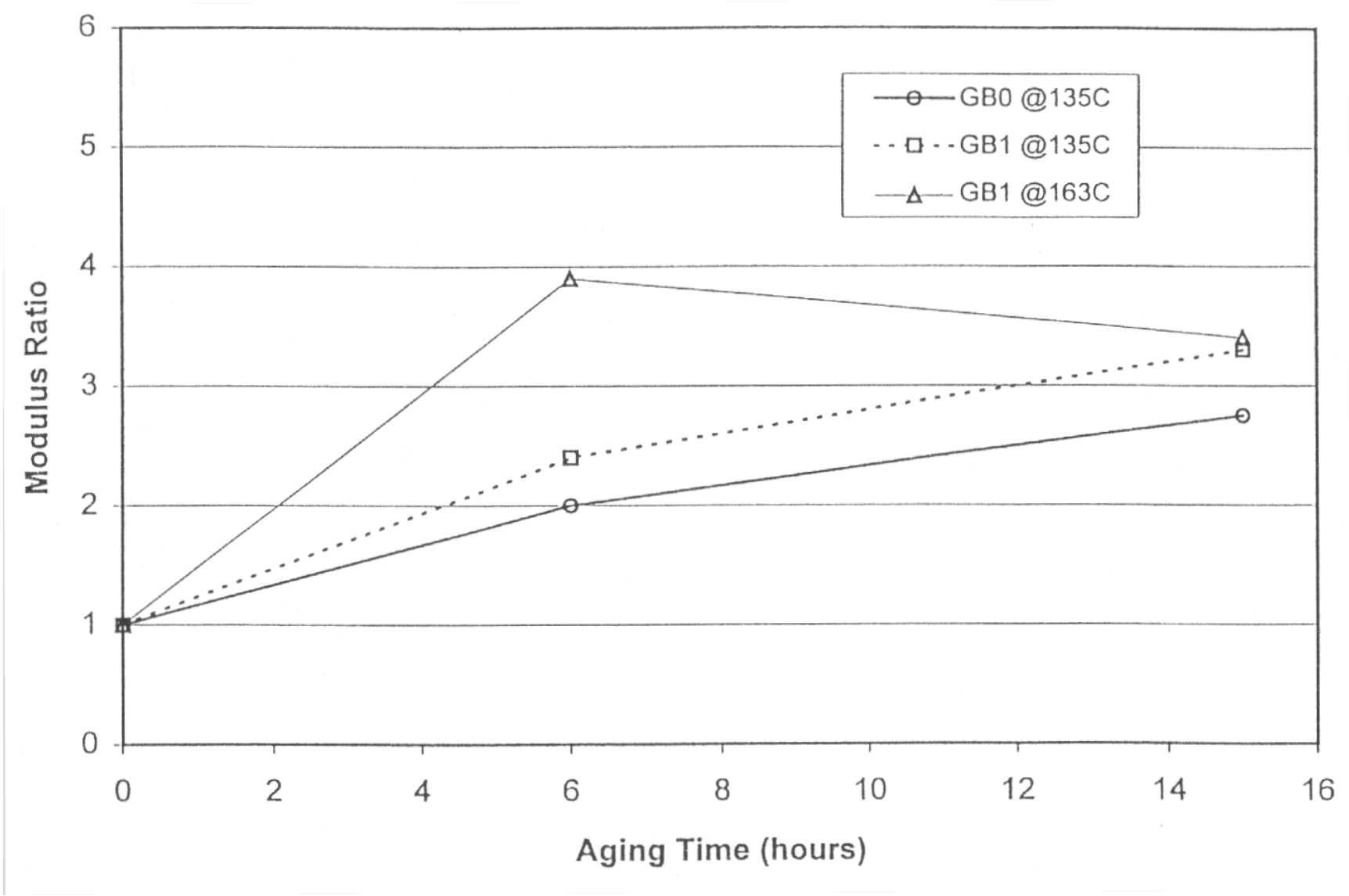


Figure 1. Example of aging effect on resilient modulus ratio (preliminary test program).

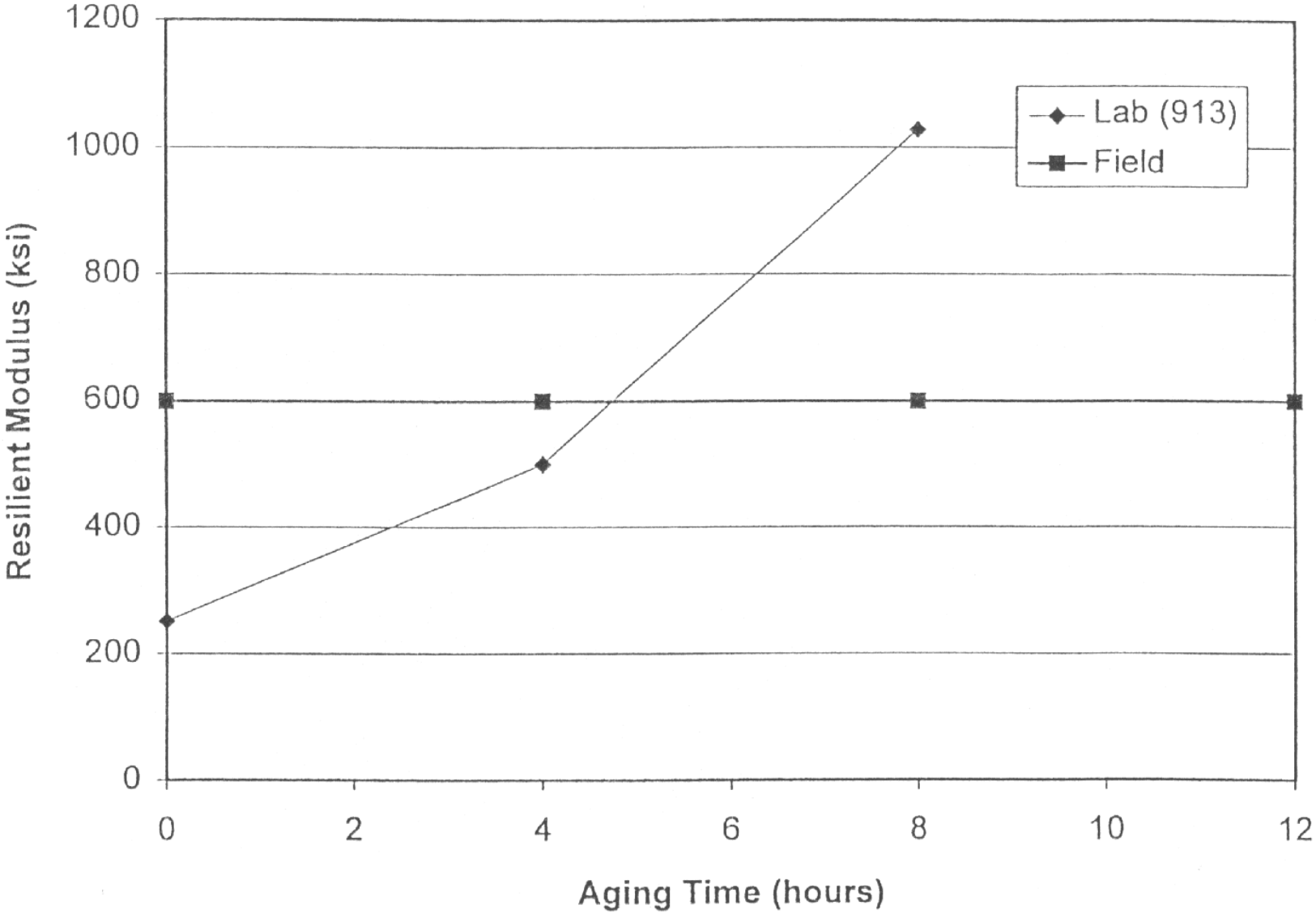


Figure 2. Project 913 short-term aging data.

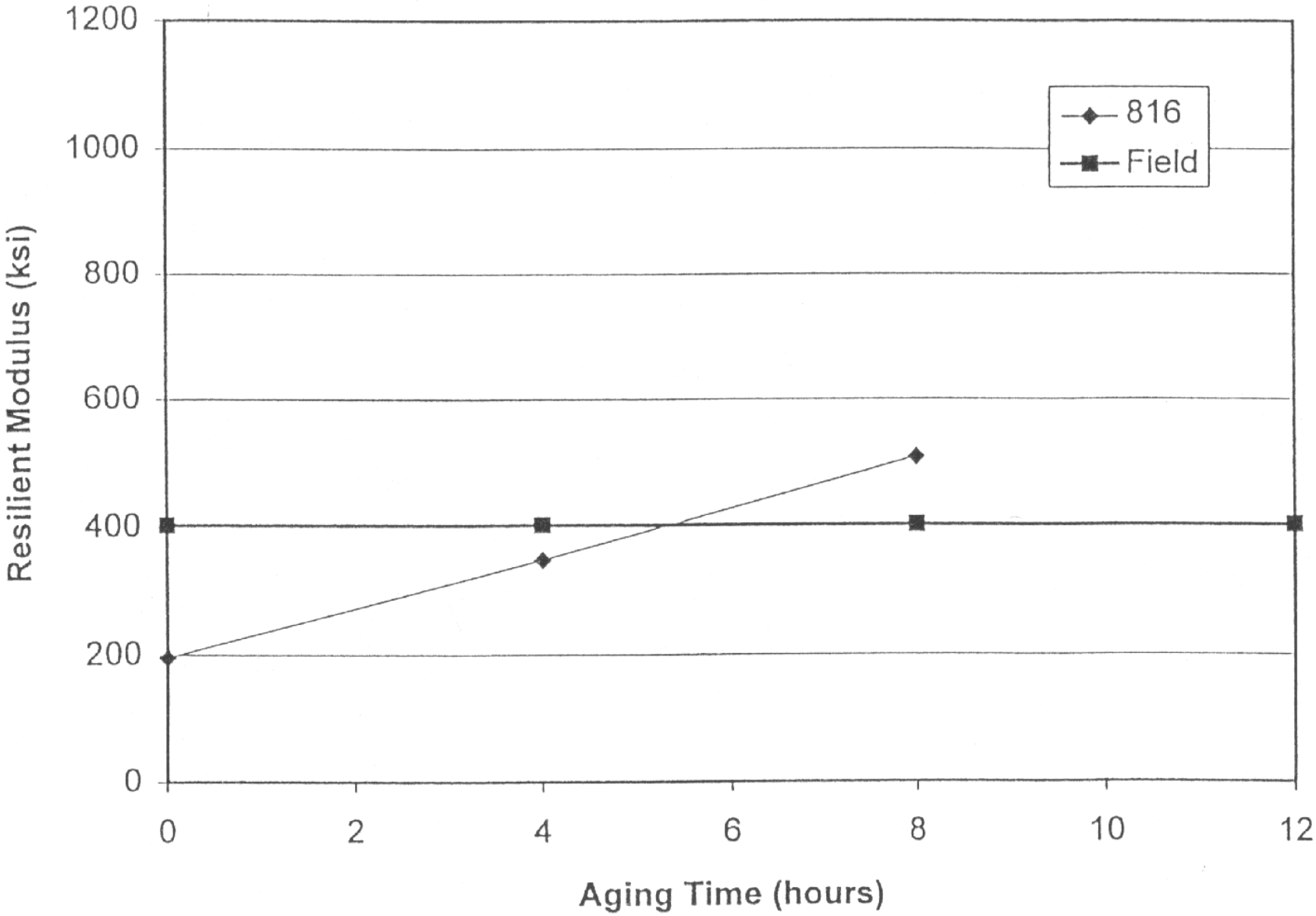


Figure 3. Project 816 short-term aging data.

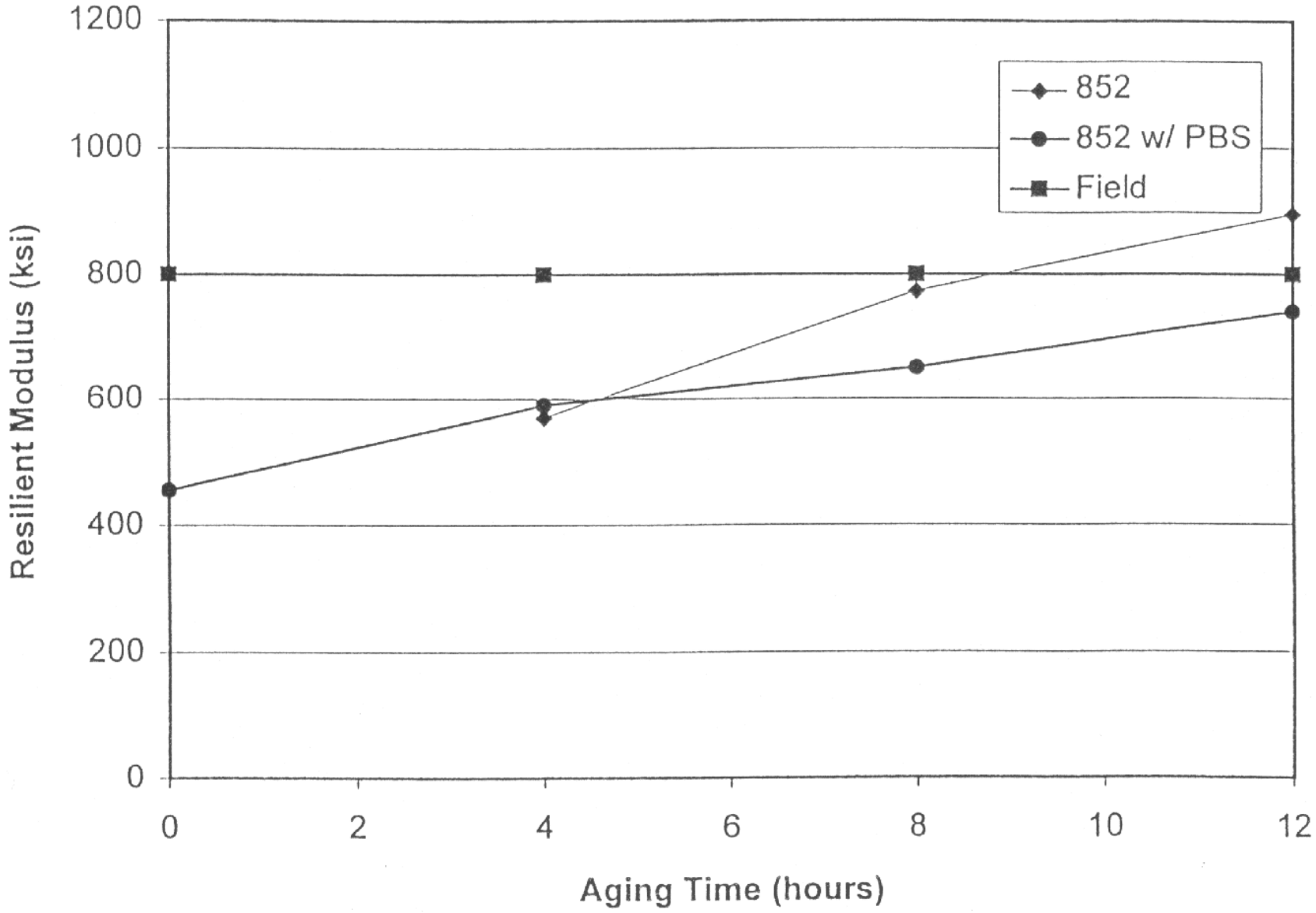


Figure 4. Project 852 short-term aging data.

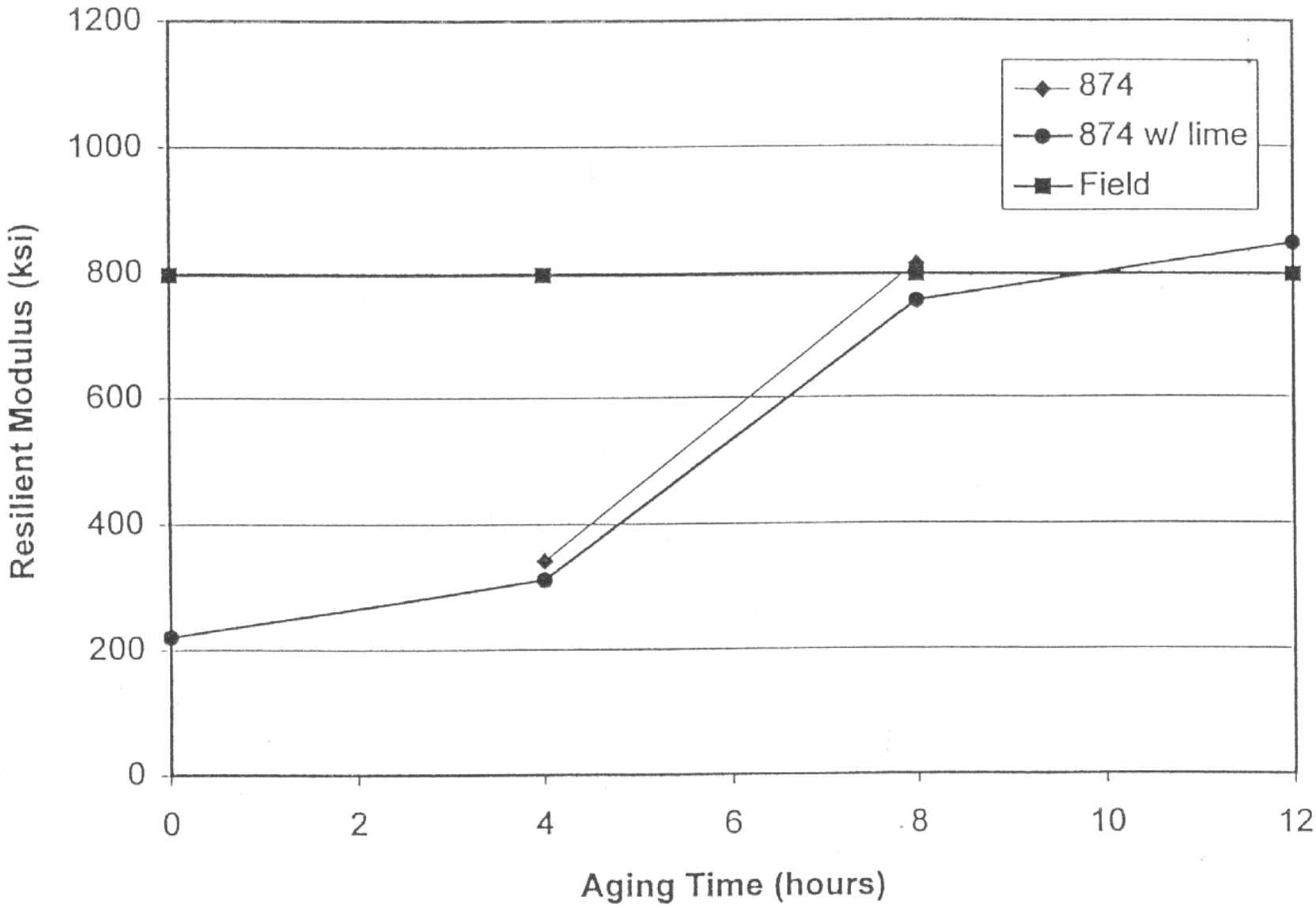


Figure 5. Project 874 short-term aging data.

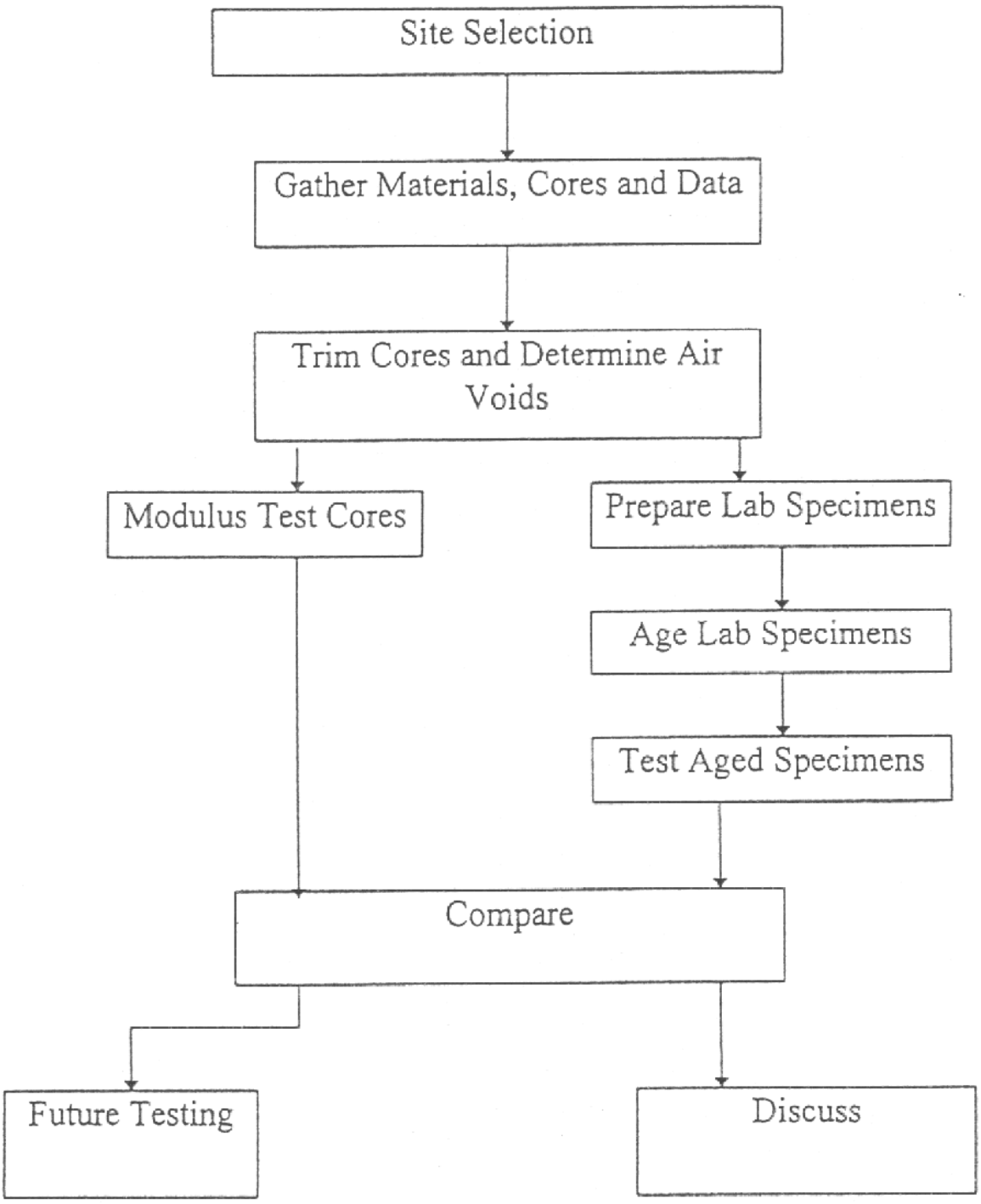


Figure 6. Expanded validation study.

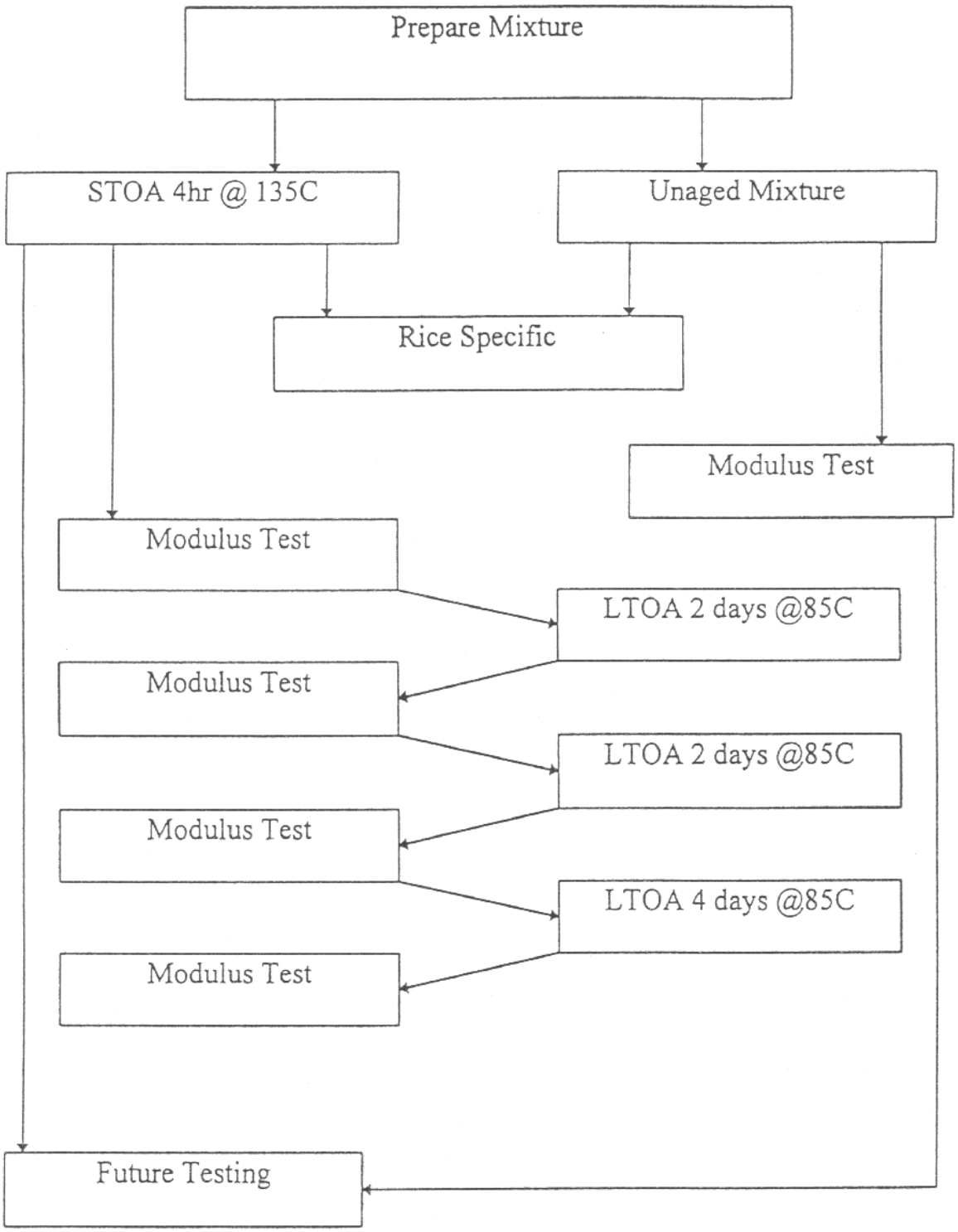


Figure 7. Expanded study – laboratory aging process (85°C).

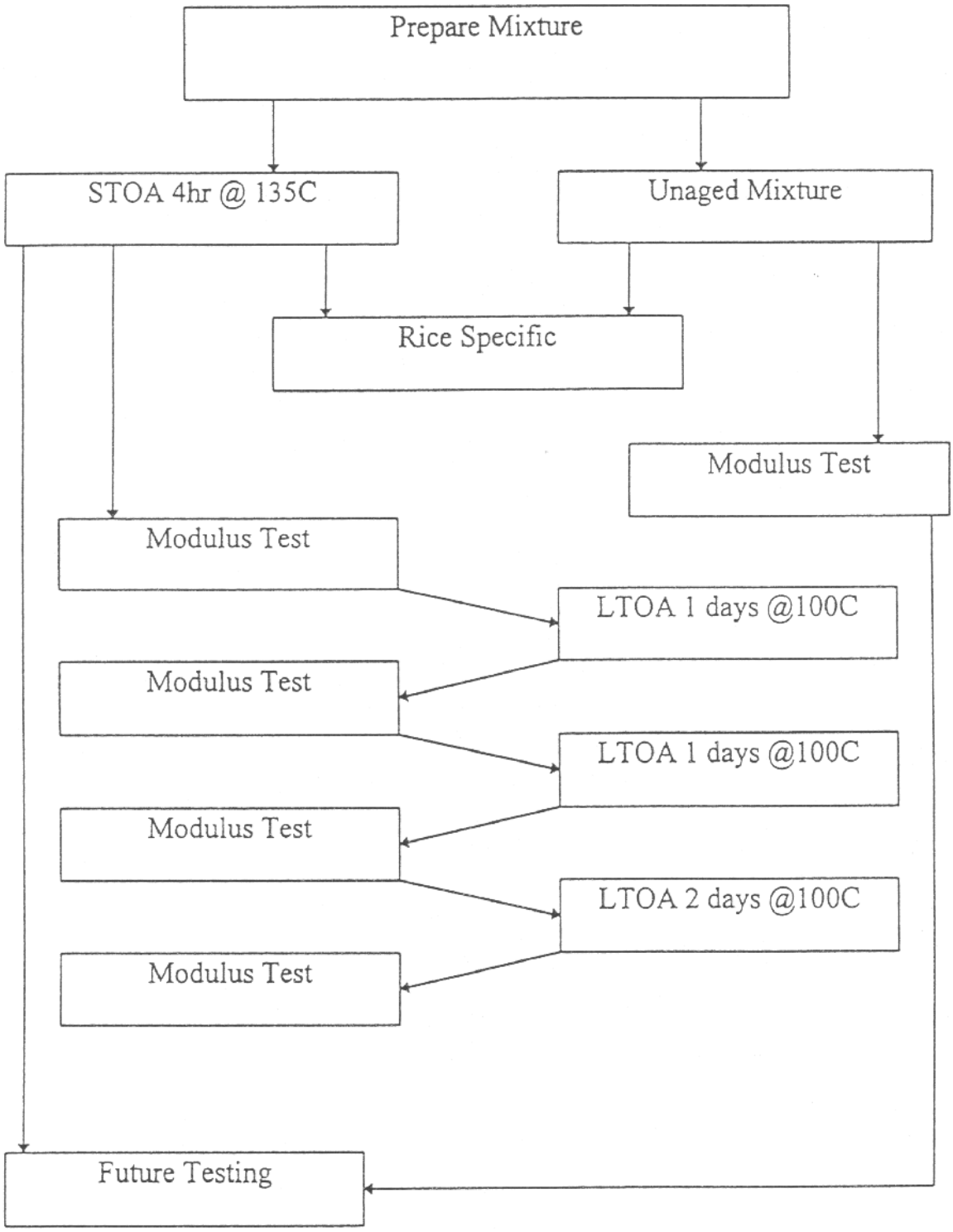


Figure 8. Expanded study – laboratory aging process (100°C).

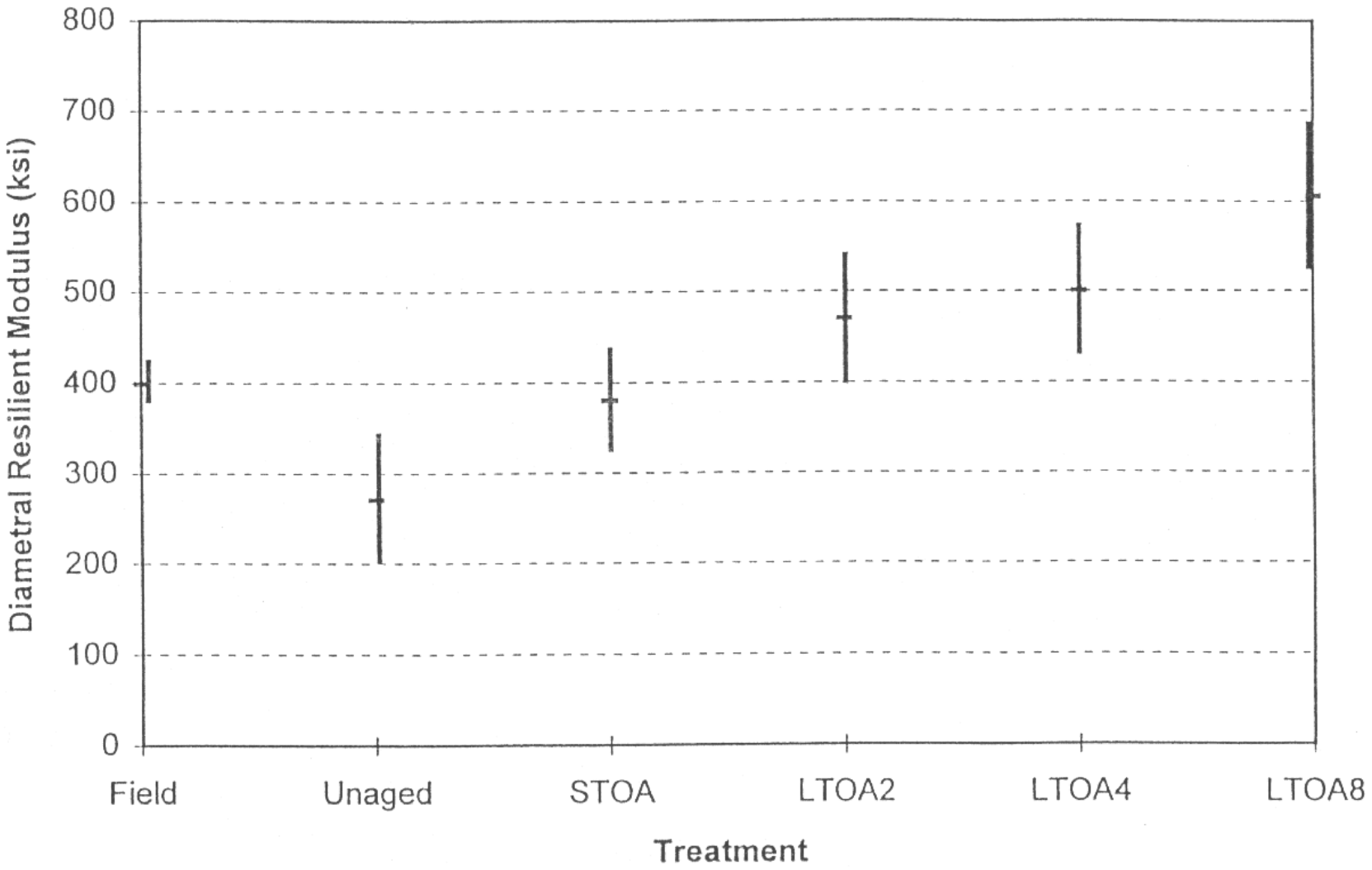


Figure 9. Example – Tukey comparison of intervals of factor means.

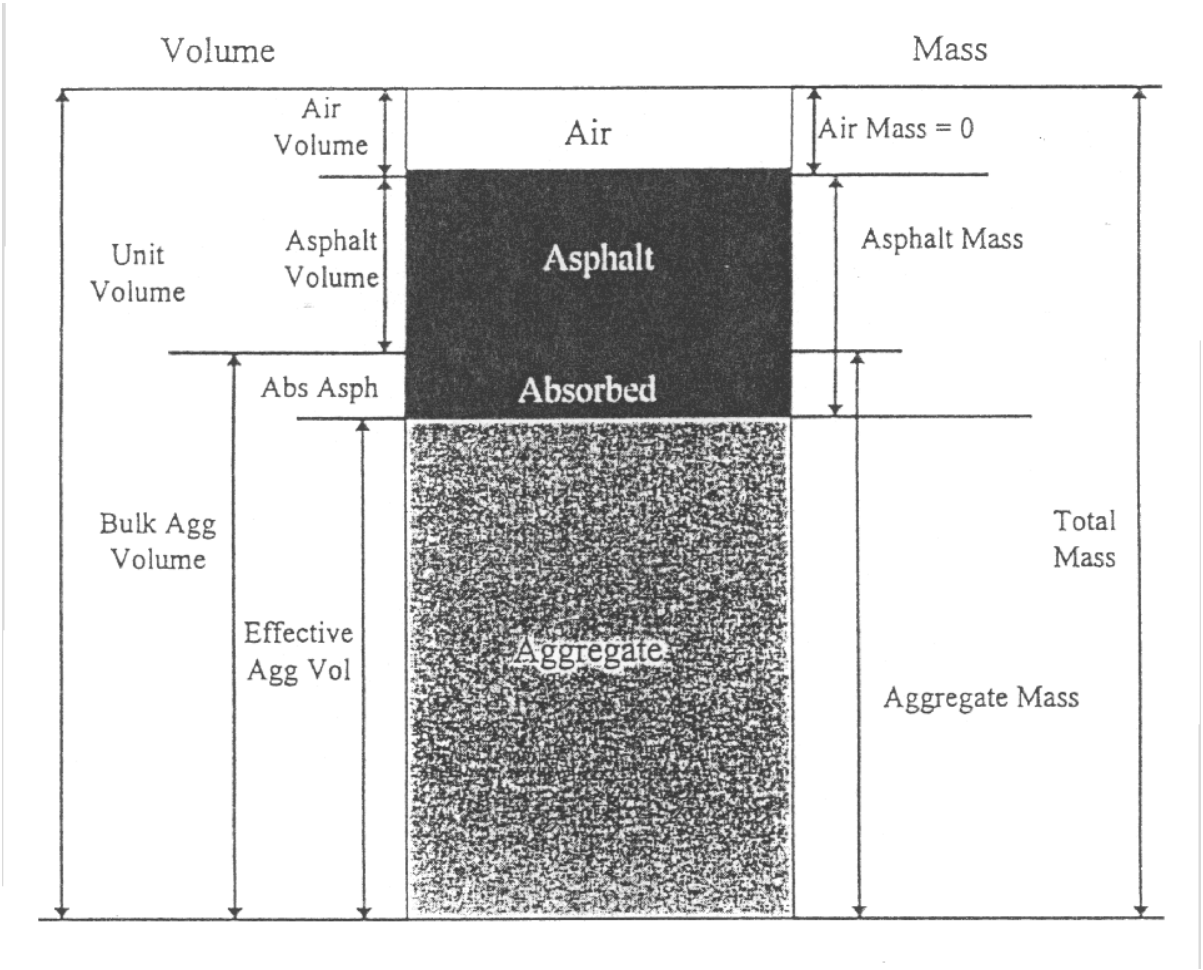


Figure 10. Component diagram of compacted HMA.

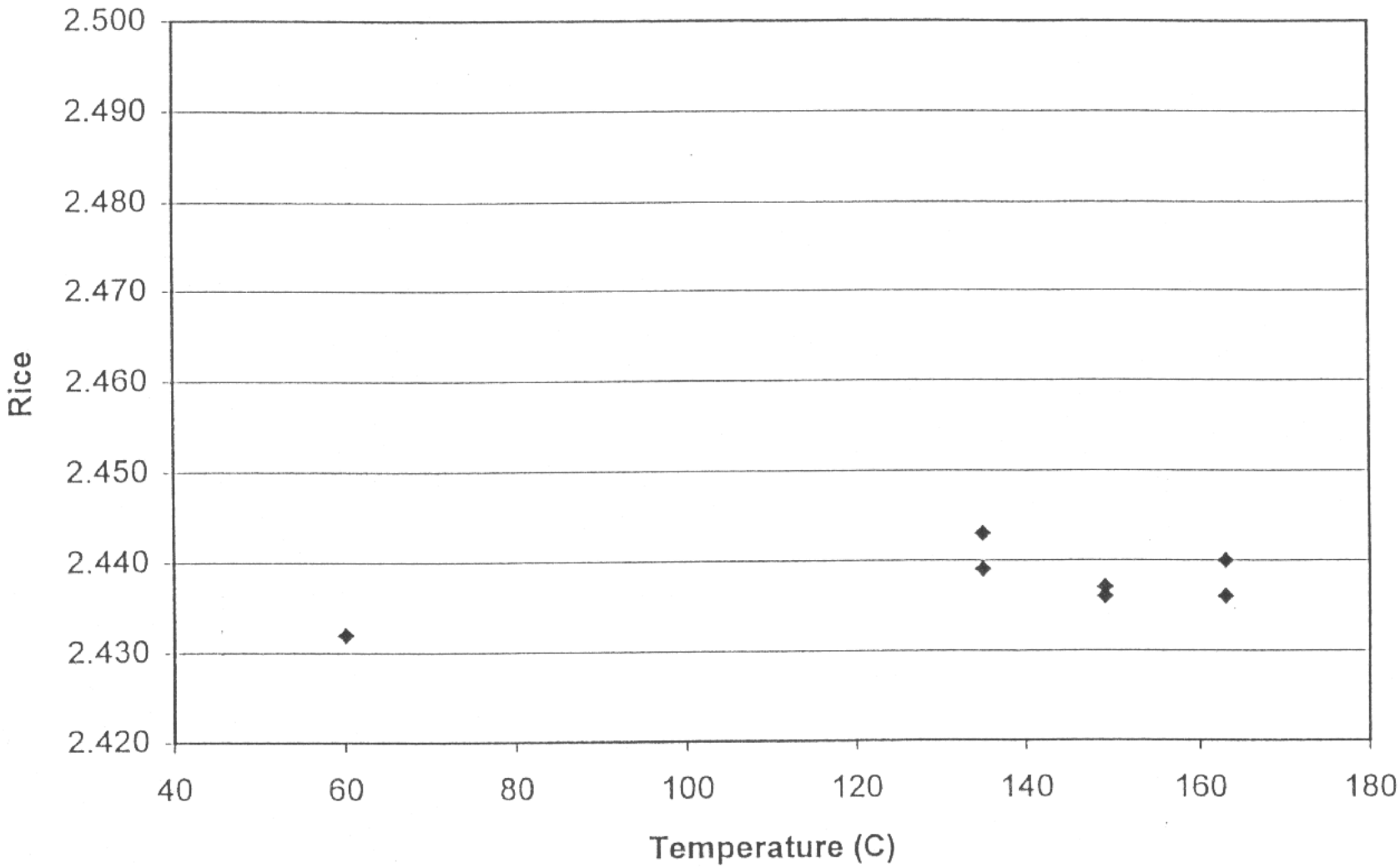


Figure 11. Measured Rices under different aging conditions.

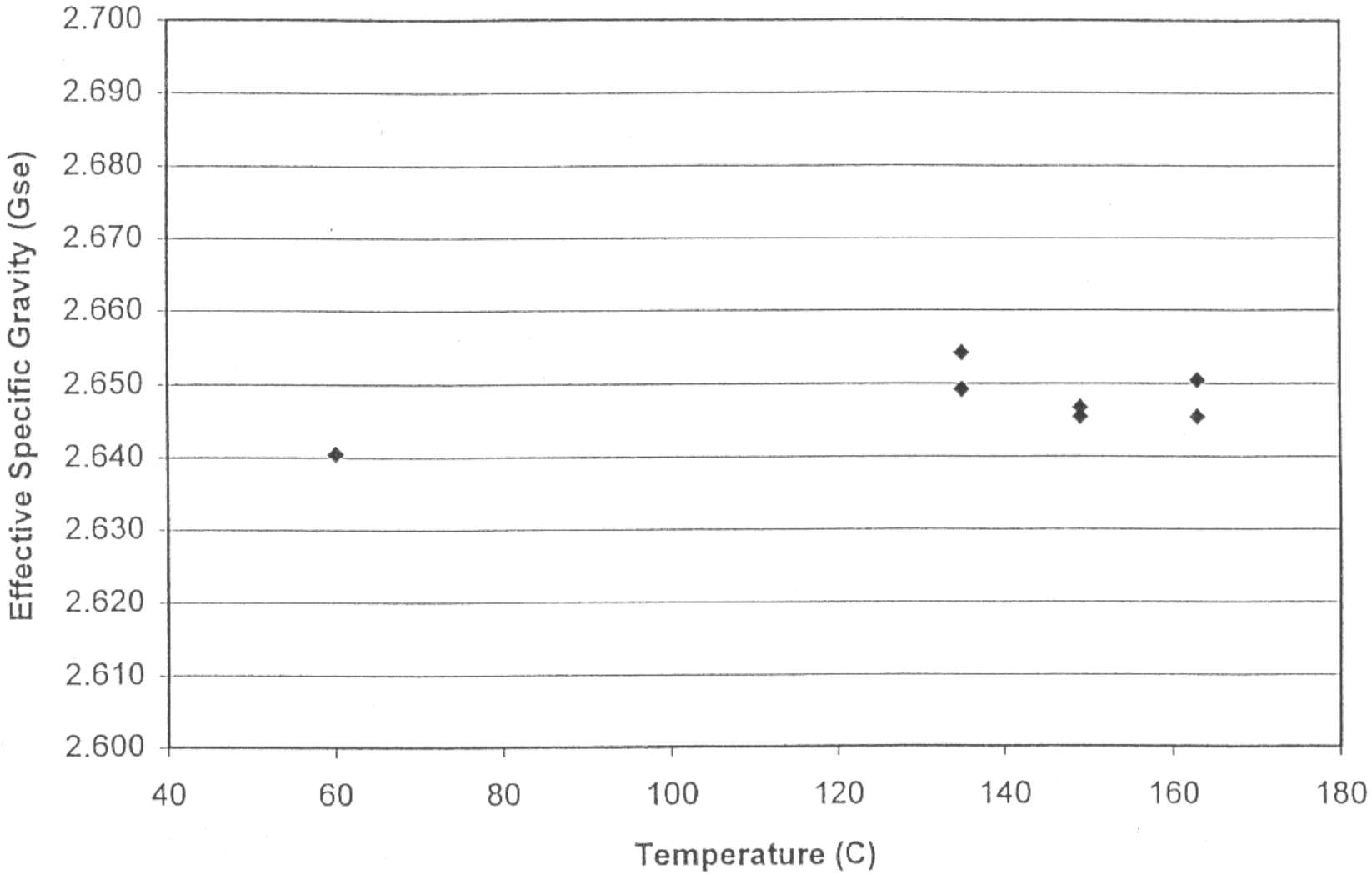


Figure 12. Effective specific gravities under different aging conditions.

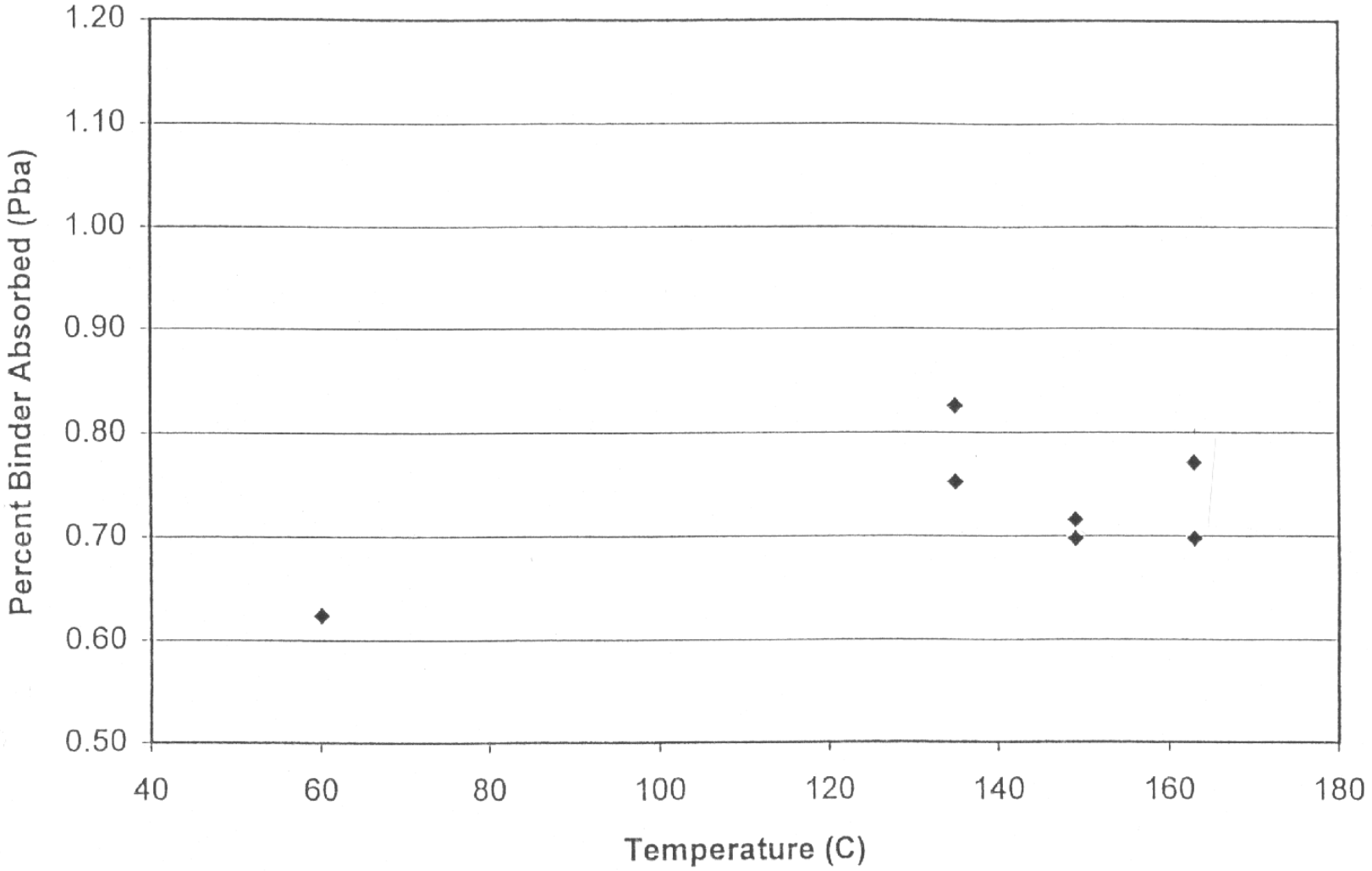


Figure 13. Percent binder absorbed under different aging conditions.

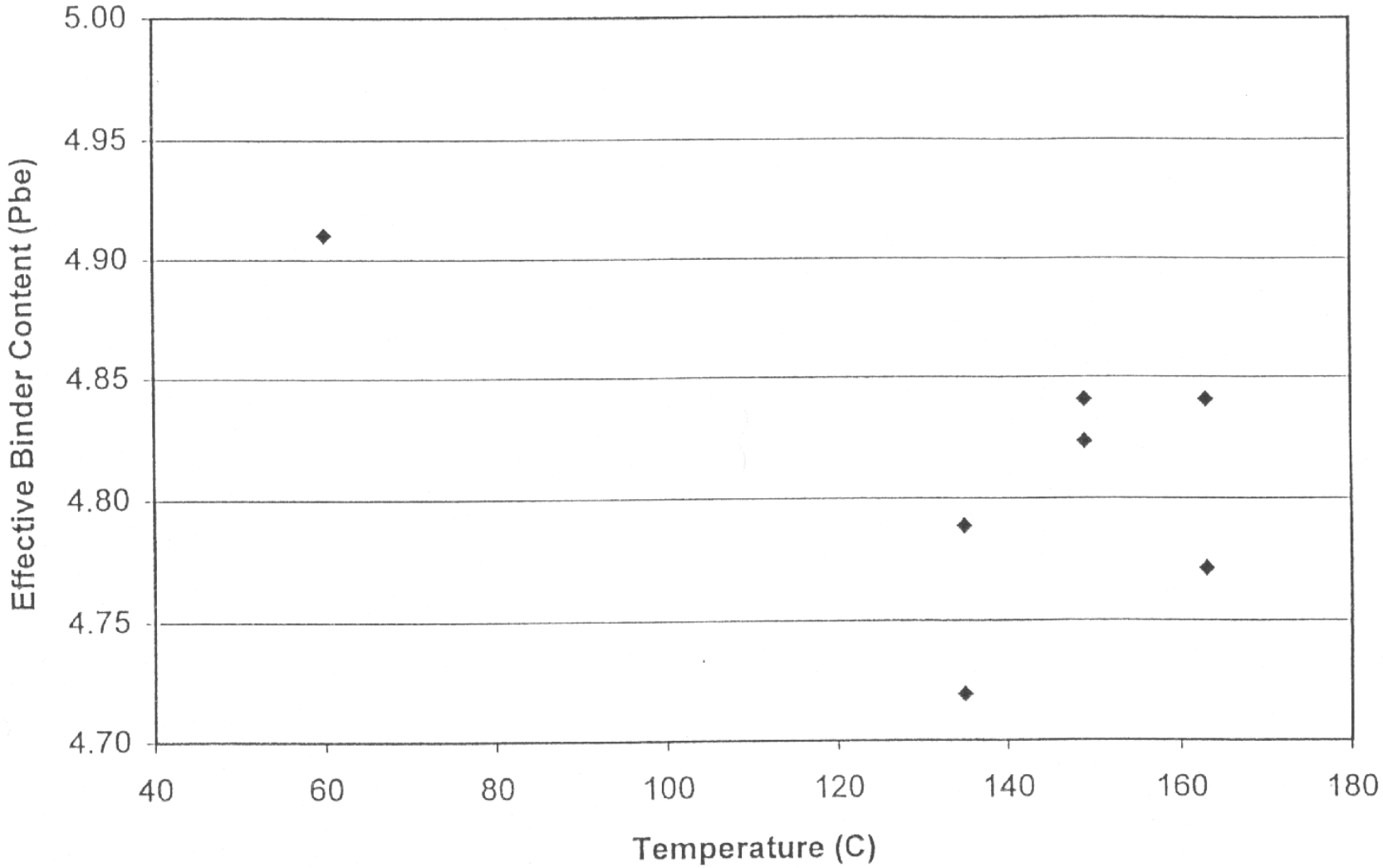


Figure 14. Effective binder contents under different aging conditions.

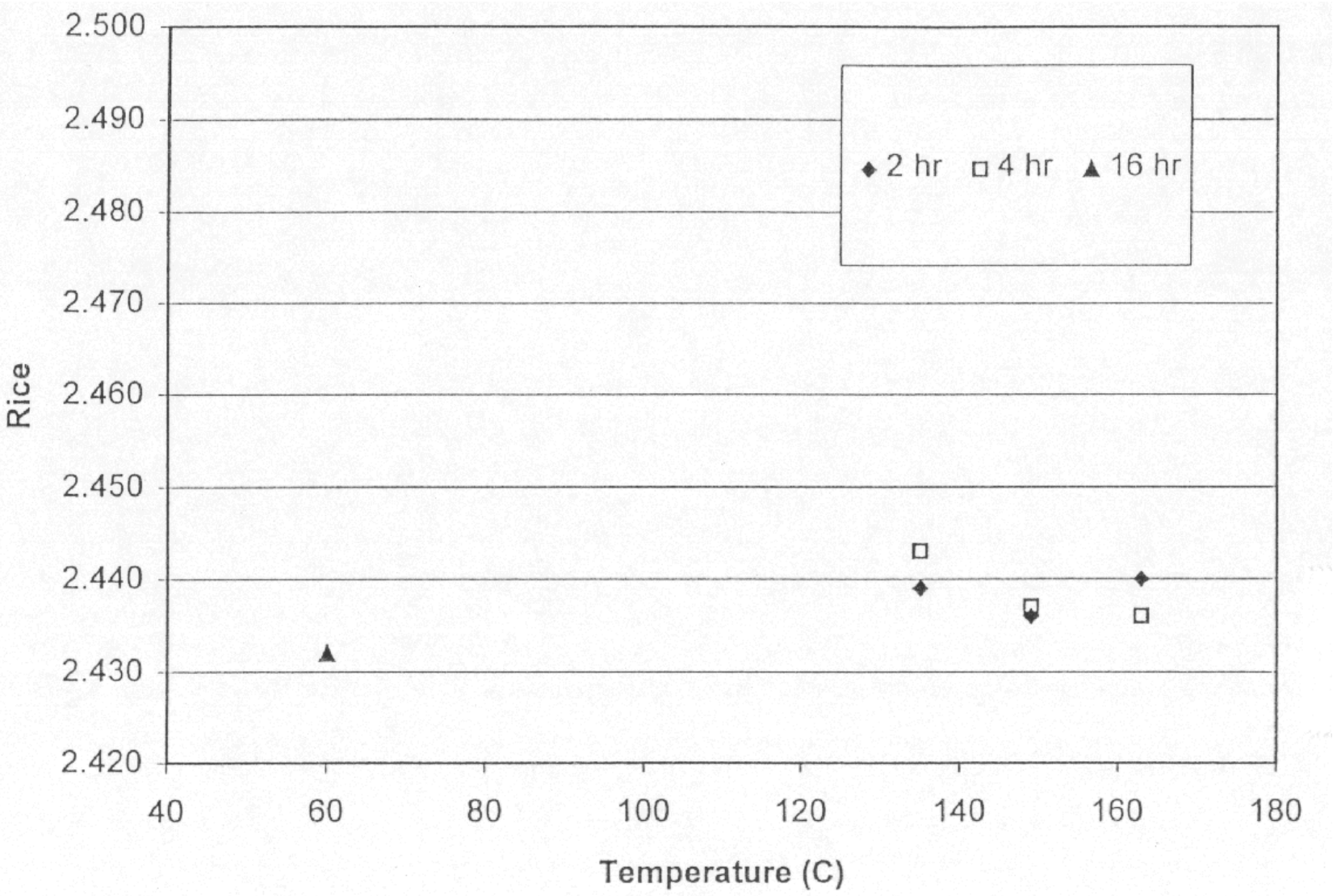


Figure 15. Effect of aging time and temperature on measured Rice.

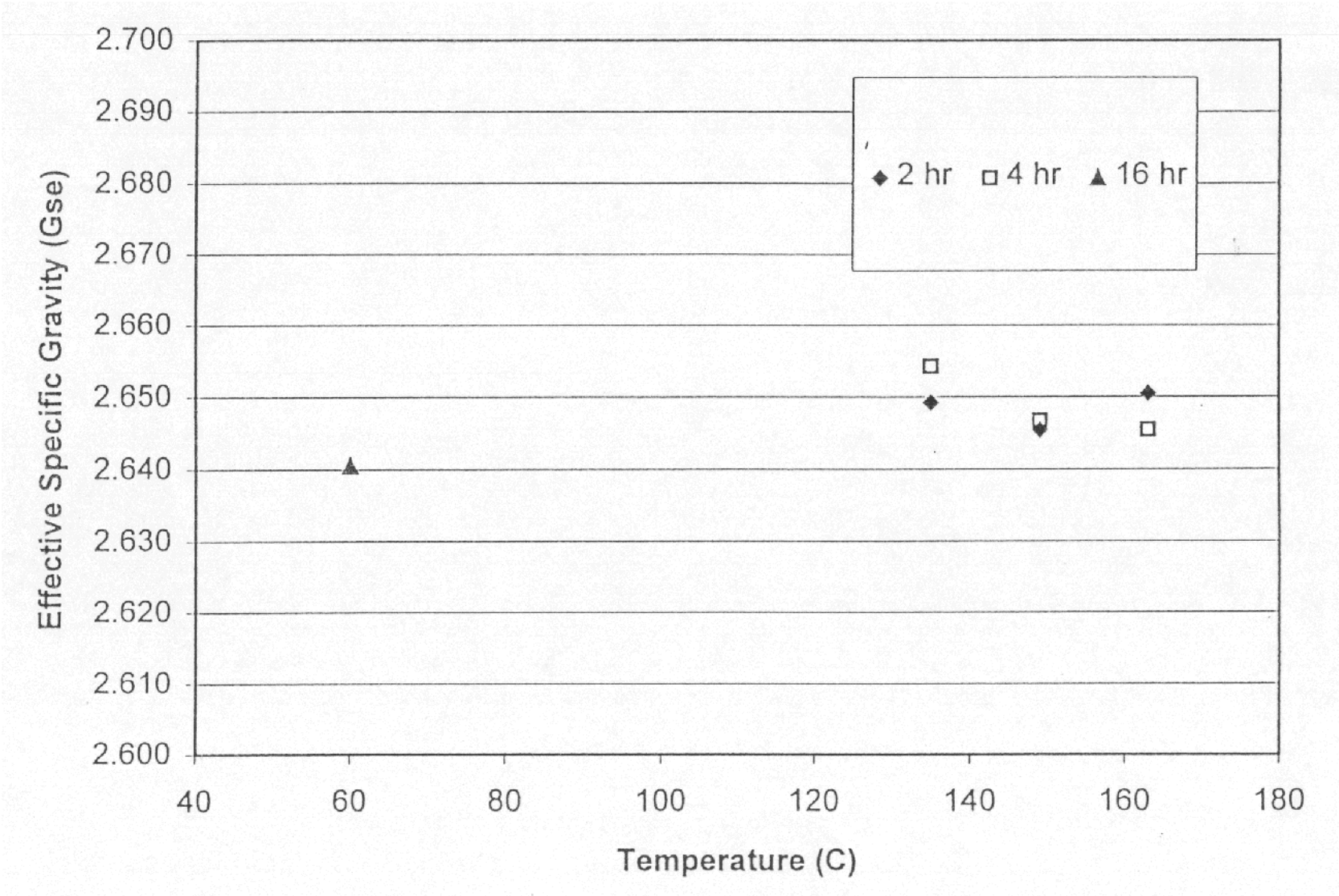


Figure 16. Effect of aging time and temperature on effective specific gravities.

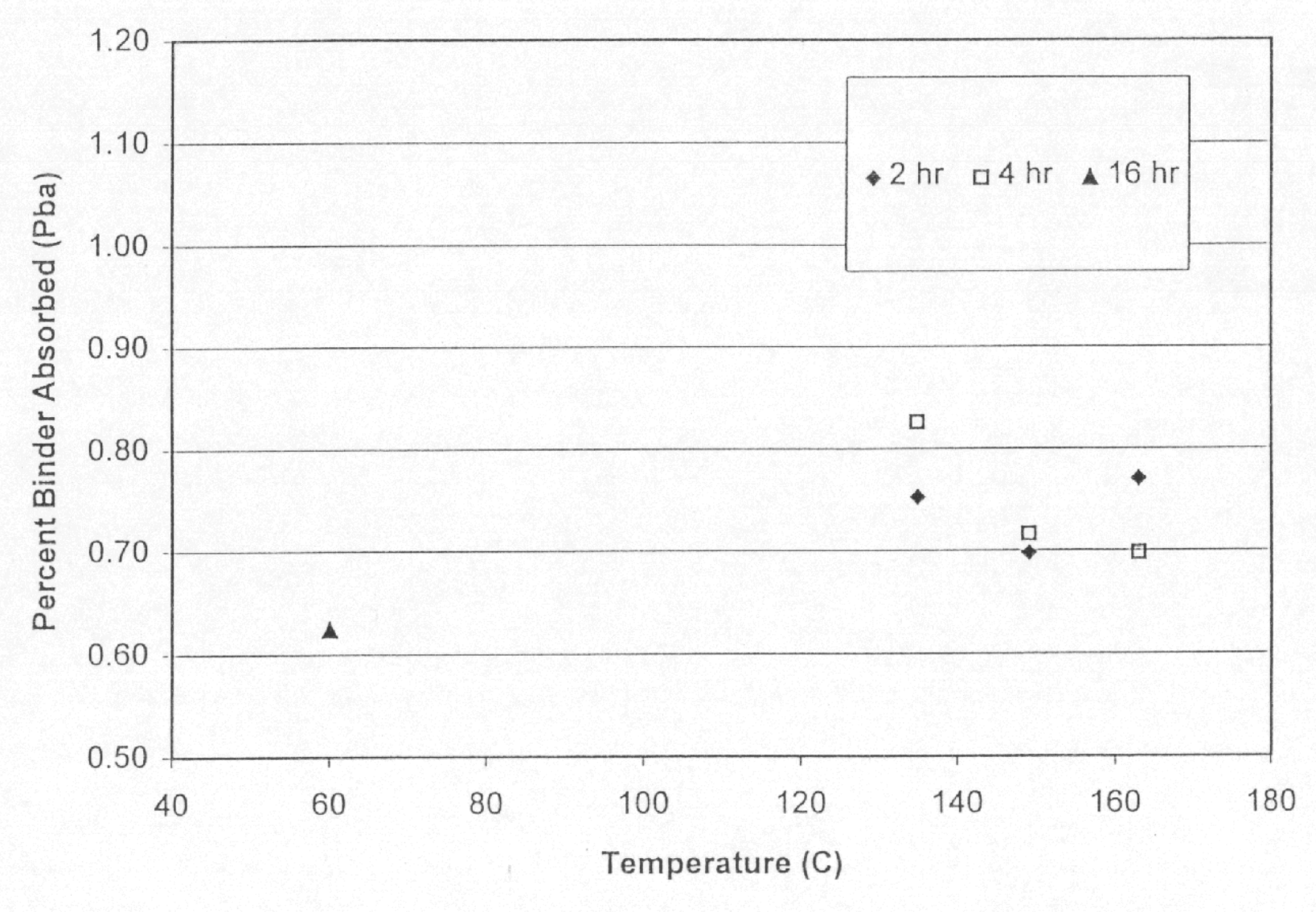


Figure 17. Effect of aging time and temperature on binder absorption.

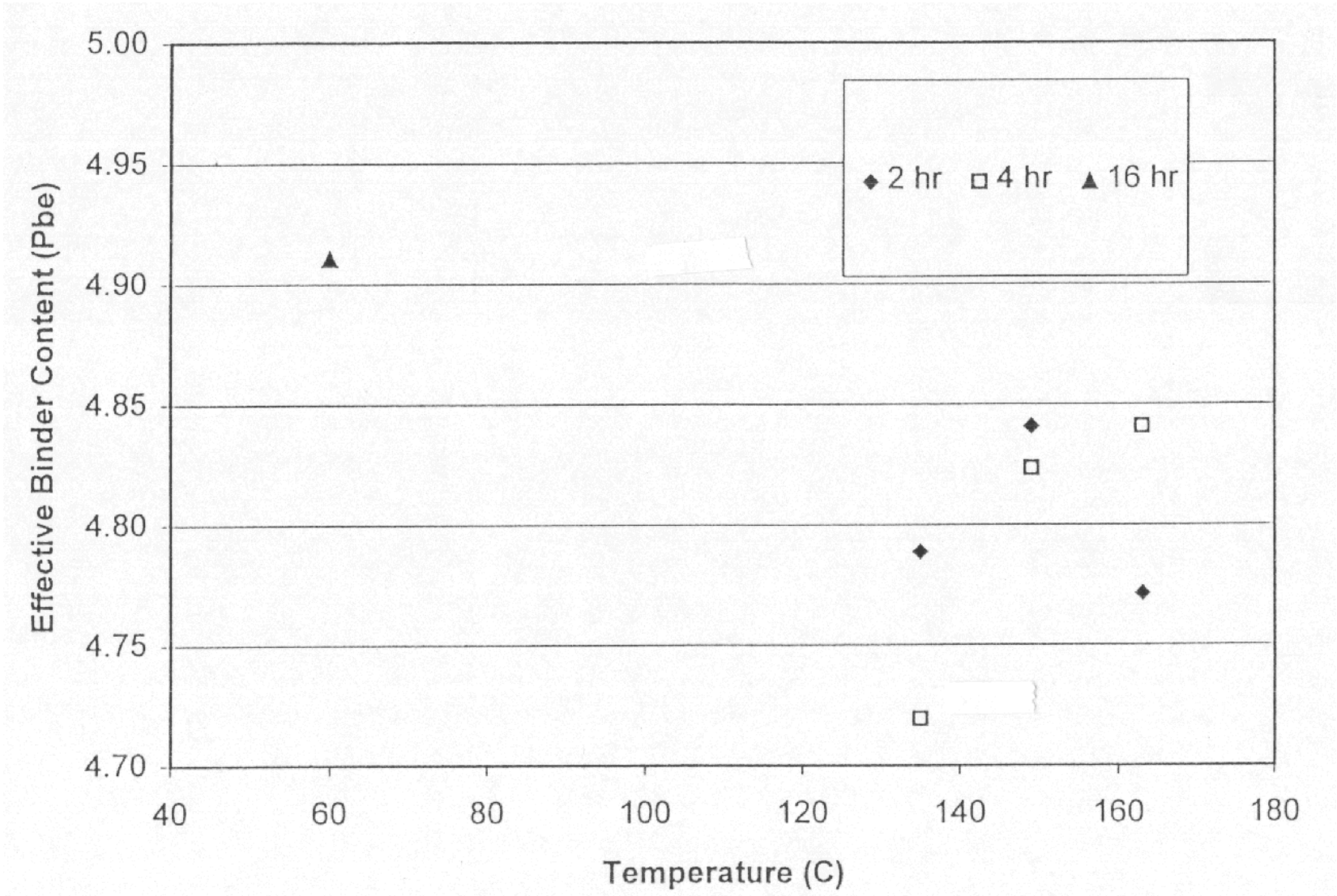


Figure 18. Effect of aging time and temperature on effective binder content.

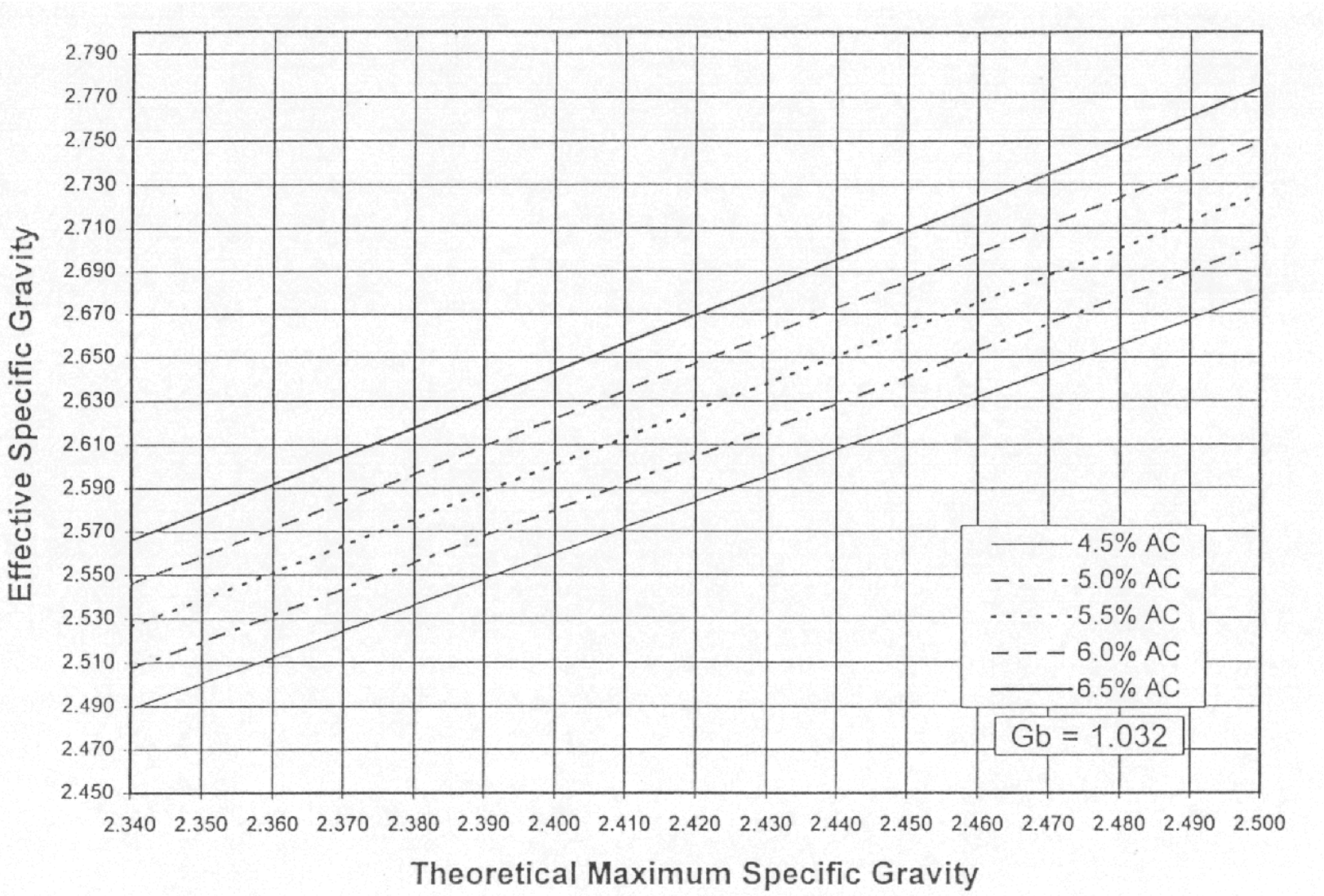


Figure 19. Theoretical maximum specific gravity and effective specific gravity relationship.

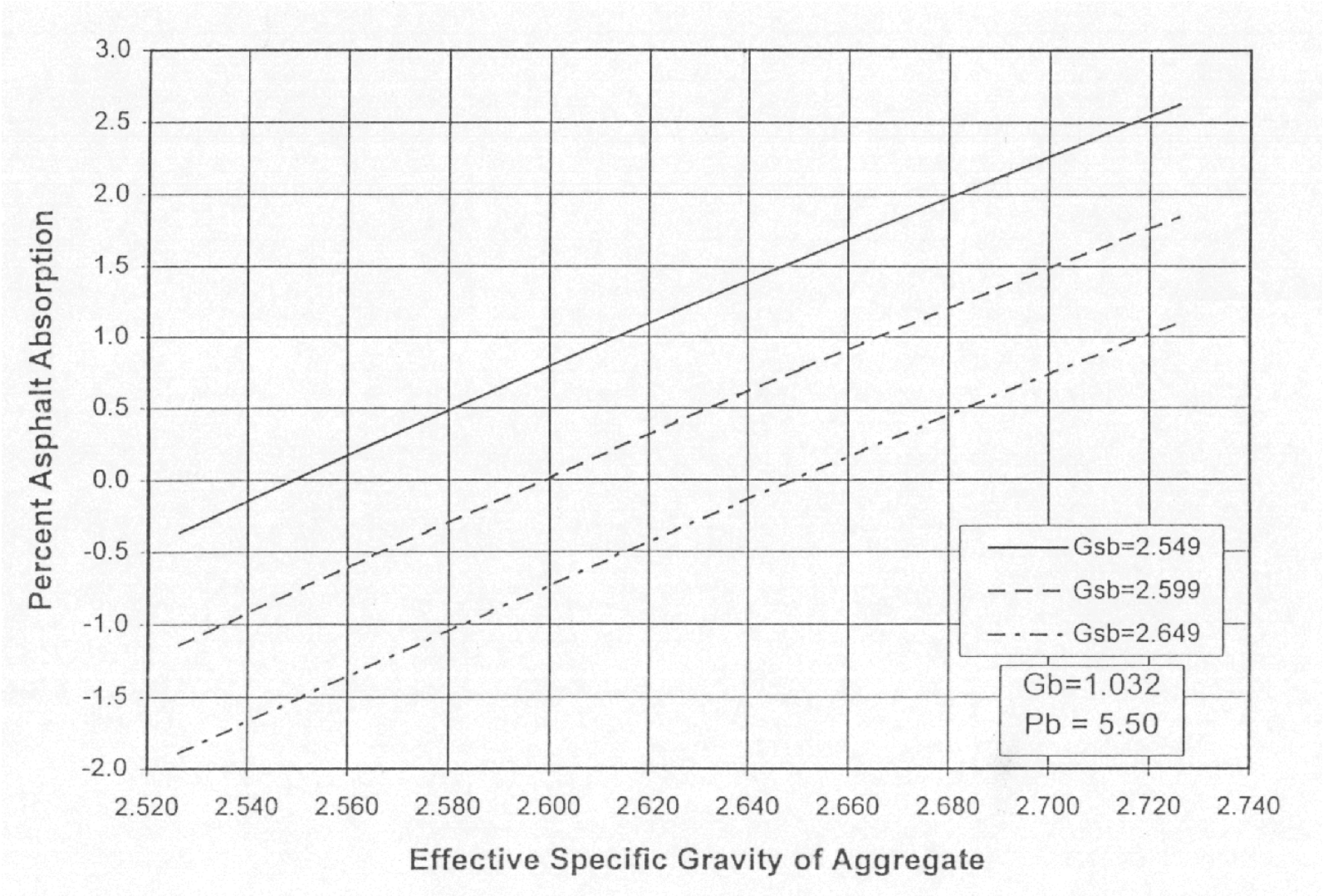


Figure 20. Relationship between aggregate effective specific gravity and asphalt absorption.

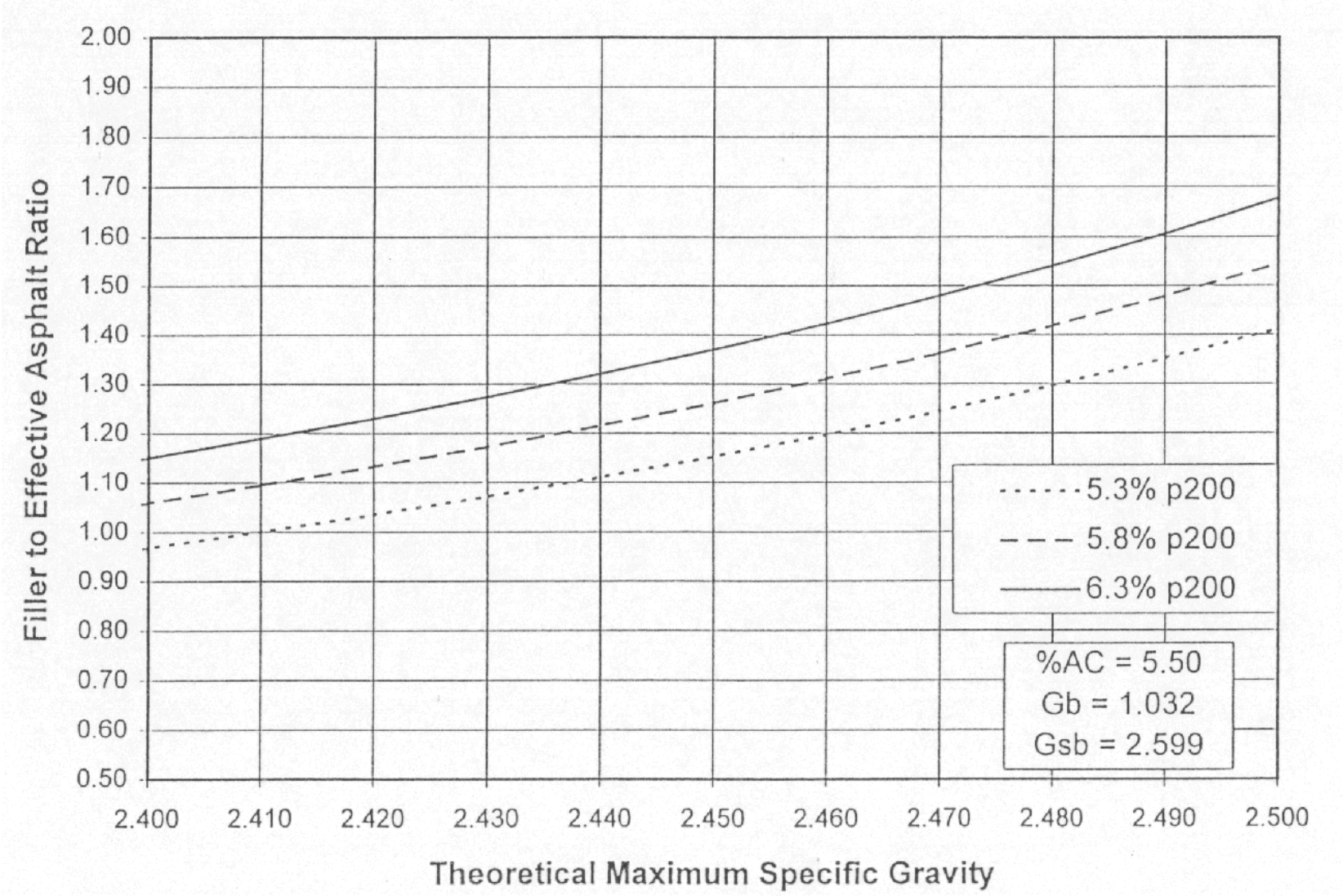


Figure 21. Relationship between theoretical maximum specific gravity and dust proportion.

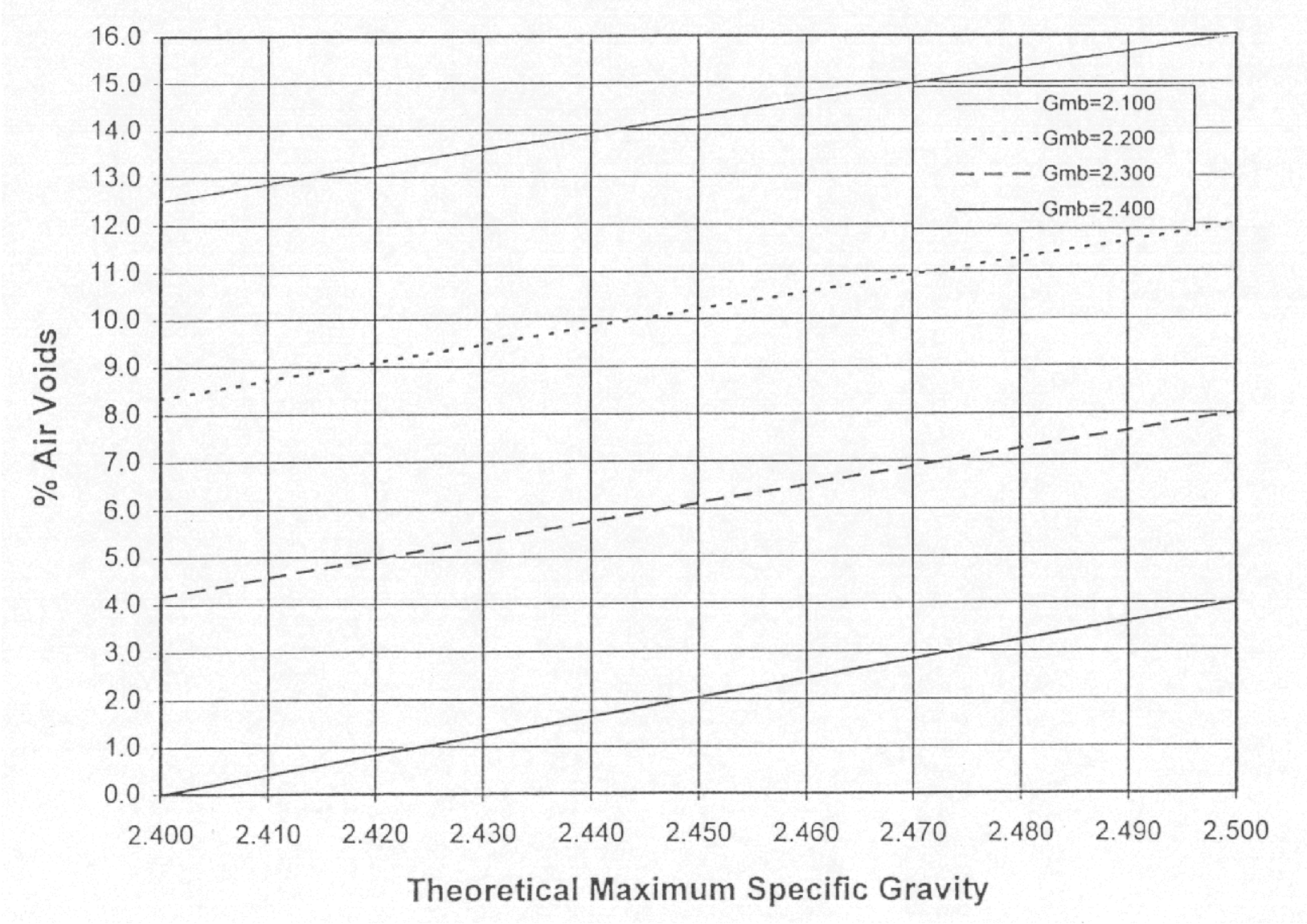


Figure 22. Relationship between theoretical maximum specific gravity and air voids.

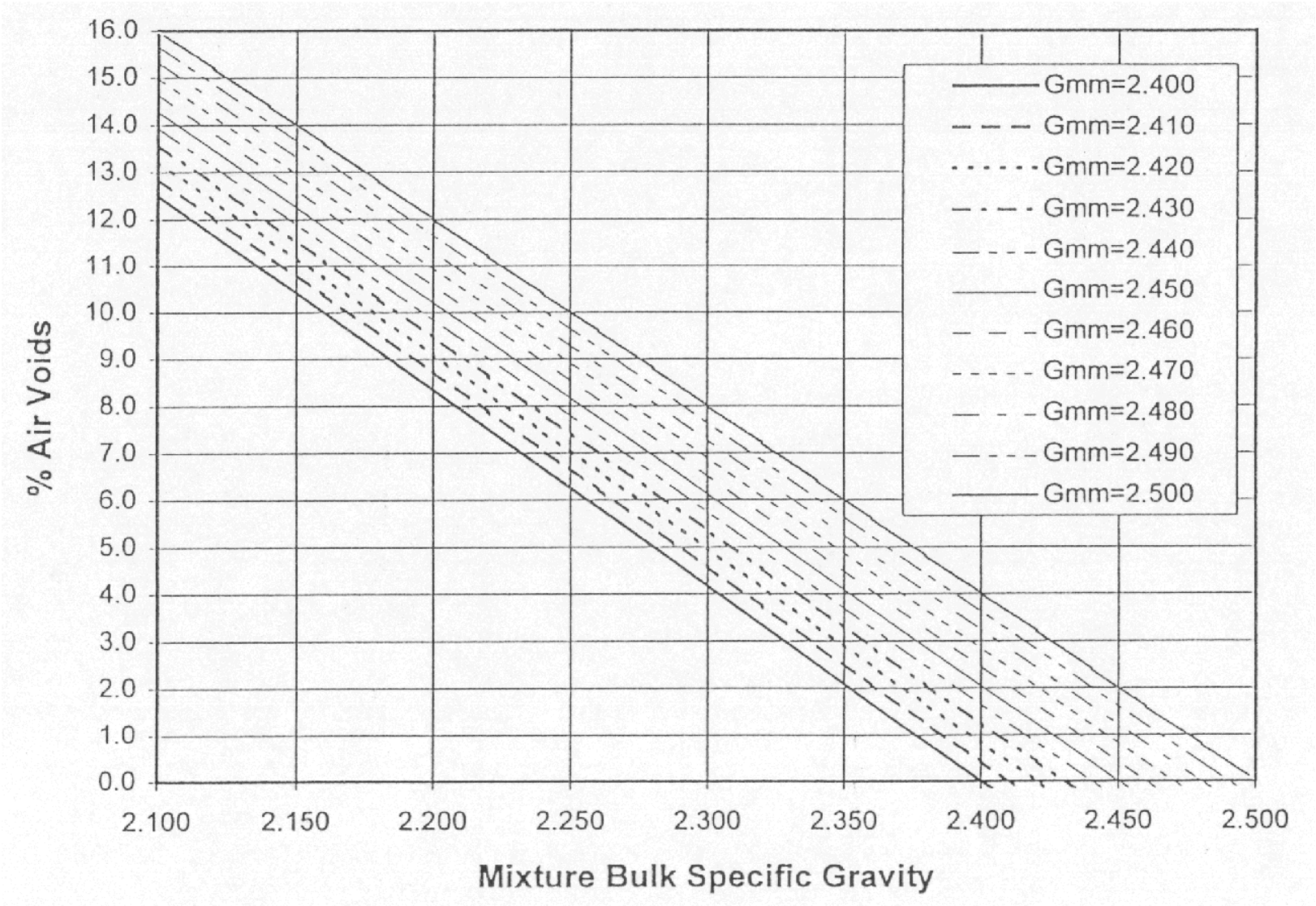


Figure 23. Relationship between mixture bulk specific gravity and air voids.

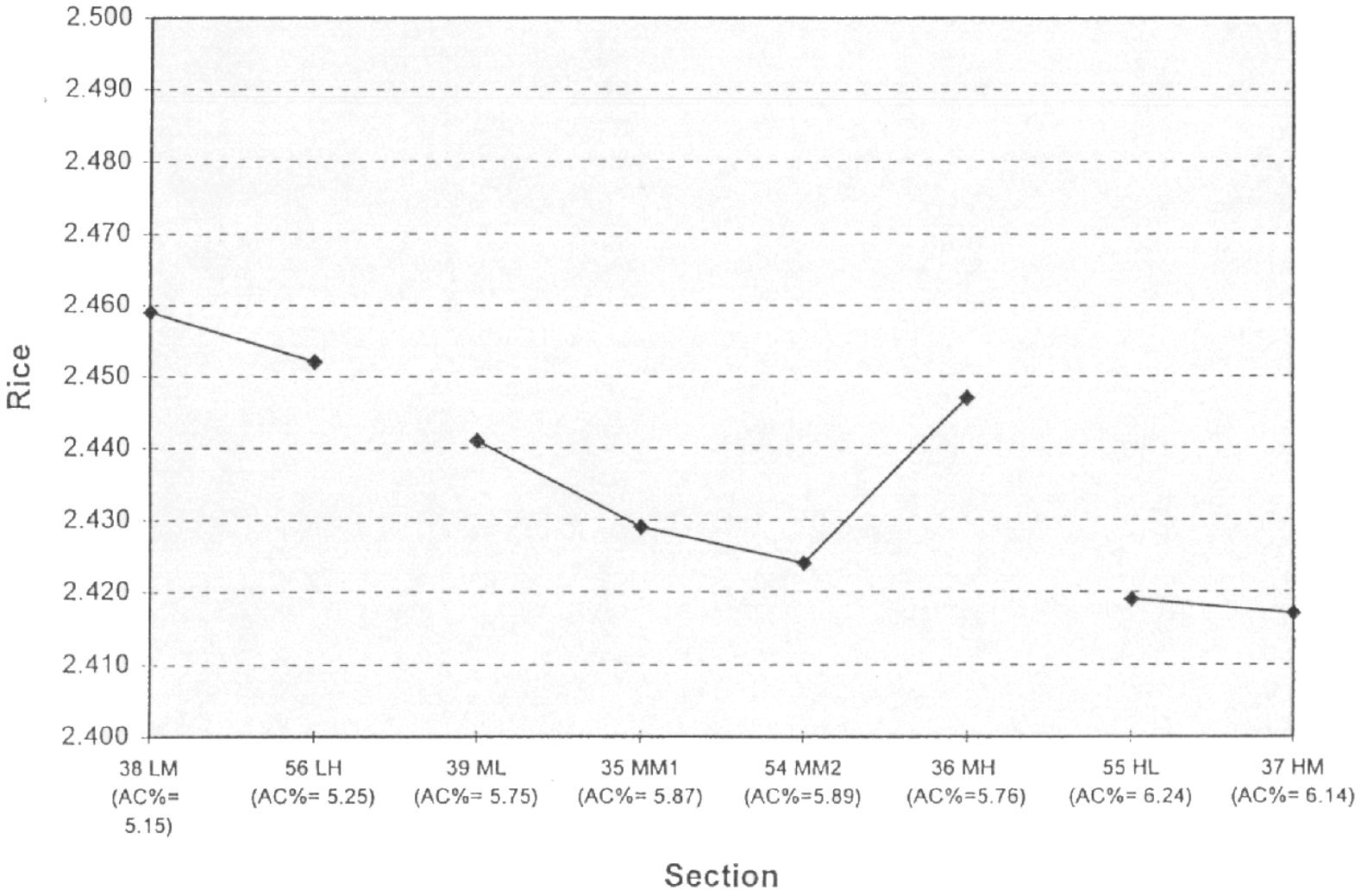


Figure 24. Measured top lift theoretical maximum specific gravities (process control).

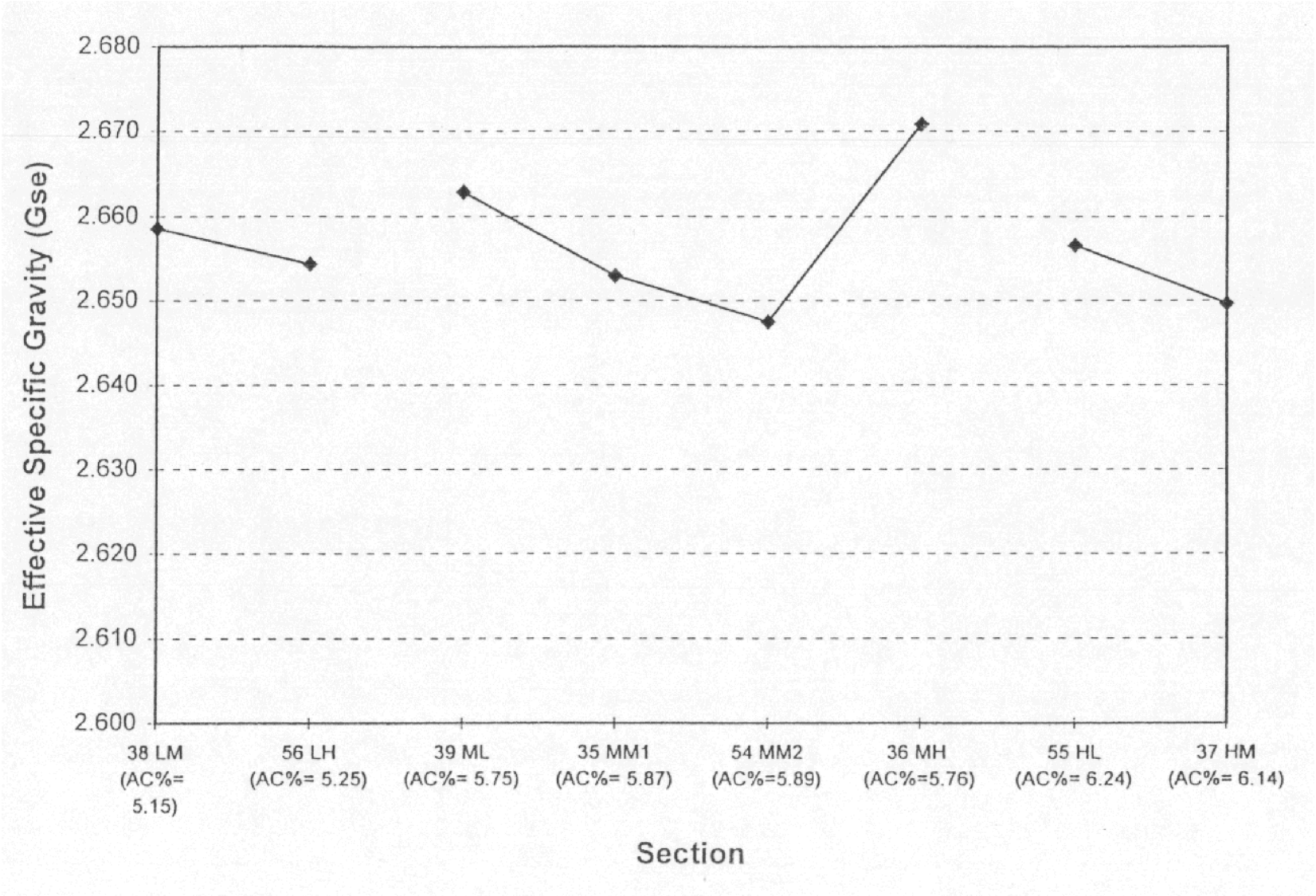
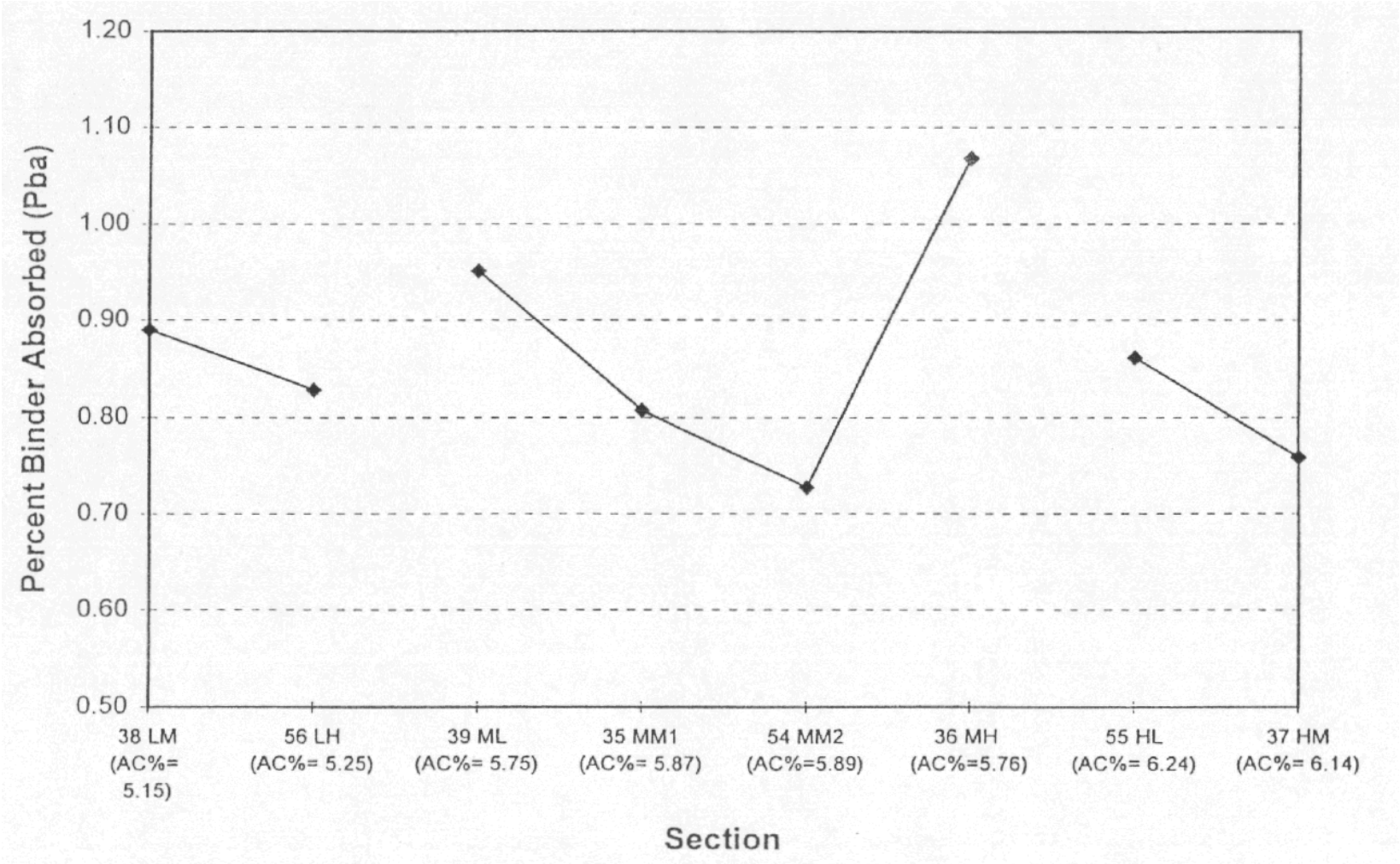


Figure 25. Top lift aggregate effective specific gravities (process control).



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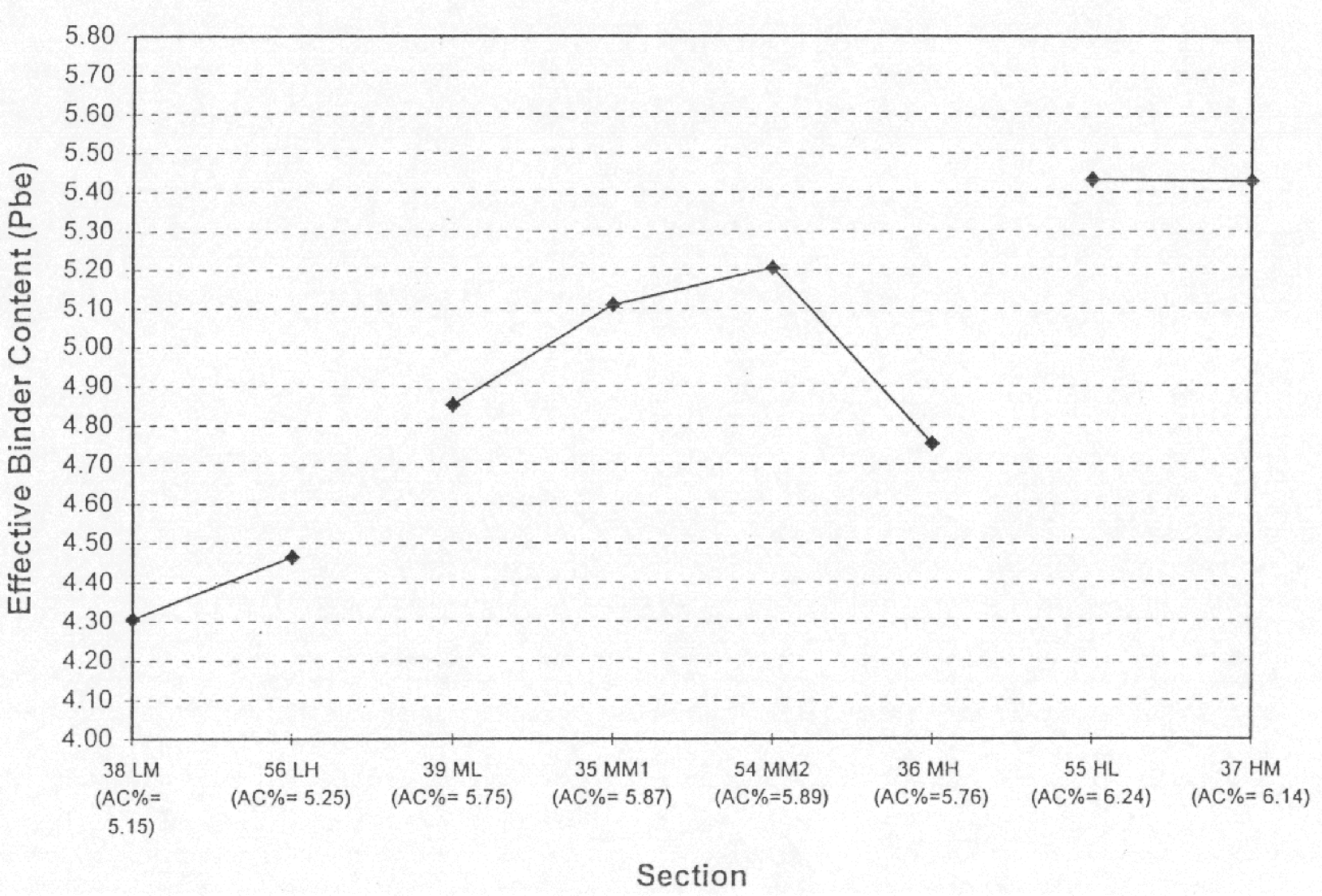

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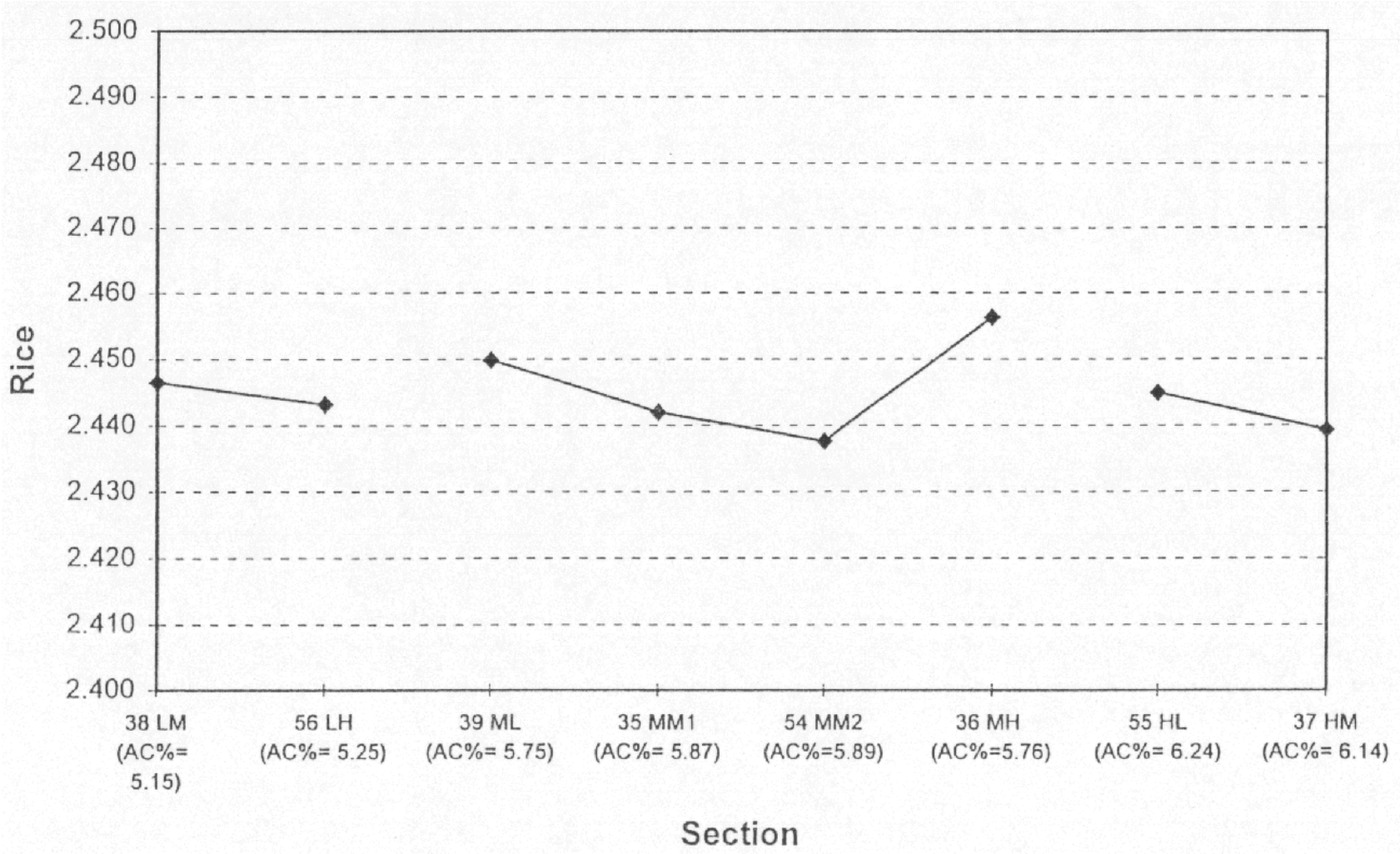


Figure 28. Top lift theoretical maximum specific gravities calculated at 5.5% asphalt (process control).

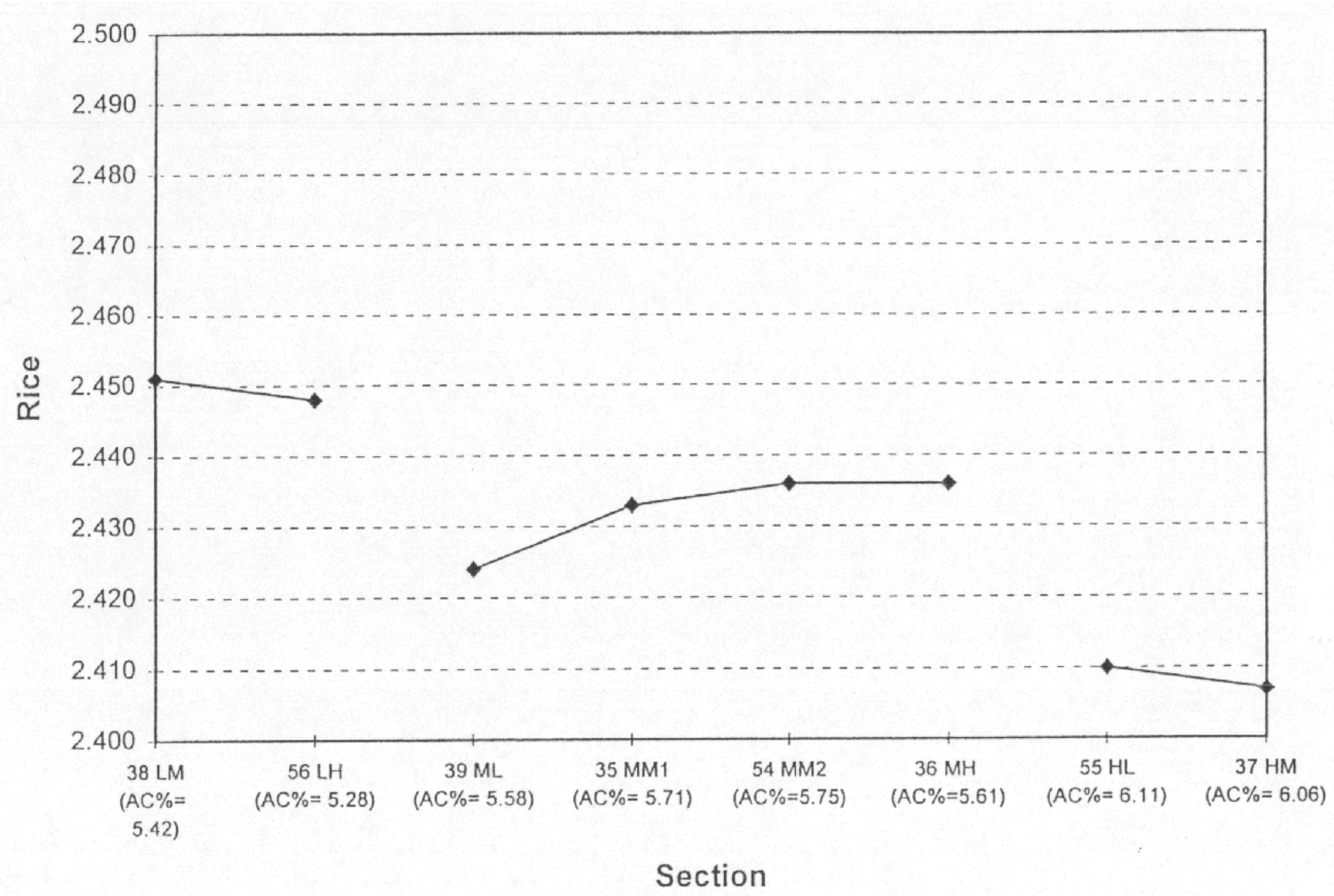
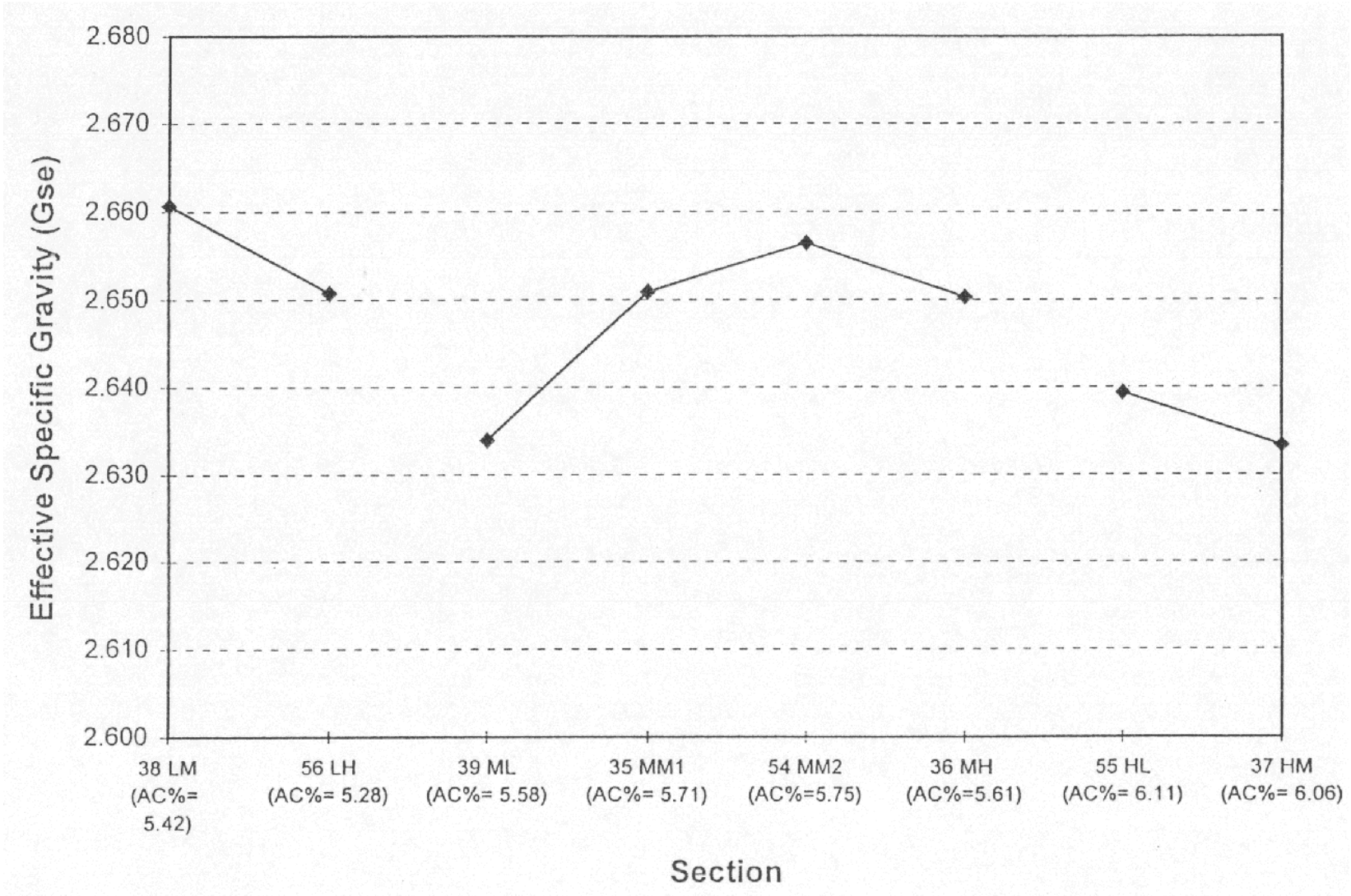


Figure 29. Measured bottom lift theoretical maximum specific gravities (process control).



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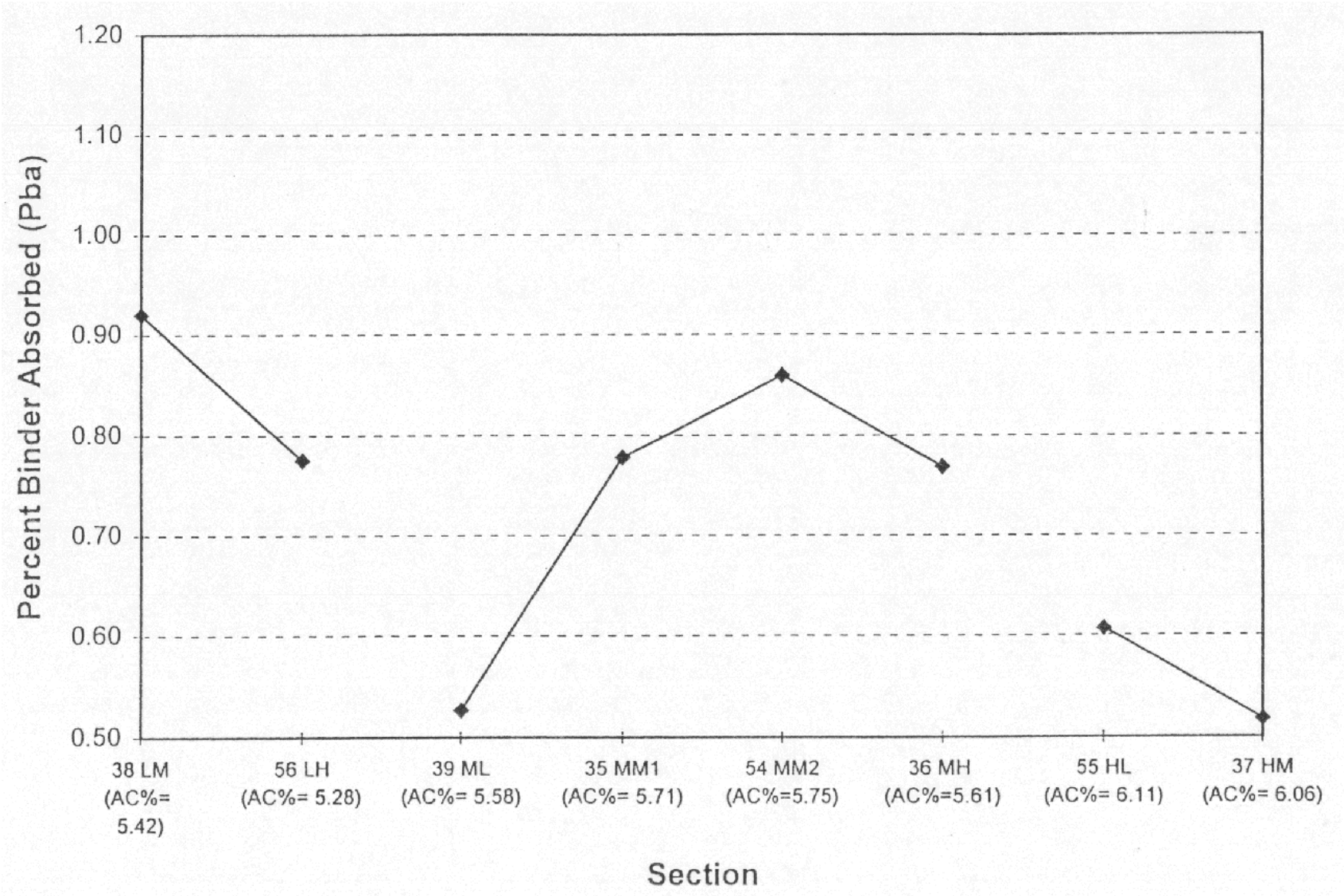


Figure 31. Bottom lift – percent binder absorbed (process control).

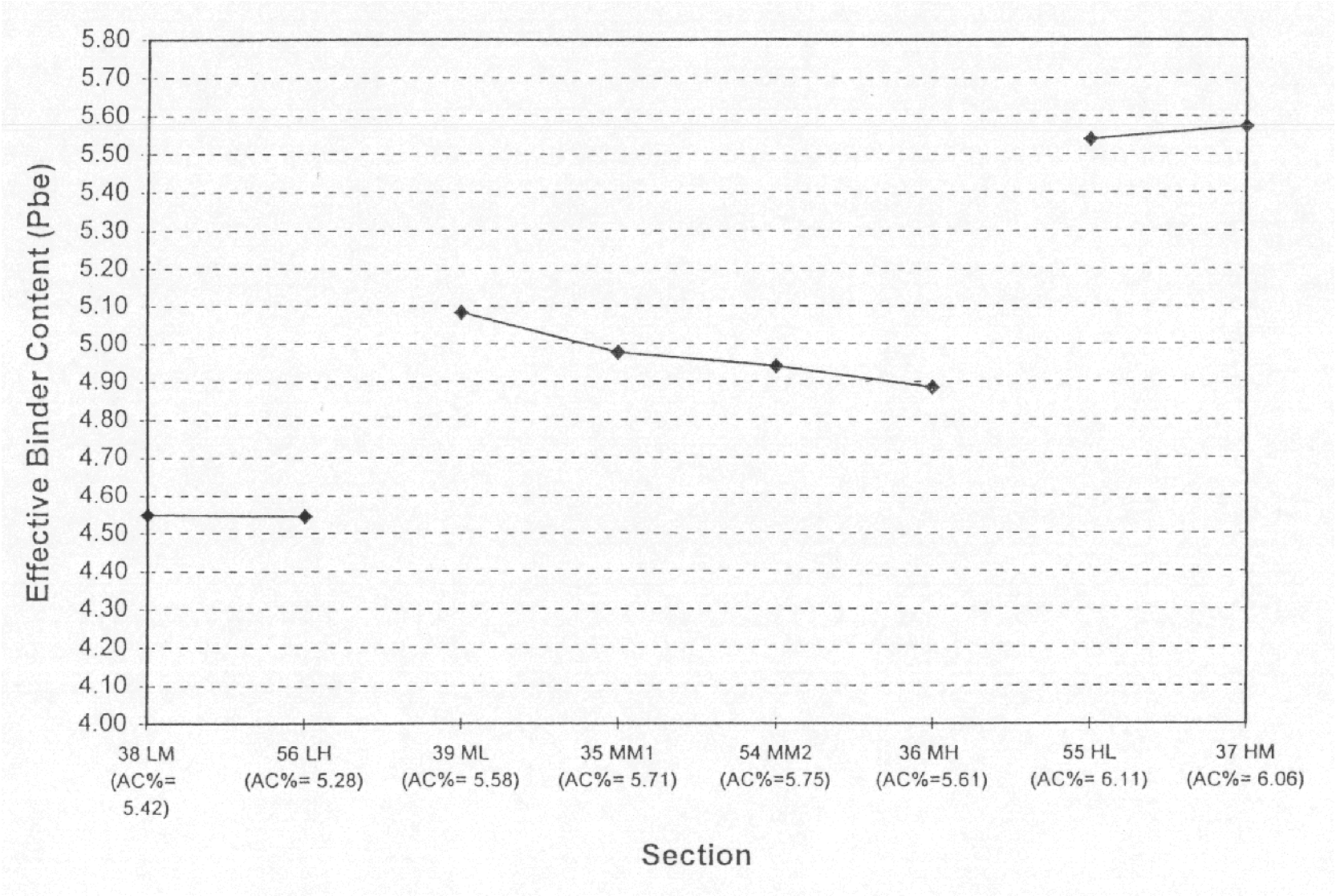


Figure 32. Bottom lift – effective binder contents (process control).

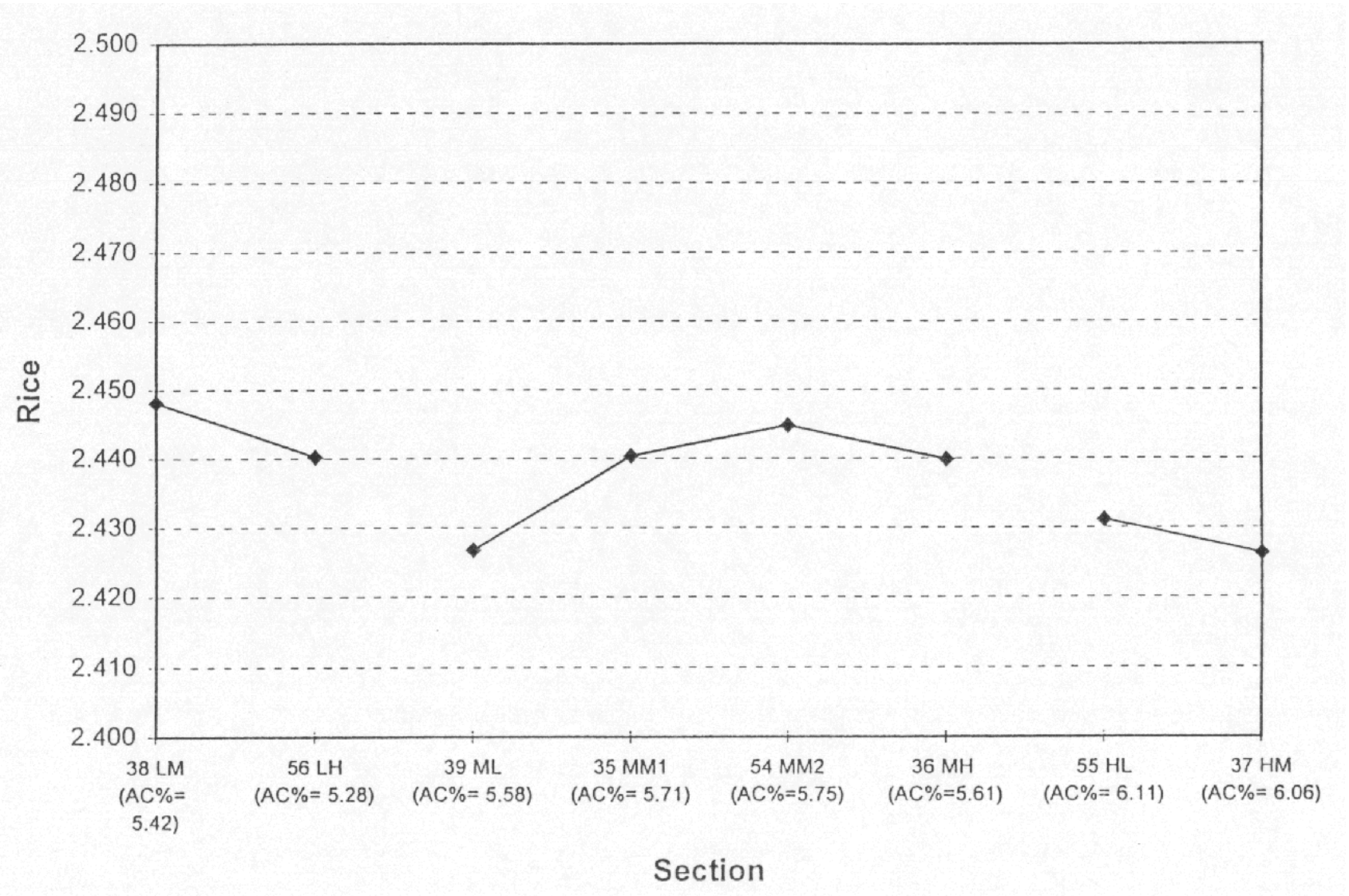
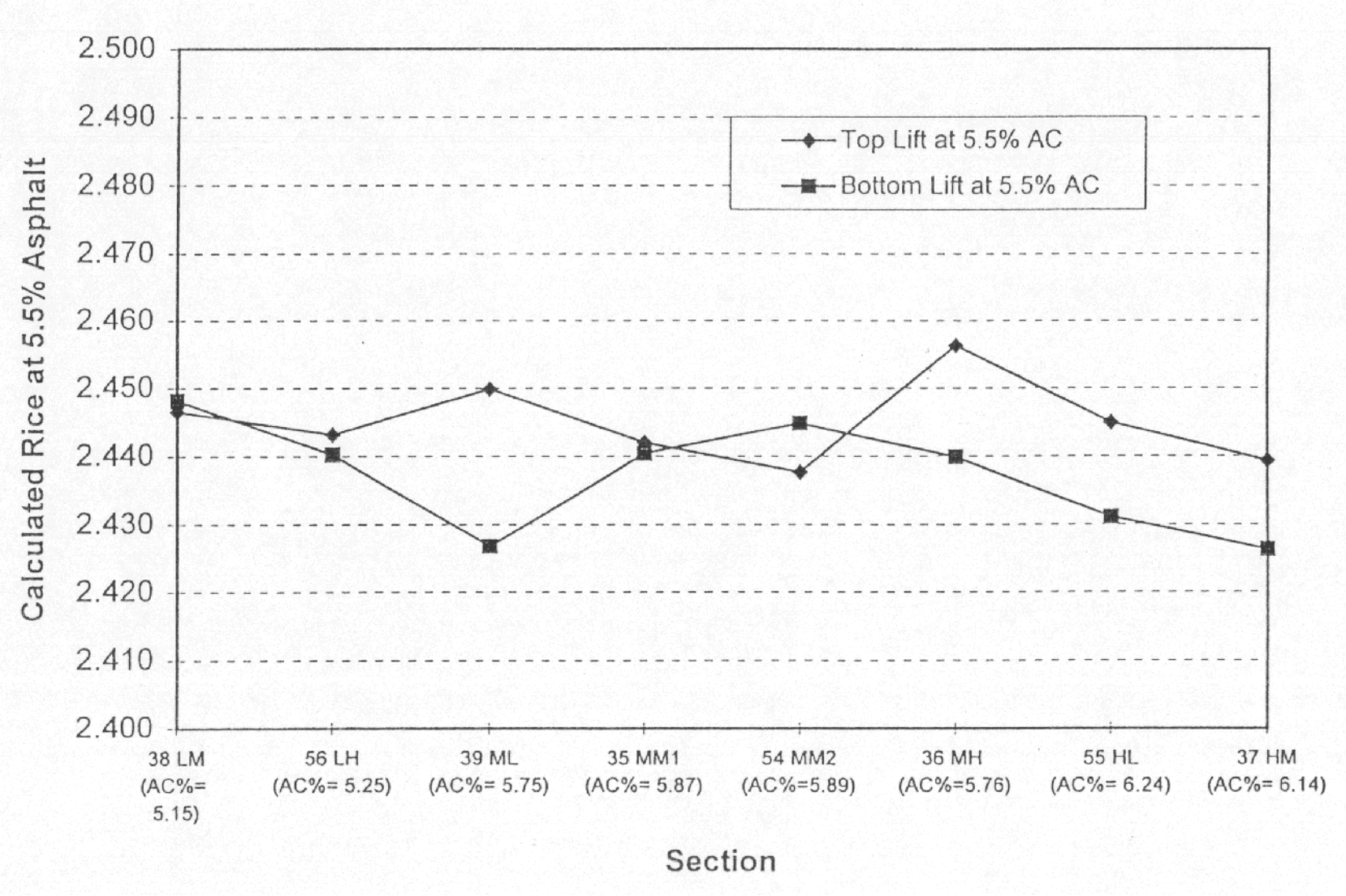


Figure 33. Bottom lift – theoretical maximum specific gravities calculated at 5.5% asphalt (process control).



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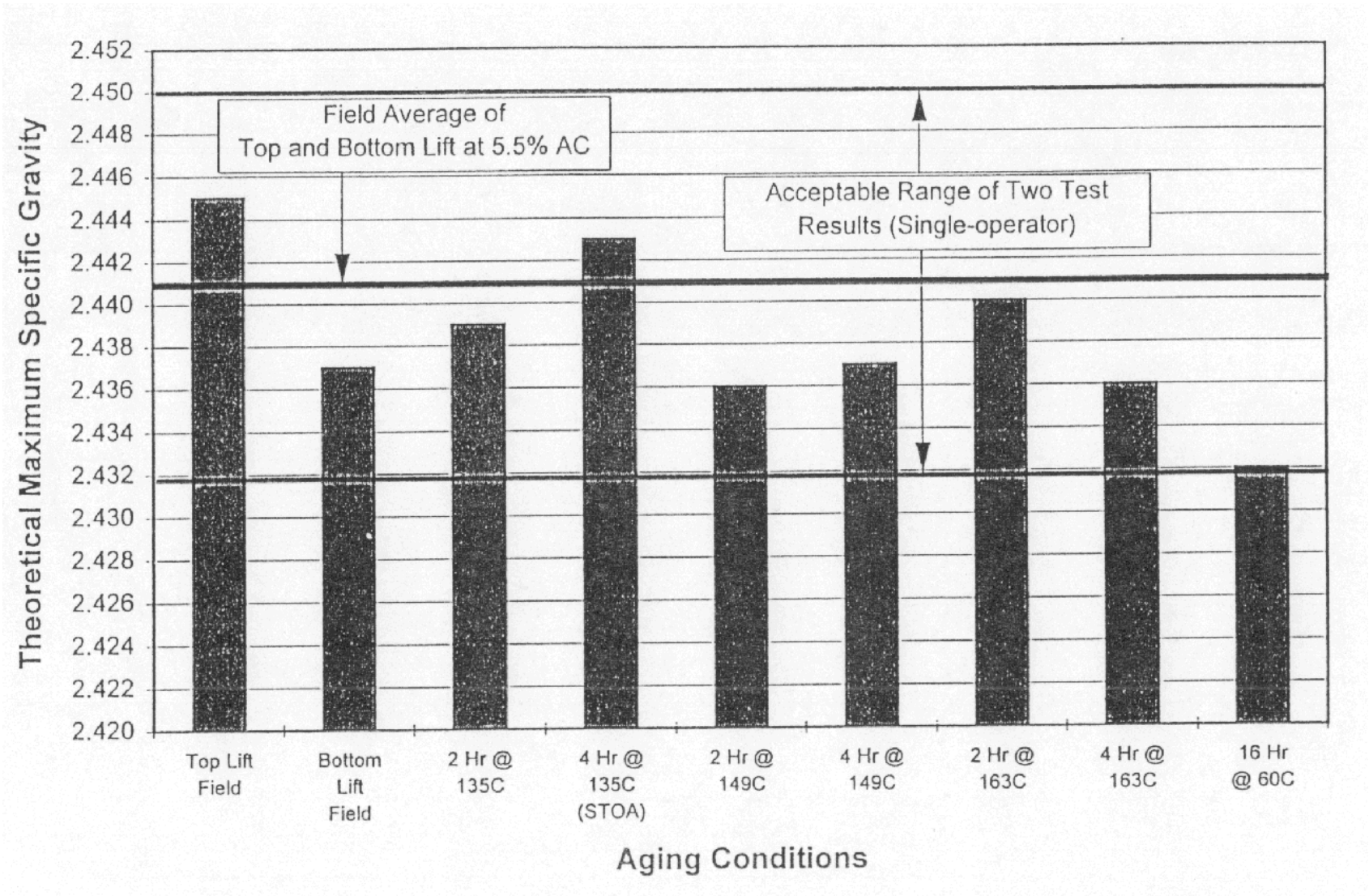

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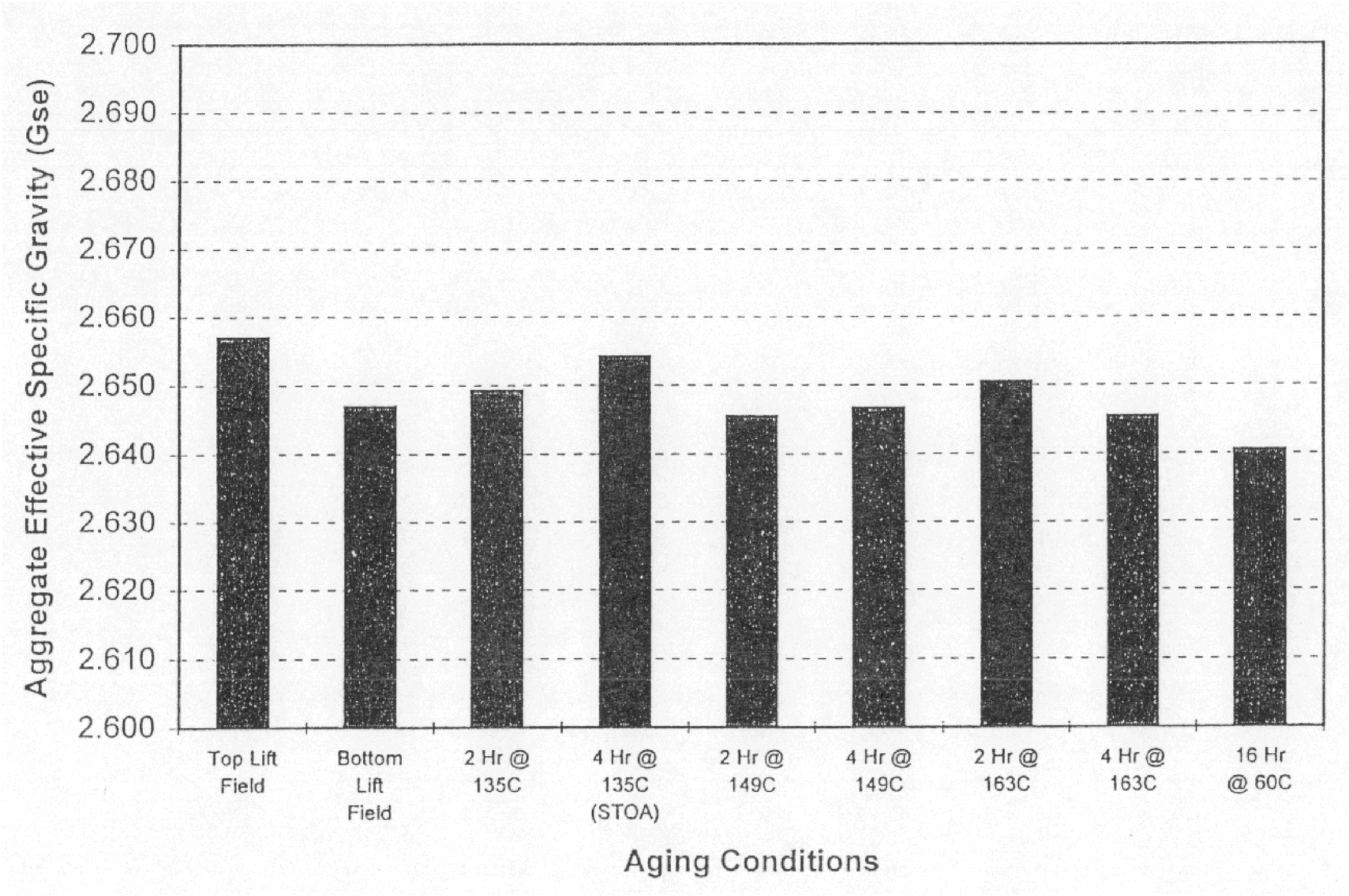

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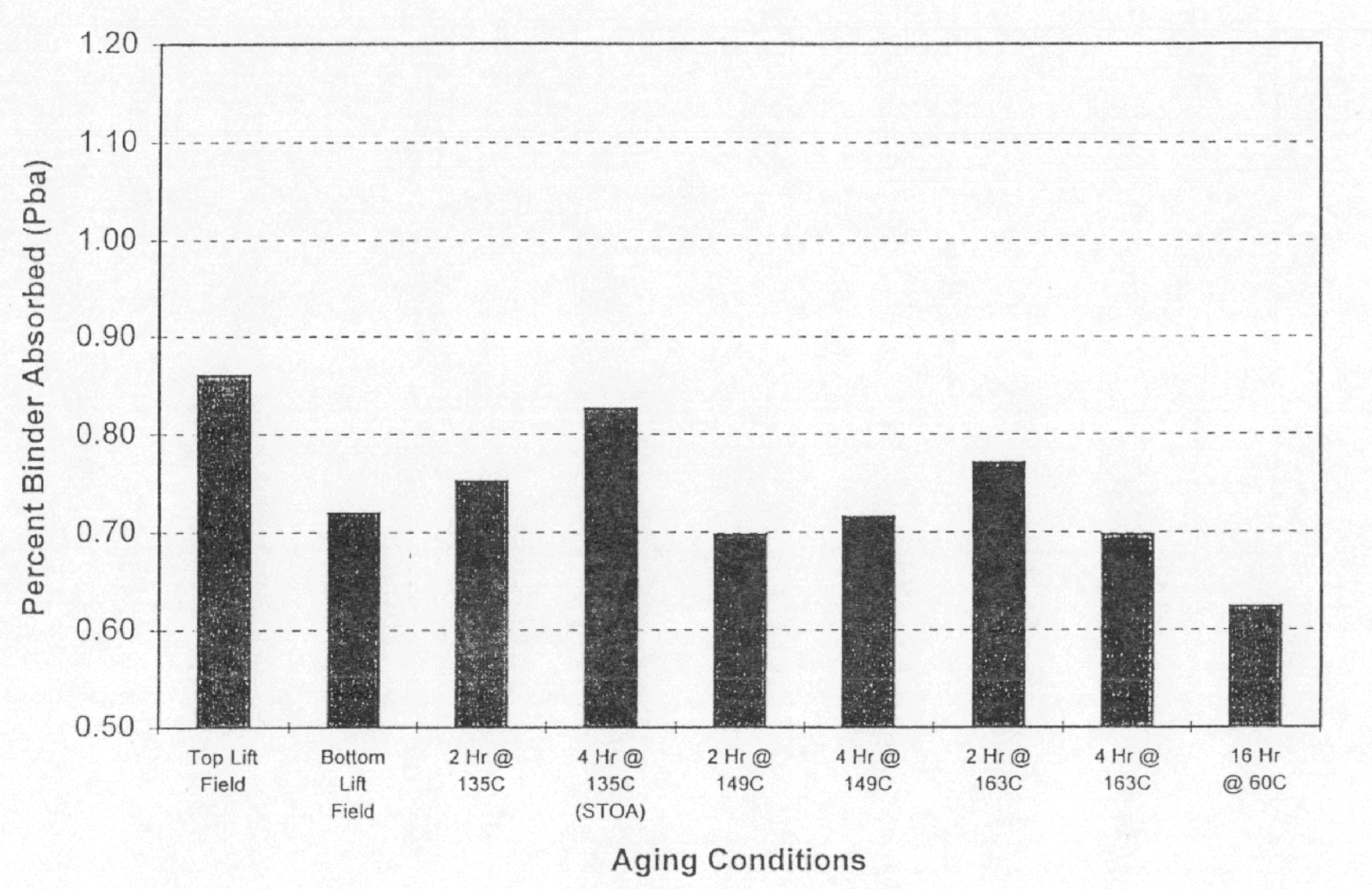

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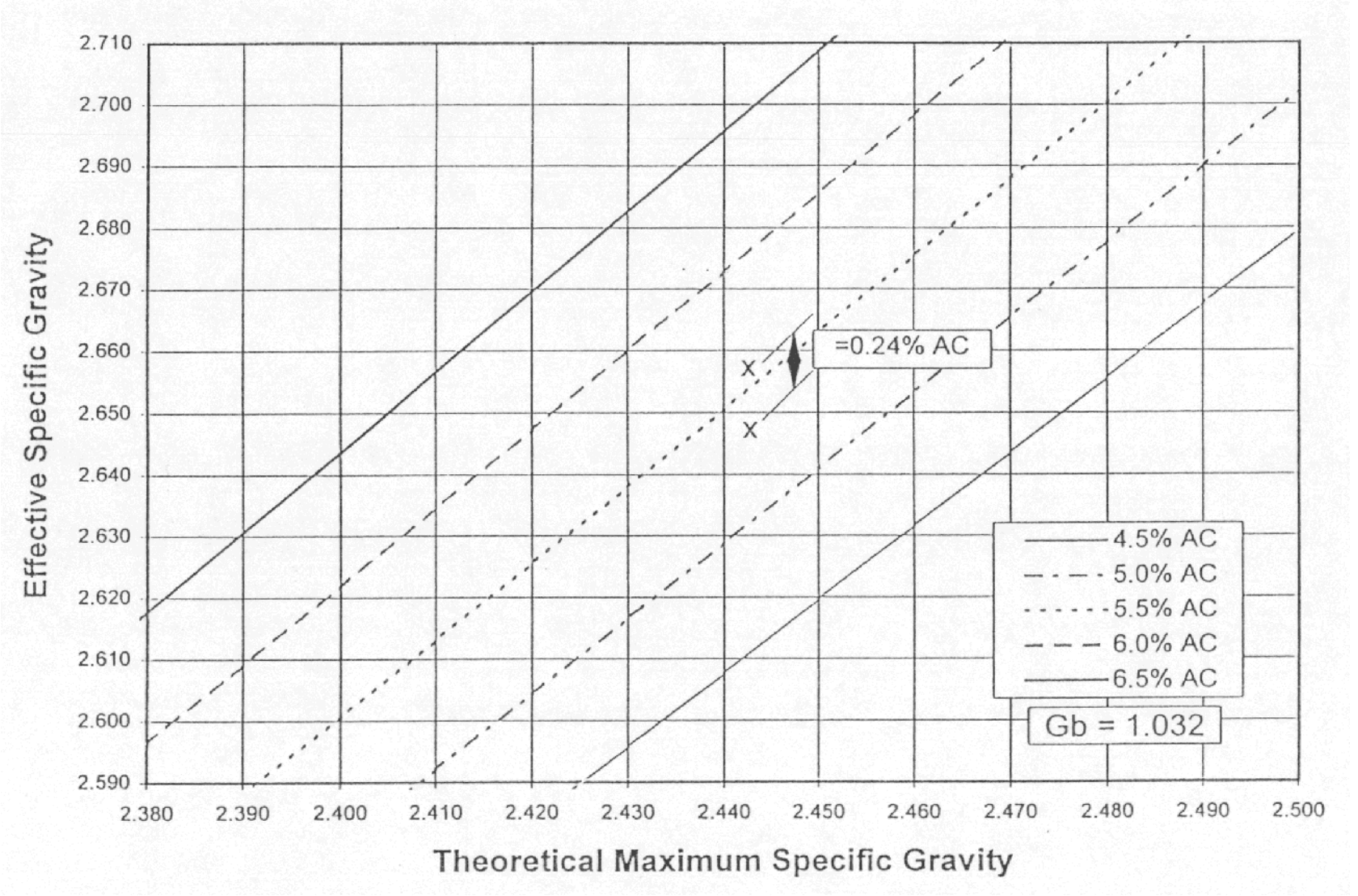

Figure 38. Theoretical maximum specific gravity and effective specific gravity relationship.

Table 1. Effects of aging on theoretical maximum specific gravities test plan.

Mixture Type					
Loose Field Mix		Laboratory Prepared Replacement Mixture			
Aging Conditions					
As Produced	Aging Time	Aging Temperature (°C)			
	(hours)	60	135	149	163
	2		X	X	X
	4		X	X	X
	16	X			

Table 2. Experimental variables considered in the oven aging and extended mixing program.

Asphalt and Aggregate Combinations	Low Air Voids (≈4%)						Medium Air Voids (≈8%)					
	Temperatures (°C)						Temperatures (°C)					
	135			163			135			163		
	Time Period*						Time Period*					
	a	b	c	a	b	c	a	b	c	a	b	c
RL + AAK-1	X	X	X				X	X	X	X	X	X
RL + AAG-1	X	X	X	X	X	X				X	X	X
RB + AAK-1	X	X	X	X	X	X				X	X	X
RB + AAG-1	X	X	X				X	X	X	X	X	X

*a = 0 hr; b = 6 hr; c = 15 hr

Table 3. Comparison of theoretical maximum specific gravity, effective specific gravities, and AC absorption under different curing conditions.

Curing Temp (C)	Curing Temp (F)	Curing Time (hr)	Lab	Mix Design	AC Type	Gb	Gsb	Rice	Gse	Pba	Pbe	% AC
135	275	2	UNR	F	Idaho	1.032	2.599	2.439	2.649	0.75	4.79	5.50
135	275	4	UNR	F	Idaho	1.032	2.599	2.443	2.654	0.83	4.72	5.50
149	300	2	UNR	F	Idaho	1.032	2.599	2.436	2.645	0.70	4.84	5.50
149	300	4	UNR	F	Idaho	1.032	2.599	2.437	2.647	0.72	4.82	5.50
163	325	2	UNR	F	Idaho	1.032	2.599	2.440	2.650	0.77	4.77	5.50
163	325	4	UNR	F	Idaho	1.032	2.599	2.436	2.645	0.70	4.84	5.50
60	140	16	UNR	F	Idaho	1.032	2.599	2.432	2.640	0.62	4.91	5.50
							Average	2.438	2.647	0.73	4.81	
							STD	0.003	0.004	0.06	0.06	
							COV	0.1	0.2	8.2	1.2	
							Range	0.011	0.014	0.20	0.19	
							n	7	7	7	7	

Table 4. Comparison of process control Rices, effective specific gravities, and AC absorptions.

Lift	Section	AC	Curing Time (hr)	Lab	Mix Design	AC Type	Gb	Gsb	Rice	Gse	Pba	Pbe	% AC	Rice @ 5.5% AC
Top	38 LM	5.15	Field	UNR	F	Idaho	1.032	2.599	2.459	2.659	0.89	4.31	5.15	2.447
	56 LH	5.25	Field	UNR	F	Idaho	1.032	2.599	2.452	2.654	0.83	4.47	5.25	2.443
	39 ML	5.75	Field	UNR	F	Idaho	1.032	2.599	2.441	2.663	0.95	4.85	5.75	2.450
	35 MM1	5.87	Field	UNR	F	Idaho	1.032	2.599	2.429	2.653	0.81	5.11	5.87	2.442
	54 MM2	5.89	Field	UNR	F	Idaho	1.032	2.599	2.424	2.647	0.73	5.21	5.89	2.438
	36 MH	5.76	Field	UNR	F	Idaho	1.032	2.599	2.447	2.671	1.07	4.75	5.76	2.456
	55 HL	6.24	Field	UNR	F	Idaho	1.032	2.599	2.419	2.657	0.86	5.43	6.24	2.445
	37 HM	6.14	Field	UNR	F	Idaho	1.032	2.599	2.417	2.650	0.76	5.43	6.14	2.439
								Average	2.436	2.657	0.86	4.94	5.76	2.445
								STD	0.015	0.007	0.103	0.395	0.360	0.006
								COV	0.6	0.3	11.9	8.0	6.3	0.2
								Range	0.042	0.023	0.34	1.13	1.09	0.019
								n	8	8	8	8	8	8

Lift	Section	AC	Curing Time (hr)	Lab	Mix Design	AC Type	Gb	Gsb	Rice	Gse	Pba	Pbe	% AC	Rice @ 5.5% AC
Bottom	38 LM	5.42	Field	UNR	F	Idaho	1.032	2.599	2.451	2.661	0.92	4.55	5.42	2.448
	56 LH	5.28	Field	UNR	F	Idaho	1.032	2.599	2.448	2.651	0.78	4.55	5.28	2.440
	39 ML	5.58	Field	UNR	F	Idaho	1.032	2.599	2.424	2.634	0.53	5.08	5.58	2.427
	35 MM1	5.71	Field	UNR	F	Idaho	1.032	2.599	2.433	2.651	0.78	4.98	5.71	2.440
	54 MM2	5.75	Field	UNR	F	Idaho	1.032	2.599	2.436	2.656	0.86	4.94	5.75	2.445
	36 MH	5.61	Field	UNR	F	Idaho	1.032	2.599	2.436	2.650	0.77	4.88	5.61	2.440
	55 HL	6.11	Field	UNR	F	Idaho	1.032	2.599	2.410	2.639	0.61	5.54	6.11	2.431
	37 HM	6.06	Field	UNR	F	Idaho	1.032	2.599	2.407	2.633	0.52	5.57	6.06	2.426
								Average	2.431	2.647	0.72	5.01	5.69	2.437
								STD	0.015	0.010	0.141	0.363	0.269	0.008
								COV	0.6	0.4	19.6	7.2	4.7	0.3
								Range	0.044	0.027	0.40	1.03	0.83	0.022
								n	8	8	8	8	8	8

Resilient Modulus and Tensile Strength Properties of WesTrack Hot-Mix Asphalt Mixtures

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-26
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on resilient modulus and tensile strength of core samples of HMA obtained from the WesTrack pavement at various ages during its service life. Information is presented for both the original construction sections and the replacement sections. The test program used for sampling and testing is contained in WesTrack Technical Reports UNR-18[4] and UNR-19.[5] Detailed test results and analyses of the resilient modulus and tensile strength data can be found in a Master of Science thesis[6] prepared for the University of Nevada.

BACKGROUND

WesTrack investigated the effect of aggregate gradation, aggregate type, asphalt binder content, and in-place air voids on the rutting and fatigue performance of HMA. The three gradations used on WesTrack were identified as fine, fine plus, and coarse graded mixtures. Figure 1 shows the three gradations used during placement of the original constructed sections and the coarse gradation used for the replacement sections. Table 1 identifies the section numbers associated with the various aggregate gradations, aggregate types, asphalt binder content, and in-place air voids. The 34 mixtures evaluated were placed at 26 different locations (test sections) on the test track as shown in figure 2 and designated in tables 2 and 3.

SAMPLING

Samples of HMA were obtained by core sampling of the WesTrack pavement sections at different locations across the pavement as shown in table 4 and described below. Twenty-six test sections were placed as part of the original construction. Construction of these test sections was completed in early October 1995. Eight replacement sections were placed in June of 1997. The original test sections were sampled at the following times for resilient modulus and tensile strength testing:

- Immediately after construction (time zero construction, October 1995).
- Just prior to start of traffic (time zero traffic, May 1996).
- After approximately 12 months of traffic (time 12-month traffic, May 1997).
- Just prior to removal of test section (post mortem).

As shown in table 2, only a limited number of sections were sampled and tested at time zero traffic. These data were used to provide a comparison between the time zero construction and the time zero traffic (7 months later) properties of the asphalt binders and mixtures tested.

The time 12-month traffic sampling was performed in May 1997. This was also the time at which the traffic was removed from the track to construct the replacement sections (May and June 1997, 12 months after the start of traffic or 20 months after original construction).

Post mortem samples were obtained at various times depending on when the test sections were removed from service (table 2). Sections 7, 9, 13, 21, and 25 were sampled in November 1996, just prior to a rehabilitation of those sections by milling and filling with new HMA (13 months after construction). Samples from sections 5, 6, 8, 24, and 26 were obtained in May 1997, approximately 20 months after construction. These samples were obtained just prior to reconstruction of the track with the replacement sections (35, 36, 37, 38, 39, 54, 55, and 56).

The replacement sections were sampled just prior to the restart of traffic (time zero traffic, July 1997). Additional sampling times were not used for the original section and post mortem sections as stiffness values for analysis purposes were being collected by use of the bending beam fatigue machine and the repeated load shear tester (Superpave shear tester).

Samples were obtained from both within the right wheelpath and between the wheelpaths. The sample locations were the designated sampling areas at the end of the test sections. Samples were not obtained at random locations along the test sections.

The cores were saw-cut in the laboratory to separate the top lift from the bottom lift. Resilient modulus and tensile strength were obtained on both top and bottom lift samples for the majority of the samples obtained.

TEST PLAN AND TEST METHODS

The information reported in this WesTrack technical report defines the resilient modulus and tensile strength of core samples. This information is part of a larger set of information collected to define the water sensitivity of the mixtures at WesTrack and reported in reference 6. Only the "dry" resilient modulus and tensile strength are reported in this report. Figures 3 and 4 describe the water sensitivity test plan from which these dry strength properties were obtained.

ASTM D 4123 and AASHTO TP 31 were used to obtain resilient modulus and tensile strength. A load pulse of 0.1- second duration was utilized. Resilient modulus was determined at -11.5°C, 2°C, 25°C, and 40°C (11°F, 36°F, 77°F, and 104°F) on selected sets of samples. Tensile strengths were determined at 25°C (77°F). Air void content information for all samples is available in reference 6.

ORIGINAL CONSTRUCTION

TIME ZERO CONSTRUCTION

As stated previously, the time zero construction samples were obtained from the designated sampling area in the test sections from between the wheelpaths and within the right wheelpath. The samples were obtained in October 1995 within a few weeks of the completion of placement of the HMA. Resilient modulus and tensile strength data from these samples are presented below.

Resilient Modulus

Tables 5 through 9 and figures 5 through 20 contain the resilient modulus information from core samples obtained immediately after construction. The resilient modulus values at 25°C obtained from top lift samples are shown in table 5. Bottom lift samples tested at 25°C are shown in table 6. Tables 7 through 9 provide data at -11.5°C, 2°C, and 40°C for top lift samples from selected sections 1, 5, 11, 15, 19, and 24. These sections represent the optimum asphalt binder content sections compacted to 8 percent in-place air void contents. Statistical information for each section is also shown in these tables (mean, standard deviation, minimum and maximum values, range, and number of replicates).

Figures 5 through 10 show resilient modulus values at 25°C for the fine, fine plus, and coarse graded mixtures with the asphalt binder content fixed and the air voids allowed to vary. Figures 5 and 6 summarize the data at low asphalt binder content for the three mixtures with various in-place air voids. Figures 7 and 8 are summaries for optimum asphalt binder content and figures 9 and 10 are summaries for the high asphalt binder content mixtures. Each figure uses the bar to define the mean value for the data set. The standard deviation of the data set is represented in the figures by the use of a vertical line with a short, terminal horizontal line. A review of the data contained in these tables and figures indicates that the resilient modulus decreases with an increase in in-place air voids for nearly all of the data set groupings that are presented by gradation (fine, fine plus, and coarse) and asphalt binder contents.

Figures 11 through 16 show resilient modulus values at 25°C for the fine, fine plus, and coarse graded mixtures with the in-place air void content fixed and the asphalt binder content allowed to vary. Figures 11 and 12 summarize the data at low (approximately 4 percent) in-place air voids for the three mixtures with various asphalt binder contents. Figures 13 and 14 are summaries for medium (approximately 8 percent) in-place percent air voids. Figures 15 and 16 are summaries for the high (approximately 12 percent) in-place air void mixtures. A review of the data presented in these figures indicates that the resilient modulus at the high asphalt binder content (approximately 0.7 percent above the optimum) was lower than the resilient modulus for the corresponding mixtures at optimum asphalt binder content. The resilient modulus values for the mixtures at the low asphalt binder content (approximately 0.7 percent below the optimum) were equal to or greater than the resilient modulus values for the corresponding mixtures at optimum asphalt binder content. These general trends in the resilient modulus data suggest that an optimum asphalt binder content exists for maximizing the resilient modulus values. This concept is supported by research previously performed by the authors.

Figures 17 through 19 show resilient modulus values by section for the fine, fine plus, and coarse graded mixtures for original construction. Figure 20 is a graph of the resilient modulus for the fine, fine plus, and coarse graded mixtures over a temperature range. Since the asphalt binder was identical in all mixtures, the temperature sensitivities of the resilient modulus values for the three different mixtures (fine, fine plus, and coarse) were similar (figure 20 and tables 7 through 9). The resilient modulus values for the fine, fine plus, and coarse graded mixtures are similar.

Tensile Strength

Indirect tensile strength values obtained immediately after construction (time zero construction) are shown in table 10 and figures 21 through 29. Indirect tensile strength values were obtained at 25°C on samples from the bottom lift. Statistical information for each section also is shown in these tables (mean, standard deviation, minimum and maximum values, range, and number of replicates).

Figures 21 through 23 show tensile strength values at 25°C for the fine, fine plus, and coarse graded mixtures with the asphalt binder content fixed and the air voids allowed to vary. Figure 21 summarizes the data at low asphalt binder content for the three mixtures with various in-place air voids. Figures 22 and 23 are summaries for optimum and high asphalt binder content, respectively. Each figure uses the bar to define the mean value for the data set. The standard deviation of the data set is represented in the figures by the use of a vertical line with a short, terminal horizontal line. A review of the data contained in this table and figures indicates that the tensile strength decreases with an increase in air voids for almost all of the data set groupings.

Figures 24 through 26 show tensile strength values at 25°C for the fine, fine plus, and coarse graded mixtures with the in-place air void content fixed and the asphalt binder content allowed to vary. Figure 24 summarizes the data at low (approximately 4 percent) in-place air voids for the three mixtures with various asphalt binder contents. Figures 25 and 26 are summaries for medium (approximately 8 percent) and high (approximately 12 percent) in-place air void

contents. A review of the data presented in these figures indicates that the tensile strength is mostly unchanged by the asphalt binder content.

Figures 27 through 29 show tensile strength values by section for the fine, fine plus, and coarse graded mixtures for original construction. Tensile strength values for the fine and fine plus mixtures are similar. The coarse graded mixtures have slightly lower values on average.

TIME-ZERO TRAFFIC

As stated previously, the time-zero traffic samples were obtained from the designated sampling area in the test sections from between the wheelpaths. The samples were obtained in May 1996, during the early stages of traffic. Limited traffic was placed on the test sections from March 1996 up to the time the core samples were obtained. The traffic during the March through May 1996 period was primarily applied to perform driverless vehicle checks. Resilient modulus data obtained from the top and bottom lift samples from sections 1, 10, 11, 19, 21, 24, 25, and 26 are described below. These specific sections were selected to ensure that the target mixtures (optimum asphalt binder content and in-place air voids) were evaluated as well as mixtures at low and high asphalt binder contents and low and high air void levels.

Resilient Modulus

Tables 11 and 12 and figure 30 contain the resilient modulus information obtained on core samples obtained at the start of traffic. The resilient modulus values at 25°C obtained for the top lifts are shown in table 11 and the data for the bottom lifts are shown in table 12. Statistical information for each section also is shown in these tables (mean, standard deviation, minimum, and maximum values, range, and number of replicates).

Figure 30 shows the resilient modulus values by section for the different mixtures and their top and bottom lifts. The resilient modulus of the bottom lift is slightly greater than the top lift throughout. The higher resilient modulus values for the bottom lift as compared to the top lift also are evident from data obtained on the time zero construction samples (figures 17, 18, and 19).

Comparisons of resilient modulus values obtained from cores at time zero construction and time zero traffic are provided later in this report.

Tensile Strength

Indirect tensile strength was not determined on the samples obtained at time zero traffic. Asphalt binder properties were establish on binder extracted and recovered from the resilient modulus samples.

TIME 12-MONTH TRAFFIC SAMPLES

As stated previously, the time 12-month traffic samples were obtained from the designated sampling area in the test sections from between the wheelpaths and within the right wheelpaths.

The samples were obtained in May 1997 just prior to placement of the replacement sections. Resilient modulus values from these samples are described below.

Sixteen sections were sampled at the time designated as 12-month traffic. The remaining 10 of the original construction sections were sampled as part of the post mortem sampling program described below. Post mortem samples for sections 7, 9, 13, 21, and 25 were obtained in November 1996, after they had failed due to rutting. Sections 5, 6, 8, 24, and 26 were sampled in May 1997, just prior to construction of the replacement sections and at the same time that the 12-month traffic samples identified above were taken.

Resilient Modulus

Tables 13 through 16 and figures 31 and 44 contain the resilient modulus information from core samples taken 20 months after the completion of construction and 12 months after initiation of traffic. The resilient modulus values at 25°C obtained for the top lifts are shown in table 13 and the data for the bottom lifts are shown in table 14; the data in both tables is for samples from within the right wheelpath. The resilient modulus values of between the wheelpath samples are shown in tables 15 and 16 for the top and bottom lifts, respectively. Statistical information for each section is also shown in these tables (mean, standard deviation, minimum and maximum values, range, and number of replicates).

Figures 31 through 36 show resilient modulus values at 25°C for the fine, fine plus, and coarse graded mixtures with the asphalt binder content fixed and the air voids allowed to vary. Figures 31 and 32 summarize the data at low asphalt binder content for the three mixtures with various in-place air voids. Figures 33 and 34 are summaries for optimum asphalt binder content and figures 35 and 36 are summaries for high asphalt binder content mixtures. A review of the data contained in these tables and figures indicates that the resilient modulus does not necessarily decrease with increases in in-place air void content as shown with time zero construction samples (figures 5 through 10).

Figures 37 through 42 show resilient modulus values at 25°C for the fine, fine plus, and coarse graded mixtures with the in-place air void content fixed and the asphalt binder content allowed to vary. Figures 37 and 38 summarize the data at low (approximately 4 percent) in-place air voids for the three mixtures with various asphalt binder contents. Figures 39 and 40 are summaries for medium (approximately 8 percent) in-place air voids and figures 41 and 42 are summaries for the high (approximately 12 percent) in-place air void content mixtures. A review of the data presented in these figures indicates that the resilient modulus is not affected by the asphalt binder content in a specific direction after 20 months of field aging.

Figures 43 and 44 show the resilient modulus values by section for the top and bottom lifts of the fine and fine plus graded mixtures, respectively. The top lift resilient modulus value is slightly larger than or equal to the bottom lift resilient modulus value throughout. This trend is the reverse of that which was observed for the time zero construction and time zero traffic samples (Bottom lift resilient modulus values were typically larger than top lift resilient modulus values; see figures 17, 18, 19, and 30).

Figure 45 shows a comparison between resilient modulus values obtained from both cores within the right wheelpath and between the wheelpaths for four sections of fine and fine plus graded mixtures. A trend of higher or lower values, for between versus within wheelpath data, is not evident. For the top lift, the resilient modulus of the wheelpath sample was greater than the between wheelpath sample for three of the four comparisons. Since the between wheelpath samples are likely to remain at nearly the same void content with time (no traffic), it is expected that they would age more rapidly and hence have a larger resilient modulus. This trend was not evident. Thus, it is likely that the increase in resilient modulus due to a decrease in in-place air voids is greater than the increased hardening in those samples not subjected to traffic and a decrease in in-place air void content.

Comparisons of resilient modulus values obtained on samples cored at time zero construction, time zero traffic, and time 12-month traffic are provided later in this report.

Tensile Strength

Indirect tensile strength was not determined on the samples obtained at time 12- month traffic. Asphalt binder properties were established on binder extracted and recovered from the resilient modulus samples.

POST MORTEM

As stated previously, the post mortem samples were obtained at the time that each test section was removed from service. Post mortem sampling was performed on sections 7, 9, 13, 21, and 25 in November 1996, approximately 7 months after the initiation of traffic or 13 months after construction. Post mortem samples were obtained on sections 5, 6, 8, 24, and 26 in May 1997, approximately 20 months after construction.

Resilient Modulus

Tables 17 through 20 and figure 46 contain the resilient modulus information obtained from core samples taken from the right wheelpath at the time the sections were removed from service as described above. The resilient modulus values at 25°C are shown for right wheelpath samples obtained from the top lift in table 17 and from the bottom lift in table 18. Tables 19 and 20 show resilient modulus values for the top and bottom lift samples obtained from between the wheelpaths.

Figure 46 shows resilient modulus values by section for the post mortem sections placed during original construction. These data were obtained from samples taken from the right wheelpath. There does not appear to be a consistent trend that can be used to describe the difference in values between the top and bottom lifts.

Tensile Strength

A limited amount of tensile strength data is available on bottom lift samples obtained during post mortem testing. These data are shown in table 21.

REPLACEMENT SECTIONS

The replacement sections (35, 36, 37, 38, 39, 54, 55, and 56) were placed in June 1997. Core samples were obtained from these sections in July 1997 prior to placing traffic on the sections. Resilient modulus and tensile strength values from these samples are described below.

RESILIENT MODULUS

Tables 22 through 26 and figures 47 through 60 contain the resilient modulus information obtained on core samples taken from the replacement sections at the time of construction. The resilient modulus values at 25°C obtained from the top lift are shown in table 22 and for the bottom lift in table 25. Tables 24 through 26 contain resilient modulus data obtained at -11.5°C, 2°C, and 40°C.

Figures 47 through 52 show resilient modulus values at 25°C for the coarse graded mixture with the asphalt binder content fixed and the air voids allowed to vary. Figures 47 and 48 summarize data at low asphalt binder content for the mixture with various in-place air voids. Figures 49 and 50 are summaries for optimum asphalt binder content and figures 51 and 52 are summaries for high asphalt binder content mixtures. A review of the data contained in these tables and figures indicates that the resilient modulus decreases with an increase in in-place air void content.

Figures 53 through 58 show resilient modulus values at 25°C for the coarse graded replacement mixture with the in-place air void content fixed and the asphalt binder content allowed to vary. Figures 53 and 54 summarize the data at low (approximately 4 percent) in-place air voids for the three mixtures with various asphalt binder contents. Figures 55 and 56 are summaries for medium (approximately 8 percent) in-place air voids and figures 57 and 58 are summaries for the high (approximately 12 percent) in-place air void content mixtures. A review of the data presented in these figures indicates that the resilient modulus, in general, is unaffected by a change in asphalt content. It should be noted that some of the figures indicate a general decrease in resilient modulus with an increase in asphalt binder content.

Figure 59 shows the resilient modulus values by section for the coarse graded replacement mixture. There is no significant difference in resilient modulus values between the top and bottom lifts. Figure 60 shows the relationship between resilient modulus and test temperature for two mixtures from the replacement sections. These are replicate sections.

TENSILE STRENGTH

Table 27 and figure 61 show the tensile strength values for the core samples from the bottom lift of the replacement sections. The replacement tensile strength values are lower than the original construction coarse graded mixtures.

RESILIENT MODULUS VERSUS TIME

Relationships between resilient modulus and time have been developed and are contained in reference 6. Figures 62 and 63 contain representative data from this reference for the optimum asphalt binder content and medium air void content mixtures. The expected trends of increase in resilient modulus with time and a larger increase in resilient modulus in the top lift as compared to the bottom lift are apparent from figures 62 and 63. Differences in gain in resilient modulus for the different gradations of the mixtures are not readily apparent.

RESILIENT MODULUS AND TENSILE STRENGTH

Figures 64 and 65 show the data and the linear regression relationships between resilient modulus and tensile strength for both the original and replacement sections. The regressions were developed from the bottom lift time zero original construction resilient modulus and tensile strength data (figure 64) and from the bottom lift time zero replacement section data (figure 65).

PREDICTION OF RESILIENT MODULUS AND TENSILE STRENGTH

Linear regression models were developed to predict resilient modulus and tensile strength from mixture properties. Data from the 26 original construction sections and the 8 replacement sections were used to develop models. The developed models are shown below.

The following equations were finally determined as the best models for the data obtained from different laboratory tests.

Considering all 26 sections, original construction:

$$1n\ (M_R) = 3.562854 + 0.512580\ (AC) - 0.138102\ (AV) + 0.871004\ (No.\ 200)$$

$$-0.161242\ (AC)\ (No.\ 200) + 0.0142404\ (AC)\ (AV)$$

$$+0.149879\ (No.\ 4/No.\ 50)$$

with:

$R^2 = 0.6232$

SE = 0.13382

N = 52

where:

M_R = resilient modulus

AC = asphalt binder content
AV = in-place air voids
No. 4 = percent passing No. 4 (4.75 - mm) sieve
No. 50 = percent passing No. 50 (0.300 - mm) sieve
No. 200 = percent passing No. 200 (0.075 - mm) sieve

Considering fine and fine plus graded original construction sections only:

$$1n (M_R) = 2.399559 + 0.643074 (AC) - 0.15330 (AV) + 1.053142 (No. 200)$$

$$-0.191168 (AC) (No. 200) + 0.0174376 (AC) (AV)$$

$$+0.261513 (No. 4/No. 50)$$

with:

$R^2 = 0.670$

SE = 0.12856

N = 36

Considering only coarse graded sections original construction and replacement sections (combined):

$$1n (M_R) = 9.51128 - 0.200032 (AC) - 0.1189736 (AV) + 0.1195675 (No. 200)$$

$$+0.01082861 (AC) (No. 200) - 0.042953 (AC) (AV)$$

$$-0.243029 (No. 4/No. 50)$$

with:

$R^2 = 0.5974$

SE = 0.15989

N = 32

The regression models to estimate tensile strength are shown below.

Considering all original 26 sections:

$$1n (TS) = 3.355125 + 0.426188 (AC) - 0.237245 (AV) + 0.821750 (No. 200)$$

$$-0.159241 (AC) (No. 200) + 0.029209 (AC) (AV)$$

with:

$R^2 = 0.812$

SE = 0.11461

N = 26

where:

TS = tensile strength

Considering fine and fine plus original sections only:

$$1n\ (TS) = 3.183817 + 0.454204\ (AC) - 0.227681\ (AV) + 0.845488\ (No.\ 200)$$

$$-0.162762\ (AC)\ (No.\ 200) + 0.027609\ (AC)\ (AV)$$

with:

$R^2 = 0.910$

SE = 0.08491

N = 18

PREDICTION OF PAVEMENT PERFORMANCE

A limited effort was made to predict the observed rutting in the pavement from resilient modulus values. Pavement rutting after 2.8 million ESAL applications was used, along with the resilient modulus values at time zero construction as measured at 25°C. Figure 66 shows the developed relationships and the data upon which the models were based. Different models were developed for the three different gradations (fine, fine plus, and coarse).

NUMBER OF REPLICATE SAMPLES

Because of the large number of samples that could be tested, it was decided to perform a limited study to determine the number of samples that needed to be tested to determine a reasonable representation of the resilient modulus of a given section. Reference 6 contains more detailed information on this activity. Figure 68 shows typical results for a number of sections in which a total of six samples were tested to determine resilient modulus. Standard deviation is plotted against the number of replicates. A review of these data indicates that the standard deviation can be estimated reasonable accurately with four or five replicates.

SUMMARY

Resilient modulus and tensile strength were obtained on core samples taken from the WesTrack pavements. These samples were used to determine water sensitivity and asphalt binder properties, as well as resilient modulus values. Resilient modulus was determined at different ages for the top and bottom lifts.

The sensitivity of the mixtures to asphalt binder content, in-place air voids, and time after construction as measured by resilient modulus and tensile strength is illustrated in this report. The tables and figures contained in this report summarize the collected data.

CONCLUSIONS

The WesTrack Team found that:

1. Relationships of resilient modulus to mixture parameters (asphalt content, air voids, gradation, etc.) and of tensile strength to mixture parameters have been developed and are shown on pages in this report.

2. A limited effort developed performance prediction equations between rutting and resilient modulus for the three original construction WesTrack mixtures (figures 66 and 67).

3. Relationships between resilient modulus and tensile strength were developed for the three original construction WesTrack mixtures (figures 64 and 65).

4. Four or five random samples from a lot of HMA can provide a reasonable estimate of resilient modulus.

REFERENCES

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4. Hand, A., and Epps, J., "WesTrack Original Hot-Mix Asphalt Preconstruction, Construction, and Postconstruction Material Sampling and Testing Plan," WesTrack Technical Report UNR-18, February 2000.

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6. Dewan, S., "Mechanical Properties of HMA Mixtures Used in WesTrack Project," Thesis, Master of Science, University of Nevada, Reno, August 1998.

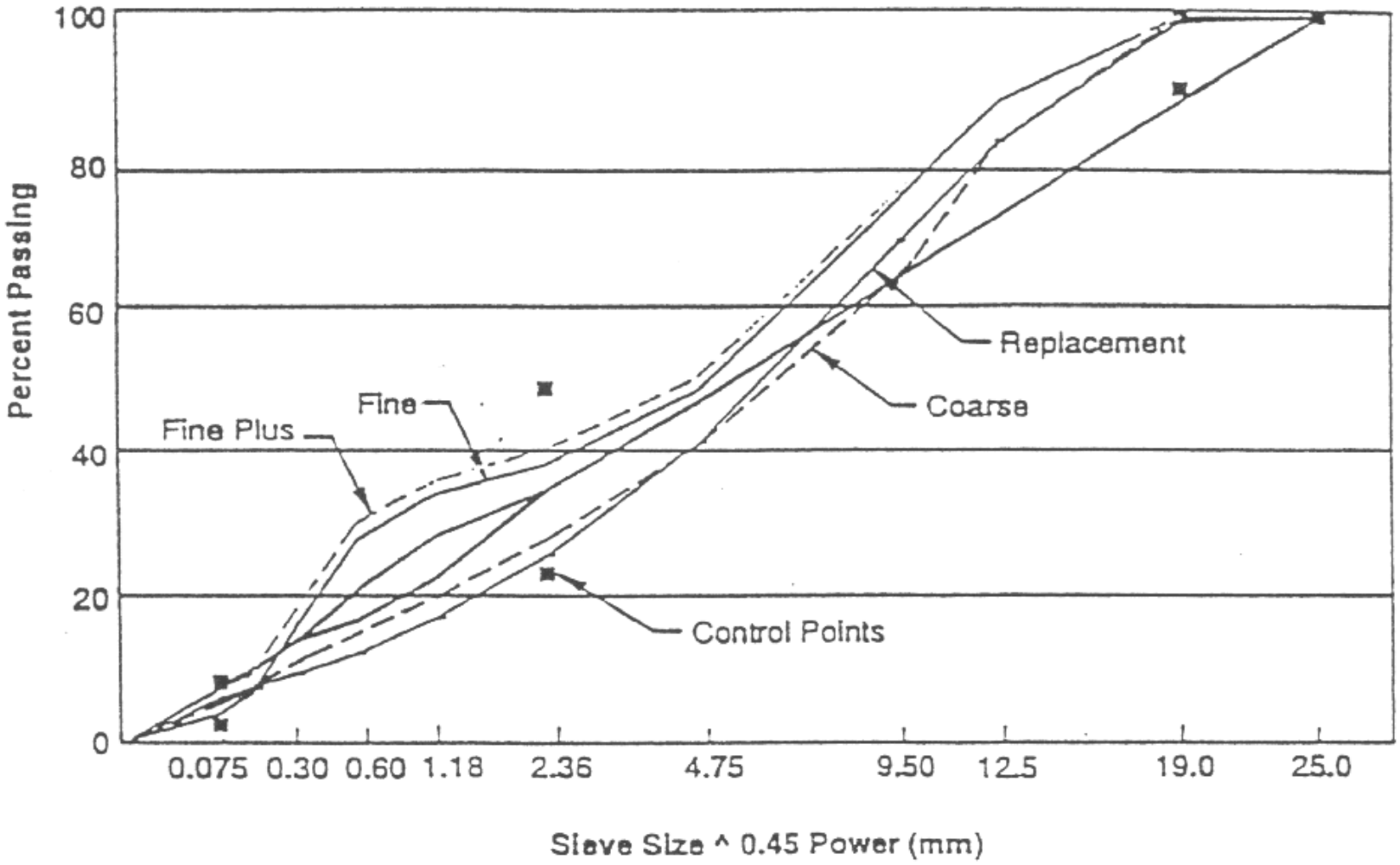
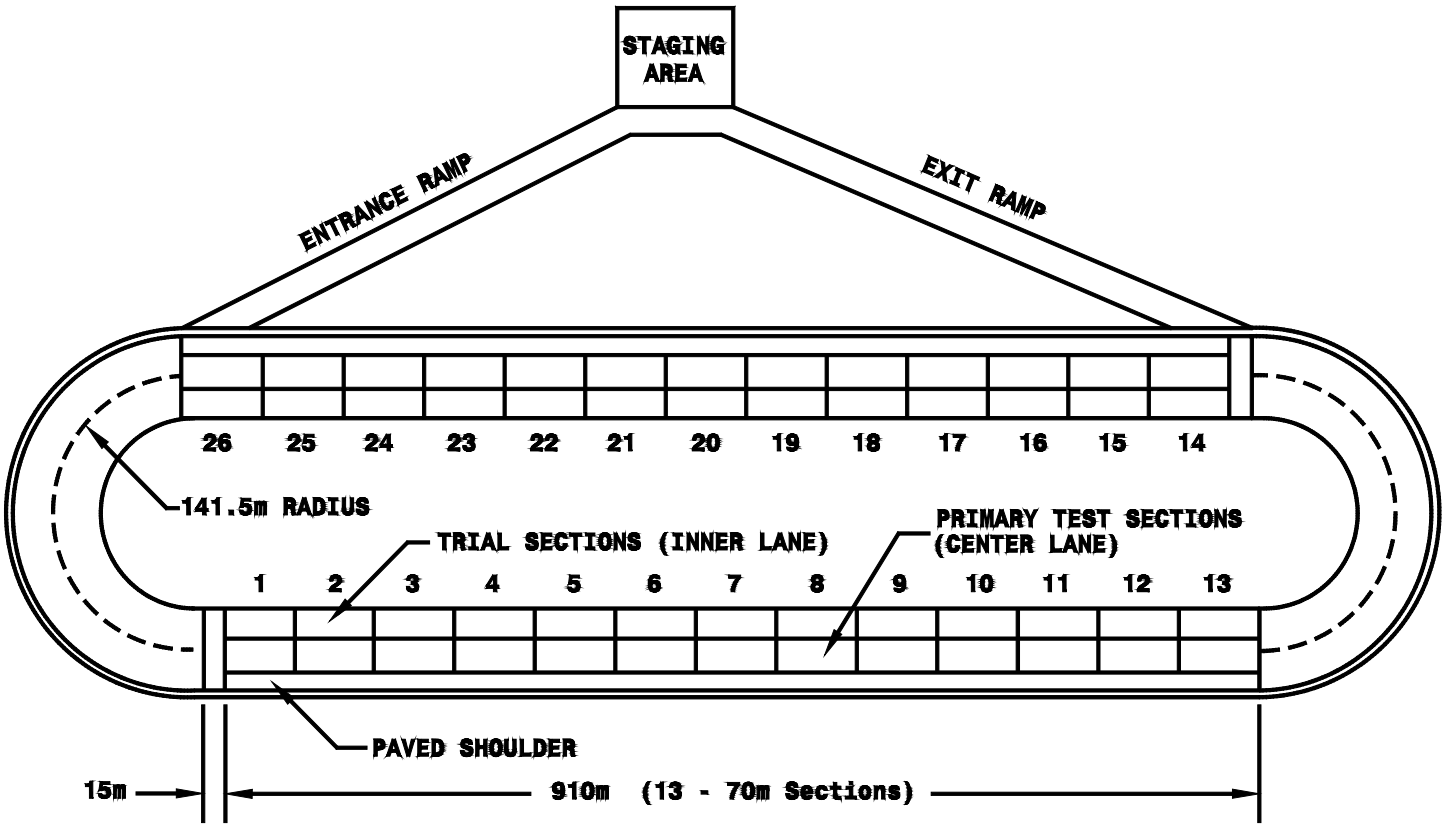
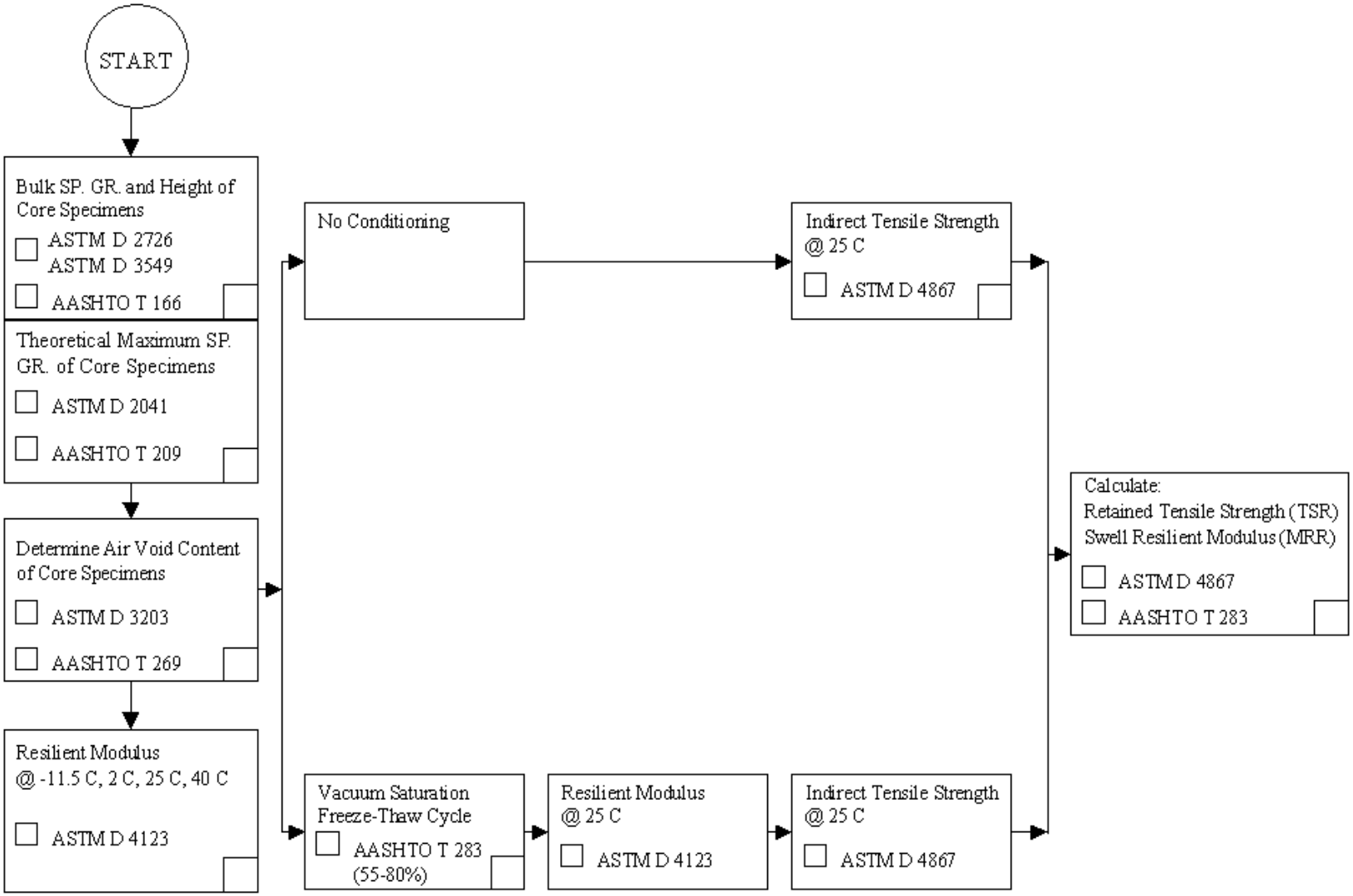


Figure 1. Mixture target gradations for WesTrack.



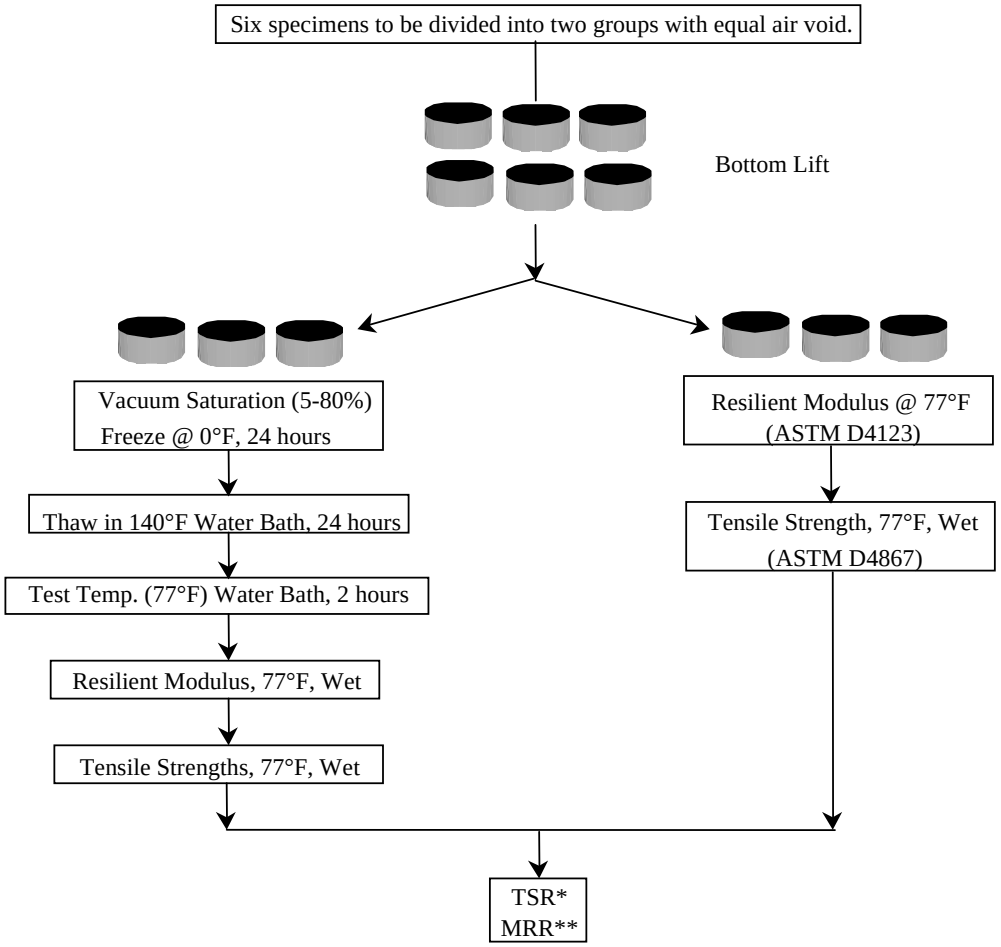
1 m = 3.3 ft

Figure 2. Layout of the test track sections.



°F = 1.8 (°C) + 32

Figure 3. Laboratory test plan.



* TSR = Tensile Strength Ratio (Conditioned / Unconditioned)
** MRR = Resilient Modulus Ratio (Conditioned / Unconditioned)

°F = 1.8 (°C) + 32

Figure 4. Modified Lottman moisture sensitivity test sequence.

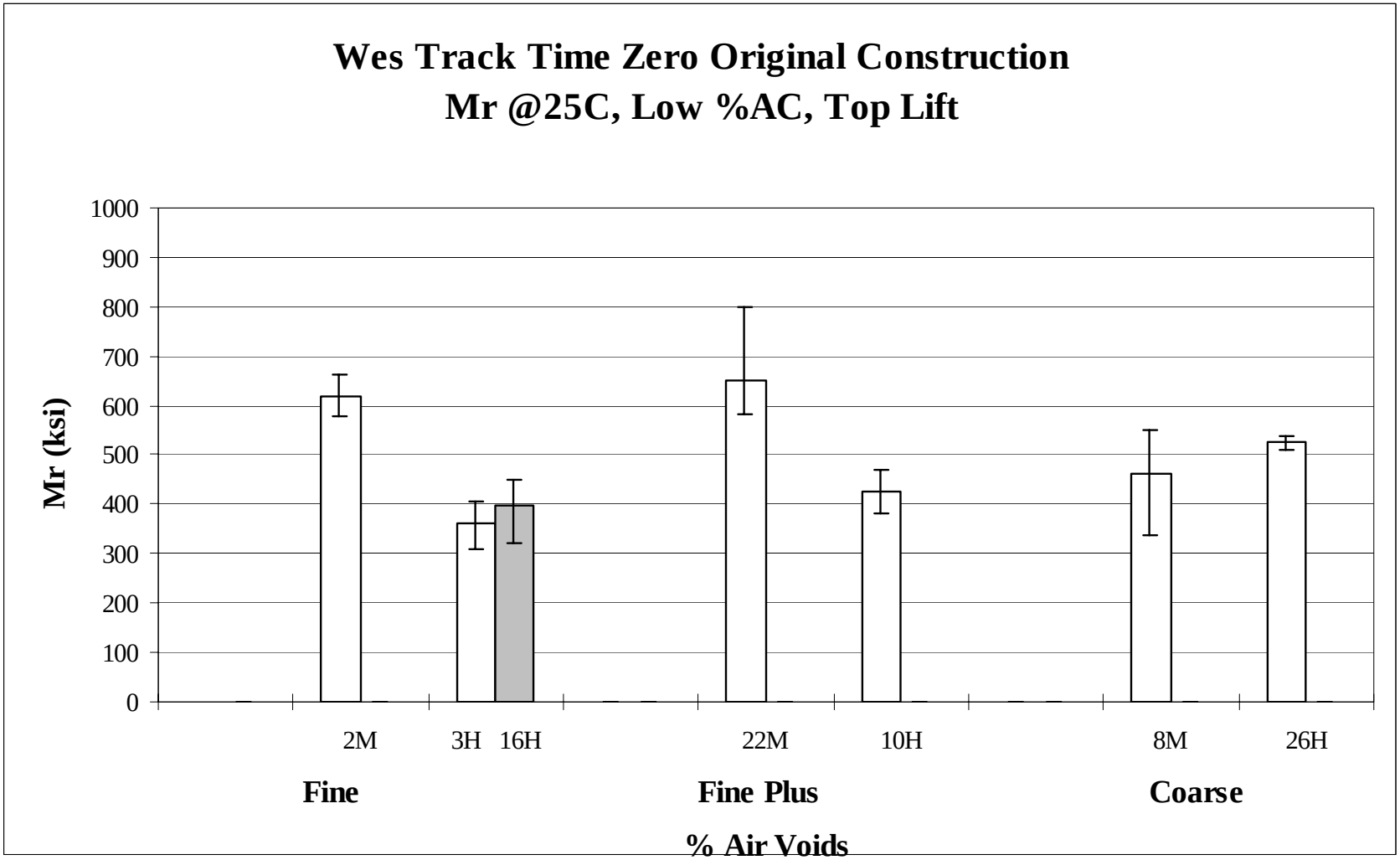


Figure 5. Resilient modulus of the mixtures designed with low asphalt content (top lifts).

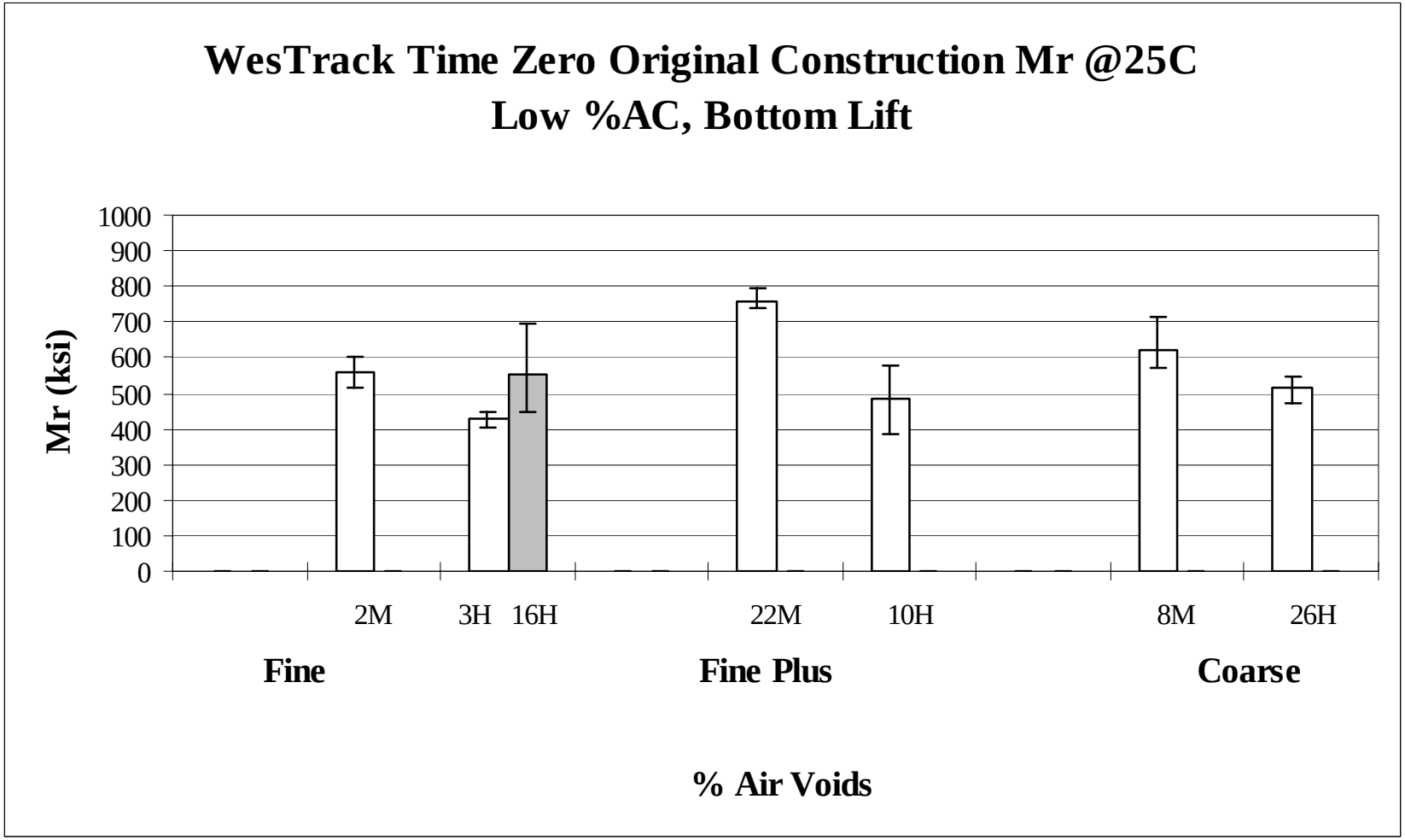


Figure 6. Resilient modulus of the mixtures designed with low asphalt content (bottom lifts).

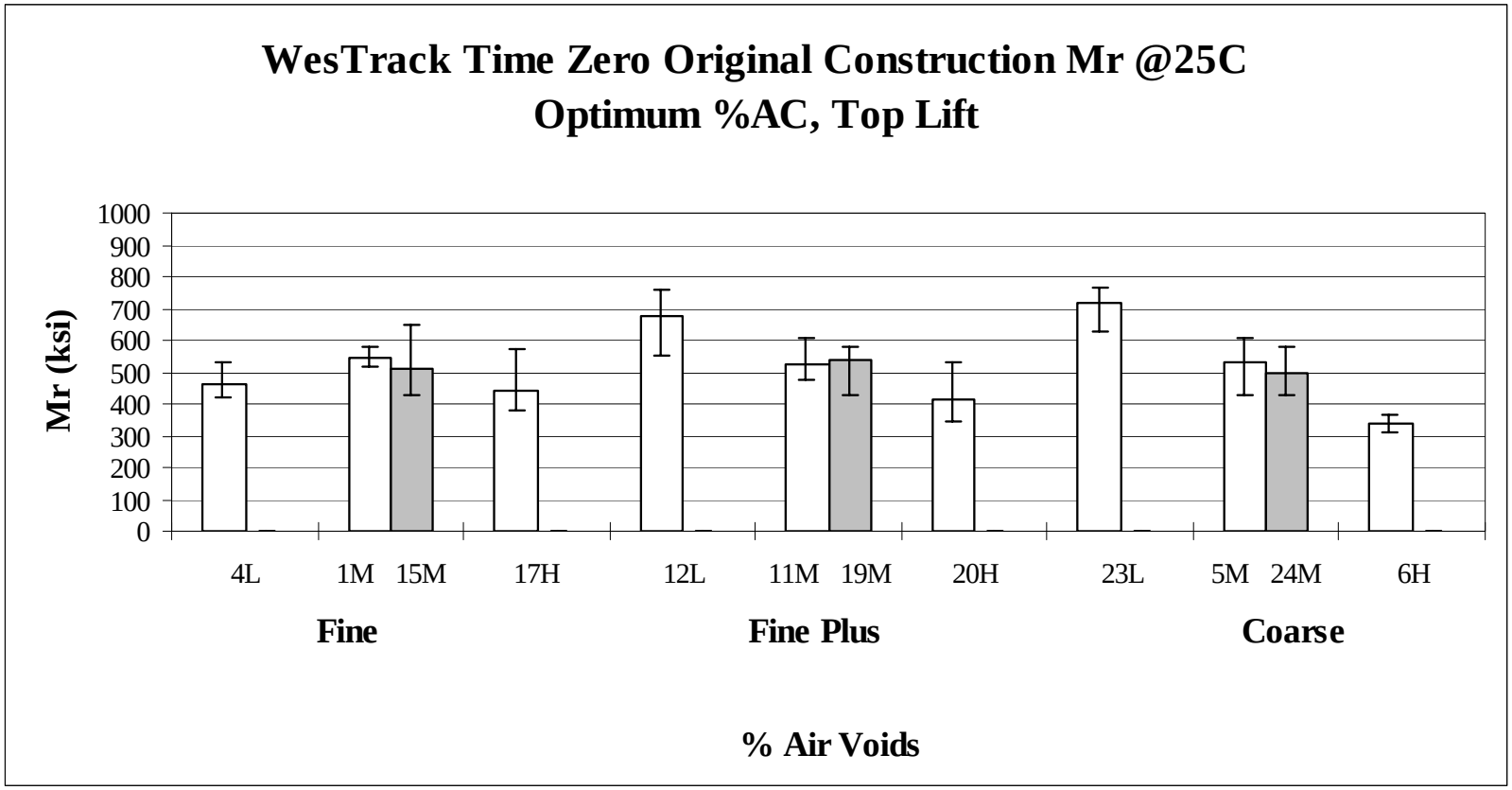


Figure 7. Resilient modulus of the mixtures designed with optimum asphalt content (top lifts).

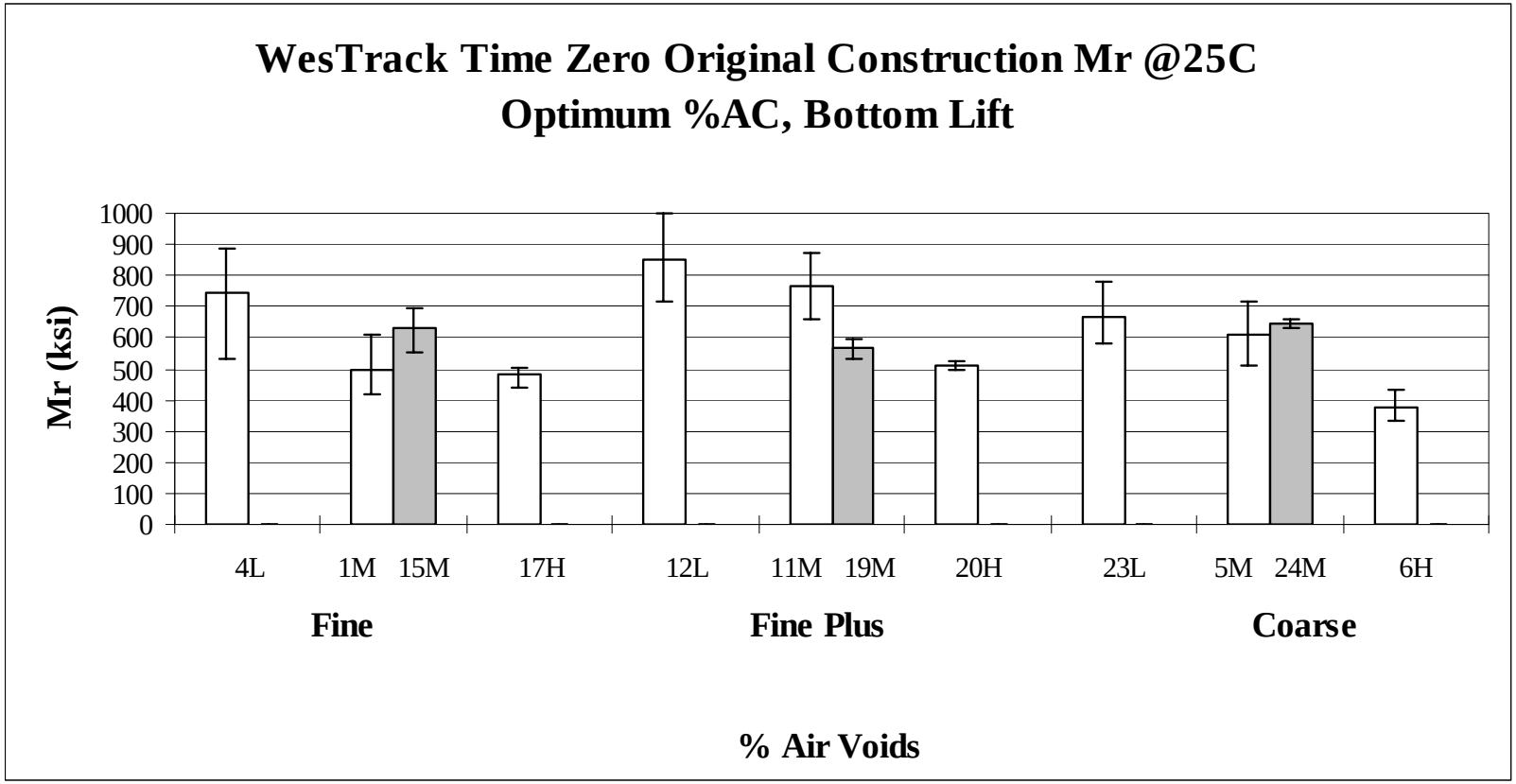


Figure 8. Resilient modulus of the mixtures designed with optimum asphalt content (bottom lifts).

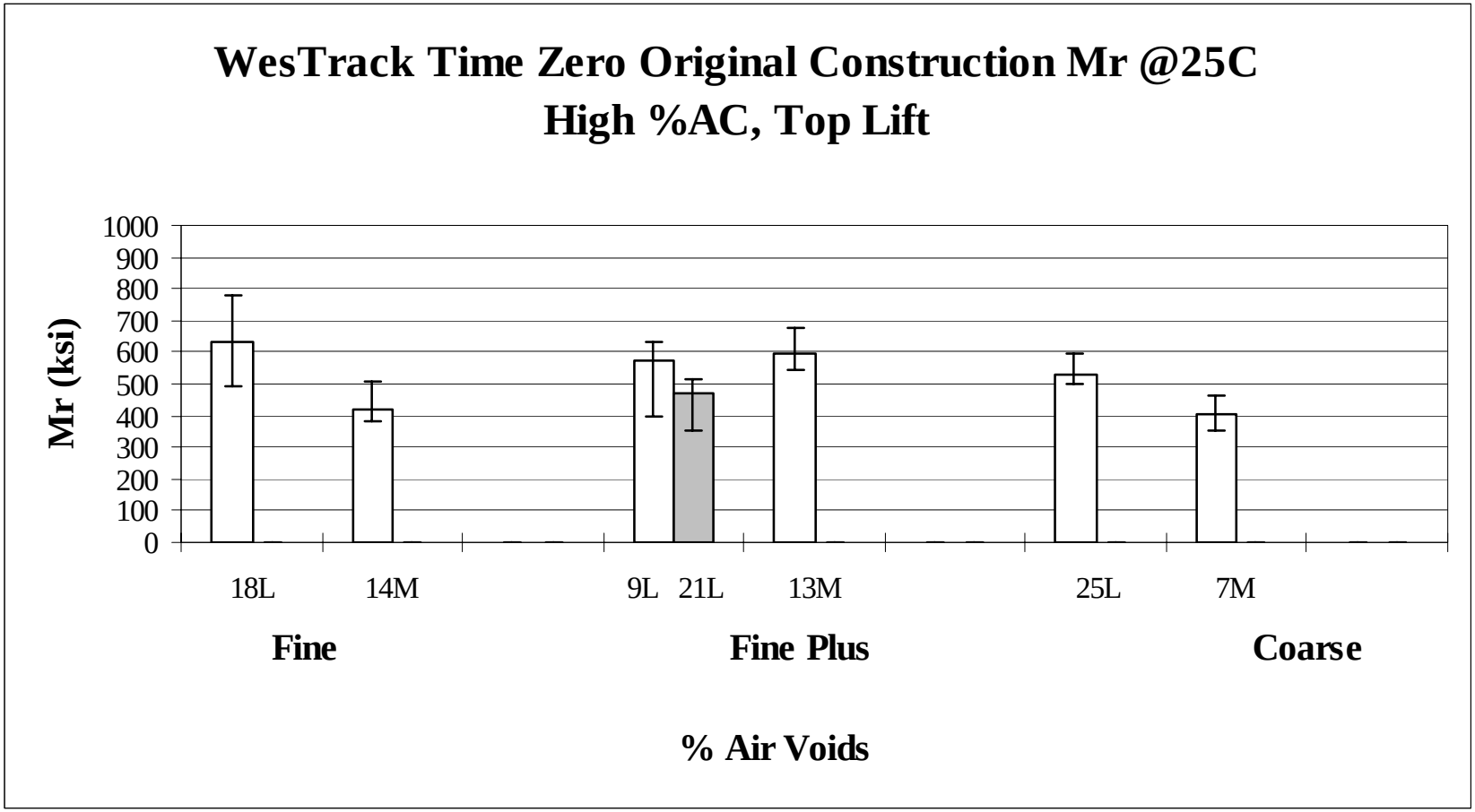


Figure 9. Resilient modulus of the mixtures designed with high asphalt content (top lifts).

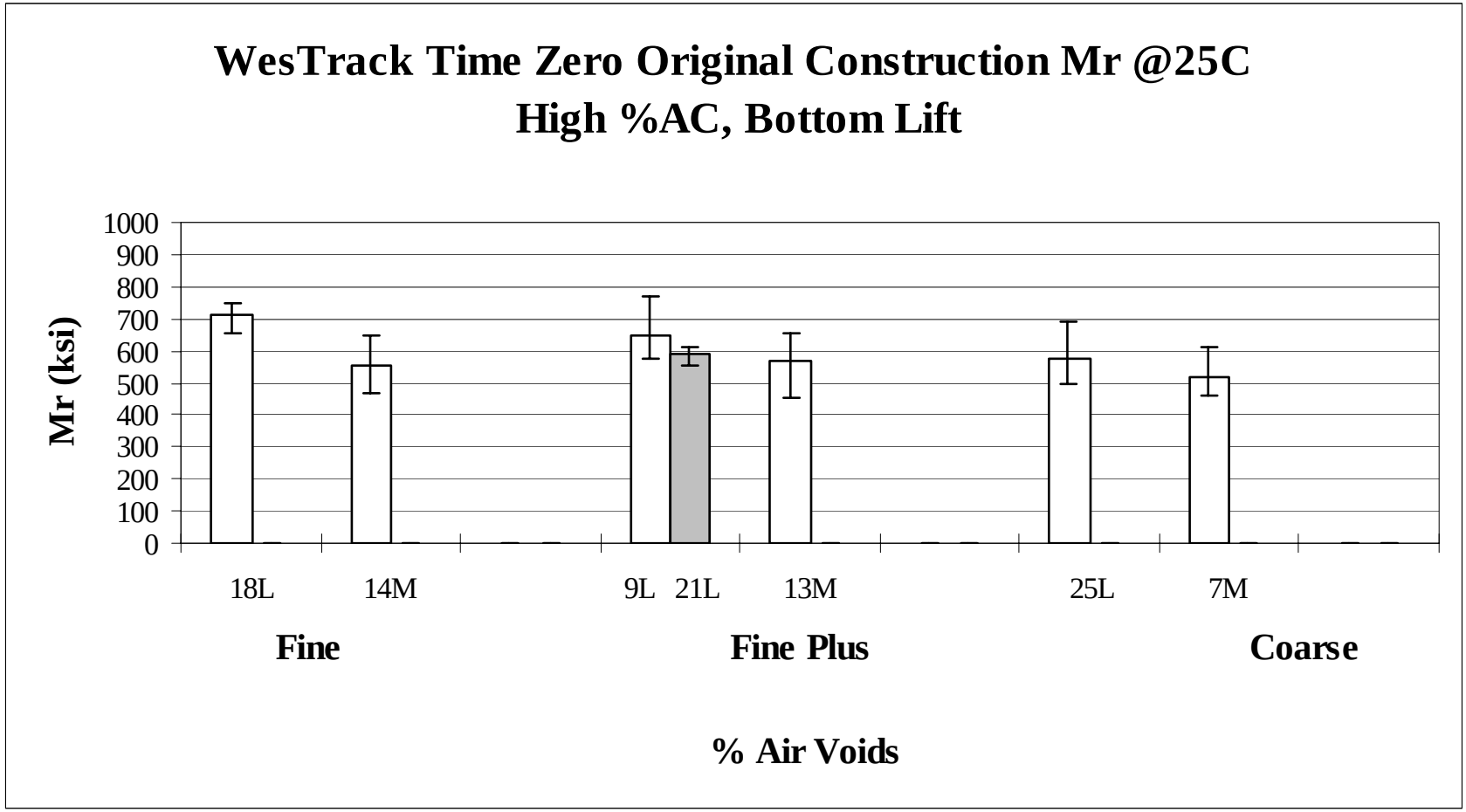


Figure 10. Resilient modulus of the mixtures designed with high asphalt content (bottom lifts).

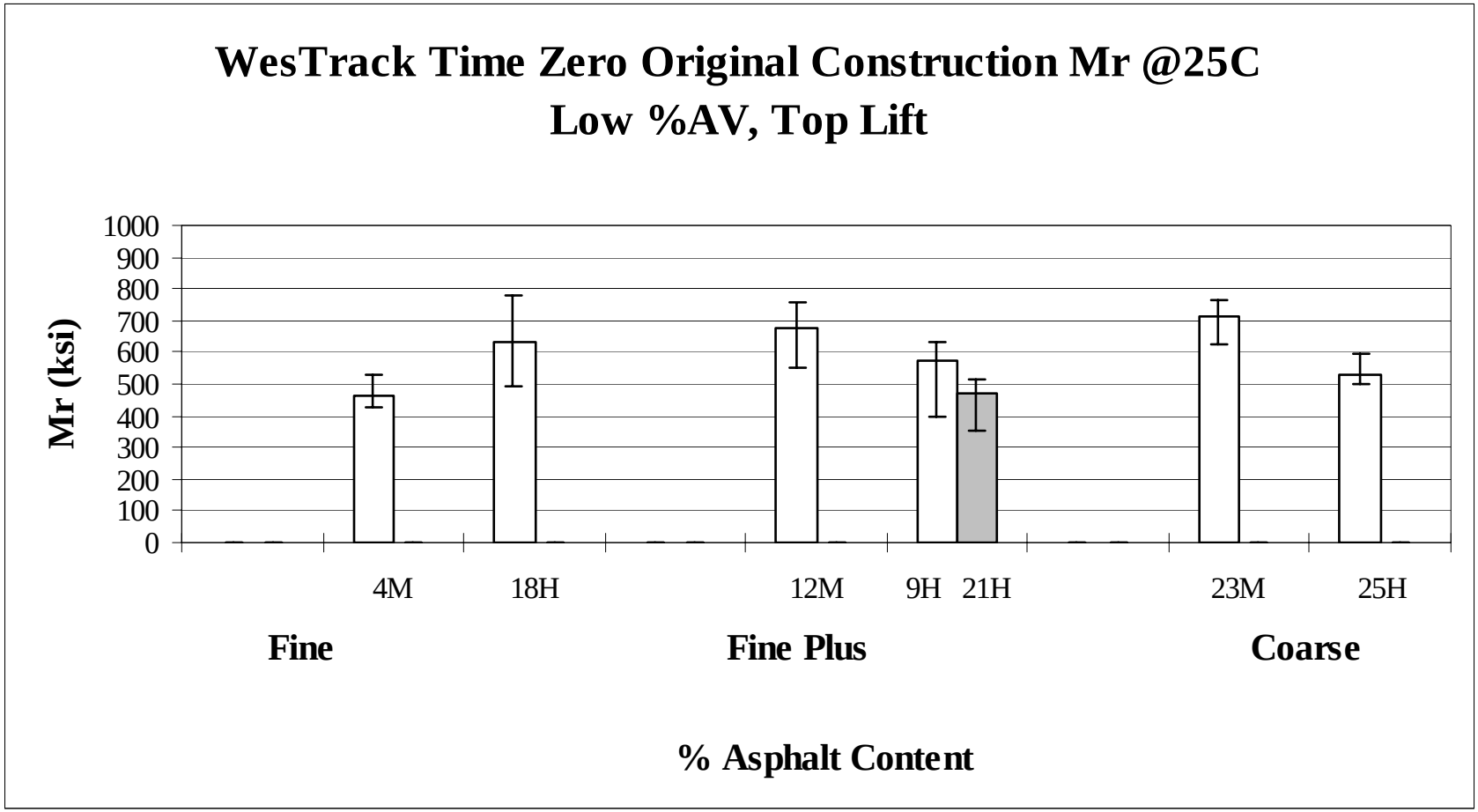


Figure 11. Resilient modulus of the mixtures designed with low air voids (top lifts).

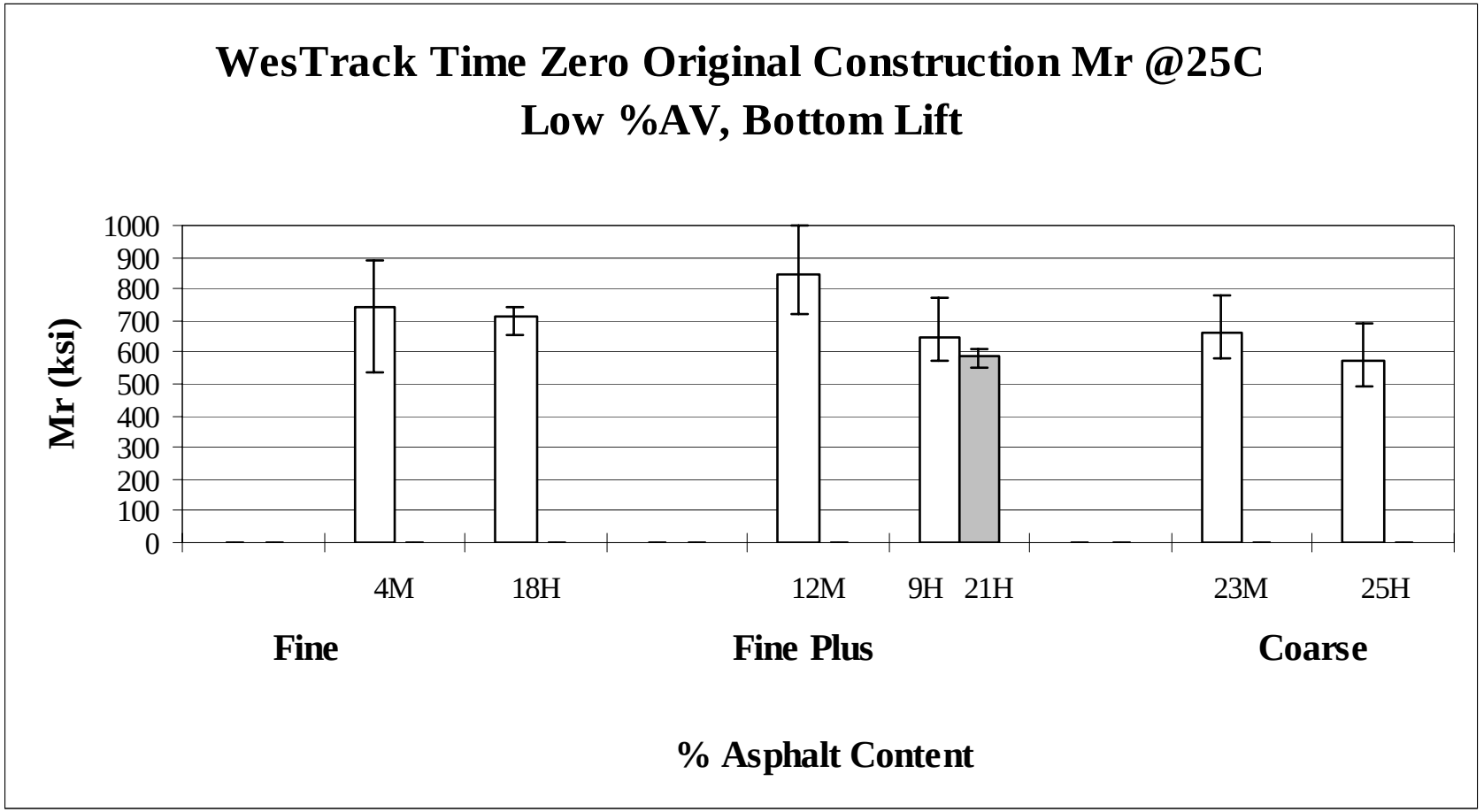


Figure 12. Resilient modulus of the mixtures designed with low air voids (bottom lifts).

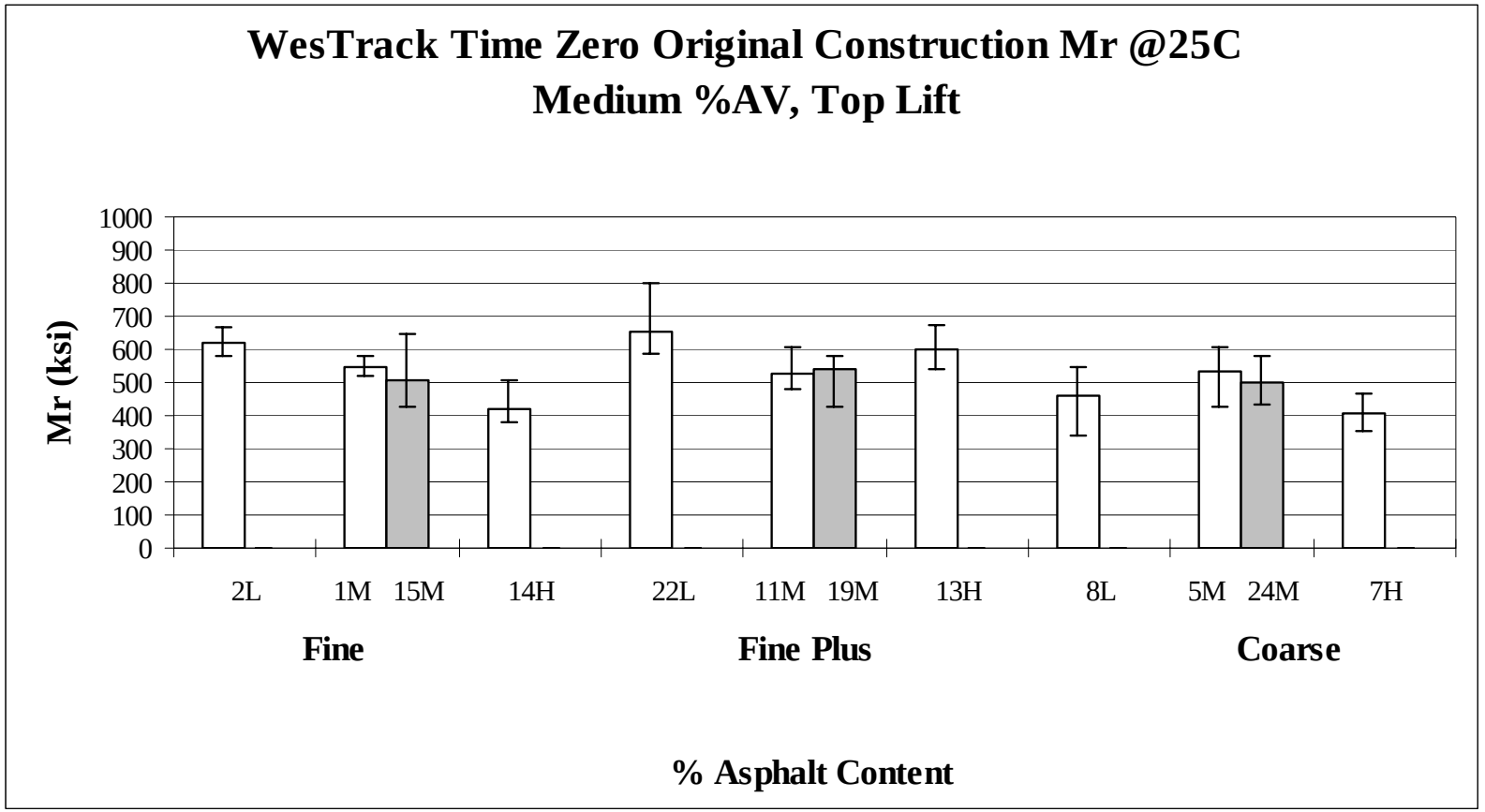


Figure 13. Resilient modulus of the mixtures designed with medium air voids (top lifts).

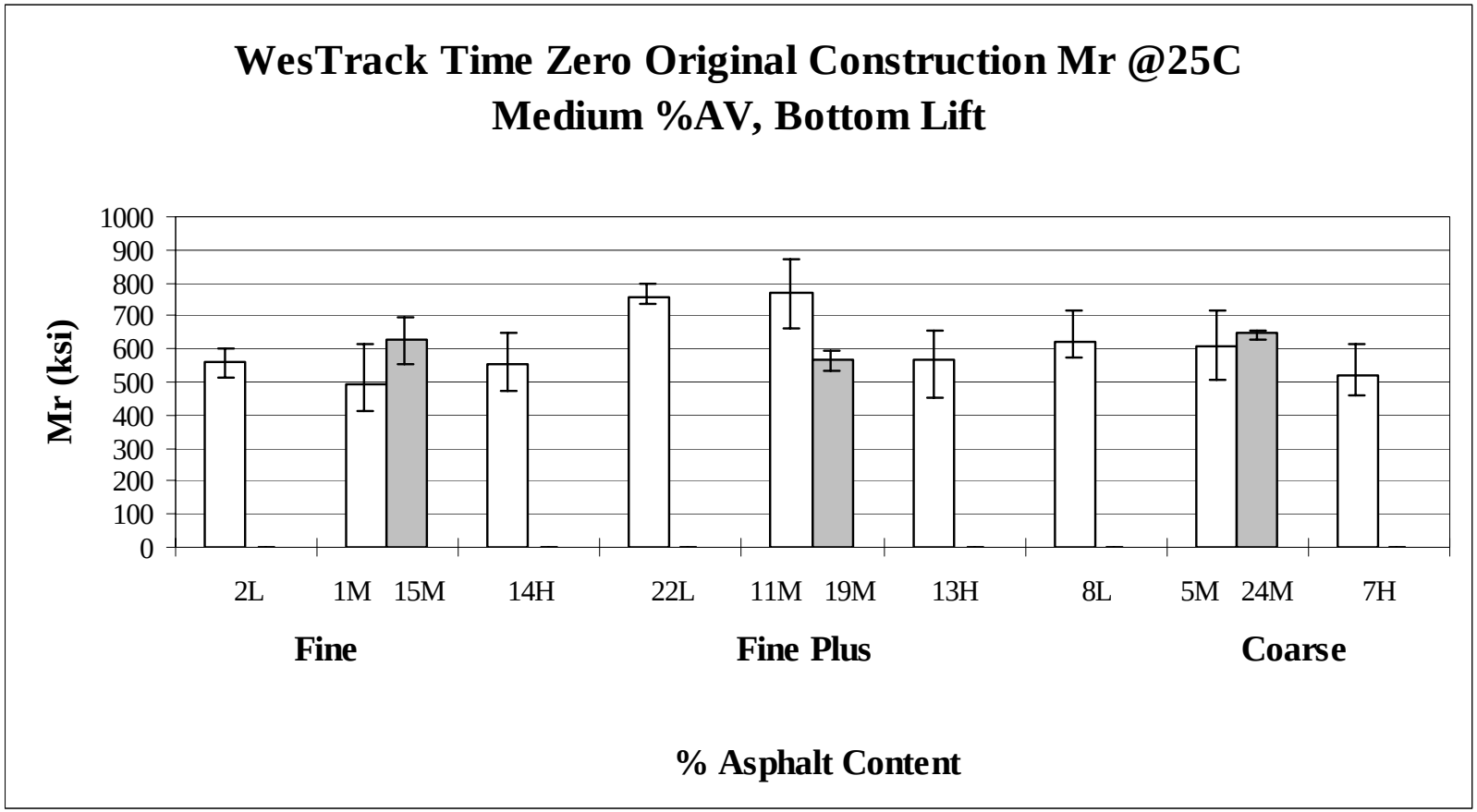


Figure 14. Resilient modulus of the mixtures designed with medium air voids (bottom lifts).

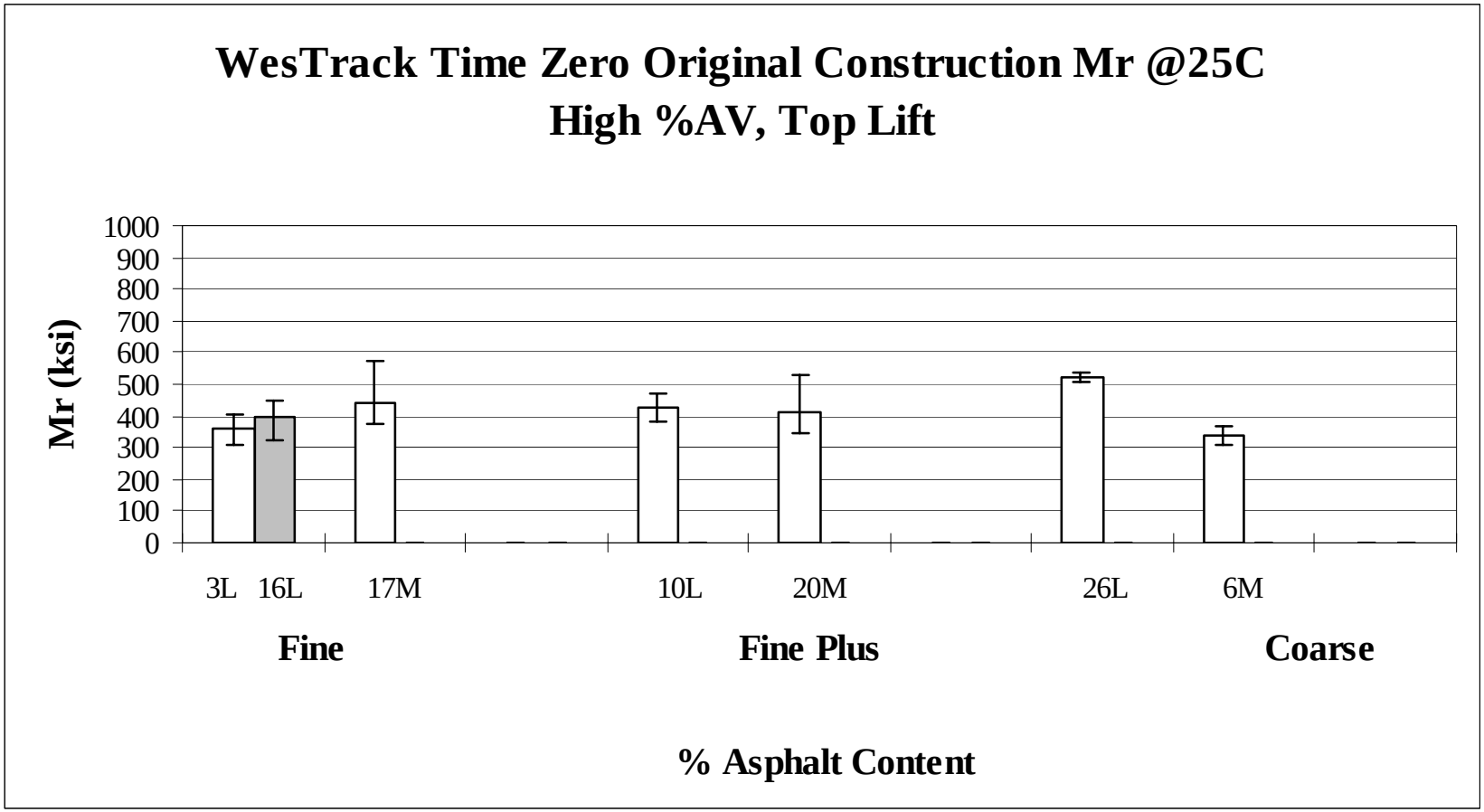


Figure 15. Resilient modulus of the mixtures designed with high air voids (top lifts).

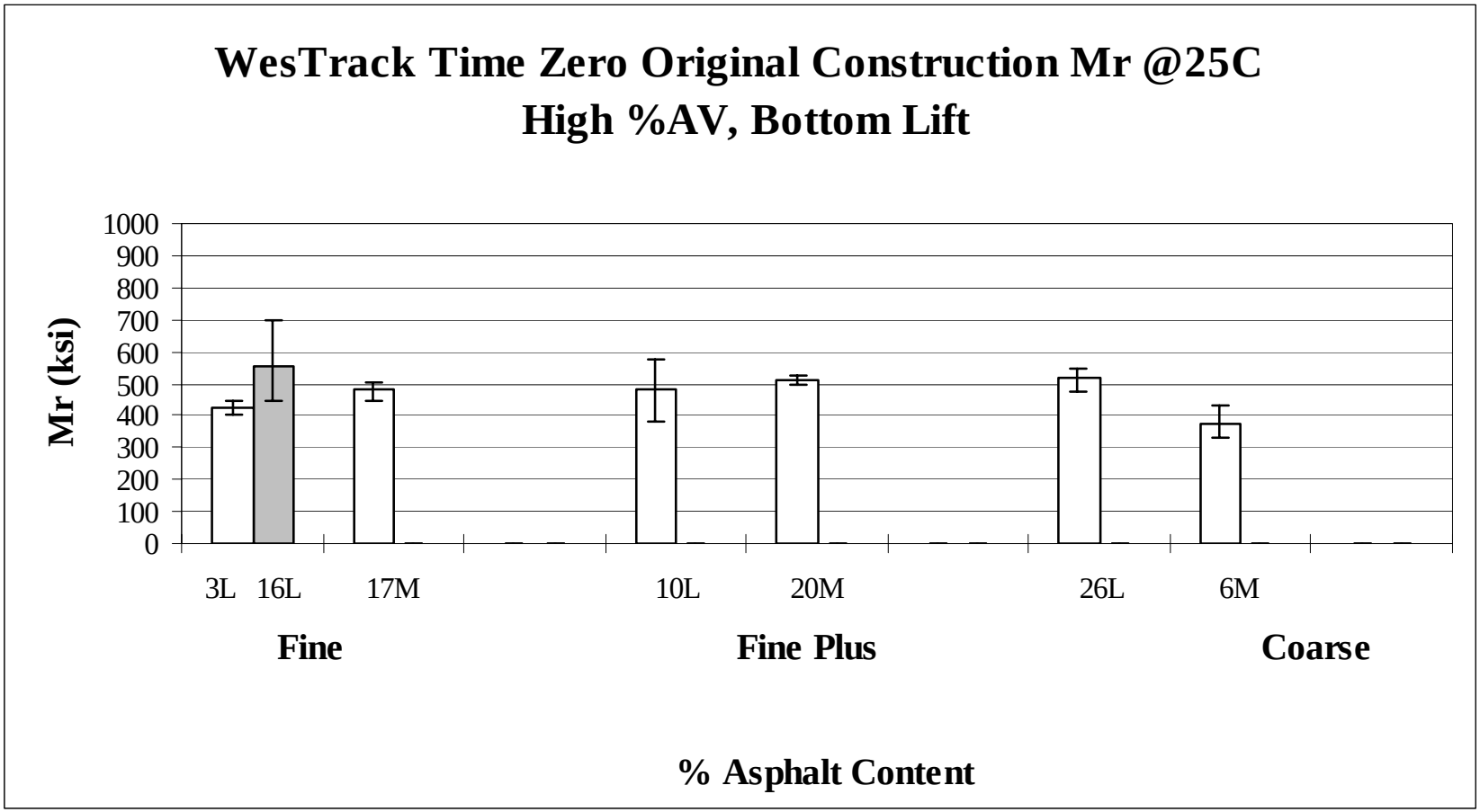


Figure 16. Resilient modulus of the mixtures designed with high air voids (bottom lifts).

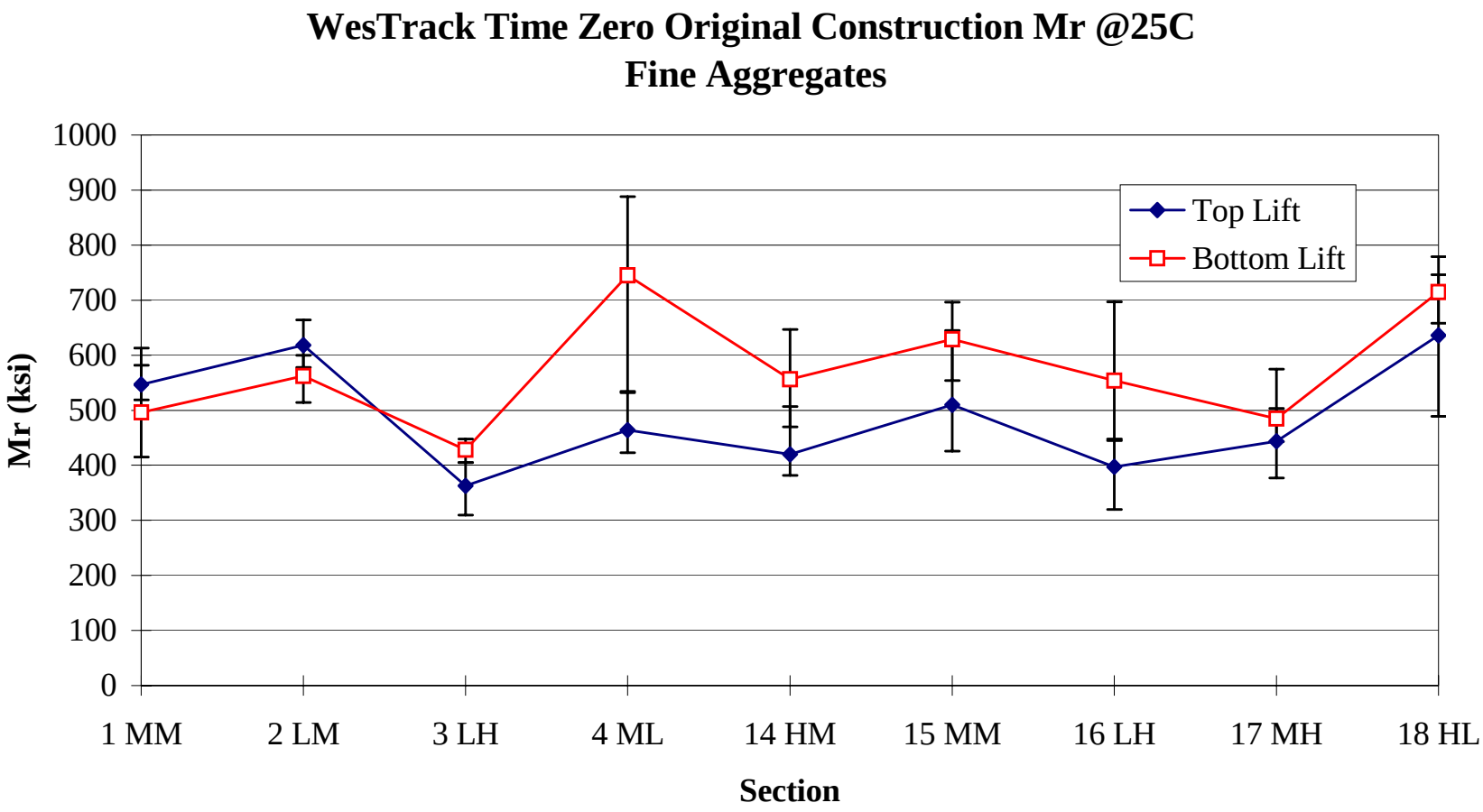


Figure 17. Resilient modulus of the mixtures designed with fine aggregate gradation.

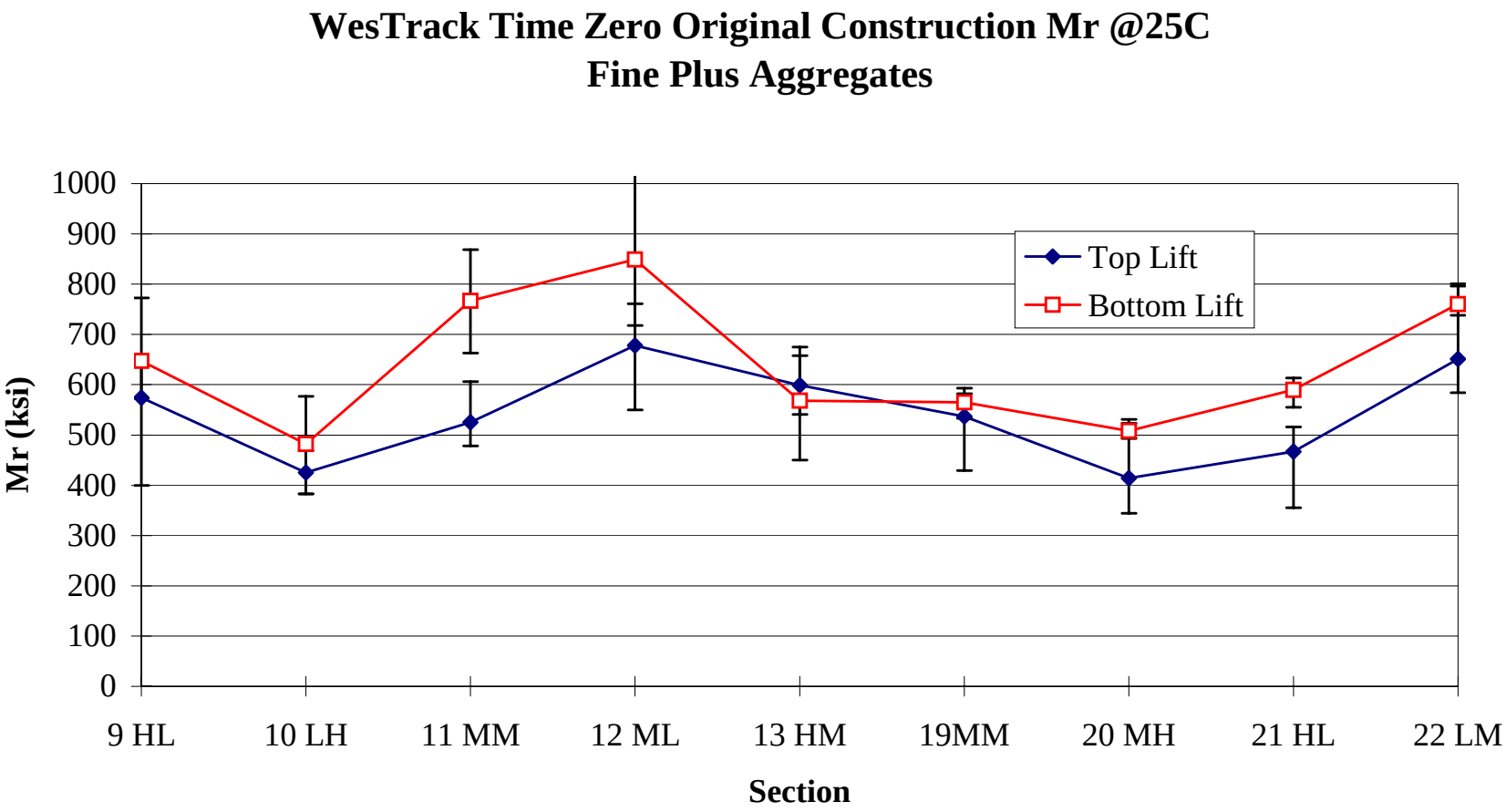


Figure 18. Resilient modulus of the mixtures designed with fine plus aggregate gradation.

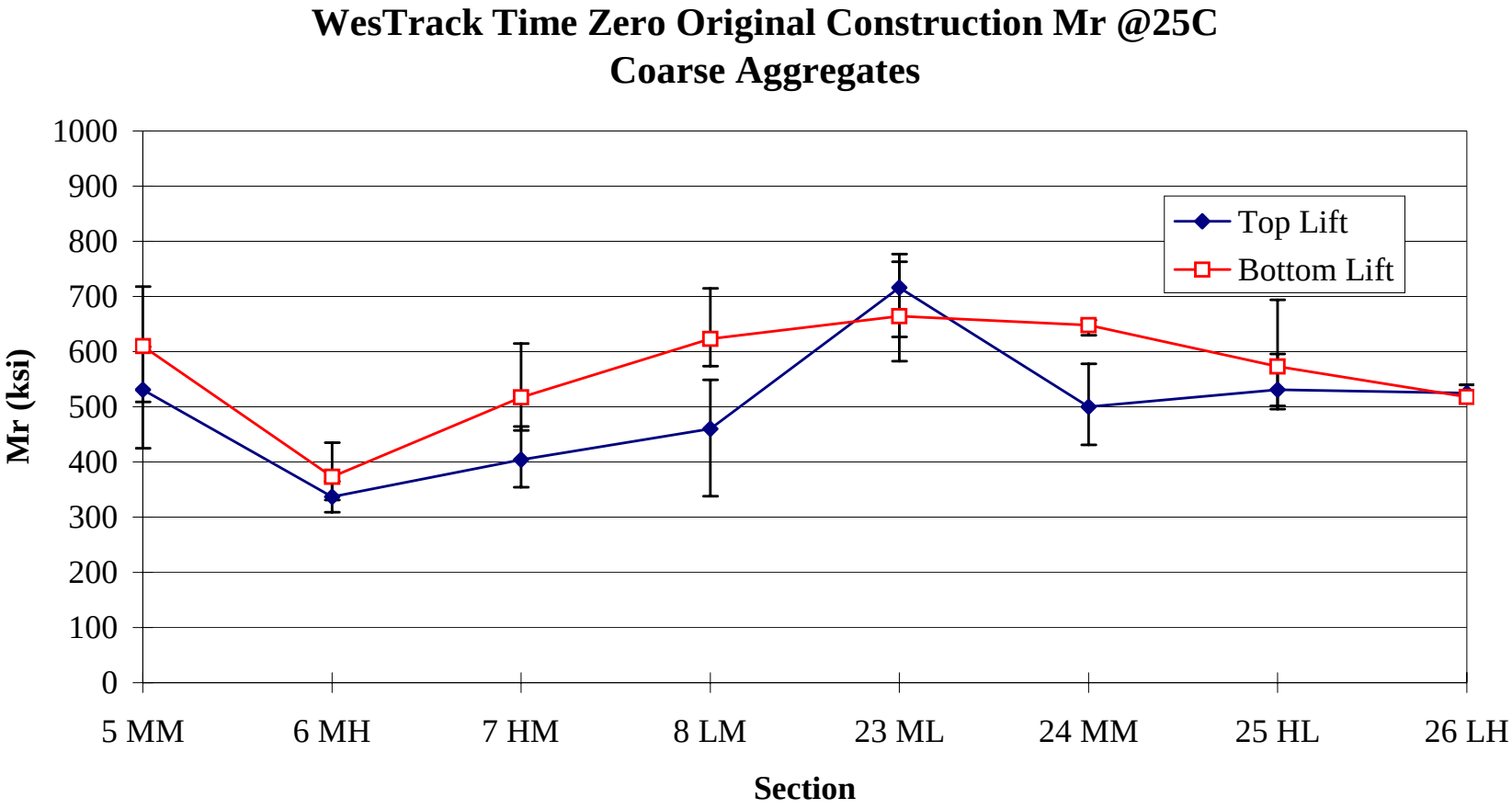


Figure 19. Resilient modulus of the mixtures designed with coarse aggregate gradation.

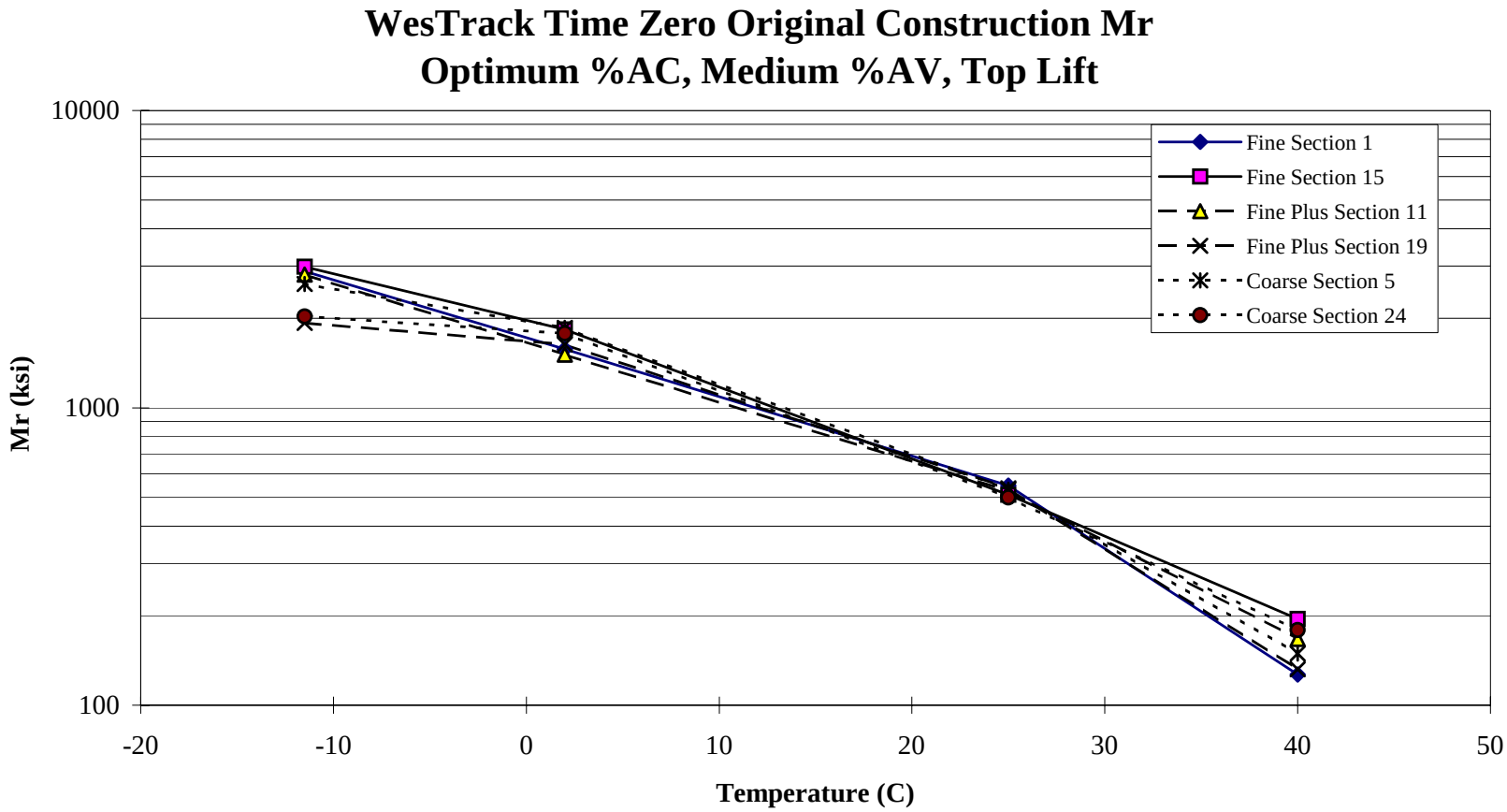


Figure 20. Variation of resilient modulus with temperature (top lifts).

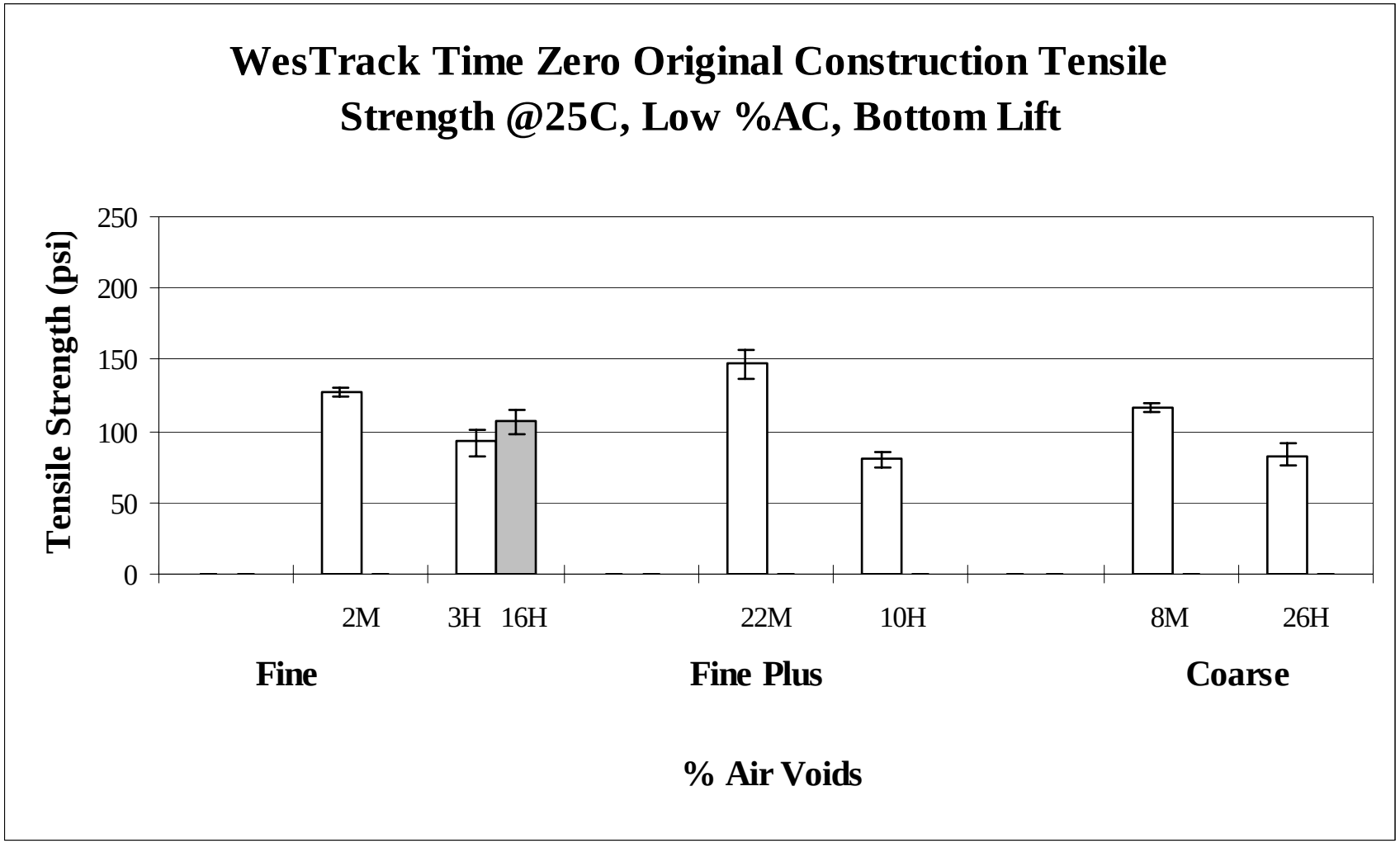


Figure 21. Tensile strengths of the mixtures designed with low asphalt content.

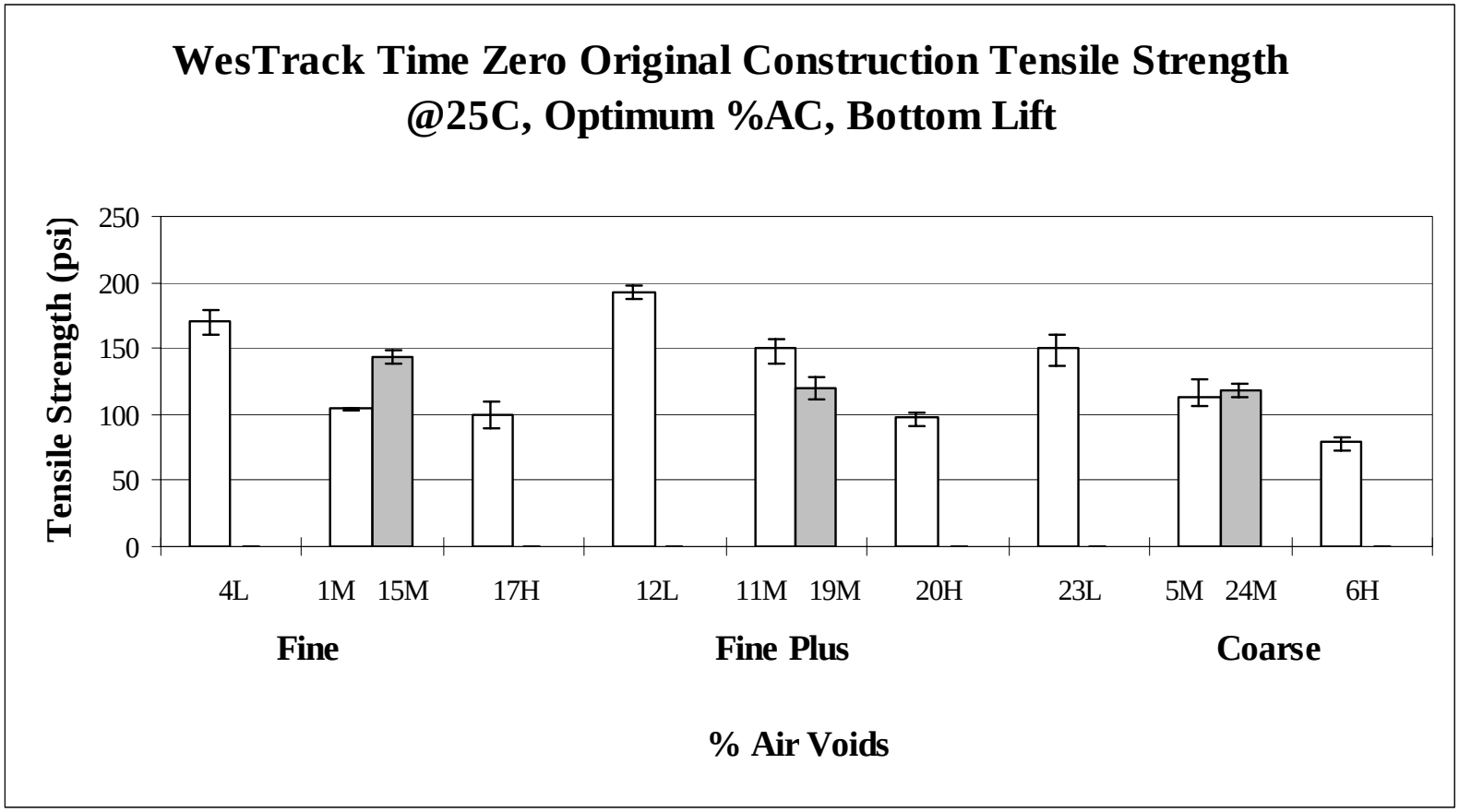


Figure 22. Tensile strengths of the mixtures designed with optimum asphalt content.

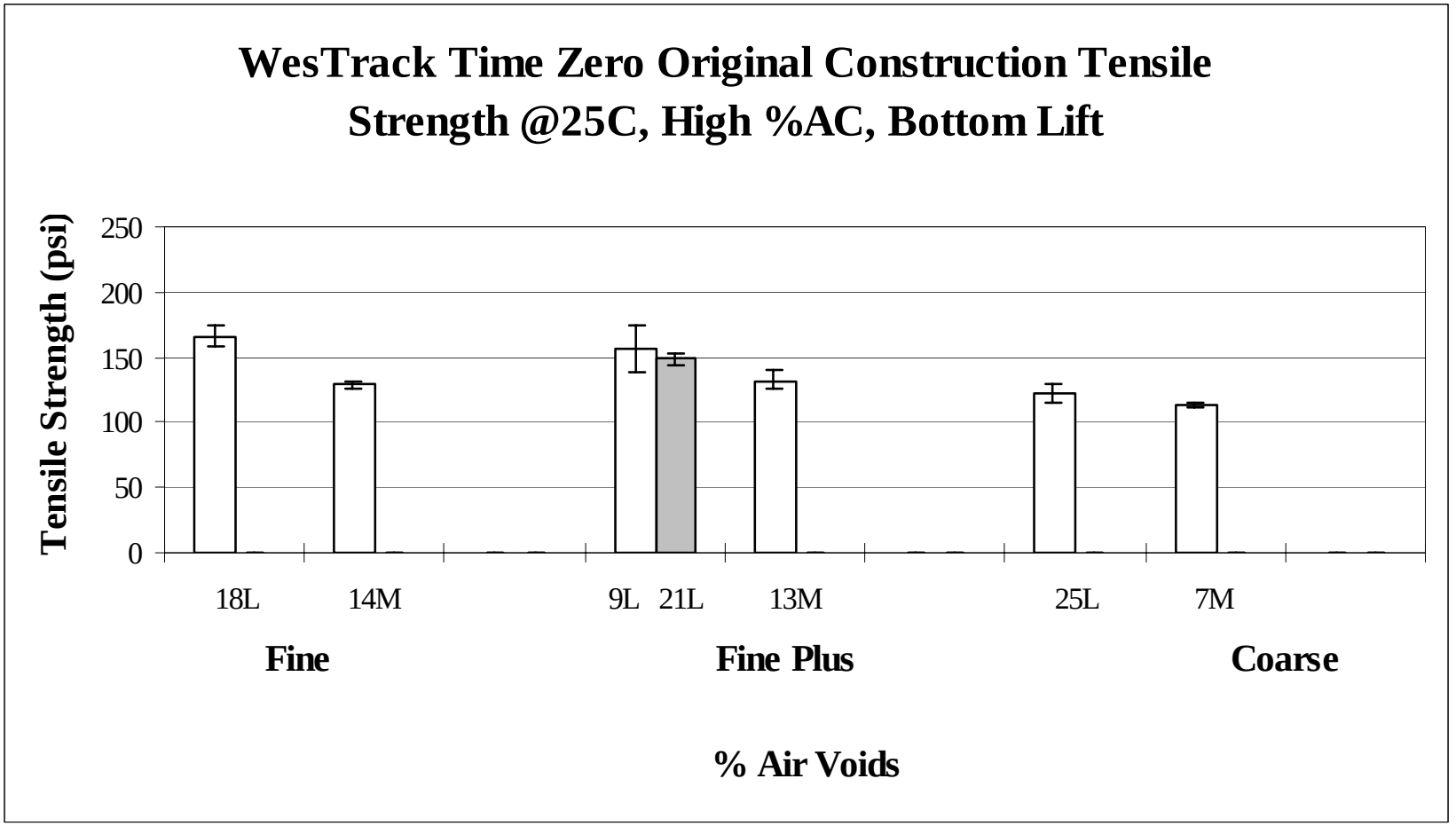


Figure 23. Tensile strengths of the mixtures designed with high asphalt content.

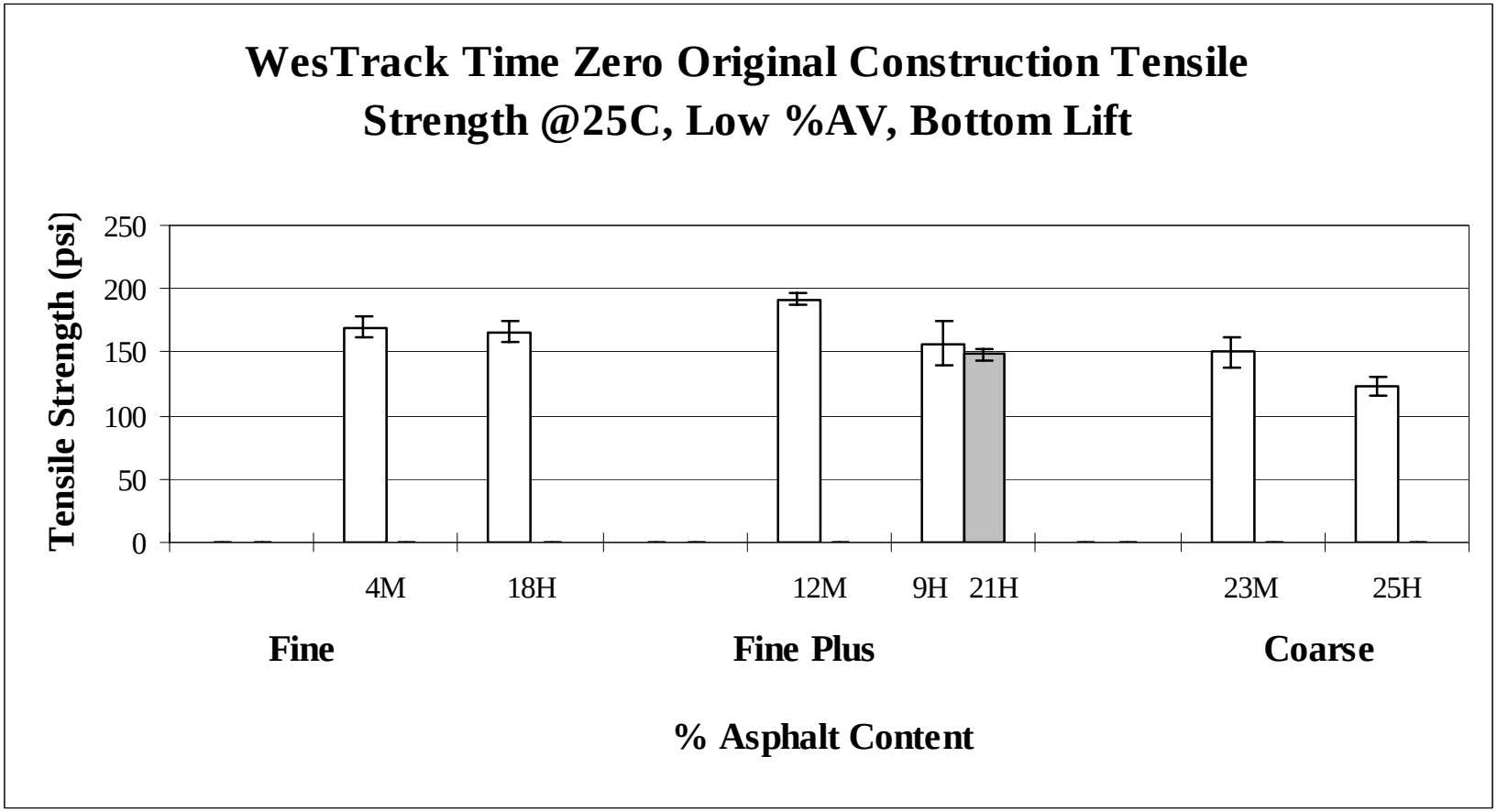


Figure 24. Tensile strengths of the mixtures designed with low air voids content.

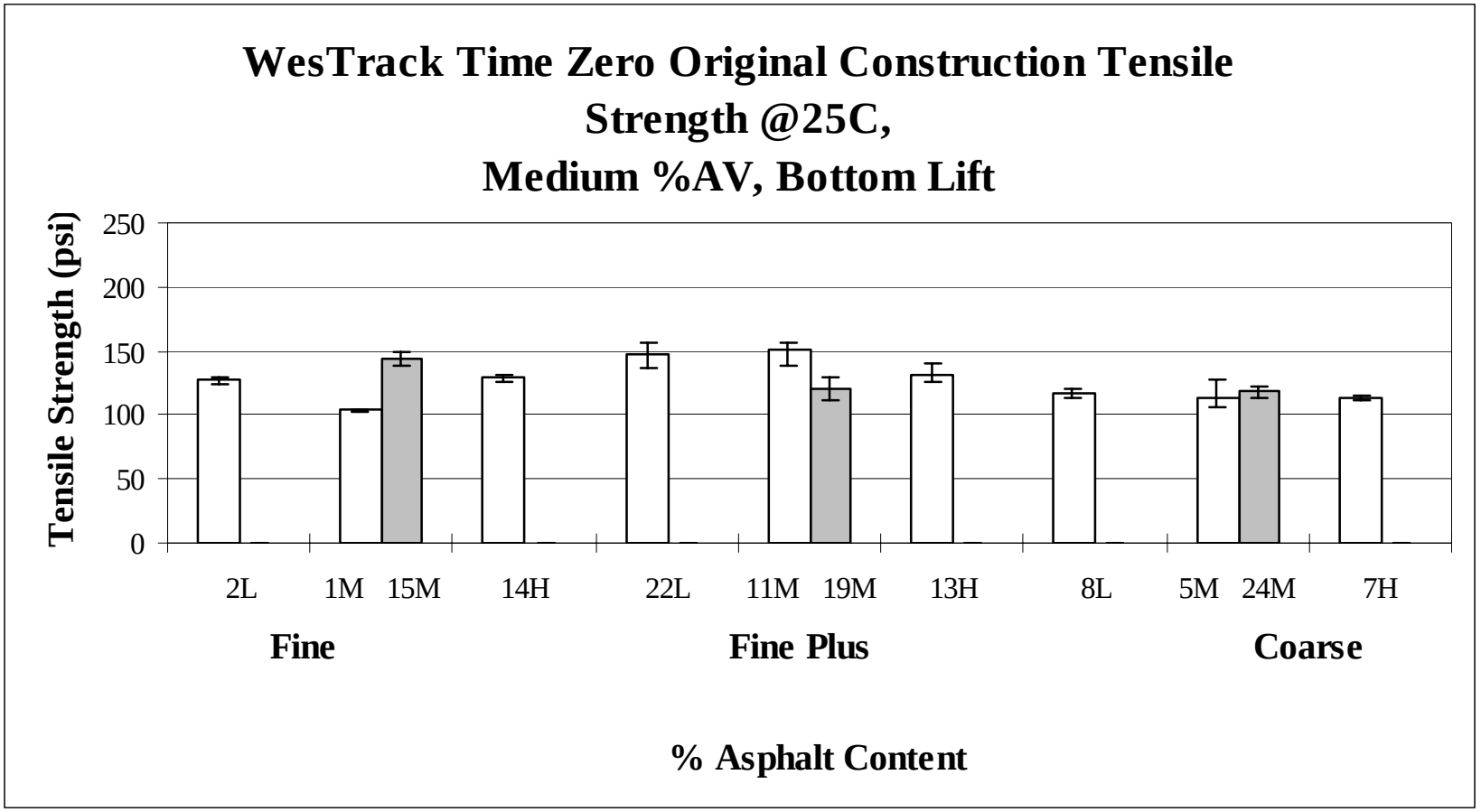


Figure 25. Tensile strengths of the mixtures designed with medium air voids content.

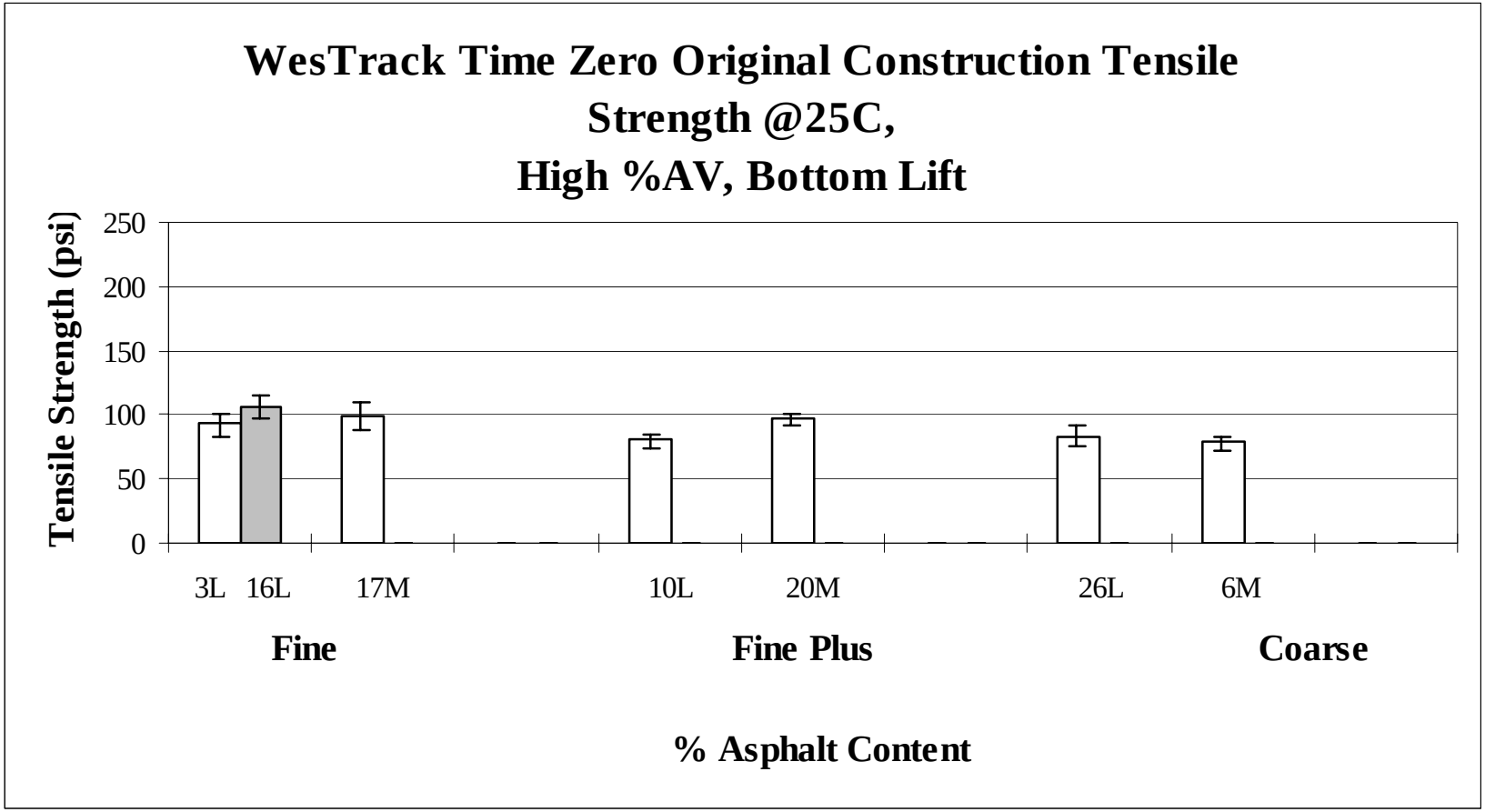


Figure 26. Tensile strengths of the mixtures designed with high air voids content.

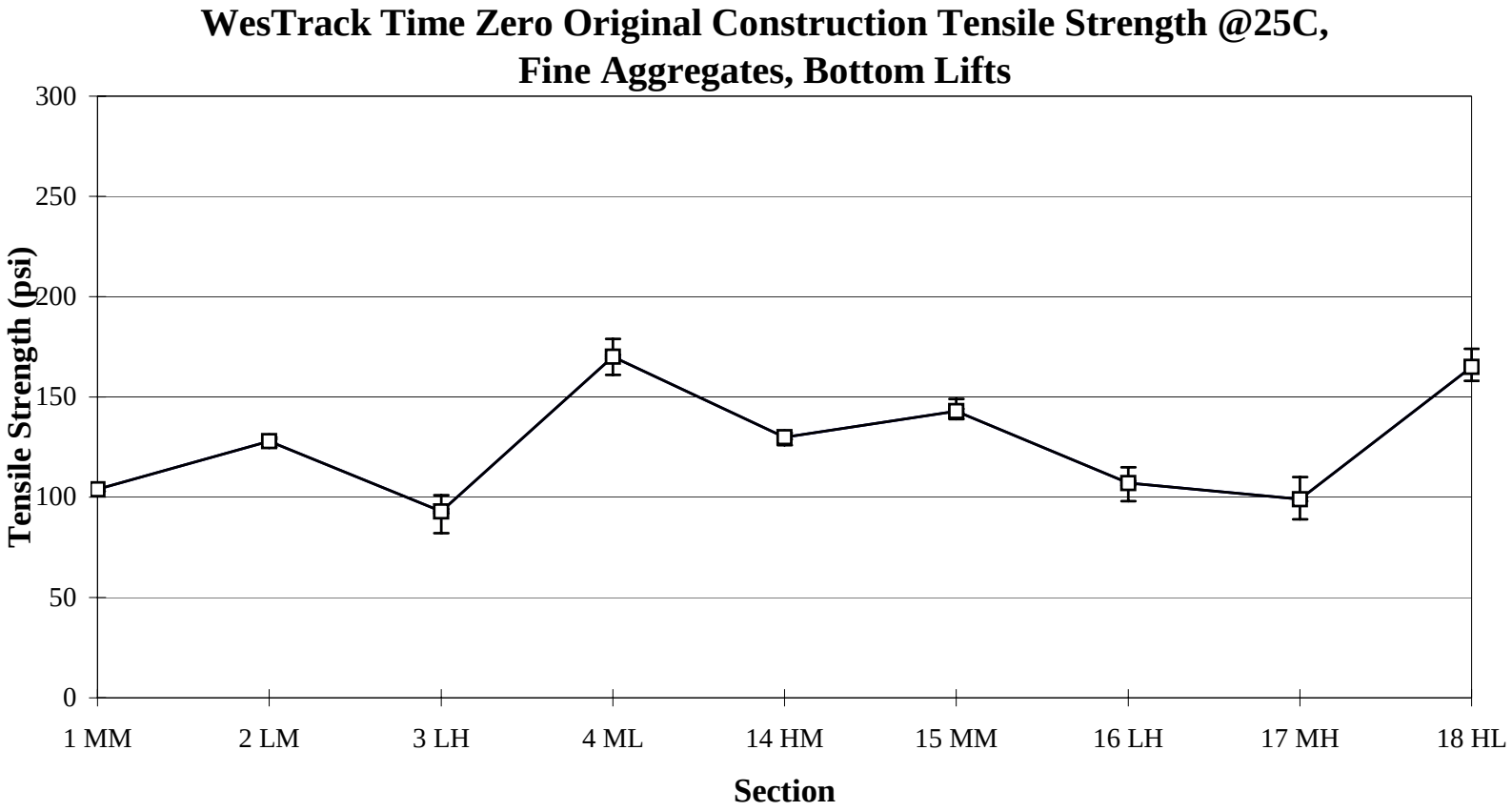


Figure 27. Tensile strengths of the mixtures designed with fine aggregate gradation.

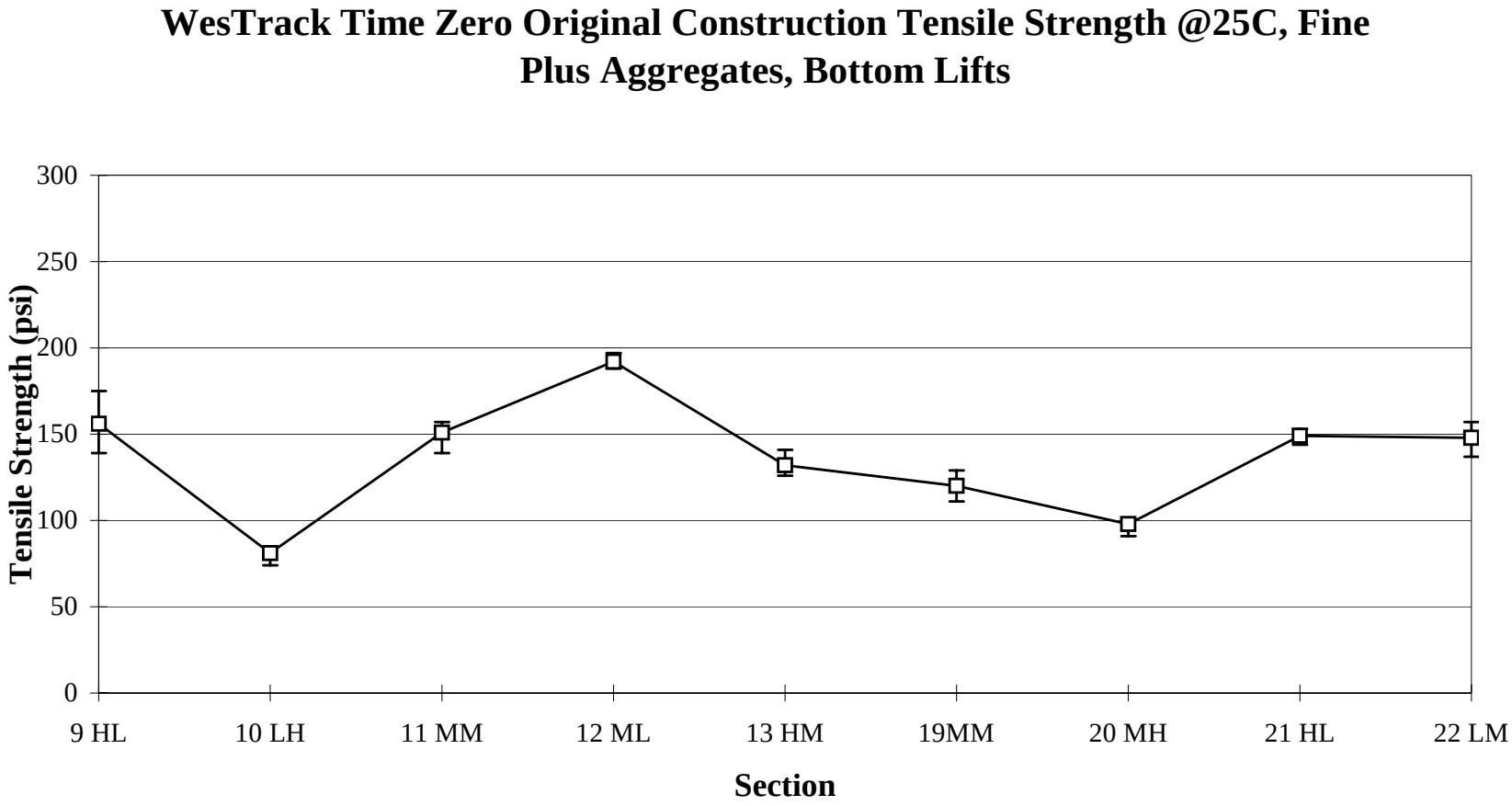


Figure 28. Tensile strengths of the mixtures designed with fine plus aggregate gradation.

Figure 29. Tensile strengths of the mixtures designed with coarse aggregate gradation.

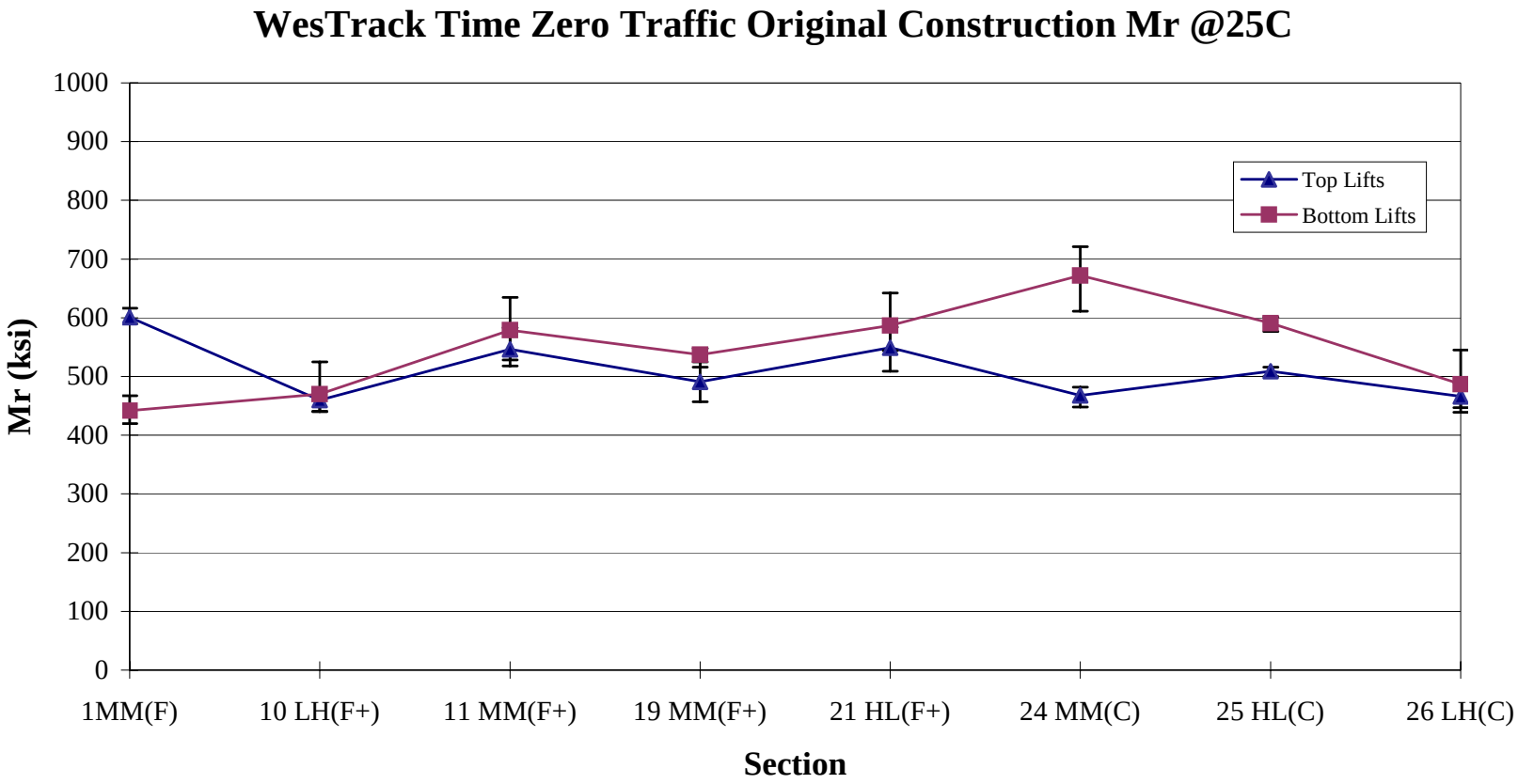


Figure 30. Resilient modulus at time-zero traffic, original construction.

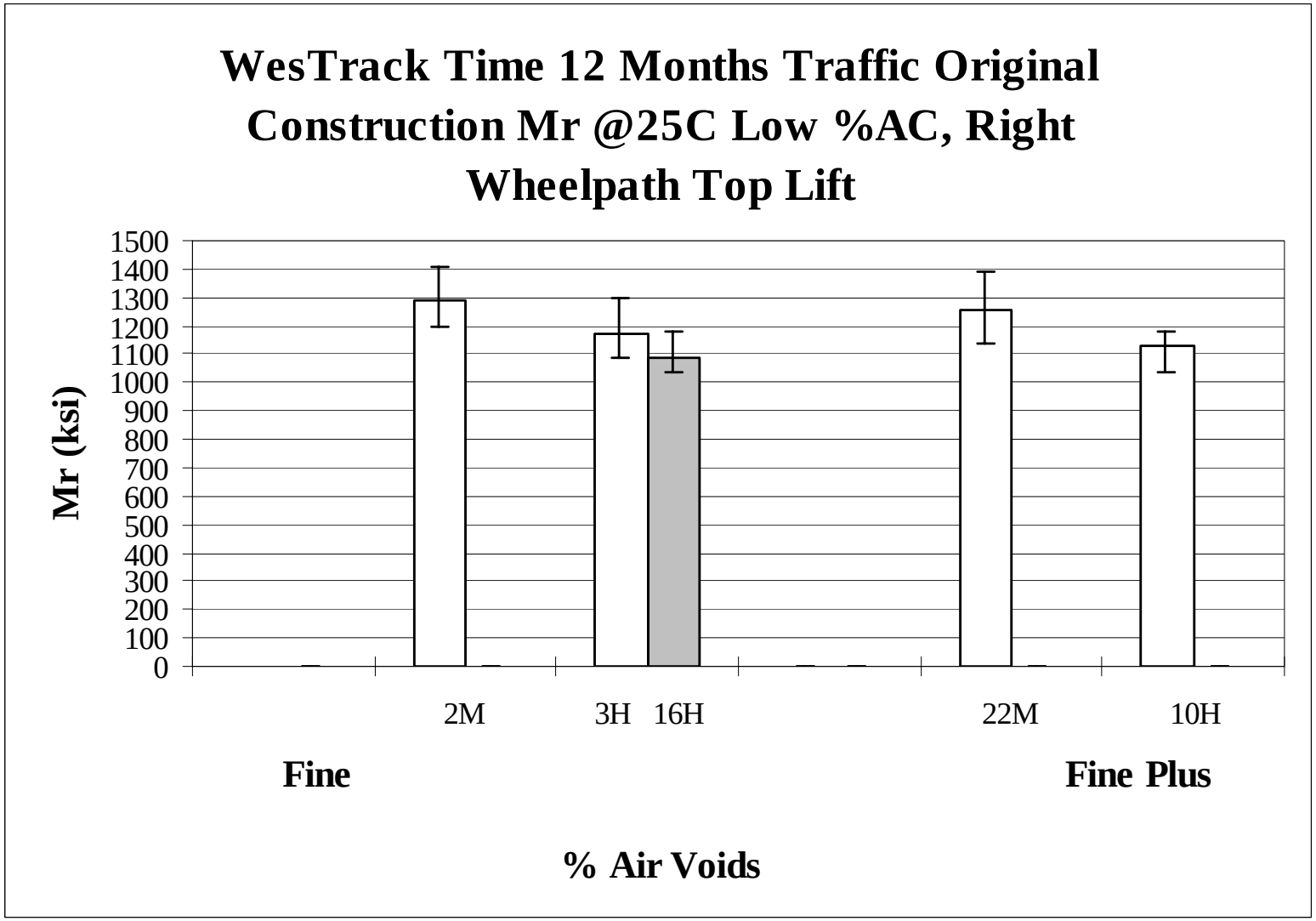


Figure 31. Resilient modulus of the mixtures designed with low asphalt content (top lifts).

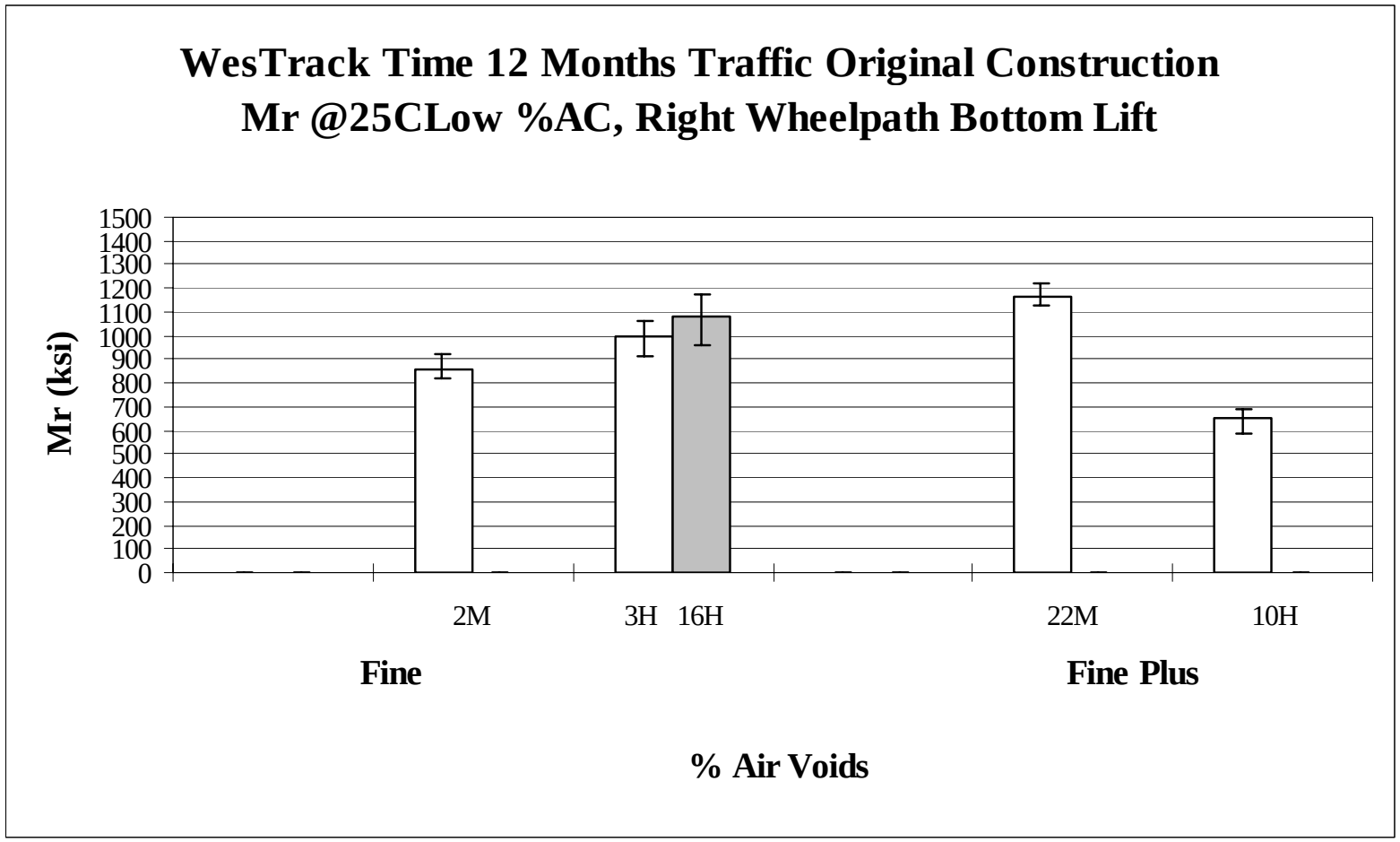


Figure 32. Resilient modulus of the mixtures designed with low asphalt content (bottom lifts).

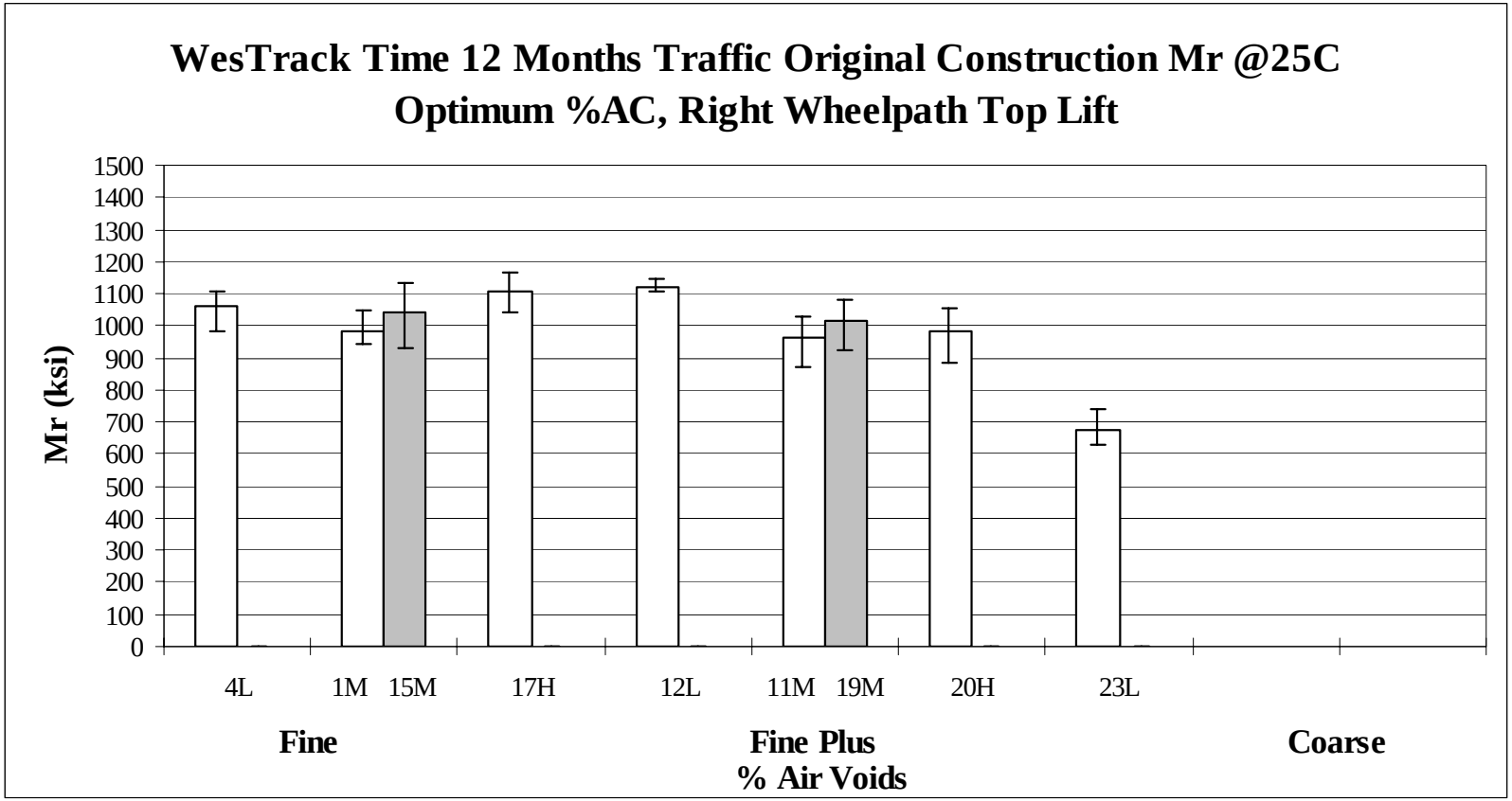


Figure 33. Resilient modulus of the mixtures designed with optimum asphalt content (top lifts).

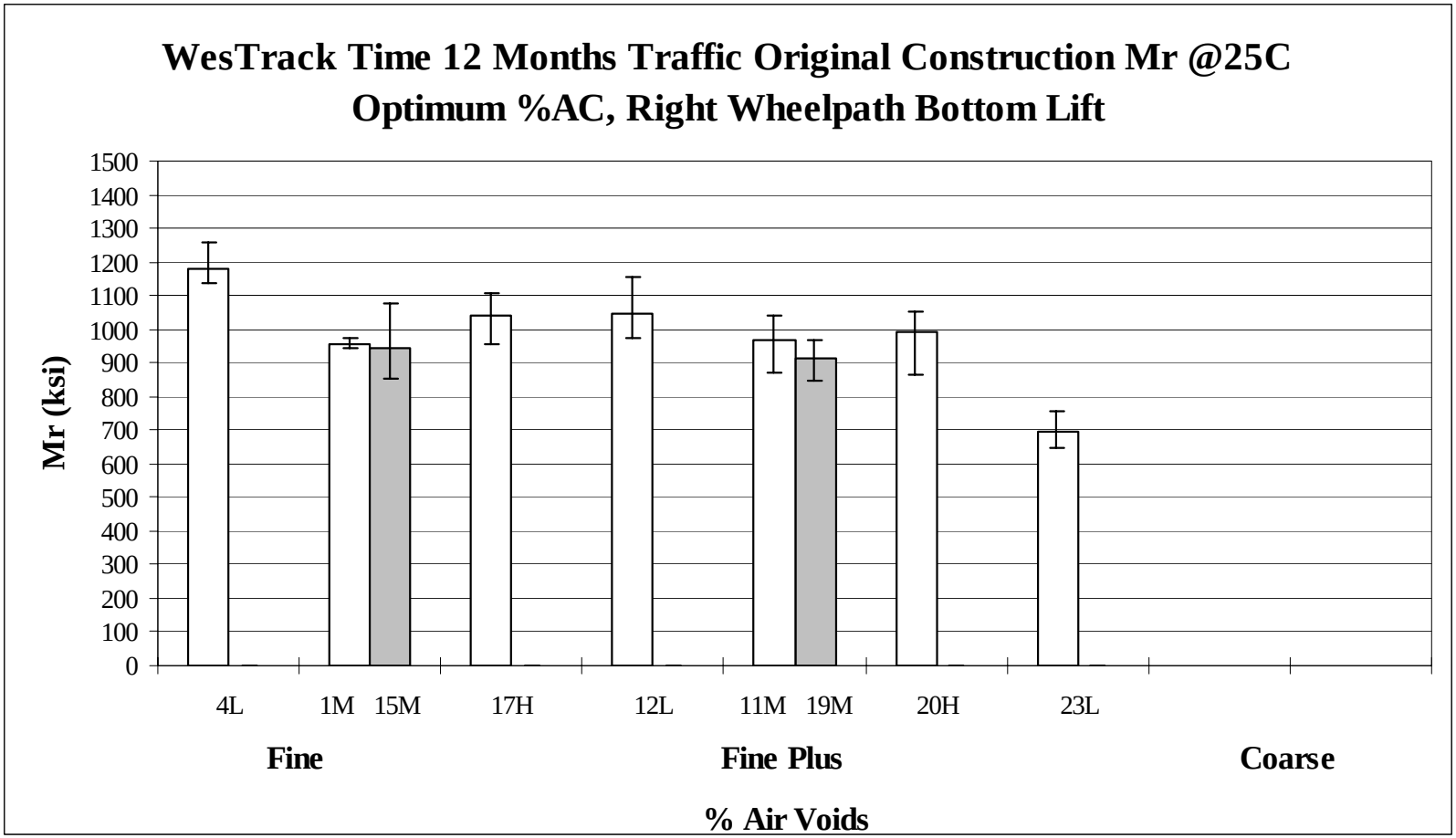


Figure 34. Resilient modulus of the mixtures designed with optimum asphalt content (bottom lifts).

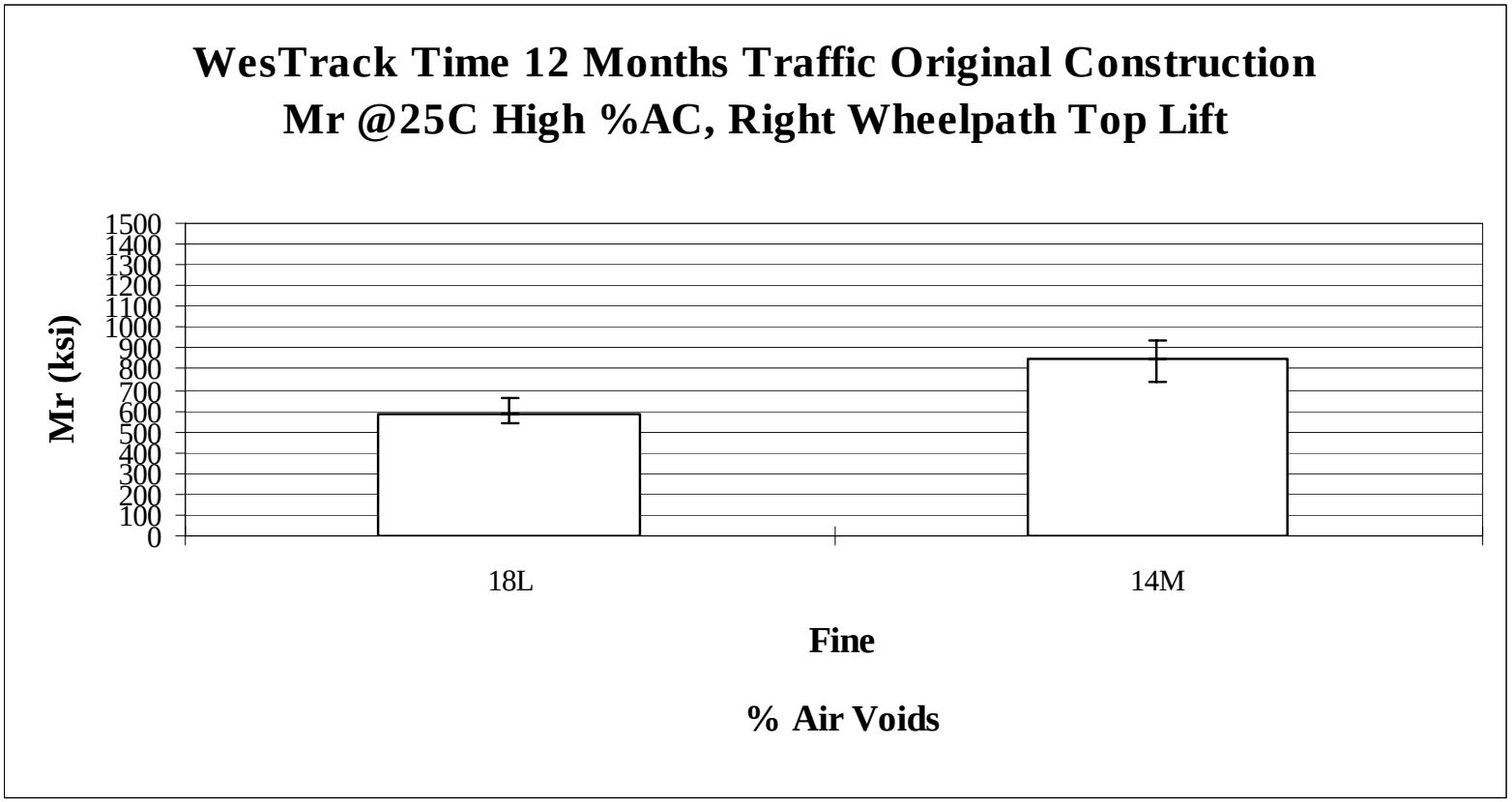


Figure 35. Resilient modulus of the mixtures designed with high asphalt content (top lifts).

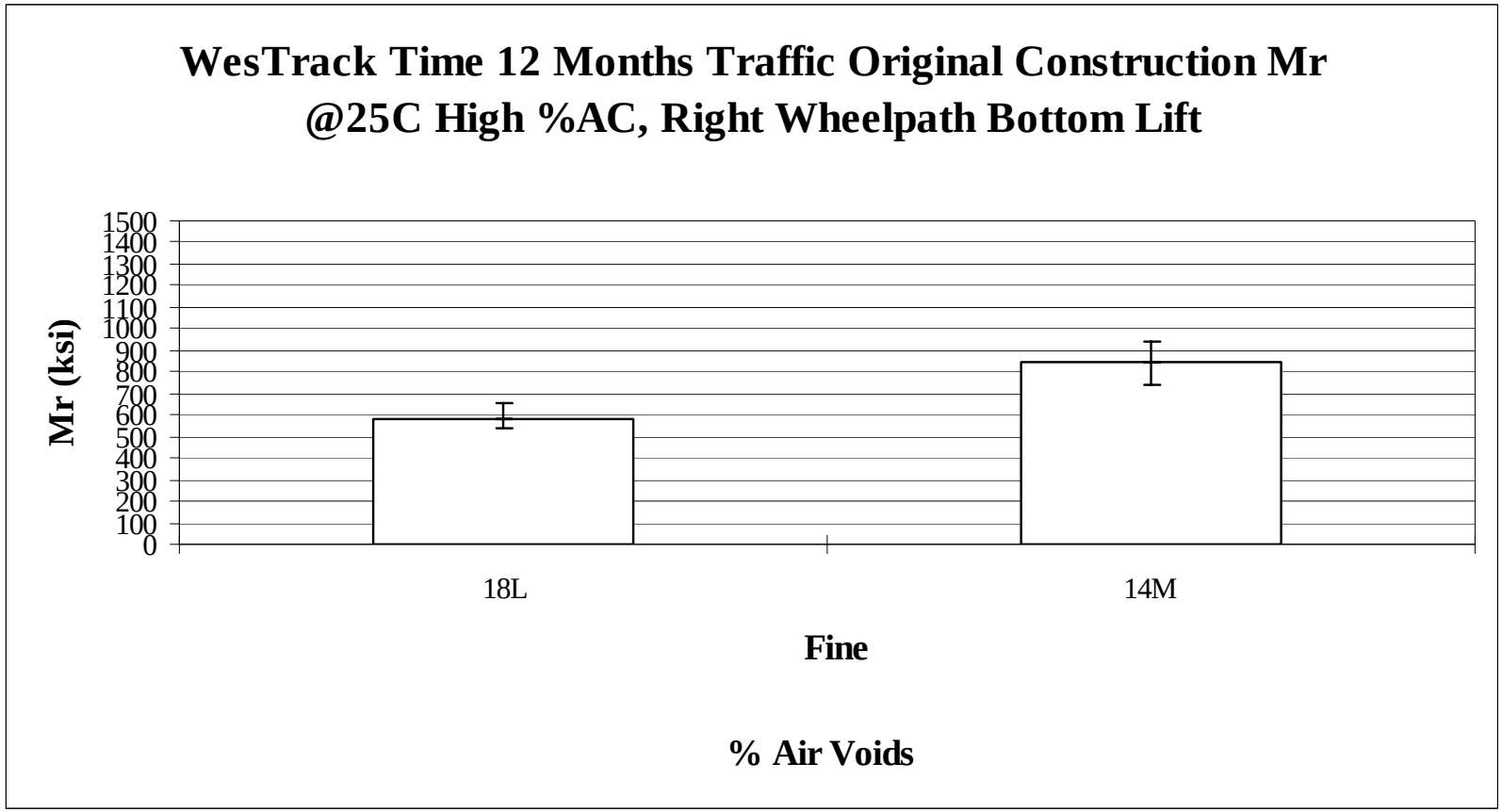


Figure 36. Resilient modulus of the mixtures designed with high asphalt content (bottom lifts).

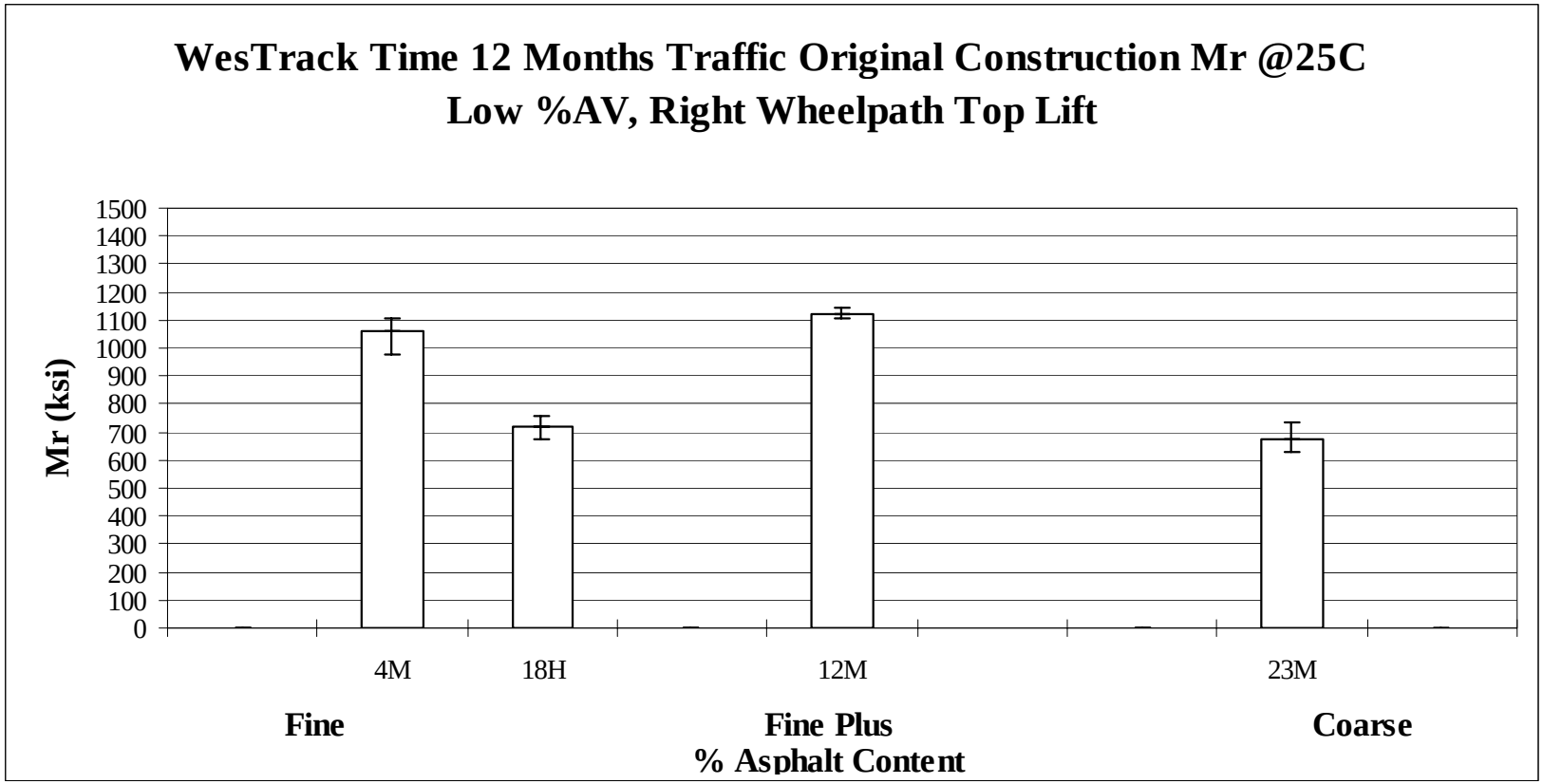


Figure 37. Resilient modulus of the mixtures designed with low air voids content (top lifts).

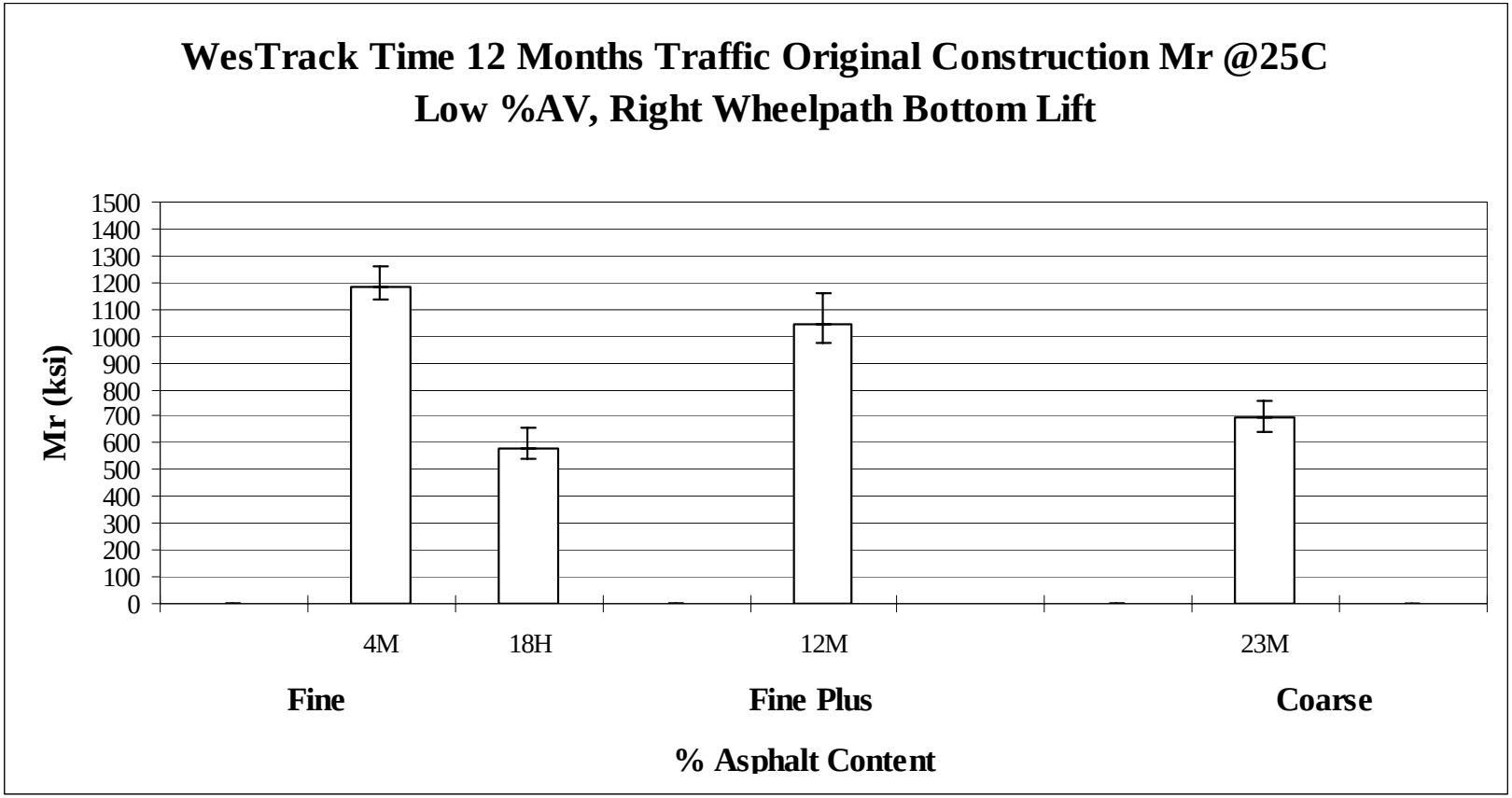


Figure 38. Resilient modulus of the mixtures designed with low air voids content (bottom lifts).

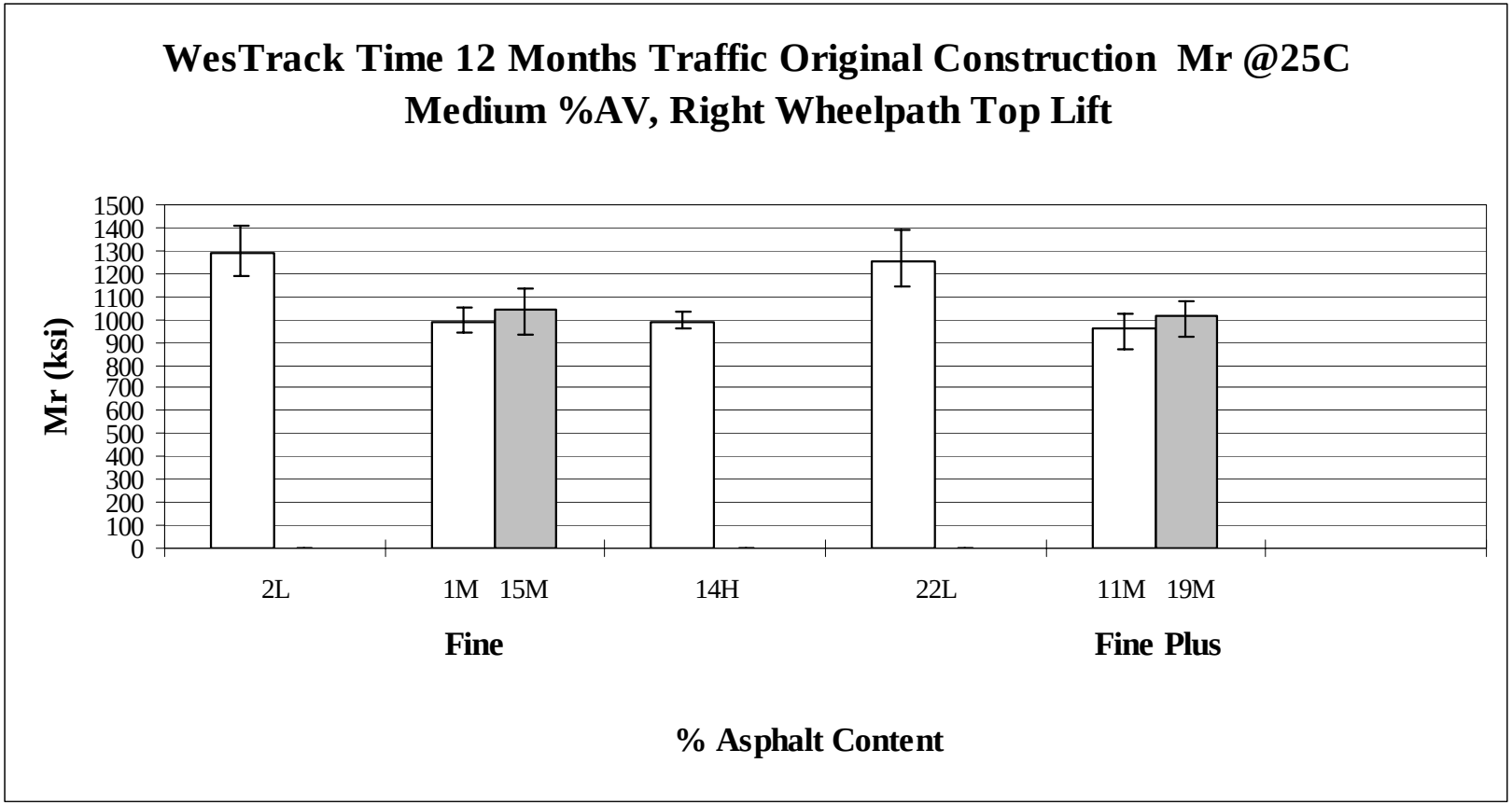


Figure 39. Resilient modulus of the mixtures designed with medium air voids content (top lifts).

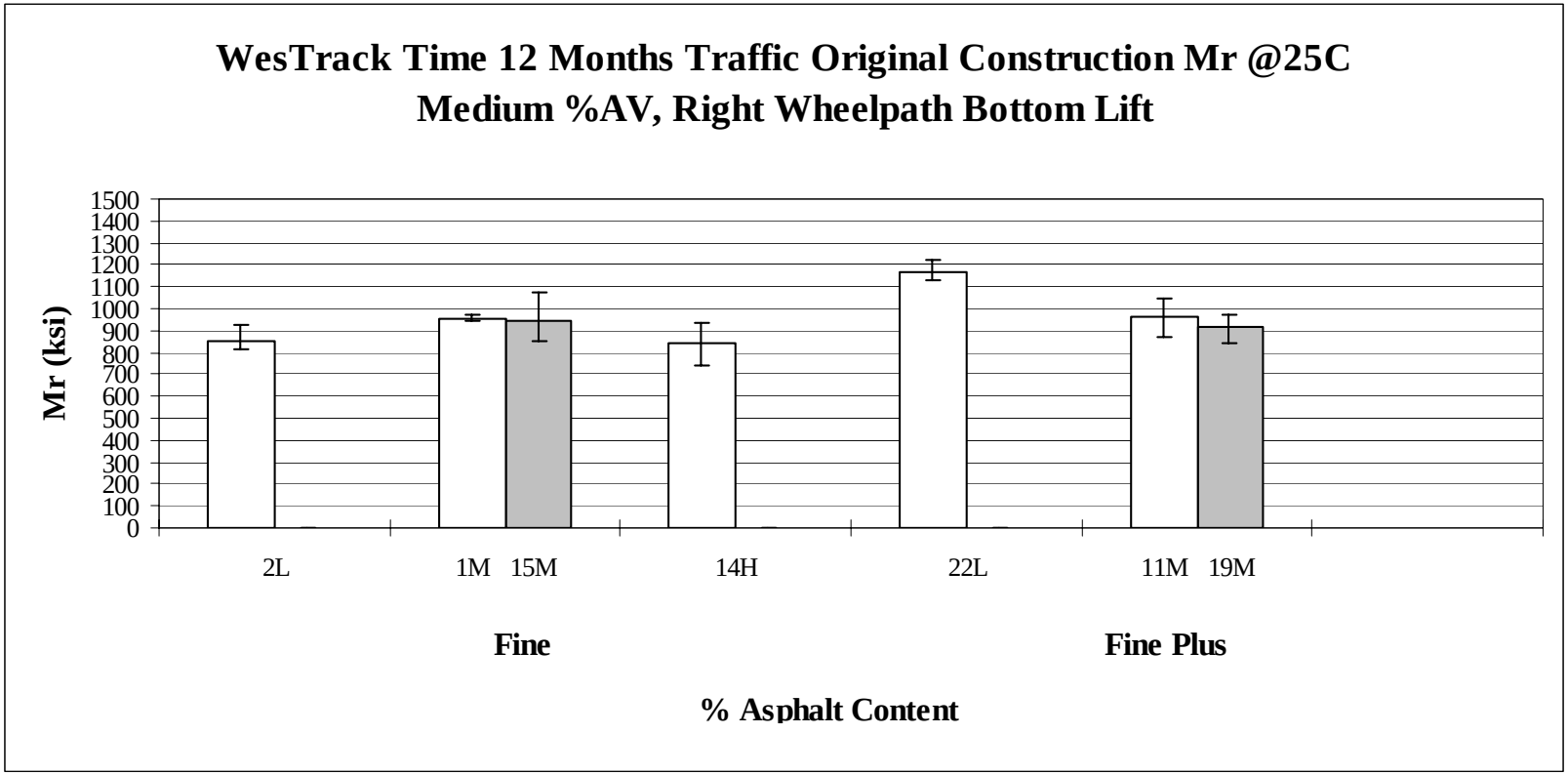


Figure 40. Resilient modulus of the mixtures designed with medium air voids content (bottom lifts).

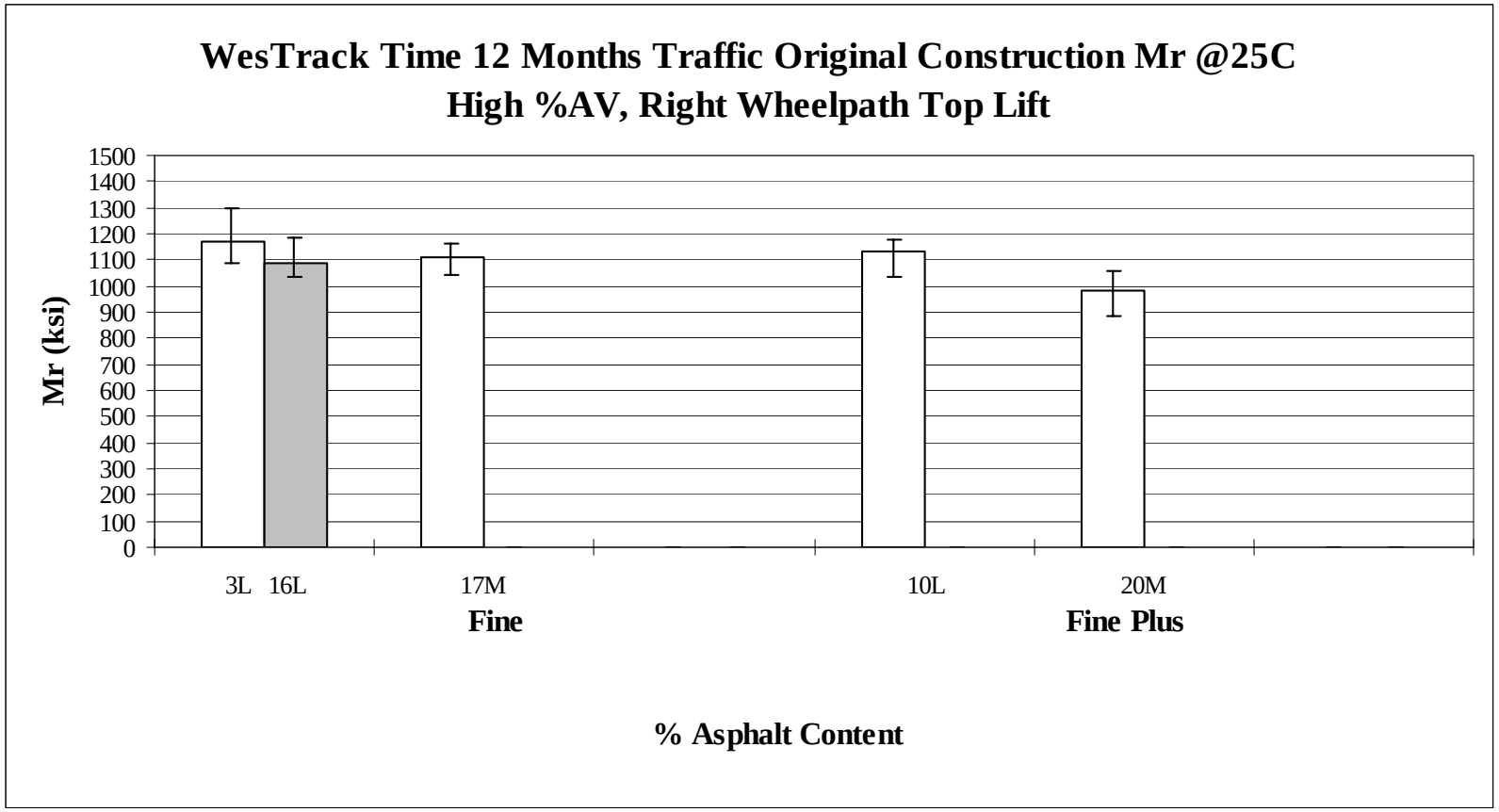


Figure 41. Resilient modulus of the mixtures designed with high air voids content (top lifts).

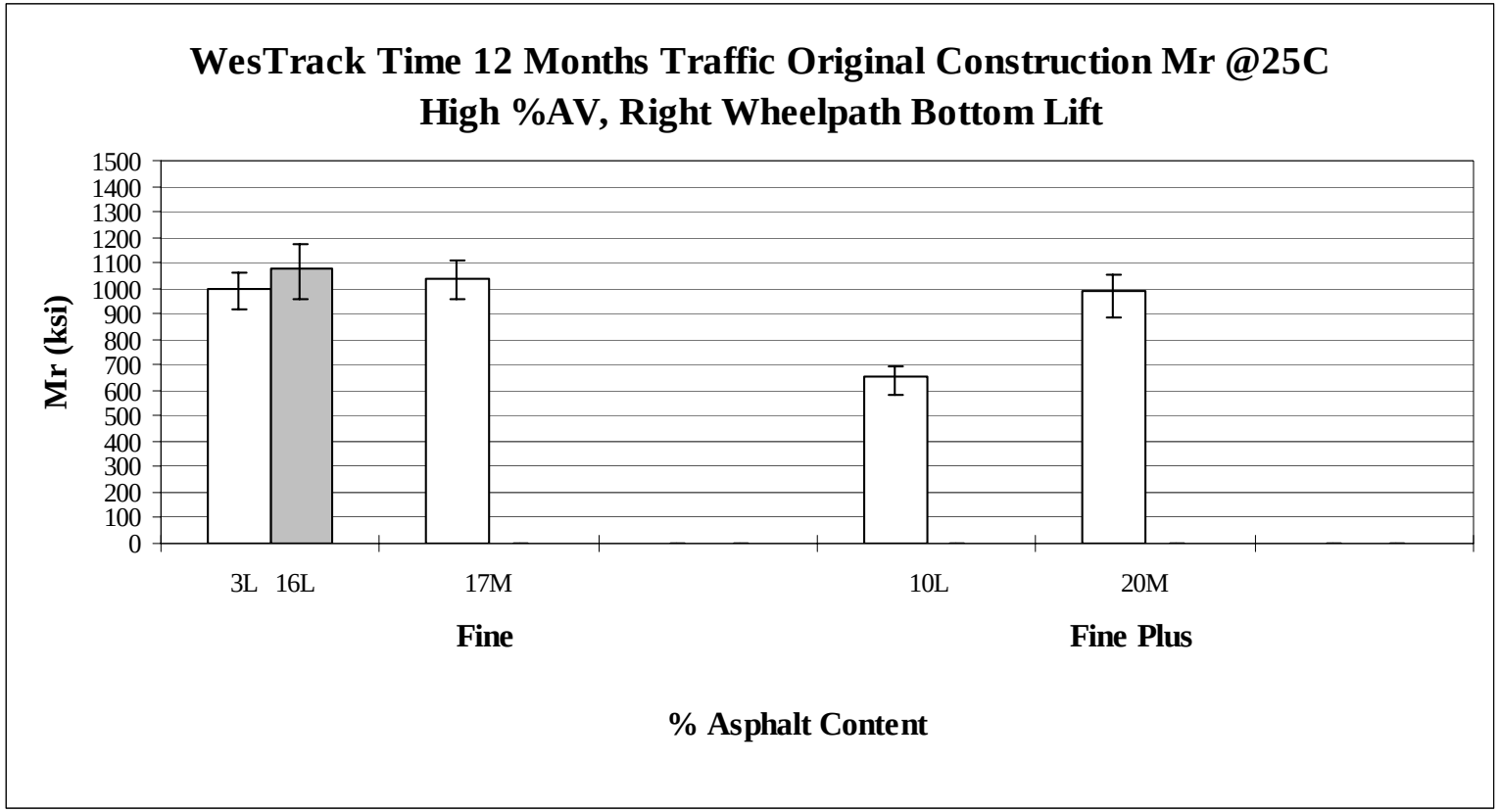


Figure 42. Resilient modulus of the mixtures designed with high air voids content (bottom lifts).

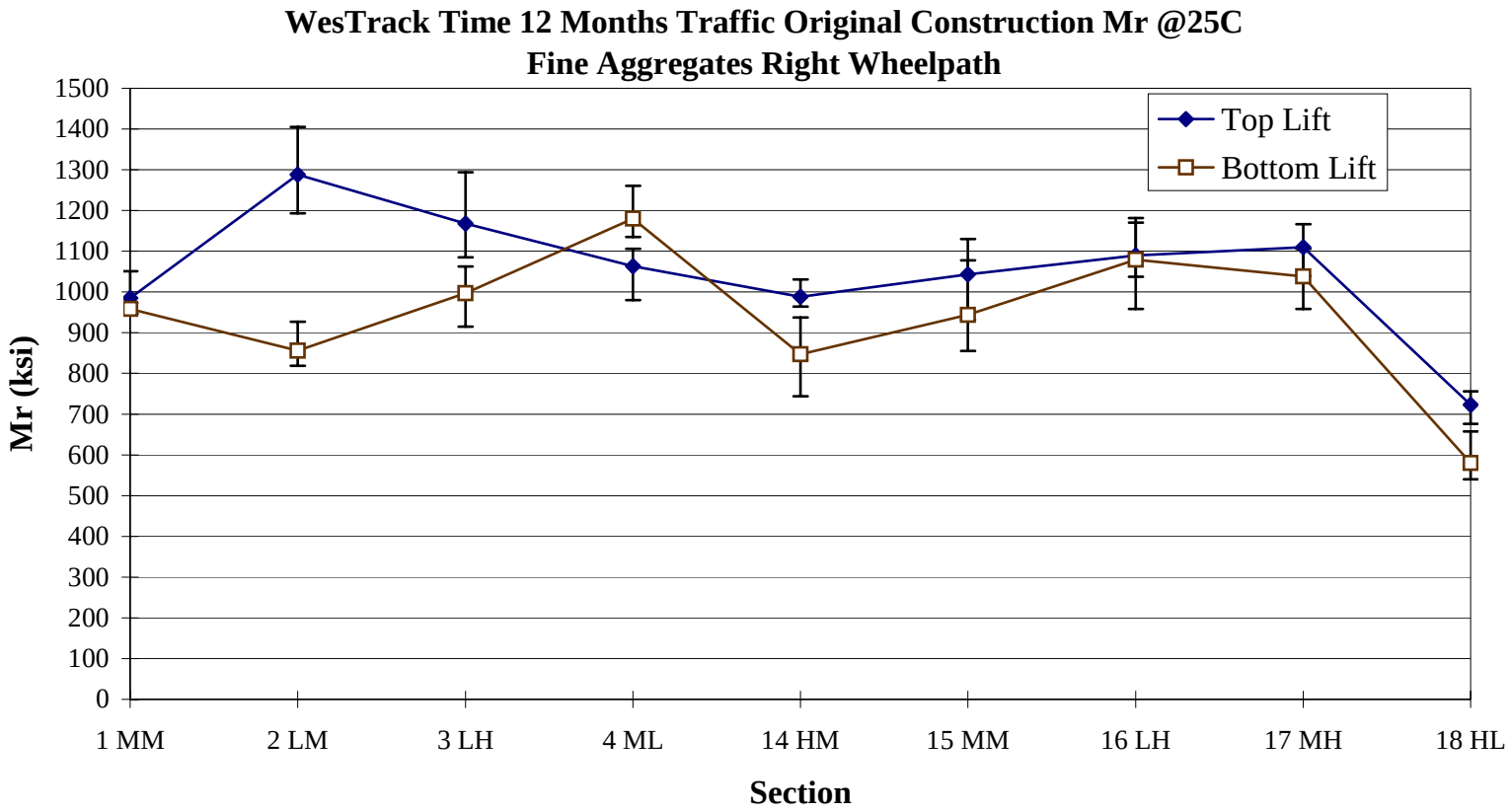


Figure 43. Resilient modulus of the mixtures designed with fine aggregate gradation.

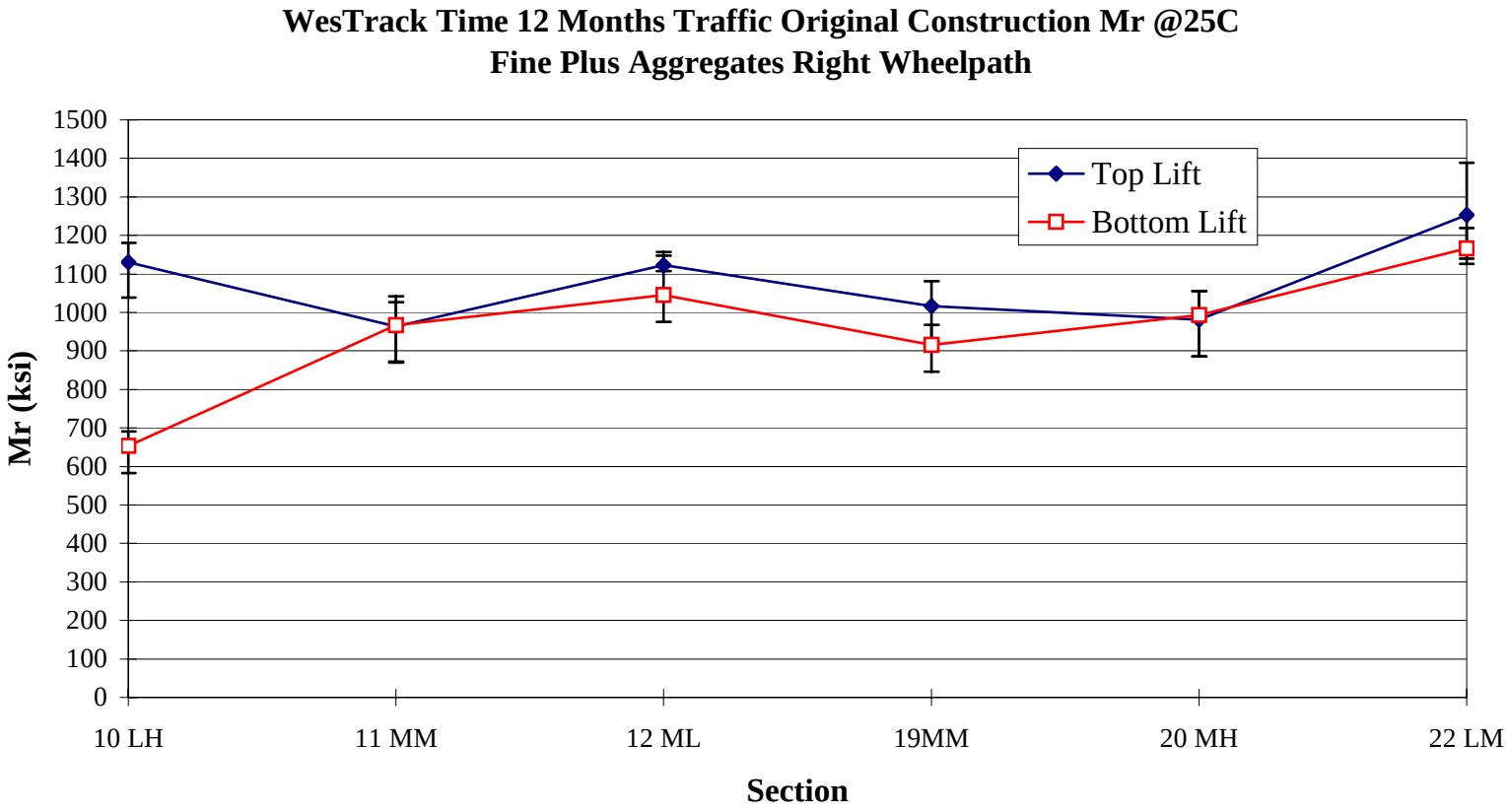


Figure 44. Resilient modulus of the mixtures designed with fine plus aggregate gradation.

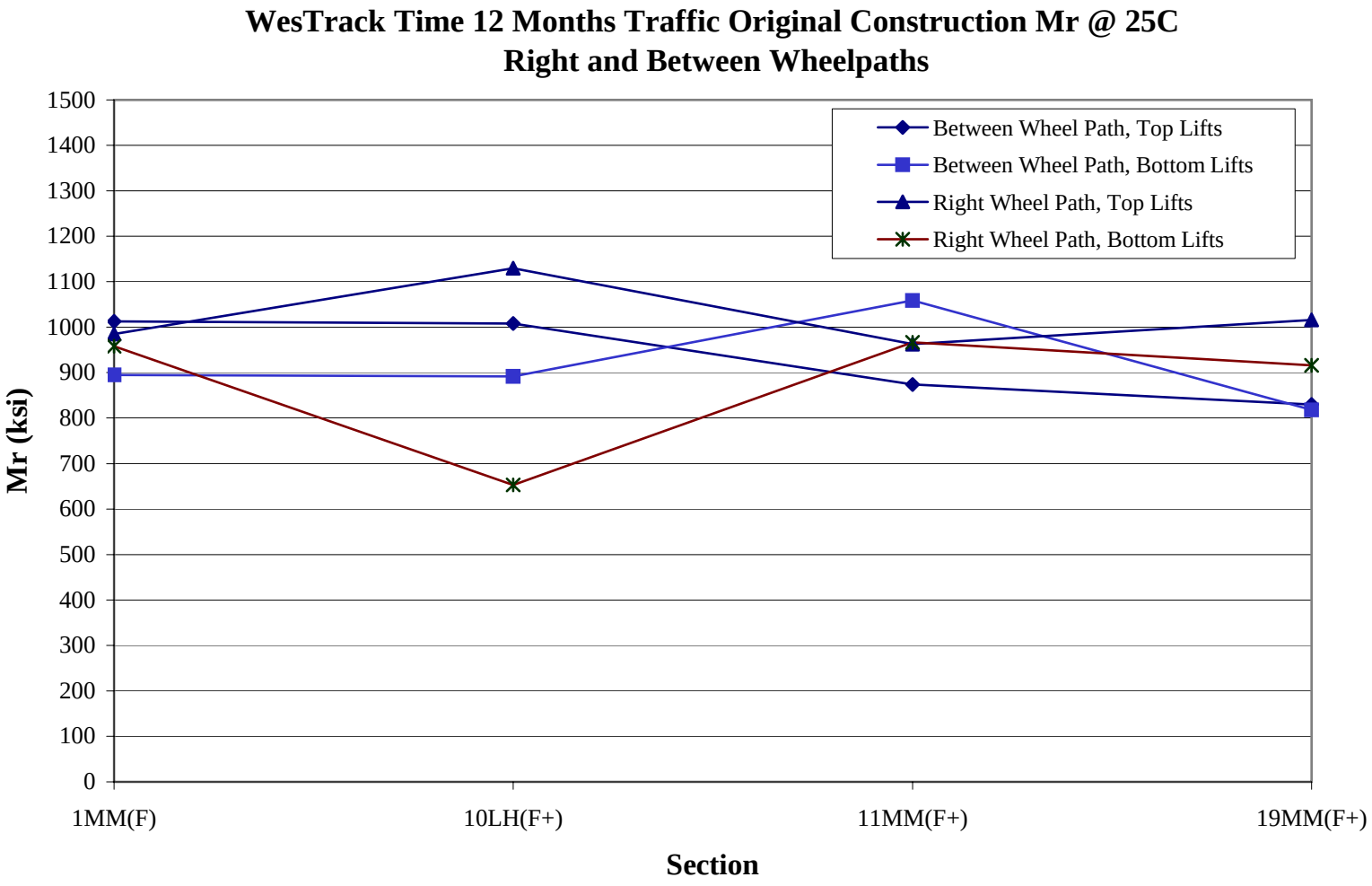


Figure 45. Resilient modulus values on right wheelpath and between wheelpaths.

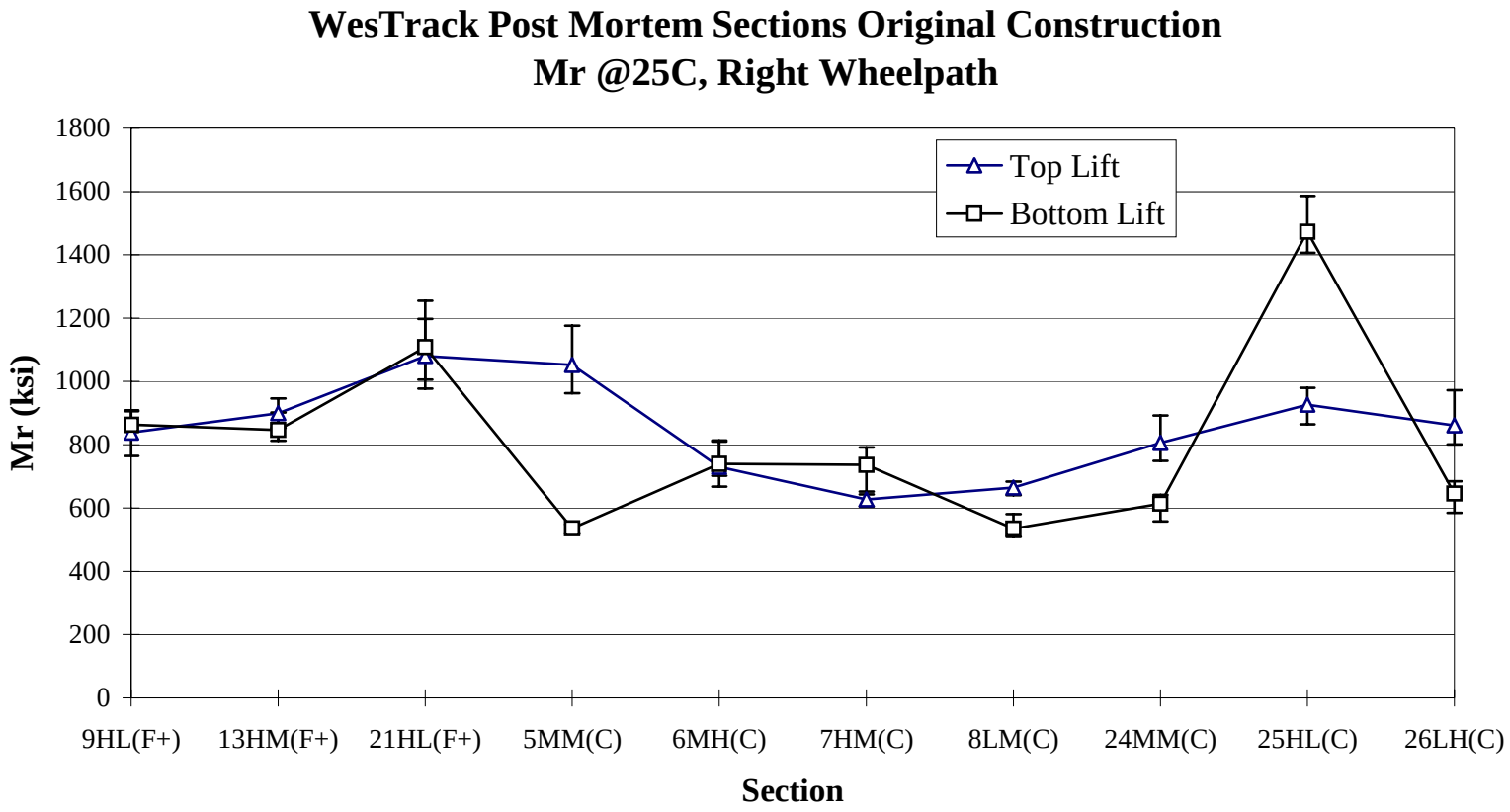


Figure 46. Resilient modulus of the post mortem sections.

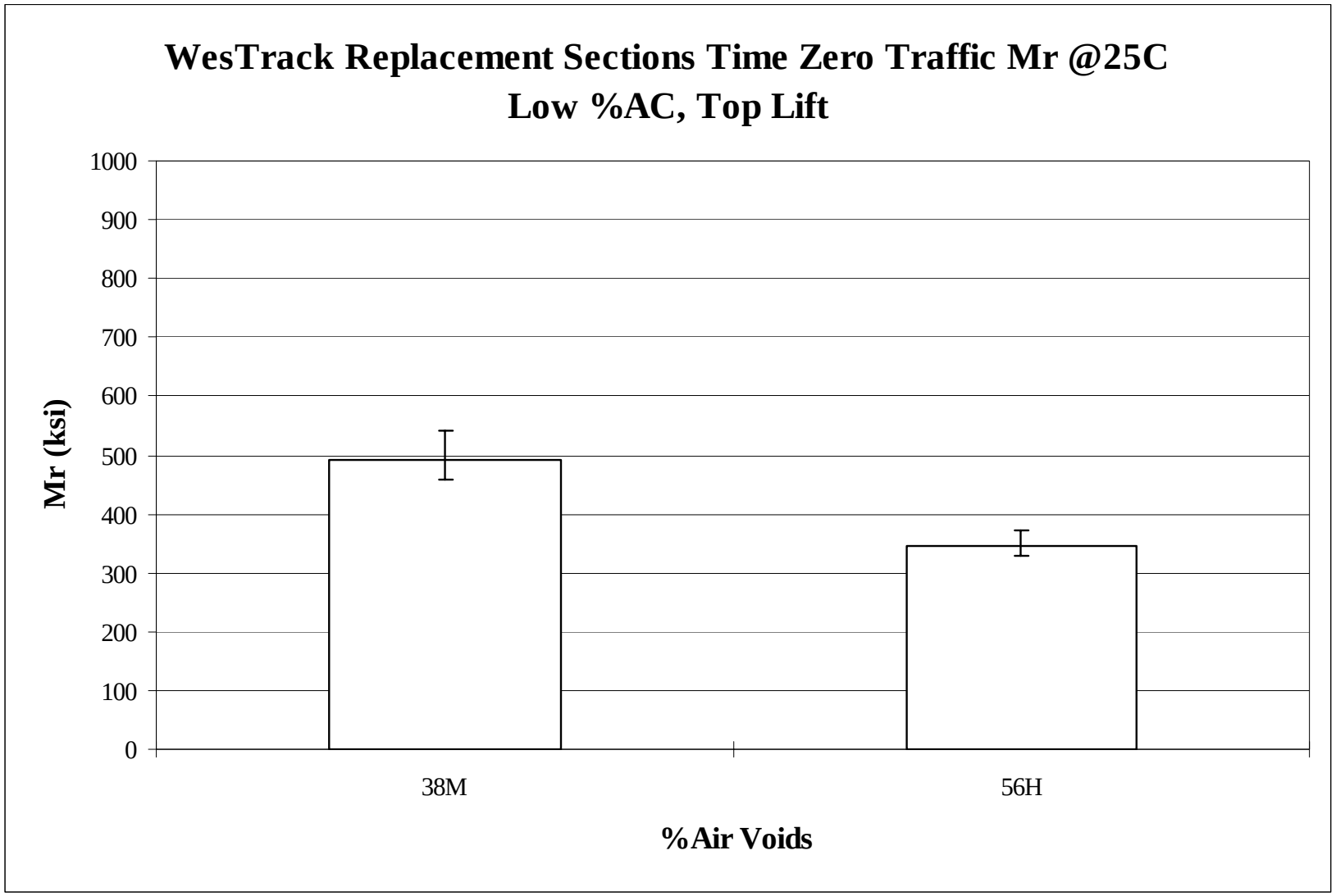


Figure 47. Resilient modulus of the mixtures designed with low asphalt content (top lifts).

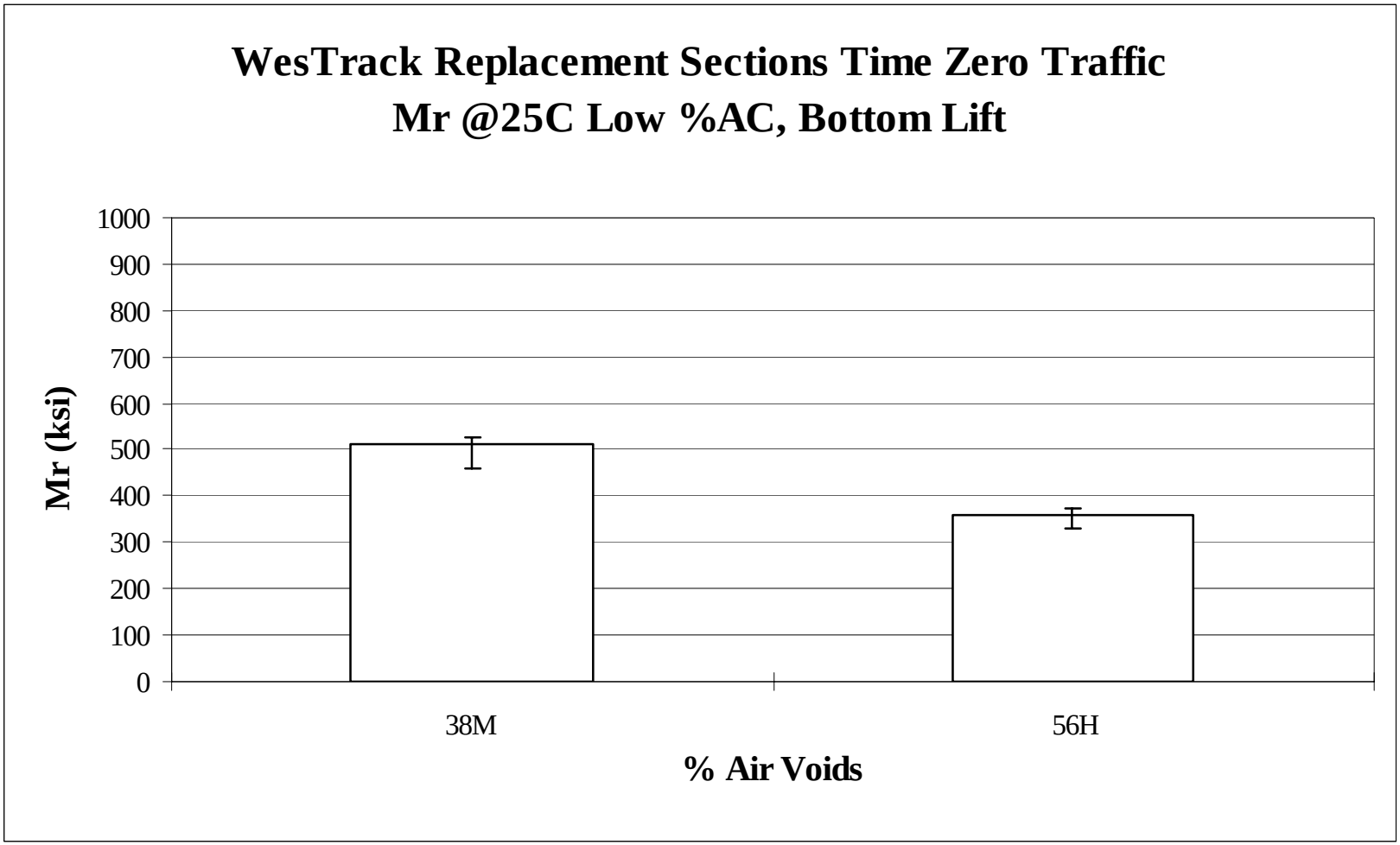


Figure 48. Resilient modulus of the mixtures designed with low asphalt content (bottom lifts).

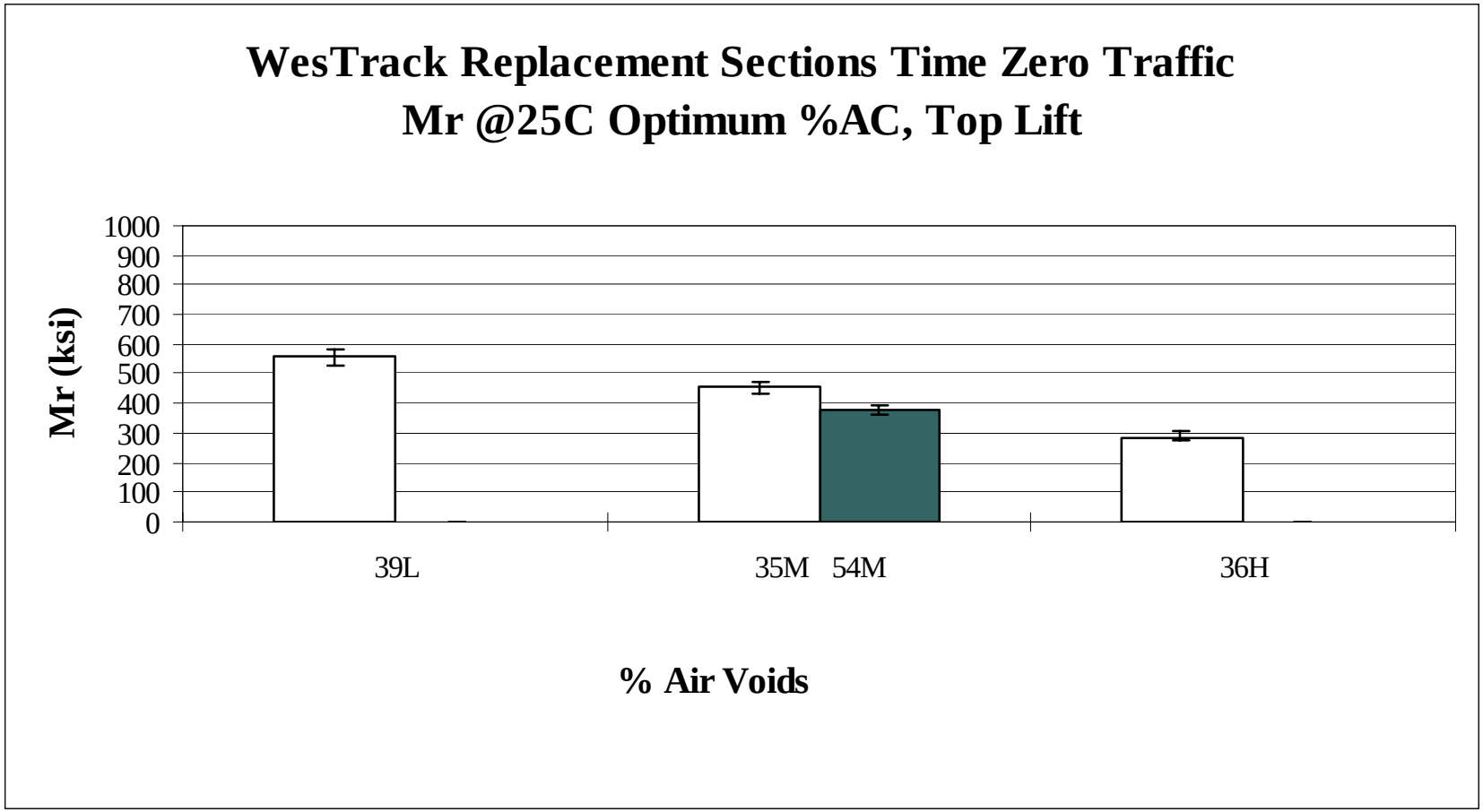


Figure 49. Resilient modulus of the mixture designed with optimum asphalt content (top lifts).

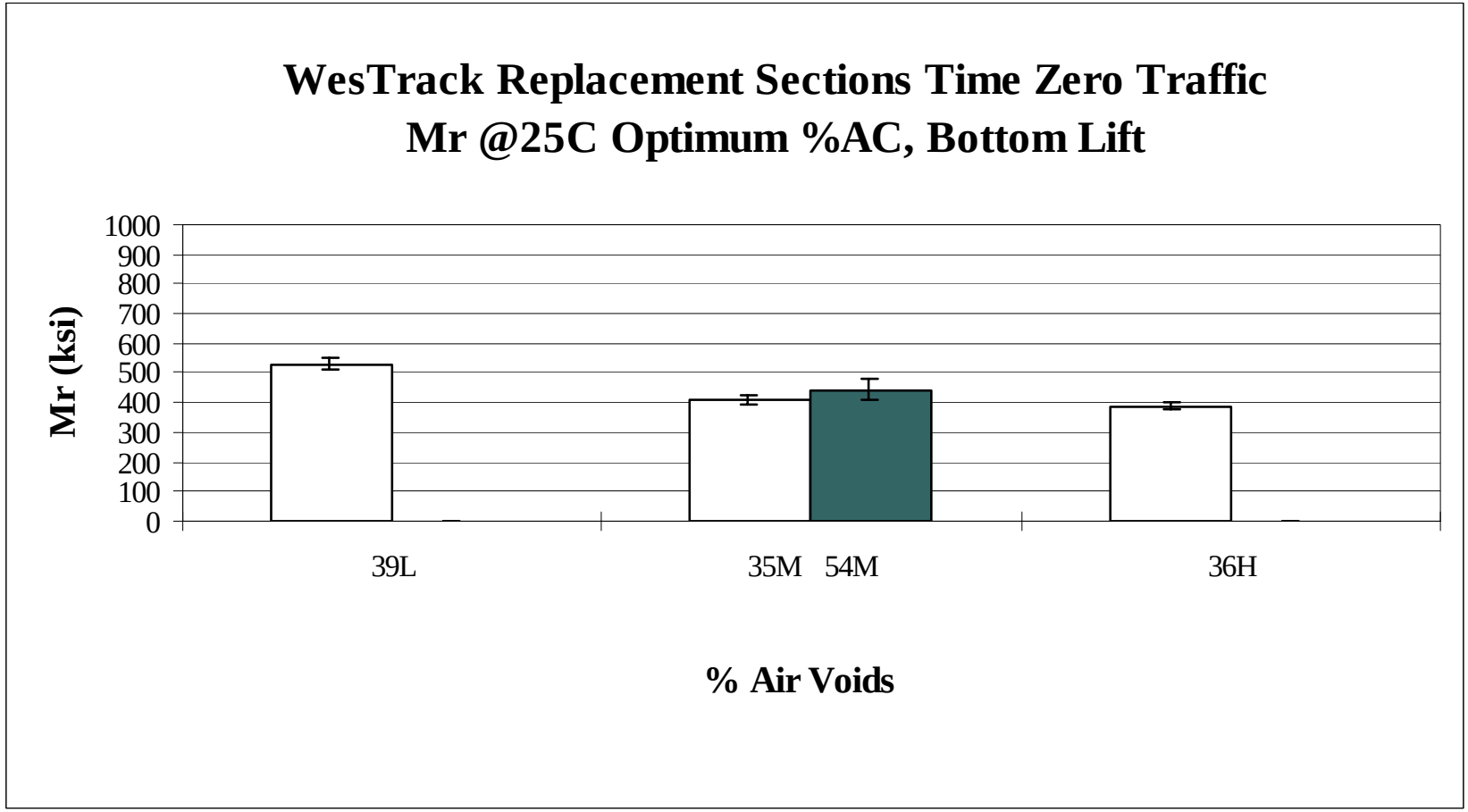


Figure 50. Resilient modulus of the mixtures designed with optimum asphalt content (bottom lifts).

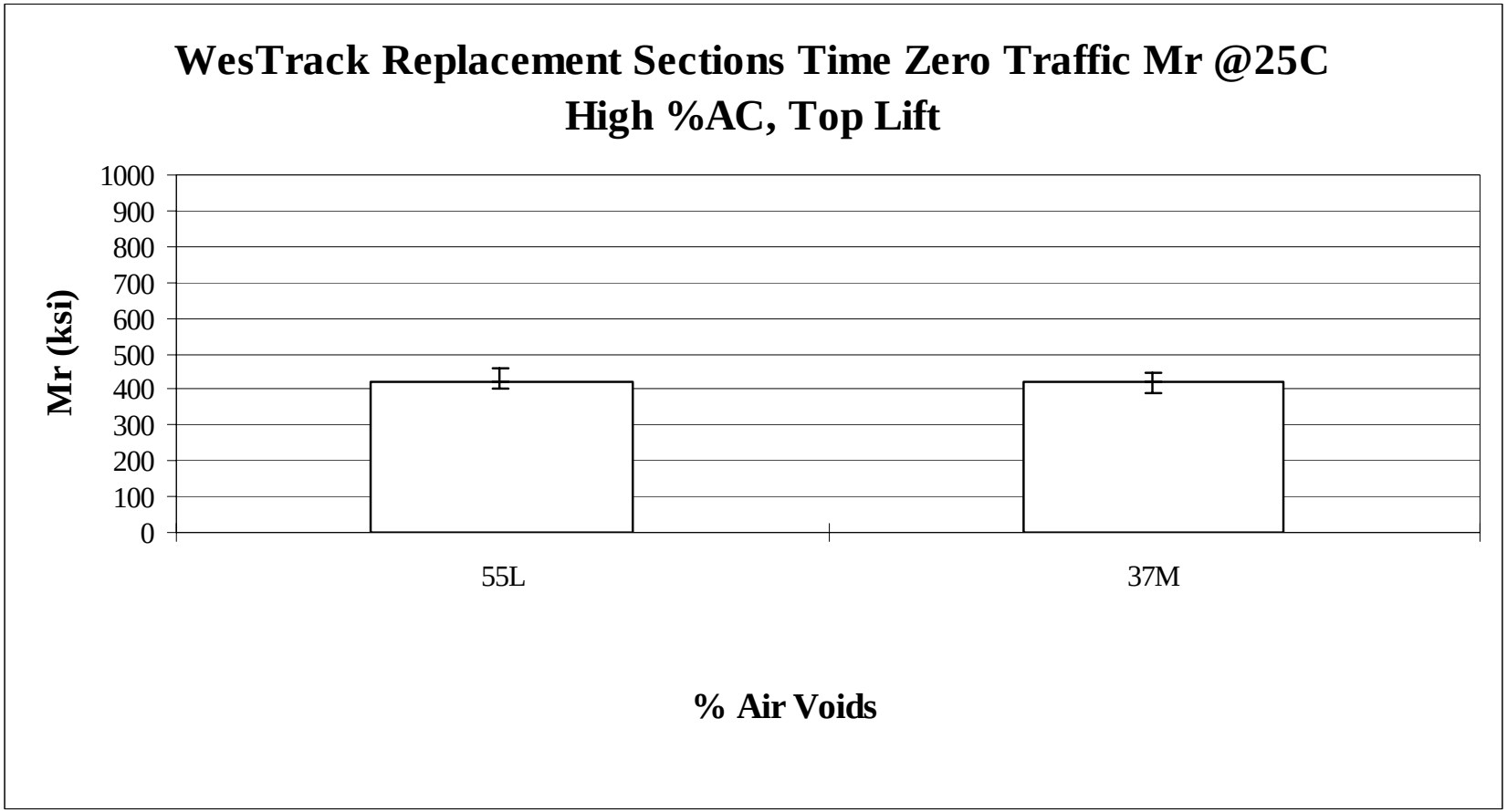


Figure 51. Resilient modulus of the mixtures designed with high asphalt content (top lifts).

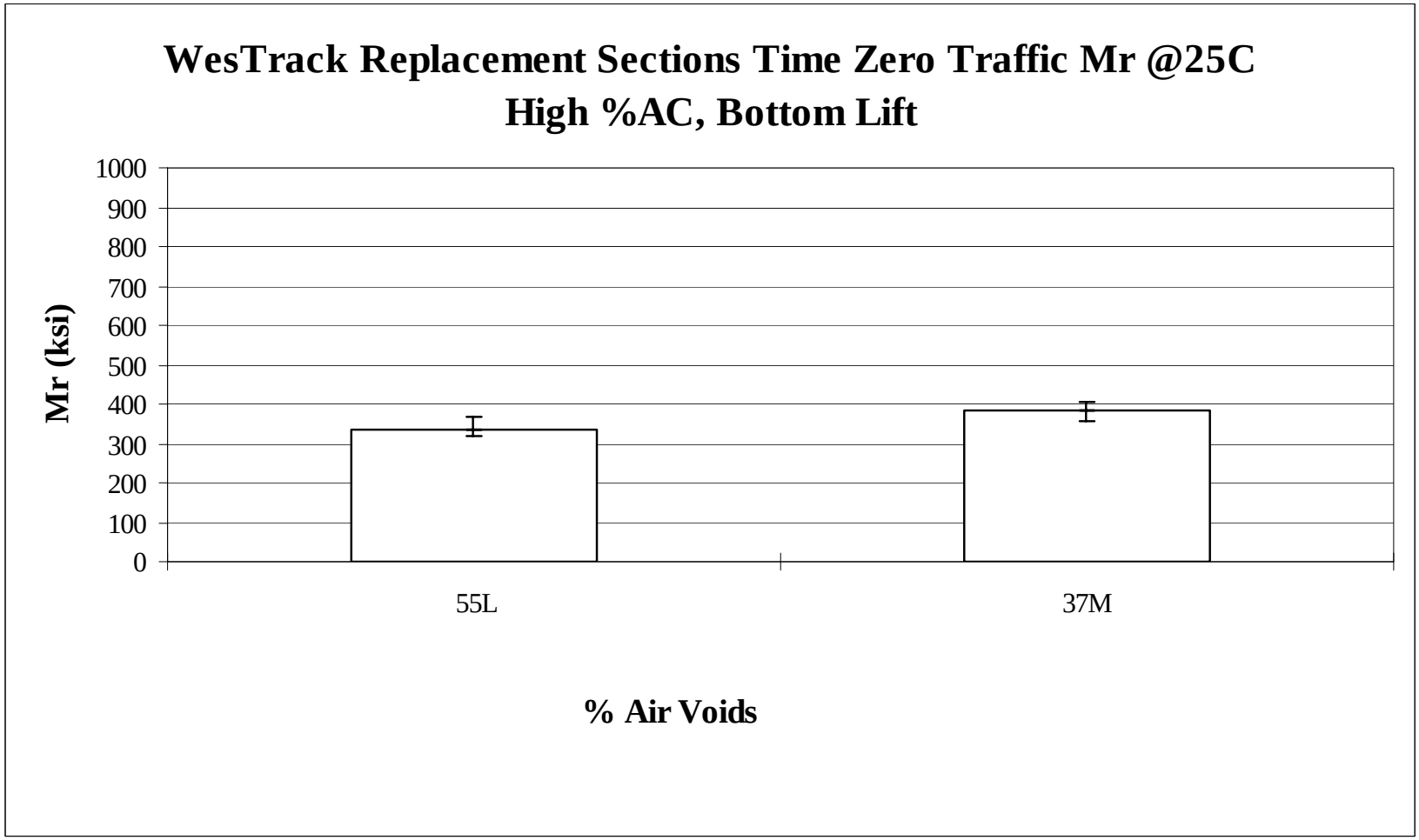


Figure 52. Resilient modulus of the mixtures designed with high asphalt content (bottom lifts).

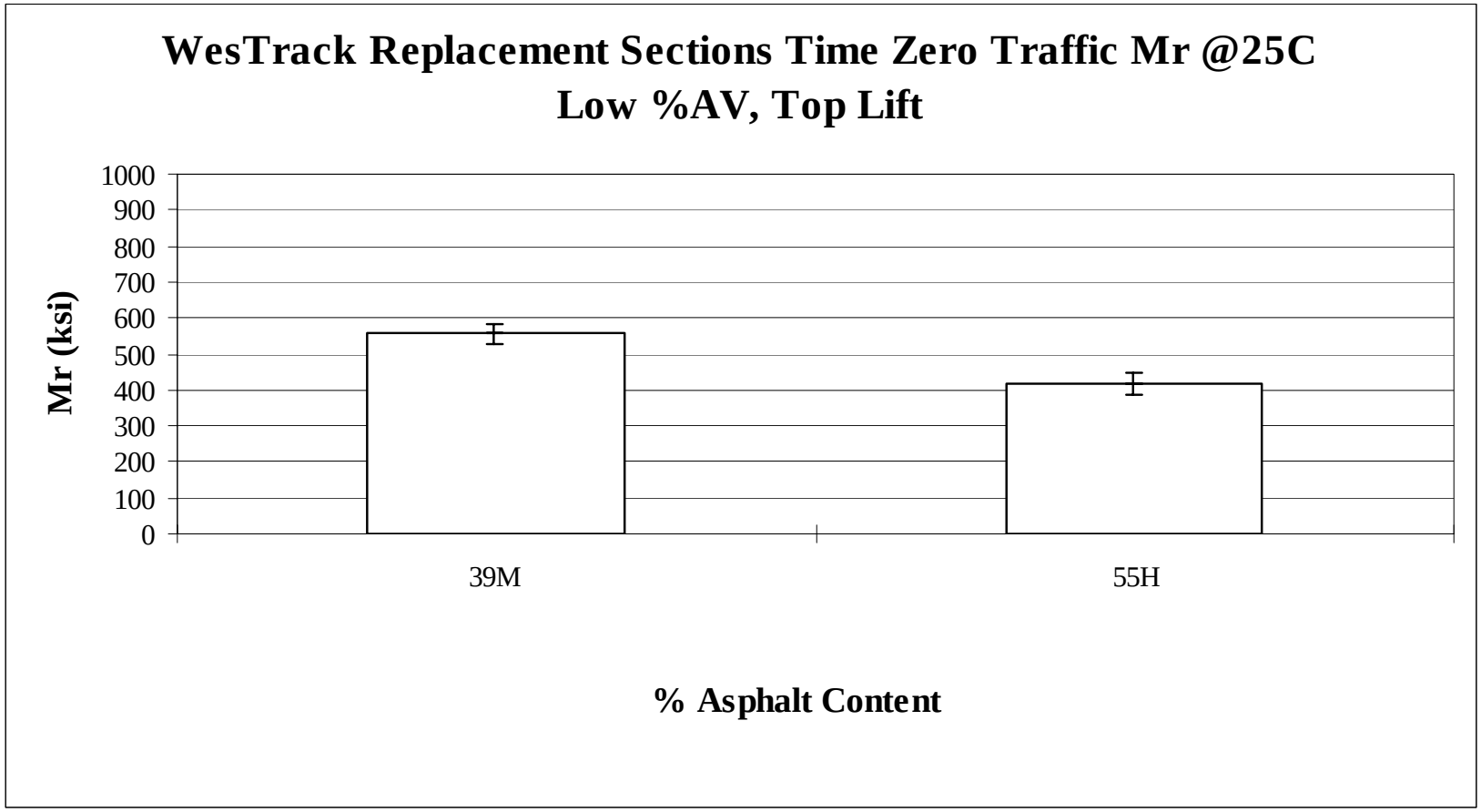


Figure 53. Resilient modulus of the mixtures designed with low air voids content (top lifts).

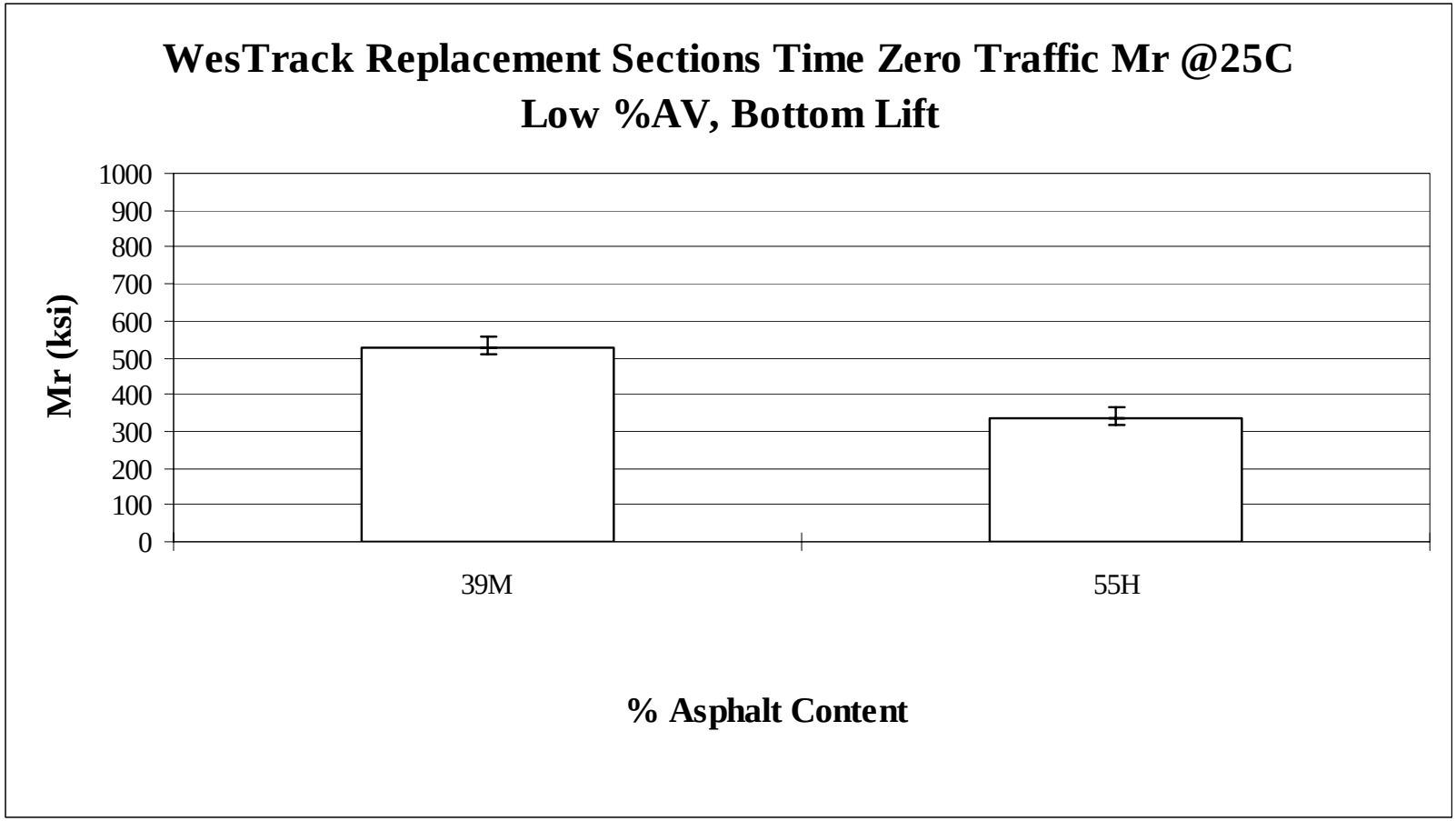


Figure 54. Resilient modulus of the mixtures designed with low air voids content (bottom lifts).

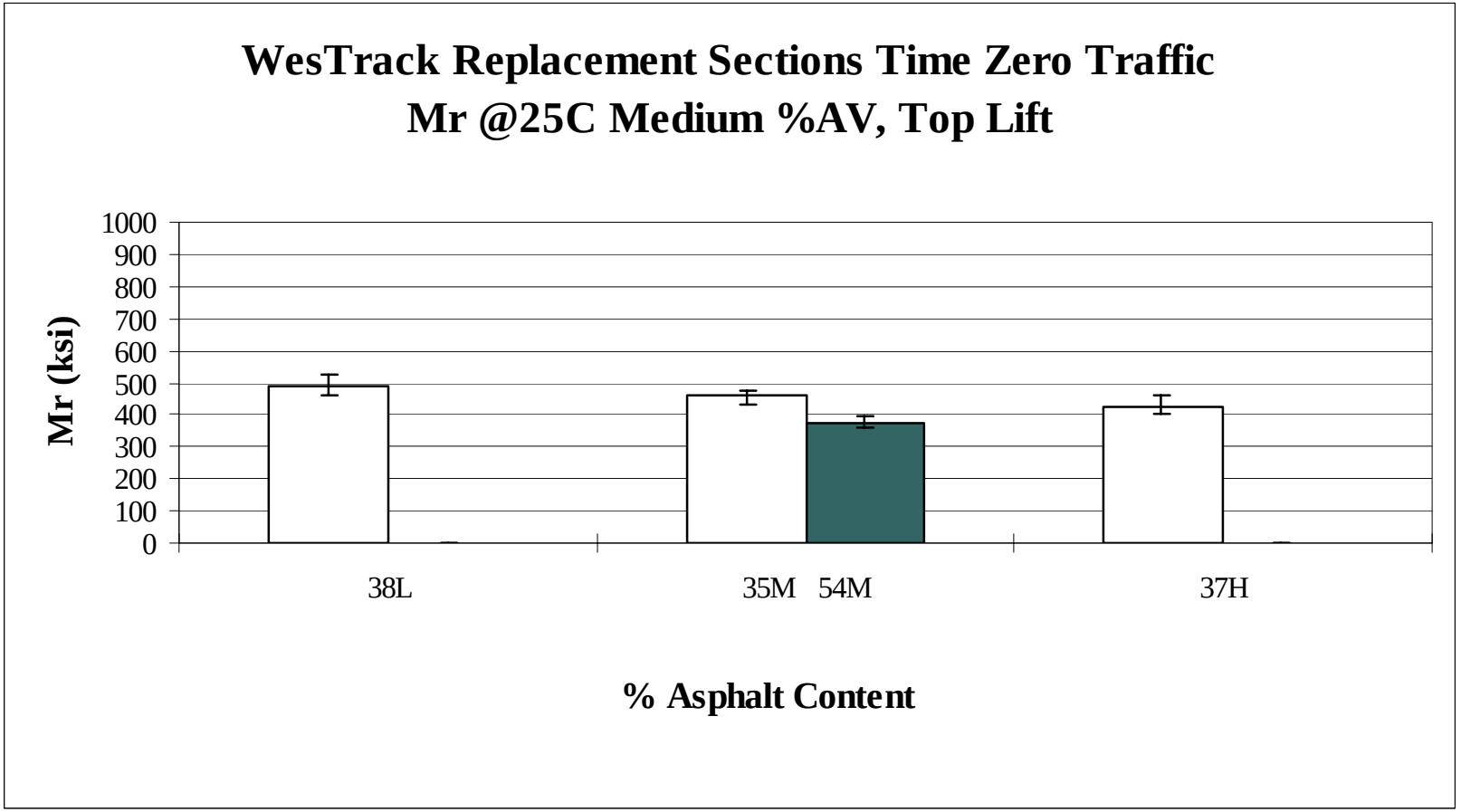


Figure 55. Resilient modulus of the mixtures designed with medium air voids content (top lifts).

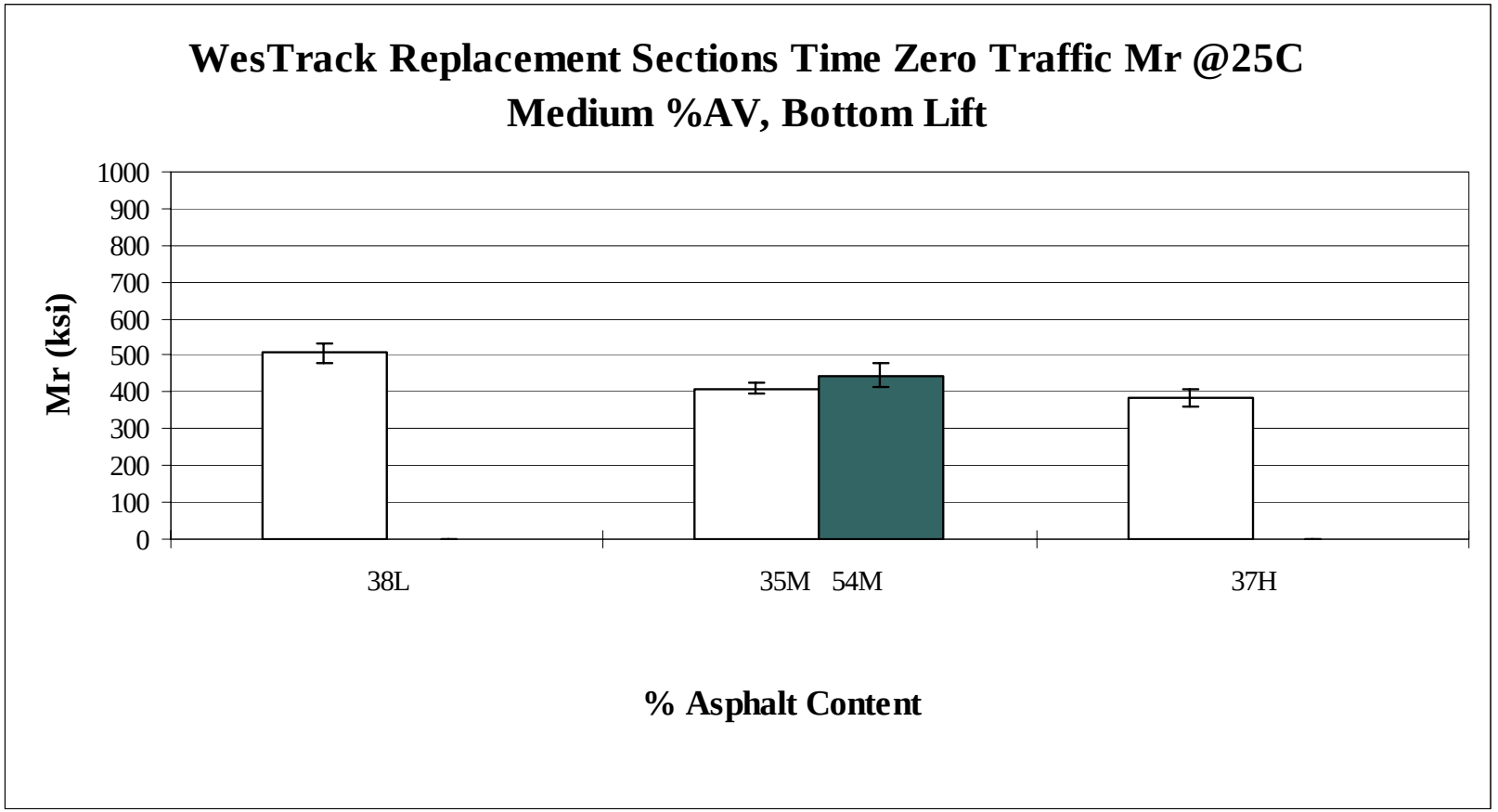


Figure 56. Resilient modulus of the mixtures designed with medium air voids content (bottom lifts).

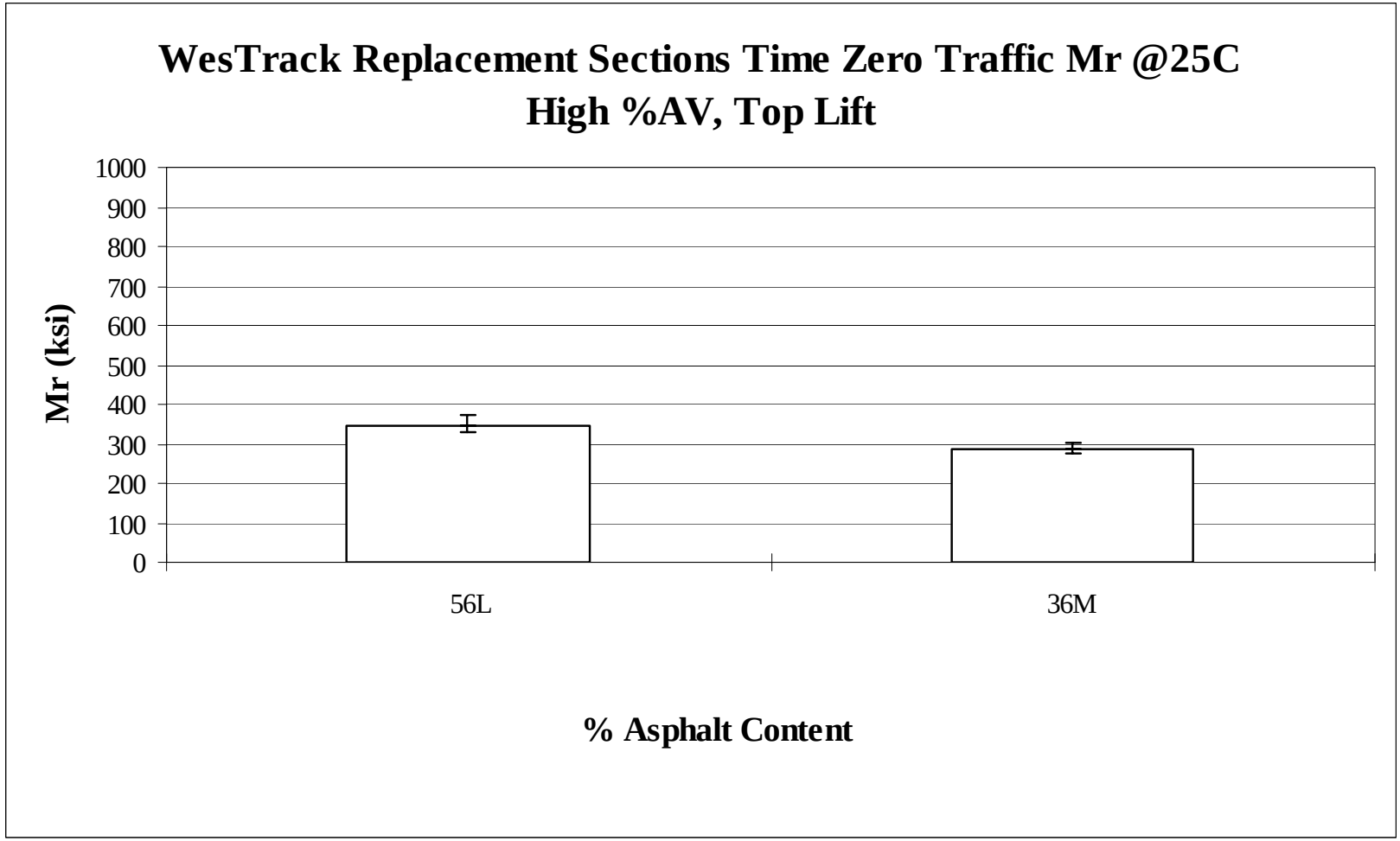


Figure 57. Resilient modulus of the mixtures designed with high air voids content (top lifts).

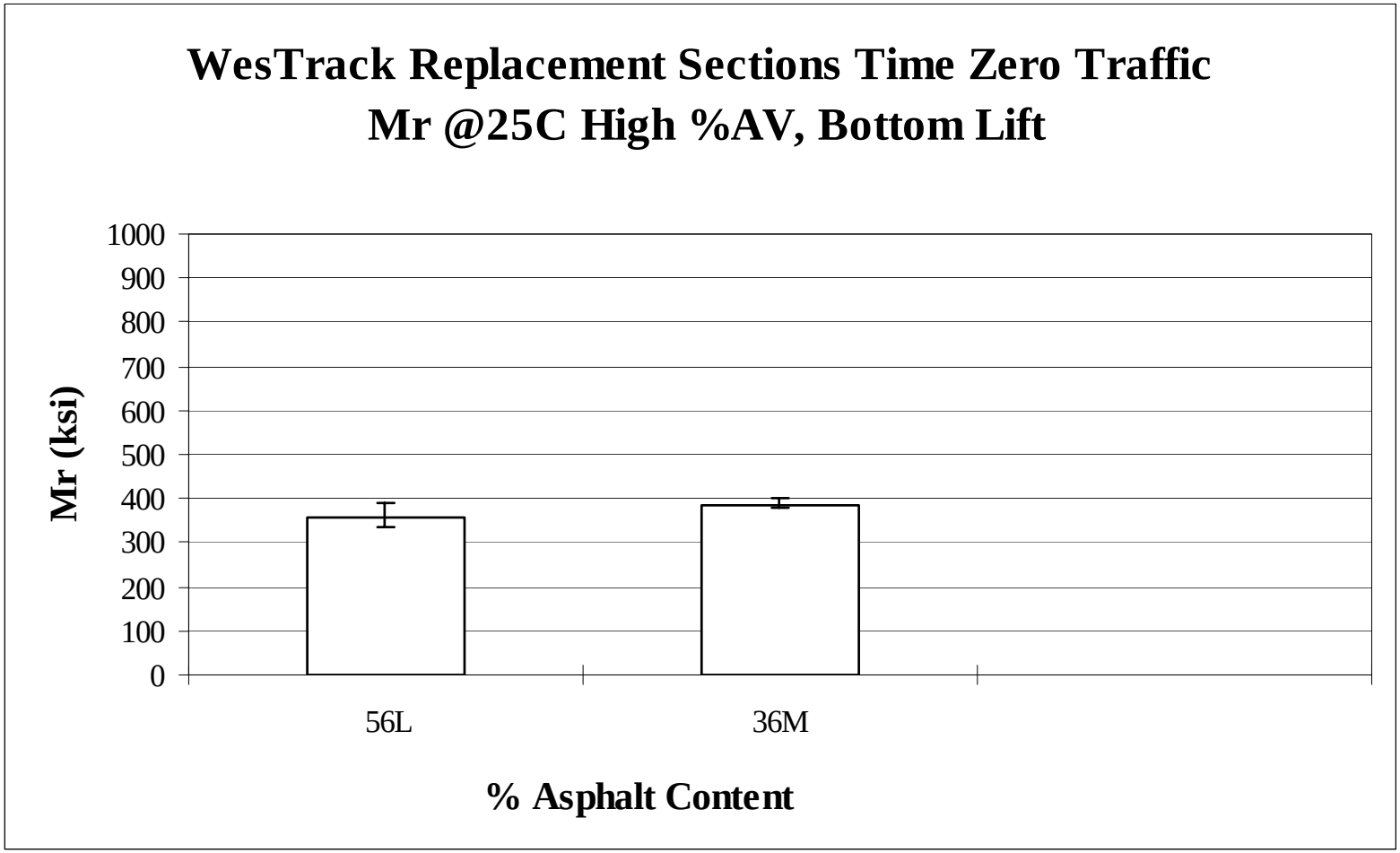


Figure 58. Resilient modulus of the mixtures designed with high air voids content (bottom lifts).

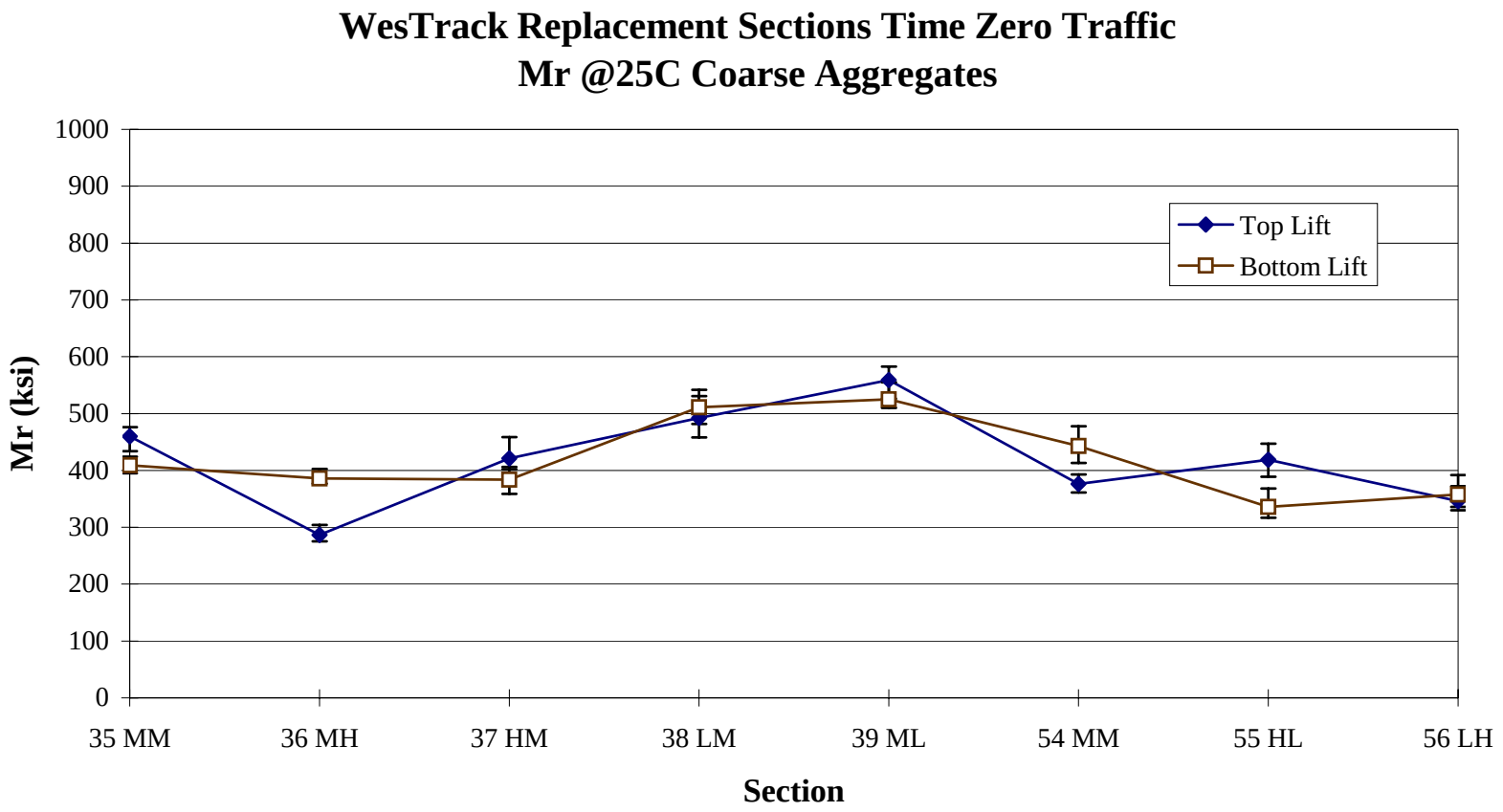


Figure 59. Resilient modulus of the mixtures designed with coarse aggregate gradation.

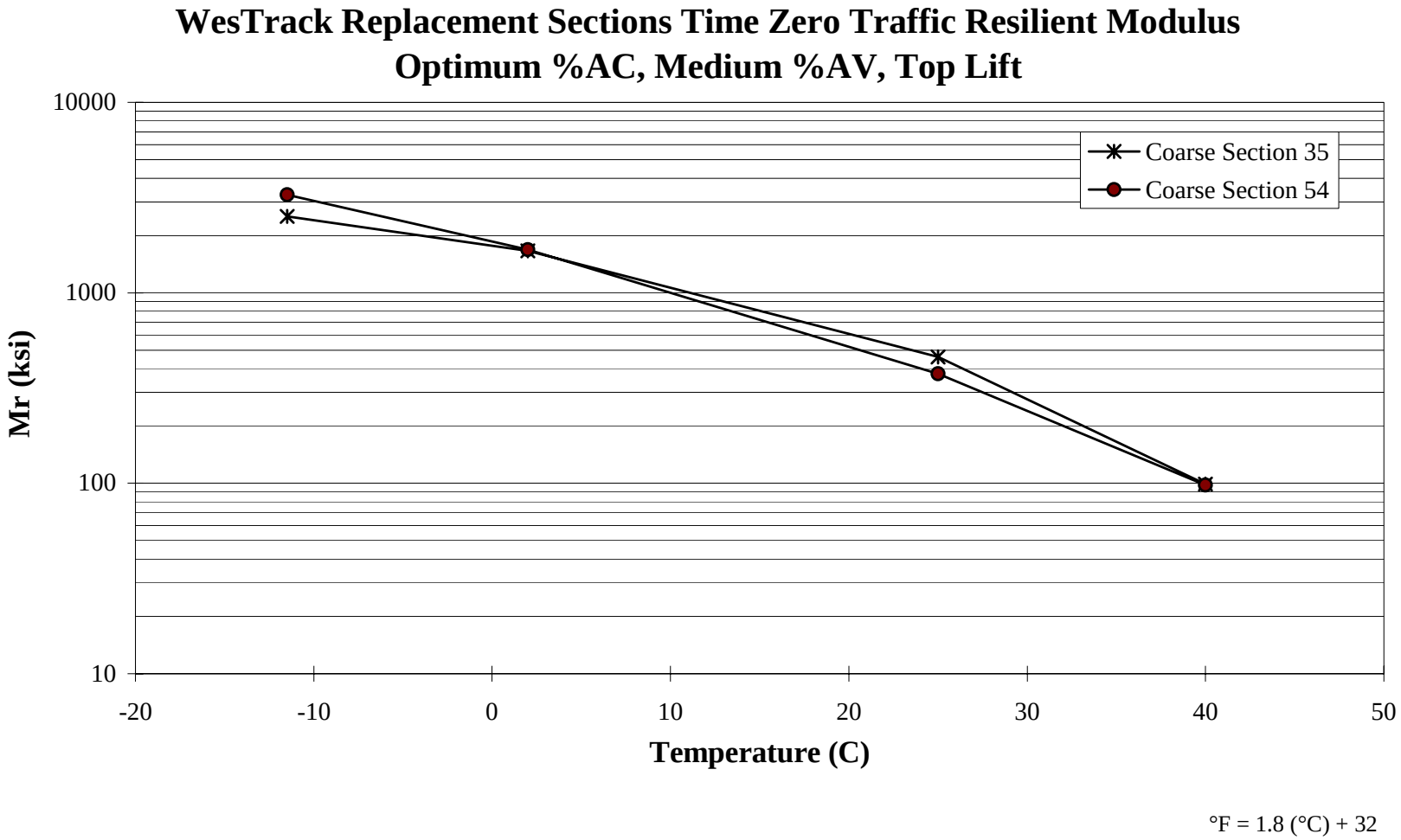


Figure 60. Variation of resilient modulus with temperature (top lifts).

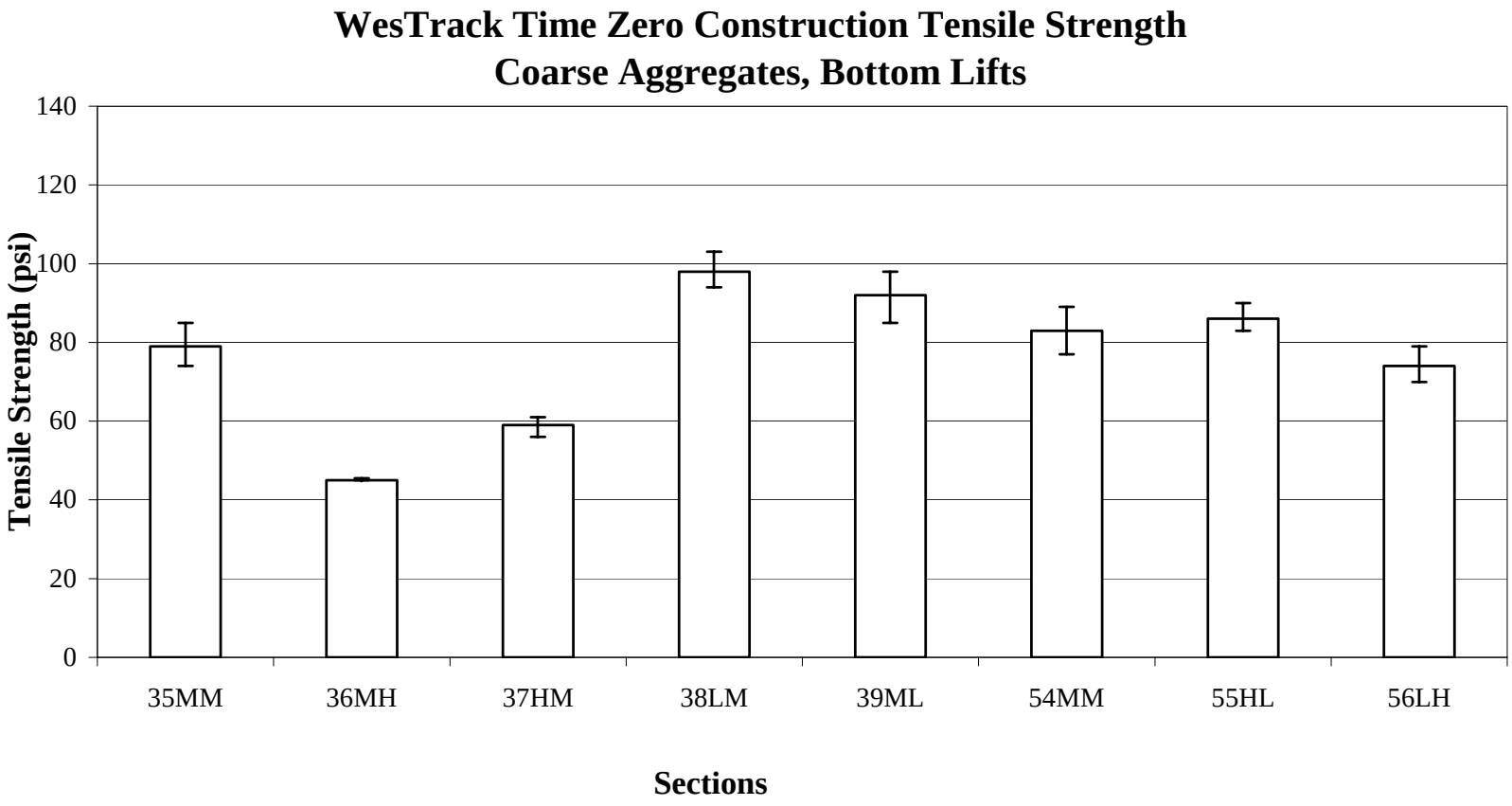


Figure 61. Tensile strengths of the replacement sections (bottom lifts).

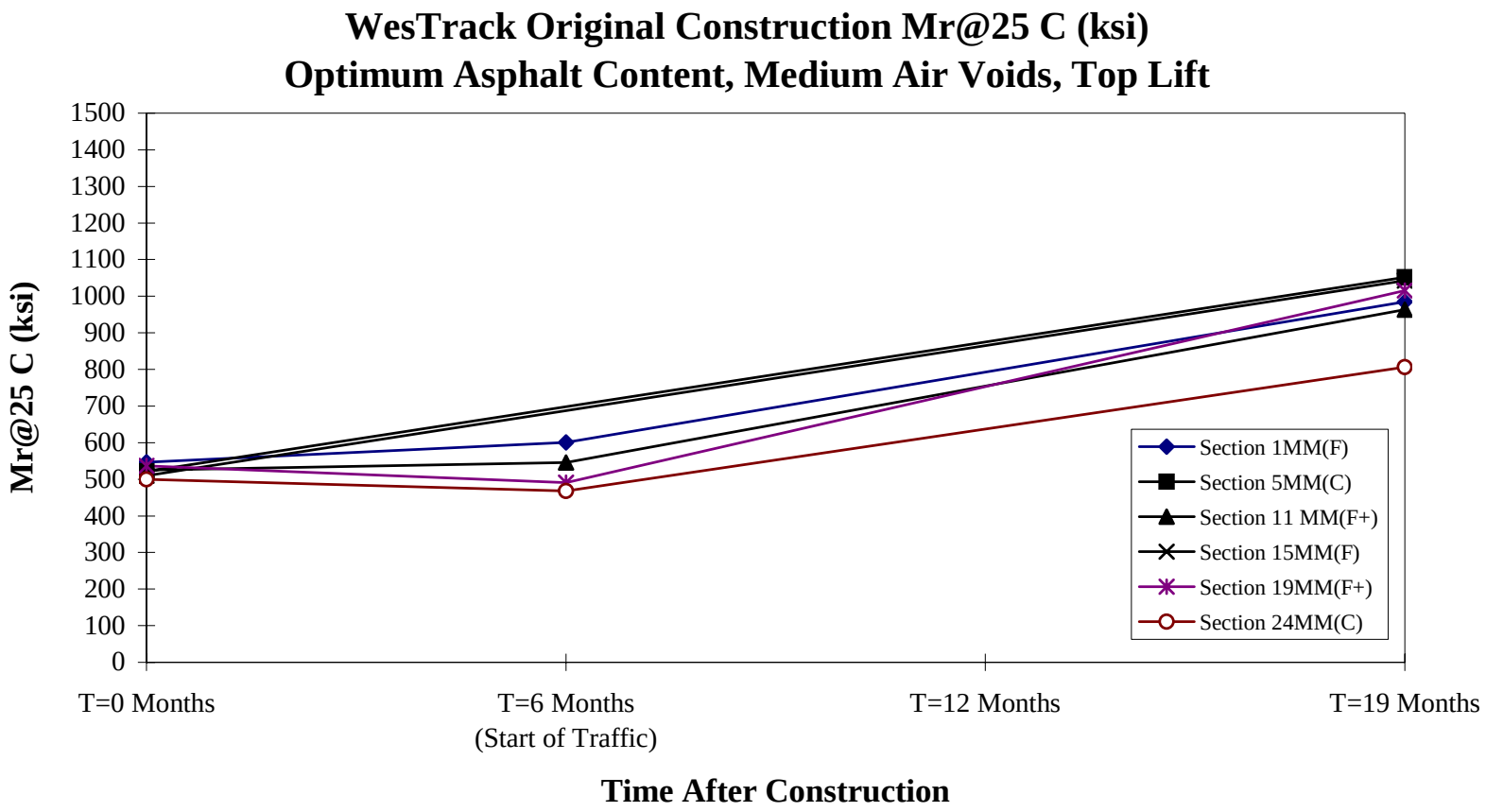


Figure 62. Resilient modulus at different times for mixtures designed with optimum asphalt content and medium air voids content (top lifts).

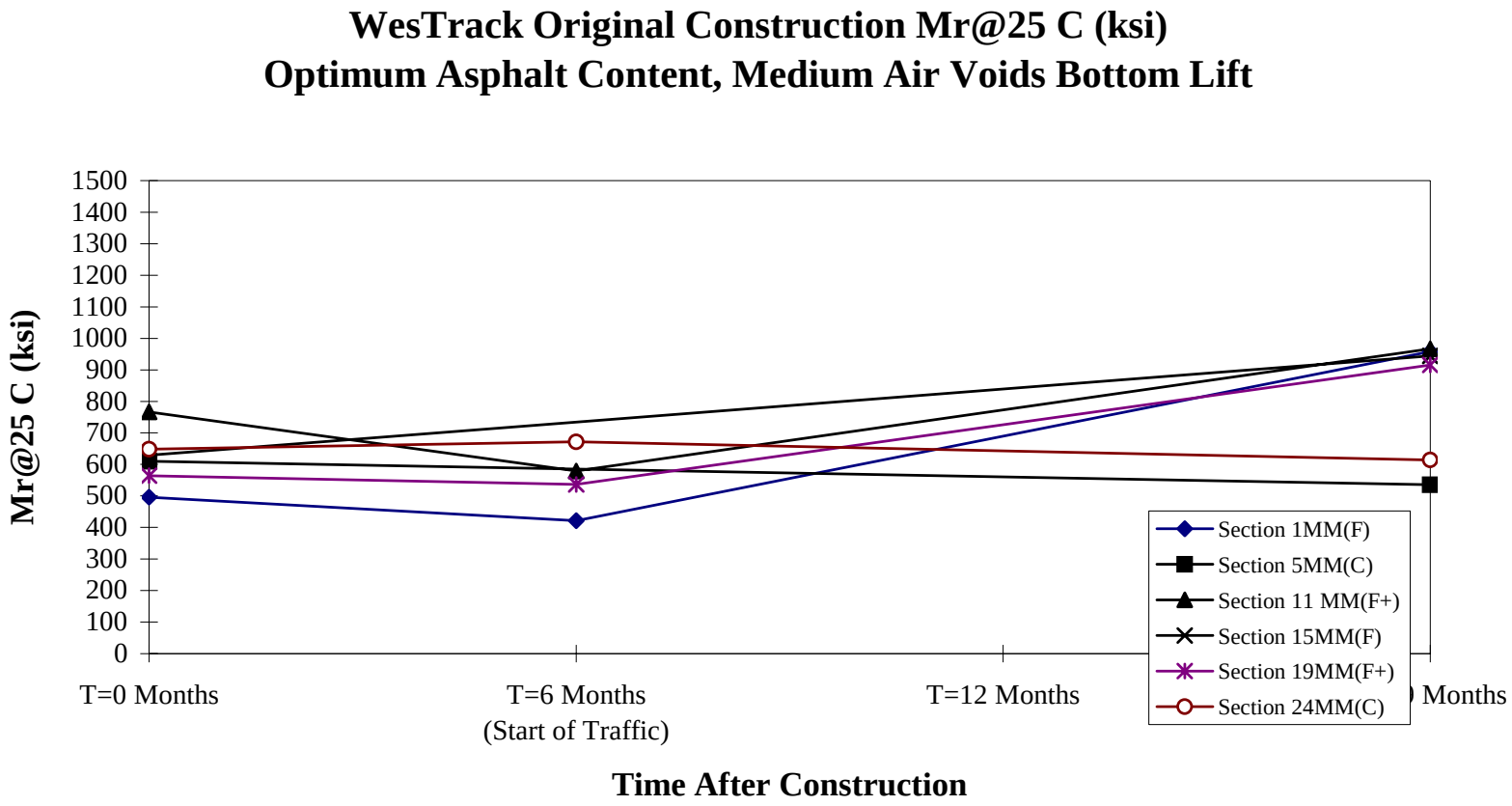


Figure 63. Resilient modulus at different times for the mixtures designed with optimum asphalt content and medium air voids content (bottom lifts).

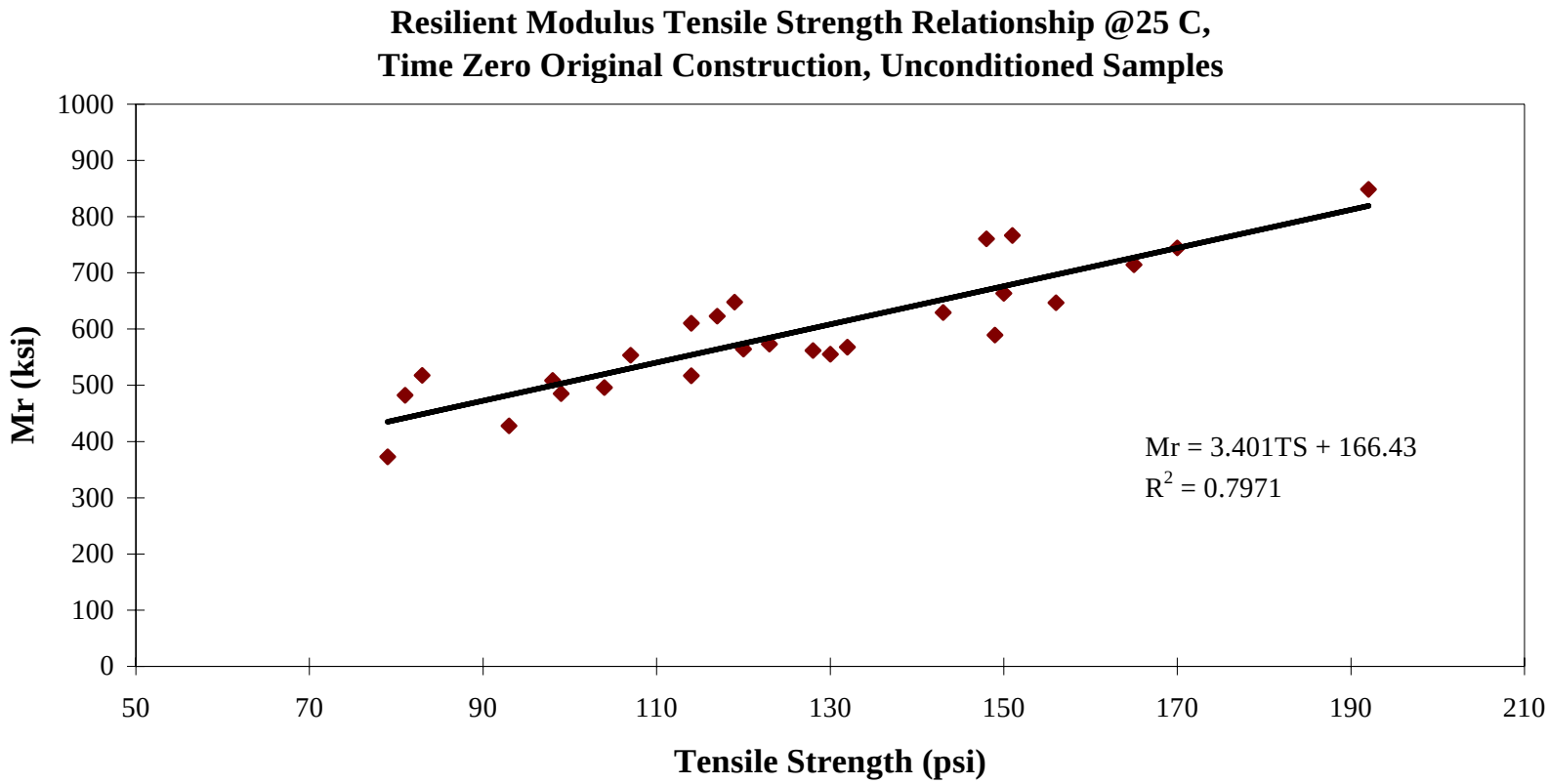


Figure 64. Correlation between resilient modulus and dry tensile strength for original construction (bottom lifts).

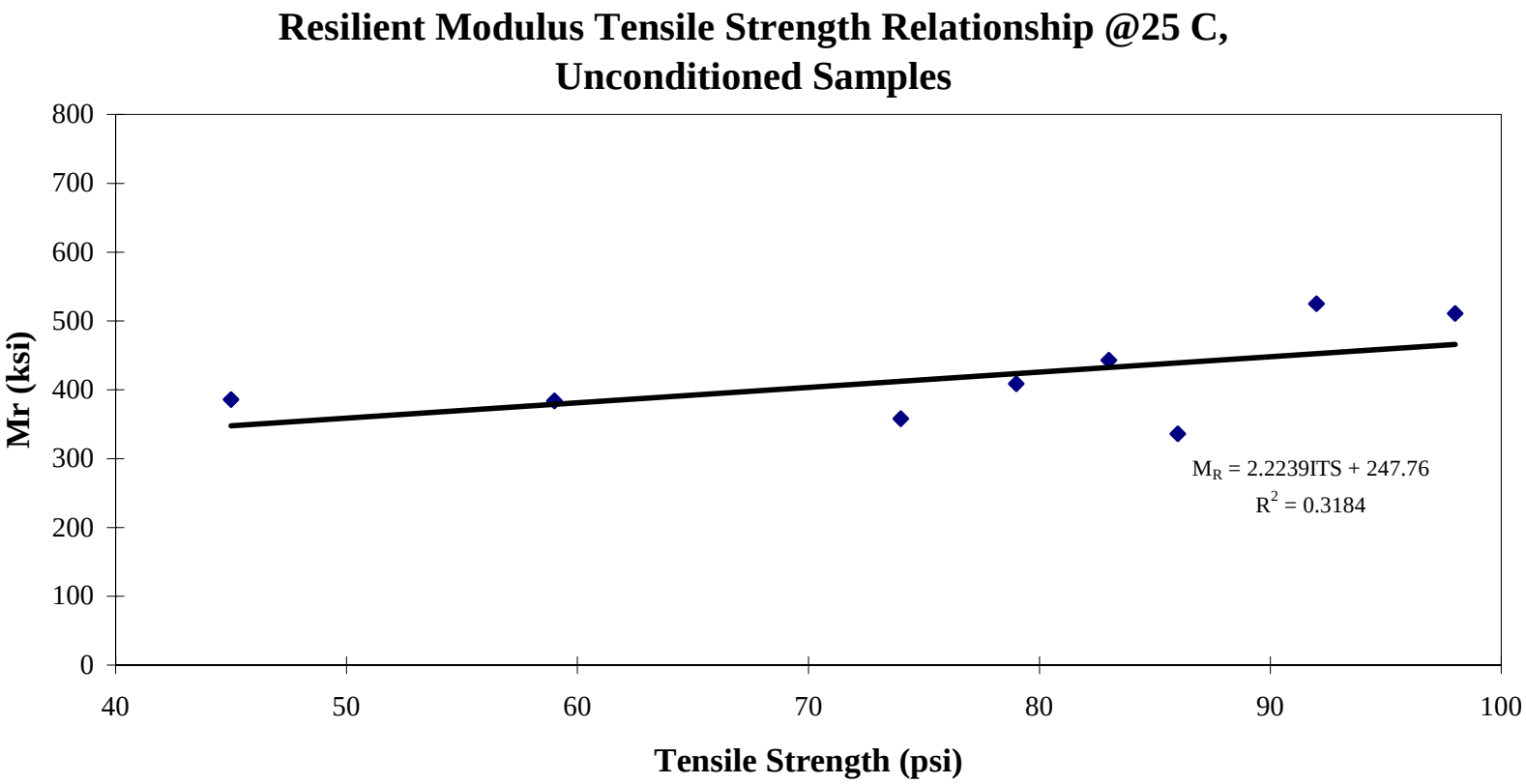


Figure 65. Correlation between resilient modulus and dry tensile strength for replacement sections (bottom lifts).

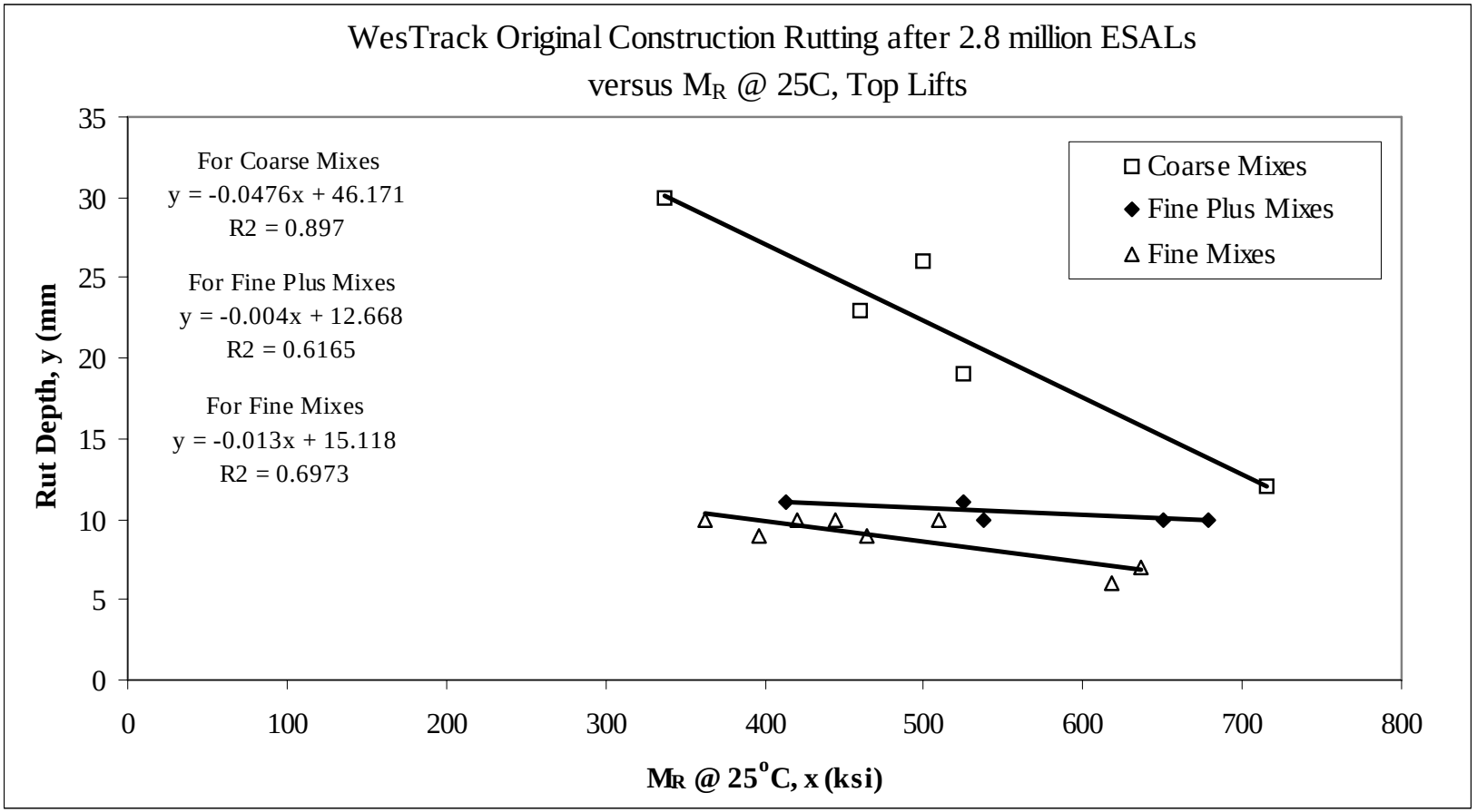


Figure 66. Relationship between pavement rutting and resilient modulus (top lifts).

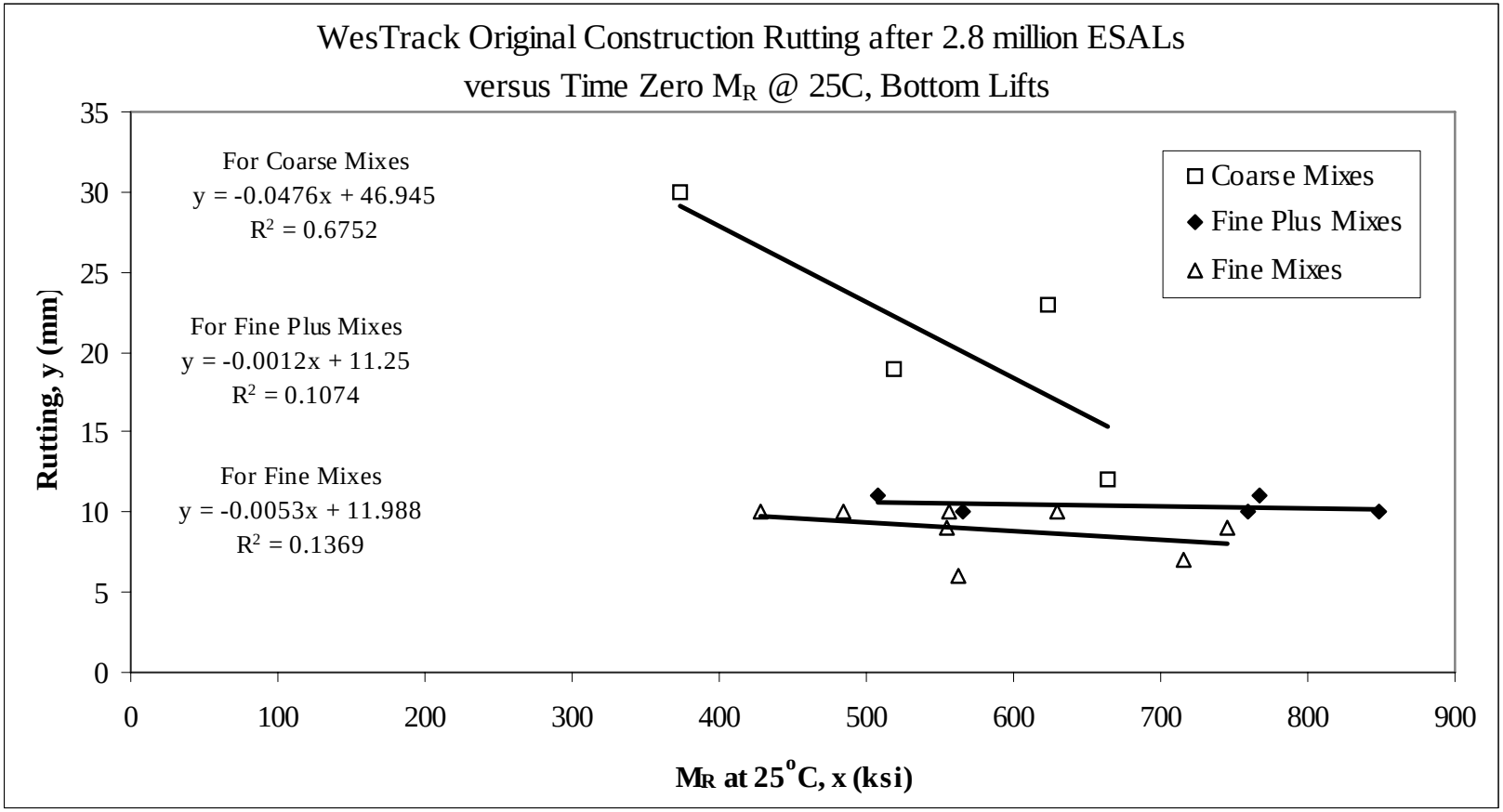


Figure 67. Relationship between pavement rutting and resilient modulus (bottom lifts).

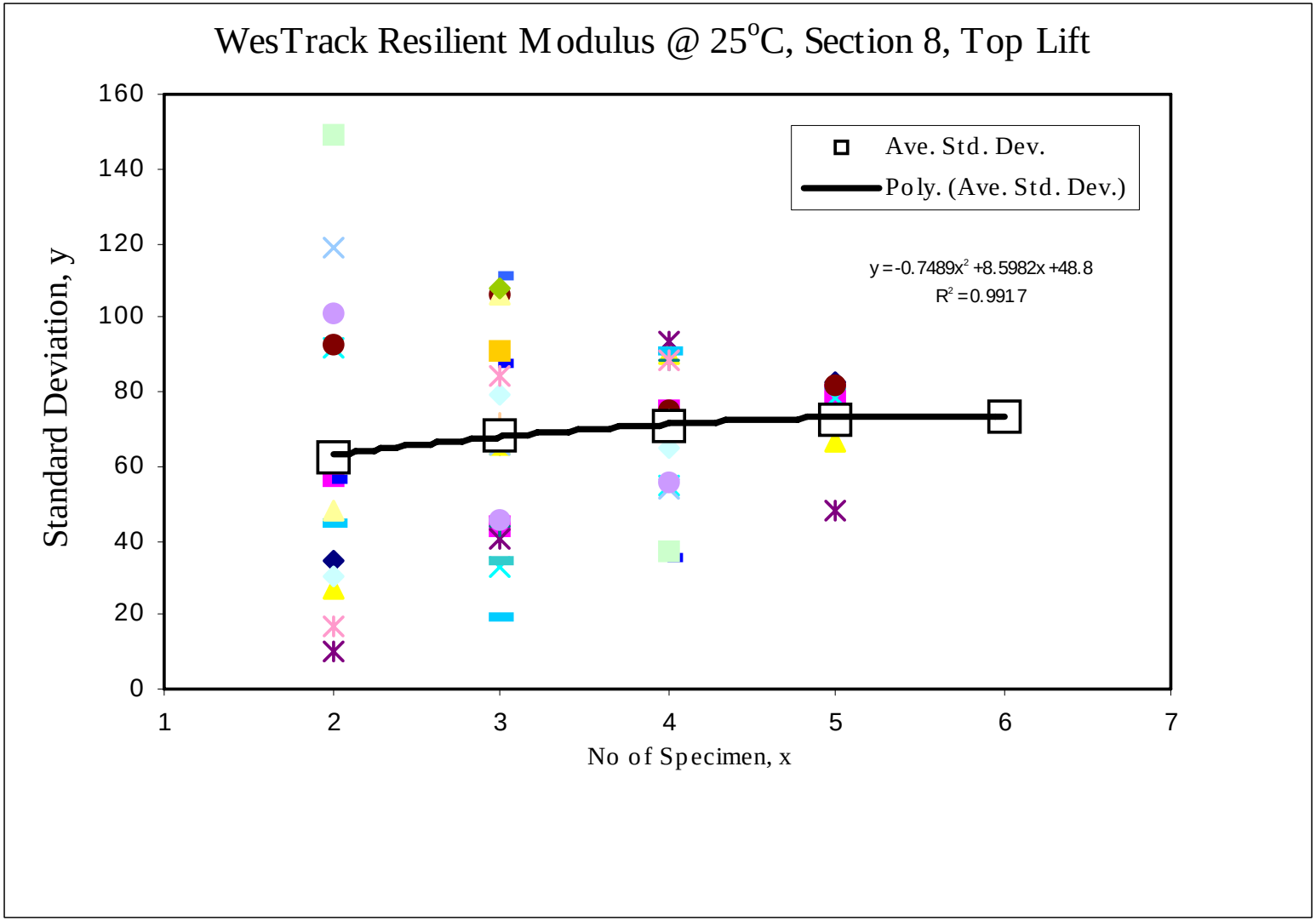


Figure 68. Determination of number of replicates.

Table 1. Material variables used in original and replacement sections of WesTrack.

	Original 1995 Construction									1997 Rehabilitation		
Design Air Void Content (%)	Aggregate Gradation Design											
	Fine			Fine Plus			Coarse			Coarse		
	Design Asphalt Contents (%)											
	47	5.4	6.1	4.7	5.4	6.1	5.0	5.7	6.4	5.1	5.8	6.5
4		4	18		12	21/9		23	25		39	55
8	2	1/15	14	22	19/11	13	8	5/24	7	38	35/54	37
12	3/16	17		10	20		26	6		56	36	

*Numbers shown in each cell represent WesTrack section numbers.

Table 2. Mixture types for the WesTrack sections.

Section No.	Asphalt Content	Air Voids	Gradation	Mixture Designation
1	M	M	F	MM(F)
2	L	M	F	LM(F)
3	L	H	F	LH(F)
4	M	L	F	ML(F)
5	M	M	C	MM(C)
6	M	H	C	MH(C)
7	H	M	C	HM(C)
8	L	M	C	LM(C)
9	H	L	F^+	HL(F^+)
10	L	H	F^+	LH(F^+)
11	M	M	F^+	MM(F^+)
12	M	L	F^+	ML(F^+)
13	H	M	F^+	HM(F^+)
14	H	M	F	HM(F)
15	M	M	F	MM(F)
16	L	H	F	LH(F)
17	M	H	F	MH(F)
18	H	L	F	HL(F)
19	M	M	F^+	MM(F^+)
20	M	H	F^+	MH(F^+)
21	H	L	F^+	HL(F^+)
22	L	M	F^+	LM(F^+)
23	M	L	C	ML(C)
24	M	M	C	MM(C)
25	H	L	C	HL(C)
26	L	H	C	LH(C)

Table 3. Mixture types designation.

C =	Coarse gradation
F =	Fine gradation
F^+ =	Fine plus gradation
AC =	Percent asphalt content
AV =	Percent air voids content
M =	Medium content (AC or AV)
H =	High content (AC or AV)
L =	Low content (AC or AV)

Section numbers from 1 through 26 indicate original construction, while any section number from 35 through 55 indicates replacement construction.

Examples:

F-24 means test section number 24 (original construction) that was designed using fine gradation.

C-39 means test section number 39 (replacement section) that was designed using coarse gradation.

HH or H/H = High AC content and high AV content

ML or M/L = Medium AC content and low AV content

LH 15 = Section 15, which has low AC content and high AV content

HM (F^+) = High AC content and medium AV content (fine plus gradation)

Table 4. Identification of samples for different tests.

	Sampling Time	Sections	Cutting Cores	Thickness & Bulk Specific Gravity		Rice	Test									
							Mr(dry)@25°C		Mr(dry)@40°C		Mr (dry)@2°C		Mr(dry)@-11.5°C		Mr(wet@25°C(Lottman)	
				RWP	BWP		RWP	BWP	RWP	BWP	RWP	BWP	RWP	BWP	RWP	BWP
ORIGINAL	T=0	26[i]		T&B		T&B	T&B									
	Construc-tion	26[i]													B	
		6[ii]							T		T		T			
	T=0 Traffic	8[iii]		T&B		T&B	T&B									
	T=12 mo. Traffic	16[iv]		T&B	T&B	T&B	T&B									
		4[v]						T&B								
	T=PM	5[vi]		T&B	T&B	T&B	T&B									
		5[vii]		T&B	T&B	T&B	T&B									
		4[viii]						T&B							B	
Replace-ment Sections	T=0 Traffic	8[ix]		T&B		T&B	T&B									
		2[x]							T		T		T			
		8[ix]													B	

26[i] Sections: 1 through 26.T = Top lift, B = Bottom lift

6[ii] Sections: 1, 5, 11, 15, 19, and 24 (optimum asphalt content and medium air voids).RWP = Right wheelpath

8[iii] Sections: 1, 10, 11, 19, 21, 24, 25, and 26.BWP = Between wheelpath

16[iv] Sections: 1, 2, 3, 4, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 22, and 23.

4[v] Sections: 1, 10, 11, 19 (out of 16[iv]).

5[vi] Sections: 7, 9, 13, 21, and 25 (Fab Five, collected in October 1996 after failure).°F = 1.8 (°C) + 32

5[vii] Sections: 5, 6, 8, 24, and 26 (collected in May 1997 after failure).

4[viii] Sections: 21, 24, 25, and 26.

8[ix] Sections: 35, 36, 37, 38, 39, 54, 55, and 56.

2[X] Sections: 35 and 54 (optimum asphalt content and medium air voids).

Table 5. WesTrack top lift time zero original construction resilient modulus (ksi) @ 25°C (77°F).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	T	M/M	547	30.0	5.5	519	582	64	4
2	F	T	L/M	618	31.3	5.1	578	664	86	6
3	F	T	L/H	363	32.2	8.9	310	405	95	6
4	F	T	M/L	464	48.9	10.5	423	532	108	4
5	C	T	M/M	531	70.8	13.3	425	609	185	6
6	C	T	M/H	337	25.2	7.5	309	365	56	6
7	C	T	H/M	404	49.8	12.3	354	464	110	6
8	C	T	L/M	460	73.7	16.0	338	549	211	6
9	F+	T	H/L	574	64.3	11.2	491	636	145	5
10	F+	T	L/H	425	40.0	9.4	383	469	85	4
11	F+	T	M/M	525	58.7	11.2	478	606	128	4
12	F+	T	M/L	678	80.4	11.9	550	761	211	5
13	F+	T	H/M	599	44.8	7.5	541	675	134	6
14	F	T	H/M	420	47.7	11.4	382	507	125	6
15	F	T	M/M	510	91.9	18.0	426	645	219	6
16	F	T	L/H	397	52.9	13.3	320	448	128	6
17	F	T	M/H	444	76.4	17.2	377	575	198	6
18	F	T	H/L	636	122.2	19.2	489	779	290	6
19	F+	T	M/M	537	72.6	13.5	429	582	154	4
20	F+	T	M/H	414	70.2	17.0	344	531	187	6
21	F+	T	H/L	467	64.1	13.7	355	516	161	5
22	F+	T	L/M	651	96.4	14.8	584	801	217	5
23	C	T	M/L	716	56.9	7.9	627	763	136	5
24	C	T	M/M	500	73.3	14.7	431	578	148	5
25	C	T	H/L	531	44.1	8.3	502	596	95	4
26	C	T	L/H	525	22.0	4.2	509	540	31	2

Table 6. WesTrack bottom lift time zero original construction resilient modulus (ksi) @ 25°C (77°F).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	B	M/M	496	67.6	13.6	415	613	198	6
2	F	B	L/M	562	37.8	6.7	514	600	86	6
3	F	B	L/H	428	21.5	5.0	405	448	43	3
4	F	B	M/L	745	133.3	17.9	534	888	355	6
5	C	B	M/M	610	84.0	13.8	509	718	209	5
6	C	B	M/H	373	40.7	10.9	331	435	104	5
7	C	B	H/M	517	53.3	10.3	457	615	157	6
8	C	B	L/M	623	62.8	10.1	574	715	141	6
9	F+	B	H/L	647	74.3	11.5	573	773	200	6
10	F+	B	L/H	482	84.6	17.5	383	577	194	5
11	F+	B	M/M	767	90.9	11.9	663	869	207	5
12	F+	B	M/L	849	154.8	18.2	718	1139	421	6
13	F+	B	H/M	568	76.9	13.5	450	658	209	6
14	F	B	H/M	556	70.1	12.6	470	647	177	6
15	F	B	M/M	629	58.7	9.3	554	696	142	6
16	F	B	L/H	554	87.9	15.7	445	697	252	6
17	F	B	M/H	485	23.9	4.9	443	503	60	5
18	F	B	H/L	715	34.9	4.9	658	746	89	6
19	F+	B	M/M	565	24.4	4.3	533	593	60	5
20	F+	B	M/H	508	12.3	2.4	493	523	30	6
21	F+	B	H/L	590	25.0	4.2	555	613	57	4
22	F+	B	L/M	760	23.0	3.0	738	796	58	5
23	C	B	M/L	664	69.2	10.4	583	777	195	6
24	C	B	M/M	648	11.0	1.7	630	657	27	5
25	C	B	H/L	573	72.3	12.6	496	694	197	6
26	C	B	L/H	518	31.1	6.0	475	549	74	4

Table 7. WesTrack time zero original construction resilient modulus (ksi) @ -11.5°C (11°F).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	T	M/M	2878	253.0	8.8	2535	3237	702	5
5	C	T	M/M	2606	387.7	14.9	2300	3168	867	4
11	F+	T	M/M	2809	250.0	8.9	2451	3034	583	4
15	F	T	M/M	2982	370.6	12.4	2386	3229	843	6
19	F+	T	M/M	1930	310.1	16.1	1643	2371	728	4
24	C	T	M/M	2031	283.8	14.0	1640	2316	677	4

Table 8. WesTrack time zero original construction resilient modulus (ksi) @ 2°C (36°F)

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	T	M/M	1578	89.3	5.7	1485	1680	195	5
5	C	T	M/M	1858	241.5	13.0	1562	2156	594	6
11	F+	T	M/M	1512	143.6	9.5	1322	1641	319	5
15	F	T	M/M	1834	286.5	15.6	1437	2186	749	5
19	F+	T	M/M	1634	205.1	12.5	1398	1889	491	5
24	C	T	M/M	1782	269.4	15.1	1402	2008	606	4

Table 9. WesTrack time zero original construction resilient modulus (ksi) @ 40°C (104 °F).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	T	M/M	127	5.6	4.4	123	134	11	4
5	C	T	M/M	149	22.4	15.1	122	182	60	5
11	F+	T	M/M	167	5.4	3.2	161	174	13	4
15	F	T	M/M	195	20.0	10.2	170	218	49	4
19	F+	T	M/M	132	14.5	11.0	107	145	38	5
24	C	T	M/M	179	9.5	5.3	173	193	20	4

Table 10. WesTrack bottom lift time zero original construction dry tensile strength (psi) @ 25°C (77°F).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	B	M/M	104	0.6	0.5	103	105	1	3
2	F	B	L/M	128	2.9	2.3	125	130	6	3
3	F	B	L/H	93	9.9	10.6	82	101	19	3
4	F	B	M/L	170	8.8	5.1	161	179	18	3
5	C	B	M/M	114	11.1	9.7	106	127	21	3
6	C	B	M/H	79	6.3	8.0	72	83	11	3
7	C	B	H/M	114	1.8	1.6	112	116	4	3
8	C	B	L/M	117	3.3	2.8	114	120	6	3
9	F+	B	H/L	156	18.2	11.6	139	175	36	3
10	F+	B	L/H	81	6.1	7.5	74	85	11	3
11	F+	B	M/M	151	10.3	6.8	139	157	18	3
12	F+	B	M/L	192	4.4	2.3	188	197	9	3
13	F+	B	H/M	132	8.6	6.5	126	141	16	3
14	F	B	H/M	130	3.1	2.4	126	132	6	3
15	F	B	M/M	143	4.9	3.4	139	149	10	3
16	F	B	L/H	107	8.5	8.0	98	115	17	3
17	F	B	M/H	99	10.7	10.8	89	110	21	3
18	F	B	H/L	165	8.3	5.0	158	174	16	3
19	F+	B	M/M	120	8.9	7.4	111	129	18	3
20	F+	B	M/H	98	5.5	5.7	91	101	10	3
21	F+	B	H/L	149	5.0	3.4	144	153	10	3
22	F+	B	L/M	148	9.9	6.7	137	157	20	3
23	C	B	M/L	150	12.6	8.4	137	161	25	3
24	C	B	M/M	119	4.9	4.1	114	123	9	3
25	C	B	H/L	123	7.6	6.1	115	130	15	3
26	C	B	L/H	83	7.6	9.2	76	91	15	3

Table 11. WesTrack time zero traffic original construction resilient modulus (ksi) @ 25°C (77°F) (top lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	T	M/M	601	13.8	2.3	590	616	27	3
10	F+	T	L/H	460	17.6	3.8	441	475	35	3
11	F+	T	M/M	546	31.5	5.8	528	583	55	3
19	F+	T	M/M	491	48.3	9.8	457	525	68	3
21	F+	T	H/L	549	37.7	6.9	509	584	75	3
24	C	T	M/M	468	18.3	3.9	448	482	35	3
25	C	T	H/L	509	8.5	1.7	500	516	16	3
26	C	T	L/H	466	21.8	4.7	447	490	43	3

Table 12. WesTrack time zero traffic original construction resilient modulus (ksi) @ 25°C (77°F) (bottom lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	B	M/M	442	23.3	5.3	420	467	47	3
10	F+	B	L/H	470	48.3	10.3	440	525	86	3
11	F+	B	M/M	579	58.6	10.1	518	635	117	3
19	F+	B	M/M	537	19.0	3.5	516	548	33	3
21	F+	B	H/L	587	50.2	8.6	544	642	98	3
24	C	B	M/M	672	56.0	8.3	611	721	110	3
25	C	B	H/L	591	12.7	2.1	577	601	24	3
26	C	B	L/H	487	53.5	11.0	439	545	105	3

Table 13. WesTrack time 12 months traffic original construction resilient modulus (ksi) @ 25°C (77°F) right wheelpath (top lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	T	M/M	985	57.3	5.8	946	1051	105	3
2	F	T	L/M	1288	108.0	8.4	1193	1405	212	3
3	F	T	L/H	1168	110.2	9.4	1085	1294	208	3
4	F	T	M/L	1063	72.2	6.8	980	1106	127	3
10	F+	T	L/H	1130	79.9	7.1	1038	1181	143	3
11	F+	T	M/M	963	80.5	8.4	872	1026	154	3
12	F+	T	M/L	1123	21.3	1.9	1107	1147	41	3
14	F	T	H/M	988	37.2	3.8	964	1031	67	3
15	F	T	M/M	1043	101.2	9.7	932	1130	198	3
16	F	T	L/H	1090	80.3	7.4	1037	1182	145	3
17	F	T	M/H	1110	64.0	5.8	1040	1166	126	3
18	F	T	H/L	723	41.8	5.8	676	756	80	3
19	F+	T	M/M	1016	81.6	8.0	924	1081	156	3
20	F+	T	M/H	981	86.8	8.8	886	1055	169	3
22	F+	T	L/M	1253	125.2	10.0	1140	1388	248	3
23	C	T	M/L	674	57.0	8.5	628	737	110	3

Table 14. WesTrack time 12 months traffic original construction resilient modulus (ksi) @ 25°C (77°F) right wheelpath (bottom lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	B	M/M	958	13.9	1.5	946	973	28	3
2	F	B	L/M	856	61.2	7.1	819	927	108	3
3	F	B	L/H	997	75.0	7.5	915	1062	147	3
4	F	B	M/L	1180	70.2	5.9	1135	1261	126	3
10	F+	B	L/H	653	60.8	9.3	583	691	108	3
11	F+	B	M/M	967	87.9	9.1	870	1042	172	3
12	F+	B	M/L	1045	98.1	9.4	975	1157	182	3
14	F	B	H/M	847	97.0	11.5	744	937	193	3
15	F	B	M/M	944	117.8	12.5	855	1078	222	3
16	F	B	L/H	1079	108.7	10.1	958	1170	212	3
17	F	B	M/H	1038	74.7	7.2	958	1106	148	3
18	F	B	H/L	580	67.3	11.6	540	658	118	3
19	F+	B	M/M	916	62.8	6.9	846	968	122	3
20	F+	B	M/H	993	93.1	9.4	886	1055	169	3
22	F+	B	L/M	1166	47.9	4.1	1126	1219	93	3
23	C	B	M/L	695	54.8	7.9	645	754	109	3

Table 15. WesTrack time 12 months traffic original construction resilient modulus (ksi) @ 25°C (77°F) between wheelpaths (top lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	T	M/M	1013	88.7	8.8	916	1091	174	3
10	F+	T	L/H	1008	83.9	8.3	925	1093	168	3
11	F+	T	M/M	874	110.0	12.6	793	999	207	3
19	F+	T	M/M	830	14.9	1.58	821	847	27	3

Table 16. WesTrack time 12 months traffic original construction resilient modulus (ksi) @ 25°C (77°F) between wheelpaths (bottom lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
1	F	B	M/M	895	75.9	8.5	816	967	151	3
10	F+	B	L/H	892	87.0	9.7	833	992	159	3
11	F+	B	M/M	1059	69.7	6.6	1003	1137	134	3
19	F+	B	M/M	818	36.6	4.5	778	850	72	3

Table 17. WesTrack post mortem sections original construction resilient modulus (ksi) @ 25°C (77°F) right wheelpath (top lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
5	C	T	M/M	1052	110.6	10.5	963	1176	213	3
6	C	T	M/H	730	74.6	10.2	668	813	145	3
7	C	T	H/M	627	24.0	3.8	605	652	48	3
8	C	T	L/M	665	21.8	3.3	641	683	42	3
9	F+	T	H/L	838	72.6	8.7	764	909	145	3
13	F+	T	H/M	899	45.5	5.2	853	946	93	3
21	F+	T	H/L	1080	111.5	10.3	977	1198	221	3
24	C	T	M/M	806	76.0	9.4	749	892	143	3
25	C	T	H/L	926	58.1	6.3	864	979	115	3
26	C	T	L/H	861	96.3	11.2	801	972	171	3

Table 18. WesTrack post mortem sections original construction resilient modulus (ksi) @ 25°C (77°F) right wheelpath (bottom lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
5	C	B	M/M	536	16.0	3.0	518	548	31	3
6	C	B	M/H	740	60.2	8.1	702	810	108	3
7	C	B	H/M	736	81.1	11.0	643	791	148	3
8	C	B	L/M	535	40.1	7.5	509	581	73	3
9	F+	B	H/L	863	37.2	4.3	840	906	66	3
13	F+	B	H/M	846	49.3	5.8	812	902	91	3
21	F+	B	H/L	1108	130.6	11.8	1005	1255	250	3
24	C	B	M/M	614	48.4	7.9	558	642	84	3
25	C	B	H/L	1473	98.3	6.7	1406	1586	180	3
26	C	B	L/H	646	52.9	8.2	585	684	99	3

Table 19. WesTrack post mortem sections original construction resilient modulus (ksi) @ 25°C (77°F) between wheelpaths (top lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
21	F+	T	H/L	1081	71.0	6.6	1004	1143	140	3
24	C	T	M/M	732	65.4	8.9	687	807	120	3
25	C	T	H/L	1022	82.6	8.1	938	1103	165	3
26	C	T	L/H	848	47.6	5.6	794	884	91	3

Table 20. WesTrack post mortem sections original construction resilient modulus (ksi) @ 25°C (77°F) between wheelpaths (bottom lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
21	F+	B	H/L	1118	29.6	2.6	1089	1148	59	3
24	C	B	M/M	733	68.9	9.4	666	803	138	3
25	C	B	H/L	923	36.4	3.9	884	956	72	3
26	C	B	L/H	702	41.6	5.9	654	728	74	3

Table 21. WesTrack port mortem sections original construction dry tensile strength (psi) @ 25°C (77°F) (bottom lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
21	F+	B	H/L	161	17.0	10.6	145	179	34	3
24	C	B	M/M	152	14.3	11.0	117	145	28	3
25	C	B	H/L	123	8.2	6.6	118	133	14	3
26	C	B	L/H	117	6.6	6.3	100	109	9	2

Table 22. WesTrack replacement sections time zero traffic resilient modulus (ksi) @ 25°C (77°F) (top lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
35	C	T	M/M	460	22.7	4.9	434	476	42	3
36	C	T	M/H	287	14.7	5.1	275	304	28	3
37	C	T	H/M	421	32.6	7.8	402	459	57	3
38	C	T	L/M	491	48.3	9.8	457	525	68	3
39	C	T	M/L	559	29.5	5.3	526	583	57	3
54	C	T	M/M	376	16.3	4.3	361	393	33	3
55	C	T	H/L	419	29.1	7.0	389	447	58	3
56	C	T	L/H	346	22.6	6.5	330	372	42	3

Table 23. WesTrack replacement sections time zero traffic resilient modulus (ksi) @ 25°C (77°F) (bottom lifts).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
35	C	B	M/M	409	14.6	3.6	395	424	29	3
36	C	B	M/H	386	14.8	3.8	377	403	26	3
37	C	B	H/M	384	23.5	6.1	359	406	47	3
38	C	B	L/M	511	25.8	5.0	482	531	50	3
39	C	B	M/L	525	26.0	4.9	510	555	45	3
54	C	B	M/M	443	32.8	7.4	413	478	65	3
55	C	B	H/L	336	28.3	8.4	317	368	51	3
56	C	B	L/H	358	29.6	8.3	336	392	56	3

Table 24. WesTrack time-zero traffic replacement sections resilient modulus (ksi) @ -11.5°C (11°F).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
35	C	T	M/M	2518	134.1	5.3	2367	2623	256	3
54	C	T	M/M	3269	136.5	4.2	3130	3403	273	3

Table 25. WesTrack time-zero traffic replacement sections resilient modulus (ksi) @ 2°C (36 °F).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
35	C	T	M/M	1659	23.4	1.4	1642	1686	44	3
54	C	T	M/M	1683	102.2	6.1	1608	1800	192	3

Table 26. WesTrack time-zero traffic replacement sections resilient modulus (ksi) @ 40°C (104 °F).

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
35	C	T	M/M	99	7.0	7.1	92	106	14	3
54	C	T	M/M	98	8.7	8.9	90	107	17	3

Table 27. WesTrack time-zero traffic replacement sections dry tensile strength (psi) @ 25°C (77°F) bottom lifts.

SECTION	GRADATION	LIFT	AC/AV	MEAN	STD DEV	COV	MIN	MAX	RANGE	REPLICATES
35	C	B	M/M	79	5.5	6.9	74	85	11	3
36	C	B	M/H	45	0.3	0.6	45	45	1	3
37	C	B	H/M	59	2.6	4.3	56	61	5	3
38	C	B	L/M	98	4.9	4.9	94	103	10	3
39	C	B	M/L	92	6.2	6.8	85	98	12	3
54	C	B	M/M	83	6.1	7.3	77	89	12	3
55	C	B	H/L	86	3.8	4.4	83	90	8	3
56	C	B	L/H	74	4.5	6.1	70	79	9	3

Recovered Asphalt Binder Properties—WesTrack Hot-Mix Asphalt Mixtures

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-27
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information on recovered asphalt binder properties from the WesTrack project. The asphalt binders were obtained by extraction and recovery procedures on core samples of HMA obtained from the WesTrack pavement at various ages during its service life. Information is presented for both the original construction sections and the replacement sections. The test program used for sampling and testing is contained in WesTrack Technical Reports UNR-1[4] and UNR-2.[5] Detailed test results and analyses of the recovered asphalt binder properties can be found in a Master of Science Thesis[6] prepared for the University of Nevada.

BACKGROUND

Cores of the HMA were obtained during the life of the test track. The cores were subjected to an extraction and recovery process to obtain samples of the asphalt binder at various ages. Both conventional and Superpave binder properties were obtained on the recovered asphalt binders. Sections placed as part of the original construction were sampled immediately after construction; and at 8 months, 14 months, 20 months, and 41 months after placement or construction. The replacement sections were sampled at 21 months after placement.

WesTrack investigated the effect of aggregate gradation, aggregate type, asphalt binder content, and in-place air voids on the rutting and fatigue performance of HMA. The three gradations

used on WesTrack were identified as fine, fine plus, and coarse graded mixtures. Figure 1 shows the three gradations used during placement of the original constructed sections and the coarse gradation used for the replacement sections. Table 1 identifies the section numbers associated with the various aggregate gradations, aggregate types, asphalt binder contents, and in-place air voids. The 34 mixtures evaluated were placed on 26 different locations (test sections) on the test track as shown in figure 2 and designated in tables 2 and 3.

SAMPLING

Samples of HMA were obtained by core sampling of the WesTrack pavement sections. Samples were obtained from between the wheelpaths. Twenty-six test sections were placed as part of the original construction. Construction of these test sections was completed in early October 1995. Eight replacement sections were placed in June 1997. The original test sections were sampled at the following times for determination of recovered asphalt binder properties:

- Immediately after construction (time zero construction, October 1995).
- At the start of traffic (time zero traffic, May 1996, 8 months after construction).
- At the time or rehabilitation of five sections (November 1996, 14 months after construction, sections 7, 9, 13, 21, and 25).
- After approximately 12 months of traffic (May 1997, 20 months after construction, sections 5, 6, 8, 24, and 26).
- After completion of traffic (February 1999, 41 months after construction, sections 1, 10, 11, 19, and 23).

As shown in table 4, only a limited number of sections were sampled and tested to determine the changes in asphalt binder properties with time. These data were used to provide a comparison between the time zero construction, the time zero traffic properties, and the properties of the asphalt binders over the life of the test track. The time of sampling for the time zero construction was October 1995 and the time of sampling for time zero traffic was May 1996 (approximately 8 months after completion of construction).

The time 12-month traffic sampling (20 months after construction) was performed in May 1997. This was also the time at which the traffic was removed from the track for construction of replacement sections (May and June 1997).

Post mortem samples were obtained at various times depending on when the test sections were removed from service (table 2). Sections 7, 9, 13, 21, and 25 were sampled in November 1996, just prior to a rehabilitation of those sections by milling and filling with new HMA (14 months after construction). Samples from sections 5, 6, 8, 24, and 26 were obtained in May 1997, approximately 20 months after construction. These samples were obtained just prior to the construction of the replacement sections (35, 36, 37, 38, 39, 54, 55, and 56).

The replacement sections were sampled just prior to the start of traffic (time zero traffic, July 1997) and at the completion of traffic (February 1999, 20 months after construction). Extracted

and recovered properties of the asphalt binders were only obtained for the February 1999 samples.

On the original test sections, only eight of the 26 test sections were selected for recovered binder property determination (table 4). Mixtures at optimum asphalt binder content and 8 percent air voids were selected for the fine (section 1), fine plus (sections 11 and 19), and coarse graded (section 24) sections to represent typical construction conditions for these three gradations. Results from these sections allow for a comparison of the effects of gradation on asphalt binder hardening with time. Two sections (sections 11 and 19) were selected for the fine plus section at the optimum asphalt binder content and 8 percent air voids to allow for replicate sections to be considered in the analysis.

Low asphalt binder content with high air void content sections were selected for the fine plus (section 21) and the coarse graded (section 25) sections to represent the extreme (maximum amount) of expected hardening of the asphalt binder. High asphalt binder content and low air void content sections were selected for the fine plus (section 10) and the coarse graded section (section 26) to represent the other extreme of expected hardening of the asphalt binder (minimum amount of hardening).

For the replacement sections four of the eight sections placed were selected for recovered asphalt binder determination (sections 35, 36, 55, and 56). Section 35 represented the coarse replacement section placed at optimum asphalt binder content and 8 percent air voids. Sections 55 and 56 represented mixtures at extremes of expected hardening with time (low asphalt binder content and high air voids, and high asphalt binder content and low air voids, respectively). Section 36 was placed at optimum asphalt binder content and high air voids.

The samples for binder property determination were obtained from between the wheelpaths. The sample locations were the designated sampling areas at the end of the test sections. Samples were not obtained at random locations along the test section.

The cores were sawcut in the laboratory to separate the top lift from the bottom lift. Recovered asphalt binder properties were determined only on the samples obtained from the top lift. Air void contents were obtained on both top and bottom lift samples.

TEST PLAN AND TEST METHODS

Figure 3 shows the test plan and test methods used in this study. The extraction and recovery process is described below, as are the test methods used to define the stiffness of the asphalt binder obtained from the field cores.

EXTRACTION AND RECOVERY

Asphalt binder was extracted from the field cores using extraction method AASHTO T 164 - Method A (ASTM D 2172). Trichloroethylene is used as a solvent in this cold process. The HMA is placed in a bowl, covered with trichloroethylene, and allowed to revolve at controlled

speeds of up to 3,600 revolutions per minute. The mixture of the asphalt binder and the solvent are collected at the drain of the device. Since the asphalt binder contains solvent, a recovery process is used to remove the solvent. AASHTO T 170 (ASTM D 1856) was used to remove the solvent. The asphalt binder/solvent mixture is centrifuged in a flask for a minimum of 30 minutes at a temperature of 138°C (280°F) and under a minimum centrifugal force of 3,000 times gravity. A vacuum pressure of about 50 mm Hg is applied to the solution and maintained for the 30 minutes or until the condensation of the evaporated solvent from the delivery tube stops. The vacuum pressure is then raised to 600 mm Hg using a vacuum pump for about 10 minutes to ensure the complete removal of the solvent and to flush the solvent vapors from the flask.

RECOVERED ASPHALT BINDER PROPERTIES

The recovered asphalt binder was tested to determine the conventional properties of penetration at 25°C (77°F) (AASHTO T 49) and viscosity at 60°C (140°F) (AASHTO T 202). Superpave asphalt binder properties also were obtained with the dynamic shear rheometer (DSR) (AASHTO TP 5) and the bending beam rheometer (BBR) (AASHTO TP 1). The DSR test was performed at 22°C, 25°C, 58°C, and 64°C (72°F, 77°F, 136°F, and 147°F). The BBR test was performed at
-12°C (10°F).

EXTRACTION AND RECOVERY TEST ACCURACY

Table 5 contains data describing errors that may have been associated with the use of extraction and recovery testing. An original sample of asphalt binder from the WesTrack project was tested to determine the viscosity at 135°C and 60°C (275°F and 140°F), as well as the mass loss after the rolling thin film oven test (RTFOT). This same original asphalt binder was subjected to a "blank recovery" process as described below.

Approximately 70 g (2.5 oz) of asphalt binder were introduced into a 1,200 ml (41 fl oz) flask and 800 ml (27 fl oz) of solvent were added. After 4 hours (to allow the solvent to dissolve the asphalt binder), the solution was subjected to the recovered asphalt binder test as described above. After recovery, the viscosity at 135°C and 60°C (275°F and 140°F) and the mass loss after the RTFOT were determined.

The test results shown in table 5 indicate that some of the solvent was probably not removed from the sample as the viscosity was lower and the mass loss was greater than the original asphalt binder samples. According to the standard test method for recovering asphalt binder from solvents (ASTM D 1856), the acceptable range of two viscosity values measured at 60°C (140°F) in the same laboratory by the same operator and the same apparatus is a maximum of 51 percent expressed as a percent of their mean value. Clearly the extraction and recovery process is highly variable.

AIR VOID CONTENT

The air void content of the core samples was found by determining the bulk specific gravity of the cut cores by use of the saturated surfaced dried method (ASTM D 2726) and the parafilm method (ASTM D 1188) and by determining the theoretical maximum specific gravity of the HMA by use of ASTM D 2141. Air voids were calculated according to ASTM D 3203 (figure 3). The top and bottom lifts of the core samples were separated by sawing. Binder was extracted and recovered from two cores and then used for determinations of the asphalt binder properties.

Table 6 contains the air void content of the top and bottom lifts of samples obtained from between the wheelpaths 40 months after placement of the HMA on the original construction sections. Table 7 contains the air void content of the top and bottom lifts of samples obtained from between the wheelpaths 19 months after placement of the HMA on the replacement sections.

ORIGINAL ASPHALT BINDER PROPERTIES

References 4, 5, and 6 contain the "original" asphalt binder properties. These asphalt binder properties were determined on samples obtained during construction prior to entry into the mixing chamber of the hot-mix plant. A Superpave PG 64-22 from the Huntway Refinery in Martinez, California, was used for the original construction of WesTrack.[4] A PG 64-22 asphalt binder from Idaho Asphalt Supply, Inc., in Nampa, Idaho, was used in the replacement sections.

Tables 8 through 11 contain a summary of the original asphalt binder properties. Table 8 shows the DSR and BBR test results at standard testing temperatures. Table 9 shows the temperatures at which the specified physical property requirements are achieved. DSR and BBR values over a range of temperatures are shown in tables 10 and 11, respectively.

RECOVERED ASPHALT BINDER PROPERTIES

Recovered asphalt binder properties were obtained on binder from core samples removed from both the original construction and replacement sections. Tables 12 through 20 and figures 4 through 27 contain recovered asphalt binder property information. These data will be presented for the original construction and the replacement sections. Penetration at 25°C (77°F), viscosity at 60°C (140°F), DSR at 64°C and 25°C (147°F and 77°F), and BBR at -12 C° (10°F) data are discussed below. It should be noted that the extraction and recovered property data for 19 months were obtained by a single technician. The 40-month data were obtained by a different technician. Inconsistent data trends are evident when comparing these two data sets.

ORIGINAL CONSTRUCTION

Penetration

The penetrations of the recovered binders were obtained at 25°C (77°F) and are shown in table 12 and figures 4, 5, and 6. As expected, the penetration decreased with an increase in aging in the field. The 41-month data are suspect due to the very low values reported. The penetration data suggest that increased hardening resulted with the use of the coarse graded mixture as compared to the fine graded mixtures at low asphalt contents and high air voids, as well as at optimum asphalt contents and medium or 8 percent air voids.

Viscosity

The viscosity of the recovered binders was obtained with capillary tubes at 60°C (140°F). Test results are shown in table 13 and figures 7, 8, and 9. As expected, the viscosity increased with time in service. The viscosity data suggest that increased hardening resulted with the use of the coarse graded mixture, as compared to the fine graded mixtures.

Dynamic Shear Rheometer at 64°C

DSR data at 58°C and 64°C (136°F and 147°F) are shown in tables 14 and 15 and figures 10 through 15. Shear modulus data are shown in figures 10 through 12 and $G^*/\sin \delta$ data are shown in figures 13 through 15. As expected, the stiffness values increased with age. The DSR data suggest that increased hardening resulted with the use of the coarse graded mixture, as compared to the fine graded mixtures.

Dynamic Shear Rheometer at 25°C

DSR data at 22°C and 25°C (72°F and 77°F) are shown in tables 16 and 17 and figures 16 through 21. Shear modulus data are shown in figures 16 through 18 and $G^*\sin \delta$ data are shown in figures 19 through 21. As expected, the stiffness values increased with age. The DSR data suggest that increased hardening resulted with the use of the coarse graded mixture, as compared to the fine graded mixtures.

Bending Beam Rheometer at -12°C

BBR data at -12°C (10°F) are shown in tables 18 and 19 and figures 22 through 24. Stiffness values are shown in table 18 and "m" values are shown in table 19. As expected, the stiffness values increase with age. The BBR data suggest that increased hardening resulted with the use of the coarse graded mixture, as compared to the fine graded mixtures.

Aging Index

The aging index was calculated by dividing the aged viscosity at 60°C (140°F) by the original viscosity at 60°C and is shown in figures 25 through 27. As expected, the aging index increases

with time in service. The aging index data suggest that increased hardening resulted with the use of the coarse graded mixture, as compared to the fine graded mixtures.

REPLACEMENT SECTIONS

Table 20 contains recovered asphalt binder property data for the replacement sections after 20 months of service. Recovered properties were not determined immediately after construction. The recovered asphalt binder properties can be compared with the original asphalt binder properties shown in tables 8 through 11.

SUMMARY

Recovered asphalt binder properties have been obtained on mixtures placed during original construction and for the replacement sections. The data show the expected trend of increasing stiffness or hardening with age in service. In addition, the data suggest that the hardening of the asphalt binder on the coarse graded mixtures was greater than on the fine graded mixtures.

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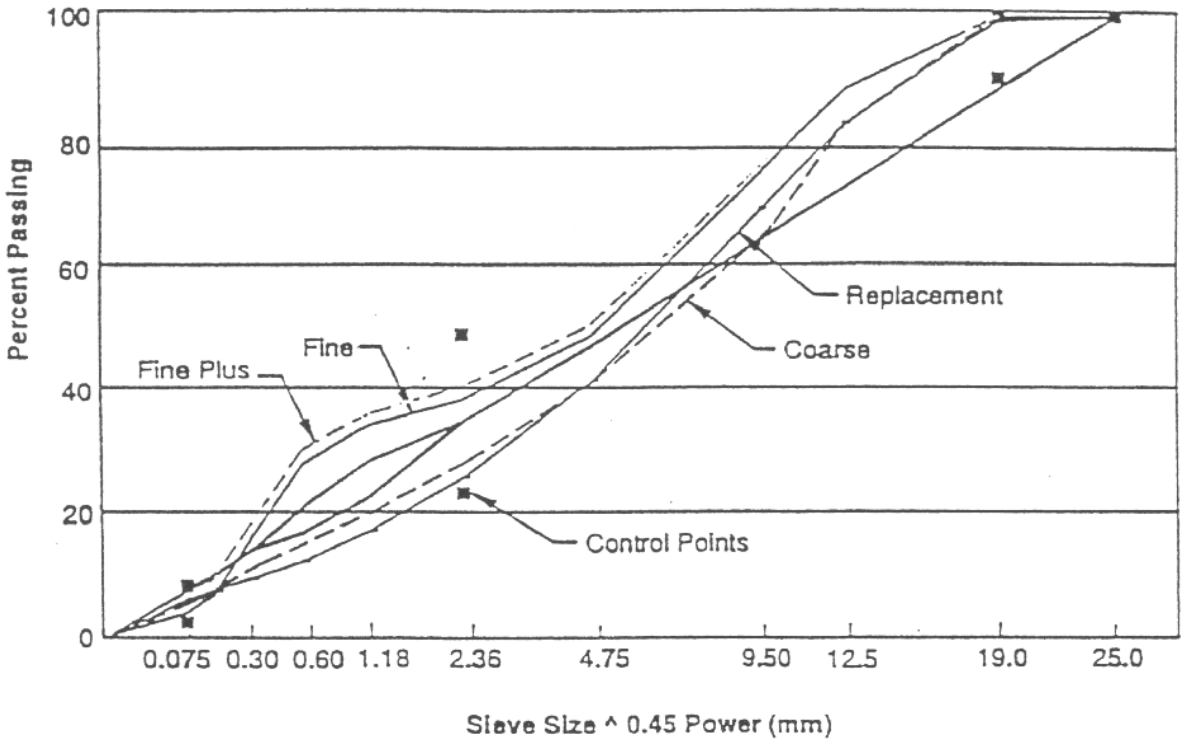

Figure 1. Mixture target gradations for WesTrack.

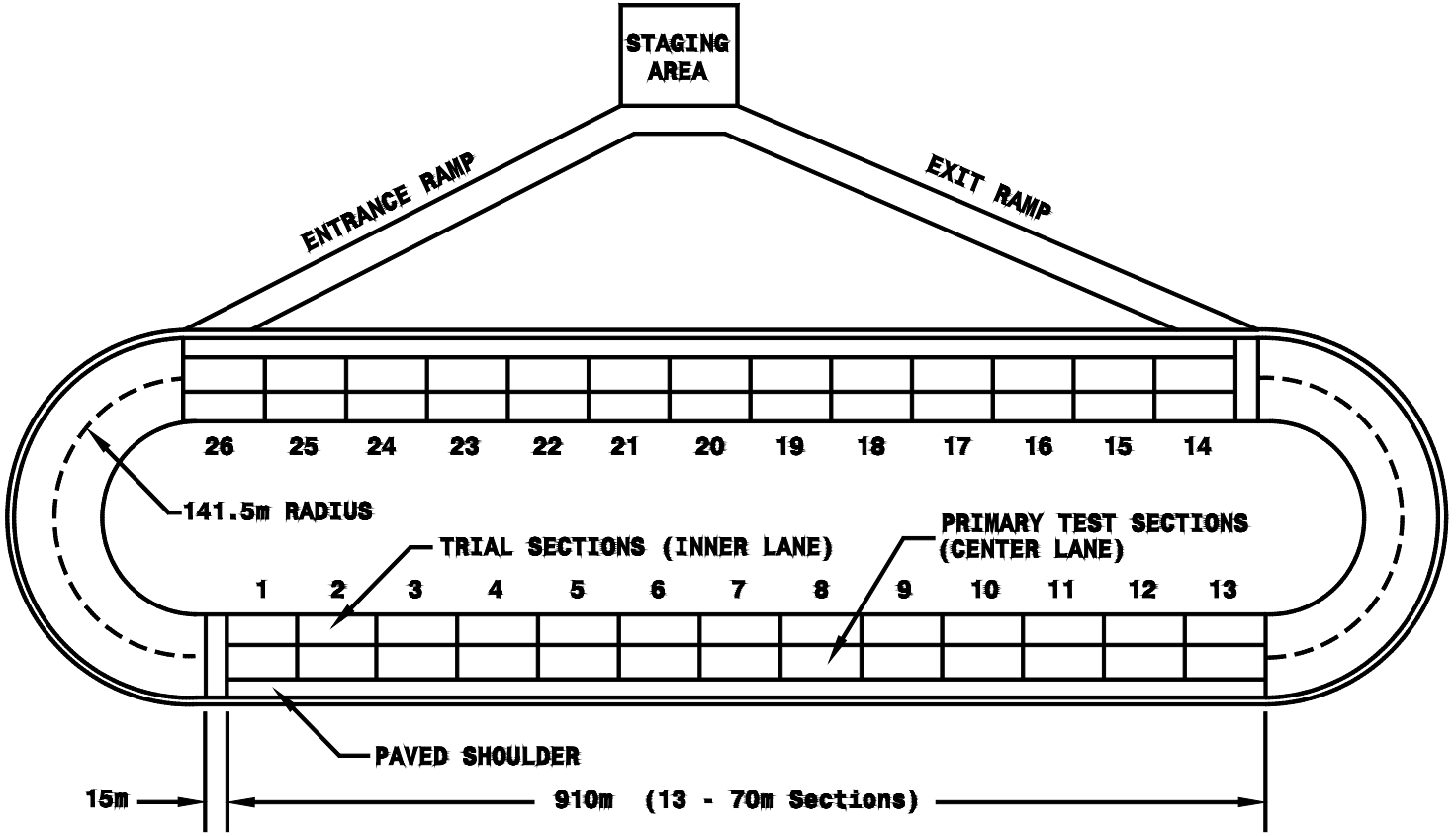

Figure 2. Layout of the test track sections.

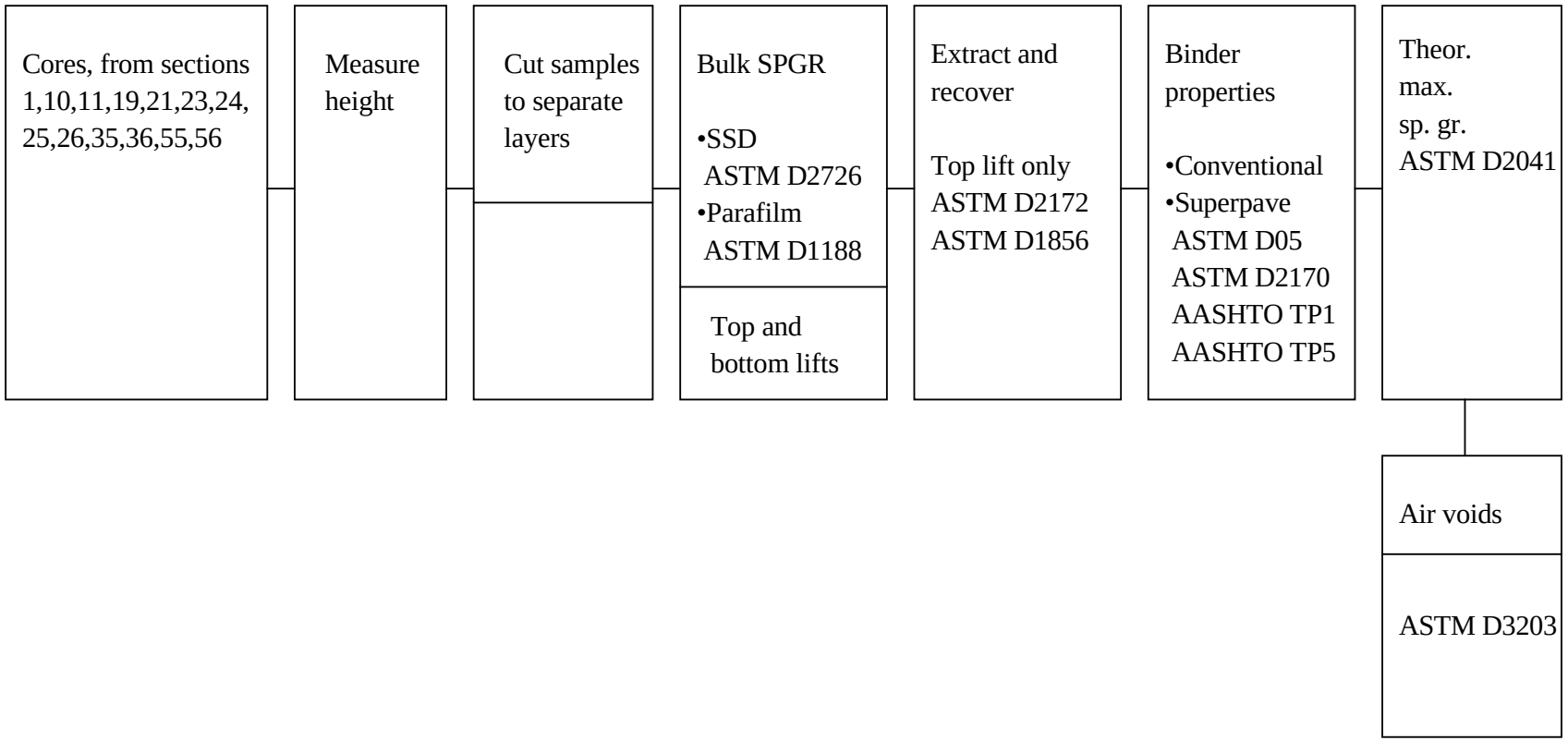

Figure 3. Recovered asphalt binder test program.

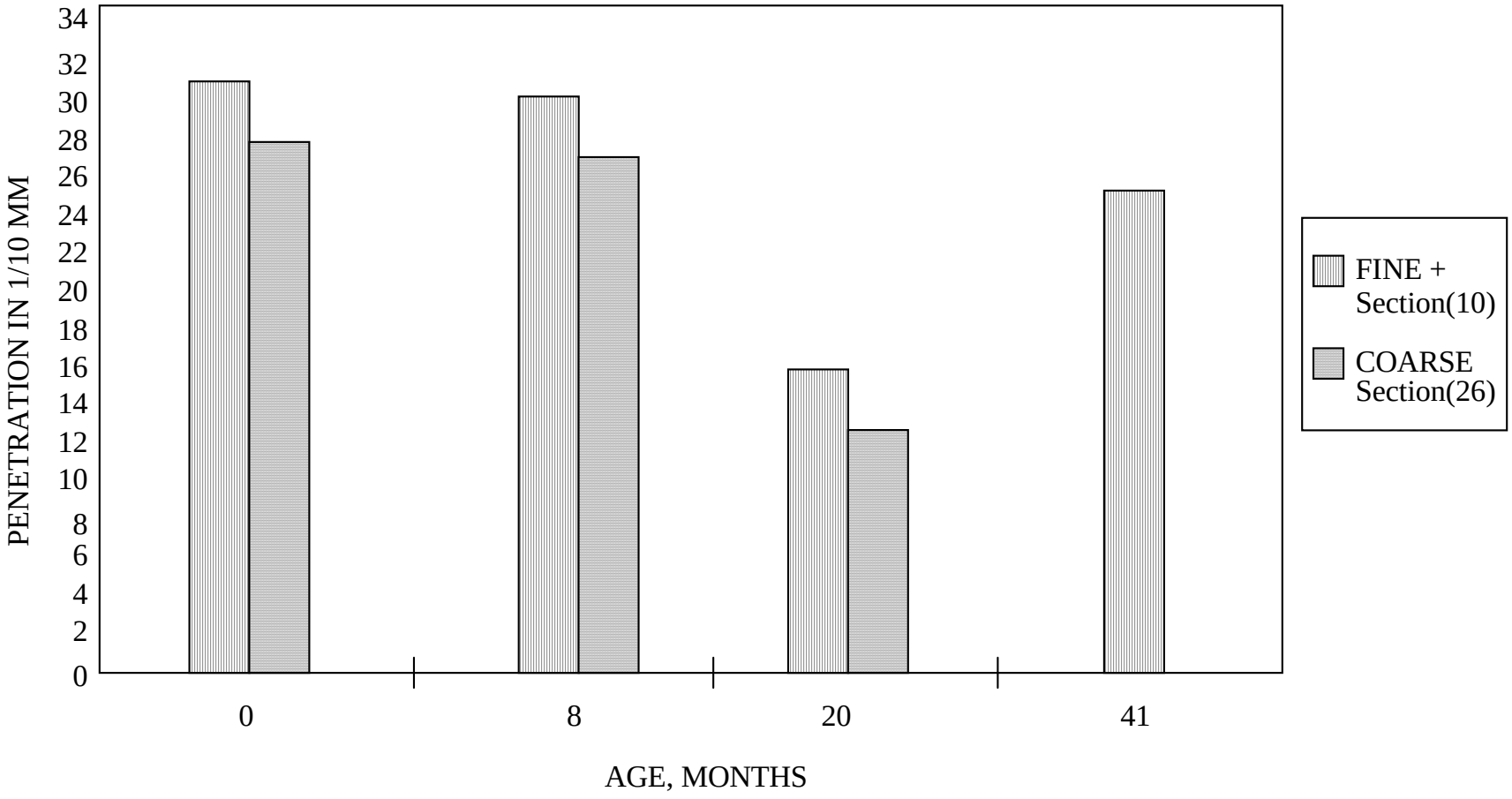

Figure 4. Penetration values for the extracted binder at different intervals of time and for mixes of low asphalt content and high air voids.

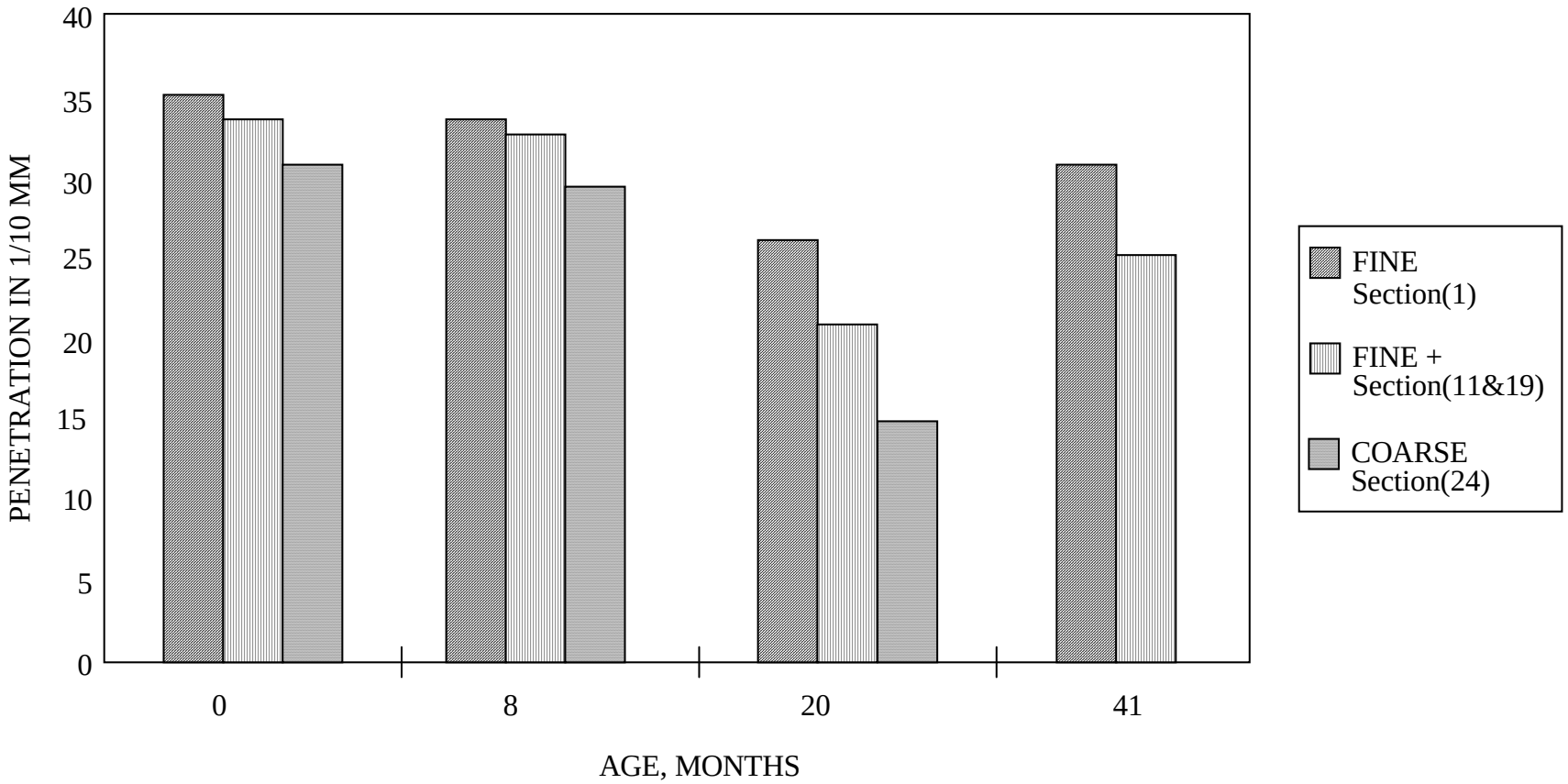

Figure 5. Penetration values for the extracted binder at different intervals of time and for mixes of medium asphalt content and medium air voids.

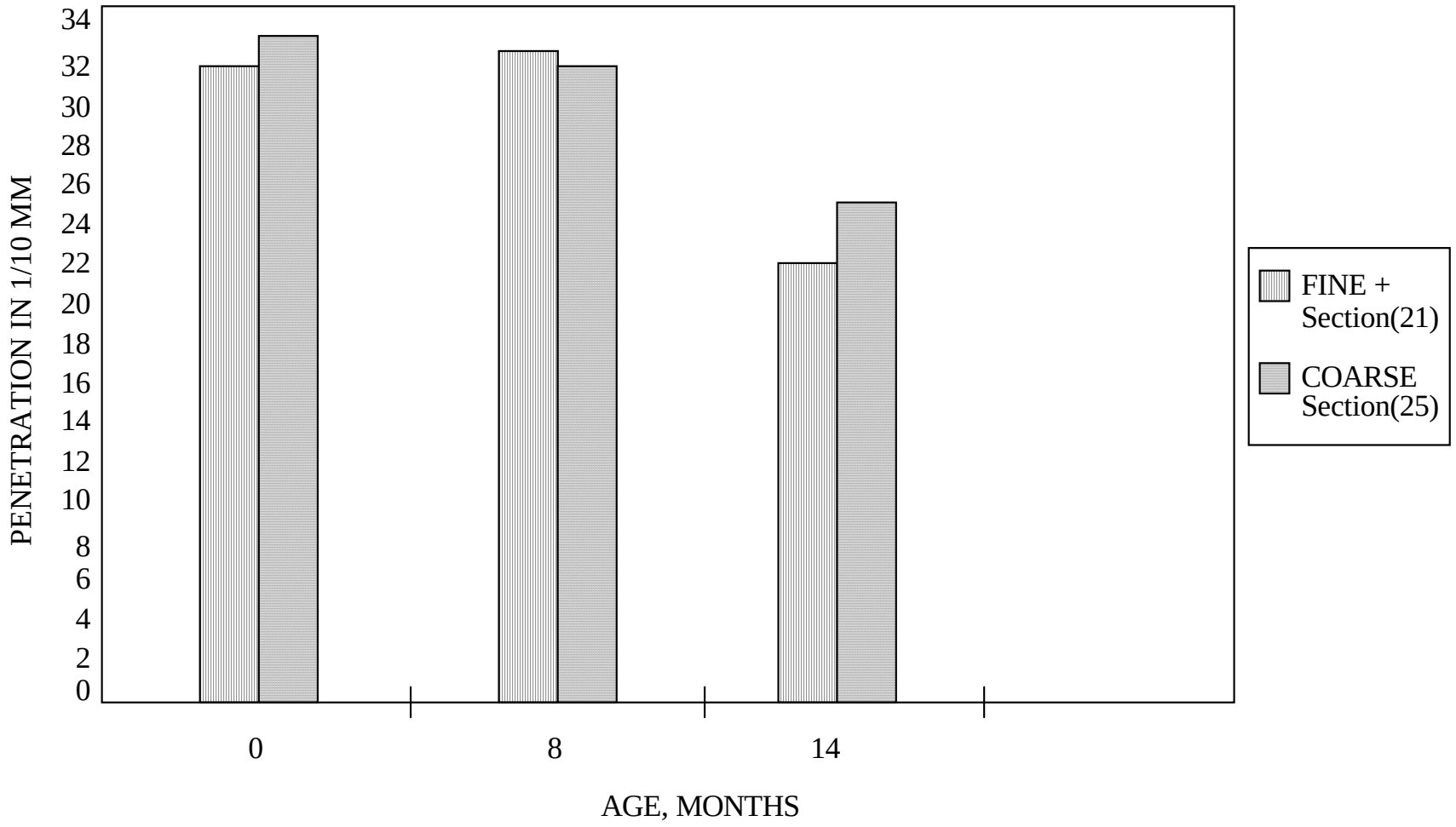

Figure 6. Penetration values for the extracted binder at different intervals of time and for mixes of high asphalt content and low air voids.

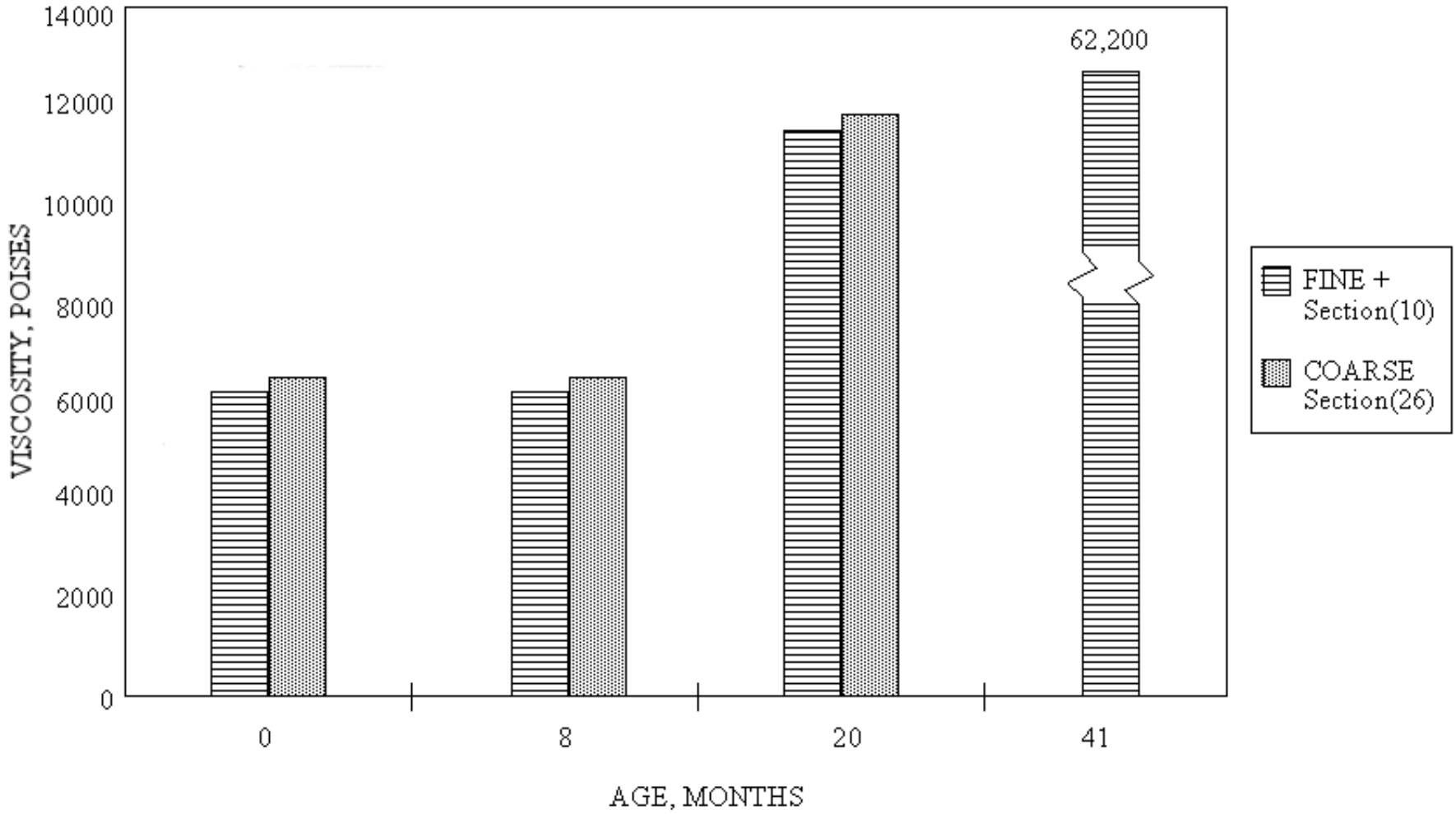

Figure 7. Absolute viscosity values for the extracted binder at different intervals of time and for mixes of low asphalt content and high air voids.

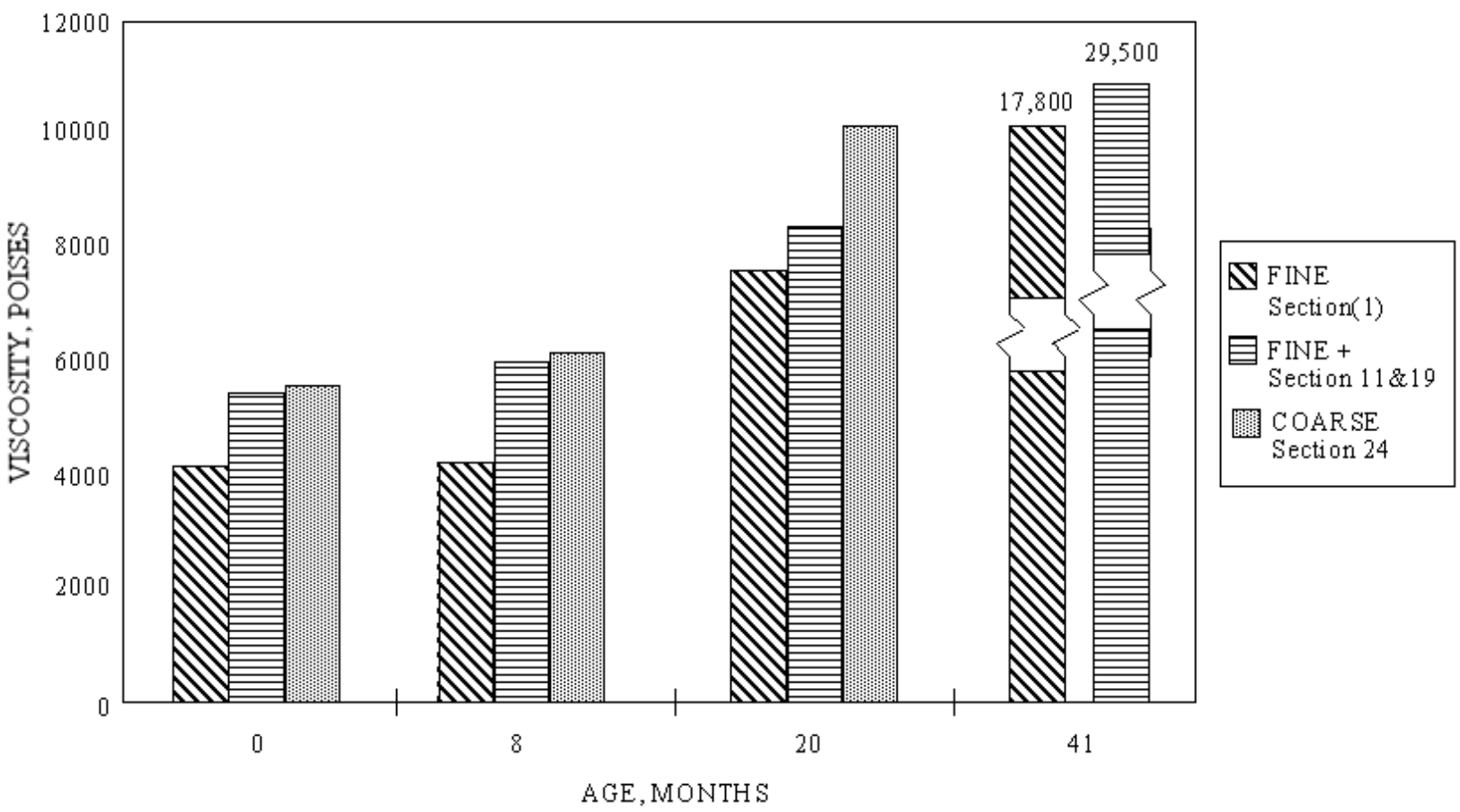

Figure 8. Absolute viscosity values for time extracted binder at different intervals of time and for mixes of medium asphalt content and medium air voids.

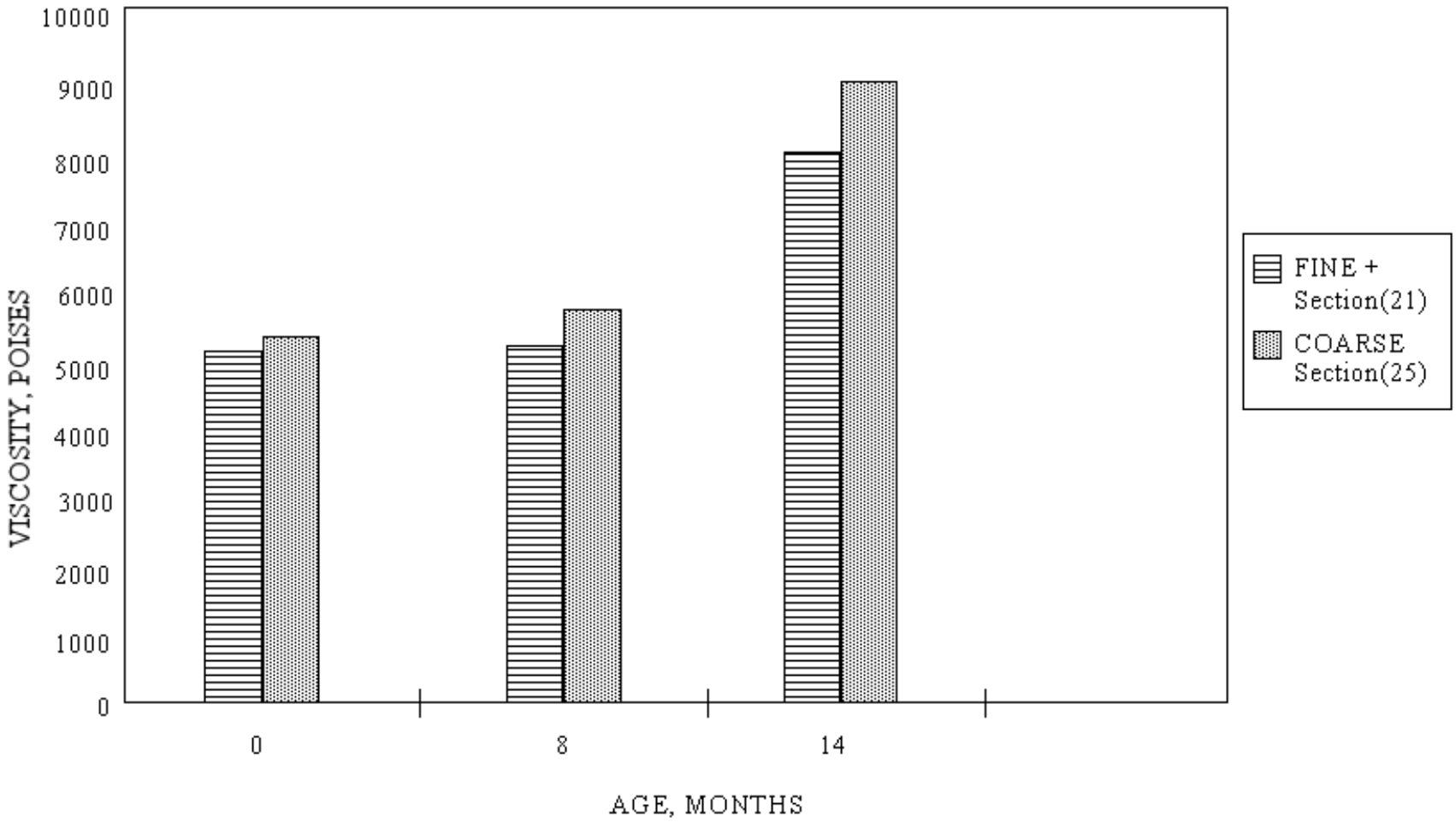

Figure 9. Absolute viscosity values for the extracted binder at different intervals of time and for mixes of high asphalt content and low air voids.

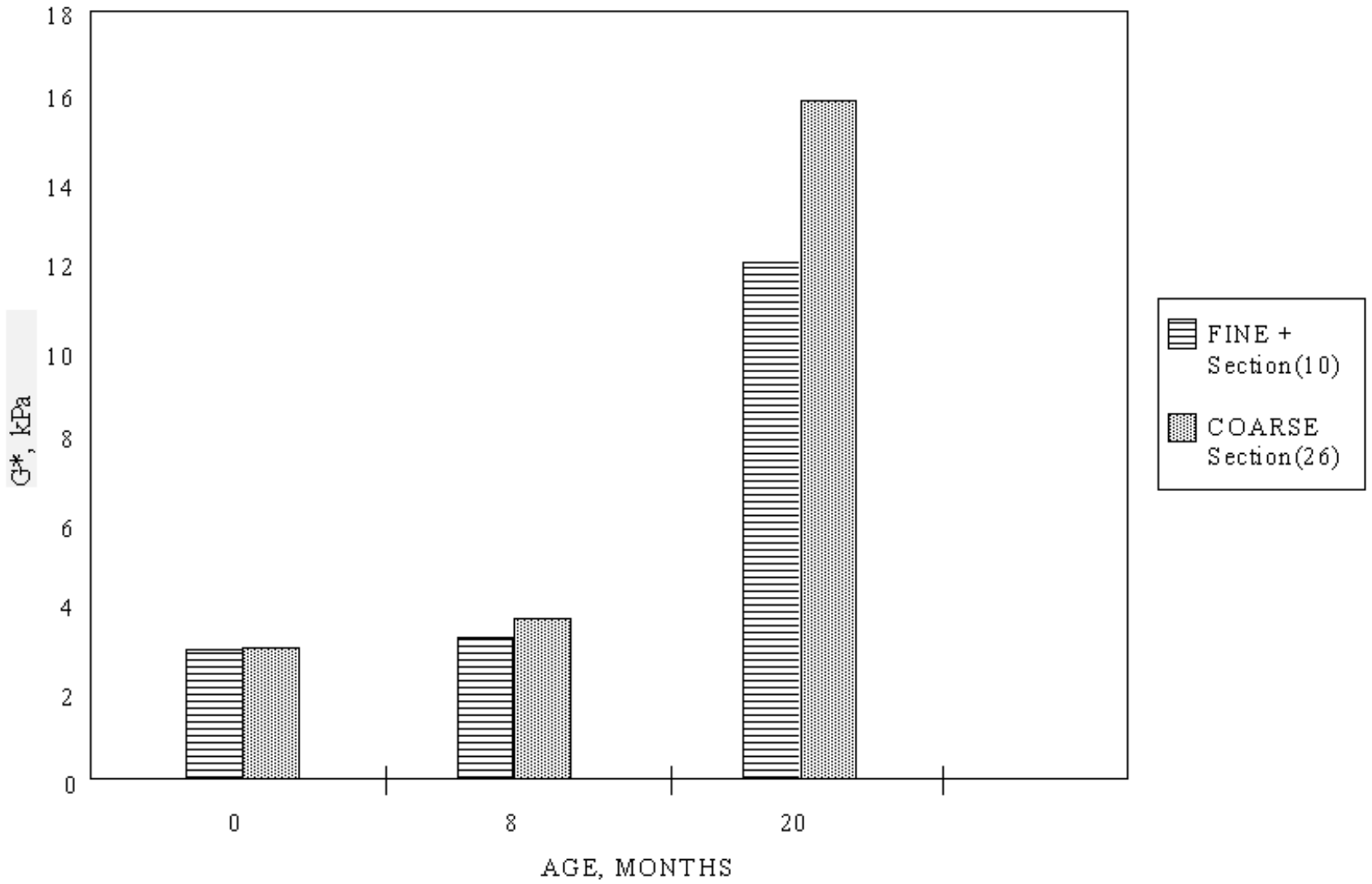

Figure 10. Shear modulus values at 64°C for the extracted binder at different intervals of time and for mixes of low asphalt content and high air voids.

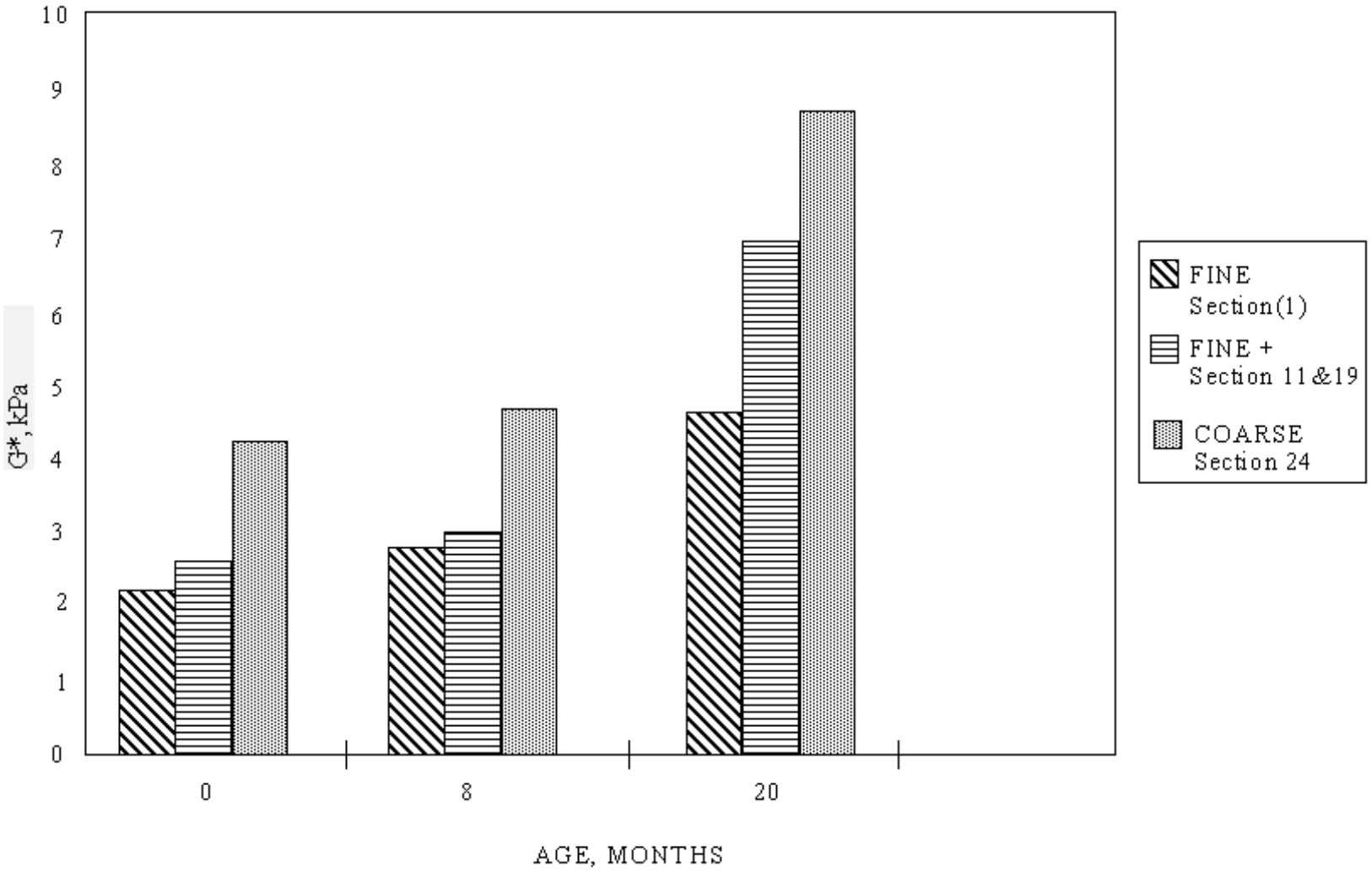

Figure 11. Shear modulus values at 64°C for the extracted binder at different intervals of time and for mixes of medium asphalt content and medium air voids.

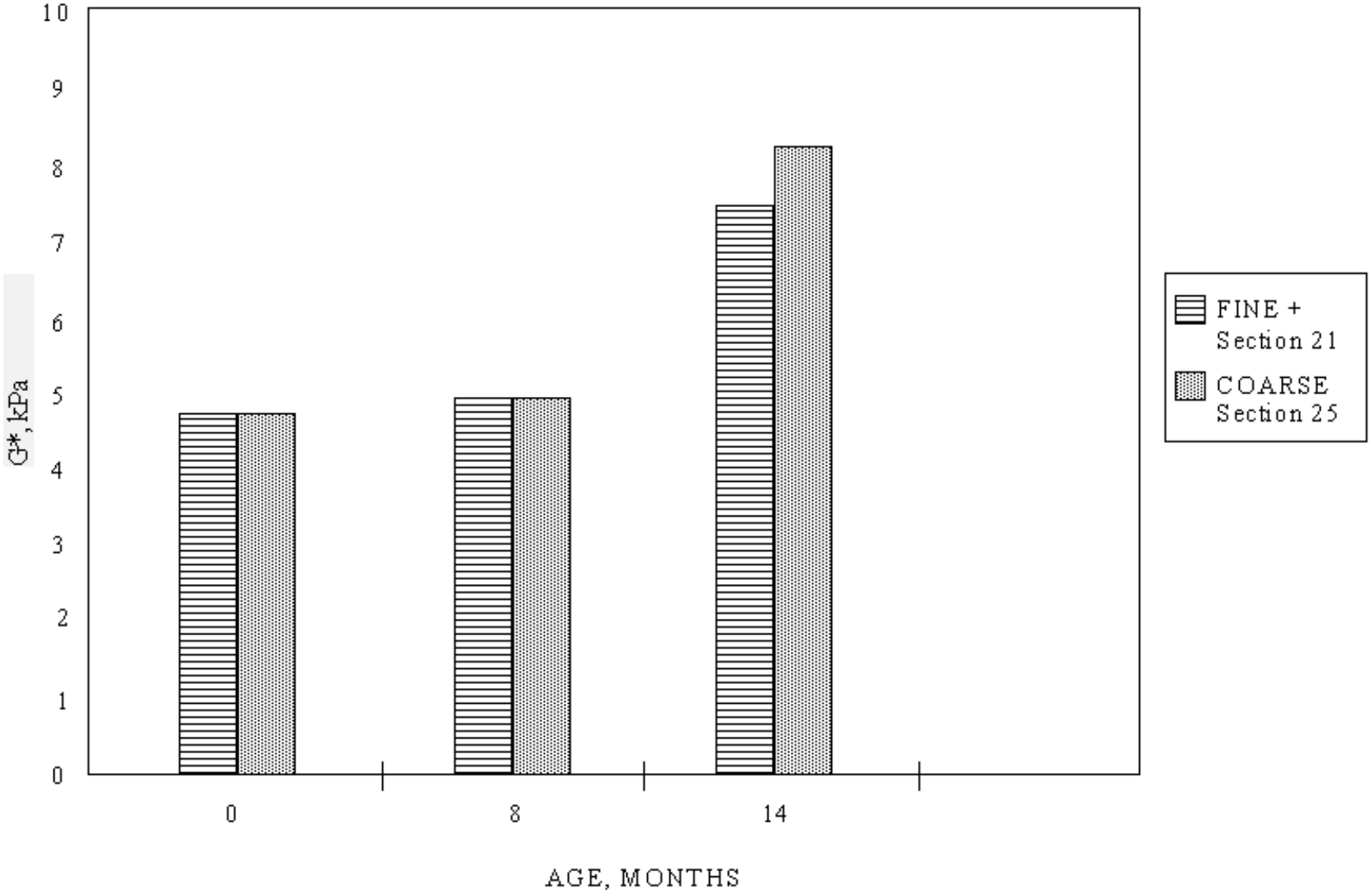

Figure 12. Shear modulus values at 64°C for the extracted binder at different intervals of time and for mixes of high asphalt content and low air voids.

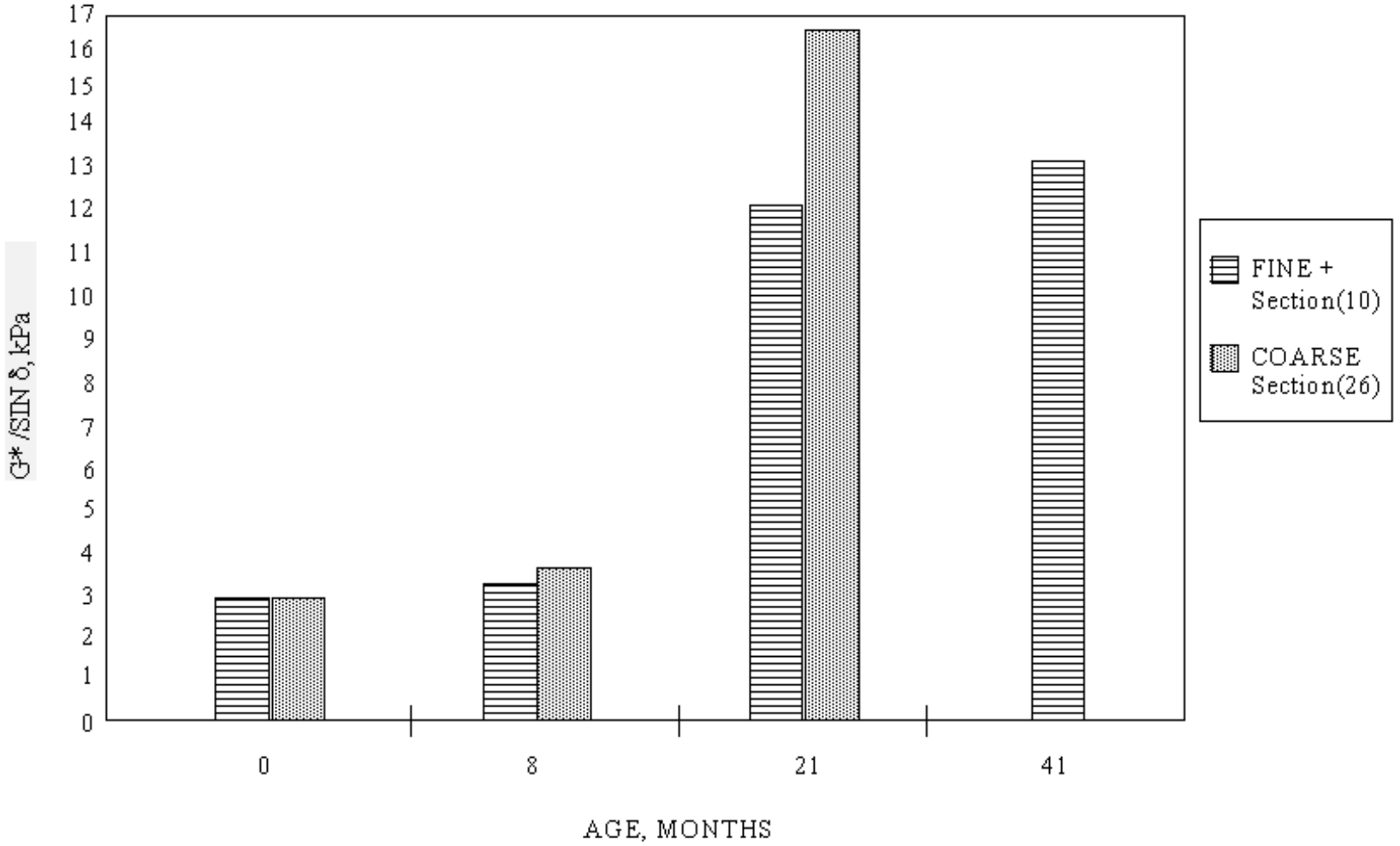

Figure 13. G*/sin δ values at 64°C for the extracted binder at different intervals of time and for mixes of low asphalt content and high air voids.

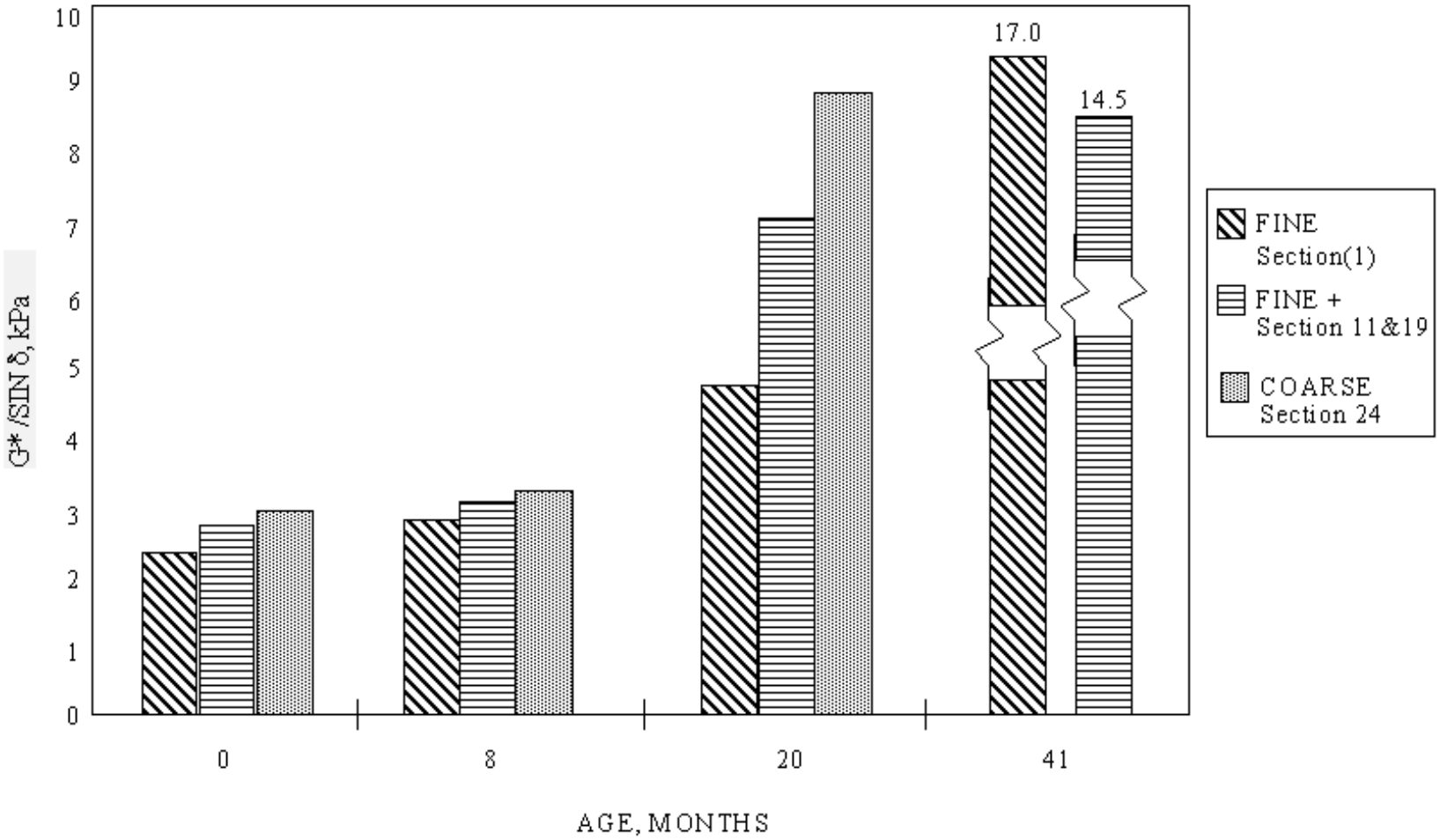

Figure 14. G*/sin δ values at 64°C for the extracted binder at different intervals of time and for mixes of medium asphalt content and medium air voids.

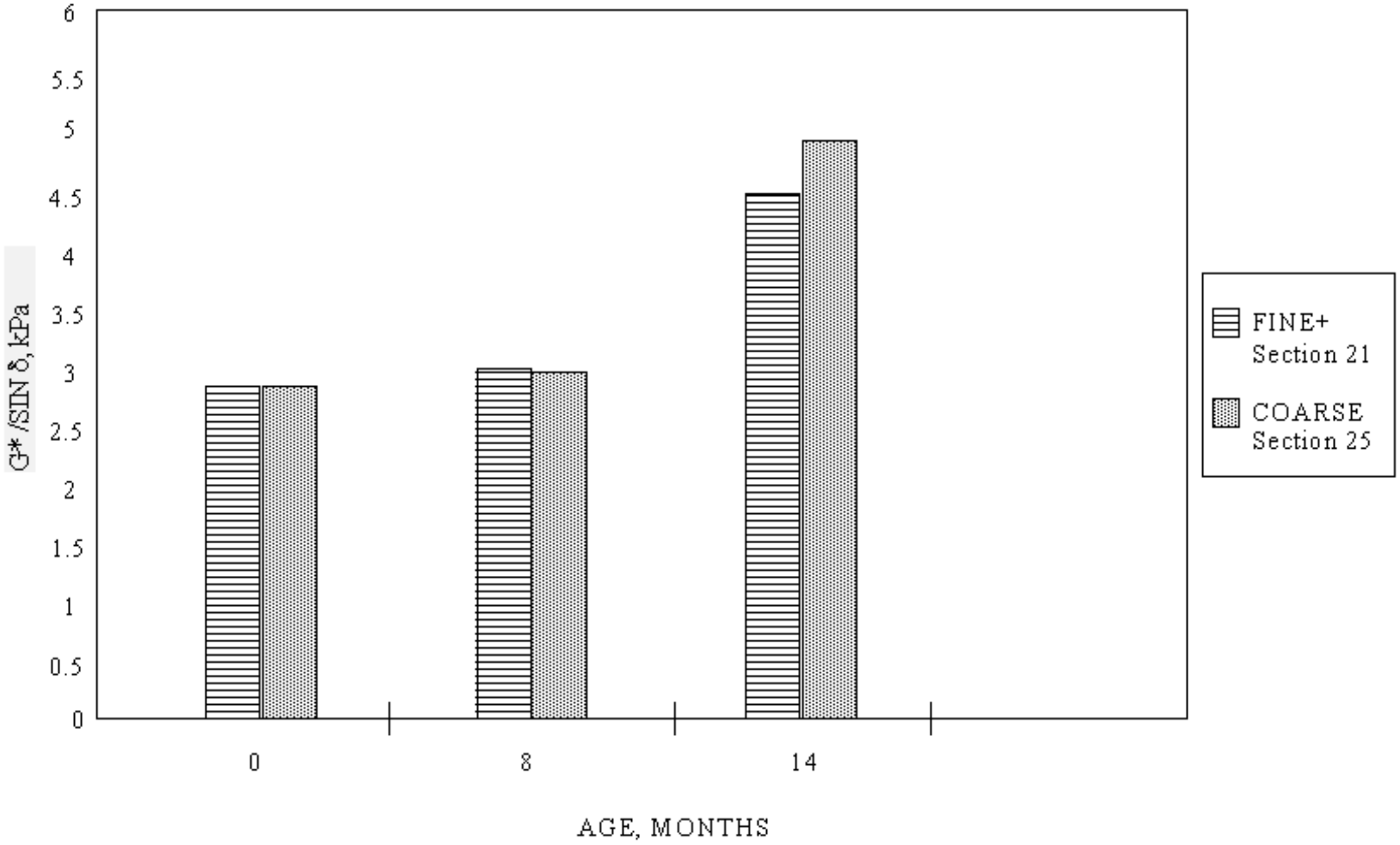

Figure 15. G*/sin δ values at 64°C for the extracted binder at different intervals of time and for mixes of high asphalt content and low air voids.

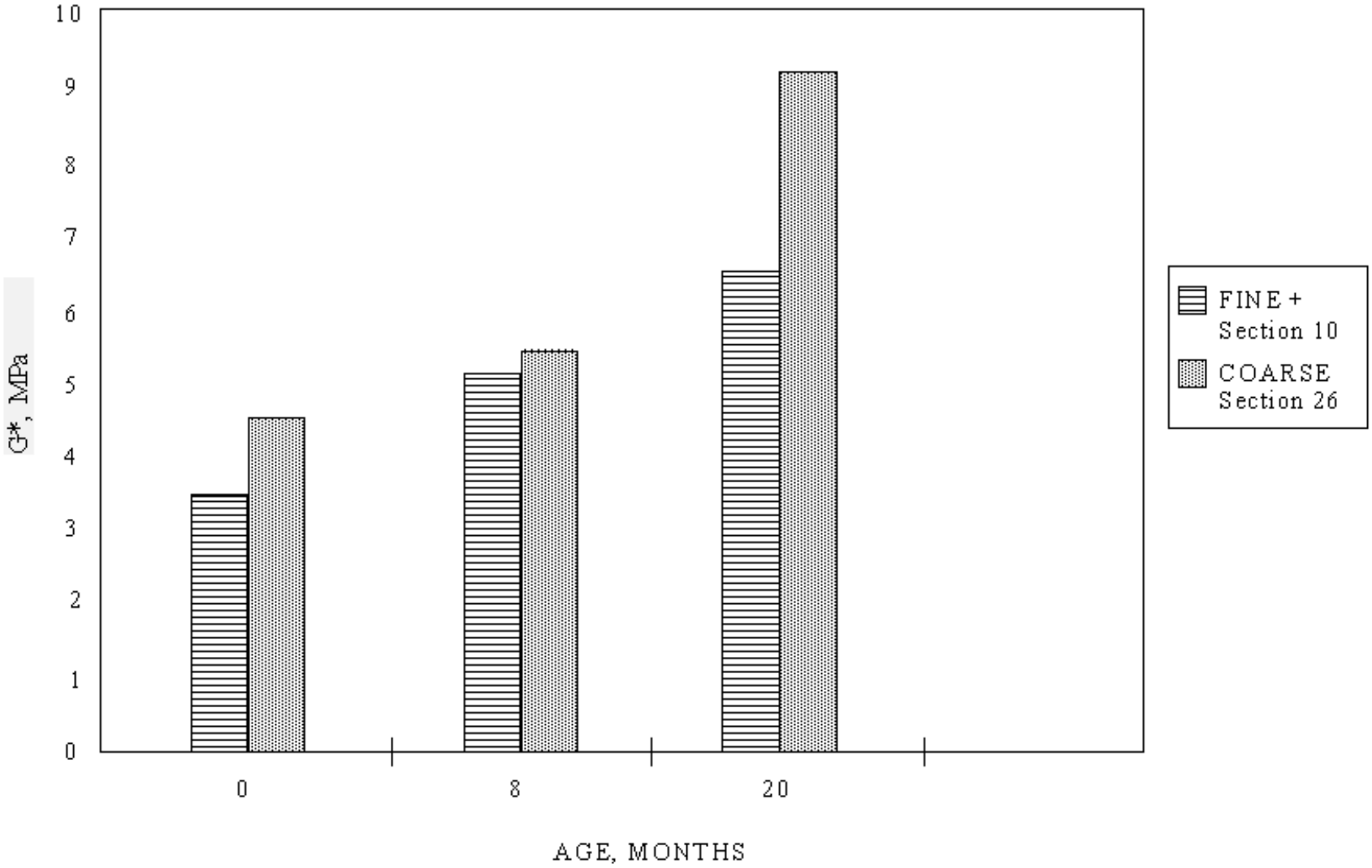

Figure 16. Shear modulus values at 25°C for the extracted binder at different intervals of time and for mixes of low asphalt content and high air voids.

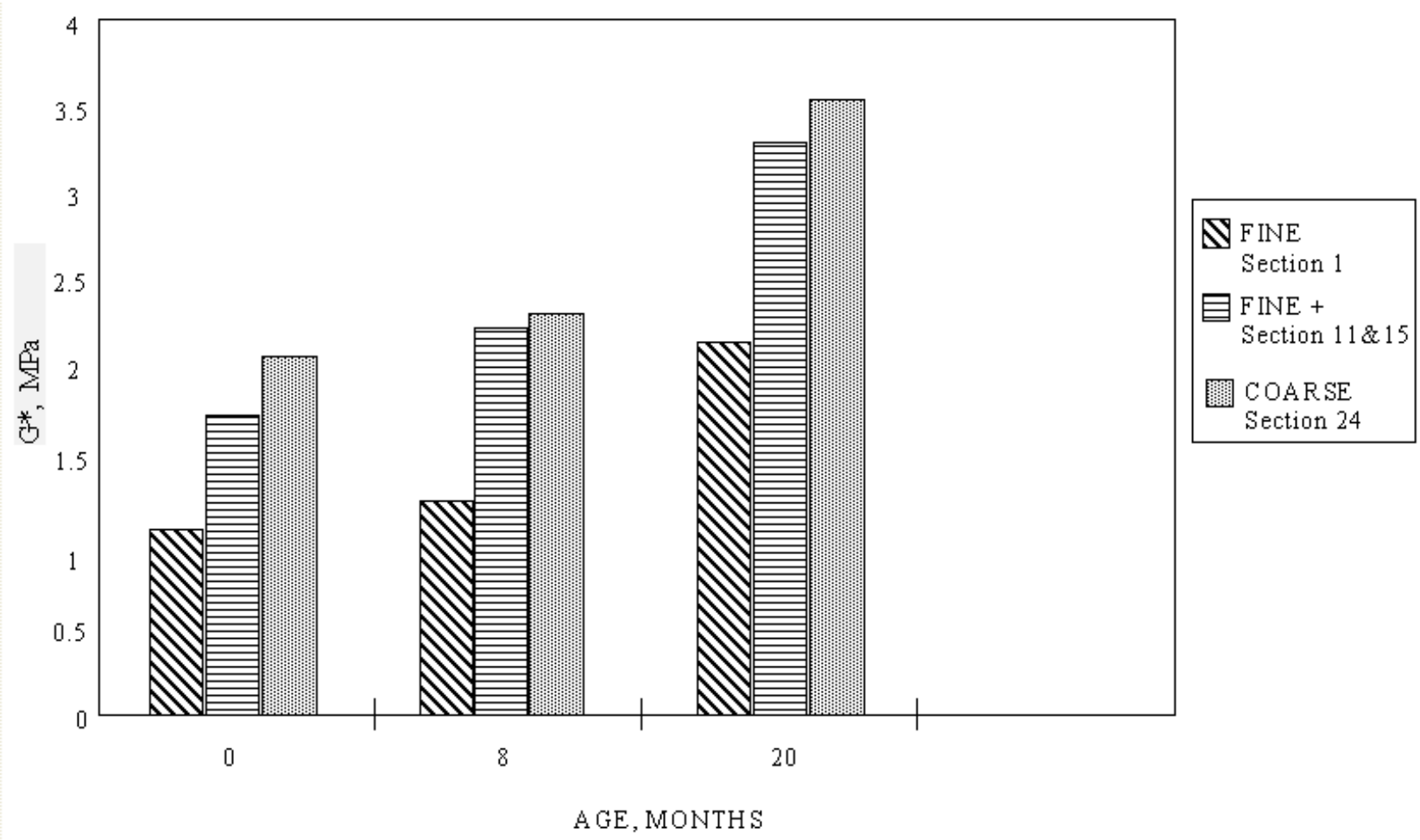

Figure 17. Shear modulus values at 25°C for the extracted binder at different intervals of time and for mixes of medium asphalt content and medium air voids.

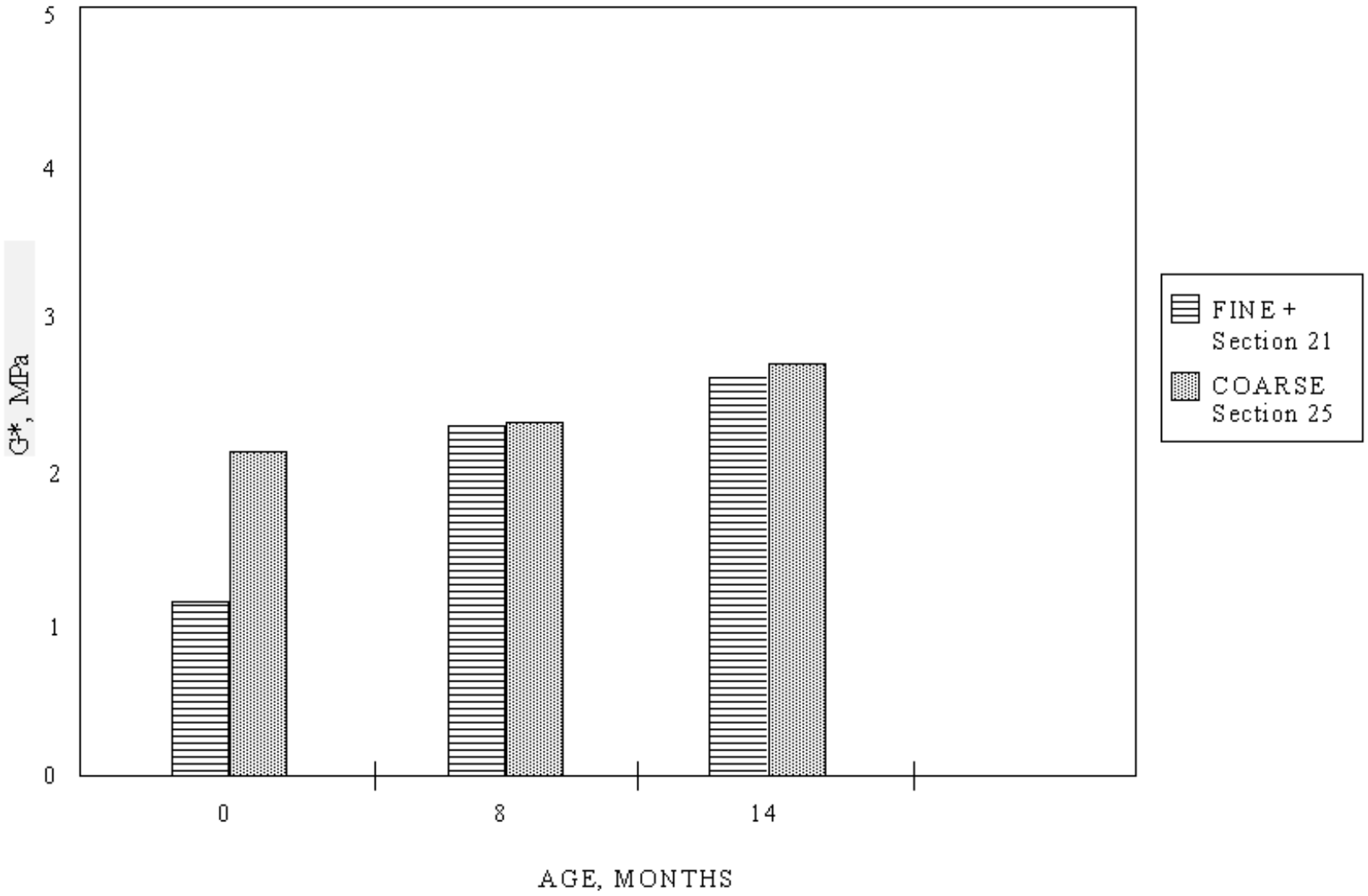

Figure 18. Shear modulus values at 25°C for the extracted binder at different intervals of time and for mixes of high asphalt content and low air voids.

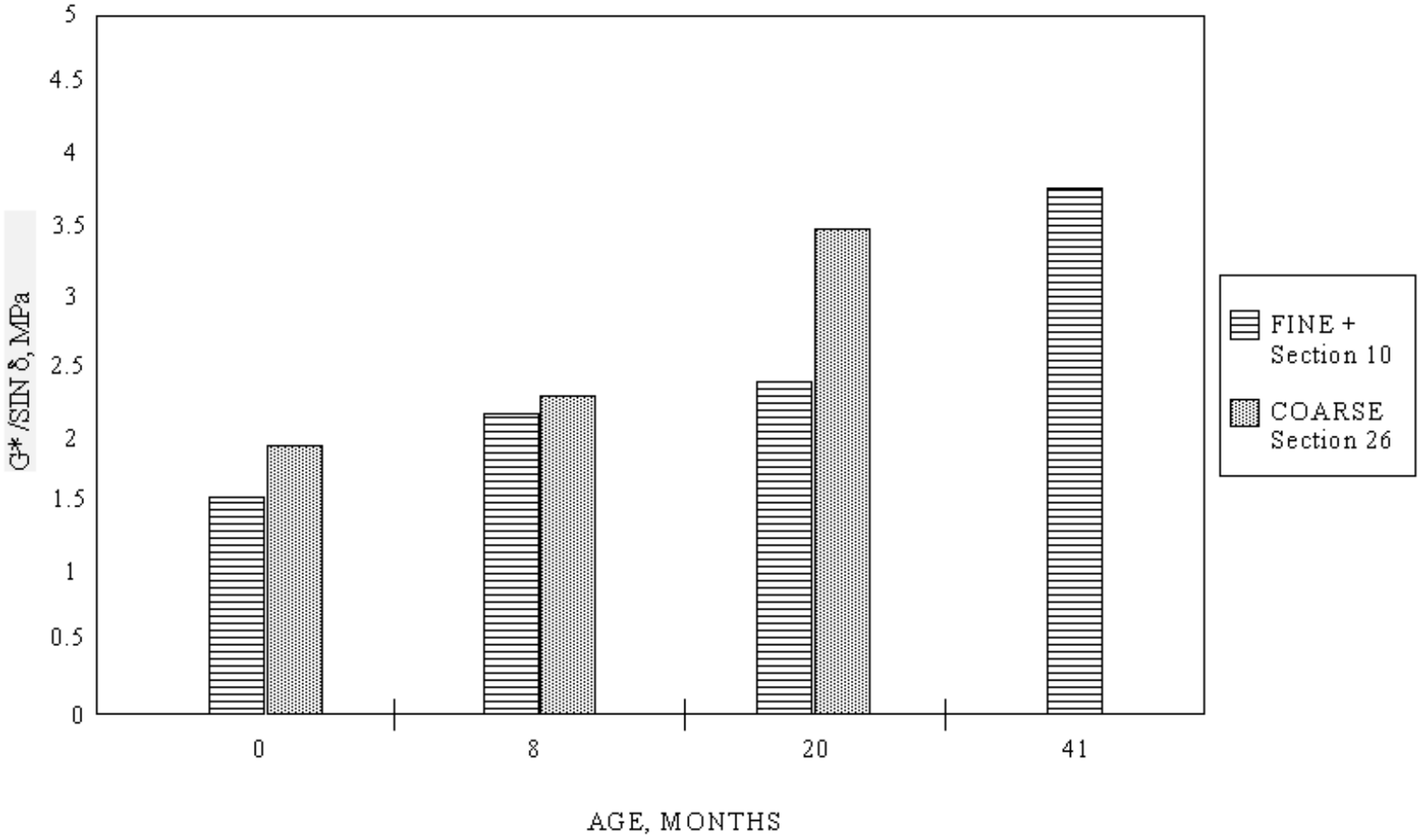

Figure 19. G*/ sin δ values at 25°C for the extracted binder at different intervals of time and for mixes of low asphalt content and high air voids.

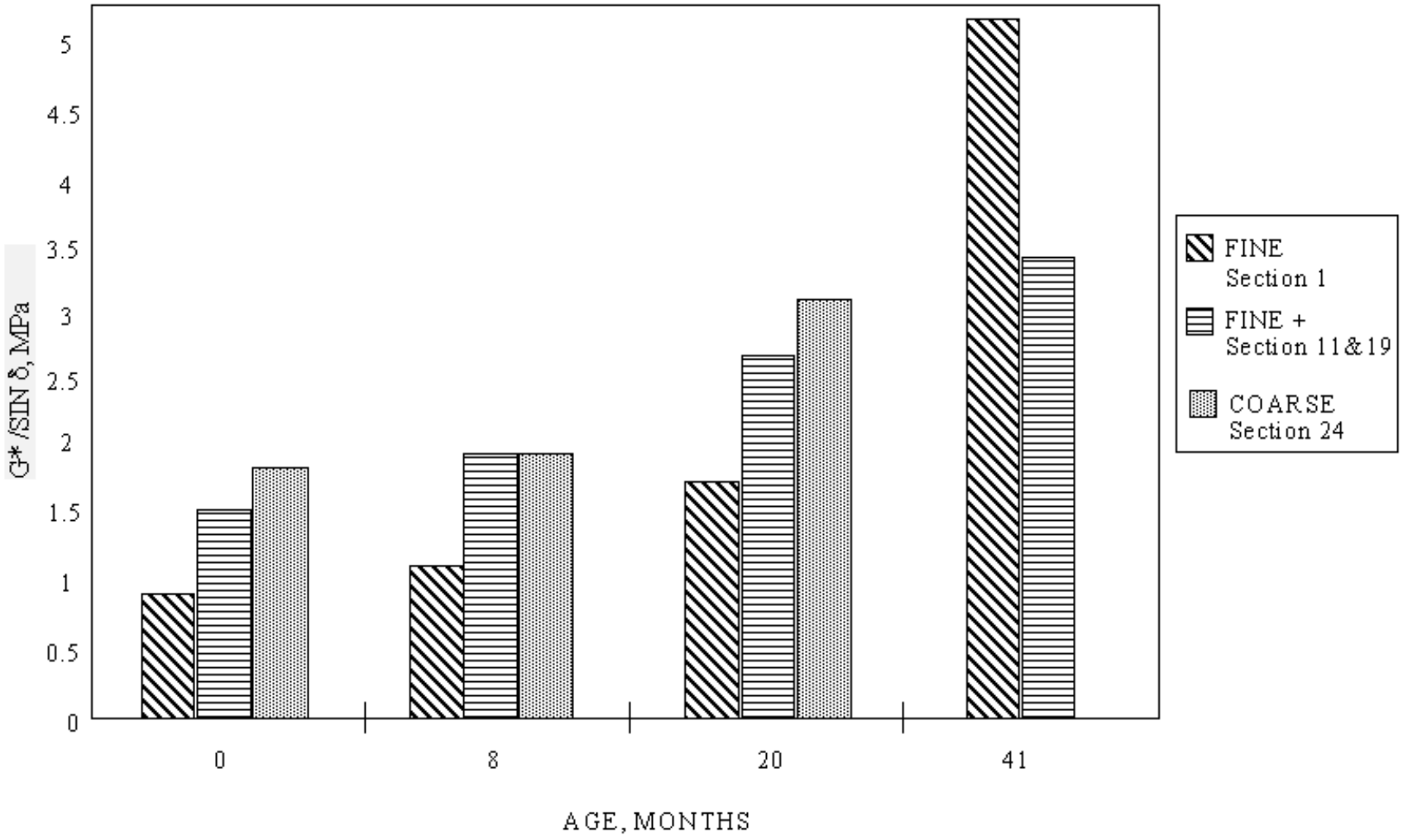

Figure 20. G*/sin δ values at 25°C for the extracted binder at different intervals of time and for mixes of medium asphalt content and medium air voids.

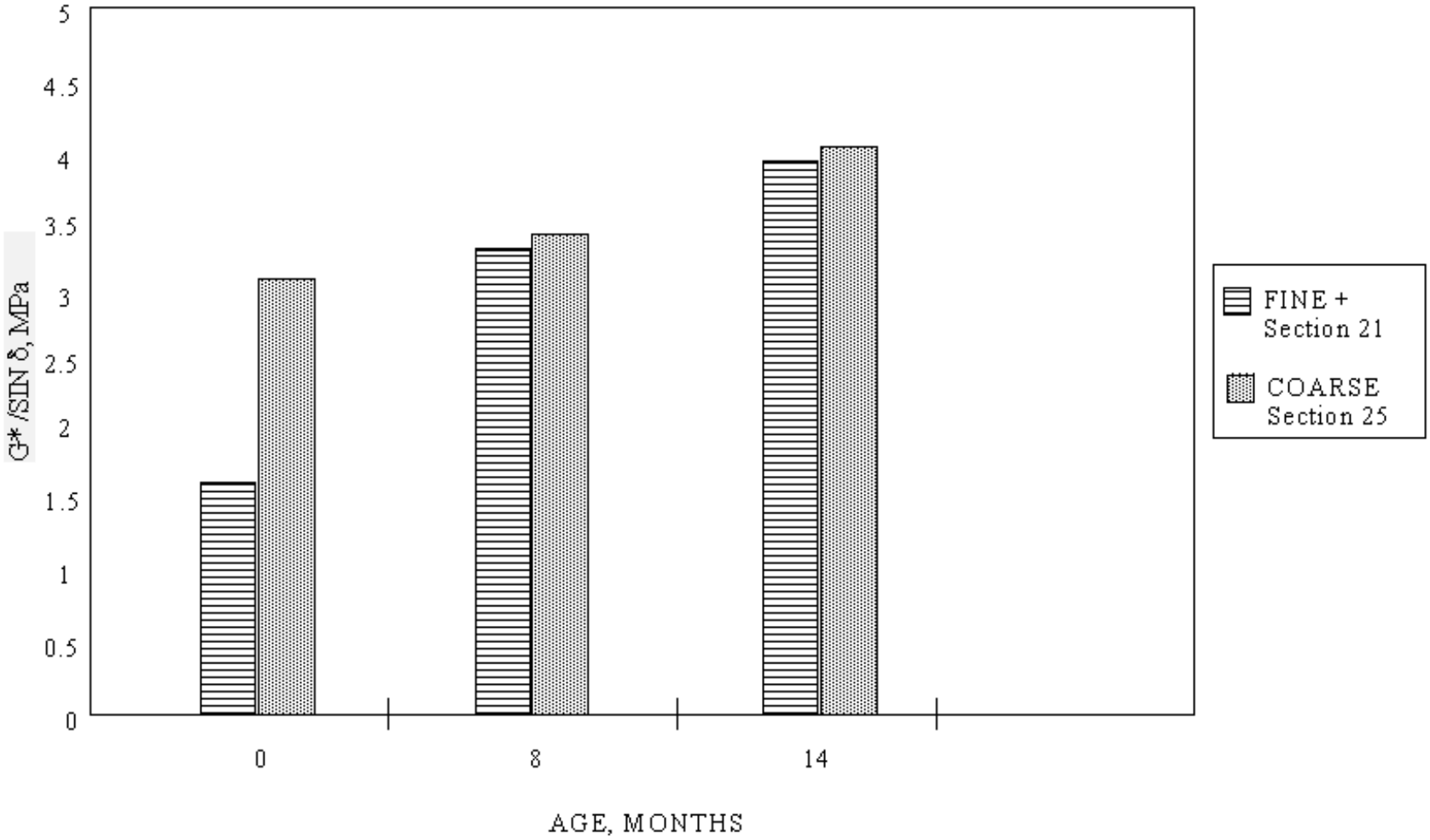

Figure 21. G*/sin δ values at 25°C for the extracted binder at different intervals of time and for mixes of high asphalt content and low air voids.

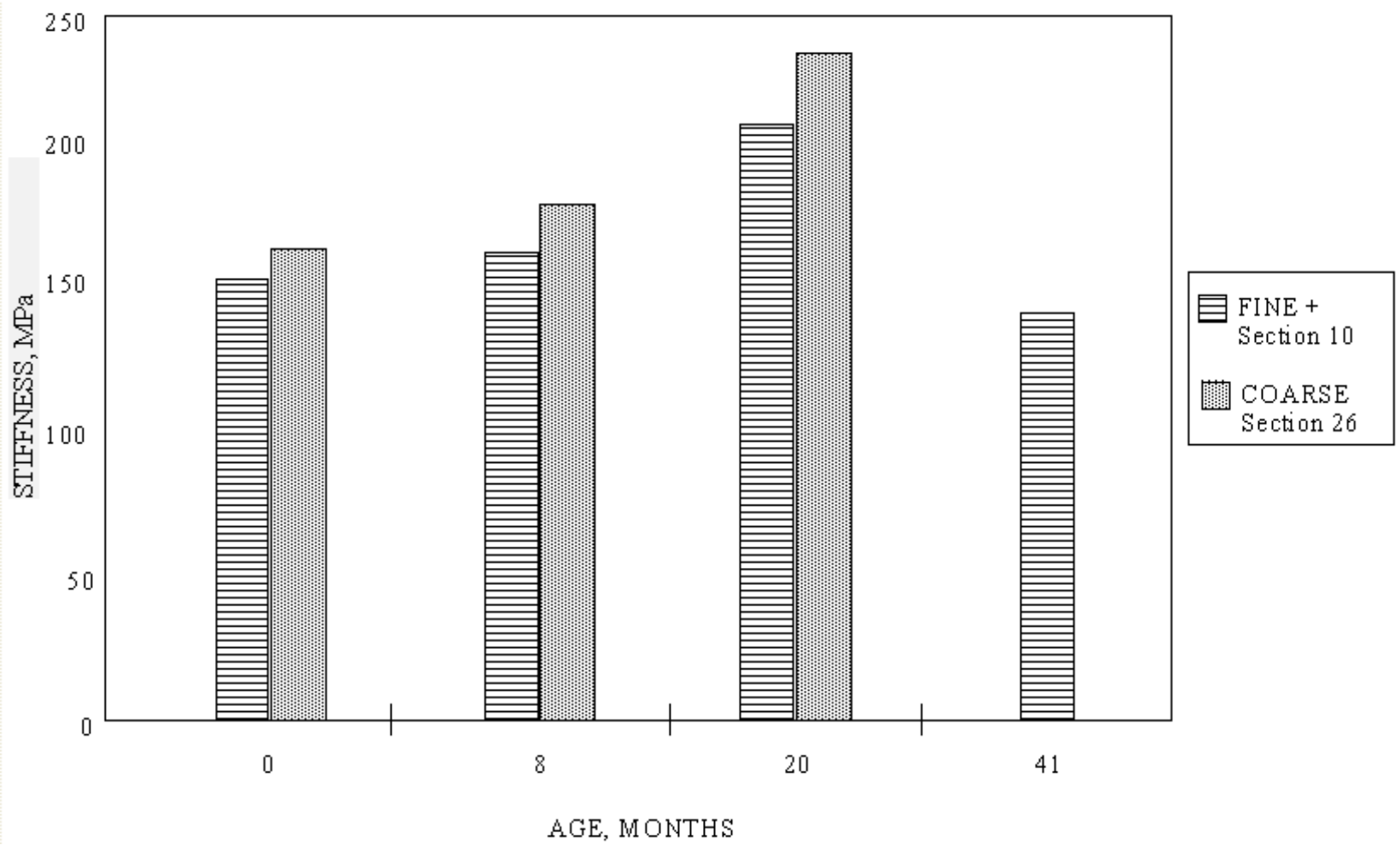

Figure 22. Creep stiffness values at -12°C for the extracted binder at different intervals of time and for mixes of low asphalt content and high air voids.

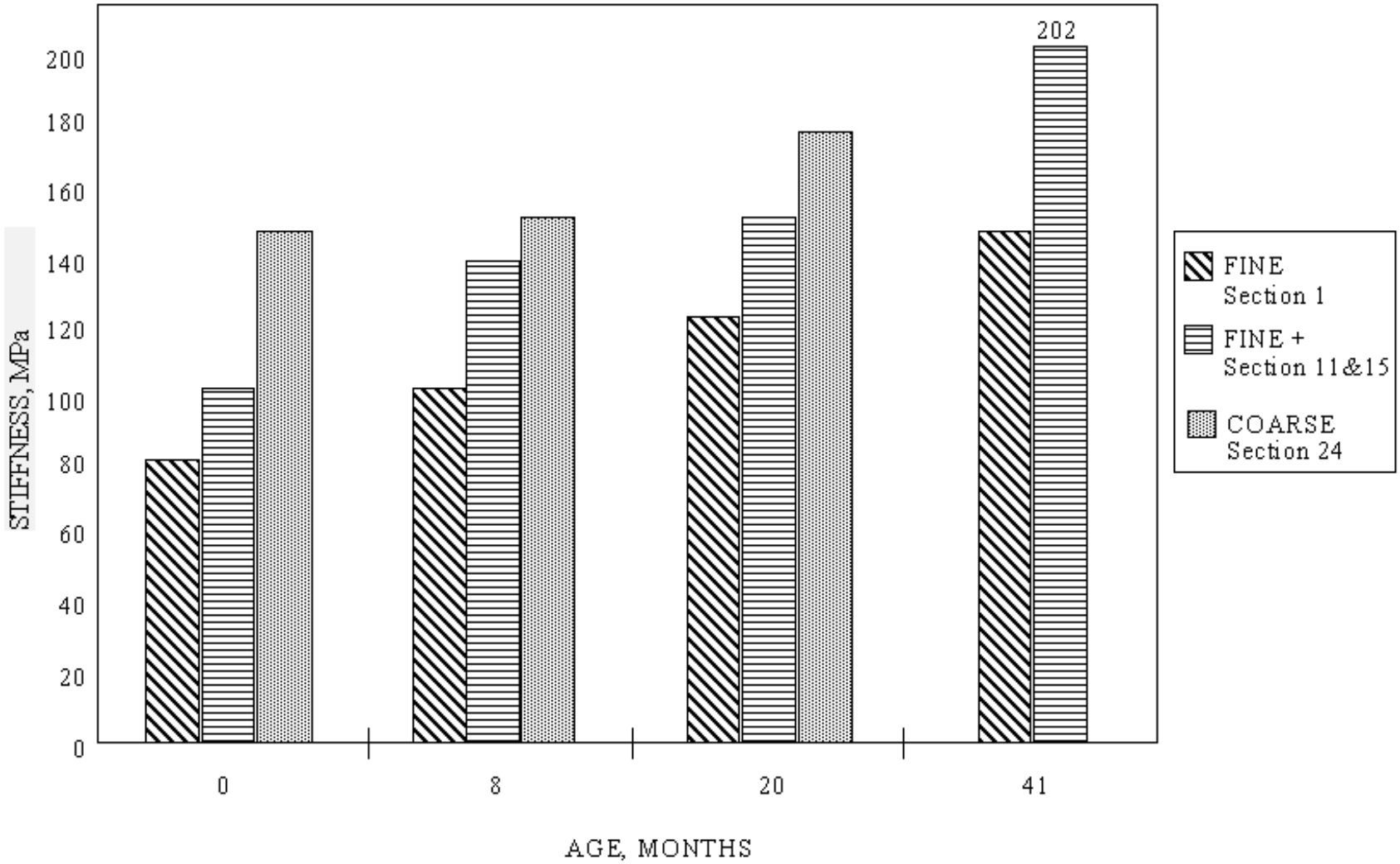

Figure 23. Creep stiffness values at -12°C for the extracted binder at different intervals of time and for mixes of medium asphalt content and medium air voids.

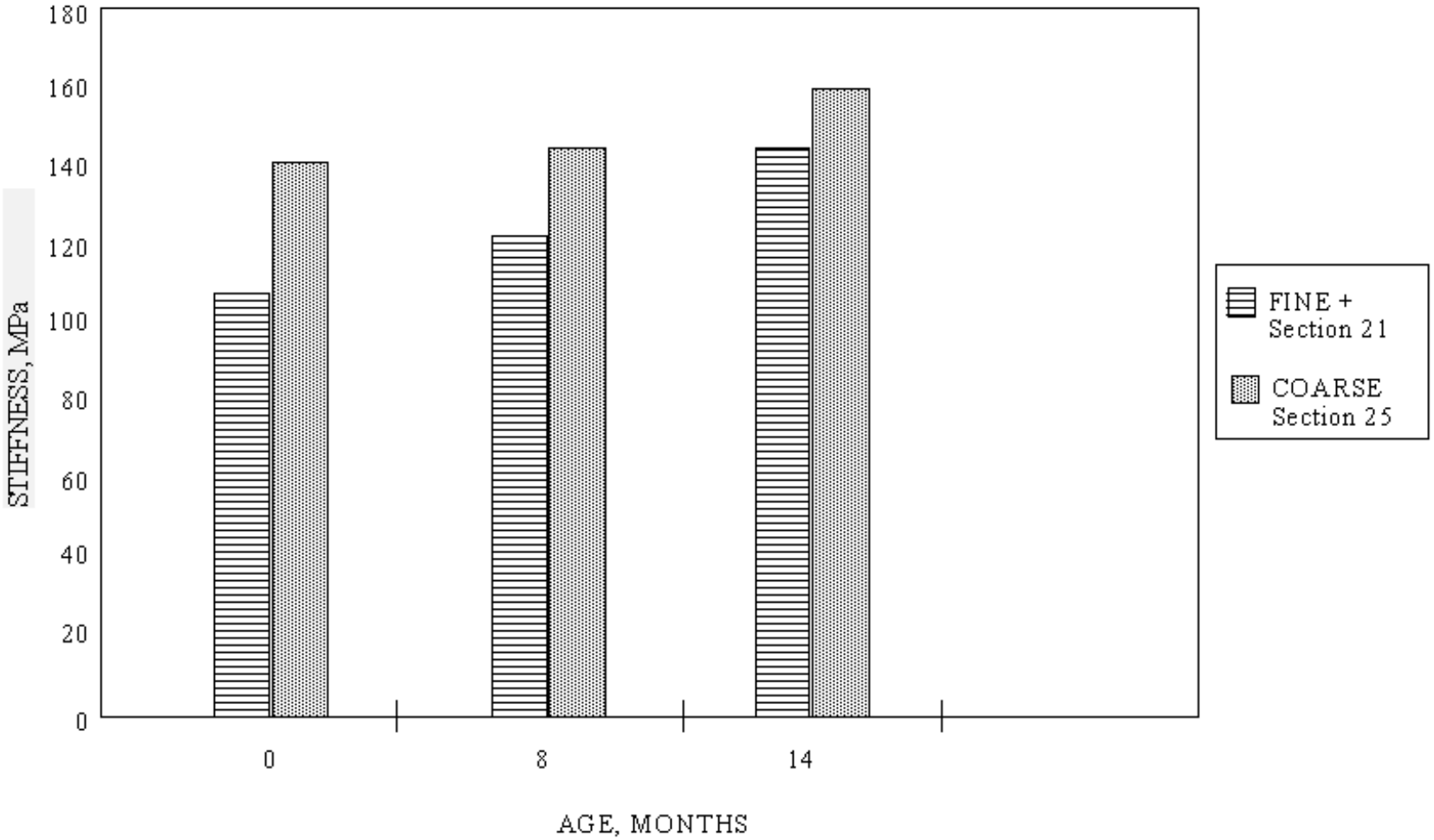

Figure 24. Creep stiffness values at -12°C for the extracted binder at different intervals of time and for mixes of high asphalt content and low air voids.

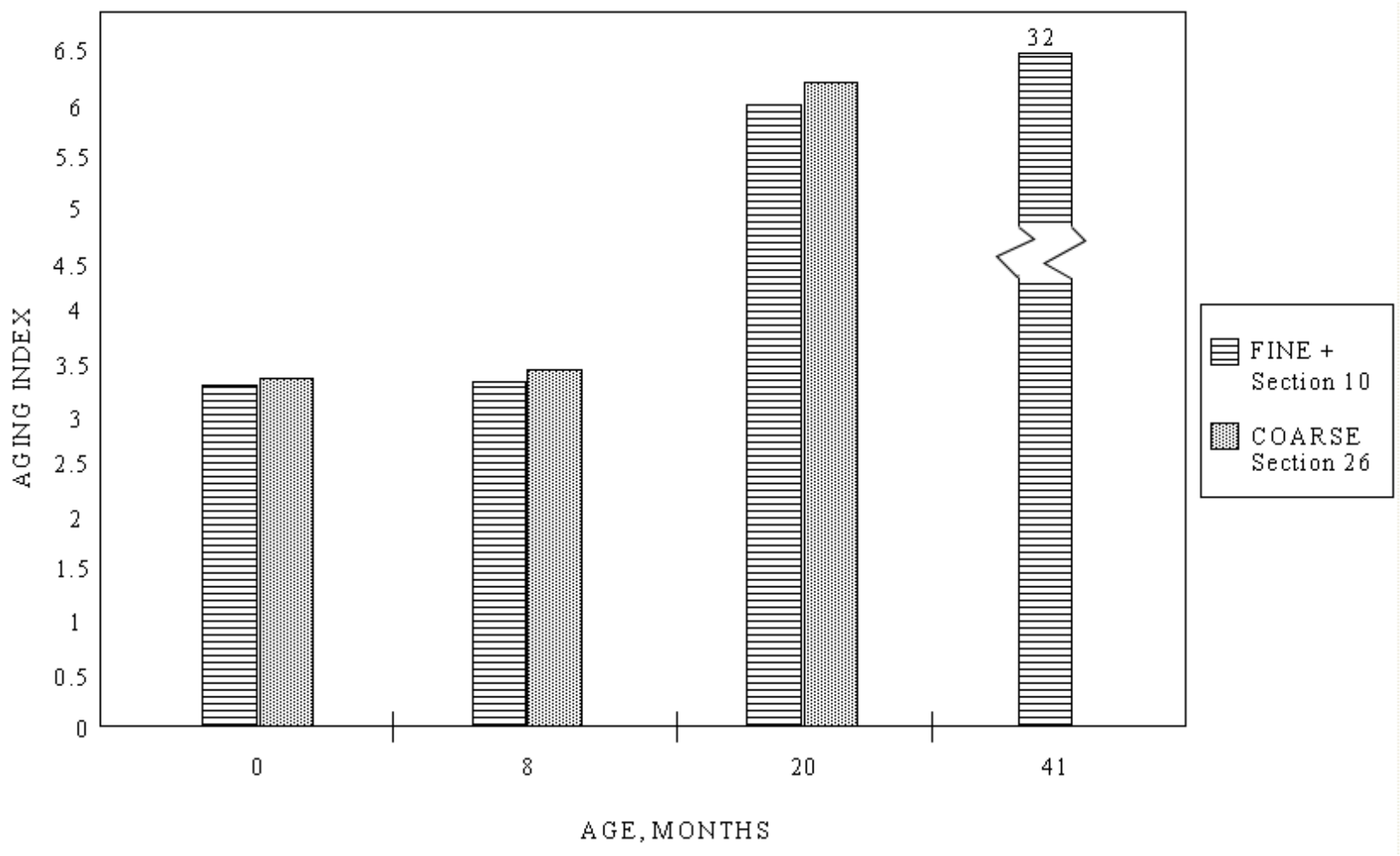

Figure 25. Aging index based on the absolute viscosity values at 60°C of the extracted binder at different intervals of time and for mixes of low asphalt content and high air voids.

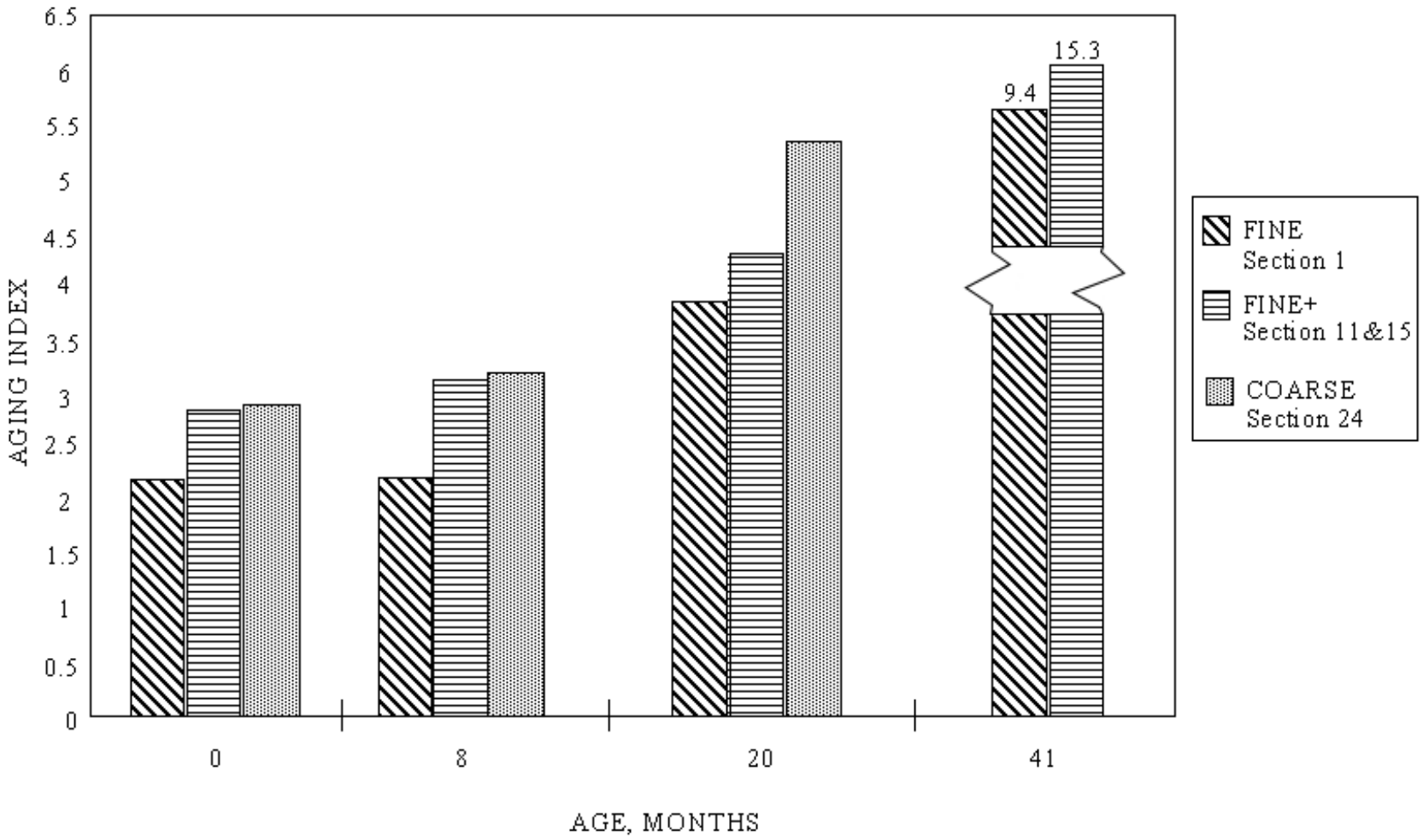

Figure 26. Aging index based on the absolute viscosity values of the extracted binder at different intervals of time and for mixes of medium asphalt content and medium air voids.

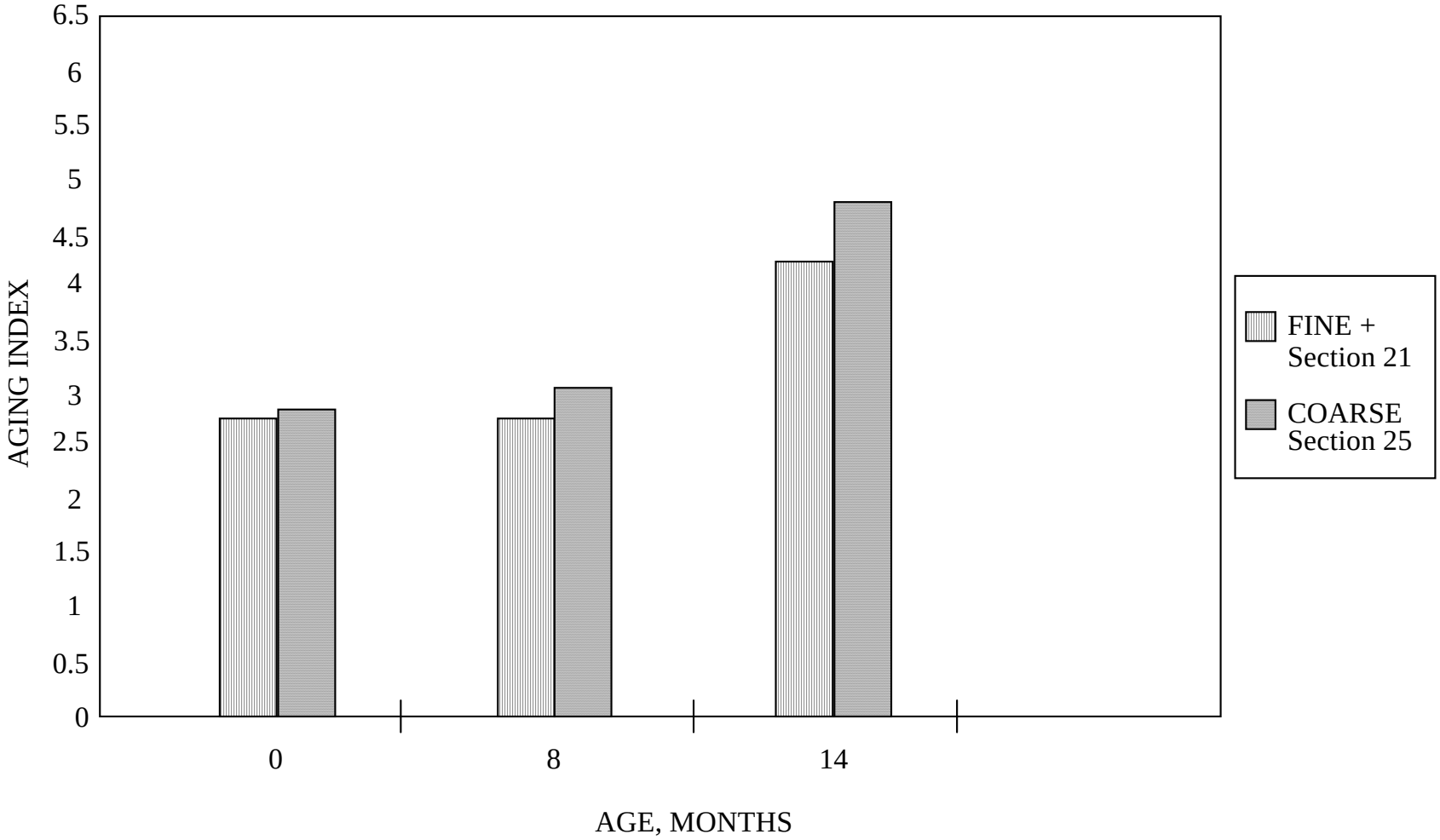

Figure 27. Aging index based on the absolute viscosity values of the extracted binder at different intervals of time and for mixes of high asphalt content and low air voids.

Table 1. Material variables used in original and replacement sections of WesTrack.

	Original 1995 Construction									1997 Replacement		
Design Air Void Content, Percent	Aggregate Gradation											
	Fine			Fine Plus			Coarse			Coarse		
	Design Asphalt Contents, Percent											
	4.7	5.4	6.1	4.7	5.4	6.1	5.0	5.7	6.4	5.1	5.8	6.5
4		4	18		12	21/9		23	25		39	55
8	2	1/15	14	22	19/11	13	8	5/24	7	38	35/54	37
12	3/16	17		10	20		26	6		56	36	

*Numbers shown in each cell represent WesTrack section numbers.

Table 2. Mixture types of the WesTrack sections.

Section No.	Asphalt Content	Air Voids	Gradation	Mixture Designation
1	M	M	F	MM(F)
2	L	M	F	LM(F)
3	L	H	F	LH(F)
4	M	L	F	ML(F)
5	M	M	C	MM(C)
6	M	H	C	MH(C)
7	H	M	C	HM(C)
8	L	M	C	LM(C)
9	H	L	F^+	HL(F^+)
10	L	H	F^+	LH(F^+)
11	M	M	F^+	MM(F^+)
12	M	L	F^+	ML(F^+)
13	H	M	F^+	HM(F^+)
14	H	M	F	HM(F)
15	M	M	F	MM(F)
16	L	H	F	LH(F)
17	M	H	F	MH(F)
18	H	L	F	HL(F)
19	M	M	F^+	MM(F^+)
20	M	H	F^+	MH(F^+)
21	H	L	F^+	HL(F^+)
22	L	M	F^+	LM(F^+)
23	M	L	C	ML(C)
24	M	M	C	MM(C)
25	H	L	C	HL(C)
26	L	H	C	LH(C)

Table 3. Mixture types designation.

C	=	Coarse gradation
F	=	Fine gradation
F^+	=	Fine plus gradation
AC	=	Percent asphalt content
AV	=	Percent air voids content
M	=	Medium content (AC or AV)
H	=	High content (AC or AV)
L	=	Low content (AC or AV)
Section numbers from 1 through 26 indicate original construction while any section number from 35 through 55 indicates replacement construction.		
Examples: F-24 means test section number 24 (original construction) that was designed using fine gradation. C-39 means test section number 39 (replacement section) that was designed using coarse gradation. HH or H/H = High AC content and high AV content ML or M/L = Medium AC content and low AV content LH 15 = Section 15, which has low AC content and high AV content HM (F^+) = High AC content and medium AV content (fine plus gradation)		

Table 4. Selected sections for WesTrack aged asphalt characterization.

Target Air Void Content	Aggregate Gradation Code								
	Fine			Fine Plus			Coarse		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Low		04	18		12	21 09		23	25
Medium	02	01 15	14	22	19 11	13	08	05 24	07
High	03 16	17		10	20		26	06	

Numbers indicate the test track section numbers.

Table 5. Variation in asphalt cement recovering process.

Asphalt Binder	**Rotational Viscosity**	**Change in Mass Using RTFOT**	**Viscosity at 60°C (140°F)**
Replicate #	CP	%	Poise
Original Asphalt Cement			
10/4-III	0.36	0.25	1999
10/1-9:50	0.36	0.25	1988
9/20-8:58	0.30	0.26	1934
Recovered Asphalt Cement			
10/4-III	0.24	1.36	1571
10/-9:50	0.28	0.58	1749
9/20-8:58	0.30	0.52	1901

Table 6. Air void content for original test sections at 41 months.

Section No.	Gradation	Asphalt Content/ Air Voids	Lift	Air Void Content, Percent			
				SSD*		Parafilm	
				No. 1**	No. 2	No. 1	No. 2
1	Fine	M/M	Top	7.1	6.7	8.3	7.9
			Bottom	9.9	10.5	11.2	11.8
10	Fine Plus	L/H	Top	13.4	11.0	15.9	14.4
			Bottom	11.7	12.3	12.3	12.9
11	Fine Plus	M/M	Top	7.1	5.4	9.5	6.3
			Bottom	9.5	5.9	10.9	6.2
19	Fine Plus	M/M	Top	5.7	5.2	6.6	6.5
			Bottom	6.5	6.0	7.0	6.3
21	Fine Plus	H/L	Top	5.0	5.3	5.4	5.9
			Bottom				
23	Coarse	M/L	Top	5.1	4.0	7.1	6.0
			Bottom				
24	Coarse	M/M	Top				
			Bottom				
25	Coarse	H/L	Top				
			Bottom				
26	Coarse	L/H	Top				
			Bottom				

*Method used to determine bulk specific gravity.
**Sample number.

Table 7. Air void content for replacement sections at 21 months.

Section No.	Gradation	Asphalt Content/ Air Voids	Lift	Air Void Content, Percent			
				SSD*		Parafilm	
				No. 1**	No. 2	No. 1	No. 2
35	Coarse	M/M	Top	7.3	7.1	8.8	8.6
			Bottom	6.3	6.9	6.7	7.3
36	Coarse	M/H	Top	12.2	12.1	14.7	13.9
			Bottom	13.3	11.5	14.8	13.1
55	Coarse	H/L	Top	2.7	2.4	4.0	3.1
			Bottom	2.6	1.5	2.99	1.8
56	Coarse	L/H	Top	1.3	1.3	1.5	1.6
			Bottom	1.4	1.4	1.5	1.5

*Method used to determine bulk specific gravity.
**Sample number.

Table 8. Asphalt binders used for original and replacement sections at WesTrack.

Sample Identification	DSR-Original @ 64°C			DSR-RTFOT @ 64°C			DSR-PAV @ 25°C			BBR @-12°C		PG
	G*, kPa	δ	G*/sin δ, kPa	G*, kPa	δ	G*/sin δ, kPa	G*, MPa	δ	G*/sin δ, MPa	S(t), MPa	m	
Original sections*	1.140	87.1	1.141	2.625	84.3	2.637	5.782	47.7	4.270	217	0.315	64-22
Replacement sections*	1.491	87.0	1.493	3.583	83.9	3.603	5.696	43.9	3.946	198	0.316	64-22

*Average values.

°F = 1.8(°C) + 32
1 psi = 6.9 kPa

Table 9. Asphalt binders used for original and replacement sections at WesTrack.

Sample Identification	Flash Point, °C	Viscosity @ 135°C, Pa.s	DSR Original Temp @ 1.0 kPa, °C	DSR RTFOT Temp @ 2.2 kPa, °C	Mass Loss, Percent	DSR PAV Temp @ 5.0 MPa, °C	BBR		PG
							Temp @ 300 MPa, °C	Temp @ m=0.30, °C	
Original sections	276*	0.31	65.3	65.5	0.25	24.0	-14.3	-13.3	64-22
Replacement sections	288*	0.36	67.3	67.9	0.26	22.8	-16.3	-15.1	64-22

*Average values.

°F = 1.8(°C) + 32
1 psi = 6.9 kPa

Table 10. Asphalt binders used for original and replacement sections at WesTrack
DSR rheologies properties over a range in temperatures.

Sample Identification	DSR-Original G*/sin δ @ Temp °C, kPa				DSR-RTFOT (G*/sin δ) @ Temp °C, kPa				DSR-PAV (G*sin δ) @ Temp °C, kPa			
	52	58	64	70	52	58	64	70	16	19	22	25
Original sections 10-1-95 9:50 a.m.	5.62	2.46	1.14	0.57	13.41	5.85	2.62	1.25	12.11	8.94	6.40	4.35
Replacement sections 6-28-97 REP 1	7.69	3.29	1.45	0.69			3.53	1.64		6.79	5.25	3.73

°F = 1.8(°C) + 32
1 psi = 6.9 kPa

Table 11. Asphalt binders used for original and replacement sections at WesTrack
BBR rheologic low temperature properties.

Sample Identification	BBR			
	Stiffness @ Temp °C MPa		m Value @ Temp °C	
	-12	-18	-12	-18
Original sections 10-1-95 9:50 a.m.	229	410	0.31	0.25
Replacement sections 6-28-97 REP 1	201	322	0.32	0.28

°F = 1.8(°C) + 32
1 psi = 6.9 kPa

Table 12. Recovered asphalt binder properties - penetration at 25°C (77°F) (0.1mm).

Section No.	Gradation	Asphalt Content/Air Voids	Time After Construction, Months				
			0	8	14	20	41
1	Fine	M/M	35	34		27	3.1
10	Fine plus	L/H	31	30		16	2.4
11	Fine plus	M/M	33	32		20	2.9
19	Fine plus	M/M	34	34		22	2.0
21	Fine plus	H/L	33	33	23		
23	Coarse	M/L					3.9
24	Coarse	M/M	31	30		15	
25	Coarse	H/L	35	33	26		
26	Coarse	L/H	28	28		13	

Table 13. Recovered asphalt binder properties - viscosity at 60°C (140°F) (poises).

Section No.	Gradation	Asphalt Content/Air Voids	Time After Construction, Months				
			0	8	14	20	41
1	Fine	M/M	4,108	4,215		7,434	17,801
10	Fine plus	L/H	6,300	6,344		11,466	62,225
11	Fine plus	M/M	4,954	5,815		9,123	29,947
19	Fine plus	M/M	5,848	6,100		7,363	28,257
21	Fine plus	H/L	5,243	5,248	8,014		
23	Coarse	M/L					5,172
24	Coarse	M/M	5,512	6,110		10,137	
25	Coarse	H/L	5,427	5,791	8,996		
26	Coarse	L/H	6,433	6,577		11,863	

Table 14. Recovered asphalt binder properties – G*/sin δ at 58°C (136°F) (kPa).

Section No.	Gradation	Asphalt Content/Air Voids	Time After Construction, Months				
			0	8	14	20	41
1	Fine	M/M	4.94	5.89		9.03	40.9
10	Fine plus	L/H	6.52	7.45		29.71	29.6
11	Fine plus	M/M	4.75	6.28		19.00	34.8
19	Fine plus	M/M	7.02	6.95		14.19	31.9
21	Fine plus	H/L	6.40	6.79	8.12		
23	Coarse	M/L					17.7
24	Coarse	M/M	6.34	6.90	10.96	15.77	
25	Coarse	H/L	6.50	6.48			
26	Coarse	L/H	6.82	8.08		27.14	

Table 15. Recovered asphalt binder properties – G*/sin δ at 64°C (147°F) (kPa).

Section No.	Gradation	Asphalt Content/Air Voids	Time After Construction, Months				
			0	8	14	20	41
1	Fine	M/M	2.29	2.74		4.60	17.0
10	Fine plus	L/H	3.03	3.34		12.43	13.1
11	Fine plus	M/M	2.21	2.83		7.66	15.2
19	Fine plus	M/M	3.16	3.12		6.16	13.7
21	Fine plus	H/L	2.86	3.03	4.49		
23	Coarse	M/L					7.6
24	Coarse	M/M	2.90	3.13		8.71	
25	Coarse	H/L	2.87	3.01	4.92		
26	Coarse	L/H	3.12	3.85		16.42	

Table 16. Recovered asphalt binder properties – G*sin δ at 22°C (72°F) (MPa).

Section No.	Gradation	Asphalt Content/Air Voids	Time After Construction, Months				
			0	8	14	20	41
1	Fine	M/M	1.38	1.72		3.40	7.27
10	Fine plus	L/H	2.40	3.67		4.79	5.07
11	Fine plus	M/M	2.42	2.99		4.33	3.49
19	Fine plus	M/M	2.25	2.96		3.98	5.43
21	Fine plus	H/L	1.60	3.05	3.98		
23	Coarse	M/L					3.27
24	Coarse	M/M	2.79	3.18		2.20	
25	Coarse	H/L	2.92	2.87	2.16		
26	Coarse	L/H	2.92	3.48		6.20	

Table 17. Recovered asphalt binder properties – G*sin δ at 25°C (77°F) (MPa).

Section No.	Gradation	Asphalt Content/Air Voids	Time After Construction, Months				
			0	8	14	20	41
1	Fine	M/M	0.90	1.12		1.73	5.23
10	Fine plus	L/H	1.54	2.15		2.37	3.69
11	Fine plus	M/M	1.56	1.89		2.83	2.96
19	Fine plus	M/M	1.44	1.98		2.62	3.80
21	Fine plus	H/L	1.00	1.98	2.36		
23	Coarse	M/L					2.32
24	Coarse	M/M	1.82	2.03		3.15	
25	Coarse	H/L	1.86	2.05	2.40		
26	Coarse	L/H	1.95	2.29		3.48	

Table 18. Recovered asphalt binder properties – BBR stiffness at -12°C (10°F) (MPa).

Section No.	Gradation	Asphalt Content/Air Voids	Time After Construction, Months				
			0	8	14	20	41
1	Fine	M/M	82.0	105.0		125.0	148
10	Fine plus	L/H	153.6	161.4		204.8	121
11	Fine plus	M/M	84.4	147.5		149.8	200
19	Fine plus	M/M	121.2	134.9		154.6	204
21	Fine plus	H/L	108.4	122.8	146.1		
23	Coarse	M/L					67
24	Coarse	M/M	148.5	154.5		175.4	
25	Coarse	H/L	142.5	144.5	159.4		
26	Coarse	L/H	163.9	178.5		226.8	

Table 19. Recovered asphalt binder properties – BBR "m" value.

Section No.	Gradation	Asphalt Content/Air Voids	Time After Construction, Months				
			0	8	14	20	41
1	Fine	M/M	0.44	0.42		0.38	0.36
10	Fine plus	L/H	0.38	0.41		0.33	0.37
11	Fine plus	M/M	0.44	0.39		0.39	0.34
19	Fine plus	M/M	0.40	0.40		0.37	0.34
21	Fine plus	H/L	0.40	0.41	0.39		
23	Coarse	M/L				0.40	0.44
24	Coarse	M/M	0.39	0.44			
25	Coarse	H/L	0.41	0.44	0.37		
26	Coarse	L/H	0.39	0.40		0.35	

Table 20. Properties of binders recovered from top lift cores of replacement sections at 21 months.

Property	Section			
	35	**36**	**55**	**56**
Penetration @ 25°C (0.1mm)	55, 54, 58	19, 19, 19	28, 27, 25	37, 35, 35
Viscosity @ 60°C (P)	5499	81121	20799	10805
G*/sin δ, @ 58°C (kPa)	7.3	79.8	15.7	6.2
G*/sin δ, @ 64°C (kPa)	3.4	36.4	7.4	1.9
G*/sin δ, @ 25°C (kPa)	1435	5761	2177	3217
BBR, m-value @ -12°C	.409/ .461	.322/ .326	.370/ .363	.398
BBR Stiffness (MPa) @ -12°C	52/ 35	128/ 133	131/ 126	85

°F = 1.8(°C) +32
1 psi = 6.9 kPa

Costs Associated with Pavement Construction, Rehabilitation, and Maintenance Activities

U.S. Department of Transportation
Federal Highway Administration

April 2006
WesTrack Report UNR-28
HRDI-11/04-06(CD-ROM)E

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides cost information for typical construction, rehabilitation, and maintenance activities for pavements. The information was obtained from previous efforts conducted at Texas A&M University[4] and from the Rubber Pavements Association.[5] Cost indexes were used to update some of the cost information presented in the report as described below.

BACKGROUND

The "pay adjustment factors" included in the PRS developed for WesTrack are determined based on the lifecycle cost difference of the "as constructed" HMA as compared to the "as designed" HMA. The cost information used as default values, and used to determine the sensitivity of the developed PRS, is based on the cost information provided in this report. Representative construction, rehabilitation, and maintenance cost information obtained from a number of public agencies is summarized below.

TYPES OF COSTS

The costs that should be considered in economic evaluations of alternative pavement construction and rehabilitation strategies include both initial and recurring costs. Haas and Hudson[6] have defined these costs as follows:

1. Agency costs.
    - Initial capital costs of construction or rehabilitation.
    - Future capital costs of reconstruction and rehabilitation (overlays, seal coats, etc.).
    - Maintenance costs recurring throughout the design period.
    - Salvage return or residual value at the end of the design period.
    - Engineering and administration.
    - Costs of investments.

2. User costs.
    - Travel time.
    - Vehicle operation.
    - Accidents.
    - Discomfort.
    - Time delay and extra vehicle operating costs during resurfacing or maintenance.

3. Non-user costs.

While all of these costs should be included if a detailed economic analysis is desired, most lifecycle costing operations presently used for pavements include only agency costs. Among the agency costs of primary interest are the following:

- Initial capital costs of construction or rehabilitation.
- Future capital costs of reconstruction and rehabilitation.
- Maintenance costs.

As user costs are better defined, it is important that they be considered in lifecycle costing operations performed by public agencies and included in the determination of "pay adjustment factors" for PRS.

COST DATA

Data are included in this technical report to define costs associated with pavement construction, reconstruction, rehabilitation, and maintenance operations. These costs are intended to be representative only. If costs for these operations are available from local agencies' historical records, they should be substituted appropriately.

CONSTRUCTION COSTS

Costs of common pavement construction operations are shown in table 1. These costs are considered representative of average in-place costs in the United States. Costs are based on pavement layers in the range of 100 to 200 mm (4 to 8 in.) for untreated base and stabilized layers. Asphalt concrete costs are typical of 38 to 75 mm (1.5 to 3 in.) lifts, while portland cement concrete (PCC) costs are typical for pavements 200 to 250 mm (8 to 10 in.) in thickness.

REHABILITATION AND PAVEMENT RECYCLING COSTS

Costs associated with selected rehabilitation and pavement recycling operations are shown in tables 2, 3, and 4. Included in these tables are the average cost, plus high and low costs found in the western United States.

MAINTENANCE COSTS

Costs associated with flexible pavement maintenance operations are shown in tables 5a through 5d and costs associated with rigid pavement maintenance operations are shown in table 6. Table 5a shows maintenance cost information collected in 1977; table 5b contains maintenance cost information collected in 1998. Due to the limited data available in 1998, the 1977 data were combined with FHWA maintenance cost index data to establish the representative values shown in table 5b. Table 5c shows data collected for 1998 for common maintenance activities. The costs in table 5d are considered the most representative costs currently available. Costs were obtained from the States of Arizona, California, Nevada, Texas, and Montana, and are representative of costs in 1998.

A general description for each maintenance activity has been prepared and is shown in the tables together with the average, low, and high unit costs for these activities. The reported suggested costs are the authors' best estimate of representative unit costs for the stated maintenance activity (table 5d). The wide range of reported unit costs for this condensed list of activities is due in part to:

- Different crew sizes utilized in the various States.
- Different equipment requirements for various States.
- Differences in maintenance work activity as defined by various States.
- Variety of traffic conditions under which maintenance is performed.
- Type of facility on which maintenance activities are performed.
- Amount of work performed per lane mile.

Maintenance unit cost information has been converted to costs per square yard (square m) of total pavement surface area treated and cost per lane mile (km). In order to develop these costs, assumptions were made as to the thickness and extent of the area treated.

The reader is reminded that the maintenance activities described in this report are normally performed on pavements with certain specific types of distress. For example, fog seals and chip seals are common maintenance or rehabilitation activities that are used to correct raveling flexible pavements. Typical types of flexible pavement distress and maintenance activities associated with maintenance for these types of distress are shown in table 7.

COST UPDATING PROCEDURES

As cost information is obtained from various sources at various times, it is necessary to bring these costs to a common timeframe. In order to convert cost figures contained in this report to a current date, the cost index method is suggested. The following equation can be used:

$$C_c = C_o \left(\frac{I_c}{I_o} \right)$$

where

C_c = current estimated cost
C_o = cost at other time "0"
I_c = current index number
I_o = index number at other time "0"

The index number of use depends upon the type of cost being estimated. Two indices are given from which to choose:

- The *Engineering News Record* (ENR) Construction Cost Index[8]
- Bid Price Trends on Federal-Aid Highway Contracts[9]

The ENR Construction Cost Index was designed as a general-purpose construction cost index to chart basic costs with time. It is a weighted index of constant quantities of structural steel, portland cement, lumber, and common labor, valued at $100 in 1913. The Composite Price Index on Federal-Aid Highway Contracts is compiled by the FHWA from reports by State transportation agencies. The base year for this index is 1987. Both of these indices are summarized in table 8.

FUTURE COST TRENDS

The information contained in table 8 can be supplemented and used to project future cost trends associated with the materials used for construction, rehabilitation, and maintenance. Figures 1 and 2 illustrate the rate of increase of costs since 1970. The rapid increases in costs between 1973 and 1974 were a result of ending Federal price controls and the Arab oil embargo. Highway price moderations during the period of 1974 through 1977, were a result of a general decrease in highway construction work (more competition for the same projects) and moderation of the general rate of inflation and crude oil prices.

It is important to realize that regional and local prices differ considerably across the United States. Figure 3 illustrates the differences in the prices of asphalt concrete in Arizona, California, and Texas, and the average price for the United States. Three reasons that are responsible for price increases throughout the United States are the price of crude oil, the price of asphalt cement, and the cost of transportation (figure 4).

A summary of FHWA cost trends[9] is shown in table 9. Annual rates of inflation for various items during the 1990s (1990-97) in the United States vary from 1.7 to 8.3 percent, as shown in the table. Based on the rates of growth from 1990 through 1997, costs for many construction-related items are expected to increase on the order of 20 to 30 percent in the next 5 to 10 years.

SUMMARY

Cost and cost updating procedures have been presented for a wide range of construction, rehabilitation, and maintenance operations. These data, together with predictions of service life, can be used to predict lifecycle costs.

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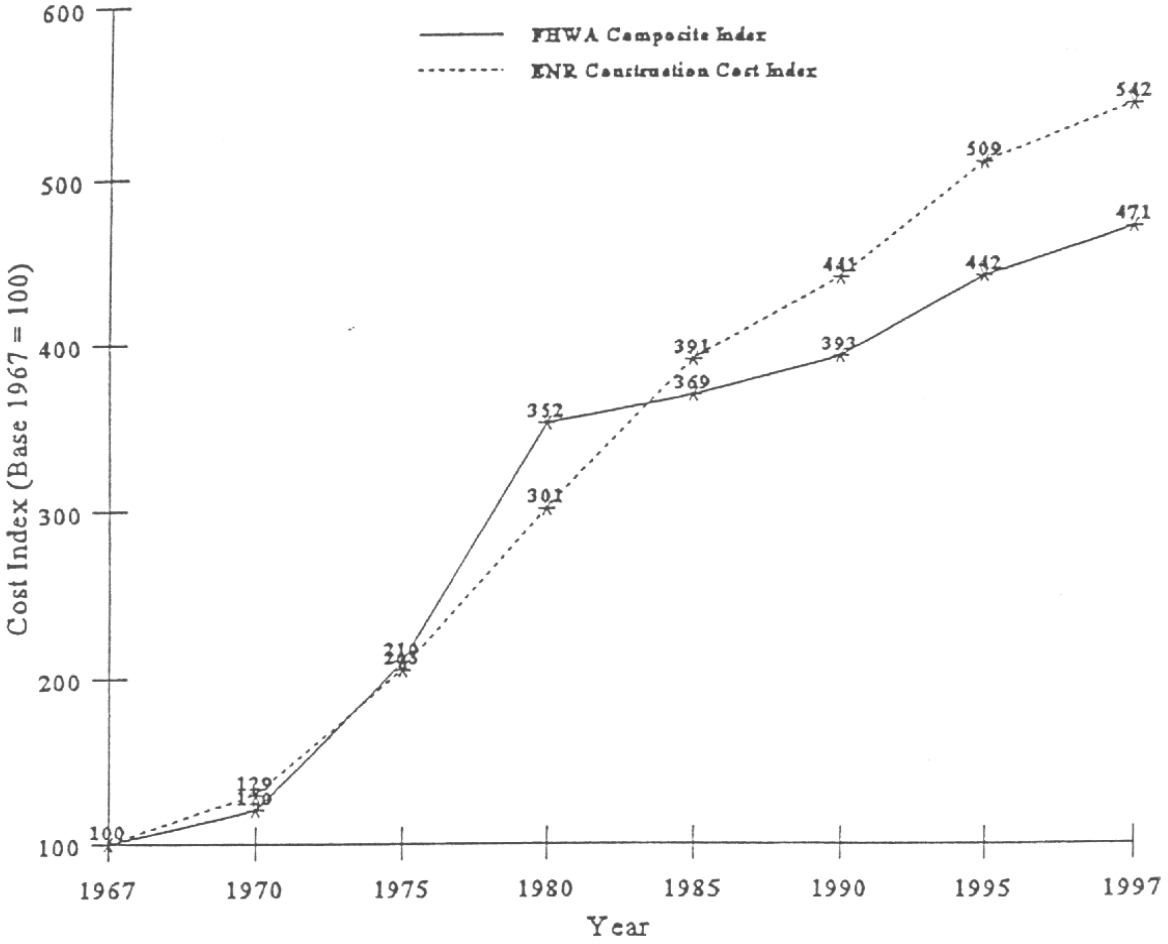


Figure 1. Change in cost index over time.

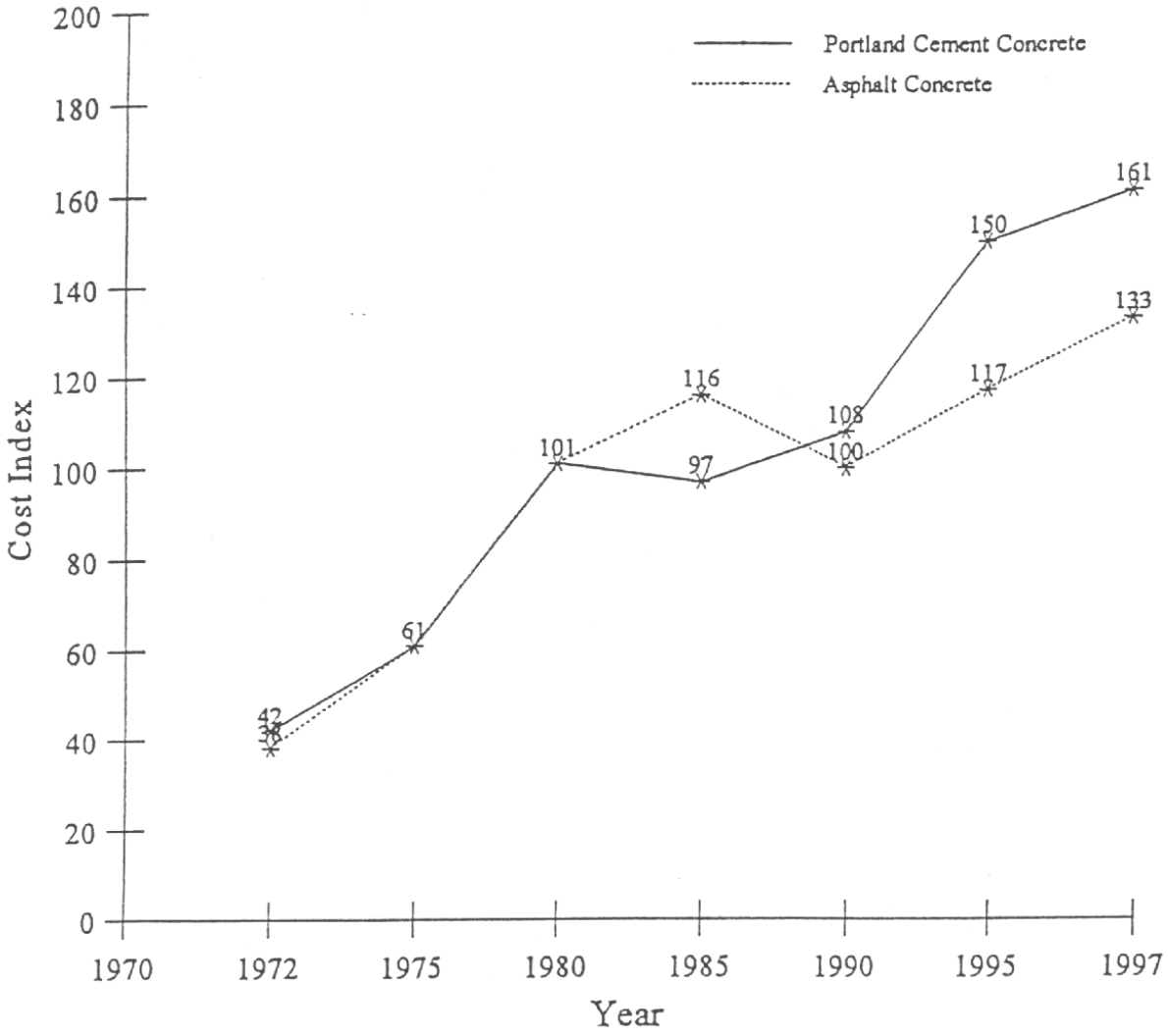
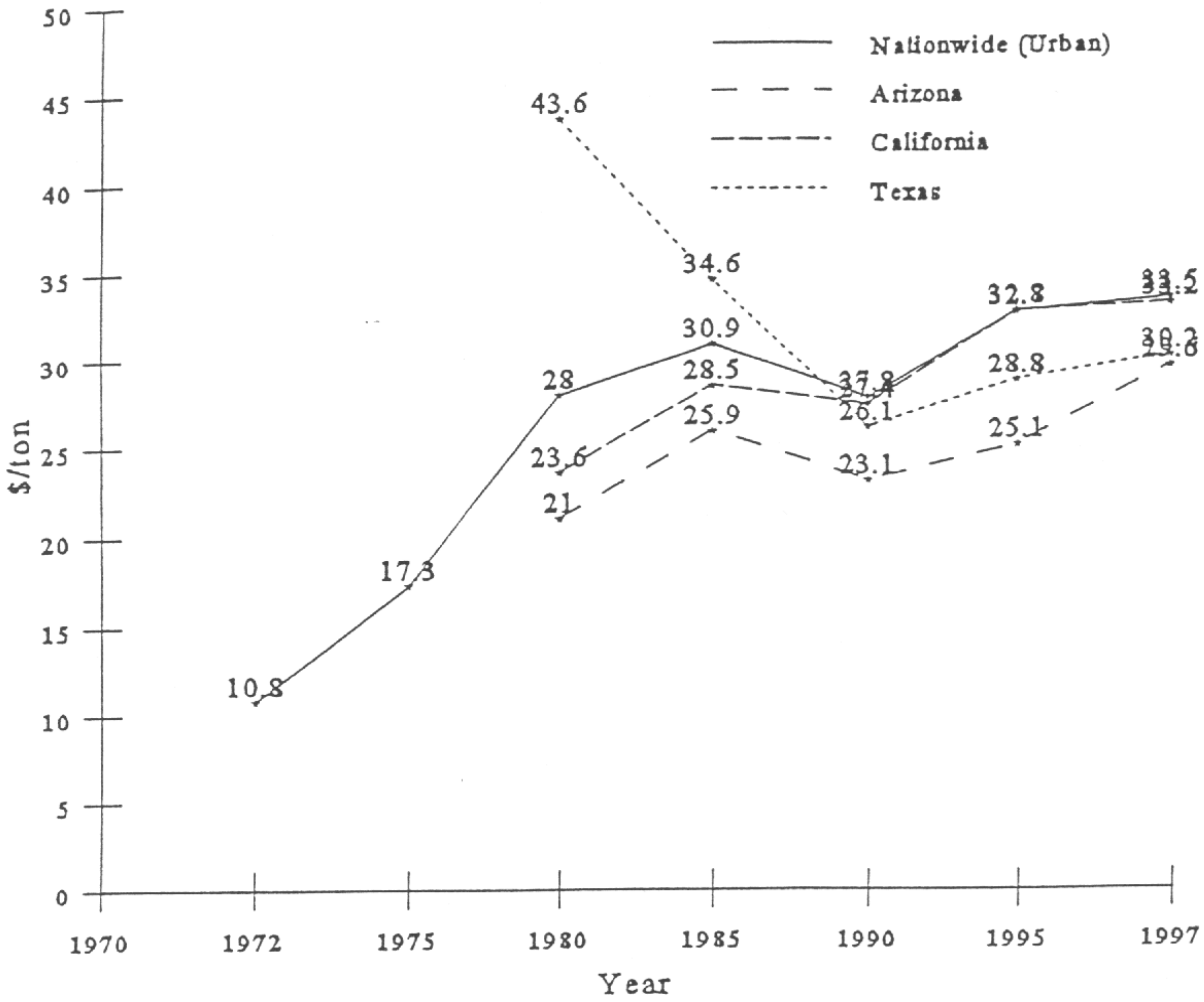
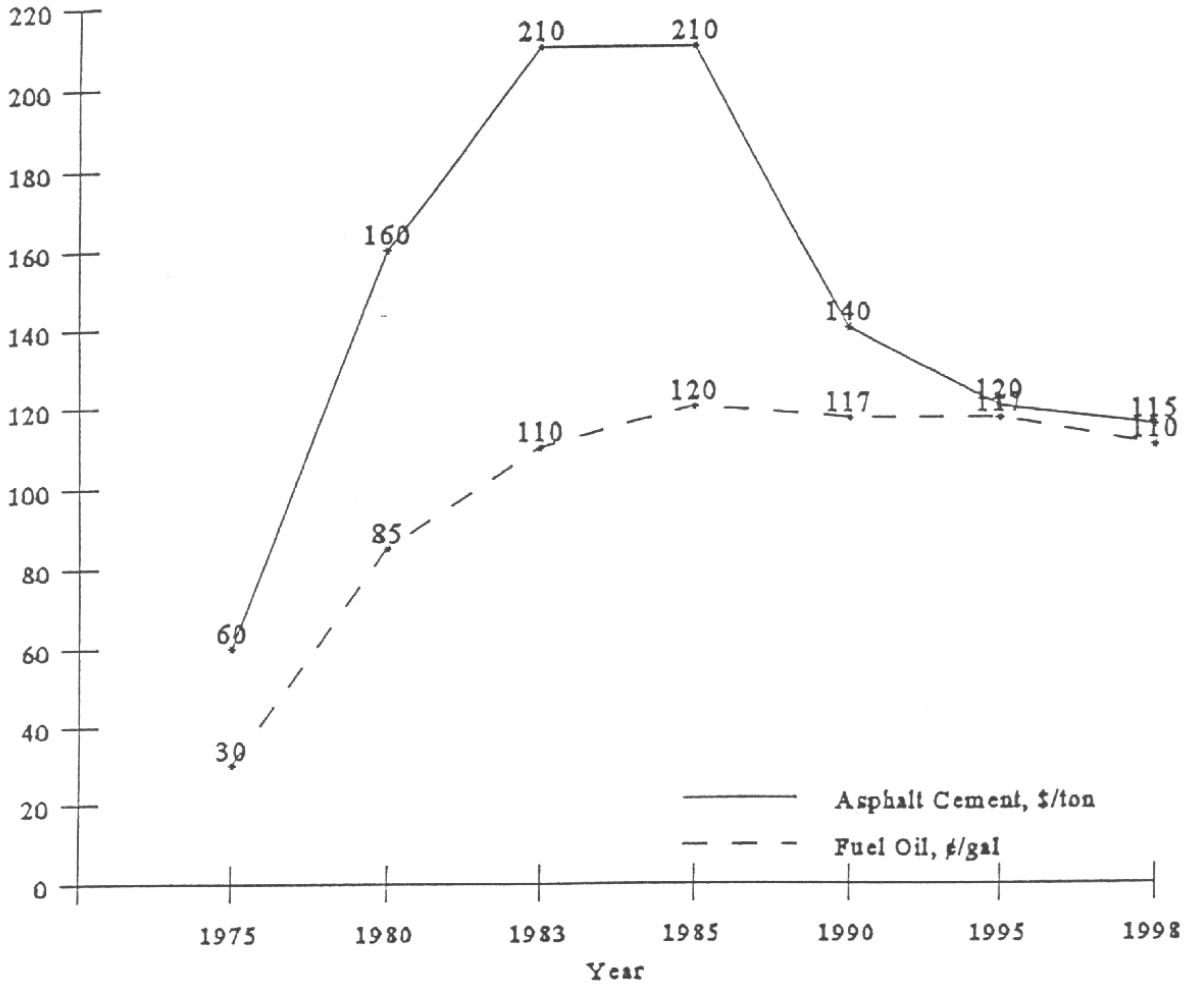


Figure 2. Pavement construction cost indexes (FHWA).



1 ton = 0.907 Mg

Figure 3. Average annual contract price for bituminous concrete.



1 ton = 0.907 Mg
1 gal = 3.79 L

Figure 4. Price trends for asphalt cement and no. 2 fuel oil.

Table 1. Typical costs of common pavement construction operations – 1998.

Construction Operation	Representative Costs $/yd^2-in.	
	Average	Range
Crushed stone base	0.60	0.30-0.75
Crushed gravel base	0.50	0.20-0.75
Lime stabilized subgrade	0.30	0.15-0.45
Cement stabilized subgrade	0.40	0.20-0.50
Cement treated base*	1.00	0.60-1.40
Asphalt treated base	1.50	1.30-2.00
Lime – fly ash – aggregate base*	0.90	0.60-1.00
Chip seal	0.85	0.70-1.00
Slurry seal	1.00	0.90-1.35
Microsurfacing	1.30	1.00-1.60
Asphalt concrete	2.00	1.80-2.30
Asphalt rubber hot-mix	2.80	2.30-3.50
Jointed PCC (10- to 12-in.)	2.00	1.80-2.30
Continuously Reinforced Concrete Pavements (10- to 12-in.)	2.90	2.50-3.20

1 yd^2 = 0.836 m^2
1 in. = 25.4 mm

Table 2. Typical costs of pavement maintenance and rehabilitation operations – 1998.

Rehabilitation Operation	Approximate Thickness, in.	Representative Costs $/yd^2-in.	
		Average	Range
Crack seal	---	0.25	0.20-0.30
Chip seal	½	0.90	0.70-1.20
Polymer-modified chip seal	½	1.10	0.90-1.30
Slurry seal	½	0.85	0.70-1.25
Microsurfacing	½	1.25	1.10-1.50
Asphalt-rubber interlayer	½	2.50	2.20-2.80
Open-graded friction course	1	2.00	1.80-2.30
Asphalt concrete (dense-graded)	1	2.00	1.80-2.30
Asphalt concrete (dense-graded)	2	4.00	3.60-4.60
Asphalt concrete (dense-graded)	4	8.00	7.20-9.60
Asphalt rubber (open-graded)	1	2.80	2.30-3.50
Asphalt rubber (gap-graded)	2	5.60	4.60-7.00

1 yd^2 = 0.836 m^2
1 in. = 25.4 mm

Table 3. Typical costs of common asphalt recycling operations – 1998.

Recycling Operation	Representative Costs $/yd^2-in.	
	Average	Range
Heat and remix pavement - 1-in. depth	1.30	1.00-1.60
Heat and scarify pavement - 3/4-in. depth	0.90	0.75-1.10
Cold mill pavement	0.35	0.20-0.50
Cold mill pavement (includes cleanup and haul)	0.85	0.30-1.25
Cold process - remove, crush, place, compact, traffic control - without stabilizer	0.50	0.30-0.75
Cold process - remove, crush, mix, place, compact, traffic control - with stabilizer	0.60	0.35-0.90
Cold in-place recycling, full depth (6- to 8-in.)	0.50	0.35-0.60
Cold in-place surface recycling (3-in.)	0.80	0.70-0.90
Hot in-place surface recycling (2-in.)	1.50	1.30-1.90
Hot plant recycling, 20-30% recycled asphalt pavement	2.00	1.90-3.00

*Costs are for a square yard inch, except where listed.
1 yd^2 = 0.836 m^2
1 in. = 25.4 mm

Table 4. Cold milling costs.[7]

Type of Operation	Thickness Milled, in.	Cost, Dollars Per*	
		yd^2	yd^2-in.
Highway half-lane milling machine	1	0.13	0.13
	2	0.18	0.09
	3	0.20	0.07
	4	0.23	0.06
Highway full-lane milling machine	1	0.07	0.07
	2	0.14	0.07
	3	0.20	0.07
	4	0.22	0.06
City half-lane milling machine	1	0.26	0.26
	2	0.38	0.19
	3	0.46	0.15
	4	0.56	0.14

*Does not include trucking costs.

1 yd^2 = 0.836 m^2
1 in. = 25.4 mm

Table 5a. Unit cost for flexible pavement maintenance operations – 1977.[4]

Descriptive Title	General Description	State	No.	Reported Avg. Unit Cost, Dollars	Suggested Cost, Dollars			
					Average	Low	High	Unit Meas.
Fog seal - partial width	Light application of diluted emulsion or a proprietary material over a partial lane.	AZ	109	0.95/sy	0.95	0.75	0.131	sy
Fog seal - full width	Light application of diluted emulsion or a proprietary material over a full lane width in a continuous section.	AZ CA NV ND	108 01.983 101.06 435	0.069/sy 0.06/sy 0.06/sy 0.11/sy	0.06	0.05	0.11	sy
Chip seal - partial width	Application of asphalt and cover aggregate to a limited area.	AZ CA NV ND	104 01-051 101.05 412	0.36/sy 0.41/sy 0.23/sy 0.26/sy	0.35	0.23	0.41	sy
Chip seal - full width	Application of asphalt and cover aggregate to a full lane width in a continuous section.	AZ CA NV ND	106 01-054 101.09 422	0.18/sy 0.24/sy 0.23/sy 0.21/sy	0.21	0.18	0.24	sy
Surface patch - hand method	Application of a premix material to the surface of the pavement by hand method.	AZ CA NV	102 01-031 101.02	34.56/cy 147.00/cy 123.60/cy	130.00	60.00	170.00	cy
Surface patch - machine method	Application of a premix material to the surface of the pavement with machine.	AZ CA CA CA CA NV ND	102 01-221 01-022 01-023 01-024 101.03 421	34.56/cy 52.50/cy 43.00/cy 28.50/cy 40.40/cy 27.96/cy 22.35/cy	28.00	20.00	40.00	cy
Digout and repair - hand method	Removal and repair of limited areas by use of hand tools.	AZ CA ND	101 01-034 411	112.29/cy 145.00/cy 55.34/cy	110.00	40.00	160.00	cy
Digout and repair - machine method	Removal and repair of limited areas by use of mechanized equipment.	AZ CA NV	105 01-011 101.01	27.38/cy 68.00/cy 17.35/cy	25.00	10.00	70.00	cy
Crack pouring	Pouring cracks in flexible pavement with asphalt material (may include cleaning with compressed air and covering with sand).	AZ CA CA NV ND	103 01-041 01-042 101.07 414	3.38/gal 4.83/gal 6.41/gal 6.41/gal 1.18/gal	3.25	1.10	6.50	gal
Asphalt concrete overlay	Application of an asphalt concrete overlay usually less than about 2 in.	TX US		21.00/ton 15.12/ton	31.00	23.00	43.00	cy

Metric conversions: 1 sy = 1 yd^2 = 0.836 m^2; 1 cy = 1 yd^3 = 0.76 m^3; 1 gal = 3.79 L; 1 ton = 0.907 Mg; 1 in. = 25.4mm

Table 5b. Unit cost for flexible pavement maintenance operations – 1998.

Descriptive Title	General Description	State	No.	Reported Avg. Unit Cost, Dollars	Suggested Cost, Dollars			
					Avg.	Low	High	Unit Meas.
Fog seal - partial width	Light application of diluted emulsion or a proprietary material over a partial lane.	CA MT NV TX WA						sy
Fog seal - full width	Light application of diluted emulsion or a proprietary material over a full lane width in a continuous section.	CA MT NV TX WA	 101.06 233,235 	 0.11/sy 0.12/sy 	0.12	0.08	0.15	sy
Chip seal - partial width	Application of asphalt and cover aggregate to a limited area.	CA MT NV TX WA	 232 	 0.98/sy 	1.00	0.70	1.20	sy
Chip seal - full width	Application of asphalt and cover aggregate to a full lane width in a continuous section.	CA MT NV TX WA	 107.05 231 	 1.05/sy 0.41/sy 0.77/sy	0.75	0.40	1.10	sy
Surface patch - hand method	Application of a premix material to the surface of the pavement by hand method.	CA MT NV TX WA	 101.02 213 	 448.66/cy 6.98/sy 	250.00	150.00	500.00	cy
Surface patch - machine method	Application of a premix material to the surface of the pavement with machine.	CA MT NV TX WA	 101.03 212 	 85.92/cy 1.94/sy 	100.00	70.00	250.00	cy
Digout and repair - hand method	Removal and repair of limited areas by use of hand tools.	CA MT NV TX WA	 242* 	 23.95/ea* 	220.00	80.00	400.00	cy
Digout and repair - machine method	Removal and repair of limited areas by use of mechanized equipment.	CA MT NV TX WA	 101.01 864 	 80.76/cy 	80.00	40.00	140.00	cy
Crack pouring	Pouring cracks in flexible pavement with asphalt material (may include cleaning with compressed air and covering with sand).	CA MT NV TX WA	 101.07 225 	 0.25/sy 1.20/lb 0.87/lb	7.00	3.00	12.00	gal

*Pothole repair.

Metric conversions: 1 sy = 1 yd^2 = 0.836 m^2; 1 cy = 1 yd^3 = 0.76 m^3; 1 lb = 0.45 kg; 1 gal = 3.79 L

Table 5c. Summary of selected cost of maintenance activity – 1998.

Activity	Public Agency	Cost, $/yd^2			
		Averages	Representative	Low	High
Fog seal	Maricopa County City of Phoenix Caltrans San Diego County Nevada DOT Texas DOT	0.16 0.18 0.20 0.20 0.11 0.12	0.15	0.10	0.20
Crack seal	Maricopa County Caltrans - District 2 Sacramento County San Diego County Montana DOT	0.12 0.30 0.50 0.10 0.25	0.15	0.10	0.30
Slurry seal	Maricopa County City of Phoenix Caltrans Sacramento County San Diego County Costa Mesa	0.50 0.55 1.20 0.90 1.00 1.38	0.90	0.50	1.20
Microsurface	Caltrans Sacramento County San Diego County	2.00 1.45 1.50	1.50	1.30	2.00
Chip seal	Maricopa County Caltrans Sacramento County San Diego County Montana DOT Nevada DOT Texas DOT	0.73 1.00 0.90 1.00 1.05 0.41 1.05	1.00	0.75	1.25

1 yd ^{2} = 0.836 m ^{2}

Table 5d. Typical costs for flexible pavement maintenance and rehabilitation activities – 1998.

Maintenance Activity	Cost, Dollars* Per		Percent of Total Pavement Area Treated
	Yd^2	Lane-Mile	
Fog seal			
•Partial width	0.12	850	50 percent
•Full width	0.15	1,060	100 percent
Chip seal			
•Partial width	0.15	1,060	15 percent
•Full width	0.75	5,310	100 percent
Surface patch			
•Hand method	0.17	1,230	2.5 percent, 1-in. thick
•Machine method	0.28	2,000	10 percent, 1-in. thick
Digout and repair			
•Hand method	0.50	3,500	2 percent, 4-in. thick
•Machine method	0.65	4,700	5 percent, 6-in. thick
Crack sealing	0.15	1,050	250 linear ft per station

*Costs are for square yards (yd^2) of total pavement surface maintained. For example, surface patching by the hand method may have been applied over only 5 percent of total pavement surface area, yet costs reported are for the total pavement area maintained or 1 mile of pavement.

Metric Conversions:

1 yd^2 = 0.836 m^2
1 mi = 1.6 km
1 in. = 25.4 mm
1 ft = 0.305 m

Table 6. Typical costs for rigid pavement maintenance and rehabilitation – 1998.

Activity	Representative Costs, Dollar Per	
	Yd ^{2}	Lane-Mile
Rubblization*	1.80-2.20	12,670-15,490
Crack and Seat*	0.50-1.00	3,520-7,040
Underseal*	3.50-4.00	26,640-28,160
Dowel Retrofit/Grind*	17.00-21.00	120,000-150,000

*Normally overlaid with 4 in. or more of asphalt concrete. Cost for overlay not included.

Metric Conversions:

1 yd^2 = 0.836 m^2

1 mi = 1.6 km

1 in. = 25.4 mm

Table 7. Maintenance activities associated with flexible pavement distresses.

Type of Distress	Maintenance Activity
Rutting	Surface patch - hand Surface patch - machine Surface grinding Microsurfacing Asphalt concrete overlay
Raveling	Fog seal - partial width Fog seal - full width Chip seal - partial width Chip seal - full width
Flushing (bleeding)	Overlay Chip seal - full width
Corrugations	Surface patch - machine Digout and repair - machine
Alligator cracking	All maintenance operations could be used.
Longitudinal cracking	Fog seal - partial width Fog seal - full width Chip seal - partial width Chip seal - full width Crack sealing Asphalt concrete overlay
Transverse cracking	Crack sealing Chip seal - full width Asphalt concrete overlay
Patching	Surface patch - machine Digout and repair - machine Chip seal - full width Asphalt concrete overlay
Failures	Surface patch - hand Surface patch - machine Digout and repair - machine Asphalt concrete overlay

Table 8. Construction cost index history (1960-1997).

Year	Average Annual Index ENR	FHWA Composite Index	
		Rural	Urban
1960	824	—	
1	847	—	
2	872	—	
3	901	—	
4	936	—	
5	971	—	
6	1019	—	
7	1074	—	
8	1155	—	
9	1269	—	
1970	1381	—	
1	1581	—	
2	1753	36.9	43.0
3	1895	40.8	46.8
4	2020	54.7	64.8
5	2212	54.9	68.2
6	2401	54.4	61.8
7	2576	57.9	65.4
8	2776	67.5	75.9
9	3003	82.5	94.0

Table 8. Construction cost index history (1960-1997) (continued).

Year	Average Annual Index ENR	FHWA Composite Index	
		Rural	Urban
1980	3237	93.1	104.6
1	3535	92.9	98.1
2	3825	87.0	92.1
3	4066	84.7	94.5
4	4146	89.4	100.6
5	4195	97.1	112.0
6	4295	97.1	110.7
7	4406	95.7	111.0
8	4519	97.9	118.2
9	4615	99.4	120.0
1990	4732	104.3	118.7
1	4835	103.5	113.8
2	4985	101.8	113.1
3	5210	105.5	116.5
4	5408	108.9	124.6
5	5471	111.5	137.2
6	5620	119.4	124.9
7	5825	121.5	146.5

Table 9. Price indexes for construction.

Item or Index	Index		% Change Between 1990 and 1997*	Annual % Rate of Inflation (1990-97)
	1990	1997		
• Composite Index				
+ Urban	118.7	146.5	23	3.3
+ Rural	104.3	121.5	16	2.3
• Surfacing Index				
+ Urban	114.7	151.4	32	4.6
+ Rural	95.5	123.4	29	4.1
• Asphalt Concrete				
+ Urban	113.0	135.8	20	2.9
+ Rural	94.1	112.4	19	1.7
• Portland Cement Concrete				
+ Urban	118.3	184.2	58	8.3
+ Rural	98.5	145.9	48	6.9
• Excavation				
+ Urban	134.9	163.4	21	3.0
+ Rural	81.6	102.1	25	3.6

Subgrade, Base Course, and Hot-Mix Asphalt Construction Variability

U.S. Department of Transportation
Federal Highway Administration

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WesTrack Report UNR-29
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides information that describes construction variability associated with the compaction of subgrade and fills, and the production and placement of granular base course and HMA. The information contained in the report was obtained from a literature review on construction variability conducted during the development of the construction specifications for WesTrack[3] and a later literature review conducted to update the construction variability information relative to HMA specified with the Superpave system of mixture design.

BACKGROUND

WesTrack specifications were developed and used to guide the construction of the project. These specifications were based on a review of existing specifications and contained acceptance limits based on historic information that described construction variability for the placement and/or production of subgrade, fill, granular base course, and HMA materials. Information was obtained from the literature and contained data that described construction variability from test roads, as well as typical highway construction projects.

The WesTrack specification limits were based largely on construction variability information obtained from the Maryland,[4] Western Association of State Highway and Transportation Officials (WASHTO),[5] and American Association of State Highway Officials (AASHO)[6,7] test

roads.[8] Since the WesTrack experiment was designed to evaluate the performance of HMA, it was critical that the subgrade, fill, and base course be prepared as uniformly as possible. Therefore, the construction variability obtained on the AASHO Road Test was used as a guide to establish compaction control for the subgrade, fill, and base course, and gradation control for the base course.

The control of the HMA during construction was also critical. In order to determine the influence of the mixture variables on the performance of the HMA, it was necessary to construct "off-target" mixtures with little variability. Thus, it was important to define the variability of typical construction operations and to construct WesTrack with less variability.

A second literature review was performed to update the information collected for the *Task G Interim WesTrack Report*.[3] Variability data associated with the construction of Superpave mixtures were generally not available during the development of the WesTrack specification. The second literature review provided variability information on Superpave-designed mixtures.

The information presented in this report was used for WesTrack specification development as well as the development of the guide specification, which is included as part of the PRS.[9] In addition, the information is used to compare with WesTrack construction variability.

CONSTRUCTION VARIABILITY

Quality control and quality assurance (QC/QA) tests performed during or after construction contain variability that is typically defined by the statistical term "standard deviation." This construction variability is due to variations associated with sampling, testing, and the construction operation. The construction operation consists of the production and placement of the material. Test method variability (for most QC/QA tests) has been defined by ASTM or AASHTO and is contained in their standardized test methods. Variability associated with sampling has been defined in only a few studies[10] and is summarized in reference 11. In the ideal world, the public agency and contractor want to define only the variability associated with the production and placement of the materials. Unfortunately, sampling and test method variability can be larger than material and placement variability.[10,11]

Information reported in the literature typically defines construction variability (sampling, testing, and construction operation) with standard deviation. Since test results from construction QC/QA operations are typically normally distributed, the standard deviation becomes a very useful parameter for process control and specification development. The information contained in this report describes variability with standard deviation.

SUBGRADE AND FILL

The construction control for subgrade and fill placement typically uses in-place relative density and moisture content. The in-place density of the subgrade of fill material is typically relative to some standard (AASHTO or ASTM) laboratory compaction method. The moisture content can

be controlled relative to the optimum moisture content at the maximum density as determined by a laboratory standard compaction procedure. Often, the moisture content is not controlled during subgrade and fill placement.

Typical variability information for relative density and moisture content for highway construction is shown in table 1. References that define the sources of the information are provided (See references 5-6 and 12-18). Standard deviations for typical highway construction are on the order of 4.5 to 6.0 (relative density). The AASHO Road Test was placed with a standard deviation of 2.0 (table 1). Standard deviations for typical highway construction for moisture content are on the order of 2.5 to 3.5 percent. The AASHO Road Test was placed with a moisture content standard deviation of 1.2 percent.

SUBBASE AND BASE COURSES

Gradation and in-place relative density and moisture content are typically used for QC/QA purposes for the production and placement of subbase and base courses. Tables 2 and 3 contain information that defines the construction variability associated with the production and placement of subbase and base course material. The AASHO Road Test information shown in table 2 indicates the variability associated with subbase material and two types of base course material (crushed stone and gravel). Both plant-produced and in-place gradation information is provided in this table.

Table 3 shows gradation variability information from California, North Carolina, Pennsylvania, and Virginia. These data were collected on a variety of materials with and without pugmill mixing. The AASHO Road Test information has less variability than the typical highway construction projects reported by the States (table 3).

Relative density and moisture content variability information for subbase and base course materials is shown in table 4 for the AASHO Road Test and the States of Alabama, Indiana, and Utah. Typical standard deviations for relative density are on the order of 2.5 to 3.5 for typical highway construction projects. The density control for the AASHO Road Test was better than these typical highway projects (table 4). Little information is available on in-place moisture content variability.

HOT-MIX ASPHALT

Construction variability information is available for HMA for the following parameters: aggregate gradation, asphalt binder content, Marshall volumetrics, Superpave gyratory compactor volumetrics, temperature, in-place air voids or density, thickness, and smoothness. Available information on these parameters is discussed below.

AGGREGATE GRADATION

Typical aggregate gradation variability information from cold-feed samples obtained in 1969 and 1993 is shown in table 5. In general, the data indicate that variability was reduced between the sample dates of 1969 and 1993. AASHO Road Test aggregate gradation information obtained from hot-bin samples is shown in table 6 for both the binder and surface courses. Over 170 samples of binder course and 130 samples of surface course were reported in this data set. Variability reported from the AASHO Road Test hot-bin samples (table 6) is considerably less than that reported for the cold-feed samples (table 5).

Aggregate gradation results after solvent extraction from the HMA are shown in tables 7 through 10. Table 7 shows information obtained from the AASHO Road Test for both the binder and surface courses. The variability is larger than that associated with the hot-bin samples shown in table 6.

The Bureau of Public Roads (BPR), now FHWA, obtained gradation information on 22 surface course mixtures in the 1960s. These data are reported in tables 8 and 9. Information on gradation after solvent extraction is shown for one eastern and one western State in table 9. Information from other States is shown in table 10 for both base and surface HMA mixtures.

ASPHALT BINDER CONTENT

Asphalt content variability information is shown in tables 11 through 13 for base, binder, and surface layers. Most of the information available was obtained from solvent extraction data; however, some nuclear and ignition asphalt content variability information is available. Table 11 contains information from the AASHO Road Test, as well as information from three States and an airport authority. The data identified with the BPR was obtained in the 1960s when batch plants were used to produce HMA. The eastern State and western State information was collected in the late 1980s from both batch and drum-mix plants. A considerable amount of data reported in table 12 was collected in the 1990s.

MARSHALL PROPERTIES

Construction variability information associated with Marshall properties, including stability, flow, and volumetrics, is shown in tables 14 and 15. Table 14 shows the Marshall property data obtained on field-produced, laboratory-compacted samples obtained from the AASHO Road Test, as well as the BPR study conducted in the 1960s and the FHWA study conducted in the 1990s. The information reported for Virginia, FHWA, and West Virginia shown in table 15 was also obtained from field-mixed, laboratory-compacted samples (FMLC). The Colorado data provide information on volumetric properties for mixtures compacted with different types of compactors. Information on the Superpave gyratory compactors is shown for a 1994 FHWA study. Additional gradation and volumetric data for Superpave projects are presented in the next section of this report.

SUPERPAVE PROJECTS

Information is available from several Superpave construction projects. Tables 16 through 23 contain these data. Tables 16 through 19 contain information obtained in NCHRP Project 9-7 from several States including Alabama, Florida, Georgia, Kansas, Kentucky, Maryland, Mississippi, Texas, and Virginia.[37] Variability for asphalt binder content, aggregate gradation, and Superpave gyratory compactor volumetrics are for these projects.

Variability for asphalt binder content, aggregate gradation, and volumetrics is shown in tables 20 through 22 for three Superpave projects constructed in Florida.[38] Superpave gyratory compactor volumetrics are shown in table 23 for 12 projects in Indiana.[39]

TEMPERATURE

Indiana completed a study to define the temperature variability associated with the production and placement of HMA. Standard deviation information on temperature at the plant, at the paver, and on the roadway prior to breakdown rolling is shown in table 24.[40,41]

IN-PLACE AIR VOIDS (DENSITY)

Tables 25 through 27 contain variability information available on in-place air voids or density. The information shown in tables 25 and 26 was obtained on the AASHO Road Test in the late 1950s, the BPR data was collected in the 1960s, and data from State public agencies was collected in the late 1980s. Data collected in the 1990s is shown in table 27.[18]

THICKNESS

A limited amount of information is available on the construction variability associated with thickness. Table 28 contains information from two States and the AASHO Road Test. The variability is dependent upon the thickness of the layer and the type of construction (new or overlay), among other factors. Coefficients of variation on the order of 10 to 15 percent can be expected.

SMOOTHNESS

Variability associated with pavement smoothness after placement of the HMA is shown in table 29. Only limited data are available. The variability will depend upon the type of measurement instrument and the type of construction (new or overlay), among other factors.

SUMMARY

The information presented above is based on a review of the literature. Several States were asked to supply additional data to enhance the database. No additional information was made available. Most States have records from which these types of data can be obtained; however,

obtaining these data is time consuming for the States. Personal visits to the public agencies is perhaps the best method available for collection of such data.

A summary of variability information for HMA is shown in table 30 based on the information presented in this report. Representative values and representative ranges of standard deviations are shown in table 30 for asphalt binder content, aggregate gradation, Marshall properties, and volumetrics and in-place air voids.

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Table 1. Subgrade soil density and moisture content statistics.

Data Source	Relative Density			Moisture Content			Comment	Ref.
	x	s	n	x	s	n		
WASHO Road Test				22.89	3.12	577	0-24" depth all sections for moisture content	3
WASHO Road Test				22.90	2.88	142	0-6" depth all sections for moisture content	3
AASHO Road Test	97.7	1.9*	3867		1.2*	3867	Flexible pavement embankments	4
AASHO Road Test	97.7	1.9*	4277		1.2*	4277	Rigid pavement embankments	4
Utah	99.1	4.46					Embankment - Sand Cone	10,11
Utah	99.0	4.55					Embankment - Nuclear	10,11
California	92.86	2.44	200				Embankment-Homogeneous, fine grained	12
California	90.45	3.09	200				Embankment-Intermediate Variability	12
California	93.64	5.52	176				Embankment-Extremely Heterogeneous	12
Alabama	97.30	3.72	100	15.02	3.61	100	Embankment	13
Indiana	100.6	5.3					Subgrade	14
Indiana	96.8	5.7					Subgrade	14
Indiana	98.2	4.5					Subgrade	14
North Dakota	88.7	4.50	100				Embankment	15
North Dakota	89.9	8.84	98				Embankment	15
North Dakota	97.8	4.86	54				Embankment	15
North Dakota	93.0	4.29	86				Embankment - Direct Transmission	15
North Dakota	94.5	5.85	86				Embankment - Backscatter	15
North Dakota	88.9	4.11	86				Embankment - Direct Transmission	15
North Dakata	87.2	6.12	86				Embankment - Backscatter	15

x = Mean
s = Standard Deviation
n = Number of observations
* = Estimated from figures

1 in. = 25.4 mm

Table 2. Gradation control for subbase and base, AASHO Road Test.[6]

Sieve Size	Statistic Type	Subbase	Subbase	Crushed Stone Base	Crushed Stone Base	Gravel Base	Gravel Base
1.5-in.	x	100	100	100	100	100	100
	s						
	n	465	99	2125	271	26	29
1.0-in.	x	100	100	90	90	98.8	98.5
	s	0.9		3.04	3.52	1.44	1.57
	n	465	99	2125	271	26	29
3/4-in.	x	96	96.9	81	80		
	s	1.96	1.97	3.65	4.59		
	n	465	99	2125	271		
½-in.	x	90	89.7	68	68	73	74.3
	s	2.39	2.49	3.53	4.69	3.66	4.32
	n	465	99	2125	271	26	29
No. 4	x	71	71.2	48	50	46.2	48.9
	s	3.13	2.79	2.24	3.56	1.96	3.41
	n	465	99	2125	271	26	29
No. 10	x	52		35	36		
	s	2.91		1.55	2.21		
	n	465		2125	271		
No. 16	x					32.5	35
	s					1.55	2.66
	n					26	29
No. 30	x						
	s						
	n						
No. 40	x	25	27	20	20	20.6	22.8
	s	2.6	1.6	0.9	1.46	1.43	2.32
	n	465	99	2125	271	26	2.9
No. 100	x			13.5	14.5	11.4	12.8
	s			0.68	1.02	0.99	1.14
	n			2125	271	26	29
No. 200	x	6.5	7.5	10	11.5	7.6	9.1
	s	0.76	1.09	0.6	0.86	0.82	0.84
	n	465	99	2125	271	26	29
COMMENTS:		Plant Production Sample	In-Place Material	Plant Production Sample	In-Place Material	Plant Production Sample	In-Place Material

1 in. = 25.4 mm

Table 3. Gradation control for subbase and base.

Sieve Size	Statistic Type	California[19]						Pennsylvania[20]	Pennsylvania[20]	Virginia[18]	Vulcan[18]	Vulcan[18]	Vulcan[18]	Vulcan[18]	Vulcan[18]	Vulcan[18]	N. Carolina[18]	N. Carolina[18]	Virginia[18]	Virginia[18]	Virginia[18]
		B1	B2	B3	S1	S2	S3														
1.0 in.	x																				
	s									1.9							2.2	1.8			
	n									8532							169	180			
3/4 in.	x																				
	s							6.8	3.5		3.9	1.8	0.9								
	n										106	65	53								
1/2 in.	x																				
	s																4.3	4.3			
	n																169	180			
3/8 in.	x																				
	s							8.3	5.6	4.2											
	n									8532											
No. 4	x	50.9	58.1	52.7	49.5	72.6	45.0														
	s	3.1	2.8	5.7	4.3	6.5	6.6	6.2	5.2		3.3	2.3	2.8	6.7	7.7	6.8	3.4	4.2	4.3	4.5	4.6
	n	200	200	200	200	200	200				106	65	53	163	25	22	169	180	30	21	68
No. 8	x																				
	s										3.7	1.7	2	2.7	3.3	2.5					
	n										106	65	53	163	25	22					
No. 10	x																				
	s									2.8	3.7	1.6	1.7	1.5	0.9	1.2	3	4.3	3.4	3	3
	n									8532	106	65	53	163	25	22	169	180	30	21	68
No. 16	x																				
	s							3.6	3.4												
	n																				
No. 30	x	23.8	27.3	23.4																	
	s	2.5	2.3	2.9																	
	n	200	200	200																	
No. 40	x																				
	s									1.7							3.2	3.3	1.9	1.7	1.7
	n									8532							169	180	30	21	68
No. 60	x																				
	s										3.1	1.5	1.0								
	n										106	65	53								
No. 200	x	6	7.9	4.6	7.8	10	8.6														
	s	0.7	1.1	0.95	1.3	1.8	1.7	1.2	1.4	0.9	1.2	1	0.7				1.0	1.3	1.0	1.2	1.2
	n	200	200	200	200	200	200			8532	106	65	53				169	180	30	21	68
Comments:		Base			Subbase			Gravel Subbase	Limestone Subbase	Base	Granite - not pug mixed	Limestone - not pug mixed	Limestone - pug mixed	Limestone - not pug mixed	Gravel Pit Run	Gravel Pit Run	Plant - not pug mixed	Roadway - not pug mixed	Select Material - Granite	Select Material - Limestone	Select Material - Traprock

1 in. = 25.4 mm

Table 4. Subbase and base course density and moisture content control.

Data Source	Relative Density			Moisture Content			Comments	Reference
	x	s	n	x	s	n		
AASHO Road Test	102.2	1.6*	979				Subbase Flexible Pavement	6
AASHO Road Test	101.6	1.6*	714				Subbase Rigid Pavement	6
AASHO Road Test	101.5	1.2*	114.9	7	0.45	165	Crushed Stone Base	6
AASHO Road Test	103.7	1.3*	105				Gravel Base	6
Utah	98.7	2.92					Sand-Cone	12,13
Utah	98.7	2.89					Nuclear	12,13
Alabama	100.72	2.31	100				Soil Subbase	15
Alabama	99.2	4.06	96				Aggregate Base	15
Indiana	89.4	3.3					Subbase	16
Indiana	91.7	3.1					Subbase	16
Indiana	93.6	2.3					Subbase	16

*Calculated from tables and figures in original reports.[6]

Table 5. Typical aggregate gradation variability from cold feed samples.

Type of Mixture	Date	No. of Sample	Standard Deviation, Percent Passing							
		n	3/8 in.	#4	#8	#16	#30	#50	#100	#200
Surface[21]	1969	36	1.1	8.4	9.6	9.2	6.9	3.6	2.4	1.5
Surface[21]	1969	36	0.8	3.9	4.7	5.7	4.3	3.9	2.8	1.5
Surface[21]	1969	36	2.3	6.5	5.8	4.9	4.1	2.6	1.4	0.9
Binder[21]	1969	36	9.4	8.4	7.9	6.1	4.6	2.9	1.5	0.5
Binder[18]	1993	32	3.2	3.3	3.2	3.3	1.8	1.0	0.6	0.6
Surface[18]	1993	21	2.4	2.1	1.8	1.3	1.0	0.7	0.6	0.5

1 in. = 25.4 mm

Table 6. AASHO Road Test hot-bin analyses
(summary of 173 tests on binder and 130 tests on surface).[6]

Sieve Size	Mix Design	Mean Value	Standard Deviation	Percent of Tests		
				Within Tolerances	Above Tolerances	Below Tolerances
(a) Binder Course for Test Tangents						
1-in.	100	100.0	—	100.0	—	—
3/4-in.	97 ± 5	95.8	0.91	100.0	—	—
1/2-in.	77 ± 5	75.2	2.36	93.1	0.0	6.9
3/8-in.	56 ± 5	55.9	1.90	100.0	—	—
No. 4	38 ± 5	35.9	1.52	97.1	0.0	2.9
No. 10	26 ± 4	24.4	0.89	99.4	0.0	0.6
No. 20	18 ± 4	19.6	1.39	99.4	0.6	0.0
No. 40	11 ± 4	13.2	1.45	96.5	3.5	0.0
No. 80	7 ± 3	7.9	1.12	98.8	1.2	0.0
No. 200	3 ± 1	3.6	0.48	97.7	2.3	0.0
(b) Surface Course for Test Tangents						
1-in.	100	100.0	—	100.0	—	—
1/2-in.	90 ± 5	91.5	1.07	100.0	—	—
3/8-in.	80 ± 5	80.7	0.86	100.0	—	—
No. 4	64 ± 5	63.6	1.91	97.7	0.0	2.3
No. 10	45 ± 4	45.7	2.11	98.5	0.0	1.5
No. 20	31 ± 4	33.3	2.29	89.2	10.0	0.8
No. 40	20 ± 4	19.8	2.19	94.6	4.6	0.8
No. 80	11 ± 3	10.7	0.92	99.2	0.8	0.0
No. 200	5 ± 1	4.8	0.30	100.0	—	—

1 in. = 25.4 mm

Table 7. Aggregate gradation from extraction tests - AASHO Road Test.[6]

Sieve Size	Standard Deviation, Percent	
	Surface Course	Binder Course
1-in.		
3/4 in.		2.21
1/2-in.	2.43	3.30
3/8-in.	3.17	2.71
No. 4	4.06	2.18
No. 10	2.99	1.29
No. 20	1.68	1.03
No. 40	2.06	0.98
No. 80	1.07	0.81
No. 200	1.16	0.49
No. of Tests	96	127

1 in. = 25.4 mm

Table 8. Bureau of Public Roads study of 22 surface course mixes.*[10]

Sieve Size	1/3 of Jobs With Most Variable Std. Deviation	Average Deviation	1/3 of Jobs With Least Variable Std. Deviation
3/4-in. or 1/2-in.	2.32	1.43	0.81
3/8-in.	3.46	2.49	1.71
No. 4	4.52	3.51	2.33
No. 8 or 10	3.85	2.81	1.90
No. 20 or 30	2.24	1.74	1.32
No. 40 or 50	1.82	1.37	0.93
No. 80 or 100	1.36	1.00	0.65
No. 200	1.45	0.94	0.51

*Surface course mixtures, solvent extraction samples. 1 in. = 25.4 mm

Table 9. Aggregate gradation construction variation.*[22]

Sieve Size	FHWA Base Course	Eastern State Base Course	Eastern State Base Course	Western State 3/4-in. Surface Course	Western State 1/2-in. Surface Course	Western Airport Authority
3/4-in. or 1/2-in.						3.86
3/8-in.	4.37		4.37	2.37	2.62	4.16
1/4-in. or No. 4	2.79	3.71	2.79			4.29
No. 8 or 10	2.59	4.15	2.59	2.50	2.38	3.94
No. 20 or 30		2.48				3.80
No. 40 or 50		1.93		1.29	1.16	2.30
No. 80 or 100	1.08		1.08			1.23
No. 200	0.63	0.96	0.63	0.41	0.42	1.03

*Results from solvent extraction samples. 1 in. = 25.4 mm

Table 10. Typical aggregate gradation variability from extraction tests.[18]

Agency	Date	Sieve Size								
		3/8-in. or 1/2-in.	3/8-in.	1/4-in. or No. 4	No. 8 or No. 10	No. 20 or No. 30	No. 40 or No. 50	No. 80 or No. 100	No. 200	No. of Samples
Surface Mixtures										
Bureau of Public Roads[23]	1960	1.4	2.5	3.5	2.8	1.7	1.4	1.0	0.9	
Virginia[24]	1968	—	1.9	3.3	3.2	2.1	1.6	1.2	0.9	
Washington[25]	1993	1.6	2.5	3.0	2.4	—	1.6	—	0.5	81
Arkansas		1.7	2.6	2.8	1.7	1.3	1.3	1.1	0.6	
Pennsylvania[26]	1982	2.3	4.4	3.4	2.5	1.9	1.5	1.2	1.0	49
Kansas (SM-2c)*	1999	1.0	3.2	2.5	1.5	0.7	0.7	0.6	0.6	127 lots
Kansas (SR-2c)*	1999	1.0	3.5	3.1	1.9	0.7	0.6	0.5	0.5	39 lots
Maryland	1999	1.7	2.8	2.8	2.1	1.6	1.4	1.4	1.7	3,604
Maryland	1999	2.3	3.4	3.5	2.6	2.0	1.8	1.3	1.1	281
Binder or Base Mixtures										
Bureau of Public Roads[23]	1964	4.3	4.9	3.9	2.5	2.2	1.7	1.2	0.9	
Indiana		3.8	—	3.0	—	1.3	—	—	0.4	

*Ignition tests.

1 in. = 25.4 mm

Table 11. Asphalt cement content construction variation.[22]

Source of Data	Layer	Std. Deviation
BPR-most variable 1/3 (nine projects)	Surface	0.42
BPR-average 26 projects	Surface	0.28
BPR-least variable 1/3 (nine projects)	Surface	0.17
Eastern State-average 95 projects	Surface	0.25
BPR-average (seven projects)	Base or binder	0.35
Eastern State-average (81 projects)	Binder	0.22
Eastern State-average (223 projects)	Base	0.24
Western State-average batch plant	Surface	0.27
Western State-average drum plant	Surface	0.31
AASHO Road Test-average	Surface	0.18
AASHO Road Test-average	Binder	0.13
Corps of Engineers	Base	0.20
Western State 1/2-in. mixture	Surface	0.24
Western State 3/4-in. mixture	Surface	0.21
Western Airport Authority	Surface	0.42

1 in. =25.4 mm

Table 12. Typical asphalt content variability.[18]

Source	Year	Test	Std. Deviation, %
BPR	1969[23]	Extraction	0.28
Virginia	1968[24]	Extraction	0.25
Virginia	1988[27]	Extraction	0.19
Virginia	1994[28]	Extraction	0.16
Virginia	1994[28]	Nuclear	0.17
WSDOT	1993[25]	Extraction	0.24
Arkansas	1994	Extraction	0.21
PENNDOT	1980[29]	Extraction	0.25
Colorado	1993[30]	Extraction	0.15
NCAT	1994[31]	Nuclear	0.19
NCAT	1994[31]	Centrifuge	0.44
NCAT	1994[31]	Ignition	0.30
Kansas (SM-2c)	1999	Ignition	0.21
Kansas (SR-2c)	1999	Ignition	0.19
Maryland	1999	Ignition	0.19
Maryland	1999	Ignition	0.20

Table 13. Asphalt content variability by plant type and fines control systems – standard deviation.

Mixture Type	Batch/Baghouse	Batch/Wet Wash	Drum/Baghouse	Drum/Wet Wash
Base	0.22	0.21	0.31	0.30
Base w/RAP	0.34	0.22	—	0.38
Binder	0.20	0.17	0.24	0.29
Binder w/RAP	0.23	0.20	0.25	0.20
Surface	0.20	0.17	0.19	0.29

(Reference 18 based on Indiana study.)

Table 14. FMLC Marshall properties variability.

Property	Study Description			
	BPR Study Four States 18 Projects[10]	FHWA Demo 74 17 Projects[32]	AASHO Road Test Surface Course 72 Tests[6]	AASHO Road Test Binder Course 100 Tests[6]
Marshall Stability, lb	283*		125	190
Marshall Flow, 0.01 in.	1.29	1.3	1.22	0.64
Air Voids, Percent	1.00	0.74	0.43	0.52
Voids in Mineral Aggregate		0.60		
Voids Filled with Asphalt			2.21	2.70

1 lb = 4.45 N; 1 in. = 25.4 mm

*Indicates standard deviations for study and project.

Table 15. Standard deviations of volumetric properties from laboratory-compacted mixtures.[18]

Source	Year	Compactor	AV, %	VMA, %	VFA, %
Virginia[27]	1989	Marshall	0.9	0.9	4.1
Virginia[28]	1994	Marshall	0.86	0.7	3.5
FHWA[32]	1991	Marshall	0.7	0.6	—
West Virginia[33]	1989	Marshall	0.5	—	—
Colorado[34]	1993	Texas Gyratory	0.3	0.3	2.7
Colorado[34]	1993	Linear Kneading	1.3	—	—
Colorado[35]	1993	French Plate, 100mm	1.4	—	—
Colorado[35]	1993	French Plate, 50mm	0.7	—	—
FHWA[36]	1994	SHRP Gyratory	0.5	0.4	—
NCHRP[37]	1994	SHRP Gyratory	0.7	0.9	4.2
Kansas (SM-2c)	1999	SHRP Gyratory	0.7	0.4	
Kansas (SR-2c)	1999	SHRP Gyratory	0.6	0.4	
Maryland	1999	Marshall	1.1	1.6	
Maryland	1999	Marshall	1.4	1.6	

Table 16. State projects designed, constructed, and sampled by the NCHRP Project 9-7 (1994).[37]

State	Route	City/ County	Plant Type	Mix Type	Nominal Max.	Binder
Florida	US 301 (SR 43)	Tampa	Drum mixer	DG HMAC with RAP	12.5 mm	PG 64-28
Kentucky #1	IH 64/75	Lexington	Drum mixer	DG HMAC	9.5 mm	PG 70-22
Mississippi	US Highway 61	Bolivar County	Batch	DG HMAC with RAP	12.5 mm	PG 64-22
Texas #1	FM 1604	San Antonio	Batch	DG HMAC	12.5 mm	PG 64-22
Texas #2	FM 1604	San Antonio	Batch	DG HMAC	12.5 mm	PG 64-22
Virginia	Route 7	Leesburg	Drum mixer	DG HMAC	9.5 mm	PG 64-22

1 in. = 25.4 mm

Table 17a. Asphalt content and volumetric standard deviations.[37]

1994 Projects	# of Samples	Gmm	Gmb	Calculated Gse	Air Voids @ N_{init}	Air Voids @ N_{des}	Air Voids @ N_{max}	VMA	VFA	Dust/AC Ratio	AC Absorption	%AC Extracted	%AC Nuc Gauge
FL	8	0.006	0.014	—	1.1	0.8	0.4	0.4	7.5	0.1	0.1	0.31	—
KY	90	0.009	0.016	—	1.2	0.8	0.6	0.6	6.4	0.1	0.1	0.15	0.22
MS	12	0.005	0.013	—	0.4	0.4	0.4	0.4	2.2	0.3	0.0	0.19	—
TX1	21	0.005	0.008	—	0.2	0.4	0.4	0.4	2.4	0.1	0.0	0.13	—
TX2	17	0.006	0.005	—	1.5	0.1	0.1	0.1	0.9	0.0	0.0	0.05	—
VA	39	0.016	0.029	—	1.5	1.5	1.4	1.4	8.6	0.1	0.0	0.34	—
Pooled std. deviation		0.010	0.018	0.000	1.1	0.9	0.8	0.8	6.3	0.1	0.1	0.21	0.22

Table 17b. Cold-feed aggregate standard deviations.[37]

1994 Projects	# of Samples	Cold Feed 19.0 mm	Cold Feed 12.5 mm	Cold Feed 9.5 mm	Cold Feed 4.75 mm	Cold Feed 2.36 mm	Cold Feed 1.18 mm	Cold Feed 0.600 mm	Cold Feed 0.300 mm	Cold Feed 0.150 mm	Cold Feed 0.075 mm
FL	8	—	—	—	—	—	—	—	—	—	—
KY	90	—	—	—	—	—	—	—	—	—	—
MS	12	0.2	1.8	3.1	3.2	2.6	1.9	1.0	0.6	0.4	0.3
TX1	21	—	—	—	—	—	—	—	—	—	—
TX2	17	—	—	—	—	—	—	—	—	—	—
VA	39	0.0	0.2	2.2	3.3	2.5	2.1	1.7	1.2	0.9	0.9
Pooled std. deviation		0.1	0.9	2.4	3.3	2.5	2.1	1.5	1.1	0.8	0.8

Table 17c. Extracted aggregate standard deviations.[37]

1994 Projects	# of Samples	Extracted 37.5 mm	Extracted 25.0 mm	Extracted 19.0 mm	Extracted 12.5 mm	Extracted 9.5 mm	Extracted 4.75 mm	Extracted 2.36 mm	Extracted 1.18 mm	Extracted 0.600 mm	Extracted 0.300 mm	Extracted 0.150 mm	Extracted 0.075 mm
FL	8	0.0	0.0	0.3	1.1	1.5	1.9	1.0	0.8	0.7	0.5	0.2	0.1
KY	90	0.0	0.0	0.0	0.0	1.7	7.2	2.9	2.0	2.7	1.4	0.9	0.6
MS	12	0.0	0.0	0.0	2.2	2.8	2.9	1.6	0.9	0.8	1.3	1.3	1.0
TX1	21	0.0	0.0	0.0	0.6	1.9	3.1	1.9	0.8	0.3	0.2	0.4	0.3
TX2	17	0.0	0.0	0.0	0.7	0.7	1.2	0.9	0.4	0.4	0.3	0.2	0.2
VA	39	0.0	0.0	0.0	0.3	2.4	2.7	2.5	2.0	1.6	1.2	0.9	0.7
Pooled std. deviation		0.0	0.0	0.1	0.7	1.9	5.4	2.5	1.7	2.0	1.2	0.8	0.6

Table 18. State projects designed, constructed, and samples by the NCHRP Project 9-7.[37]

State	Route	City/ County	Plant Type	Mix Type	Nominal Max.	Binder
Alabama #1	SR 165	Russell	Drum	DG HMAC	37.5 mm	PG 76-22
Alabama #2	SR 165	Russell	Drum	DG HMAC	25 mm	PG 76-22
Georgia	—	Marietta	Drum	DG HMAC	12.5 mm	PG 64-22
Kansas	I-70	Salina	Drum	DG HMAC	9.5 mm	PG 70-28
Kentucky #2	SR 676	Frankfort	Drum	DG HMAC	19.0 mm	PG 70-22
Maryland #1	I-68	Hancock	Batch	SMA	12.5 mm	PG 70-22
Maryland #2	US Rt 40A	Grantsville	Drum	DG HMAC	12.5 mm	PG 64-22
WesTrack	—	Silver Springs, NV	Drum	DG HMAC	19.0 mm	PG 64-22

Table 19a. Asphalt content and volumetric standard deviations.[37]

1995 Projects	# of Samples	Gmm	Gmb	Calculated Gse	Air Voids @ N_{init}	Air Voids @ N_{des}	Air Voids @ N_{max}	VMA	VFA	Dust/AC Ratio	AC Absorption	%AC Extracted	%AC Nuc Gauge
AL1	28	0.015	0.015	0.011	1.1	0.8	0.8	0.7	5.9	0.1	0.2	0.40	—
AL2	26	0.017	0.016	0.018	1.0	0.9	0.9	0.6	6.1	0.1	0.3	0.39	—
GA	8	0.004	0.013	0.004	1.0	0.5	0.5	0.5	3.1	0.2	0.0	0.12	—
KS	12	0.009	0.008	—	1.2	0.4	0.3	0.3	3.2	0.1	—	0.20	—
KY2	2	0.006	0.012	—	0.7	0.7	0.7	0.4	4.4	0.1	—	0.16	—
MD1	30	0.009	0.034	0.012	0.7	1.0	1.0	0.5	5.3	0.2	0.1	0.22	0.10
MD2	30	0.006	0.043	0.007	1.0	0.9	0.8	1.0	5.0	0.2	0.1	0.21	0.09
TX3	16	0.011	0.016	0.012	0.8	0.9	0.8	0.5	6.0	0.1	0.2	0.08	—
Pooled std. deviation		0.011	0.025	0.012	1.0	0.9	0.8	0.6	5.3	0.1	0.2	0.27	0.10
94 and 95 pooled std. dev.		0.011	0.022	0.012	1.0	0.9	0.8	0.6	5.8	0.1	0.1	0.24	0.18

Table 19b. Extracted aggregate standard deviations.[37]

1995 Projects	# of Samples	Extracted 37.5 mm	Extracted 25. 0mm	Extracted 19.0 mm	Extracted 12.5 mm	Extracted 9.5 mm	Extracted 4.75 mm	Extracted 2.36 mm	Extracted 1.18 mm	Extracted 0.600 mm	Extracted 0.300 mm	Extracted 0.150 mm	Extracted 0.075 mm
AL1	28	0.0	1.3	3.2	2.5	2.7	3.2	2.6	2.0	1.6	1.3	1.0	0.8
AL2	26	0.0	0.0	0.4	2.0	3.0	3.5	2.2	1.5	1.1	0.7	0.5	0.4
GA	8	0.0	0.0	0.0	1.0	1.7	3.5	3.2	2.6	2.1	1.6	1.2	0.7
KS	12	0.0	0.0	0.0	0.2	0.6	1.5	1.1	0.7	0.4	0.3	0.2	0.2
KY2	22	0.0	0.0	0.0	0.0	1.3	2.3	1.7	1.1	0.9	0.4	0.2	0.2
MD1	30	0.0	0.0	1.1	2.4	2.3	1.3	1.0	1.0	1.0	1.1	1.1	1.6
MD2	30	0.0	0.0	0.0	1.2	2.0	2.8	1.6	1.1	0.9	0.9	0.9	0.9
TX3	16	0.0	0.0	0.0	1.0	1.7	2.8	1.7	0.9	0.5	0.4	0.3	0.2
Pooled std. deviation		0.0	0.5	1.4	1.7	2.2	2.7	1.9	1.4	1.1	0.9	0.8	0.9
94 and 95 pooled std. dev.		0.0	0.4	1.0	1.3	2.1	4.3	2.2	1.6	1.7	1.1	0.8	0.7

Table 20. Mix design and production characteristics for I-75, Columbia Co., Florida.[38]

Mix Characteristics	12.5 mm Mix			19.0 mm Mix		
	Design Values	Production Average	Production Standard Deviation	Design Values	Production Average	Production Standard Deviation
Number of tests		40			65	
25.0 mm	100	100.00	0.00	100	100.00	0.00
19.0 mm	100	99.96	0.18	98	98.05	1.40
12.5 mm	98	98.95	0.54	89	90.17	2.88
9.5 mm	89	89.76	1.92	84	83.04	6.22
4.75 mm	47	46.94	3.14	41	41.00	3.17
2.00 mm	27	27.65	1.83	21	21.44	3.43
425 µm	16	16.99	1.11	13	13.97	0.96
180 µm	10	10.27	0.89	8	8.81	0.57
75 µm	4.0	4.52	0.61	4.0	4.61	0.43
AC, %	5.7	5.64	0.24	4.9	4.93	0.34
Gmb @ N_{design}	2.367	2.380	0.021	2.413	2.388	0.040
Lab Density, kg/m^3	2367	2380	21	2413	2388	40
Gmm	2.470	2.470	0.011	2.514	2.508	0.014
Air Voids, %	4.2	3.75	1.04	4.0	4.77	1.76
VMA, %	14.4	13.87	0.64	13.2	14.33	1.52
VFA, %	70.8	73.17	6.36	69.7	67.35	8.40
Effective AC, %	4.4	4.38	0.25	3.93	4.12	0.32
Dust to Eff. AC Ratio	0.91	1.03	0.15	1.02	1.12	0.12
Gmm @ $N_{initial}$, %	85.3	86.13	1.03	85.6	84.7	1.29
Gmm @ N_{design}, %	95.8	96.25	1.04	96.0	95.2	1.76
Gmm @ N_{max}, %	97.4	97.78	1.02	97.4	96.9	1.43

Table 21. Mix design and production characteristics for I-10, Columbia Co., Florida.[38]

Mix Characteristics	12.5 mm Mix			19.0 mm Mix		
	Design Values	Production Average	Production Standard Deviation	Design Values	Production Average	Production Standard Deviation
Number of tests		19			35	
25.0 mm	100	100.00	0.00	100	100.00	0.00
19.0 mm	100	100.00	0.00	98	98.48	0.89
12.5 mm	98	98.19	0.61	89	89.12	4.54
9.5 mm	89	86.74	2.47	82	82.30	3.24
4.75 mm	45	46.26	3.45	39	41.61	2.98
2.36 mm	29	28.53	1.43	24	23.37	1.58
1.18 mm	23	22.59	0.96	18	18.57	1.25
600 µm	19	18.51	0.77	15	15.49	1.17
300 µm	13	14.45	0.62	11	12.20	1.04
150 µm	8	8.58	0.47	8	7.61	0.86
75 µm	4.2	4.81	0.36	4.0	4.64	0.75
AC, %	5.3	5.39	0.15	5.2	5.35	0.35
Gmb @ N_{design}	2.374	2.378	0.011	2.409	2.398	0.029
Lab Density, kg/m^3	2374	2378	11	2409	2398	29
Gmm	2.473	2.473	0.007	2.505	2.492	0.022
Air Voids, %	4.0	3.87	0.66	3.8	3.79	1.09
VMA, %	14.0	13.89	0.34	13.1	13.64	1.16
VFA, %	71.4	72.21	4.20	71.0	72.40	7.21
Effective AC, %	4.3	4.34	0.17	4.0	4.23	0.49
Dust to Eff. AC Ratio	1.0	1.11	0.09	1.0	1.11	0.20
Gmm @ $N_{initial}$, %	86.1	85.5	0.73	84.6	84.97	0.97
Gmm @ N_{design}, %	96.0	96.1	0.66	96.2	96.21	1.09
Gmm @ N_{max}, %	97.5	97.7	0.64	97.8	97.85	1.04

Table 22. Mix design and production characteristics for I-10, Suwannee Co., Florida.[38]

Mix Characteristics	12.5 mm Mix			19.0 mm Mix		
	Design Values	Production Average	Production Standard Deviation	Design Values	Production Average	Production Standard Deviation
Number of tests		29			26	
25.0 mm	100	100.00	0.00	100	100.00	0.00
19.0 mm	100	100.00	0.00	98	98.05	0.97
12.5 mm	98	98.42	0.38	89	88.37	2.31
9.5 mm	89	87.24	1.57	82	80.73	4.29
4.75 mm	45	46.19	2.35	39	39.80	2.86
2.36 mm	29	29.07	1.10	24	22.91	1.31
1.18 mm	23	23.11	0.69	18	17.98	0.87
600 µm	19	18.95	0.61	15	15.27	0.80
300 µm	13	14.50	0.72	11	12.17	0.66
150 µm	8	8.69	0.39	8	7.84	0.52
75 µm	4.2	4.76	0.31	4.0	4.91	0.43
AC, %	5.3	5.35	0.19	5.2	5.33	0.16
Gmb @ N_{design}	2.374	2.373	0.014	2.409	2.403	0.018
Lab Density, kg/m^3	2374	2373	14	2409	2403	18
Gmm	2.473	2.476	0.008	2.505	2.498	0.007
Air Voids, %	4.0	4.20	0.72	3.8	3.79	0.81
VMA, %	14.0	14.06	0.45	13.1	13.44	0.63
VFA, %	71.4	70.25	4.42	71.0	71.97	4.91
Effective AC, %	4.3	4.28	0.10	4.0	4.13	0.15
Dust to Eff. AC Ratio	1.0	1.12	0.18	1.0	1.19	0.12
Gmm @ $N_{initial}$, %	86.1	85.4	0.68	84.6	84.75	0.65
Gmm @ N_{design}, %	96.0	95.8	0.72	96.2	96.21	0.81
Gmm @ N_{max}, %	97.5	97.4	0.70	97.8	97.93	0.80

Table 23. Indiana construction variability Superpave gyratory compaction.[39]

Location	Air Voids			VMA		
	X	SD	n	X	SD	n
US 41 (19 mm)	4.2	0.6	26	14	0.5	26
US 41 (19 mm)	4.2	0.7	14	15	0.6	14
US 231 (19 mm)	4.2	0.4	6	14	0.3	6
US 231 (19 mm)	4.7	0.1	5	17	0.4	5
I 69 (19 mm)	4.4	0.8	18	14	0.8	18
I 69 (9.5 mm)	4.6	0.5	5	16	0.4	5
I 74 (19 mm)	4.2	0.6	28	13	0.4	28
I 74 (9.5 mm)	4	0.6	11	16	0.3	11
I 64 (25 mm)	4.1	0.4	17	13	0.4	17
I 64 (19 mm)	3.7	0.5	11	14	0.3	38
I 69 (19 mm)	3.5	1.2	38	14	1.3	38
I 69 (9.5 mm)	4.5	2.0	9	16.0	1.2	9

Table 24. HMA temperature variability.

Location of Measurement	Standard Deviation, °F (Four Projects, 180-190 measurements)*	Standard Deviation, °F (Ten projects)
Plant	11	—
Paver	21	15
On roadway prior to breakdown rolling	19	—

°F = 1.8(°C) + 32

Based on results of four projects with 180 to 190 measurements in Indiana.

*References 40 and 41.

Table 25. AASHO Road Test, report 2 asphaltic concrete compaction data.[6]

Loop	Laboratory Data				Field Data								
	Max. Lab. Density (pcf)	Voids (%)		No. Tests	Density (pcf)		Voids (% tot. vol.)		Voids (% filled)		% Max. Lab. Den.		Tests Within Spec.[1] (%)
		Tot. Val.	Filled		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
(a) Binder Course													
1	152.7	5.35	65.3	64	148.7	1.45	7.84	0.87	55.8	3.16	97.3	0.98	92.2
2	153.9	4.63	68.7	12	148.6	0.67	7.92	0.42	55.3	1.43	96.5	0.41	100.0
3	153.6	4.69	68.4	86	148.5	1.52	7.90	0.94	55.6	3.48	96.6	0.97	74.1
4	153.2	4.94	67.5	128	149.5	1.49	7.31	0.87	58.0	3.35	97.5	0.84	97.7
5	153.4	4.95	67.0	128	148.5	1.38	8.02	0.88	54.9	3.24	96.8	0.89	85.2
6	153.6	4.77	68.0	192	149.3	1.77	7.46	1.09	57.2	3.84	97.2	1.07	88.0
All	153.4	4.87	67.6	609	149.0	1.60	7.66	0.99	56.5	3.49	96.9	1.00	88.2
(b) Surface Course													
1	151.2	3.64	77.6	64	144.4	2.52	8.00	1.61	60.4	4.89	95.5	1.68	50.0
2	150.8	40.7	75.0	44	145.3	2.41	7.58	1.52	61.2	4.88	96.3	1.45	68.2
3	151.8	3.56	77.7	84	147.4	2.33	6.32	1.43	66.1	5.36	97.2	1.57	81.0
4	152.1	2.93	81.5	84	147.8	1.70	5.68	1.05	69.0	4.15	97.2	1.06	91.7
5	151.3	3.67	77.2	84	146.7	1.92	6.60	1.09	64.9	3.87	97.0	1.16	83.3
6	151.3	3.81	76.3	84	148.2	1.31	5.76	0.82	67.7	3.18	98.0	0.85	98.8
All	151.5	3.57	77.8	443	146.8	2.40	6.51	1.49	65.4	5.29	97.0	1.50	81.1

1 pcf = 1 lb/ft ^{3} = 16.0 kg/m ^{3}

[1]Specifications not less than 96 percent of maximum laboratory density.
Void computations based on apparent specific gravity of aggregates, AASHO Designation: T 84-57 and T 85-45.

Table 26. In-place density variation.[22]

Source of Data	Layer	Std. Deviation
BPR - % of theoretical max, 15 projects	Surface core	1.57
BPR - % of theoretical max, three projects	Base core	2.90
BPR - % of Marshall, 12 projects	Surface	1.53
AASHO Road Test - %	Surface	1.50
AASHO Road Test - %	Binder	1.00
State Highway Department - %		1.51
Western State (0.50-in.) - lb/ft^3	Surface	1.92
Western State (0.75-in.) - lb/ft^3	Surface	2.03
Western Airport Authority - % of Marshall, 14 projects	Surface	1.23

1 in. = 25.4 mm; 1 lb/ft^3 = 16.0 kg/m^3

Table 27. Standard deviation of air voids for roadway compacted mixtures.[18]

Source	Year	Method	AV, %
Caltrans[42]	1995	Cores	1.9
WSDOT[25]	1993	Nuclear	0.9
Virginia[43]	1984	Cores	1.3
New Jersey[44]	1995	Cores	1.5
Ontario[45]	1995	Cores	1.6
Colorado[30]	1993	Cores	1.0
Kansas	1999	Nuclear	0.8
Kansas	1999	Nuclear	0.3

Table 28. Average standard deviations for HMA pavement thickness.

State	Design Thickness	Average Thickness	Standard Deviation	COV, %
BPR[10]			0.26	
New Jersey[46]	Surface, 1.5-in.	1.73	0.26	15.0
New Jersey[46]	Surface/binder, 2-in.	2.25	0.33	14.7
New Jersey[46]	Surface/binder, 3-in.	3.37	0.42	12.5
New Jersey[46]	Base, 4-in.	4.00	0.56	14.0
New Jersey[46]	Base, 6-in.	5.99	0.56	9.3
Virginia[18]	Overlay, 1.5-in.		0.40	
AASHO Road Test[6]	New construction		0.13	

1 in. = 25.4 mm

Table 29. Smoothness variability.[18]

Study	Equipment	Standard Deviation	
NCHRP Project 20-7, Task 53	Computerized profilographs	0.5- to 1.0-in./mi	
FHWA Central Federal Lands Highway Division[38]	California-type profilograph Hand reduced data	Smooth ---------- - Rough	1.7- to 2.4-in./mi
FHWA Western Federal Lands Highway Division	California-type profilograph new dense grade HMA	1.9-in./mi	
FHWA Western Federal Lands Highway Division	California-type profilograph overlay	2.2-in./mi	
Center for Transportation Research, University of Texas	Ames-California-type and McCracken-California-type profilograph	0.2- to 1.6-in./mi*	
ERES Consultants	Mays meter	2.1-in./mi	

1 in./mi = 0.0158 m/km

*Average of two results.

Table 30. Typical construction variability - standard deviation.

Property	Typical Variability	
	Representative Range	Representative Value
A. Asphalt content	0.15-0.45	0.30
B. Sieve analysis 3/4-in.	1.5-4.0	2.7
1/2-in.	1.5-4.0	2.7
3/8-in.	2.0-4.5	3.3
No. 4	2.5-4.0	3.3
No. 8 and No. 10	2.0-3.5	2.8
No. 16		
No. 30	1.5-3.5	2.0
No. 50	1.2-1.9	1.5
No. 100	1.0-1.4	1.1
No. 200	0.5-1.5	0.9
C. Marshall properties stability	150-400	275
Flow	1.5-4.0	3.0
Air voids	0.3-1.2	0.7
D. In-place air voids	1.0-2.5	1.5

1 in. = 25.4 mm

Guide Performance–Related Specification for WesTrack

U.S. Department of Transportation
Federal Highway Administration

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WesTrack Report UNR-30
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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling, and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000 lb) equivalent single-axle loads ESALs were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report provides a summary of the information used to develop the "WesTrack Guide Specification" that is contained within the Performance-Related Specifications Software developed in the WesTrack project. The "WesTrack Guide Specification" was developed with background provided by references 4 through 28 and the NCHRP 9-20 Panel's specific guidance to use the guide specification resulting from NCHRP Project 9-7.[16] The first author's experience as a team member for the development of three State quality control/quality assurance (QC/QA) specifications also was used in the development of the "WesTrack Guide Specification."

BACKGROUND

A review of existing QC/QA specifications (references 4 to 20) indicates that a wide variety of methods are used to describe the workings of the specification. This specification has attempted to simplify the QC/QA specification formats currently used, while providing the basic elements of this type of specification.

This specification was developed based on several basic assumptions and decisions made by the authors:

- AASHTO test methods and specifications are used wherever possible.
- ASTM test methods and specifications are used when AASHTO methods are not available.
- A quality control plan is required with minimum sampling and testing requirements.
- All personnel performing the sampling, testing, and inspection must be certified.
- All testing must be performed in an accredited laboratory.
- Recycled asphalt pavement is allowed in the HMA.
- Baghouse fines can be reintroduced into the HMA.

- A construction section is included in the specification.
- Superpave mixture design methods are utilized.
- Multiple mixture designs can be used on a project.
- The laboratory mixture design is approved based on a paper review of information.
- The field trial section information provides the mixture design for the project.
- Multiple Job Mix Formulas can be used on a project.
- QC/QA sampling, testing, and pay are based on lots/sublots.
- An HMA lot is 2,000 tons, regardless of the number of days required to produce the tonnage.
- An HMA sublot is 400 tons (5 sublots per lot).
- Sampling is performed by the contractor and witnessed by the engineer.
- The contractor is responsible for QC testing.
- The engineer is responsible for QA testing and testing for pay.
- QC/QA sampling and testing are included for the asphalt binder, aggregate, HMA, and ride quality.
- Statistical QC/QA techniques are utilized for sampling, quality control charts, comparison of data sets, and determination of percent within limits (PWL).
- HMA production is separated from HMA placement for QC testing, QA testing, and acceptance.
- Acceptance is based on QC and QA tests.
- Pay adjustment factors are used for the asphalt binder, the HMA, and ride quality.
- Pay adjustment factors for HMA are based on WesTrack performance models for rutting and fatigue.

KEY SECTIONS

The sections and first order subsections of the specification are shown in figure 1. The section titles are listed below.

- 1.0 Introduction
- 2.0 Materials
- 3.0 Construction
- 4.0 Mixture Design
- 5.0 Job Mix Formula
- 6.0 Lot and Sublot
- 7.0 Quality Control
- 8.0 Quality Assurance
- 9.0 Acceptance
- 10.0 Measurement
- 11.0 Pay Adjustment Factor and Payment

The sections of the specification and their interaction that control the acceptance activities are shown in figure 2. Both QC and QA testing are used to control the quality of the project. The specification will not allow for more than 3 consecutive days of pay adjustment factors below 1.00.

INTRODUCTION

The “Introduction” section of the specification defines the material, its use, and the scope of the specification. Relevant documents are identified, as is terminology associated with the specification. Requirements for personnel (certification) and laboratories (accreditation) are

defined. Sampling and testing standards and the required QC plan are defined in this section of the specification.

MATERIALS

The "Materials" section of the specification defines the requirements for the asphalt binder, aggregate, mineral filler, lime, baghouse fines, and recycled asphalt pavement.

CONSTRUCTION

The "Construction" section of the specification describes the materials handling requirements, mixing plant requirements, hauling equipment, and the laydown and compaction operations. General restrictions on placement of the HMA also are included in the specification. The equipment section has been included as it is typically included in current State highway agency specifications.

MIXTURE DESIGN

The "Mixture Design" section of the specification defines the material and mixture design requirements. The HMA mixture design is performed by the contractor and approved by the engineer. The approval process includes the engineer performing tests on the asphalt binder and aggregate and a "paper" review of the submitted laboratory-mixed, laboratory-compacted mix (LMLC) design submitted by the contractor.

The engineer does a complete set of tests on the field-mixed, laboratory-compacted (FMLC) samples obtained from the trial field section placed by the contractor. New mixture designs can be developed as frequently as necessary to produce a quality HMA pavement. New mixture designs are required with a change in asphalt binder source or grade and with a change in aggregate source or with aggregate variability.

JOB MIX FORMULA

The "Job Mix Formula" section of the specification defines the process of developing the Job Mix Formula to be used on the project. Multiple Job Mix Formulas can be developed for a project to ensure that a quality HMA is produced. Job Mix Formula adjustments can be made during the construction of the project.

LOT AND SUBLOT

The "Lot and Sublot" section of the specification defines the lot and sublot size for asphalt binder sampling and testing, aggregate sampling and testing, HMA sampling and testing for production, and placement and ride quality determination. The sublot size for asphalt binder and aggregate is a production day for HMA. Five production days form a lot for the asphalt binder and aggregate.

An HMA lot is defined as 2,000 tons, regardless of the number of days required to produce the HMA. Five sublots, each 400 tons, form a lot.

QUALITY CONTROL

The "Quality Control" section of the specification defines the QC sampling and testing requirements for the contractor. Sampling and testing is required for the asphalt binder, aggregate, HMA production, HMA placement, and ride quality as shown in figure 2. Statistical QC charts are used, as well as statistical comparison techniques (QC tests versus QA tests).

QUALITY ASSURANCE

The "Quality Assurance" section of the specification defines the QA sampling and testing requirements for the engineer. Testing is required for the asphalt binder, aggregate, HMA production, HMA placement, and ride quality as shown in table 2. Referee testing is also identified in this section of the specification.

ACCEPTANCE

The "Acceptance" section of the specification defines the acceptance procedure for the engineer. Both QC and QA test results are required for acceptance. Mat irregularities and individual loads of HMA are addressed in this section of the specification. Acceptance programs are described for asphalt binders, aggregate, HMA, and ride quality.

MEASUREMENT, PAY ADJUSTMENT FACTORS, AND PAYMENT

The "Measurement, Pay Adjustment Factors, and Payment" section of the specification defines the procedure to be used by the engineer to determine payment for the HMA. Separate pay adjustments are made for asphalt binder, HMA, and ride quality.

The HMA pay adjustment factors are based on performance of fine and coarse graded Superpave mixtures at WesTrack. Different pay adjustment factors are used for fine and coarse graded mixtures. Fine graded mixtures are those with gradations that are above the lower limits of the restricted zone. Coarse graded mixtures are those with gradations below the lower limits of the restricted zone.

The HMA is paid for on a per ton basis. If lightweight aggregates are used, payment programs on a volume basis will have to be developed by the State highway agency.

COMMENTS

ACCEPTANCE TOLERANCES FOR MIX DESIGN, QC AND QA TESTING

The requirements for "field trial section" mixture acceptance based on Job Mix Formula 1 and the tolerances shown in tables 1 and 2 (tables 15 and 16 of the specification) are based on NCHRP Project 9-7 recommendations.[16] These limits are too restrictive and cannot be met on most projects. These same tolerances also are used in the QC/QA plans for control and acceptance purposes. Based on field construction variability information presented in reference 29, the limits are very restrictive and will not be accepted by State highway agencies and by contractors.

SUPERPAVE ASPHALT BINDERS AND MIXTURE DESIGN

The latest approved specifications for Superpave Performance-Graded Binders and the Superpave Volumetric Mixture Design have been used in this specification. Additional changes to these specifications are expected in the near future and should be incorporated as part of the specification.

QC/QA TESTING AND SAMPLING

Tables 3 and 4 (tables 18 and 19 of the specification) contain a summary of the QC/QA sampling and testing requirements for asphalt binders and aggregates. Tables 5 and 6 (tables 20 and 21 of the specification) contain a summary of the QC/QA sampling and testing requirements for HMA production and placement. In general, the frequency of testing is reduced for the QA testing as compared to the QC testing. The test results used for determining pay adjustment factors (with the exception of gyratory compacted air voids) are those used for QA purposes.

In-place air voids determined from cores are used for QA and pay adjustment factor determination for HMA placement. Nuclear or other approved methods may be used for QC purposes.

ASPHALT BINDERS

Table 7 (table 22 of the specification), which defines the acceptable difference between contractor and engineer test results for asphalt binders, was obtained from the Utah Department of Transportation. This table is expected to be revised by the Utah Department of Transportation prior to the Year 2000 construction season.

Table 8 (table 24 of the specification), which defines pay adjustment factors for asphalt binders, was obtained from the Utah Department of Transportation. This table is also expected to be revised by the Utah Department of Transportation prior to the Year 2000 construction season.

AGGREGATES

Table 9 (table 23 of the specification), which defines the acceptable difference between contractor and engineer test results for aggregates, was developed from AASHTO and ASTM precision and bias statements for the test methods listed in the table. The acceptable difference for the flat and elongated particles was estimated by the authors.

SPECIFICATION

A draft of the guide specification developed in the WesTrack project is provided in appendix A.

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Figure 1. HMA QC/QA guide specification section designations.

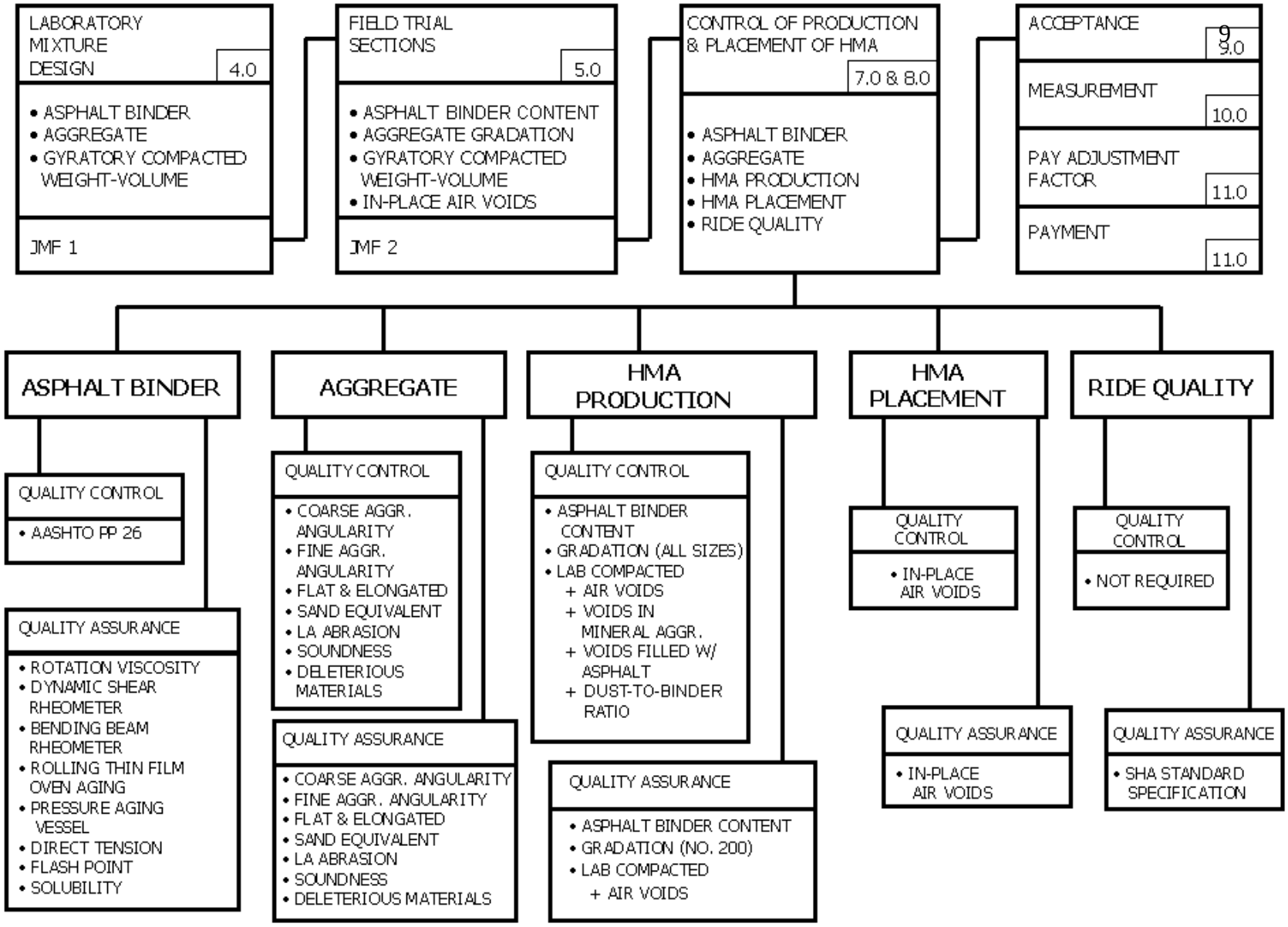


Figure 2. HMA control and acceptance activities.

Table 1. Aggregate gradation and asphalt binder content tolerances for field trial section acceptance.

Sieve Size*		Tolerance, Percent by Mass
U.S. Customary	Metric, mm	
2.0-in.	50	± 3.0
1.5-in.	37.5	± 3.0
1-in.	25	± 3.0
3/4-in.	19	± 3.0
1/2-in.	12.5	± 3.0
3/8-in.	9.5	± 3.0
No. 4	4.75	± 3.0
No. 8	2.36	± 2.0
No. 16	1.18	± 2.0
No. 30	0.600	± 2.0
No. 50	0.300	± 2.0
No. 100	0.150	± 2.0
No. 200	0.075	± 0.7
Asphalt binder content,** percent by mass		± 0.13

*The gradation (AASHTO T27) shall be determined after the asphalt content is determined by the Ignition Test (ASTM D6307).
**Asphalt content determined by ASTM D6307 (Ignition Test).

Note: Tolerances based on Job Mix Formula 1.

Table 2. Volumetric tolerances for field trial section acceptance.

Test Method			Tolerances
Description	Number		
	AASHTO	ASTM	
A. Gyratory-compacted sample properties at N_{design}	TP4		
1. Air voids (Va)	T269	D3203	± 1
2. Voids in mineral aggregate (VMA)	PP28		± 1
3. Voids filled with asphalt (VFA)	PP28		± 5
4. Bulk specific gravity (Gmb)	T166	D2726	± 0.022
5. Dust-to-binder ratio	PP28		0.6 to 1.6
6. Theoretical maximum specific gravity (Gmm)	T209	D2041	± 0.015
B. In-place air voids	T269	D3203	2 to 7

Note: Tolerances based on Job Mix Formula 1.

Table 3. Asphalt binder sampling and testing.

Test Method			Contractor's Quality Control Testing*		Engineer's Verification Testing		Engineer's Quality Assurance Testing		Engineer's Pay Factor Testing	
Description	Number		Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency
	AASHTO	ASTM								
Rotational viscometer (original asphalt)		D4402					Feed line**	1 per lot***		
Dynamic shear rheometer (original asphalt)	TP5						Feed line	1 per lot		
Dynamic shear rheometer (RTFO aged)	TP5 T240						Feed line	1 per lot		
Dynamic shear rheometer (PAV aged)	TP5 PP1						Feed line	1 per lot		
Bending beam rheometer (PAV aged)	TP1 PP1						Feed line	1 per lot		
Direct tension (PAV aged)	TP3 PP1						Feed line	1 per lot		
Flash point	T48	D92					Feed line	1 per lot		
Solubility	T44	D2042					Feed line	1 per lot		
Specific gravity	T228	D70								

*Meet requirements of PP26.
**Asphalt binder feed line between contractor's storage tank and plant mixing chamber.

Table 4. Aggregate sampling and testing.

Test Method			Contractor's Quality Control Testing		Engineer's Verification Testing		Engineer's Quality Assurance Testing		Engineer's Pay Factor Testing	
Description	Number		Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency
	AASHTO	ASTM								
Coarse aggregate angularity		D5821	Combined cold feed	1 sample per sublot*			Combined cold feed	1 sample per lot		
Fine aggregate angularity	T304		Combined cold feed	1 sample per sublot			Combined cold feed	1 sample per lot		
Flat and elongated particles		D4791	Combined cold feed	1 sample per sublot			Combined cold feed	1 sample per lot		
Sand equivalent	T176	D2419	Combined cold feed	1 sample per sublot			Combined cold feed	1 sample per lot		
Los Angeles abrasion	T96	C131, C535	Combined cold feed	1 sample per lot			Combined cold feed	1 sample per 3 lots		
Soundness	T104	C88	Combined cold feed	1 sample per lot			Combined cold feed	1 sample per 3 lots		
Deleterious materials	T112	C142	Combined cold feed	1 sample per sublot			Combined cold feed	1 sample per lot		

*Five sublots per lot.

Table 5. Quality control, quality assurance, and pay factor tests for hot-mix asphalt production and placement.

Test Method			Contractor's Quality Control Testing		Engineer's Verification Testing		Engineer's Quality Assurance Testing		Engineer's Pay Factor Testing	
Description	Number		Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency
	AASHTO	ASTM								
Gradation	T27	C136	Behind paver	1 per sublot			Behind paver	1 per sublot	Behind paver	1 per sublot
Asphalt binder content		D6307	Behind paver	1 per sublot			Behind paver	1 per sublot	Behind paver	1 per sublot
Gyratory-compacted sample properties at N_{design}	TP4		Behind paver	1 per sublot			Behind paver	1 per sublot		
Air voids (Va)	T269	D3203		1 per sublot				1 per sublot		
Voids in mineral aggregates (VMA)	PP28			1 per sublot						
Voids filled with asphalt (VFA)	PP28			1 per sublot						
Bulk specific gravity (Gmb)	T166	D2726		1 per sublot				1 per sublot		
Dust-to-binder ratio	PP28			1 per sublot						
Theoretical max. specific gravity (Gmm)	T209	D2041		1 per sublot				1 per sublot		1 per sublot
In-place air voids	T269	D3203	Cores from pavement	2 per sublot			Cores from pavement	2 per sublot	Cores from pavement	2 per sublot

Table 6. Aggregate gradation determination requirements for quality control, quality assurance, and pay factor testing.

Sieve Size		Contractor Quality Control Testing	Engineer's Quality Assurance Testing	Engineer's Pay Factor Testing
U.S. Customary	Metric, mm			
2.0-in.	50			
1.5-in.	37.5			
1-in.	25	X*		
3/4-in.	19	X		
1/2-in.	12.5	X		
3/8-in.	9.5			
No. 4	4.75			
No. 8	2.36	X		X
No. 16	1.18	X		
No. 30	0.600	X		
No. 50	0.300	X		
No. 100	0.150			
No. 200	0.075	X	X	X

*Use gradation control sieves for nominal maximum aggregate specified (19-mm [3/4-in.] nominal maximum size aggregate requirements shown).

Table 7. Acceptable difference between contractor's and engineer's test results for asphalt binders.

Test Method			
Designation	Number		Acceptable Difference*
	AASHTO	ASTM	
Dynamic shear rheometer on original asphalt, G*/sin δ	TP5		20 percent**
Dynamic shear rheometer on RTFOT-aged binder, G*/sin δ	TP5 TP240	D2872	20 percent**
Dynamic shear rheometer on PAV-aged binder, G* sin δ	TP5 PP1		20 percent**
Bending beam rheometer on PAV-aged binder, S value	TP1 PP1		10 percent**
Bending beam rheometer on PAV-aged binder, m value	TP1 PP1		0.015
Fracture strain on PAV-aged binder, fracture strain	TP3 PP1		30 percent

*Based on Utah DOT specification.
**Percent of average value of two test results.

Table 8. Pay adjustment for asphalt binders.

Property	Compliance Limit for Price Adjustment of 1.00	Rejection Limit for Price Adjustment of 0.75
G*/sin δ of the original PGAB at high grade temperature (kPa)	0.84 Min.	0.70 Min.
G*/sin δ of RTFO residue at high grade temperature (kPa)	1.74 Min.	1.40 Min.
Stiffness of the PAV residue at low grade temperature + 10°C (MPa)	311 Max.	355 Max.
Slope (m-value) of the creep curve at low grade temperature +10°C	0.294 Min.	0.265 Min.
Failure strain of PAV residue in direct tension at low grade temperature + 10°C[1]	1.04 Min.	0.78 Min.

[1]Use only for binders for which the test temperature fo the low temperature properties is -18°C or colder.

Table 9. Acceptable difference between contractor's and engineer's test results for aggregates.

Test Method			
Designation	Number		Acceptable Difference*
	AASHTO	ASTM	
Coarse aggregate angularity		D5821	28
Fine aggregate angularity	T304		1
Flat and elongated particles		D4791	3**
Sand equivalent	T176	D2419	9
Los Angeles abrasion	T96	C131, C535	13***
Soundness	T104	C88	70 percent***
Deleterious materials	T112	C142	1.7

*Represents multilaboratory precision for AASHTO or ASTM test methods.
**Estimated.
***Magnesium sulfate, percent of average value of test results.

APPENDIX A

GUIDE SPECIFICATION
FOR
HOT-MIX ASPHALT PAVEMENT MATERIAL
(WESTRACK)

SEPTEMBER 2000

September 2000

GUIDE SPECIFICATION
FOR
HOT-MIX ASPHALT PAVEMENT MATERIAL
AASHTO PP 400

1.0 INTRODUCTION

1.1 DESCRIPTION

A mixture composed of aggregate, asphalt cement with or without mineral filler, modifiers and/or additives, recycled asphalt and baghouse fines which has been designed, mixed at an elevated temperature at a central plant, transported, laid, and compacted in compliance with the lines, grades, thickness and typical cross sections shown on the plans.

1.2 USE

The mixture shall be used as a base course, leveling course or surface course, or any combination of these courses as shown on the plans.

1.3 SCOPE

This specification provides the framework (figures 1 and 2) for a quality control/quality assurance specification for hot-mix asphalt (HMA) pavement material. Included in the specification are requirements for the following:

- Laboratories facilities.
- Laboratory equipment.
- Sampling and testing personnel.
- Sampling, testing methods and testing frequencies for quality control and quality assurance.
- Quality control plans.
- Materials.
- Construction practices.
- Mixture design method.
- Acceptance plan.
- Measurement.
- Pay adjustment factors.
- Payment.

This standard may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this practice to consult and establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.

1.4 REFERENCED DOCUMENTS

Procedures, guides, sampling methods, test methods, and specifications are referenced in this specification.

1.4.1 Quality Control/Quality Assurance

Table 1 contains procedures, guides, specifications, and general references associated with quality control and quality assurance types of specifications.

1.4.2 Asphalt Binder Tests

Table 2 contains sampling methods, test methods, and specifications for asphalt binders.

1.4.3 Aggregate Tests

Table 3 contains sampling methods, test methods and specifications for aggregates used in HMA.

1.4.4 Hot-Mix Asphalt Tests

Table 4 contains sampling methods, test methods, specifications, and mixture design methods for HMA.

1.4.5 Pavement Roughness Measurement

Table 5 contains test methods for measuring pavement roughness.

1.5 TERMINOLOGY

1.5.1 Standard Terminology

Definition of terms common to quality control and quality assurance standards are contained in AASHTO R10.

Definition of many common terms relating to HMA are contained in ASTM D 8.

Definitions of terms used in reference to other standards are as defined therein.

Definition of terms in mathematical expressions are as generally used in standard practice. Unique terms are defined in the section containing the first presentation of such terms.

1.5.2 Definitions

AAP	AASHTO Accreditation Program
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials

HMA	Hot-Mix Asphalt
JMF	Job mix formula
JMF1	Job mix formula number 1 obtained from laboratory mixture design process
JMF2	Job mix formula number 2 obtained from trial field section placed at start of field production of the HMA
JMF3	Job mix formula number 3 defined by contractor and approved by engineer to represent acceptable mixture during production of HMA
JMFi	Job mix formula number i defined by contractor and approved by engineer to represent acceptable mixture during production of HMA
PG	Performance-Graded Asphalt Binder
QA	Quality Assurance
QC	Quality Control
QCP	Quality Control Plan
SHA	State Highway Agency

1.6 LABORATORY, EQUIPMENT AND PERSONNEL

1.6.1 Laboratory

Laboratories (contractor, engineer and referee) performing tests in accordance with these standards shall be currently accredited by the AASHTO Accreditation Program (AAP) for the materials being tested (asphalt binders, aggregates, or HMA). Testing laboratories conducting inspections or tests not covered by the AAP shall comply with the applicable requirements of AASHTO R 18 and ASTM D 3666.

1.6.2 Equipment

All laboratory equipment (contractor, engineer, and referee laboratory) used to perform tests in accordance with these standards shall be calibrated and calibration verified at established intervals by the State Highway Agency according to relevant State Highway Agency standards.

1.6.3 Personnel

All personnel (contractor, State Highway Agency and referee) shall be appropriately qualified through certification procedures established by the State Highway Agency. Certification shall ensure that minimum standards are in place for personnel to obtain samples; process samples; operate necessary equipment; verify equipment accuracy and calibration; interpret test results; and inspect the construction operation. Tables 2 through 5 show

the requirements for certification for individual test methods.

1.7 SAMPLING AND TESTING

1.7.1 Quality Control Sampling and Testing

The contractor shall perform the sampling, testing, inspection, and calibrations as shown in Table 1 and as defined in the quality control plan.

1.7.2 Quality Assurance Sampling and Testing

The engineer will perform the sampling, testing and inspection as shown in Table 1 and as defined in the specification as quality assurance sampling and testing.

1.7.3 Referee Sampling and Testing

This sampling and testing will be performed by a third party mutually agreed upon at the start of the project. The third party sampling and testing group can be the State Highway Agency central laboratory or a commercial laboratory which has the proper certifications and accreditations.

1.7.4 Independent Assurance Program

An unbiased and independent evaluation of all sampling and testing used in the acceptance program shall be performed by the State Highway Agency in conformance with Federal Highway Administration policies.

1.8 QUALITY CONTROL PLAN

1.8.1 General

The contractor shall maintain a quality control system that is based on an established Quality Control Plan. The Quality Control Plan shall be prepared by the contractor and will be approved by the engineer. The Quality Control Plan shall be a written document covering all personnel, equipment, supplies, and facilities necessary to obtain samples, perform and document tests, and otherwise ensure the quality of the product.

A draft, written Quality Control Plan for this specification item shall be presented at the Preconstruction Conference for the project. The contractor proposed Quality Control Plan for this specification item shall be submitted to the engineer for approval at least 10 working days before the start of HMA production. The engineer will accept or reject the Quality Control Plan within 5 working days of submittal.

The Quality Control Plan shall reference the following standards for qualification, control, and guidelines (Table 1).

AASHTO R 4	Statistical Procedures
AASHTO R 9	Acceptance Sampling Plans for Highway Construction
AASHTO R 10	Definition of Terms for Specifications and Procedures
AASHTO R 11	Using Significant Digits in Test Data to Determine Conformance with Specifications
AASHTO R 18	Establishing and Implementing a Quality System for Construction Materials Testing Laboratories
ASTM D 3666	Minimum Requirements for Agencies Testing and Inspecting Bituminous Paving Materials

The Quality Control Plan's administration, including compliance with the Plan and its modifications, is the responsibility of the contractor. The Quality Control Plan can be wholly performed by the contractor or, wholly or in part, by an independent organization under contract to the contractor.

The engineer will make no partial payments for materials that are subject to specific quality control requirements without an approved Quality Control Plan.

1.8.2 Requirements of Quality Control Plan

The Quality Control Plan shall, as a minimum, address the items contained in AASHTO R 18 and ASTM D 3666 as briefly summarized below.

1.8.2.1 Personnel

The Quality Control Plan shall provide an organization chart defining the area of responsibility and authority of each individual. This organization chart shall show all quality control personnel by name, function and experience, and how these individuals integrate with other management,
production and construction functions, and workforce.

The names and qualification of personnel shall be provided in the Quality Control Plan. The plan will

indicate the total staff required to implement all elements of the quality control programs, including inspection, testing and reporting functions.

If an outside organization or an independent laboratory is used for implementation of all or part of the Quality Control Plan, the personnel assigned are subject to the qualification requirements of this section. The Quality Control Plan shall indicate on the organization chart which personnel are contractor employees and which are provided by an outside organization and define the lines of reporting.

The Quality Control Manager shall be defined in the Quality Control Plan and is responsible for the successful operation of the plan to ensure compliance with the specifications. The Quality Control Manager reports directly to a responsible officer in the contractor's organization.

Quality Control Technicians shall be certified as defined in Section 1.6.3 and as shown in Tables 2 through 5 of this specification and shall perform the following functions:

- Inspect all plant equipment used in proportioning and mixing to ensure proper calibration and operating condition.
- Perform quality control tests necessary to adjust and control mix proportioning in accordance with the job mix formula.
- Inspect all equipment used in placing, finishing, and compacting material to ensure proper operating condition.
- Inspect during construction to ensure placing, joint construction, and compaction are in conformance with the specifications.
- Perform all quality control testing as required in this specification.
- Detail the criteria to be utilized to correct unsatisfactory production processes and construction practices.
- Perform all reporting required in the specification.

The Quality Control Manager and Quality Control Technicians shall by their actions address all

elements that affect the quality of the HMA including:

- HMA mixture design.
- Aggregate gradation.
- Quality of materials.
- Aggregate stockpile management.
- Proportioning of HMA.
- Mixing of materials.
- Storage of materials.
- Transportation of materials.
- Placing, compaction and finishing (joints, in-place density, smoothness, segregation, etc.).
- Sampling and testing.

1.8.2.2 Quality Control Testing Laboratory

The Quality Control Testing Laboratory shall be accredited by the AAP as defined in Section 1.6.1 of these specifications. Testing laboratories conducting inspections or tests not covered by the AAP shall comply with the applicable requirements of AASHTO R 18 and ASTM D 3666.

1.8.2.3 Sampling

Random sampling techniques as defined in ASTM D 3665 and Attachment A to this specification shall be used.

1.8.2.4 Records and Control Charts

The contractor shall record all sampling, testing, and inspection data on forms as defined in the Quality Control Plan. The contractor shall maintain complete testing and inspection records and post all test data in the Quality Control Laboratory within 2 hours of completion of the daily testing as defined in the approved Quality Control Plan.

Mean and range control charts shall be prepared by the contractor and shall be posted on a daily basis. Attachment B contains methods for preparing mean and range control charts.

1.8.2.5 Sample Management

The Quality Control Plan shall contain a description describing procedures for sample identification, storage, retention, and disposal.

1.8.2.6 Internal Quality Assurance System

The Quality Control Plan shall contain a description of the contractor internal quality assurance system. This system shall contain, as a minimum, inspections, the testing of proficiency samples, and other activities as defined in AASHTO R 18.

2.0 MATERIALS

2.1 ASPHALT BINDER

The asphalt binder shall meet the requirements of AASHTO MP 1 (Specification for Performance-Graded Asphalt Binder as shown in Table 6).

2.2 AGGREGATE

The coarse and fine aggregate shall meet the requirements for aggregates as defined in AASHTO MP 2 Specification for Superpave Volumetric Design as shown in Tables 7 through 10.

2.2.1 Coarse Aggregate

Coarse aggregate shall be retained on the 4.75-mm (No. 4) sieve and shall consist of clean, hard durable particles and shall be free from frozen lumps, deleterious matter, and harmful coatings.

2.2.2 Fine Aggregate

Fine aggregate shall be passing the 4.75-mm (No. 4) sieve and shall consist of clean, hard, durable particles and shall be free from frozen lumps, deleterious matter, and harmful coating.

2.3 MINERAL FILLER

Mineral filler shall meet the requirements of AASHTO M 17 or ASTM D 242 (Mineral Filler for Bituminous Paving Mixtures).

2.4 LIME

Hydrated lime shall meet the requirements of AASHTO M 303 or ASTM C 1097 (Lime for Asphalt Mixtures).

2.5 BAGHOUSE FINES

The addition of fines collected by a baghouse in the HMA plant is permitted when a metering system is provided. The baghouse fines shall be considered as part of the aggregate for gradation purposes and gradation compliance.

2.6 RECYCLED ASPHALT PAVEMENT (RAP)

Recycled asphalt pavement (RAP) is defined as salvaged, milled, pulverized, broken or crushed asphalt bound pavement. RAP is allowed in HMA provided all requirements contained in this specification are met.

3.0 CONSTRUCTION

3.1 GENERAL

The contractor shall maintain all equipment for the handling of materials, mixing, and hauling, placing, and compaction of the mixture in good repair and operating condition to produce a quality product.

3.2 STOCKPILING, STORING, FEEDING, AND DRYING MATERIALS

3.2.1 Stockpiling of Aggregate(s)

Prior to stockpiling aggregates the contractor shall clear the area of trash, weeds, and grass. The area shall be relatively smooth and well-drained.

The contractor shall perform stockpiling in a manner that will minimize aggregate degradation, segregation, and/or mixing of one stockpile with another.

The contractor shall not allow foreign material to contaminate the stockpile(s).

The contractor shall separate aggregates proportioned prior to the heating and drying process into a minimum of two sizes, one coarse and one fine. The contractor shall keep all stockpiles separate.

3.2.2 Feeding and Drying of Aggregate

If applicable, the contractor shall feed the various sizes of aggregate through the cold aggregate bins and a proportioning device that will provide a uniform and constant flow of material in the required proportions.

3.2.3 RAP Feed System

If RAP is used, the contractor shall introduce the RAP through a separate cold feed bin that has adequate controls to provide a uniform and consistent flow of material in the required proportion.

3.2.4 Storing and Heating Asphalt Binders

The contractor shall equip tanks for the storage of asphalt binders for heating and holding the asphalt binder at the required temperatures.

The contractor shall keep all equipment in a clean condition at all times and operate it in such a manner that there shall be no contamination with foreign material.

The contractor shall store asphalt binder in tanks separate and apart from the dryer burner fuel. Tanks with separate compartments that (1) may be used to store two or more products in a single enclosure or

casing, and (2) that share any common components (bulkheads, heating coils, valves, etc.) that would allow either product to contaminate the other, will not be permitted for asphalt cement storage unless all of the compartments are filled with the same product.

The contractor shall equip the heating apparatus with a continuous recording thermometer with a 24-hour chart that shall record the temperature of the asphalt binder at the location of the highest temperature. This thermometer shall be in operation during production of the HMA.

The temperature of the asphalt binder just prior to mixing shall be that defined by AASHTO PP 28 for laboratory preparation of HMA samples.

When modified asphalt binders are used, the material shall be stored and maintained in storage tanks as recommended by the supplier.

The contractor shall equip tanks to allow for measuring the quantities of asphalt binder remaining in the tank.

The circulating system shall provide proper and continuous circulation during the operating period.

The contractor shall provide a sampling port in the feed line between the asphalt binder plant storage tank and the mixing chamber.

3.2.5 Feeding Mineral Filler and Baghouse Fines

Mineral filler and/or baghouse fines shall be drawn from a storage facility in which the mineral filler is agitated by air or other means to keep it in a uniform free flowing condition. The mineral filler and/or baghouse fines shall be delivered to the mixer from a vane type metering device which is interlocked (electric driven feeders shall be actuated from the same circuit) to the flow of each aggregate feeder. The drive shaft on the vane feeder for the mineral filler, baghouse fines or both shall be equipped with a revolution counter reading to one-tenth (1/10) of a revolution and a means for varying the rate.

3.2.6 Modifiers/Additives

All storage and feeding systems for modifiers and additives must be approved by the engineer.

3.3 MIXING PLANTS

The contractor shall use mixing plants of either the weigh-batch, continuous mixing (proportioning

after drying), continuous mixing (proportioning before drying), or drum mixing type.

3.3.1 Burner Fuel and Burner

The contractor shall limit fuel used for heating aggregates to the following types: natural gas, liquefied natural gas, fuel oil (ASTM D 396, grades No. 1 and No. 2), butane, propane, and diesel fuel oil (ASTM D 975, grades No. 1-D and No. 2-D).

The contractor shall certify that burner fuels comply with the above requirements.

The contractor shall ensure that the burner used for heating the aggregate shall achieve complete combustion of the approved fuel and not leave any fuel residue that will adhere to the heated aggregate.

3.3.2 Requirements for All Plants

The contractor shall install and maintain adequate equipment and take necessary precautions to meet applicable federal, state, and local government air quality and water quality regulations.

The contractor shall install or have available platform scales to determine the weights of HMA and hauling vehicles.

The contractor shall provide adequate and safe access to the top of the truck bodies by a platform or other suitable access ports in the truck bodies to enable the engineer to obtain the mix temperature.

The contractor shall provide adequate and safe equipment at the plant to afford access for plant operation, maintenance, sampling, and calibration.

The contractor shall calibrate the plant in accordance with the Quality Control Plan.

3.3.3 Batch Plant

The contractor shall use a fully automated and computerized batch plant.

The contractor shall provide a twin shaft pugmill-type batch mixer that is steam-jacketed or heated by other approved methods and operated to produce a uniform mixture.

The contractor shall equip the mixer with an accurate time lock to control the operations of a complete mixing cycle with an accuracy of 2 sec.

3.3.4 Continuous Mixing Plants (Proportioned After Drying, Proportioned Before Drying, Drum Mixer)

The contractor shall provide a fully automated and computerized plant with satisfactory means to provide a positive interlocking control between the flow of each feeder and the flow of the asphalt binder, mineral filler, and baghouse fines.

The contractor shall provide the plant with a continuous mixer, adequately heated and operated to produce a uniform mixture with a uniform coating of asphalt binder on the aggregate at the discharge.

3.4 SURGE-STORAGE SYSTEM

3.4.1 Capacity

The contractor shall equip all continuous and drum mixer plants with a surge-storage system having a capacity in excess of 18 Mg (20 tons).

3.4.2 Segregation

The contractor shall equip the surge-storage system with an approved surge batcher or other approved method that will prevent segregation of the HMA as it is being stored or discharged into the hauling vehicle.

3.4.3 Storage

Temporary storage or holding of HMA during the production day will be allowed. Storage for periods exceeding 24 hours will not be permitted unless authorized.

3.5 HAULING EQUIPMENT

3.5.1 Trucks

The contractor shall use trucks for hauling HMA with tight, clean, smooth metal beds which have been thinly coated with a minimum amount of lime solution or other approved release agent to prevent the mixture from adhering to the truck beds. The contractor shall not use diesel or kerosene as a release agent.

3.5.2 Discharge Into Hauling Vehicles

The contractor shall discharge the HMA from the surge-storage system directly into the hauling vehicle.

3.6 SURFACE PREPARATION

3.6.1 Utilities and Drainage Structure

The contractor shall locate, reference, and protect all utility covers, monuments, curbs and gutters, and other items affected by the paving operations.

3.6.2 Objectionable Material

The contractor shall remove all dirt, sand, leaves, and other objectionable material from the prepared surface before placing the HMA.

3.7 PLACING

3.7.1 Equipment

When the HMA is being produced by more than one HMA mixing plant, the contractor shall place the material produced by each plant with separate spreading and compacting equipment.

The contractor shall dump and spread the HMA on the prepared surface with the spreading and finishing machine.

If windrow pick-up equipment is used, the contractor will provide equipment capable of removing and loading substantially all of the mixture deposited on the roadbed into the spreading and finishing machine.

The contractor shall use bituminous pavers that are self-contained, power-propelled units, provided with an activated screed or strike-off assembly, heated if necessary, and capable of spreading and finishing courses of HMA in lane and shoulder widths applicable to the specified typical section and thicknesses shown on the plans.

The contractor shall equip pavers with a receiving hopper having sufficient capacity for a uniform spreading operation and a distribution system to place the mixture uniformly in front of the screed.

The contractor shall equip the screed with automatic controls which will make adjustments in both transverse and longitudinal directions.

3.7.2 Operation

The contractor shall provide a placing operation to provide a smooth, uniform textured surface without tearing, shoving, gouging, segregation, or streaks.

3.8 JOINTS

3.8.1 Longitudinal

The contractor shall offset longitudinal construction joints of successive courses of HMA at least 150-mm (6 in.)

The contractor shall place the HMA so that any longitudinal joints constructed are within 300 mm (12 in.) of the final traffic lane lines.

3.8.2 Transverse Joints

The contractor shall place additional HMA to provide a temporary 1:50 transition at the end of placement.

The contractor shall form transverse joints by removing the temporary transition material, exposing the full depth of the previous layer, and forming a clean, vertical edge.

The contractor shall place a brush coat of asphalt emulsion on the contact surface of the joint before any additional mixture is placed.

3.9 COMPACTION

3.9.1 General

The contractor shall compact the pavement thoroughly and uniformly, with the necessary equipment, to obtain the density and cross-section of the finished paving mixture, meeting the requirements of the plans and specifications.

The contractor shall thoroughly compact the edges of pavement not accessible to conventional rollers with suitable types of tampers, plates, trench rollers, etc.

The contractor shall commence initial rolling at the lower edge and progress towards the highest portion of the roadbed.

The contractor shall perform rolling in a manner that cracking, shoving, or displacement are avoided. The contractor shall use rollers in good condition and capable of rolling and changing direction without adversely affecting the mat.

The contractor shall properly moisten the wheels of the rollers to prevent adhesion of the HMA. The contractor shall not use diesel or kerosene for this purpose.

3.9.2 Specified Air Void Requirements

The contractor shall compact the pavement to conform to the specified in-place air void requirements.

3.10 RESTRICTIONS

3.10.1 Frozen Base

The contractor shall not place the HMA when frozen materials are present in the base.

3.10.2 Adverse Weather

The contractor shall not place the HMA during rain or snowfall or when the roadway is wet.

4.0 MIXTURE DESIGN

4.1 GENERAL

4.1.1 Description

HMA shall be a uniform mixture of asphalt binder, aggregate and/or mineral filler, recycled asphalt pavement, additives, modifiers, and baghouse fines.

4.1.2 Responsibility

The mixture design shall be the responsibility of the contractor.

4.1.3 Required Information

The information describing the mixture design shall be submitted by the contractor and contain all information obtained during the mixture design process as defined in AASHTO PP 28 (Superpave Volumetric Design for Hot-Mix Asphalt).

4.2 REQUIREMENTS

4.2.1 Asphalt Binder

The asphalt binder grade shall meet the requirements of AASHTO MP 1 (Performance-Graded Asphalt Binder) (Table 6) and shall conform to the grade as shown on the plans. The asphalt binder grade selection will be selected with consideration given to AASHTO MP 2 (Superpave Volumetric Mix Design) requirements.

The asphalt binder samples for mixture design purposes and for approval of the mixture design by the engineer shall be obtained by the contractor. The asphalt binder shall be sampled from the refinery or contractor's storage plant in accordance with AASHTO T 40 and shall be representative of the asphalt binder that will be used during construction of the project. The asphalt binder will be tested by the engineer according to Table 11 and AASHTO PP 6.

4.2.2 Aggregate

The aggregates shall meet the requirements of AASHTO MP 2 (Superpave Volumetric Mix

Design (Tables 7 through 9) and the source properties shown in Table 10, and they shall conform to the gradation as shown on the plans.

Aggregate samples for mixture design purposes and for approval of the mixture design by the engineer shall be obtained by the contractor. The aggregate samples shall not be obtained until a minimum of 4,500 Mg (5,000 tons) or 25 percent of the required contract quantity of aggregate has been proportionately produced (whichever is less) and placed in stockpiles. The sampled aggregate shall be representative of the aggregate to be used during construction of the project. The aggregate will be tested by the engineer according to Table 12.

4.2.3 Mixture Design

The HMA mixture design shall be performed in accordance with AASHTO PP 28 (Superpave Volumetric Design for Hot-Mix Asphalt) with the compactive effort defined by use of Table 13.

4.2.4 Mixture Properties

The designed HMA shall meet the mixture properties contained in AASHTO PP 28 (Superpave Volumetric Design for HMA) and shown in Table 14.

4.3 SUBMITTALS

4.3.1 Materials

Split samples of the asphalt binder used by the contractor for mixture design purposes shall be submitted to the engineer a minimum of 30 working days prior to the start of the HMA production. The asphalt binder shall be supplied in four, 0.95-L (1-qt) containers of the "paint can type."

Split samples of aggregates used by the contractor for mixture design purposes shall be submitted to the engineer a minimum of 30 working days prior to the start of the HMA production.

The contractor shall submit the HMA mixture design 15 working days prior to the start of the HMA production. This submittal shall contain asphalt binder, aggregate, and HMA mixture properties as defined in Section 4.2 of this specification.

4.4 APPROVAL

4.4.1 Responsibility

The approval of the laboratory mixture design will be the responsibility of the engineer.

4.4.2 Basis of Approval

Approval of the mixture design will be based on the engineer's test results for the asphalt binder and the aggregate and a "paper" review of the submitted mixture design. The asphalt binder and the aggregate must meet the requirements of AASHTO PP 1 (Performance-Graded Asphalt) (Table 6) and

AASHTO MP 2 (Superpave Volumetric Mix Design) (Tables 7 through 10).

4.4.3 Time Required for Approval

The laboratory HMA mixture design will be approved or disapproved within 5 working days of submittal.

4.4.4 Mixtures Not Approved by the Engineer

If the furnished materials or mixture design are not approved by the engineer, the contractor shall resubmit new materials or a new mixture design after amending, correcting, or developing a new mixture design or obtaining new materials. The approval process will start over with the submittal of the new mixture design.

4.5 NEW LABORATORY MIX DESIGN

4.5.1 Asphalt Binder Source

If the asphalt binder source or grade changes, the contractor shall submit a new mixture design.

4.5.2 Aggregate Source

If the aggregate source changes or the aggregate material characteristics change significantly within the source, the contractor shall submit a new mixture design.

4.5.3 Number of New Mix Designs

New mixture designs shall be submitted as frequently as necessary to produce a quality HMA pavement.

4.5.4 Approval

All new mixture designs are subject to the approval process defined in Section 4.4 of this specification.

5.0 JOB MIX FORMULA

5.1 DESCRIPTION

The Job Mix Formula shall include single values for the following:

- Percent by weight of aggregate passing each specified sieve size (whole number percent).
- Bin percentage of each aggregate used (whole number percent).

- Percent of asphalt binder by total weight of HMA (0.1 percent).
- Percent of baghouse fines by dry weight of aggregate (0.1 percent).
- Percent of mineral filler by dry weight of aggregate (0.1 percent).
- Gyratory compacted weight-volume values at design asphalt binder content.
    - Air voids (0.1 percent).
    - Voids in mineral aggregate (0.1 percent).
    - Voids filled with asphalt (0.1 percent).
    - Dust-to-binder ratio (0.1 percent).
    - Bulk specific gravity of compacted mixture (0.001).
    - Theoretical maximum specific gravity of HMA (0.001).
    - Temperature for mixing and compaction for laboratory and field operations (whole number °C).

5.2 JOB MIX FORMULA 1 (LABORATORY MIXTURE DESIGN)

The approved laboratory mixture design (Section 4 of these specifications) shall be JMF 1. JMF 1 shall be the targets for aggregate gradation and asphalt binder content for the "Field Trial Section."

5.3 FIELD TRIAL SECTION(S)

5.3.1 Period of Production

On the first day of HMA production, three trial mixtures of a minimum of 450 Mg (500 tons) each shall be produced. The trial mixtures shall be produced at the medium hot-mix plant speed used during the calibration of the plant. The trial mixtures may be placed on the shoulder of the roadway, in a passing lane on a multilane highway, or in another location approved by the engineer. The field trial sections shall become a section of the completed roadway. Production of HMA shall be suspended for a maximum of 3 working days or until the production job mix formula has been approved. Working days will not be charged during the work suspension period.

5.3.2 Composition of Field Trial Mixtures

JMF 1 shall be the target for the Field Trial Mixture No. 1. Field Trial Mixture No. 2 shall conform to JMF 1, except the asphalt binder content shall be 0.4 percent above the target asphalt binder content of JMF 1. Field Trial Mixture No. 3 shall conform to JMF 1, except the asphalt binder content shall be 0.4 percent below the target asphalt binder content of JMF 1. The contractor may request the placement of additional trial mixtures. The placement of additional trial mixtures must be approved by the engineer.

5.3.3 Approval of Field Trial Mixtures

A loose sample of HMA shall be obtained by the contractor from behind the laydown machine prior to compaction from each 90 Mg (100 tons) of HMA placed. The sample will be split by the contractor into three, approximately equal proportions suitable for mixture testing as outlined below. The engineer will receive and test one portion of the sampled mixture. The contractor shall test the second portion of the sampled mixture. The third portion of the sampled mixture will be retained for referee testing if required.

The loose mixture will be tested by the engineer and shall be tested by the contractor to determine conformance to JMF 1 as determined by Tables 14, 15, and 16. For each of the three Field Trial Mixtures, a minimum of five gradations (AASHTO T 27), asphalt binder contents (ASTM D 6307), theoretical maximum specific gravity (AASHTO T 209), and mixture volumetric (AASHTO TP 4 and PP 28) values will be reported. The gyratory-compacted weight-volume properties reported (air voids, voids in mineral aggregate, voids filled with asphalt and bulk specific gravity of compacted samples) will be the average of three compacted samples for each of the 90 Mg (100 tons) of HMA sampled.

5.3.4 Comparison of Contractor and Engineer's Test Results

For each of the three Field Trial Mixtures, a comparison shall be made between the contractor and engineer's test results using the t-test (alpha = 0.01) described in Attachment D. Field Trial Mixture No. 1 shall be used initially to perform the comparison. If the contractor’s and engineer's test results are not determined to be statistically similar for Field Trial Mixture No. 1, an investigation will be performed to determine the reason for the difference(s). After appropriate changes are made, Field Trial Mixture No. 2 will be tested and

evaluated. If the contractor's and engineer's test results are not determined to be statistically similar for Field Trial Mixture No. 2, an investigation will be performed to determine the reason for the difference(s). After appropriate changes are made, Field Trial Mixture No. 3 will be tested and evaluated. If the contractor's and engineer's test results are not determined to be statistically similar for Field Trial Mixture No. 3, an investigation will be performed to determine the reason for the difference(s). The contractor and engineer will perform an agreed upon test program on laboratory prepared samples to resolve differences between test results. If this laboratory test program does not resolve the differences, a referee testing program will be initiated. At the conclusion of this effort, the contractor's and engineer's test results are to be statistically similar in value as determined by Attachment D.

5.3.5 Acceptance of Field Trial Section

Acceptance of the Field Trial Section will be based on the engineer's test results. The acceptable mixture shall meet the requirements of Table 14 and shall have an acceptable quality level (percent within limits [PWL]) of 90 percent within the JMF 1 limits as determined by Attachment C with the tolerances shown in Tables 15 and 16 for aggregate gradation and weight-volume properties. The asphalt binder content may vary from the limits shown in Table 15 to provide the desired weight-volume properties.

5.3.6 Pay Adjustment Factor

The pay adjustment factor for the field trial sections will be 1.00.

5.4 JOB MIX FORMULA 2 (FIELD TRIAL SECTION)

JMF 2 shall be determined based on the results of the Field Trial Sections. If none of the three Field Trial Sections placed (as described in Section 5.3 of the specification) meet the acceptance requirements of Section 5.3.5 of these specifications, additional field trial sections shall be placed until the requirements of Section 5.3 are met or a new mixture design is prepared by the contractor and approved by the engineer (Section 4 of specification).

Job Mix Formula 2 is described in Section 5.1 of these specifications.

5.5 SECOND DAY PRODUCTION

The second day of production shall be based on JMF 2. Pay adjustment factors will be calculated based on JMF 2. Pay adjustment factors will be applied to the second day of production and thereafter.

5.6 JOB MIX FORMULA ADJUSTMENT

5.6.1 Changes Allowed

If adjustments to the JMF 2 are needed during production to meet the specification requirements or to maximize the quality of the mixture, the JMF shall be adjusted prior to the start of the production of the lot. This new JMF shall be identified as JMF 3. The contractor shall notify the engineer of these changes. A lot may be terminated at the end of a sublot if requested by the contractor and approved by the engineer. The pay factor for the early, terminated lot will be based on the tests obtained for the sublot(s) produced.

5.6.2 Acceptance of Change

Changes in asphalt binder content and aggregate gradation "single values" will be allowed provided the changes do not exceed the specification limits as defined in Tables 7 and 8 and the tolerances shown in Table 17 which are based on JMF 1.

The contractor shall obtain five samples of loose mixture behind the paver during the production of the first lot produced with JMF 3 as target values (Field Trial Section). The gyratory-compacted weight-volume requirements shown in Table 14 shall be met. The mixture shall meet the acceptable quality level of 90 percent within JMF 2 limits as determined by Attachment C with the tolerances shown in Table 16 for air voids, voids in mineral aggregate, voids filled with asphalt, and dust-to-binder ratio.

5.6.3 Job Mix Formula 3

JMF 3 shall be based on the results of the Field Trial Section placed as described in Section 5.6.2 of the specification. JMF 3 is described in Section 5.1 of this specification.

5.6.4 New Job Mix Formulae

Additional Job Mix Formulae will be allowed provided they meet the requirements contained in Section 5.6 of this specification.

5.7 COMPACTION ROLLING PATTERN

During placement of the Field Trial Sections, the contractor shall establish a roller pattern(s) to ensure that the produced HMA meets the in-place

air void requirements of 99.7 percent within the limits of 2 to 7 percent air voids as determined by AASHTO T 269. An acceptable roller pattern must be established prior to the start of "day two" production.

6.0 LOT AND SUBLOT

6.1 GENERAL

Acceptance of the HMA will be based on the acceptance on lot quantities. Random sampling of asphalt binder, aggregate, and the HMA shall be performed on a lot and sublot basis according to Attachment A. Lots and sublots shall be established for asphalt binder, aggregate, HMA production and placement, and ride quality as defined below. Lots can be terminated at any time with approval of the engineer.

6.2 ASPHALT LOT/SUBLOT

6.2.1 Definition

An asphalt binder lot shall consist of five (5) equal sublots. An asphalt binder sublot shall equal a day's production.

6.2.2 Incomplete Production Lots

If a lot is begun and cannot be completed due to the end of the project, an incomplete lot is created. The sublot test results from this incomplete lot will be combined with the previous lot.

6.2.3 Small Production Quantities

When the anticipated daily production is less than 450 Mg (500 tons) of HMA, the engineer may elect to either waive all sampling and testing for that day or to follow Section 6.2.2 of this specification. If the engineer elects to waive sampling and testing, the pay adjustment factor for the asphalt binder will be 1.00.

6.3 AGGREGATE LOT/SUBLOT

6.3.1 Definition

An aggregate lot shall consist of five (5) equal sublots. An aggregate sublot shall equal a day's production.

6.3.2 Incomplete Production Lots

If a lot is begun and cannot be completed due to the end of the project, an incomplete lot is created. The sublot test results from this incomplete lot will be combined with the previous lot.

6.3.3 Small Production Quantities

When the anticipated daily production is less than 450 Mg (500 tons) of HMA, the engineer may elect

either to waive all sampling and testing for that day or to follow Section 6.3.2 of this specification.

6.4 HOT-MIX ASPHALT PRODUCTION LOT/SUBLOT

6.4.1 Definition

A production lot shall consist of five equal sublots. The production/placement sublot shall be 360 Mg (400 tons).

6.4.2 Incomplete Production Lots

If a lot is begun and cannot be completed due to weather, equipment breakdown, end of the project or other circumstances, an incomplete lot is created. The sublot test results from this incomplete lot will be combined with the previous production lot or the next lot produced. If two or less sublot test results are available from the incomplete lot, these test results will be combined with the previous production lot. If three or more sublot test results are available from the incomplete lot, these test results will be combined with the next lot produced.

6.4.3 Small Production Quantities

When the anticipated daily production is less than 450 Mg (500 tons), the engineer may elect either to waive all sampling and testing requirements or to follow Section 6.4.2 of this specification. If the engineer elects to waive sampling and testing, the pay adjustment factor will be 1.00.

6.5 HOT-MIX ASPHALT PLACEMENT LOT/SUBLOT

6.5.1 Definition

A placement lot shall consist of the area of HMA placed in a production lot, excluding miscellaneous areas. A placement sublot shall consist of one-fifth of the area of the placement lot.

6.5.2 Incomplete Placement Lots

An incomplete placement lot shall consist of the area placed in an incomplete production lot as described in Section 6.4.2 of this specification, excluding miscellaneous areas. For these incomplete placement lots, one placement sample location shall be selected for each production sublot placed and the test results combined with the

previous lot or the next lot produced as defined in Section 6.4.2 of this specification.

6.5.3 Miscellaneous Areas

Areas that are not generally subject to primary traffic such as driveways, mailbox turnouts, crossovers, gores, and other similar areas are considered to be miscellaneous areas. Shoulders and ramps are not considered miscellaneous areas. Miscellaneous areas are the only areas that are not eligible for random placement locations and will be assigned a pay factor of 1.00.

6.5.4 Shoulders and Ramps

Shoulders and ramps are not subject to in-place air voids determination, unless otherwise shown on the plans. When shoulders and ramps are not subject to in-place air voids determination, the compaction shall be in accordance with roller patterns established in Section 5.7 of this specification. The contractor may declare the shoulders and/or ramps as eligible for in-place air void testing and pay adjustments; however, the contractor must notify the engineer in writing prior to beginning of the mix production. The engineer must approve this request.

6.5.5 Level-ups and Thin Overlays

For the purpose of calculating placement pay adjustment factors, level-ups and thin overlays will be considered as miscellaneous areas and will be assigned a placement pay factor of 1.00. The placement pay adjustment factor will be 1.00 for any layer thickness designated on the plans less than 38 mm (1.5 in.) or for level-up areas. The contractor shall establish a rolling pattern that shall achieve in-place air voids in accordance with the roller patterns established in Section 5.7 of this specification.

6.6 RIDE QUALITY LOT

A ride quality lot is equal to 1.6 lane-km (1 lane-mi). A lane-km is defined as a kilometer length of a mainline travel lane shown on the permanent striping plan. Pay factors for ride quality are based on a lot; therefore, the definition of a sublot is not needed.

7.0 QUALITY CONTROL

7.1 QUALITY CONTROL SAMPLING AND TESTING FOR ASPHALT BINDERS

7.1.1 Sampling

Stratified random sampling procedures shall be used as described in Attachment A. Each day the HMA is being produced, a single asphalt binder

sample shall be taken at randomly determined times from the feed line located between the contractor's storage tank and plant mixing chamber according to AASHTO T 40. The samples shall be split into three individual 0.95-L (1-qt) cans. The samples shall be obtained by the contractor and witnessed by the engineer. One of the split samples will be tested by the engineer for quality assurance purposes as shown in Table 18. The second split sample shall be held by the contractor and can be used for testing. The third sample will be retained by the engineer for referee testing.

7.1.2 Lots and Sublots

Each day's production shall constitute an asphalt binder sublot (represented by one random sample) and each 5 days of production shall represent an asphalt binder lot (Section 6.2). The quantity of binder represented by a sublot or lot may vary.

7.1.3 Quality Control Testing (optional)

The requirements contained in AASHTO PP 26 shall be the quality control testing requirements for the asphalt binder. Additional quality control testing by the contractor is at the contractor's discretion. The contractor is encouraged to perform the high temperature Dynamic Shear Rheometer (AASHTO TP 5) rheometer tests on original and rolling thin film oven (AASHTO T 240) aged samples obtained as described in Section 7.1.1.

7.1.4 Comparison of Quality Control and Quality Assurance Tests

Split samples of asphalt binder tested by the contractor for quality control and the engineer for quality assurance will be within the allowable differences shown in Table 22. If the split sample data are not within these allowable differences, an immediate investigation shall be conducted to determine the cause(s) of the differences. Unless available facts indicate otherwise, the investigation shall include a review of sampling and testing procedures used by both the contractor and engineer.

7.2 QUALITY CONTROL SAMPLING AND TESTING FOR AGGREGATES

7.2.1 Sampling

Stratified random sampling procedures shall be used as described in Attachment A. Each day the HMA
is being produced, a single aggregate sample shall be taken at randomly determined times from the

combined cold feed according to AASHTO T 2. The sample shall be split into three individual samples of sufficient size for performing the tests shown in Table 19. The samples shall be obtained by the contractor and witnessed by the engineer.

One of the split samples shall be tested by the contractor for quality control purposes and one sample will be tested by the engineer for quality assurance purposes as described in Table 19. The third sample will be retained by the engineer for referee testing.

7.2.2 Lots and Sublots

Each day's production shall be constituted an aggregate sublot (represented by one random sample) and each 5 days of production shall represent an aggregate lot (Section 6.3). The quantity of aggregate represented by a sublot or lot may vary.

7.2.3 Quality Control Testing

The requirements shown in Table 19 shall be the quality control testing requirements for the aggregate. The Coarse Aggregate Angularity (ASTM D 5821), Fine Aggregate Angularity (AASHTO T 304), Flat and Elongated Particles (ASTM D 4791), Sand Equivalent (ASSHTO T 176) and Deleterious Materials (AASHTO T 112) tests shall be performed on each sublot sample. Los Angeles Abrasion (AASTO T 96) and soundness tests (AASHTO T 104) shall be performed on each lot from a randomly selected sublot sample.

7.2.4 Comparison of Quality Control and Quality Assurance Tests

Split samples of aggregate tested by the contractor for quality control purposes and by the engineer for quality assurance purposes shall be within the allowable differences shown in Table 23. If the split sample data are not within these allowable differences, an investigation shall be conducted immediately to determine the cause(s) of the differences. Unless available facts indicate otherwise, the investigation shall include a review of sampling and testing procedures used by both the contractor and the engineer.

7.2.5 Quality Control Requirements

The aggregate quality control process shall be considered in control if two general criteria are met. The first criteria requires that the aggregate meet the requirements of Tables 7 through 10 for each sample tested.

The second general criteria requires that the test results obtained by the contractor for quality control and the engineer for quality assurance are within the differences shown in Table 23 as described in Section 7.2.4.

7.3 QUALITY CONTROL SAMPLING AND TESTING FOR HMA PRODUCTION

7.3.1 Sampling

Stratified random sampling procedures shall be used as described in Attachment A. A sample of HMA shall be obtained at randomly determined tonnages from behind the paver prior to compaction for each sublot according to AASHTO T 168. The sample shall be split into three individual samples of sufficient size for performing the tests shown in Tables 20 and 21. The samples shall be obtained by the contractor and witnessed by the engineer. One of the samples shall be tested by the contractor for quality control purposes and one sample will be tested by the engineer for quality assurance purposes as described in Tables 20 and 21. The third sample will be retained by the engineer for referee testing.

7.3.2 Lots and Sublots

A production lot shall consist of five equal sublots. A production sublot shall be 360 Mg (400 tons) (Section 6.4).

7.3.3 Quality Control Testing

The requirements shown in Tables 20 and 21 shall be the quality control testing requirements for HMA production. The asphalt binder content shall be determined by the Ignition Method (ASTM D 6307) and the Aggregate Gradation by AASHTO T 27. The loose HMA shall be compacted by the Superpave Gyratory Compactor (AASHTO TP 4) and the following weight-volume parameters determined at N_{design} number of gyrations: Bulk Specific Gravity (AASHTO T 166), Theoretical Maximum Specific Gravity (AASHTO T 209), Air Voids (AASHTO T 269), Voids in Mineral Aggregate (AASHTO PP 28), Voids Filled with Asphalt (AASHTO PP 28) and Dust-to-Binder Ratio (AASHTO PP28).

The aggregate gradation shall be determined with those sieves used to specify the gradation for mixture design purposes (Tables 7, 8, and 21). The average of three Superpave gyratory-compacted samples shall be reported as the mixture volumetrics parameters from each sublot sample of HMA.

7.3.4 Quality Control Requirements

The contractor shall determine and record the following in a daily summary: quantities of asphalt binder, aggregate, mineral filler and fibers (if required) used; the quantities of HMA produced; the HMA production and compaction temperatures (hourly basis as a minimum); and the results of the testing shown in Tables 20 and 21.

The HMA production process shall be considered in control if two general criteria are met. The first general criteria requires that the asphalt binder content, aggregate gradation and the field-mixed, laboratory-compacted weight-volume parameters identified in Table 20 be within the limits shown in Tables 15 and 16 for each sublot. The target values used to determine compliance are those for the last approved JMF (JMF 2, JMF 3, etc.).

The second general criteria requires that the contractor meet the requirements associated with statistical control charts as outlined below. The contractor shall use statistical control charts to determine if the variability in HMA properties and/or variability is due to random causes or assignable causes.

Statistical control charts shall be prepared for aggregate gradation on the 2.36-mm (No. 8) and 0.075-mm (No. 200) sieves, asphalt binder content and gyratory-compacted air void contents. Target values and upper and lower control limits for the control charts are determined from the Field Trial Sections (Section 5.0) and the first few days of production. The initial production test results that are utilized to develop these statistical control charts shall agree with the production results obtained during the Field Trial Sections (Section 5.0).

The grand mean and average range of these test data shall be used to develop x-bar (mean) and R (range) control charts for each property: gradation on the 2.36-mm (No. 8) and 0.075-mm (No. 200) sieves, asphalt binder content, and gyratory-compacted air void content) according to Attachment B. The upper and lower control limits shall be set at plus or minus 2 times the standard deviation and plus or minus 3 times the standard deviation, defined as the warning and action control limits, respectively. If the warning and action control limits are not within the allowable JMF tolerances (Tables 15 and 16) for the approved JMF, the contractor shall modify the HMA production process to reduce the variability and bring the control limits within the tolerances.

Eight consecutive plotted points on either side of the target value, or one point outside the warning or action limit, indicates an HMA mixture compositional change. If any one or more of these conditions occurs, the next sublot shall be immediately tested. If the next sublot test result indicates non-compliance with the above-stated criteria, the contractor shall adjust the asphalt binder
content, aggregate gradation, or both, to provide mixture compliance. The mixture produced after these changes have been made shall be subject to the evaluation process identified in Section 5.6.

7.3.5 Comparison of Quality Control and Quality Assurance Tests

Split production samples of HMA tested by the contractor for quality assurance and by the engineer for quality assurance and pay factor shall be compared by the Student t-test as described in Attachment D, with alpha equal to 0.10. Comparisons are possible for gradation on the 2.36-mm (No. 8) and 0.075-mm (No. 200) sieves, asphalt binder content, gyratory-compacted air voids and bulk specific gravity, and theoretical maximum specific gravity (Table 20). If the results do not compare favorably for a given lot, the reason(s) should be immediately determined and resolved. Unless available facts indicate otherwise, the investigation shall include a review of sampling and testing procedures used by both the contractor and engineer.

7.4 QUALITY CONTROL SAMPLING AND TESTING FOR HMA PLACEMENT

7.4.1 Sampling

Stratified random sampling procedures shall be used as described in Attachment A. Nondestructive or destructive sampling and testing procedures may be used by the contractor to determine in-place air void content. When nondestructive measurements (ASTM D 2950) are used, a minimum of four locations shall be used in each sublot. When pavement core samples (ASTM D 5361) are used, a minimum of two locations shall be used in each sublot. When nondestructive testing is utilized, the device shall be calibrated with core samples to determine air void content. The Field Trial Sections shall be used to determine roller patterns to obtain the desired in-place air voids (Section 5.7). In-place air void determinations shall not be made within 0.45 m (18 in.) of a longitudinal joint or within1.5 m (60 in.) inches of a transverse joint.

7.4.2 Lots and Sublots

A placement lot shall consist of the area of HMA placed in a production lot, excluding miscellaneous areas as described in Section 6.5.3. A placement sublot shall consist of one-fifth of the area of the placement lot (Section 6.5).

7.4.3 Quality Control Testing

The requirements shown in Table 20 shall be the quality control testing requirements for HMA placement (in-place air voids). The in-place air voids shall be determined from core samples according to AASHTO T 269 based on Bulk Specific Gravity determinations of core samples by AASHTO T 166 or T 275 and on Theoretical Maximum Specific Gravity according to AASHTO T 209. Theoretical specific gravity values determined by sublot for the quality control production testing (Section 7.3) shall be used. If in-place air voids are determined by use of the Nuclear Gage (ASTM D 2950), correlation between the gage and core samples shall be required.

7.4.4 Quality Control Requirements

The contractor shall determine and record in a daily summary: the amount of HMA delivered to the paver (truck loads and Mg [or tons] per truck); temperature of the HMA in the truck at the plant (hourly basis as a minimum); and temperature of the HMA in the mat prior to initial compaction (hourly basis as a minimum).

The HMA production process shall be considered in control if two general criteria are met. The first general criteria requires that the in-place air voids be within the limits shown in Table 16 (2 to 7 percent) for each sublot (average of two samples if cores are utilized and average of four samples if nondestructive methods are utilized).

The second general criteria requires that the contractor meet the requirements associated with statistical control charts as outlined below. The contractor shall use statistical control charts to determine if the HMA properties, their variability, or both, are due to random causes or assignable causes.

Statistical control charts shall be prepared for in-place air voids according to Attachment B. Target values and control limits for in-place air voids shall be based on information obtained during the placement of the Field Trial Sections (Section 5.0) and the first day's pavement construction. The first day's pavement construction test results that are

utilized to develop these statistical control charts shall agree with the production results obtained during the Field Trial Sections (Section 5.0).

The grand mean and average range of these test data shall be used to develop x-bar (mean) and R (range) control charts for in-place air voids according to Attachment B. The upper and lower control limits shall be set at plus or minus 2 times the standard deviation and plus or minus 3 times the standard deviation, defined as the warning and action control limits, respectively. If the warning and action control limits are not within the allowable range of 2 to 7 percent (Table 16), the contractor shall modify the HMA placement and perhaps the production process to reduce the variability and bring the control limits within the tolerances.

One test point outside the upper or lower warning control limit shall be considered an indication that the control of the laydown and compaction process may be unsatisfactory and shall require the contractor to confirm that the process parameters are within acceptable bounds by obtaining additional core samples.

One test point outside the upper or lower action control limit or eight consecutive test points on one side of the target value shall be judged as a lack of control in the laydown and compaction process. The contractor shall stop production of the HMA until the assignable cause(s) for the lack of control is identified and remedied. The contractor shall report within 24 hours to the engineer the assignable cause(s) for the stop in production and the action taken to remedy the assignable cause.

7.4.5 Comparison of Quality Control and Quality Assurance Test

In-place air void determinations performed by the contractor for quality control testing and by the engineer for quality assurance (Table 20) shall be compared by the Student t-test, as described in Attachment D, with alpha equal to 0.10. If the test results do not compare favorably for a given lot, the reason(s) should be immediately determined and resolved. Unless available facts indicate otherwise, the investigation shall include a review of sampling and testing procedures used by both the contractor and engineer.

7.5 QUALITY CONTROL SAMPLING AND TESTING FOR RIDE QUALITY

Quality control testing for ride quality is not required. The contractor is encouraged to determine
a ride quality evaluation according to ASTM E 1274
or other suitable method (Table 5).

8.0 QUALITY ASSURANCE

8.1 QUALITY ASSURANCE SAMPLING AND TESTING FOR ASPHALT BINDERS

8.1.1 Sampling

Stratified random sampling procedures shall be used as described in Attachment A. Each day the HMA is being produced, a single asphalt binder sample shall be taken at randomly determined times from the feed line located between the contractor's storage tank and the plant mixing chamber according to AASHTO T 40. The sample shall be split into three individual 0.95-L (1-qt) cans. The samples shall be obtained by the contractor and witnessed by the engineer. One of the split samples will be tested by the engineer for quality assurance and pay factor determination. The second sample shall be held by the contractor and can be used for testing. The third sample will be retained by the engineer for referee testing.

8.1.2 Lots and Sublots

Each day's production shall constitute an asphalt binder sublot (represented by one random sample) and each 5 days of production shall represent an asphalt binder lot. The quantity of binder represented by a sublot or lot may vary.

8.1.3 Quality Assurance Testing

The testing shown in Table 18 will be the minimum quality assurance testing requirements for the asphalt binder.

8.1.4 Quality Assurance Requirements

The quality assurance tests will be used to determine compliance to the specification for performance-graded asphalt binder shown in Table 6. If the sample tested does not meet the specification for the grade specified for the project, the engineer will immediately contact the contractor and testing will be initiated on the other four sublot samples of asphalt binder by the engineer. An investigation will be conducted to determine the cause(s) for not meeting the specification. The asphalt binder test results obtained by the contractor will be included in this investigation, as well as the results from Section 7.1.4 of the specification.

If differences between contractor and engineer test results cannot be resolved, referee testing will be conducted by the engineer's central laboratory or a third party laboratory. The referee testing will be performed on the split samples retained by the engineer and the results will be used for final acceptance and pay adjustments.

8.2 QUALITY ASSURANCE SAMPLING AND TESTING FOR AGGREGATES

8.2.1 Sampling

Stratified random sampling procedures shall be used as described in Attachment A. Each day the HMA
is being produced, a single aggregate sample shall be taken at randomly determined times from the combined cold feed according to AASHTO T 2. The sample shall be split into three individual samples of sufficient size for performing the tests shown in Table 19. The samples shall be obtained by the contractor and witnessed by the engineer. One of the split samples shall be tested by the contractor for quality control purposes as described in Section 7.2 of this specification. One sample will be tested by the engineer for quality assurance purposes as described in Table 19. The third sample will be retained by the engineer for referee testing.

8.2.2 Lots and Sublots

Each day's production shall constitute an aggregate sublot (represented by one random sample) and each 5 days of production shall represent an aggregate lot. The quantity of aggregate represented by a sublot or lot may vary.

8.2.3 Quality Assurance Testing

The testing shown in Table 19 will be the minimum quality assurance testing requirements for the aggregate.

8.2.4 Quality Assurance Requirements

The quality assurance test results will be used to determine compliance to the specification for aggregates as shown in Tables 9 and 10. If the sample tested does not meet the specification for the aggregates, the engineer will immediately contact the contractor and testing will be initiated on the other four sublot samples of aggregate by the engineer. An investigation will be conducted to determine the cause(s) for not meeting the specification. The aggregate test results obtained by the contractor will be included in this

investigation, as well as the results from Section 7.2.4 of this specification.

If differences between the contractor and engineer test results cannot be resolved, referee testing will be conducted by the engineer's central laboratory or a third party laboratory. The referee testing will be performed on the split samples retained by the engineer and the results will be used for final acceptance.

8.3 QUALITY ASSURANCE SAMPLING AND TESTING FOR HMA PRODUCTION

8.3.1 Sampling

Stratified random sampling procedures shall be used as described in Attachment A. A sample of HMA shall be obtained at randomly determined tonnages
from behind the paver prior to compaction for each sublot according to AASHTO T 168. The sample shall be split into three individual samples of sufficient size for performing the tests shown in Tables 20 and 21. The samples shall be obtained by the contractor and witnessed by the engineer. One of the samples shall be tested by the contractor for quality control purposes and one sample will be tested by the engineer for quality assurance purposes and pay factor determination. The third sample will be retained by the engineer for referee testing.

8.3.2 Lots and Sublots

A production lot shall consist of five equal sublots. A production sublot shall be 360 Mg (400 tons).

8.3.3 Quality Assurance Testing

The requirements shown in Tables 20 and 21 will be the minimum quality assurance testing requirements for HMA production.

8.3.4 Quality Assurance Requirements

The quality assurance test results will be used to determine compliance to the specification for HMA production as described below.

PWL will be determined according to Attachment C for asphalt binder content (ASTM D 6307), gradation 0.075 mm (No. 200) (AASHTO T 27), and gyratory-compacted air voids (AASHTO TP 4

and AASHTO T 269) on a lot basis. The last JMF approved according to Section 5.0 of this specification will provide the target values for all specified properties. The upper and lower specification limits will be determined from tolerances shown in Tables 16 and 17 for asphalt binder content, gradation, and gyratory-compacted air voids. The lot tested must be 100 percent within limits for asphalt binder content, gradation, and gyratory-compacted air voids to be accepted. If the lot tested does not meet this requirement, the engineer will immediately contact the contractor. An investigation will be conducted to determine the cause(s) for not meeting the specification. The HMA production sample testing conducted by the contractor will be included in this investigation, as well as the results from Section 7.3.4 of this specification.

If differences between the contractor's and engineer's test results cannot be resolved, referee testing will be conducted by the engineer's central laboratory or a third party laboratory. The referee testing will be performed on the split samples retained by the engineer and the results will be used for final acceptance.

8.4 QUALITY ASSURANCE SAMPLING AND TESTING FOR HMA PLACEMENT

8.4.1 Sampling

Stratified random sampling procedures shall be used as described in Attachment A. Core samples shall be used by the engineer to determine in-place air void contents. A minimum of two locations will be used for each sublot. In-place air voids determinations shall not be made within 0.45 m (18 in.) of a longitudinal joint or within 1.5 m (60 in.) of a transverse joint.

8.4.2 Lots and Sublots

A placement lot shall consist of the area of HMA placed in a production lot, excluding miscellaneous areas as described in Section 6.5.3. A placement sublot shall consist of one-fifth of the area of the placement lot (Section 6.5).

8.4.3 Quality Assurance Testing

The requirements shown in Table 20 will be the minimum quality assurance testing requirements for HMA placement. The in-place air voids shall be determined from core samples according to AASHTO T 269 based on Bulk Specific Gravity determination of core samples by AASHTO T 166

or AASHTO T 275, and on the Theoretical Maximum Specific Gravity according to AASHTO T 209.

8.4.4 Quality Assurance Requirements

The quality assurance test results will be used to determine compliance to the specification for HMA placement as described below.

PWL will be determined according to Attachment C for the core sample test results. The upper and lower specification limits will be 7 and 2 percent air voids, respectively. The lot tested must be 99.7 percent within limits to be accepted. If the lot tested does not meet this requirement, the engineer will immediately contact the contractor. An investigation will be conducted to determine the cause(s) for not meeting the specification. The HMA placement sampling and testing performed by the contractor will be included in this investigation, as well as the results from Section 7.4.3 of this specification.

If differences between the contractor's and engineer's test results can not be resolved, referee testing will be conducted by the engineer's central laboratory or a third party laboratory. The referee testing will be performed on the cores obtained by the engineer and the results will be used for final acceptance.

8.5 RIDE QUALITY

8.5.1 Sampling

Ride quality is determined by continuous measurement along a pavement and hence sampling is not required.

8.5.2 Lot and Sublot

A ride quality lot is equal to 1.6 lane-km (1 lane-mi). A lane-km is defined as a kilometer length of a mainline travel lane shown on the permanent striping plan. Pay factors for ride quality are based on a lot; therefore, the definition of a sublot is not needed.

8.5.3 Quality Assurance Testing

Quality assurance testing for acceptance will be performed by one of the methods identified in Table 5.

8.5.4 Quality Assurance Requirements

The quality assurance tests will be used to determine compliance to the specification. The

method of acceptance is contained in the standard specification.

9.0 ACCEPTANCE

9.1 GENERAL

The acceptance of the HMA is based on the acceptance plan described below for the asphalt binder, aggregate, HMA production, HMA placement, ride quality, and other requirements as defined below.

9.2 ASPHALT BINDER

The acceptance of the asphalt binder is based on compliance to (a) the quality control sampling and testing plan and (b) the quality assurance sampling and testing plan contained in Sections 7.1 and 8.1, respectively, of this specification.

9.3 AGGREGATE

The acceptance of the aggregate is based on compliance to (a) the quality control sampling and testing plan and (b) the quality assurance sampling and testing plan contained in Sections 7.2 and 8.2, respectively, of this specification.

9.4 HOT-MIX ASPHALT PRODUCTION

The acceptance of the HMA production is based on compliance to (a) the quality control sampling and testing plan and (b) the quality assurance sampling and testing plan contained in Sections 7.3 and 8.3, respectively, of this specification.

9.5 HOT-MIX ASPHALT PLACEMENT

The acceptance of the HMA placement is based on compliance to (a) the quality control sampling and testing plan and (b) the quality assurance sampling and testing plan contained in Sections 7.4 and 8.4, respectively, of this specification.

9.6 RIDE QUALITY

The acceptance of the ride quality is based on compliance to the quality assurance plan contained in Section 8.5 of these specifications.

9.7 IRREGULARITIES AND/OR SEGREGATION

If a pattern of surface irregularities, including but not limited to color, texture, roller marks, tears, uncoated aggregate particles, or segregation is detected by either the contractor or engineer, the contractor shall make an investigation into the cause(s) and immediately take the appropriate corrective action. With approval of the engineer, placement may continue for no more than 1 day of production from the time the engineer first notified the contractor if corrective actions are being taken. If no appropriate action is taken or if the problem

exists after 1 day, paving shall cease until the contractor further investigates the cause(s) and the engineer approves further production to determine the effectiveness of corrective action.

Segregated areas shall be corrected at the contractor's expense as directed by the engineer. Correction may include removal and replacement. Disputes will be resolved at the district or regional level.

9.8 INDIVIDUAL LOADS

Individual loads of HMA in the truck can be rejected by the engineer. Except for rejection based on temperature, uncoated aggregate or non-uniformity, each rejected load will be tested by the engineer if requested by the contractor. The request for testing by the contractor must be made to the engineer within 4 hours of rejection. Tests shall be conducted by the engineer according to the quality assurance testing plan described in Tables 20 and 21 and Section 8.3 of this specification for HMA production. If tests are within limits as described in Section 8.3.4, payment will be made for the load at a pay factor of 1.0. If test results are not within limits described in Section 8.3.4, no payment will be made for the load. The engineer will perform the sampling and testing on the disputed loads.

10.0 MEASUREMENT

10.1 GENERAL

The quantity of HMA will be measured by mass Mg (or ton) of the type actually used in the completed and accepted work in accordance with the plans and specification for the project. The composite HMA is defined as the asphalt binder, aggregate, recycled asphalt pavement, additives, and modifiers as noted on the plans, approved by the engineer, or both.

If mixing is performed by a drum-mix plant, measurement will be made on scales as described in the standard specifications. If mixing is performed by a weigh-batch or modified weight-batch plant, measurement will be determined on the batch scales unless surge storage is used. Records of the number of batches, batch design, and the mass of the completed HMA shall be supplied by the contractor. Where surge storage is used, measurement of the material will be made on truck scales or suspended hopper scales.

11.0 PAY ADJUSTMENT FACTOR AND PAYMENT

11.1 GENERAL

Separate pay adjustment factors and payments will be calculated for asphalt binders, HMA, and ride

quality. Pay adjustment factors and payment methods are described below.

11.2 ASPHALT BINDER

11.2.1 Pay Adjustment Factor

Asphalt binder pay adjustment will be determined by an adjustment to the price of the HMA contained in an asphalt binder lot. The pay adjustment factor will be determined by use of Table 24. If the values of the measured properties meet the compliance limits of Table 24, the price adjustment factor is 1.00. The price adjustment factor will be 0.75 at the rejection limit. If any measured property is outside the rejection limit (less than 0.75), the HMA will be rejected.

For each property whose value lies between the compliance limit and the rejection limit, the pay adjustment factor will be calculated assuming a linear variation between 1.00 and 0.75. For a lot having more than one parameter out of specification, a composite pay adjustment will be calculated by summing the reduction of each individual property calculation.

The HMA will be accepted with reduced composite price reduction if none of the properties are outside the rejection limit and the composite pay adjustment factor is above 0.75. The HMA will be rejected if one or more of the properties of the asphalt binder fall outside of the rejection limits or if the composite pay factor is below 0.75.

11.2.2 Payment

The amount of price reduction will be based on the HMA price quoted in the contractor’s bid. If the price per Mg (or ton), of HMA is unbalanced, the previous year's average bid price per Mg (or ton) will be used. The pay for HMA considering the asphalt binder pay adjustment factor is equal to the HMA price (per Mg or ton) times the asphalt binder pay adjustment factor.

11.3 AGGREGATE

Aggregates do not have pay adjustment factors.

11.4 HOT-MIX ASPHALT

11.4.1 General

11.4.2 Method "A" Pay Adjustment Factors

The engineer will determine pay adjustment factors using the October 2000 release of the software for

the "Performance-Related Specification for Hot-Mix Asphalt" for each pavement lot.

The engineer will perform the testing for pay factor determination as described in Tables 20 and 21. Pay factor testing shall be performed as part of the quality assurance testing program for HMA production and placement described in Section 8.0 of this specification.

11.4.3 Method "B" Pay Adjustment Factors

The engineer will develop a matrix of input values to cover a range of functional classifications, pavement structures, traffic levels, and decision tree criteria. Use the software for the "Performance-Related Specification for Hot-Mix Asphalt" to generate a pay factor for each set of inputs and fill the cells within the matrix with the pay factors generated by the software. To determine the pay factor, the engineer will use the values within the table in lieu of the software.

11.4.4 Payment

The amount of payment will be based on the HMA price quoted in the contractor's bid. If the price per Mg (or ton) of HMA is unbalanced, the previous year's average bid price per Mg (or ton) will be used. The payment for HMA considering the HMA pay adjustment factor is equal to the hot-mix price (per Mg or ton) times the HMA pay adjustment factor.

11.5 RIDE QUALITY

The ride quality payment will be based on of the standard specification.

11.6 CONTRACTOR ACCEPTANCE OF PAY ADJUSTMENT FACTORS

If the pay adjustment or pay factor for any lot of HMA is below 1.00, the contractor has the option (a) to remove and replace the lot or (b) to agree to accept the lot at an adjusted unit price determined by Section 11.4 of this specification. If the pay adjustment factor for any lot is less than 0.70, the HMA shall be removed at the expense of the contractor. Replacement material shall meet the requirements of this specification. The contractor and engineer will sign for acceptance of payment on a lot by lot basis.

11.7 PAY ADJUSTMENT FACTORS BELOW 1.00

The contractor shall take corrective action if any one of the asphalt binder, HMA, or ride quality pay adjustment factors is below 1.00 for a lot. If three consecutive pay adjustment factors for any single

item (asphalt binder, HMA, or ride quality) are below 1.00 (for example, three consecutive pay factors for HMA), construction shall terminate. An investigation will be conducted by the contractor and engineer to determine the cause(s) for not receiving a 1.00 pay adjustment factor. The HMA sampling and testing performed by the contractor will be included in this investigation.

If differences between the contractor's and engineer's test results cannot be resolved, referee testing will be conducted by the engineer's central laboratory or third party laboratory. The referee testing will be performed on split samples retained by the engineer and the results will be used for determination of the final pay factors and payment.

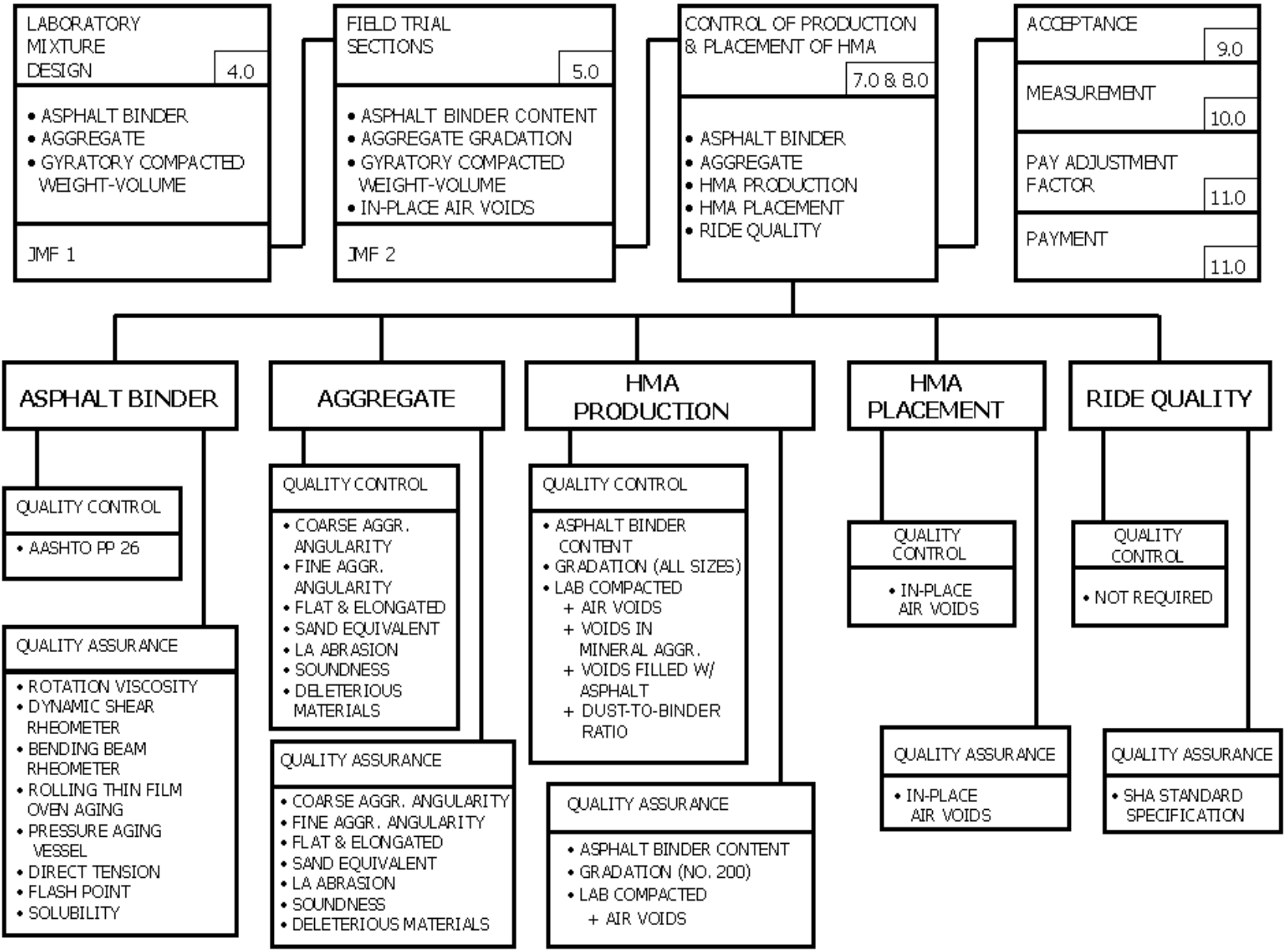


Figure 2. HMA control and acceptance activities.

Table 1. General quality control/quality assurance specification references.

Test Designation	Test Method Number	
	AASHTO	ASTM
Statistical procedures	R 4	
Acceptance sampling plans for highway construction	R 9	
Definition of terms for specifications and procedures	R 10	
Indicating which places are to be considered significant in specified limiting values	R 11	
Establishing and implementing a quality system for construction materials testing laboratories	R 18	
Terminology relating to materials for roads and pavements		D 8
Random sampling of construction materials		D 3665
Minimum requirements for agencies testing and inspecting bituminous paving materials		D 3666
Probability sampling of materials		E 105
Choice of sample size to estimate the average quality of a lot or process		E 122
Acceptance of evidence based on the results of probability sampling		E 141
Quality control systems for organizations producing and applying bituminous paving materials		D 4561
Organizations engaged in the certification of personnel testing and inspecting bituminous paving materials		D 5506

Table 2. Asphalt binder tests.

Test Designation	Test Method Number		Certification Level
	AASHTO	ASTM	
Rotational Viscometer (RV)	TP 48	D 4402	
Dynamic Shear Rheometer (DSR)	TP 5		
Bending Beam Rheometer (BBR)	TP 1		
Direct Tension Test (DTT)	TP 3		
Rolling Thin Film Oven (RTFO)	T 240	D 2872	
Pressure Aging Vessel (PAV)	PP 1		
Flash point	T 48	D 92	
Sampling bituminous materials	T 40	D 140	
Solubility of bituminous materials	T 44	D 2042	
Performance-graded binders	MP 1		
Specific gravity of bituminous materials	T 228	D 70	
Certifying suppliers of performance-graded asphalt binders	PP 26		
Grading or verifying the performance grade of an asphalt binder	PP 6		

Table 3. Aggregate tests.

Test Designation	Test Method Number		Certification Level
	AASHTO	ASTM	
Sieve analysis (gradation)	T 27	C 136	
Sieve analysis of extracted aggregate (gradation) Minus 0.075 mm (No. 200) by washing	T 30 T 11	C 117	
Specific gravity and absorption of fine aggregate	T 84	C 128	
Specific gravity and absorption of coarse aggregate	T 85	C 127	
Coarse aggregate (angularity) fractured particles (CAA)		D 5821	
Uncompacted void content of fine aggregate (fine aggregate angularity) (FAA)	T 304		
Flat or elongated particles in coarse aggregates		D 4791	
Sand equivalent	T 176	D 2419	
Los Angeles abrasion	T 96	C 131, C 535	
Soundness	T 104	C 88	
Deleterious materials	T 112	C 142	
Sampling aggregates	T 2	D 75	
Reducing samples of aggregate to testing size	T 248	C 702	
Bulk specific gravity of mineral filler	T 100	D 854	
Sieve analysis of mineral filler	T 37	D 546	
Liquid limit, plastic limit, and plastic index	T 89, T 90	D 4318	
Shrinkage limit	T 92		
Moisture content of aggregate	T 255	C 566	

Table 4. HMA tests.

Test Designation	Test Method Number		Certification Level
	AASHTO	ASTM	
Bulk specific gravity of compacted HMA - saturated surface dry (SSP)	T 166	D 2726	
Bulk specific gravity of compacted HMA - paraffin	T 275		

Bulk specific gravity of compacted HMA - parafilm		D 1188	
Percent air voids of compacted HMA	T 269	D 3203	
Theoretic max specific gravity of HMA	T 209	D 2041	
Superpave volumetric mix design (Spec)	MP 2		
Superpave volumetric mix design for HMA	PP 28		
Mixture conditioning of HMA	PP 2		
SHRP gyratory compactor	TP 4		
Sampling HMA	T 168	D 979	
Sampling compacted HMA		D 5361	
Resistance of HMA to moisture damage	T 283	D 4867	
Thickness of compacted HMA		D 3549	
Nuclear density		D 2950	
Asphalt content by nuclear method	T 287	D 4125	
Asphalt content by solvent extraction	T 164	D 2172	
Asphalt content by ignition method		D 6307	
Marshall and Hveem mixture design	R 12		
Marshall stability	T 245	D 1559	
Hveem stability	T 246	D 1560	
California kneading compactor	T 247	D 1561	

Table 5. Pavement roughness measurement.

Test Designation	Test Method Number		Certification Level
	AASHTO	ASTM	
Measurement of vehicular response to traveled surface roughness	T 286	E 1082	
Trailers used for measuring vehicle response to road roughness		E 1215	
Longitudinal profile of traveled surface with an accelerometer-established inertial profiling reference		E 950	
Pavement roughness using a profilograph		E 1274	
Road roughness by static level method		E 1364	

Table 6. Performance-graded asphalt binder specification.

PERFORMANCE GRADE	PG 46			PG 52							PG 58					PG 64					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day Maximum Pavement Design Temperature, °C[a]	<46			<52							<58					<64					
Minimum Pavement Design Temperature, °C[a]	>-34	>-40	>-46	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40
ORIGINAL BINDER																					
Flash Point Temp, T 48: Minimum °C	230																				
Viscosity, ASTM D 4402:[b] Maximum, 3Pa•s, Test Temp, °C	135																				
Dynamic Shear, TP 5:[c] G*/sinδ[g], Minimum, 1.00 kPa Test Temp @ 10 rad/s, °C	46			52							58					64					
ROLLING THIN FILM OVEN RESIDUE (T 240)																					
Mass Loss, Maximum, percent	1.00																				
Dynamic Shear, TP 5: G*/sinδ[g], Minimum, 2.20 kPa Test Temp @ 10 rad/s, °C	46			52							58					64					
PRESSURE THIN FILM OVEN RESIDUE (PP 1)																					
PAV Aging Temperature, °C[d]	90			90							100					100					
Dynamic Shear, TP 5: G*/sinδ[g], Maximum, 5000 kPa Test Temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Physical Hardening[e]	Report																				
Creep Stiffness, TP 1:[f] S, Maximum, 0.300 MPa, *m* - value, Minimum, 0.300 Test Temp @ 60s, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30
Direct Tension, TP 3:[f] Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30

°F = 1.8(°C) + 32

1 psi = 6.9 kPa

1 in. = 25.4 mm

Table 6. Performance-graded asphalt binder specification (continued).

PERFORMANCE GRADE	PG 70						PG 76					PG 82				
	10	16	22	28	34	40	10	16	22	28	34	10	16	22	28	34
Average 7-day Maximum Pavement Design Temperature, °C[b]	<70						<76					<82				
Minimum Pavement Design Temperature, °C[b]	>-10	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-10	>-16	>-22	>-28	>-34
ORIGINAL BINDER																
Flash Point Temp, T 48: Minimum °C	230															
Viscosity, ASTM D 4402:[b] Maximum, 3Pa•s, Test Temp, °C	135															
Dynamic Shear, TP 5:[c] G*/sinδ, Minimum, 1.00 kPa Test Temp @ 10 rad/s, °C	70						76					82				
ROLLING THIN FILM OVEN RESIDUE (T 240)																
Mass Loss, Maximum, percent	1.00															
Dynamic shear, TP 5: G*/sinδ, Minimum, 2.20 kPa Test Temp @ 10 rad/s, °C	70						76					82				
PRESSURE THIN FILM OVEN RESIDUE (PP 1)																
PAV Aging Temperature, °C[d]	100(110)						100(110)					100(110)				
Dynamic Shear, TP 5: G*/sinδ, Maximum, 5000 kPa Test Temp @ 10 rad/s, °C	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Physical Hardening[e]	Report															
Creep Stiffness, TP 1:[f] S, Maximum, 300.0 MPa, *m* - value, Minimum, 0.300 Test Temp @ 60s, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24
Direct Tension, TP 3:[f] Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-0	-6	-12	-18	-24

°F = 1.8(°C) + 32
1 psi = 6.9 kPa
1 in. = 25.4 mm

Table 6. Performance-graded asphalt binder specification (continued).

[a] Pavement temperatures are estimated from air temperatures using an algorithm contained in the Long-Term Pavement Performance program (LTPP Bind), may be provided by the specifying agency, or by following the procedures as outlined in MP 2 and PP 28.

[b] This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

[c] For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be used to supplement dynamic shear measurements of $G^*/\sin\delta$ at test temperatures where the asphalt is a Newtonian fluid.

[d] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures 90°C (194°F), 100°C (212°F), or 110°C (230°F). The PAV aging temperature is 100°C for PG 58- and above, except in desert climates, where it is 110°C.

[e] Physical Hardening - TP1 is performed on a set of asphalt beams according to Section 13.1, except the conditioning time is extended to 24 hours ± 10 minutes at 10°C (18°F) above the minimum performance temperature. The 24-hour stiffness and *m*-value are reported for information purposes only.

[f] If the creep stiffness is below 300 Mpa (43.5 ksi), the direct tension test is not required. If the creep stiffness is between 300 and 600 Mpa (43.5 and 87.0 ksi), the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The *m*-value requirement must be satisfied in both cases.

[g] $G^*/\sin\delta$ = high temperature stiffness and $G^*\sin\delta$ = intermediate temperature stiffness.

Table 7. Aggregate gradation control points.

	Nominal Maximum Aggregate Size - Control Point (Percent Passing)									
	37.5 mm		25.0 mm		19.0 mm		12.5 mm		9.5 mm	
Sieve Size	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
50.0 mm	100	–	–	–	–	–	–	–	–	–
37.5 mm	90	100	100	–	–	–	–	–	–	–
25.0 mm	–	90	90	100	100	–	–	–	–	–
19.0 mm	–	–	–	90	90	100	100	—	—	—
12.5 mm	–	–	–	–	–	90	90	100	100	–
9.5 mm	–	–	–	–	–	–	–	90	90	100
4.75 mm	–	–	–	–	–	–	–	–	–	90
2.36 mm	15	41	19	45	23	49	28	58	32	67
0.075 mm	0	6	1	7	2	8	2	10	2	10

1 in. = 25.4 mm

Table 8. Boundaries of aggregate restricted zone.

Sieve Size Within Restricted Zone	Minimum and Maximum Boundaries of Sieve Size for Nominal Maximum Aggregate Size (Minimum and Maximum Percent Passing)									
	37.5 mm		25.0 mm		19.0 mm		12.5 mm		9.5 mm	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
0.300 mm	10.0	10.0	11.4	11.4	13.7	13.7	15.5	15.5	18.7	18.7
0.600 mm	11.7	15.7	13.6	17.6	16.7	20.7	19.1	23.1	23.5	27.5
1.18 mm	15.5	21.5	18.1	24.1	22.3	28.3	25.6	31.6	31.6	37.6
2.36 mm	23.3	27.3	26.8	30.8	34.6	34.6	39.1	39.1	47.2	47.2
4.75 mm	34.7	34.7	39.5	39.5	–	–	–	–	–	–

1 in = 25.4 mm

Table 9. Superpave aggregate consensus property requirements.

Design ESALs[1] (million)	Coarse Aggregate Angularity (Percent), minimum		Uncompacted Void Content of Fine Aggregate (Percent), minimum		Sand Equivalent (Percent), minimum	Flat and Elongated[3] (Percent), maximum
	≤ 100 mm	> 100 mm	≤ 100 mm	> 100 mm		
< 0.3	55/-	-/-	-	-	40	-
0.3 to < 3	75/-	50/-	40	40	40	10
3 to < 10	85/80[(2)]	60/-	45	40	45	
10 to < 30	95/90	80/75	45	40	45	
≥ 30	100/100	100/100	45	45	50	

[1] Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years, and choose the appropriate N_{design} level.
[2] 85/80 denotes that 85% of the coarse aggregate has one fractured face and 80% has two or more fractured faces.
[3] Criterion based upon a 5:1 maximum-to-minimum ratio.

Note - If less than 25 percent of a layer is within 100 mm (4 in.) of the surface, the layer may be considered to be below 100 mm (4 in.) for mixture design purposes.

Table 10. Source aggregate property requirements.

Test Method			Requirement
Description	Number		
	AASHTO	ASTM	
Los Angeles abrasion (500 rev.)	T 96	C 131, C 535	45 percent maximum
Soundness ($MgS0_4$) (5 cycles)	T 104	C 88	18 percent maximum
Deleterious materials	T 112	C 142	1 percent maximum

Table 11. Asphalt binder sampling and testing for mixture design acceptance.

Test Method			Location of Sampling	Frequency
Description	Number			
	AASHTO	ASTM		
Rotational viscometer (original asphalt)		D 4402		1
Dynamic shear rheometer (original asphalt)	TP 5			1
Dynamic shear rheometer (RTFO-aged)	TP 5			1
Dynamic shear rheometer (PAV-aged)	TP 5			1
Bending beam rheometer (PAV-aged)	TP 1			1
Direct tension (PAV-aged)	TP 3			1
Flash point (original asphalt)	T 48	D 92		1
Solubility (original asphalt)	T 44	D 2042		1
Specific gravity (original asphalt)	T 228	D 70		1

Table 12. Aggregate sampling and testing for mixture design acceptance.

Test Method			Location of Sampling	Frequency
Description	Number			
	AASHTO	ASTM		
Coarse aggregate angularity		D 5821	Stockpiles	1
Fine aggregate angularity	T 304		Stockpiles	1
Flat and elongated particles		D 4791	Stockpiles	1
Sand equivalent	T 176	D 2419	Stockpiles	1
Los Angeles abrasion	T 96	C 131, C 535	Stockpiles	1
Soundness	T 104	C 88	Stockpiles	1
Deleterious materials	T 112	C 142	Stockpiles	1

Table 13. Superpave gyratory compaction effort.

Design ESALs[1] (million)	Compaction Parameters			Typical Roadway Application[2]
	$N_{initial}$	N_{design}	N_{max}	
< 0.3	6	50	75	Applications include roadways with very light traffic volumes such as local roads, county roads, and city streets where truck traffic is prohibited or at a very minimal level. Traffic on these roadways would be considered local in nature, not regional, intrastate, or interstate. Special purpose roadways serving recreational sites or areas may also be applicable to this level.
0.3 to < 3	7	75	115	Applications include many collector roads or access streets. Medium-trafficked city streets and the majority of county roadways may be applicable to this level.
3 to < 30	8	100	160	Applications include many two-lane, multilane, divided, and partially or completely controlled access roadways. Among these are medium to highly trafficked city streets, many state routes, US highways, and some rural interstates.
≥ 30	9	125	205	Applications include the vast majority of the US Interstate system, both rural and urban in nature. Special applications such as truck-weighing stations or truck-climbing lanes on two-lane roadways may also be applicable to this level.

[1] Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years, and choose the appropriate N_{design} level.

[2] Typical Roadway Applications as defined by *A Policy on Geometric Design of Highway and Streets*, 1994, AASHTO.

Note 1 – When specified by the agency and the top of the design layer is ≥ 100 mm from the pavement surface and the estimated design traffic level ≥ 0.3 million ESALs, decrease the estimated design traffic level by one, unless the mixture will be exposed to significant main line and construction traffic prior to being overlaid. If less than 25% of the layer is within 100 mm of the surface, the layer may be considered to be below 100 mm for mixture design purposes.

Note 2 – When the design ESALs are between 3 to < 10 million ESALs the agency may, at its discretion, specify $N_{initial}$ at 7, N_{design} at 75, and N_{max} at 115, based on local experience.

Table 14. Superpave volumetric mixture design requirements.

Design ESALs[1] (million)	Required Density (% of Theoretical Maximum Specific Gravity			Voids-in-the Mineral Aggregate, (Percent) minimum					Voids Filled With Asphalt, (Percent) minimum	Dust-to-Binder Ratio
				Nominal Maximum Aggregate						
	$N_{initial}$	N_{design}	N_{max}	37.5	25.0	19.0	12.5	9.5		
< 0.3	≤ 91.5	96.0	≤ 98.0	11.0	12.0	13.0	14.0	15.0	70 - 80[3,4]	0.6 - 1.2
0.3 to < 3	≤ 90.5								65 - 78[4]	
3 to < 10	≤ 89.0								65 - 75[2,4]	
10 to < 30										
≥ 30										

[1] Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years, and choose the appropriate N_{design} level.

[2] For 9.5-mm (3/8-in.) nominal maximum size mixtures, the specified VFA range shall be 73% to 76% for design traffic levels ≥3 million ESALs.

[3] For 25.0-mm (1.0-in.) nominal maximum size mixtures, the specified lower limit of the VFA shall be 67% for design traffic levels < 0.3 million ESALs.

[4] For 37.5-mm (1.5-in.) nominal maximum size mixtures, the specified lower limit of the VFA shall be 64% for all design traffic levels.

Note 18 – If the aggregate gradation passes beneath the boundaries of the aggregate restricted zone specified in Table 3 of MP2, consideration should be given to increasing the dust-to-binder ratio criteria from 0.6 - 1.2 to 0.8 - 1.6.

Table 15. Aggregate gradation and asphalt binder content tolerances for field trial section acceptance.

Sieve Size*		Tolerance, Mass
Metric, mm	U.S. Customary	
50	2.0-in.	± 3.0
37.5	1.5-in.	± 3.0
25	1-in.	± 3.0
19	3/4-in.	± 3.0
12.5	1/2-in.	± 3.0
9.5	3/8-in.	± 3.0
4.75	No. 4	± 3.0
2.36	No. 8	± 2.0
1.18	No. 16	± 2.0
0.600	No. 30	± 2.0
0.300	No. 50	± 2.0
0.150	No. 100	± 2.0
0.075	No. 200	± 0.7
Asphalt binder content,** percent by mass		± 0.13

*The gradation (AASHTO T 27) shall be determined after the asphalt content is determined by the Ignition Test (ASTM D 6307).
**Asphalt content determined by ASTM D 6307 (Ignition Test).

Note: Tolerances based on JMF1.

Table 16. Volumetric tolerances for field trial section acceptance.*

Test Method			Tolerances
Description	Number		
	AASHTO	ASTM	
• Gyratory-compacted sample properties at N_{design}	TP 4		
• Air voids (Va)	T 269	D 3203	± 1
• Voids in mineral aggregate (VMA)	PP 28		± 1
• Voids filled with asphalt (VFA)	PP 28		± 5
• Bulk specific gravity (Gmb)	T 166	D 2726	± 0.022
• Dust-to-binder ratio	PP 28		0.6 to 1.6
• Theoretical maximum specific gravity (Gmm)	T 209	D 2041	± 0.015
• In-place air voids	T 269	D 3203	2 to 7

Note: Tolerances based on JMF 1.

Table 17. Aggregate gradation and asphalt binder content tolerances for acceptance of JMF 3.

Sieve Size*		Tolerance, Mass
Metric, mm	U.S. Customary	
50	2.0-in.	± 5
37.5	1.5-in.	± 5
25	1-in.	± 5
19	3/4-in.	± 5
12.5	1/2-in.	± 5
9.5	3/8-in.	± 5
4.75	No. 4	± 5
2.36	No. 8	± 5
1.18	No. 16	± 3
0.600	No. 30	± 3
0.300	No. 50	± 3
0.150	No. 100	± 3
0.075	No. 200	± 1.6
Asphalt binder content,** percent by mass		± 0.4

*The gradation (AASHTO T 27) shall be determined after the asphalt content is determined by the Ignition Test (ASTM D 6307).
**Asphalt content determined by ASTM D 6307 (Ignition Test).

Note: Tolerances based on JMF 1.

Table 18. Asphalt binder sampling and testing.

Test Method			Contractor's Quality Control Testing*		Engineer's Verification Testing		Engineer's Quality Assurance Testing		Engineer's Pay Factor Testing	
Description	Number		Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency
	AASHTO	ASTM								
Rotational viscometer (original asphalt)		D 4402					Feed line**	1 per lot		
Dynamic shear rheometer (original asphalt)	TP 5						Feed line	1 per lot		
Dynamic shear rheometer (RTFO- aged)	TP 5 T 240						Feed line	1 per lot		
Dynamic shear rheometer (PAV- aged)	TP 5 PP 1						Feed line	1 per lot		
Bending beam rheometer (PAV- aged)	TP 1 PP 1						Feed line	1 per lot		
Direct tension (PAV- aged)	TP 3 PP 1						Feed line	1 per lot		
Flash point	T 48	D 92					Feed line	1 per lot		
Solubility	T 44	D 2042					Feed line	1 per lot		
Specific gravity	T 228	D 70								

*Meet requirements of PP 26.
**Asphalt binder feed line between contractor's storage tank and plant mixing chamber.

Table 19. Aggregate sampling and testing.

Test Method			Contractor's Quality Control Testing		Engineer's Verification Testing		Engineer's Quality Assurance Testing		Engineer's Pay Factor Testing	
Description	Number		Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency
	AASHTO	ASTM								
Coarse aggregate angularity		D 5821	Combined cold feed	1 sample per sublot*			Combined cold feed	1 sample per lot		
Fine aggregate angularity	T 304		Combined cold feed	1 sample per sublot			Combined cold feed	1 sample per lot		
Flat and elongated particles		D 4791	Combined cold feed	1 sample per sublot			Combined cold feed	1 sample per lot		
Sand equivalent	T 176	D 2419	Combined cold feed	1 sample per sublot			Combined cold feed	1 sample per lot		
Los Angeles abrasion	T 96	C 131, C 535	Combined cold feed	1 sample per lot			Combined cold feed	1 sample per 3 lots		
Soundness	T 104	C 88	Combined cold feed	1 sample per lot			Combined cold feed	1 sample per 3 lots		
Deleterious materials	T 112	C 142	Combined cold feed	1 sample per sublot			Combined cold feed	1 sample per lot		

*Five sublots per lot.
1 lot = 1 day's production.

Table 20. Quality control, quality assurance, and pay factor tests for HMA production and placement.

Test Method			Contractor's Quality Control Testing		Engineer's Verification Testing		Engineer's Quality Assurance Testing		Engineer's Pay Factor Testing	
Description	Number		Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency	Location of Sampling	Frequency
	AASHTO	ASTM								
A. Gradation	T 27	C 136	Behind paver	1 per sublot			Behind paver	1 per sublot	Behind paver	1 per sublot
B. Asphalt binder content		D 6307	Behind paver	1 per sublot			Behind paver	1 per sublot	Behind paver	1 per sublot
C. Gyratory-compacted sample properties at N_{design}	TP 4		Behind paver	1 per sublot			Behind paver	1 per sublot		
1. Air voids (Va)	T 269	D 3203		1 per sublot				1 per sublot		
2. Voids in mineral aggregates (VMA)	PP 28			1 per sublot						
3. Voids filled with asphalt (VFA)	PP 28			1 per sublot						
4. Bulk specific gravity (Gmb)	T 166	D 2726		1 per sublot				1 per sublot		
5. Dust-to-binder ratio	PP 28			1 per sublot						
6. Theoretical maximum specific gravity (Gmm)	T 209	D 2041		1 per sublot				1 per sublot		1 per sublot
D. In-place air voids	T 269	D 3203 D 2950		2 per sublot			Cores from pavement	2 per sublot	Cores from pavement	2 per sublot

Table 21. Aggregate gradation determination requirements for quality control, quality assurance, and pay factor testing.

Sieve Size		Contractor Quality Control Testing	Engineer's Quality Assurance Testing	Engineer's Pay Factor Testing
Metric, mm	U.S. Customary			
50	2.0-in.			
37.5	1.5-in.			
25	1-in.	X*		
19	3/4-in.	X		
12.5	1/2-in.	X		
9.5	3/8-in.			
4.75	No. 4			
2.36	No. 8	X	X	X
1.18	No. 16	X		
0.600	No. 30	X		
0.300	No. 50	X		
0.150	No. 100			
0.075	No. 200	X	X	X

*Use gradation control sieves for nominal maximum aggregate specified (19-mm [3/4-in.]) nominal maximum size aggregate requirements shown.

Table 22. Acceptable difference between contractor's and engineer's test results for asphalt binders.

Test Method			
Designation	Number		Acceptable Difference*
	AASHTO	ASTM	
Dynamic shear rheometer on original asphalt, G*/sin δ	TP 5		20 percent**
Dynamic shear rheometer on RTFOT-aged binder, G*/sin δ	TP 5 T 240	D 2872	20 percent**
Dynamic shear rheometer on PAV-aged binder, G* sin δ	TP 5 PP 1		20 percent**
Bending beam rheometer on PAV-aged binder, S-value	TP 1 PP 1		10 percent**
Bending beam rheometer on PAV-aged binder, m-value	TP 1 PP 1		0.015
Fracture strain on PAV-aged binder, fracture strain	TP 3 PP 1		30 percent

*Based on Utah DOT specification.
**Percent of average value of two test results.

Table 23. Acceptable difference between contractor and engineer's test results for aggregates.

Test Method			
Designation	Number		Acceptable Difference*
	AASHTO	ASTM	
Coarse aggregate angularity		D 5821	28
Fine aggregate angularity	T 304		1
Flat and elongated particles		D 4791	3**
Sand equivalent	T 176	D 2419	9
Los Angeles abrasion	T 96	C 131, C 535	13
Soundness	T 104	C 88	70 percent***
Deleterious materials	T 112	C 142	1.7

*Represent multi-laboratory precision for AASHTO or ASTM test methods.
**Estimated.
***Magnesium sulfate, percent of average value of test results.

Table 24. Pay factor adjustment for asphalt binder.

Property	Compliance Limit for Price Adjustment of 1.00	Rejection Limit for Price Adjustment of 0.75
G*/sin δ of the original performance-graded asphalt binder at high grade temperature, kPa	0.84 Min.	0.70 Min.
G*/sin δ of RTFO residue at high temperature, kPa	1.74 Min.	1.40 Min.
Stiffness of the PAV residue at low grade temperature + 10°C, MPa	311 Max.	355 Max.
Slope (m-value) of the creep curve at low grade temperature +10°C	0.294 Min.	0.265 Min.
Failure strain of PAV residue in direct tension at low grade temperature + 10°C[1]	1.04 Min.	0.78 Min.
[1]Use only for binders for which the test temperature for the low temperature properties is -18°C or colder.		

1 psi = 6.9 kPa
°F = 1.8(°C) + 32
Source: Utah DOT

ATTACHMENT A
STRATIFIED RANDOM SAMPLING

1.0 SCOPE

1.1 This method outlines the procedures for selecting sampling sites in accordance with appropriate random sampling techniques. Random sampling is the selection of a sample in such a manner that every portion of the material or construction to be sampled has an equal change of being selected as the sample. It is intended that all samples, regardless of size, type, or purpose, shall be selected in an unbiased manner, based entirely on chance.

2.0 SECURING SAMPLES

2.1 Samples shall be taken as directed by the contractor's Quality Control Representative for quality control purposes and by the SHA representative for acceptance purposes.

2.2 Sample location and sampling procedure are as important as testing. It is essential that the sample location be chosen in an unbiased manner.

3.0 RANDOM NUMBER TABLE

3.1 For test results or measurements to be meaningful, it is necessary that the material to be sampled or measured, be selected at random, which means using a table of random numbers. The following table of random numbers has been devised for this purpose. To use the table in selecting sample locations, proceed as follows.

3.2 A random number table is a collection of random digits. The random numbers that are presented in this annex are shown in a two-place decimal format. Note that there are two columns, labeled X and Y. The numbers in either column can be used to locate a random sample when only a single dimension is required to locate the sample (e.g., time, tonnage, and units). When two dimensions are required to locate the sample, the number in the X column is used to calculate the longitudinal location, and the number in the Y column is used to calculate the transverse location. In the Y column, each number is preceded by an L or R, designating that the sample increment is to be located transversely from the left or right edge of the pavement. Figure 1 illustrates the procedure.

3.3 Determine the lot size (continuous production for quality control at HMA plant) and stratify the lot into a number of sublots per lot for the material being sampled.

3.4 For each lot, use consecutive two-digit random numbers from Table 1. For example, if the

specification specifies five sublots per lot and the number 15 is randomly selected as the starting point for the first lot, number 15 through 19 would be the five consecutive two-digit random numbers. For the second lot, another random starting point, number 91, for example, is selected and the numbers 91 through 95 are used for the five consecutive two-digit random numbers. The same procedure is used for additional lots.

3.5 For samples taken from the roadway, use the decimal values in column X and column Y to determine the coordinates of the sample locations.

3.6 In situations where coordinate locations do not apply (i.e., plant samples, stockpile samples, etc.), use those decimal values from column X *or* column Y.

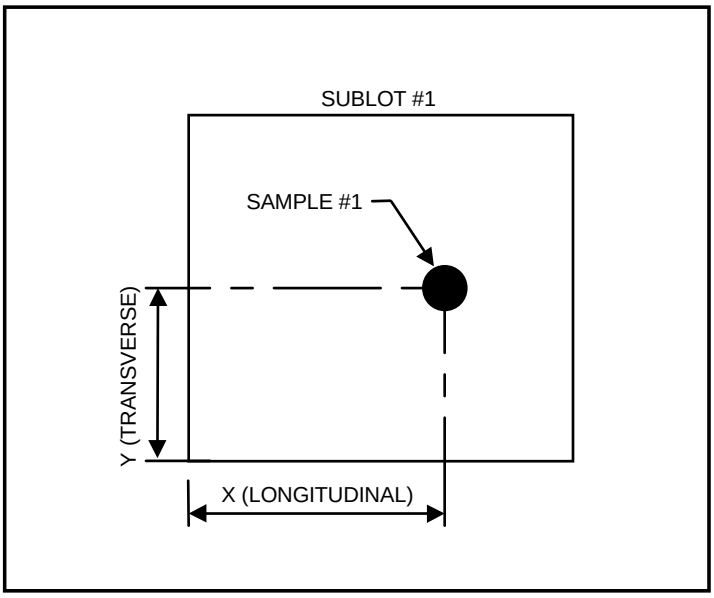
4.0 THE RANDOM SAMPLE

4.1 Examples demonstrating the use of the random sampling technique under various conditions are shown in Sections 4.1.1 through 4.1.3.

4.1.1 Sampling by Time Sequence

Assume that HMA for use in paving is to be sampled to determine the percentage of asphalt. It will be sampled at the place of manufacture. The task is to select a random sampling plan in order to distribute

Figure 1. Determination of sample location using random numbers.



the sampling over the half-day or the full-day, whichever is more applicable. Assume that the lot size is a day's production and that five samples are required from each lot. The plant is assumed to operate continuously for 9 hours (beginning at 7:00 a.m. and continuing until 4:00 p.m., with no break for lunch).

4.1.1.2 Lot Size. The lot size is a day's production. The plant starts at 7:00 a.m. and stops at 4:00 p.m. Hence, the lot size is 9 hours of production.

4.1.1.3 Sublot Size. Stratify the lot into five equal sublots, because five samples are required. To accomplish this, select five equal time intervals during the 9 hours that the plant is operating, as follows:

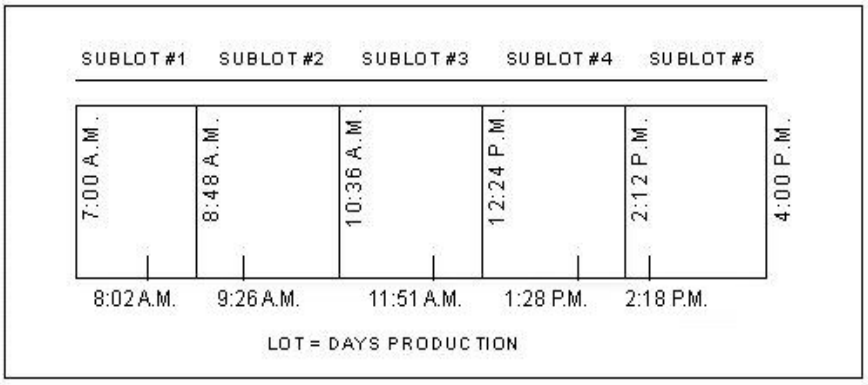
Sublot Time Interval =
[(9h / lot)(60 min / h)] / [5 sublots / lot]

Sublot Time Interval = 108 min/sublot

4.1.1.4 Sublot Samples. Next, choose five random numbers from the random number table. The first block randomly selected is reproduced below.

Sequence Number	X	Y	
12		0.57	R 0.49
13		0.35	R 0.90
14		0.69	L 0.63
15		0.59	R 0.68
16		0.06	L 0.03

4.1.1.5 The selected random numbers taken from the X column are 0.57, 0.35, 0.69, 0.56, and 0.06. To randomize the sampling times within each sublot,



the time interval (108 minutes) computed in Section 4.1.1.3 is used. This time interval is multiplied by each of the five random numbers previously selected:

Sublot 1: 0.57 x 108 = 62 min.
Sublot 2: 0.35 x 108 = 38 min.
Sublot 3: 0.69 x 108 = 75 min.
Sublot 4: 0.59 x 108 = 64 min.
Sublot 5: 0.06 x 108 = 6 min.

4.1.1.6 The times calculated in Section 4.1.1.5 are added to the starting times for each sublot. This results in the randomized times at which the samples are to be obtained. The sampling sequence is as follows:

Sublot Number	Sampling Time
1	7:00 a.m. + 62 min. = 8:02 a.m.
2	8:48 a.m. + 38 min. = 9:26 a.m.
3	10:36 a.m. + 75 min. = 11:51 a.m.
4	12:24 p.m. + 64 min. = 1:28 p.m.
5	2:12 p.m. + 6 min. = 2:18 p.m.

4.1.1.7 The random sampling times from Section 4.1.1.6 are shown in figure 2. If production is not available at the indicated time, a sample should be obtained at the first opportunity following the indicated time. Sampling on a time-basis is practical only when the process is continuous. Intermittent processes obviously present many difficulties.

Figure 2. Sublot sample times based on time sequence.

4.1.2 Sampling by Material Mass

4.1.2.1 HMA for use in paving must be sampled to determine the asphalt content. The specifications define the lot size as 4,500 Mg (5,000 tons) and state that five samples must be obtained from the

lot. The sampling is to be done from the hauling units at the manufacturing source. The total tonnage for the project is 18,000 Mg (20,000 tons).

4.1.2.2 Lot Size and Number of Lots. The lot size is 4,500 Mg (5,000 tons). Because there are 18,000 Mg (20,000 tons) of bituminous mix required for the project, the total number of lots is as follows:

Number of Lots =
[18,000 Mg (20,000)]/[4,500 Mg (5,000 tons)/lot] =
4 lots

4.1.2.3 Sublot Size. Stratify each lot into five equal sublots. The sublot size is as follows:

Sublot Size = [4,500 Mg (5,000 tons)/lot]/[5 sublots / lot]

Sublot Size = 900 Mg (1,000 tons)/sublot

The relationship between lot and sublot size is shown in figure 3.

sublot #1	sublot #2	sublot #3 900 Mg (typical)	sublot #4	sublot #5

<----------4,500 Mg (5,000 ton) lot---------->

Figure 3. Relationship between lot and sublots based on mass.

4.1.2.4 Sublot Samples. The number of samples per lot is five (one per sublot). Five random numbers are, therefore, selected from the table of random numbers. Again, the first block of numbers from the random number table is reproduced below. Note that a different set of numbers than that used in Section 4.1.1.4 is selected:

Sequence Number	X	Y
67	0.93	R 0.17
68	0.40	R 0.50
69	0.44	R 0.15
70	0.03	L 0.60
71	0.19	L 0.37

4.1.2.5 Select random numbers this time from the Y column, disregarding the L or R: 0.17, 0.50, 0.15, 0.60, and 0.37. Multiply the numbers by each of the five sublots as follows:

Sublot Number	Sublot Random Number	Size Mg (tons)	Sample from Mg (ton) No.
1	0.17	900 (1,000)	150 (170)

2	0.50	900 (1,000)	450 (500)
3	0.15	900 (1,000)	140 (150)
4	0.60	900(1,000)	540 (600)
5	0.37	900 (1,000)	330 (370)

4.1.2.5.1 The technician must obtain the first sample at approximately the 150th Mg (170th ton) of the first sublot. The technician must then wait until the first sublot is completed, 900 Mg (1,000 tons), before selecting the second sample at the 450th Mg (500th ton) of the second sublot. The same sequence is followed for obtaining the remaining three samples.

4.1.2.5.2 The sampling sequence for the lot of 4,500 Mg (5,000 tons) should be:

Sublot 1: 150th Mg (170th ton)
Sublot 2: 900+450 (1,000+500) = 1350th Mg (1500th ton)
Sublot 3: 1800+140 (2,000+150) = 1940th Mg (2150th ton)
Sublot 4: 2700+540 (3,000+600) = 3240th Mg (3600th ton)
Sublot 5: 3600+330 (4,000+370) = 3930th Mg (4370th ton)

4.1.2.5.3 Different random numbers are selected for the other four lots.

4.1.2.6 Sampling by production unit is a simple means of obtaining a random sample. Interruptions in the process do not affect randomization, and the relationship between the number of samples and the lot remains unchanged. Sublot sampling based on mass is illustrated in figure 4.

sublot #1 sample #1 150 Mg ■	sublot #2 sample #2 1350 Mg ■	sublot #3 sample #3 1940 Mg ■	sublot #4 sample #4 3340 Mg ■	sublot #5 sample #5 3930 Mg ■

<----------4,500 Mg (5,000 ton) lot---------->

Figure 4. Sublot sample based on mass.

4.1.3 Sampling an Area

4.1.3.1 Suppose that HMA from the roadway is to be sampled to determine the density for quality control or acceptance purposes. The specifications state that the lot size is 1,524 linear meters (5,000 ft), and five samples per lot are required. In addition, assume that the paving width is 3.66 m (12 ft) and that the project begins at Station 100+00 (100+00ft) and ends at Station 160+96 (300+00 ft).

4.1.3.2 Lot Size and Number of Lots

4.1.3.2.1 The specifications require a lot size of 1,524 linear meters (5,000 feet). The distance from Station 100+00 (100+00 ft) to Station 160+96 (300+00 ft) is 6,096 m (20,000 ft). The number of lots is calculated as follows:

Number of Lots =
[6,096 m (20,000 ft)]/[1,524 m (5,000 ft)/lot] =
4 lots

4.1.3.3 Sublot Size

4.1.3.3.1 The beginning station for the first lot is 100+00 (100+00 ft) This lot ends at Station 115+24 (150+00 ft) as shown in figure 5. This is equal to 1,524 m (5,000 ft). The 1,524 m (5,000 ft) of paving must be stratified into five equal sublots, since five samples per lot are required. The sublot size is calculated as follows:

Sublot Size =[1,524 m (5,000 ft)/lot]/[5 sublots / lot] =
304.8 m (1,000 ft) / sublot

4.1.3.3.2 Figure 5 shows how this lot is divided.

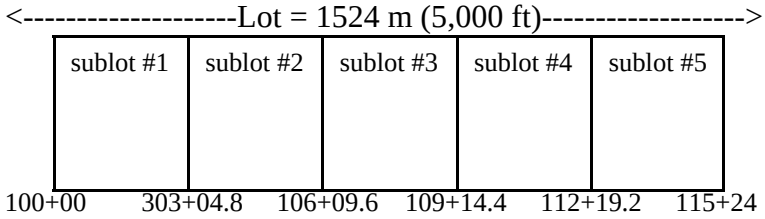


Figure 5. Relationship between lot and sublots based on area.

4.1.3.4 Sublot Samples

4.1.3.4.1 The location at which each sample will be obtained must be randomized in the longitudinal and the transverse directions. This was previously illustrated in figure 1.

4.1.3.4.2 The random number selection procedure is the same as used for the previous examples, except that two sets (columns and rows) of random numbers are selected: one for the transverse position, and one for the longitudinal position.

4.1.3.4.3 A set of five random numbers for the longitudinal (X) and transverse (Y) positions of the sample is chosen by using the first and second blocks of random numbers from the random number table. These are reproduced as follows:

Sequence Number	X	Y	
37		0.41	L 0.10
38		0.28	R 0.23
39		0.22	L 0.18
40		0.21	L 0.94
41		0.27	L 0.52

4.1.3.4.4 The X and Y random numbers in Section 4.1.3.4.3 are multiplied by the sublot length and paving width respectively, as shown below:

Sublot 1 (starting Station 100+00)
Coordinate X = 0.41 x 304.8 m (1,000 ft) = 125 m (410 ft)
Coordinate Y = 0.10 x 3.66 m (12 ft) = 0.4 m (1.2 ft)

Sublot 2 (starting Station 103+04.8 [110+00 ft])
Coordinate X = 0.28 x 304.8 m (1,000 ft) = 85.3 m (280 ft)
Coordinate Y = 0.23 x 3.66 m (12 ft) = 0.8 m (2.8 ft)

Sublot 3 (starting Station 106+09.6 [120+00 ft])
Coordinate X = 0.22 x 304.8 m (1,000 ft) = 67 m (220 ft)
Coordinate Y = 0.18 x 3.66 m (12 ft) = 0.7 m (2.2 ft)

Sublot 4 (starting Station 109+14.4 [130+00 ft])
Coordinate X = 0.21 x 304.8 m (1,000 ft) = 64 m (210 ft)
Coordinate Y = 0.94 x 3.66 m (12 ft) = 3.4 m (11.3 ft)

Sublot 5 (starting Station 112+19.2 [140+00 ft])
Coordinate X = 0.27 x 304.8 m (1,000 ft) = 82.3 m (270 ft)
Coordinate Y = 0.52 x 3.66 m (12 ft) = 1.9 m (6.2 ft)

4.1.3.4.5 The longitudinal distance (X) is added to the beginning station of the sublot and the companion transverse distance (Y) is measured from the selected edge of paving. The L values of Y will be measured from the left edge of paving (looking ahead) and the R values of Y will be measured from the right edge of paving.

Sample No.
1. Station 100+00 + 125 m (410 ft) = 101+25 (104+10 ft) @ 0.37 m (1.2 ft) from left edge
2. Station 103+04.8 (110+00 ft) + 85.3 m (280 ft) = 103+90.1 (112+80 ft); @ 0.8 m (2.8 ft) from right edge
3. Station 106+09.6 (120+00 ft) + 67 m (220 ft) = 106+76.6 (122+ 20 ft); @ 0.7 m (2.2 ft) from left edge
4. Station 109+14.4 (130+00 ft) + 64 m (210 ft) = 109+78.4 (132+10 ft); @ 3.4 m (11.3 ft) from left edge
5. Station 112+19.2 (140+00 ft) + 82.3 m (270 ft) = 113+01.5 (142+70 ft); @ 1.9 m (6.2 ft) from left edge

4.1.3.4.6 Figure 6 illustrates the sampling locations based on these calculations.

Figure 6. Sublot sample location based on area

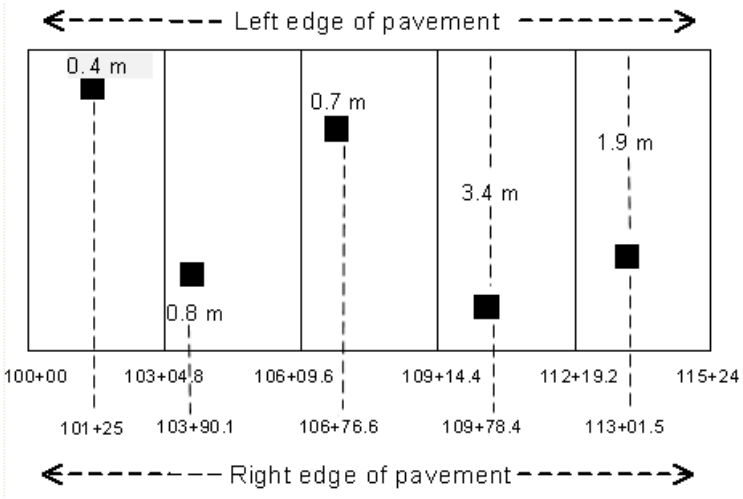


Table 1. Random positions in decimal fractions (two places).

Sequence No.	X	Y	Sequence No.	X	Y
1.	0.29	R 0.66	51.	0.87	L 0.36
2.	0.74	R 0.49	52.	0.34	L 0.19
3.	0.89	L 0.79	53.	0.37	R 0.33
4.	0.60	R 0.39	54.	0.97	L 0.79
5.	0.88	R 0.31	55.	0.13	R 0.56
6.	0.72	L 0.54	56.	0.85	R 0.64
7.	0.12	R 0.08	57.	0.14	L 0.04
8.	0.09	L 0.94	58.	0.99	R 0.74
9.	0.62	L 0.11	59.	0.40	L 0.76
10.	0.71	R 0.59	60.	0.37	L 0.09
11.	0.36	L 0.38	61.	0.90	R 0.74
12.	0.57	R 0.49	62.	0.09	L 0.70
13.	0.35	R 0.90	63.	0.66	L 0.97
14.	0.69	L 0.63	64.	0.89	L 0.55
15.	0.59	R 0.68	65.	0.67	L 0.44
16.	0.06	L 0.03	66.	0.02	R 0.65
17.	0.08	L 0.70	67.	0.93	R 0.17
18.	0.67	L 0.68	68.	0.40	R 0.50
19.	0.83	R 0.97	69.	0.44	R 0.15
20.	0.64	R 0.58	70.	0.03	L 0.60
21.	0.82	R 0.50	71.	0.19	L 0.37
22.	0.66	R 0.73	72.	0.92	L 0.45
23.	0.06	L 0.27	73.	0.20	L 0.85
24.	0.03	L 0.13	74.	0.05	R 0.56
25.	0.55	L 0.29	75.	0.46	R 0.58
26.	0.64	L 0.77	76.	0.43	R 0.91
27.	0.30	R 0.57	77.	0.97	L 0.55
28.	0.51	R 0.67	78.	0.06	R 0.51
29.	0.29	R 0.09	79.	0.72	L 0.78
30.	0.63	R 0.82	80.	0.95	L 0.36
31.	0.53	L 0.86	81.	0.16	L 0.61
32.	0.99	R 0.22	82.	0.29	R 0.47
33.	0.02	R 0.89	83.	0.48	R 0.15
34.	0.61	L 0.87	84.	0.73	R 0.64
35.	0.76	R 0.16	85.	0.05	L 0.94
36.	0.87	L 0.77	86.	0.43	L 0.05
37.	0.41	L 0.10	87.	0.87	R 0.98
38.	0.28	R 0.23	88.	0.37	L 0.71
39.	0.22	L 0.18	89.	0.94	L 0.26
40.	0.21	L 0.94	90.	0.57	L 0.63
41.	0.27	L 0.52	91.	0.26	R 0.80
42.	0.39	R 0.91	92.	0.01	L 0.79
43.	0.57	L 0.10	93.	0.83	R 0.59
44.	0.82	L 0.12	94.	O.71	L 0.21
45.	0.14	L 0.94	95.	0.65	L 0.63
46.	0.50	R 0.58	96.	0.65	L 0.87
47.	0.93	L 0.03	97.	0.72	R 0.92
48.	0.43	L 0.29	98.	0.85	L 0.78
49.	0.99	L 0.36	99.	0.04	L 0.46
50.	0.61	R 0.25	100.	0.29	L 0.95

X = Decimal fraction of total length measured along the road from starting point.
Y = Decimal fraction measured across the road from either outside edge towards center line of the paved lane.

ATTACHMENT B
STATISTICAL CONTROL CHARTS

1.0 PROCESS CONTROL

1.1 PROCESS CONTROL

The process control procedure recommended is the use of control charts, particularly statistical control charts. Control charts provide a means of verifying that a process is in control. It is important to understand that statistical control charts do not get or keep a process under control. The process must still be controlled by the plant or construction personnel. Control charts simply provide a visual warning mechanism to identify when the contractor or material supplier should look for possible problems with the process.

1.2 Variation of construction materials is inevitable and unavoidable. The purpose of control charts, then, is not to eliminate variability, but to distinguish between the inherent or chance causes of variability and a system of assignable causes. Chance causes (sometimes known as common causes) are a part of every process, and can be reduced but generally not eliminated. Assignable causes (sometimes known as special causes) are factors that can be eliminated, thereby reducing variability. Chance causes are something that a contractor or material supplier must learn to live with. They cannot be eliminated, but it may be possible to reduce their effects. The second cause of variation, assignable causes, can create major problems. However, assignable causes can be eliminated if they can be identified. Examples of assignable causes include gradation for an aggregate blend being out of specification because of a hole in one of the sieves or the cold feed conveyor setting being incorrectly adjusted.

1.3 The statistical control chart enables the contractor to distinguish between chance and assignable causes. Based upon statistical theory, construction materials under production control exhibit a "bell-shaped" or normal distribution curve.

1.4 Statistical control charts for averages or means rely on the fact that, for a normal distribution, essentially all of the values fall within ±3 standard deviations from the mean. The normal distribution can be used because the distribution of sample means is normally distributed. The data, therefore, can be assumed to be within $\pm 3\sigma$ of the mean or target when the process is in control and only chance causes are acting on the system.

1.5 A statistical control chart can be viewed as a normal distribution curve on its side (Figure 1). For a normal curve, only about 0.27% (1 out of 370) of the measurements should fall outside ± 3 standard

deviations from the mean. Therefore, control limits (indicating that an investigation for an assignable cause should be conducted) are set at $+3\sigma_{\bar{x}}$ and $-3\sigma_{\bar{x}}$.

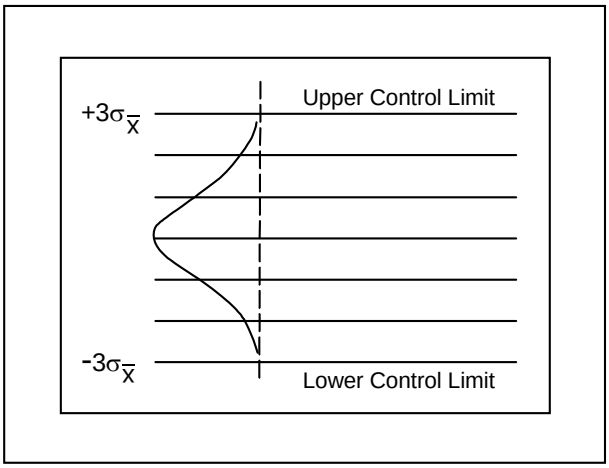


Figure 1. Example of statistical control chart.

1.6 A statistical control chart includes a target value, upper and lower control limits and a series of data points that are plotted. The target is based on the population or production mean and the control limits are established from the population or production standard deviation as shown in Figure 2.

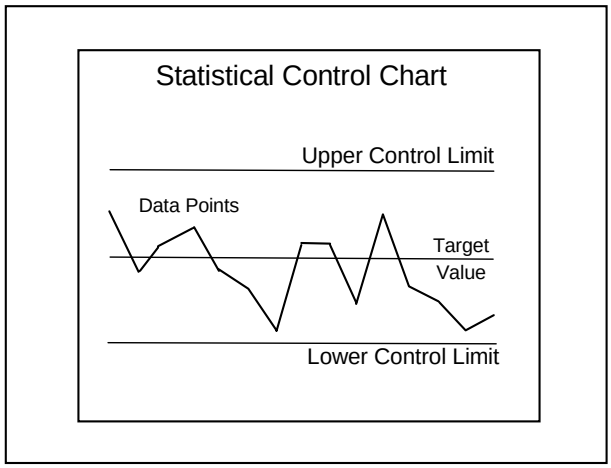


Figure 2. Elements of statistical control chart.

2.0 FORM OF STATISTICAL CONTROL CHARTS

2.1 Of the many forms of statistical control charts, two are most practical and useful for construction materials and processes. These are the control chart for means or averages (referred commonly to as x-bar chart or $\bar{x}$ chart) and the control chart for ranges (referred to commonly as an R-chart). The x-bar chart is typically used to control the production process about the average or target value. The R-chart considers the variability of the material and prevents extremely large positive and negative results from canceling out and not being detectable on the control chart for means or averages. The range, which is the easiest measure of spread to use in the field, is usually used in place of the standard deviation.

2.2 Population or production parameters (i.e., averages and ranges) are either known (or specified) or estimated from the early stages of the production process. In most cases, they are estimated. It is not a good idea for a producer to use the mean, range, or standard deviation specified or used by the highway agency when it developed the specification limits. The mean, range, or standard deviation of a producer's process is independent of the specification limits; each is established by the process capability.

2.3 When the mean and standard deviation are not known, they are estimated by the *grand average or mean* ($\bar{\bar{x}}$) and the *average range* (R-bar). The grand average or mean is defined as the average value of a group of averages. The average range is defined as the average of individual range values. The grand mean becomes the target value for the $\bar{x}$ chart and the average range becomes the target value for the R-bar chart.

2.4 The following formulae are used to construct the two control charts:

$\bar{x}$ Chart

$$\text{Upper Control Limit (UCL)} = \bar{x} + (A_2 \times \bar{R})$$

$$\text{Lower Control Limit (LCL)} = \bar{x} - (A_2 \times \bar{R})$$

R Chart

$$\text{Upper Control Limit (UCL)} = D_4 \times \bar{R}$$

$$\text{Lower Control Limit (LCL)} = D_3 \times \bar{R}$$

The factors A_2, D_3, and D_4 are obtained from Table 1 for the appropriate sample size, n. Note that the sample size is always greater than one. For each quality control test, the samples are grouped to form a subgroup two or more.

Table 1. Factors for statistical control charts.

n	A_2	D_3	D_4
2	1.88	0	3.27
3	1.02	0	2.58
4	0.73	0	2.28
5	0.58	0	2.12
6	0.48	0	2.00
7	0.42	0.08	1.92

3.0 CONTROL CHARTS WHEN MEAN AND STANDARD DEVIATION ARE UNKNOWN

3.1 The data shown in Table 2 will be used to illustrate the calculation for a control chart when the population parameters are unknown and are estimated from the early production process. The table contains the gradation results for percent passing the 4.75- mm (No. 4) sieve for 40 production days (4 tests per day). The average and range of the first 20 subgroups are

used to estimate the mean and standard deviation of the population. When this is done:

$\bar{\bar{x}}$ = (18.4 + 18.0 +. . .+ 18.4 + 16.4)/20 = 365.9/20 = 18.3

= (2.1 + 4.1 +. . .+ 4.7 + 3.9)/20 = 83.6/20 = 4.2

3.2 Subsequent to estimating $\bar{\bar{x}}$ and R-bar in accordance with Section 3.1, the upper and lower control limits can be calculated from the formulas in Section 2.4. Note that the values for A_2, D_3, and D_4 are for a sample subgroup of n = 4 because four samples are used to find each average, $\bar{x}$, and range, R-bar.

$\bar{R}$ $\bar{\bar{x}}$ Chart

UCL = $\bar{\bar{x}}$ + (A_2 x R-bar) = 18.3 + (0.73 x 4.2) = 21.4

LCL = $\bar{\bar{x}}$ - (A_2 x R-bar) = 18.3 - (0.73 x 4.2) = 15.2

Target Value = $\bar{\bar{x}}$ = 18.3

R-bar Chart

UCL = D_4 x R-bar = 2.28 x 4.2 = 9.6

LCL = D_3 x R-bar 0.0 x 4.2 = 0.0

Target Value = R-bar = 4.2

3.3 After establishing the target value and control limits, construct the control charts using the data in Table 2. Figures 3 and 4 illustrate the $\bar{\bar{x}}$ and R-bar charts for the data.

Table 2. Data for demonstration example.

Percent Passing 4.75-mm (No. 4) Sieve						
No.	**X_1**	**X_2**	**X_3**	**X_4**	**$\bar{\bar{x}}$**	**R**
1	18.9	18.2	19.3	17.2	18.4	2.1
2	18.2	16.3	17.2	20.4	18.0	4.1
3	18.5	19.5	17.8	19.1	18.7	1.7
4	19.7	17.6	18.3	19.2	18.7	2.1
5	23.5	22.5	14.9	23.6	21.1	8.7
6	16.6	16.9	17.4	18.8	17.4	2.2
7	19.0	17.9	15.8	18.4	17.8	3.2
8	14.5	17.7	18.0	20.1	17.6	5.6

9	18.5	16.3	17.3	17.2	17.3	2.2
10	15.2	20.4	20.4	16.4	18.1	5.2
11	19.5	16.4	20.7	17.7	18.6	4.3
12	17.4	17.9	17.7	22.4	18.9	5.0
13	15.6	18.1	18.7	19.8	18.1	4.2
14	22.2	17.1	16.7	21.2	19.3	5.5
15	20.1	12.8	18.5	17.0	17.1	7.3
16	19.6	18.0	17.4	14.8	17.5	4.8
17	19.5	19.9	20.1	15.7	18.8	4.4
18	19.9	20.7	19.8	18.3	19.7	2.4
19	20.9	19.9	16.5	16.3	18.4	4.7
20	14.2	18.1	17.1	16.2	16.4	3.9
21	16.7	13.6	11.4	18.4	15.0	7.0
22	18.7	17.3	16.1	15.8	17.0	2.9
23	22.7	18.3	23.8	15.3	20.0	8.5
24	17.3	18.2	16.8	17.2	17.4	1.4
25	20.8	16.7	16.0	22.1	18.9	6.1
26	17.5	21.3	19.1	20.2	19.5	3.8
27	13.6	16.8	19.2	12.1	15.4	7.1
28	19.5	18.3	16.5	18.1	18.1	3.0
29	17.7	18.5	17.4	16.9	17.6	1.6
30	16.4	17.5	15.2	17.8	16.7	2.6
31	15.3	14.5	17.3	21.2	17.1	6.7
32	13.7	18.4	16.1	19.1	16.8	5.4
33	13.4	20.3	18.8	19.5	18.0	6.9
34	14.6	21.9	18.5	14.9	17.5	7.3
35	16.0	20.4	14.7	20.0	17.8	5.7
36	17.2	18.5	15.8	20.0	17.9	4.2
37	18.8	15.0	20.2	15.2	17.3	5.2
38	21.4	17.7	13.1	19.6	18.0	8.3
39	16.5	18.8	20.0	19.2	18.6	3.5
40	19.4	18.6	15.4	22.0	18.9	6.6

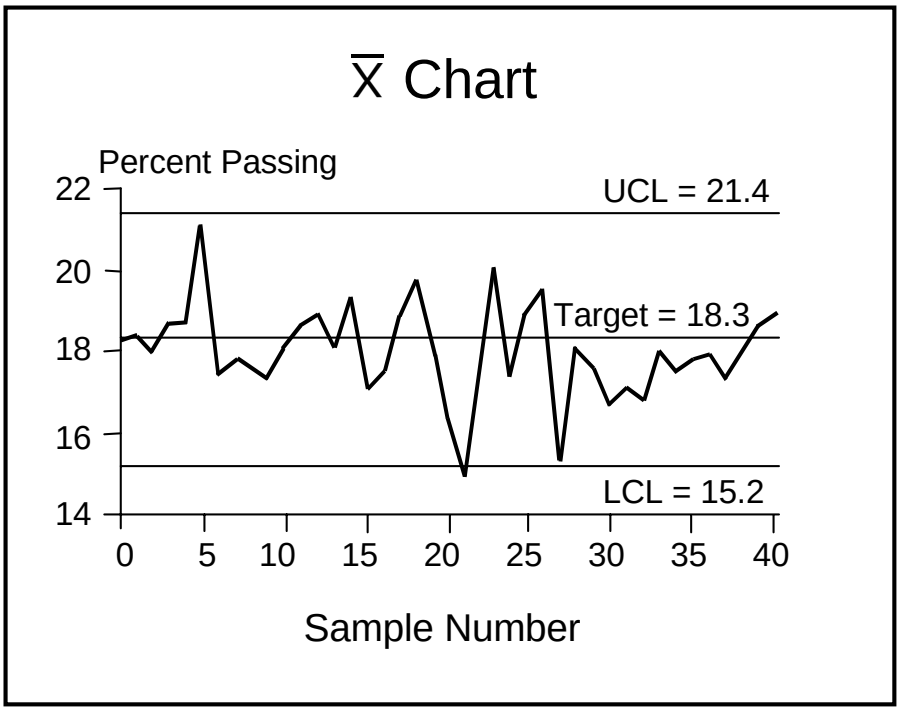


Figure 3. X-bar chart for percent passing 4.75-mm (No. 4) sieve.

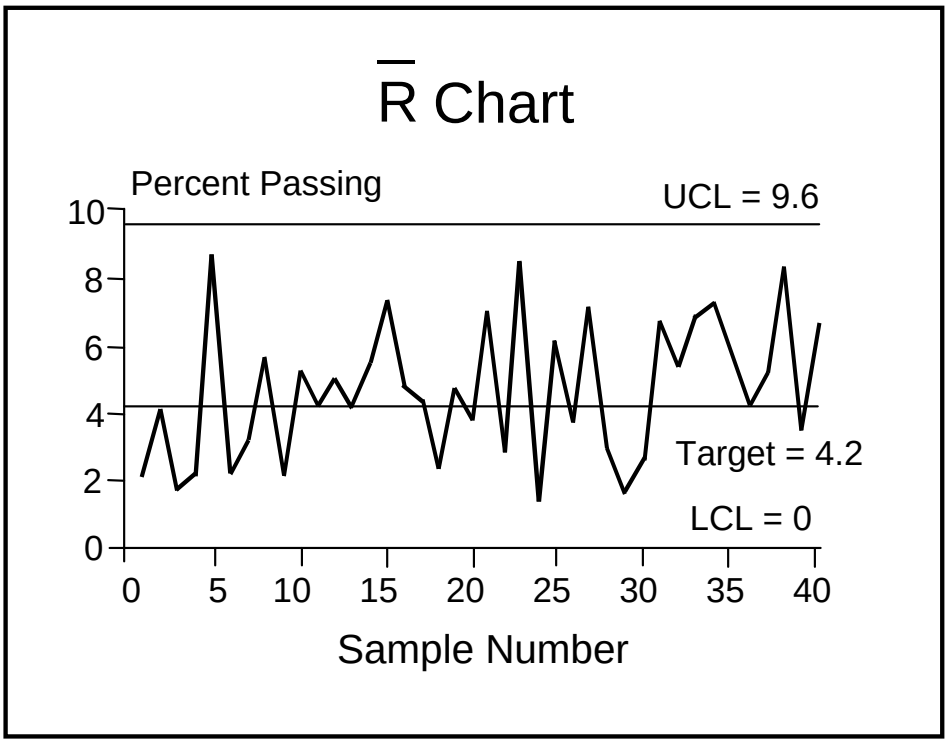


Figure 4. R-bar chart for percent passing 4.75-mm (No.4) sieve.

ATTACHMENT C
PERCENT WITHIN LIMITS FOR SUPERPAVE-DESIGNED HMA

1.0 SCOPE

1.1 This attachment provides the procedure for determinating of the percent of material or construction within the specification limits (PWL) established for the Superpave-designed HMA.

2.0 SIGNIGICANCE AND USE

2.1 The PWL is the principal calculation used in the Acceptance Plan to determine the acceptability of material or construction on the project.

3.0 PWL CALCULATION

3.1 Estimate the PWL in accordance with Sections 3.1.1 through 3.1.9.

3.1.1 Locate n sampling positions in the lot by use of Table 1 or other appropriate random number tables.

3.1.2 Make a measurement at each location or take a test portion and make the measurement on the test portion, as appropriate.

3.1.3 Average the lot measurements to find $\bar{x}$.

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

3.1.4 Determine the sample standard deviation, "s", of the lot measurements.

$$s = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1}}$$

3.1.5 Find the Quality Index, Q_u, by subtracting the average ($\bar{x}$) of the measurements from the upper specification limit (U) and dividing the results by "s".

3.1.6 Find the Quality Index Q_L by subtracting the lower specification limit (L) from the average ($\bar{x}$) and dividing the results by "s".

$$Q_L = \frac{\bar{x} - L}{s}$$

3.1.7 Estimate the percentage of material or construction that will fall within the upper tolerance limit (UTL) by locating the entry in Table 1 nearest the calculated Q_u, in the column appropriate to the total number (n) of measurements.

3.1.8 Estimate the percentage of material or construction that will fall within the lower tolerance limit (LTL) by

locating the entry in Table 1 nearest the calculated Q_L in the column appropriate to the total number (n) of measurements.

3.1.9 In cases where both upper (UTL) and lower (LTL) tolerance limits are concerned, find the percent of material that will fall within tolerances by adding P_u, the percent within the upper tolerance limit (UTL), to P_L, the percent within the lower tolerance limit (LTL) and subtract 100 from the sum.

Total PWL = $(P_u + P_L) - 100$

Table 1. Quality index values for estimating percent within limits.

PWL	n = 3	n = 4	n = 5	n = 7	n = 10	n = 15
99	1.16	1.47	1.68	1.89	2.04	2.14
98	1.15	1.44	1.61	1.77	1.86	1.93
97	1.15	1.41	1.55	1.67	1.74	1.80
96	1.15	1.38	1.49	1.59	1.64	1.69
95	1.14	1.35	1.45	1.52	1.56	1.59
94	1.13	1.32	1.40	1.46	1.49	1.51
93	1.12	1.29	1.36	1.40	1.43	1.44
92	1.11	1.26	1.31	1.35	1.37	1.38
91	1.10	1.23	1.27	1.30	1.32	1.32
90	1.09	1.20	1.23	1.25	1.26	1.27
89	1.08	1.17	1.20	1.21	1.21	1.22
88	1.07	1.14	1.16	1.17	1.17	1.17
87	1.06	1.11	1.12	1.12	1.13	1.13
86	1.05	1.08	1.08	1.08	1.08	1.08
85	1.03	1.05	1.05	1.05	1.04	1.04
84	1.02	1.02	1.02	1.01	1.00	1.00
83	1.00	0.99	0.98	0.97	0.96	0.96
82	0.98	0.96	0.95	0.94	0.93	0.92
81	0.96	0.93	0.92	0.90	0.89	0.89
80	0.94	0.90	0.88	0.87	0.85	0.85
79	0.92	0.87	0.85	0.83	0.82	0.82
78	0.89	0.84	0.82	0.80	0.79	0.78
77	0.87	0.81	0.79	0.77	0.76	0.75
76	0.84	0.78	0.76	0.74	0.72	0.72
75	0.82	0.75	0.73	0.71	0.69	0.69
74	0.79	0.72	0.70	0.67	0.66	0.66
73	0.77	0.69	0.67	0.64	0.63	0.62
72	0.74	0.66	0.64	0.61	0.60	0.59
71	0.71	0.63	0.60	0.58	0.57	0.56
70	0.68	0.60	0.58	0.55	0.54	0.54
69	0.65	0.57	0.55	0.53	0.51	0.51
68	0.62	0.54	0.52	0.50	0.48	0.48
67	0.59	0.51	0.49	0.47	0.46	0.45
66	0.56	0.48	0.46	0.44	0.43	0.42
65	0.53	0.45	0.43	0.41	0.40	0.40
64	0.49	0.42	0.40	0.38	0.37	0.37
63	0.46	0.39	0.37	0.35	0.35	0.34
62	0.43	0.36	0.34	0.33	0.32	0.31
61	0.39	0.33	0.31	0.30	0.30	0.29
60	0.36	0.30	0.28	0.25	0.25	0.25

Note 1: For negative values of Q_U or Q_L, P_U or P_L is equal to 100 minus the tabular P_U or P_L.
Note 2: If the value of Q_U or Q_L does not correspond exactly to a value in the table, use the next higher value.

ATTACHMENT D
STATISTICAL VERIFICATION TEST

1.0 SCOPE

1.1 The engineer will determine the acceptability of the contractor's quality control test data for material acceptance purposes using the *t*-test for sample means.

2.0 SIGNIFICANCE AND USE

2.1 The contractor's quality control test data will be considered verified at a level of significance, α = 0.01.

3.0 STATISTICAL VERIFICATION

3.1 The *t*-value, *t*, of the group of test data to be verified is computed as follows:

and

$$s_p^2 = \frac{s_c^2(n_c - 1) + s_v^2(n_v - 1)}{n_c + n_v - 2} \qquad t = \frac{|\bar{x}_c - \bar{x}_v|}{s_p\sqrt{\frac{1}{n_c} + \frac{1}{n_v}}}$$

where:

n_c = number of contractor's quality control tests (minimum of two required)

n_v = number of verification tests (minimum of one required)

x_c = mean of the contractor's quality control tests

x_v = mean of the verification tests

s_p = pooled standard deviation (when $n_v = 1$, $s_p = s_c$)

s_c = standard deviation of the contractor's quality control tests

s_v = standard deviation of the verification tests or, when $n_v = 1$, use s_c

3.2 Compute *t* using the equation above and compare to the critical *t*-value, t_{crit}, from the following table:

Critical *t*-value for verification testing.

degrees of freedom ($n_c + n_v - 2$)	t_{crit} for $\alpha = 0.01$
1	63.657
2	9.925
3	5.841
4	4.604
5	4.032
6	3.707
7	3.499
8	3.355
9	3.250
10	3.169
11	3.106
12	3.055
13	3.012
14	2.977
15	2.947
16	2.921
17	2.898
18	2.878
19	2.861
20	2.845
21	2.831
22	2.819
23	2.807
24	2.797
25	2.787
26	2.779
27	2.771
28	2.763
29	2.756
30	2.750
31 - 40	2.704
41 - 60	2.660
61 - 120	2.617
greater than 120	2.576

3.3 When the *t*-values of the test data from the engineer's verification tests and the contractor's quality control tests are compared with t_{crit} from the previous table, if *t* is less than or equal to t_{crit} ($t \leq t_{crit}$), the difference between the contractor's quality control test data and the corresponding engineer's

verification test data is not significant, and the contractor's test data are verified.

When n t is greater than t_{crit} ($t > t_{crit}$), the difference between the contractor's quality control test data and the corresponding engineer's verification test data is significant, and the contractor's test data are not verified.

WesTrack
Construction Specifications

WesTrack Technical Report
UNR-31

Prepared by:
Federal Highway Administration; Granite Construction; Nevada Automotive Test Center;
Nichols Consulting Engineers, Chtd.; Oregon State University;
University of California at Berkeley; University of Nevada, Reno

Primary Authors:
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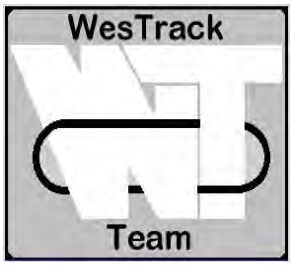

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INTRODUCTION

WesTrack[1,2,3] was a hot-mix asphalt (HMA) accelerated pavement test (APT) facility located in the State of Nevada approximately 100 km (60 mi) southeast of Reno, Nevada. The pavement test facility was designed, constructed, and operated by a team of private companies and universities (WesTrack Team) under contract to the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) from September 1994 through January 2000. The research contract was awarded in September 1994. The test track was designed and constructed during the period between October 1994 and October 1995, and was subjected to traffic from March 1996 through February 1999.

Track maintenance activities (including surface patching, digging out and replacing patches, milling and milling and filling with HMA) took place during the life of the facility. Ten of the 26 test sections on the 3-km (1.8-mi) oval track were replaced in June 1997. Approximately 5 million 80-kN (18,000-lb) equivalent single-axle loads (ESALs) were applied to the track.

The project had two primary objectives:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA volumetric design method.

This WesTrack technical report contains the construction specifications developed for construction of the project.

BACKGROUND

The construction specifications were prepared by Harding Lawson and Associates (under the direction of John Welsh) and by Jon Epps. The specification sections used on the projects are listed below and contained in appendix A.

- Section 201 Clearing and Grubbing
- Section 203 Excavation and Embankment
- Section 206 Structure Excavation
- Section 207 Backfill
- Section 302 Aggregate Base Course
- Section 406 Prime Coat
- Section 410 Hot-Mix Asphalt Pavement (Dense Graded)
- Section 502 Concrete Structures
- Section 601 Pipe Culverts
- Section 603 Reinforced Concrete Pipe

- Section 610 Riprap

The HMA specification contained an extensive set of guidelines for producing uniform paving mixtures. The hot-mix specification used the results of the AASHO Road Test and other literature[3] as a general guide for the specification limits.

SUMMARY

The specifications used in this document were used for the construction of WesTrack. During the construction of the project, some changes in the specification requirements were made to accommodate the actual construction operations. Properties of the subgrade, fill, base course, and HMA actually placed with these specifications are shown in other WesTrack technical reports (See references 4-15).

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1. Epps, J., Monismith, C., Seeds, S., Alavi, S., Ashmore, C., Leahy, R., and Mitchell, T., "WesTrack Performance – Interim Findings," *Journal of the Association of Asphalt Paving Technologists*, Volume 67, 1998.

2. Epps, J., Monismith, C., Seeds, S., Alavi, S., Ashmore, C., and Mitchell, T., "WesTrack Full-Scale Test Track: Interim Findings," *Proceedings*, Eighth International Conference on Asphalt Pavements, Volume III, August 10-14, 1997, Seattle, WA.

3. "Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction," *Task G Interim Report*, Final Draft, WesTrack Team, March 1996.

4. Ott, W., Seeds, S., Alavi, S., and Mactutis, J., "Outline for Preconstruction, Construction, and Materials Characterization for Natural Soil, Engineered Fill, and Base Course Material Placed at WesTrack," WesTrack Technical Report NCE-8, November 2000.

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13. Hand, A., and Epps, J., "WesTrack Replacement Construction Quality Assurance Asphalt Contents," WesTrack Technical Report UNR-17, July 2000.

14. Epps, J., Hand, A., and Sebaaly, P., "Quality Assurance Aggregate Gradations – Original

Construction," WesTrack Technical Report UNR-22, July 2000.

15. Epps, J., Hand, A., and Sebaaly, P., "Quality Assurance Aggregate Gradations – Replacement Sections," WesTrack Technical Report UNR-24, July 2000.

APPENDIX A

WESTRACK CONSTRUCTION SPECIFICATIONS

SECTION 201

CLEARING AND GRUBBING

PART 1 GENERAL

1.1 SECTION INCLUDES

A. Removal of surface debris within the construction limits.

B. Clearing and grubbing vegetation within the construction limits.

1.2 RELATED SECTIONS

A. SAMPLING AND TESTING by Harding Lawson and Associates

B. ANALYSIS AND DESIGN by Nichols Consulting Engineers

C. QA/QC DOCUMENT

D. SECTION 203 EXCAVATION AND EMBANKMENT

E. SECTION 206 STRUCTURE EXCAVATION

F. SECTION 207 BACKFILL

1.3 REGULATORY REQUIREMENTS

A. Conform to applicable State of Nevada and Lyon County codes for dust control.

PART 2 PRODUCTS (NOT USED)

PART 3 EXECUTION

3.1 CLEARING

A. All areas to receive fill shall be cleared and grubbed. All surface objects and protruding obstruction, grass and other vegetation shall be cleared and grubbed to a depth of 150 mm.

B. Contractor may place cleared and grubbed material as fill material in non-tangent sections and in on- and off-ramp areas. No cleared and grubbed material shall be placed as fill in tangent sections. Cleared and grubbed material placed as fill shall be placed and compacted according to the requirements of section 203 EXCAVATION AND EMBANKMENT.

C. Contractor shall leave the construction area with a neat and finished appearance.

3.2 DISPOSAL OF SURPLUS AND WASTE MATERIALS

A. Dispose of materials that are unsuitable in designated area.

B. Debris and waste generated by construction operations will be disposed of off-site.

C. Burning of refuse, debris or other materials will not be permitted on the site.

PART 4 MEASUREMENT AND PAYMENT

4.1 MEASUREMENT

A. The quantity of clearing and grubbing in hectares by plan dimensions, plus or minus authorized quantity changes, by the Principal Investigator will be the quantity used for payment.

4.2 PAYMENT

A. The accepted quantity of clearing and grubbing as measured in subsection 4.1 will be paid for at the contract unit price. That price will be considered full compensation for removing, hauling, disposing, filling, and compacting of all voids left by removals, trimming, grading, and dressing the area to drain, and all other work necessary to leave the area in a clean, presentable condition, and no further compensation shall be allowed therefore.

END OF SECTION

SECTION 203

EXCAVATION AND EMBANKMENT

PART 1 GENERAL

1.1 SECTION INCLUDES

A. Roadway excavation shall consist of all excavation involved in grading and constructing the roadway and appurtenances, irrespective of the nature or type of material encountered, except excavation designated as structure excavation.

1.2 APPLICABLE PUBLICATIONS

A. American Association of State Highway and Transportation Officials (AASHTO)

T 2-91	Sampling Aggregates
T 11-91	Material Finer than 75-μm Sieve in Mineral Aggregate by Washing
T 27-93	Sieve Analysis of Fine and Coarse Aggregates
T 89-93	Determining the Liquid Limit of Soils
T 90-92	Determining the Plastic Limit and Plasticity Index of Soils
T 180-93	Moisture Density Relations of Soils Using 4.54-kg Rammer and 457-mm Drop
T 191-93	Density of Soil In Place by the Sand Cone Method
T 283-89	Density of Soil and Soil-Aggregate In Place by Nuclear Methods (Shallow Depth)

B. American Society for Testing and Materials (ASTM)

E 11-87	Wire Cloth Sieves for Testing Purposes
D 2487-85	Classification of Soils for Engineering Purposes

1.3 RELATED SECTIONS

A. SAMPLING AND TESTING by Harding Lawson and Associates

B. ANALYSIS AND DESIGN by Nichols Consulting Engineers

C. QA/QC DOCUMENT

D. SECTION 201 CLEARING AND GRUBBING

E. SECTION 206 STRUCTURE EXCAVATION

F. SECTION 207 BACKFILL

G. SECTION 302 AGGREGATE BASE COURSE

1.4 REGULATORY REQUIREMENTS

A. Conform to applicable State of Nevada and Lyon County codes for dust control.

1.5 SUBMITTALS

A. Calibration data on testing devices and related test results, prior to using the device or equipment.

B. Five copies of field test results within 24 hours after tests are performed to the Principal Investigator.

1.6 DEFINITION

A. Lot: The definition of a lot shall be one of the following.

1. A lot shall constitute one lift (150 mm [compacted thickness]) in the test lane (3.7 m) for a length of 70 m on tangent sections.

2. A lot shall constitute one lift (150 mm [compacted thickness]) in the shoulders and bypass lane (4.9 m) for a length of 70 m on tangent sections.

3. A lot shall constitute one lift (150 mm [compacted thickness]) of 4300 square meters or portion thereof for non-tangent sections.

PART 2 PRODUCTS

2.1 SOIL MATERIALS

A. Engineered Fill: Soils free from stones or lumps of material exceeding 75 mm in greatest dimension and free from sod, frozen earth and organic materials. Contractor should be aware of varying on-site soil plasticities and moisture contents in order to properly prepare and place fill materials.

2.2 UNSUITABLE MATERIAL

A. Unsuitable material shall be defined as saturated or unsaturated mixtures of soils or organic matter not suitable for foundation material regardless of moisture content. Material that is unsuitable for planned use, including material below the natural ground surface in embankment areas, shall be excavated and disposed of in a manner approved by the Principal Investigator.

B. When unsuitable material is removed and disposed of, the resulting space shall be filled with material suitable for the planned use. Such suitable material shall be placed and compacted in layers as hereinafter specified.

PART 3 EXECUTION

3.1 PREPARATION

A. Protect subgrades and foundation soils against freezing temperatures or frost. Provide protective insulating materials as necessary.

B. Provide erosion control measures to prevent erosion or displacement of soils and discharge of soil-bearing water runoff or airborne dust to adjacent properties.

3.2 DEWATERING

A. Prevent surface water and subsurface or ground water from entering excavations, from ponding on prepared subgrades, and from flooding Project site and surrounding area.

B. Protect subgrades and foundation soils from softening and damage by rain or water accumulation.

C. Should rainfall or snowmelt occur, dry the structural fill to near optimum moisture and recompact the subgrade to between 90 and 94 percent of the maximum density as determined by AASHTO T-180.

D. Use of frozen fill material will not be allowed. Placement of fill on frozen ground will not be allowed.

E. When rains or snow-melt interrupt fill operations, the Principal Investigator shall inspect the surface before more fill is placed to verify that detrimental conditions do not exist.

3.3 STABILITY OF EXCAVATIONS

A. Comply with local codes, ordinances, and requirements of authorities having jurisdiction to maintain stable excavations.

B. The Contractor is cautioned to not cause a yielding or pumping of subgrade soils by overworking the subgrade soils with his construction equipment.

3.4 APPROVAL OF SUBGRADE

A. Notify Principal Investigator when excavations have reached required subgrade.

B. When Principal Investigator determines that unforeseen unsatisfactory soil is present, continue excavation and replace with satisfactory material as directed by the Principal Investigator.

C. Reconstruct subgrades damaged by freezing temperatures, frost, rain, accumulated water, or construction activities, as directed by the Principal Investigator.

3.5 STORAGE OF SOIL MATERIALS

A. Stockpile excavated materials acceptable for backfill and fill soil materials. Place, grade, and shape stockpiles to drain surface water. Cover to prevent wind-blown dust. Stockpile soil materials away from edge of excavations.

3.6 PREPARATION OF SUBGRADE

A. Remove vegetation, topsoil, debris, wet, and unsatisfactory soil materials, obstructions, and deleterious materials from ground surface prior to placing fills.

B. Original ground shall be stripped to sufficient depth to remove all loose surface soils.

C. Before fill placement, exposed surfaces should be scarified to a minimum depth of 150 mm and recompacted to between 90 and 94 percent relative compaction at or near optimum moisture content.

3.7 REWORKED MATERIAL

A. Reworked material shall be placed in one lift, 150 mm (cornpacted thickness), on prepared subgrade and compacted to between 90 and 94 percent relative compaction at or near optimum moisture content.

3.8 FILL

A. Engineered fill shall be placed in two lifts of not more than 150 mm (compacted thickness). Minimum thickness of the engineered fill shall be 300 mm (compacted thickness).

B. Fill shall be placed in lifts not to exceed 150 mm (compacted thickness). Fill shall be placed at the lowest point, of the fill below the grade. Individual layers shall be spread evenly to uniform thickness and parallel with the finished grade for the full width of the embankment.

C. Contractor may place cleared and grubbed material as fill material in non-tangent areas. No cleared and grubbed material shall be placed as fill in tangent sections or be used as engineered fill in tangent sections or beneath a test section.

3.9 GRADING

A. General: Uniformly grade areas to a smooth surface, free from irregular surface changes. Comply with compaction requirements and grade to cross sections, lines, and elevations indicated.

1. Provide a smooth transition between existing adjacent grades and new grades.

2. Cut out soft spots, fill low spots, and trim high spots to conform to required surface tolerances.

3. Holes or overexcavated area shall have the sideslopes laid back at 5:1 (horizontal:vertical) and fill placed in accordance with this specification.

3.10 MOISTURE CONTROL

A. Uniformly moisten or aerate subgrade and each subsequent fill or backfill layer before compaction at or near optimum moisture content.

1. Do not place backfill or fill material on surfaces that are muddy, frozen, or contain frost or ice.

2. Remove and replace, or scarify and air-dry satisfactory soil material that is too wet to compact to specified density.

a. Stockpile or spread and dry removed wet satisfactory soil material.

3.11 COMPACTION

A. When necessary, each layer of reworked material, fill or engineering fill shall be processed as required in order to bring its moisture content at or near the optimum moisture content before being compacted. The material shall be wetted by the application of water or dried as necessary and either process may be carried out either on the embankment or at the source of the material.

B. Hauling and leveling equipment shall be routed and distributed full width over each layer of the fill in such a manner as to uniformly distribute the compaction afforded thereby. In addition to hauling and leveling equipment, the Contractor shall provide compaction equipment that is specifically designed and manufactured for the purpose of compacting dirt embankments. Said compaction equipment shall work continuously with the grading equipment.

C. Reworked material, fill, or engineered fill, shall be compacted at or near optimum moisture content to between 90 and 94 percent of the maximum density as determined by AASHTO T 180-93. AASHTO T 191-93 or AASHTO T 238-86 may be used to determine the in-place density.

D. It is to be expected that a loss of density in the upper portion of each subgrade may occur due to the elements, or for lapse of time, or for other reasons. Recompaction to the specified density will be required prior to placement of any subsequent course and no additional compensation will be allowed therefore.

3.12 FIELD QUALITY CONTROL

A. Calibration curves and calibration test shall be furnished within 24 hours of the test.

B. For each lot of scarified and recompacted, reworked material, fill or engineered fill, five in-place field density tests, performed in accordance with AASHTO T 238-86, and two in-place field density tests, performed in accordance with AASHTO T 191-93, shall be required.

C. For each lot in non-tangent sections of reworked material, fill and engineered fill, the following tests shall be required: moisture content (AASHTO T 180-93), gradation (AASHTO T 27-93 and AASHTO T 11-91), plastic index (AASHTO T 90-92), and soil classification (ASTM D 2487-85).

D. Test Lane: For each lift of engineered fill, five in-place field density tests, performed in accordance with AASHTO T 238-86, and two in-place field density tests, performed in accordance with AASHTO T 191-93, shall be required for each test section.

3.13 PROTECTION

A. Protecting Graded Areas: Protect newly graded areas from traffic, freezing, and erosion. Kept free of trash and debris.

B. Repair and re-establish grades to specified tolerances where completed or partially completed surfaces become eroded, rutted, settled, or lose compaction due to subsequent construction operations or weather conditions.

1. Scarify or remove and replace materials to depth directed by the Principal Investigator; reshape and recompact at optimum moisture content to the required density.

C. Settling: Where settling occurs, remove finished surfacing, backfill with additional approved material, compact, and reconstruct surfacing.

1. Restore appearance, quality, and condition of finished surfacing to match adjacent work, and eliminate evidence of restoration to the greatest extent possible.

3.14 DISPOSAL OF SURPLUS AND WASTE MATERIALS

A. Materials that are unsuitable or material that is removed for the required correction of defective areas shall be disposed of in designated area.

B. Debris and waste generated by construction operations will be disposed of off-site.

C. Burning of refuse, debris or other materials will not be permitted on the site.

PART 4 MEASUREMENT AND PAYMENT

4.1 MEASUREMENT

A. The quantity of excavation cubic meters, by plan dimensions, plus or minus authorized quantity changes, by the Principal Investigator, will be the quantity used for payment.

4.2 PAYMENT

A. The accepted quantities of excavation measured as specified in subsection 4.1 will be paid for at the contract unit price bid based on the percent within limits (pwl). (Refer to the QA/QC Document for percent within limits (pwl) calculation). Such price shall include excavating, loading, hauling, depositing, spreading, watering, compacting and maintaining the material complete and in place.

END OF SECTION

SECTION 206

STRUCTURE EXCAVATION

PART 1 GENERAL

1.1 SECTION INCLUDES

A. This work shall consist of the removal of all material of whatever nature encountered for the excavation of trenches for pipe. Structure excavation shall include dewatering and the furnishing of all equipment and installation of all pipe as required.

1.2 APPLICABLE PUBLICATIONS

A. American Association of State Highway and Transportation Officials (AASHTO)

T 180-93	Moisture Density Relations of Soils Using 4.54 kg-Rammer and 457-mm Drop
T 191-93	Density of Soil In Place by the Sand Cone Method
T 265-91	Laboratory Determination of Moisture Content of Soils
T 238-86	Density of Soil and Soil Aggregate In Place by Nuclear Methods (Shallow Depth)
T 239-91	Moisture Content of Soil and Soil-Aggregate In Place by Nuclear Methods (Shallow Depth)

1.3 RELATED SECTIONS

A. SAMPLING AND TESTING by Harding Lawson and Associates

B. ANALYSIS AND DESIGN by Nichols Consulting Engineers

C. QA/QC DOCUMENT

D. SECTION 201 CLEARING AND GRUBBING

E. SECTION 203 EXCAVATION AND EMBANKMENT

F. SECTION 207 BACKFILL

G. SECTION 302 AGGREGATE BASE COURSE

1.4 REGULATORY REQUIREMENTS

A. Conform to applicable State of Nevada and Lyon County codes for dust control.

1.5 SUBMITTALS

A. Calibration data on testing devices and related test results, prior to using the device or equipment.

B. Provide five copies of field test results within 24 hours after tests are performed, to the Principal Investigator.

PART 2 PRODUCTS

2.1 SOIL MATERIALS

A. Suitable Material: Soils free from stone or lumps of material exceeding 75 mm in greatest dimension and free from sod, frozen earth, and organic materials.

PART 3 EXECUTION

3.1 EXCAVATION

A. Trenching: The width of trenches at any point below the top of the pipe shall not be greater than the outside diameter of the pipe plus 600 mm to permit satisfactory jointing and thorough tamping of the bedding material under and around the pipe. Sheeting and bracing where required shall be placed within the trench width as specified. Care shall be taken not to overexcavate.

B. Removal of Unsuitable Material: Where wet or otherwise unsuitable soil incapable of properly supporting the pipe, as determined by the Principal Investigator, is unexpectedly encountered in the bottom of the trench, such material shall be removed to the depth required and replaced to the proper grade with suitable material according to the requirements of Section 207 "Backfill."

C. Foundations for reinforced concrete pipe shall be compacted to between 90 and 94 percent of the maximum density as determined by AASHTO T 180-93. AASHTO T 191-93 or AASHTO T 283-86 may be used to determine the in-place density. See Section 207 BACKFILL for compaction requirements.

D. Should the Contractor remove foundation excavation below grade, he shall backfill to the required elevation at his own expense with suitable material in a manner satisfactory to the Principal Investigator.

E. Excavated material which is suitable for backfilling shall be so utilized or used in embankments, in a manner satisfactory to the Principal Investigator.

3.2 STABILITY OF EXCAVATIONS

A. Comply with local codes, ordinance, and requirements of authorities having jurisdiction to maintain stable excavations.

B. The Contractor is cautioned to not cause a yielding or pumping of subgrade soils by overworking the subgrade soils with his construction equipment.

3.3 DISPOSAL OF SURPLUS AND WASTE MATERIALS

A. Materials that are unsuitable or material that is removed for the required correction of defective areas shall be disposed of in designated area.

B. Debris and waste generated by construction operations will be disposed of off-site.

C. Burning of refuse, debris or other materials will not be permitted on the site.

PART 4 MEASUREMENT AND PAYMENT

4.1 PAYMENT

A. Structure excavation will be considered as incidental to the installation of the structure and compensation shall be considered as being included in the contract prices for other items of work.

END OF SECTION

SECTION 207

BACKFILL

PART 1 GENERAL

1.1 SECTION INCLUDES

A. This work shall consist of placing and compacting backfill material in trenches for pipes.

1.2 APPLICABLE PUBLICATIONS

A. American Association of State Highway and Transportation Officials (AASHTO)

T 180-93	Moisture Density Relations of Soils Using 4.54 kg -Rammer and 457- mm Drop
T 191-93	Density of Soil In Place by the Sand Cone Method
T 265-91	Laboratory Determination of Moisture Content of Soils
T 238-86	Density of Soil and Soil-Aggregate In Place by Nuclear Methods (Shallow Depth)
T 239-91	Moisture Content of Soil and Soil Aggregate In Place by Nuclear Methods (Shallow Depth)

1.3 RELATED SECTIONS

A. QA/QC DOCUMENT

B. SECTION 206 STRUCTURE EXCAVATION

C. SECTION 604 CORRUGATED METAL PIPE AND METAL ARCH PIPE

1.4 REGULATORY REQUIREMENTS

A. Conform to applicable State of Nevada and Lyon County codes for dust control.

1.5 SUBMITTALS

A. Calibration data on testing devices and related test results, prior to using the device or equipment.

B. Provide five copies of field test results within 24 hours after tests are performed to the Principal Investigator.

PART 2 PRODUCTS

2.1 BACKFILL

A. Satisfactory Soil Materials: Soils free from stones or lumps of material exceeding 75 mm in greatest dimension and free from sod, frozen earth, and organic materials. Contractor should be aware of varying on-site soil plasticities and moisture content in order to properly prepare and place fill materials.

PART 3 EXECUTION

3.1 PLACING BACKFILL

A. Foundations for culvert pipe shall be compacted to between 90 and 94 percent of the maximum density as determined by AASHTO T 180-03. AASHTO T 191-93 or AASHTO T 283-86 may be used to determine the in-place density.

B. Backfill material shall be placed in uniform horizontal layers not exceeding 200 mm in loose thickness before compaction and shall be brought up uniformly on all sides of the structure or improvement. Each layer of backfill shall be moistened or dried as necessary and thoroughly compacted to between 90 and 94 percent of the maximum density.

C. Compaction of backfill material by ponding or jetting will not be permitted.

3.2 PLACING AND COMPACTING CULVERTS

A. After the bedding has been prepared and the culverts installed or constructed as required by the pertinent specifications, acceptable material from excavation or from other sources shall be placed along both sides of the culvert equally in uniform layers not exceeding 200 mm in depth (loose measurements), wetted as required, and thoroughly compacted to the density requirements as set forth in subsection 3.1 "Placing Backfill."

B. Special care shall be taken in placing and thoroughly compacting the material under the haunches of all pipe.

C. No construction or other traffic shall be permitted to cross any culvert until a safe minimum depth of fill above the culvert has been placed and consolidated in accordance with these specifications. The contractor shall be solely responsible for protecting the structure from superimposed loading created by construction equipment or otherwise and shall repair any damage done to the structure or replace the structure as ordered without extra compensation.

3.3 TESTING

A. Field in-place density shall be determined in accordance with AASHTO T 191-93 or AASHTO T 238-86. When test results indicate that compaction is not as specified, the material shall be removed, replaced and recompacted to meet specification requirements at no additional expense to the owner. Tests on recompacted areas shall be performed to determine conformance with specification requirements.

B. One in-place field density test shall be required for each lift of backfill placed.

3.4 DISPOSAL OF UNSATISFACTORY MATERIALS

A. Dispose of removed in-place materials that are unsuitable and material that is removed for the required correction of defective areas shall be disposed of in designated area.

B. Debris and waste generated by construction operations will be disposed of off-site.

C. Burning of refuse, debris or other materials will not be permitted on the site.

PART 4 MEASUREMENT AND PAYMENT

4.1 PAYMENT

A. Backfill will be considered as incidental to the installation of the structure and compensation shall be considered as being included in the contract prices for other items of work.

END OF SECTION

SECTION 302

AGGREGATE BASE COURSE

PART 1 GENERAL

1.1. WORK INCLUDED

A. This work shall consist of placing and compacting aggregate base courses constructed in accordance with the requirements hereinafter set forth and in reasonably close conformity with the lines grades thickness and cross sections shown on the plans.

1.2 APPLICABLE PUBLICATIONS

A. American Society for Testing and Materials (ASTM)

E 11-87	Wire-Cloth Sieves for Testing Purposes

B. American Association of State Highway and Transportation Officials (AASHTO)

T 2-91	Sampling Aggregates
T 11-91	Materials Finer than 75-μm Sieve in Mineral Aggregate by Washing
T 27-93	Sieve Analysis of Fine and Coarse Aggregates
T 88-93	Particle-Size Analysis of Soils
T 89-93	Determining the Liquid Limits of Soils
T 90-92	Determining the Plastic Limit and Plasticity Index of Soils
T 96-92	Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
T 180-93	Moisture-Density Relations of Soils Using 4.54-kg Rammer and 457-mm Drop
T 190-93	Resistance R-Value and Expansion Pressure of Compacted Soils
T 191-93	Density of Soil in Place by the Sand-Cone Method
T 265-91	Laboratory Determination of Moisture Content of Soils
T 238-86	Density of Soil and Soil Aggregate in Place by Nuclear Methods (Shallow Depth)
T 239-91	Moisture Intent of Soil and Soil Aggregate In Place by Nuclear Methods (Shallow Depth)

C. Nevada Test Methods

Nev. T230	Fractured Faces

1.3 RELATED SECTIONS

A. SAMPLING AND TESTING by Harding Lawson and Associates

B. ANALYSIS AND DESIGN by Nichols Consulting Engineers

C. QA/QC DOCUMENT

D. SECTION 203 EXCAVATION AND EMBANKMENT

E. SECTION 406 PRIME COAT

1.4 SUBMITTALS

A. List of proposed equipment to be used in performance of construction work including descriptive data.

B. Certified copies of aggregate base test results for approval not less than 10 days before material is required for the work.

C. Calibration data on testing devices and related test results, prior to using the device or equipment.

D. Provide five copies of field test results within 24 hours after tests are performed to the Principal Investigator.

1.5 DEFINITION

A. Lot: The definition of a lot shall be one of the following.

1. A lot shall constitute one lift (112.5 mm [compacted thickness]) in the test lane (3.7 m) for a length of 70 m on tangent sections.

2. A lot shall constitute one lift (112.5 mm [compacted thickness]) in the shoulder and bypass lane (4.0 m) for a length of 70 m on tangent sections.

3. A lot shall constitute one lift (112.5 mm [compacted thickness]) of 4500 square meters or portion thereof for non-tangent sections.

PART 2 PRODUCTS

2.6 AGGREGATES

A. Gradation requirements specified herein shall apply to the completed base course. The aggregates shall be graded continuously well within the limits specified below. Sieves shall conform to ASTM E 11.

Aggregate Base Requirements		
Sieve Size	% Passing by Weight	
25 mm	100	
19 mm	90-100	
4.75 mm	35-65	
1.18 mm	15-40	
75.4 μm	2-10	
Test	Test Method	Requirement
Sieve Analysis	AASHTO T27-93	Above
Sampling Aggregate	AASHTO T2-91	-
Fractured Faces	Nev T230	50% min.
Liquid Limit	AASHTO T89-93	35% max.
Resistance (R-value)	AASHTO T190-93	78% min.
Percentage of Wear (500 rev)	AASHTO T96-92	45% max.
Plasticity Index	AASHTO T90-92	6 max.

PART 3 EXECUTION

3.1 PREPARATION

A. Any ruts, holes, defects, or soft yielding places which occur in the subgrade for any cause whatsoever shall be corrected and compacted to required density and stability before the aggregate base course is placed thereon. The above-mentioned repairs are to be made at the expense of the contractor.

3.2 STOCKPILING MATERIAL

A. Prior to stockpiling of material, storage sites shall be cleared and leveled by the Contractor. All materials shall be stockpiled on the cleared and leveled areas so as to prevent segregation. Materials obtained from different sources shall be stockpiled separately.

3.3 PLACING

A. The aggregate shall be uniformly deposited on the approved subgrade by means of the hauling vehicle with or without spreading devices. Aggregate shall be distributed over the surface to the depth specified on the plans.

After base course material has been deposited, it shall be thoroughly blade-mixed to full depth of the layer by alternately blading the entire layer to the center and back to the edges of the road. It shall be spread and finished to the required cross section by means of a self-propelled pneumatic tired motor grader.

At the option of the Contractor, the aggregate may he spread with a self-propelled spreader with the aggregate ready for compaction without further shaping. If this option is exercised, however, the Contractor shall follow subsection 3.5 WATERING AND MIXING FOR SELF-PROPELLED SPREADER.

3.4 WATERING

A. Water shall be applied prior to and during all blading and processing operations to moisten the material sufficiently to prevent segregation of the fine and coarse particles. Water shall be applied during the compaction and maintenance stages in sufficient amounts to assist in compaction and prevent raveling.

3.5 WATERING AND MIXING FOR SELF-PROPELLED SPREADER

A. The base course material and water shall be mixed in a mixer approved by the Principal Investigator. Water may be added during the mixing operation by means of spray bars in the amount necessary to provide the optimum moisture content for compacting. After mixing to the extent that the product has a uniform homogeneous appearance, the base material shall be transported to the job while it contains the proper moisture content and shall be placed on the roadbed by means of an approved self-propelled aggregate spreader. If the material has dried appreciably prior to final compacting, additional water shall be added by means of a pressurized water truck to assist in compaction and to prevent raveling.

B. Equipment used for applying water shall be pressure type distributors equipped with a spray system that will ensure uniform application of water. All watering equipment used for the application of water shall be equipped with a positive means of shutoff and the use of equipment not so equipped will not be permitted.

C. The self-propelled spreader shall be equipped with a control system which will automatically control the trimming of the base material to the specified transverse slope and established longitudinal grade. The control system shall be automatically activated from an independent line and grade control reference through a system of electronically controlled mechanical sensors which will maintain the trimmer screed at the proper transverse slope and at the proper elevation to obtain the required surface. In case of failure of the control system, the trimmer shall be operated by mechanical control only until the material on the roadbed at the time of breakdown is placed.

D. Motor patrols will not be considered to be self-propelled mechanical spreaders unless they are equipped with end wings on the blade, have the blade locked in a position normal to the direction of travel, and are equipped with cross slope and automatic grade controls that are capable of picking up grade from a wire control, and from an external sensing wheel. When motor patrols are used, the initial pass for final grade elevation will be controlled by the wire line. Subsequent passes will be controlled by an electronic sensing device capable of maintaining grade.

3.6 COMPACTION

A. The total compacted aggregate base course thickness shall be 225 mm, shall be compacted in two equal lifts and shall be compacted to between 90 and 95 percent of the maximum density at ±1/2% optimum water content as determined by AASHTO T 180-03. Rolling shall begin at the outside edge of the surface and proceed to the center, overlapping on successive trips at least one-half the width of the roller. Alternate trips of the roller shall be slightly different lengths. Speed of the roller shall be such that displacement of the aggregate does not occur. Areas inaccessible to the rollers shall be compacted with mechanical tampers and shall be shaped and finished by hand methods.

B. It is to be expected that the loss of density in the upper portions of the material may occur due to the elements or to a lapse in time, or for other reasons. Recompaction to the specified density will he required prior to the placement of any subsequent course and no additional compensation will be allowed for such recompaction.

3.7 FINISHING AND SURFACE TOLERANCE

A. The surface of the top layer shall be finished to grade and cross section shown on the plans. Finished surface shall be of uniform texture. Light blading during compaction may be necessary for the finished surface to conform to the lines, grades and cross sections shown on the plans. Should the surface for any reason become rough, corrugated, uneven in texture, or traffic marked prior to completion, such unsatisfactory portion shall be scarified, reworked, recompacted or replaced as directed by the Principal Investigator.

B. When a 3.7 m straight edge is laid in any direction, the finished surface shall not deviate at any point more than 10 mm.

3.8 FIELD QUALITY CONTROL

A. Calibration curves and calibration test shall be furnished within 24 hours of the test to the Principal Investigator.

B. For each lot, five in-place field density tests, performed in accordance with AASHTO T 238-86, and two in-place field density tests, performed in accordance with AASHTO T 191-93, shall be required.

3.9 TRAFFIC

A. Heavy equipment shall not be permitted except when necessary to construction, and then the area shall be protected against marring or damage to the completed work.

3.10 DISPOSAL OF SURPLUS AND WASTE MATERIALS

A. Dispose of removed in-place materials that are unsuitable and material that is removed for the required correction of defective areas shall be disposed of in designated area.

B. Debris and waste generated by construction operations will be disposed of off-site.

C. Burning of refuse, debris or other materials will not be permitted on the site.

PART 4 MEASUREMENT AND PAYMENT

4.1 MEASUREMENT

A. The quantity of aggregate base measured for payment will be the number of cubic meters by plan dimensions, plus or minus authorized quantity changes by the Principal Investigator, will be the quantity used for payment.

4.2 PAYMENT

A. The accepted quantity of aggregate base measured in subsection 4.1 Measurement id for at the contract unit price based on the percent within limits (pwl). (Refer to the QA/QC Document for percent within limits calculation.) Such payment will be considered full compensation for hauling, depositing, spreading, placing, compacting and maintaining the material complete in place.

END OF SECTION

SECTION 406

PRIME COAT

PART 1 GENERAL

1.1 SECTION INCLUDES

A. This work shall consist of preparing and treating an existing surface with bituminous material, in accordance with these specifications and in reasonably close conformity with the lines shown on the plans.

1.2 APPLICABLE PUBLICATIONS

A. American Association of State Highway and Transportation Officials (AASHTO)

T 40-78 Sampling Bituminous Materials

B. American Society for Testing and Materials (ASTM)

D 2027-76 Cutback Asphalt (Medium-Curing Type)

D 1250-80 Petroleum Measurement Tables

1.3 RELATED SECTIONS

A. QA/QC DOCUMENT

B. SECTION 302 AGGREGATE BASE COURSE

1.4 SUBMITTALS

A. Manufacturer's certified test results 30 days prior to application. Sampling and testing shall be performed by an approved commercial testing laboratory.

1.5 EQUIPMENT

A. The Contractor shall provide equipment for heating and applying the bituminous material.

B. The distributor shall be so designed, equipped, maintained and operated that bituminous material at even heat may be applied uniformly on variable widths of surface up to 4 meters at readily determined and controlled rates from 0.25 to 9.0 liters per square meter, with uniform pressure, and with an allowable variation from any specified rate not to exceed 0.10 liters per square meter. Distributor equipment shall include a tachometer, pressure gauges, accurate volume measuring devices or a calibrated tank, and a thermometer for measuring temperatures of tank contents. Distributors shall be equipped with a power unit for the pump, and full circulating spray bars adjustable laterally and vertically.

1.6 WEATHER LIMITATIONS

A. Bituminous material shall not be applied on a wet surface, when the temperature is below fifty degrees Fahrenheit (ten degrees celsius), or when weather conditions, in the opinion of the Principal Investigator, would prevent the proper construction of the prime coat.

PART 2 PRODUCTS

2.1 BITUMINOUS MATERIAL.

A. Emulsified asphalt shall conform to ASTM D 2027, Grade MC-70.

PART 3 EXECUTION

3.1 PREPARATION OF SURFACE

A. The surface upon which the bituminous prime coal is to be placed shall conform to the established lines and grades, shall be reasonably smooth and uniform and shall be compacted to the required density. If the required density deteriorates from the time the gravel course was compacted originally and the time the prime coat is placed, for any reason whatsoever, then the surface shall be recompacted to the required density at the expense of the Contractor. When required by the Principal Investigator, an application of water shall be applied immediately before the bituminous application.

3.2 APPLICATION OF BITUMINOUS MATERIAL

A. Bituminous material shall be applied to the width of the section to be primed by means of a pressure distributor in a uniform, continuous spread. Care shall be taken that the application of bituminous material at the junction of the spreads is not in excess of the specified amount.

Excess bituminous material shall be squeegeed from the surface. Skipped areas or deficiencies shall be corrected.

B. The bituminous material shall be applied at a rate of not less than 0.65 liters per square meter nor more than 1.43 liters per square meter of pavement surface. The exact quantity within the range specified will be determined by the Principal Investigator.

C. The bituminous material shall be applied at a temperature not less than 48 degrees Celsius nor more than 82 degrees Celsius.

3.3 TESTING AND SAMPLING

A. The samples of bituminous material shall be taken in accordance with AASHTO T 40-78.

B. Sources from which bituminous materials are to be obtained shall be selected and notification thereof furnished to the Principal Investigator 15 days after the Award of the Contract. Certified copies of the manufacturer's test reports indicating compliance with applicable specified requirements shall be submitted to the Principal Investigator not less than 30 days before material is required in the work.

C. Sample of the material shall be taken from the field and tested as directed by the Principal Investigator.

PART 4 MEASUREMENT AND PAYMENT

4.1 MEASUREMENT

A. The quantity of bituminous material to be measured for payment will be the number of liters at 15.6 degrees Celsius conforming to all the requirements in the completed work. Volumes measured at temperatures other than 15.6 degrees Celsius shall be corrected in accordance with ASTM D 1250-80 for liquid asphalt.

4.2 PAYMENT

A. The accepted quantity of bituminous material measured as provided in subsection 4.1 will be paid for at the contract unit price per liter.

END OF SECTION

SECTION 410
HOT-MIX ASPHALT PAVEMENT (DENSE-GRADED)

PART 1 DESCRIPTION

1.1 DEFINITION

Mix, transport, lay and compact a mixture composed of aggregate, asphalt cement with or without baghouse fines.

1.2 USE

The mixture shall be used as a surface as shown on the plans.

1.3 MIX

Mix materials at a central plant at elevated temperatures.

1.4 PLACEMENT

The mixture shall be placed in close compliance with the lines, grades, thickness and typical cross sections shown on the plans.

PART 2 MATERIALS

2.1 ASPHALT CEMENT

Asphalt cement shall be a PG 64-22 or 64-28 and meet the requirements as shown in Table 410.1.

2.2 AGGREGATE

Aggregate shall meet the requirements shown in Table 410.2 for a 19-mm nominal maximum size aggregate.

2.2.1 COARSE AGGREGATES

A. Coarse aggregate shall be retained on the No. 4 sieve.

2.2.2 FINE AGGREGATES

A. Fine aggregate shall be passing the No. 4 sieve. The fine aggregate must be stockpiled separately from other sizes of aggregate.

Table 410.1 AASHTO performance graded binder specification (MP1). WesTrack

Performance Grade	PG 52							PG 58					PG 64					PG 70			
	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-16	-22	-28	-34	-40	-10	-16	-22	-28
Average 7-day Maximum Pavement Design Temperature, °C [a]	<52							<58					<64					<70			
Minimum Pavement Design Temperature, °C [a]	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28
Original Binder																					
Flash Point Temp, T48 Minimum °C	230																				
Viscosity ASTM D 4402: [b] Maximum 3 pa-s (3000 cP), Test Temp, °C	135																				
Dynamic Shear, TP5: [c] G*/sin δ, Minimum 1.00 kPa Test Temp @ 10 rad/sec, °C	52							58					64					70			
Rolling Thin Film Oven (T240) or Thin Film Oven (T179) Residue																					
Mass Loss, Maximum, %	1.00																				
Dynamic Shear, TP5: G*/sin δ, Minimum 2.20 kPa Test Temp @ 10 rad/sec, °C	52							58					64					70			
Pressure Aging Vessel Residue (PPI)																					
PAV Aging Temperature, °C [d]	90							100					100					100(110)			
Dynamic Shear, TP5: G*/sin δ, Minimum 5000 kPa Test Temp @ 10 rad/sec, °C	25	22	19	16	13	10	7	25	22	19	16	13	28	25	22	19	16	34	31	28	25
Physical Hardening [e]	Report																				
Creep Stiffness, TP1: [f] S, Maximum, 300 MPa m-value, Minimum, 0.300 Test Temp @ 60 sec, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18
Direct Tension, TP3 : [f] Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18

Notes:

a. Pavement temperatures can be estimated from air temperatures using an algorithm contained in the SUPERPAVE™ software program or may be provided by the specifying agency, or by following the procedures as outlined in PPX.

b. This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

c. For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be substituted for dynamic shear measurements of G*/sin δ at test temperatures where the asphalt is a Newtonian fluid. Any suitable standard means of viscosity measurement may be used, including capillary of rotational viscometry (AASHTO T 201 or T 202).

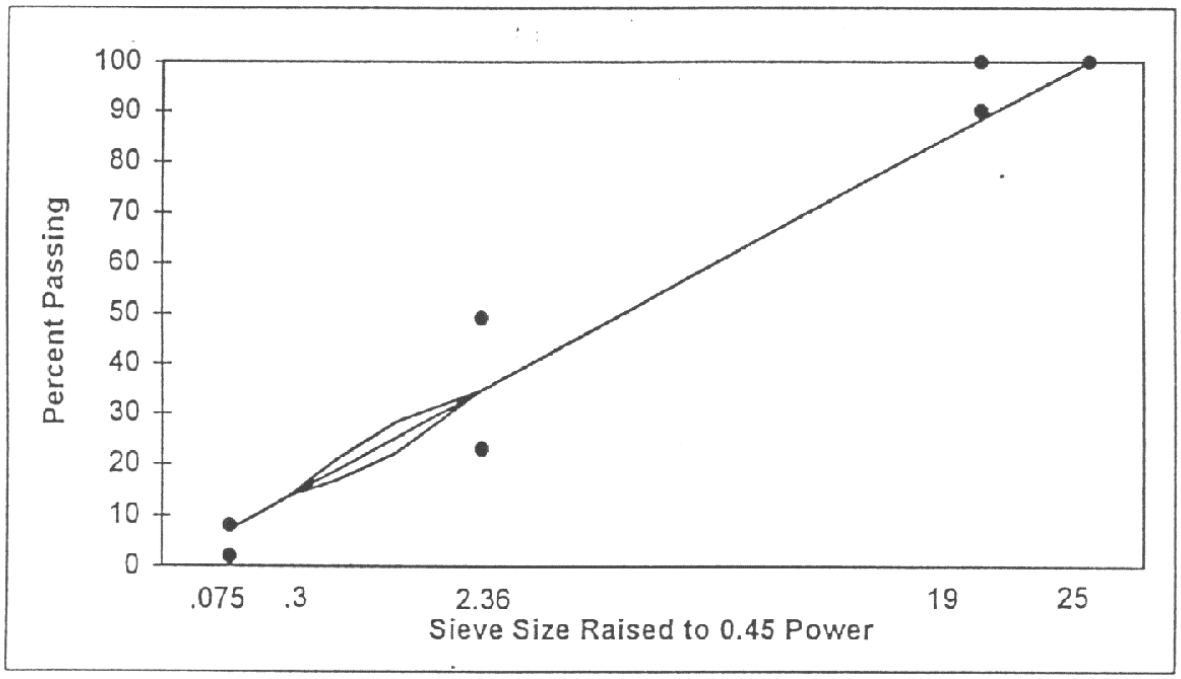
d. The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures 90°C, 100°C, or 110°C. The PAV aging temperature is 100°C for PG 58- and above, except in desert climates, where it is 110°C.

e. Physical Hardening - TP 1 is performed on a set of asphalt beams according to Section 13.1, except the conditioning time is extended to 24 hours ± 10 minutes at 10°C above the minimum performance temperature. The 24-hour stiffness and m-value are reported for information purposes only.

f. If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value requirement must be satisfied in both cases.

Table 410.2 SUPERPAVE, 19-mm nominal size.

Sieve mm	µm	0.45	Control Points		0.45 chart Max Dens	Restricted Zone Minimum Boundary	Restricted Zone Maximum Boundary
25.00	25000	95		100.00	100.00		
19.00	19000	84	100.00	90.00	88.40		
12.50	12500	70			73.20		
9.50	9500	62			64.70		
4.75	4750	45			47.40		
2.36	2360	33	49.00	23.00	34.60	34.6	34.6
1.18	1180	24			25.30	22.3	28.3
0.60	600	18			18.70	16.7	20.7
0.30	300	13			13.70	13.7	13.7
0.15	150	10			10.00		
0.075	75	7	8.00	2.00	7.30		



2.3 MINERAL FILLER

Commercial mineral filler shall be hydrated lime conforming to the requirements of ASTM C 1097 and shall be considered as part of the aggregate for gradation testing and gradation compliance.

2.4 BAGHOUSE FINES

2.4.1 PERMITTED USE

A. The addition of fines collected by a baghouse is permitted.

2.4.2 PART OF AGGREGATE

A. Baghouse fines shall be considered as part of the aggregate for gradation testing and gradation compliance.

PART 3 CONSTRUCTION REQUIREMENT

3.1 GENERAL

A. All equipment for the handling of materials, mixing, placing and compaction of the mixture shall be maintained in good repair and operating condition to produce a quality product.

3.2 STOCKPILING, STORAGE, FEEDING AND DRYING MATERIAL

3.2.1 STOCKPILING OF AGGREGATES

A. Prior to stockpiling of aggregates, the area shall be cleared of trash, weeds and grass and shall be relatively smooth and well drained.

B. Stockpiling shall be done in a manner that will minimize aggregate degradation, segregation and/or mixing of one stockpile with another.

C. Foreign material shall not be allowed to contaminate the stockpile(s).

D. Aggregates proportioned prior to the heating and drying process shall be separated into a minimum of two (2) sizes, one (1) coarse and one (1) fine.

E. All stockpiles shall remain separate.

F. Aggregates proportioned immediately after the heating and drying process shall be screened into a minimum of two (2) sizes, one (1) coarse and one (1) fine, if minus 12.5 mm (1/2 in.) aggregate is produced, and a minimum of three (3) sizes if larger-sized aggregate is produced. The screened material shall be conveyed to separate compartments ready for proportioning and mixing with bituminous material.

3.2.2 FEEDING AND DRYING OF AGGREGATE

A. If applicable, the feeding of various sizes of aggregate shall be done through the cold aggregate bins and a proportioning device that shall insure a uniform and constant flow of materials in the required proportions.

3.2.3 STORAGE AND HEATING ASPHALT BINDERS

A. Tanks for the storage of asphalt binders shall be equipped to heat and hold the material at the required temperatures.

B. All equipment shall be kept in a clean condition at all times and shall be operated in such a manner that there shall be no contamination with foreign material.

C. Asphalt cement shall be stored in tanks separate and apart from dryer burner fuel. The use of tanks with separate compartments that may be used to store two (2) or more products in a single enclosure or casing, and share any common components (bulkheads, heating coils, valves, etc.) that would allow either product to contaminate the other, will not be permitted for asphalt cement storage, unless all of the compartments are filled with the same product.

D. The heating apparatus shall be equipped with a continuous recording thermometer with a 24-hour chart that shall record the temperature of the asphalt binder at the location of the highest temperature. This thermometer shall be in operation during production of the HMA.

E. The temperature of the bituminous material just prior to mixing shall be established at a viscosity of 1.7 centistokes.

F. The heating shall be accomplished by any approved means that will not damage the asphalt cement.

G. Tanks shall be equipped to allow for measuring quantities of asphalt binder remaining in the tank.

H. The circulating system shall assure proper and continuous circulation during the operating period.

3.2.4 MINERAL FILLER FEEDING

Mineral filler shall be added by one of the following methods.

3.2.4.1 COLD-FEED METHOD

A. Hydrated lime (hereinafter referred to as mineral filler) shall be added to all plant- mix bituminous aggregates at the rate of not less than one (1) percent nor more than two and one-half (2-1/2) percent of the weight of the dry aggregate. The exact rate of application shall be as approved by the Principal Investigator.

B. Mineral filler shall be drawn from a storage facility in which the mineral filler is agitated by air or other means to keep it in a uniform free flowing condition. The mineral filler for delivery to the mixer shall be from a vane type metering device which is interlocked (electric driven feeders shall be actuated from the same circuit) to the flow of each aggregate feeder. The drive shaft on the mineral filler vane feeder shall be equipped with revolution counter reading to one-tenth (1/10) of a revolution, and means for varying the rate.

C. In continuous mix and/or drum dryer plants the mineral filler shall be added to the aggregate after the aggregate is proportioned.

D. In batch plants the mineral filler shall be added to the aggregate prior to drying.

E. Regardless of which type of plant is used, the following methods shall be utilized:

-- Prior to the introduction of the mineral filler sufficient moisture shall be added by way of spray bars at the aggregate bins to bring the aggregate to a moisture content at which enough free surface moisture is available to thoroughly wet the aggregate and activate the lime. This content is recommended to be between four (4) and five (5) percent. The actual amount of moisture required will be determined by the Principal Investigator. After the addition of water and mineral filler the aggregate shall be mixed using a horizontal twin-shaft pugmill. The mixing paddles shall be adjustable for angular position on the shaft to permit altering of the mixing pattern or retarding the flow to assure that the aggregate is thoroughly coated with mineral filler. The volume of material in the pugmill shall not extend above the vertical position of the blade tips. The completed mixture shall be directly introduced into the hot plant. Stockpiling of the completed mixture is strictly prohibited.

-- The moisture control valve shall be interlocked with the hot-plant control room so the moisture control valve is automatically turned off when the cold feed belts are shut off. The control valve shall also turn on automatically when the cold-feed belts are activated. The moisture control valve shall also be interlocked to the speed of the cold-feed belt so that an increase or decrease in the cold-feed belt speed shall result in proportional increase or decrease in moisture.

3.2.4.2 MARINATION METHOD

A. Mineral filler shall be added to all plant mix bituminous aggregates. The coarse aggregates are to be wet cured with mineral filler at a rate of one (1) percent of the weight of dry aggregate. The fine aggregates are to be wet cured with mineral filler at a minimum rate of two (2) percent of the weight of the dry aggregate. The aggregates are to be marinated (wet cured) in stockpiles for a minimum of forty-eight (48) hours.

B. The wet cured aggregate in the stockpile shall be used within forty-five (45) calendar days. Material marinated in stockpile in excess of forty-five (45) calendar days shall not be used for the production of HMA unless otherwise approved by the Principal Investigator.

C. Prior to the introduction of the mineral filler, sufficient moisture shall be added by way of spray bars at the aggregate bins to bring the aggregates to a moisture content where enough free surface moisture is available to thoroughly wet the aggregate and activate the lime. This content is recommended at three (3) percent for coarse aggregates and six (6) percent for the fine aggregates. The actual amount of moisture required will be determined by the Principal Investigator. After the addition of water and mineral filler, the aggregate shall be mixed using a horizontal twin-shaft pugmill. The mixing paddles shall be adjustable for angular position on the shaft to permit altering of the mixing pattern or retarding the flow to assure that the aggregate is thoroughly coated with mineral filler. The volume of material in the pugmill shall not extend above the vertical position of the

blade tips.

D. Mineral filler shall be drawn from a storage facility in which the mineral filler is agitated by air or other means to keep it in a uniform free flowing condition. The mineral filler for delivery to the mixer shall be from a vane type metering device which is interlocked (electric driven feeders shall be actuated from the same circuit) to the flow of each aggregate feed. The drive shaft on the mineral filler vane feeder shall be equipped with a revolution counter reading to one-tenth (1/10) of a revolution, and a means for varying the rate.

3.2.5 BAGHOUSE FEEDING

A. The feeding system used for baghouse fines shall be the same type as used for mineral filler. Calibration of the feed system shall be required.

B. In batch plants, the baghouse fines shall be added by the use of a separate bin.

C. In a continuous mix and/or a dryer drum plant, the baghouse fines shall be added at or near the asphalt feed line.

3.3 MIXING PLANT

The mixing plant shall be a drum mixing plant.

3.3.1 BURNER FUEL AND BURNER

A. Fuel used for heating aggregates shall be limited to the following types: natural gas, liquified natural gas, fuel oil (ASTM D 396, Grades No. 1 and No. 2), butane, propane, diesel fuel oil (ASTM D 975, Grades No. 1-D and No. 2-D).

B. The Contractor shall certify that burner fuels comply with the foregoing and the Certificate of Compliance shall conform to the requirements of Subsection 106.05 of the Standard Specifications.

C. The burner used for heating the aggregate shall achieve complete combustion of the approved fuel and not leave any fuel residue that will adhere to the heated aggregate.

D. Alternative burner fuels may be used when requested in writing and approved by the Principal Investigator. The request shall identify the proposed burner fuel and certify to its compliance with all local, State and Federal environmental requirements.

E. If, in the opinion of the Principal Investigator, the alternative burner fuel is detrimental to the final product, and upon written notice, its use shall cease immediately and one of the approved burner fuels shall be used.

3.3.2 REQUIREMENTS FOR ALL PLANTS

A. The Contractor shall install and maintain adequate equipment and take necessary precautions to meet federal, state and local government air quality and water quality regulations.

B. The Contractor shall install or have available platform scales to determine the weights of bituminous mixtures and hauling vehicles. Platform scales shall conform to the provisions of Subsection 109.01 “Measurement of Quantities.”

C. Adequate and safe access must be provided to the top of the truck bodies by a platform or other suitable access ports in the truck bodies to enable the Principal Investigator to obtain mixture temperature data.

D. Adequate safety equipment shall be provided on the plant to afford access for plant operation, maintenance, sampling and calibration.

3.3.3 BATCH PLANT

A. Shall not be used.

3.3.4 CONTINUOUS MIXING PLANTS
(Proportioned After Drying, Proportioned Before Drying, Drum Mixer)

A. A fully automated and computerized plant shall be provided with satisfactory means to afford a positive interlocking control between the flow of each feeder and the flow of the bituminous material, mineral filler and baghouse fines.

B. The plant shall include a continuous mixer, adequately heated and operated to produce a uniform mixture with a uniform coating of asphalt binder on the aggregate.

3.4 SURGE-STORAGE SYSTEM

3.4.1 CAPACITY

A. All continuous and drum mixer plants shall be equipped with a surge-storage system with a capacity in excess of 20 tons.

3.4.2 SEGREGATION

A. The surge-storage system shall be equipped with an approved surge batcher or other approved method satisfactory to the Principal Investigator that will prevent segregation of the HMA as it is being stored or discharged into the hauling vehicle.

3.4.3 STORAGE

A. Temporary storage or holding of hot-mix asphalt during the production day will be allowed. Storage for periods exceeding eight (8) hours shall not be permitted unless authorized by the Principal Investigator.

3.5 HAULING EQUIPMENT

3.5.1 TRUCKS

A. Trucks used for hauling hot-mix asphalt shall have tight, clean, smooth metal beds which have been thinly coated with a minimum amount of lime solution or other

approved material to prevent the mixture from adhering to the truck beds. Diesel or kerosene will not be allowed.

3.5.2 DISCHARGE INTO HAULING VEHICLES

A. The hot-mix asphalt shall be discharged from the surge-storage system directly into the hauling vehicle.

3.6 SURFACE PREPARATION

3.6.1 UTILITIES AND DRAINAGE STRUCTURE

A. Locate, reference and protect all instrumentation and other items affected by the paving operations.

3.6.2 OBJECTIONABLE MATERIAL

A. Remove all dirt, sand, leaves and other objectionable material from the prepared surface before placing the HMA.

3.7 PLACING

3.7.1 EQUIPMENT

A. The hot-mix asphalt shall be dumped and spread on the prepared surface with the spreading and finishing machine.

B. If windrow pick-up equipment is used, it shall be capable of removing and loading substantially all of the mixture deposited on the roadbed into the spreading and finishing machine.

C. Bituminous pavers shall be self-contained, power-propelled units, provided with an activated screed or strike-off assembly, heated if necessary, and capable of spreading and finishing courses of HMA in lane and shoulder widths applicable to the specified typical section and thicknesses shown on the plans.

D. Pavers shall be equipped with a receiving hopper having sufficient capacity for a uniform spreading operation. The hopper shall be equipped with a distribution system to place the mixture uniformly in front of the screed.

E. The screed shall be equipped with automatic controls which will make adjustments in both transverse and longitudinal direction. The external longitudinal reference devices used to pick up grade information for the automatic sensing control shall conform to the following:

-- When picking up grade information from an underlying base, the external longitudinal reference device shall be a floating beam or ski at least thirty (30) feet long.

-- When picking up grade information from an adjacent compacted pavement course or a concrete surface, the external longitudinal reference device shall not be less than ten (10) feet in length.

-- A “joint matching” shoe may be used to pick up grade information from a newly placed adjacent compacted course, if approved by the Principal Investigator.

-- Should the automatic controls fail to function properly, work shall be discontinued until repairs have been made.

3.7.2 OPERATION

A. The placing operation shall be performed to provide a smooth, uniform textured surface without tearing, shoving, gouging, segregation and streaks.

B. HMA shall be placed in courses not exceeding three (3) inches in compacted thickness. When more than one (1) course is placed, the courses shall be of approximately equal thickness, unless otherwise shown in the plans or special provisions.

3.8 JOINTS

3.8.1 LONGITUDINAL

A. Longitudinal construction joints of successive courses of HMA shall be offset at least six (6) inches.

B. HMA shall be placed so that any longitudinal joints constructed are within one (1) foot of the final traffic lane lines.

C. No two (2) longitudinal joints in the same course shall be constructed within the same traffic lane.

3.8.2 TRANSVERSE JOINTS

A. Transverse joints shall be formed by cutting back on the previous placement to expose the full depth of the layer and form a clean, vertical edge.

B. A brush coat of asphalt emulsion shall be placed on the contact surface of the joint before additional mixture is placed.

3.9 COMPACTION

3.9.1 GENERAL

A. The pavement shall be compacted thoroughly and uniformly with the necessary equipment to obtain the density and cross section of the finished paving mixture meeting the requirements of the plans and specifications.

B. The edges of pavements not accessible to conventional rollers shall be thoroughly compacted with suitable types of tampers, plates, trench rollers, etc.

C. Initial rolling shall commence at the lower edge and shall progress towards the highest portion of the roadbed.

D. Rolling shall be performed in a manner that cracking, shoving or displacement shall not occur.

E. All rollers shall be in good condition and be capable of rolling and changing direction without adversely affecting the mat.

F. The wheels of the rollers shall be properly moistened to prevent adhesion of the HMA. Diesel or kerosene will not be allowed.

G. All compactive rolling defined as initial or intermediate shall be performed while the internal temperature of the mid-depth of the mat is above 82˚ C (180˚ F).

H. Finish rolling shall be completed within the same day of placement of the HMA.

3.9.2 SPECIFIED AIR VOID REQUIREMENTS

A. The HMA shall conform to the in-place air void requirements.

B. The type and size of compaction equipment and the roller patterns used for the hot-mix asphalt will be entirely at the discretion of the Principal Investigator and Contractor. The equipment used must be designed for the compaction of HMA.

3.10 RESTRICTIONS

3.10.1 FROZEN BASE

A. HMA shall not be placed when frozen materials are present in the base.

3.10.2 ADVERSE WEATHER

A. HMA shall not be placed during rain or snowfall or when the roadway is wet.

3.10.2.1 AIR VOIDS REQUIRED

A. The HMA shall be placed only when the atmospheric temperature and the pavement surface temperature are above 5˚ C (40˚ F).

PART 4 COMPOSITION OF HOT-MIX ASPHALT

4.1 GENERAL

4.1.1 DESCRIPTION

A. The hot-mix asphalt shall be composed of a uniform mixture of aggregate, asphalt cement, with mineral filler and with or without baghouse fines.

4.1.2 PROPORTIONS

A. The materials shall be combined in such proportions that the resulting mixture meets the gradation requirements and asphalt binder content of the job mix formula for the 21 mixes designated.

4.2 MIX DESIGN

4.2.1 RESPONSIBILITY

A. The Principal Investigator shall perform the mixture design.

4.2.2 REQUIRED INFORMATION

A. The Principal Investigator's mix design submittal shall contain all information required in the specifications.

PART 5 JOB MIX FORMULA

5.1 GENERAL

5.1.1 DESCRIPTION

A. The 21 job mix formulas shall include definite single values for:

- Percent by weight of aggregate passing each specified sieve (whole percent).
- Bin percentage of each aggregate type to be used.
- Percent of asphalt binder by dry weight of aggregate to one-tenth (0.1) percent.

B. The temperature of the HMA at the plant in the haul vehicle and at laydown shall be within the ranges specified in Table 410.3.

Table 410.3 Temperature control requirements for hot-mix asphalt.

Measurement	Tolerance	Percent Within Limits (PWL) for Individual Lots	Percent Within Limits (PWL) for Project	Standard Deviation for Project
Plant Temperature, °F	± 20	65	80	10
Laydown Temperature, °F	± 20	65	80	15

PART 6 LOT AND SUBLOT

6.1 DEFINITION

6.1.1 GENERAL

A. Lots and sublots shall be established for production, placement and ride quality when specified.

6.1.2 TANGENT LOT/SUBLOT

A. A tangent lot shall be a section as shown on the plans and shall contain five (5) sublots.

6.1.3 CURVE LOT/SUBLOT

A. A curve lot is equal to the area of HMA placed in one curve lot. A curve sublot is equal to approximately one-fifth of the area of hot-mix placed in one curve lot.

6.1.4 RIDE QUALITY LOT

A. A ride quality lot is equal to the area of hot-mix asphalt placed in one tangent or curve lot.

PART 7 SAMPLING AND TESTING

7.1 ASPHALT CEMENT

7.1.1 SAMPLING

A. Preconstruction and construction sampling of the asphalt cement shall be performed as shown

in Table 410.4.

Table 410.4 Preconstruction and construction sampling of asphalt binder.

A. Refinery 1. Sampling Dates February 1995 June 1995 July 1995
B. Transport Sampling Sample each transport Perform SHRP tests Perform AC Table 2 tests

7.1.2 TESTING

A. Preconstruction and construction testing shall be performed as shown on Table 410.5.

7.1.3 ACCEPTANCE

A. The asphalt cement shall meet the requirements of a PG 64-22 or PG 64-28.

7.2 AGGREGATES

7.2.1 SAMPLING

A. Preconstruction and cold feed sampling shall be performed as shown on Tables 410.6 and 410.7, respectively.

7.2.2 TESTING

A. Cold-feed testing shall be performed as shown on Tables 410.6 and 410.7.

7.2.3 ACCEPTANCE

A. Cold-feed aggregate gradations (relative to job mix formula) shall meet the requirements shown in Table 410.8.

Table 410.5 Asphalt binder testing.

Specification	Binder Aging	Test Method		Pre-Construction	Construction		Post Construction			
					Truck	Extracted	Extracted			
							0	3	12	24***
SUPERPAVE™	Original	Flash Point Brookfield DSR	T48 D4402 TPS	3 3 3	8 8 17					
	RTFOT	Mass Loss DSR	T240 TP5	3 3	17 17	26*		26**	8**	26**
	PAV	DSR BBR DTT	TP5 TP1 TP3	3 3 3	17 17 3	8*		8**	8**	8**
ASTM & AASHTO	Original	Viscosity @ 60°C Viscosity @ 135°C Pen @ 25°C Flash Point Solubility	D2171 D2170 D5 D92 D2042	3 3 3 3 3	17 8 17 8 3	26*		26** 26**	8** 8**	26** 26**
	RFOT	Viscosity @ 60°C Ductility @ 25°C								
		Ball Indentation	Special	3	17	8				

* Aged in operation
** Aged in construction operation and in service
*** At end of service life
NOTE: Assume that 17 truck loads of asphalt cement will be needed.

Table 410.6 Preconstruction aggregates for HMA.

Specification	Test Method		Individual Stockpile Samples*	Combined Aggregate**
General	Gradation	C 117,C 136	5	
	Apparent Specific Gravity	C 127,C 128	1	3
	Bulk Specific Gravity	C 127,C 128	1	3
	Absorption Capacity	C 127,C 128	1	3
	Absorption Capacity	D 2041		3
SUPERPAVE	C.A. Angularity	Penn DOT 621	1	3
	F.A. Angularity	TP 33	1	3
	Flat or Elongated	ASTM D 4791	1	3
	Sand Equivalent	AASHTO T 176	1	3
	L.A. Abrasion	AASHTO T 96	1	3
	Soundness	AASHTO T 104	1	3
	Deleterious Materials	AASHTO T 112	1	3
	Plasticity Index	D 4319		3

* Samples per stockpile
** Two critical mix gradations, one non-critical mix gradation - 3 samples each

Note: Aggregates will also be tested by NCAT for NCHRP project.

Table 410.7 QC/QA aggregate testing for HMA cold-feed samples.

*Two critical mix gradations, one non-critical mix gradation - 5 samples each

Note: Aggregates will also be tested by NCAT for NCHRP project.

Specification	Test Method		Sublots Per Lot	Lots Per Section	Comments
General	Gradation	C117,C136	5	1	
	Apparent Specific Gravity	C127,C128			5 samples per gradation*
	Bulk Specific Gravity	C127,C128			5 samples per gradation*
	Absorption Capacity	C127,C128			5 samples per gradation*
	Absorption Capacity	D2041			5 samples per gradation*
SUPERPAVE™	C.A. Angularity	PennDOT 621			5 samples per gradation*
	F.A. Angularity	TP 33			5 samples per gradation*
	Flat or Elongated	ASTM D4791			5 samples per gradation*
	Sand Equivalent	AASHTO T176			5 samples per gradation*
	L.A. Abrasion	AASHTO T96			5 samples per gradation*
	Soundness	AASHTO T104			5 samples per gradation*
	Deleterious Materials	AASHTO T112			5 samples per gradation*
	Plasticity Index	D4319			5 samples per gradation*

Table 410.8 Gradation acceptance requirements for cold-feed samples.

Sieve Size	Tolerance	PWLs for Individual Lots	PWLs for Project	Standard Deviation for Project
1 in.	100	100	100	2.5
3/4 in.	± *5*	60	100	2.5
1/2 in.	±5	60	85	2.5
3/8 in.	±5	60	*85*	2.5
No. 4	±5	60	85	2.5
No. 8	±4	60	85	2.0
No. 16	±4	60	85	2.0
No. 30	±4	60	85	2.0
No. 50	±4	60	85	1.5
No. 100	±3	60	85	1.0
No. 200	±1	60	85	0.5

Aggregate properties shall meet the requirements shown on Table 410.9.

Table 410.9 Aggregate requirements (Superpave).

Property	Test Method	Superpave Criteria
Course Aggregate, Angularity Minimum	PennDOT 621	80 Percent
Uncompacted Air Content of Fine Aggregate, Minimum	AASHTO T P33	45
Elongated Particles, Maximum Percent	AASHTO D 4791	10
Sand Equivalent, Minimum	AASHTO T 176	45
Los Angeles Abrasion, Maximum Percent	AASHTO T 196	35
Soundness *5* Cycles, Maximum Percent Loss	AASHTO T 104	10
Deleterious Materials, Weight Percent Maximum	AASHTO T 112	0.2

7.3 HMA GRADATIONS

7.3.1 SAMPLING

A. Construction sampling shall be performed as shown on Table 410.10.

7.3.2 TESTING

A. Testing shall be performed as shown on Table 410.10.

7.3.3 ACCEPTANCE

A. The aggregate gradations obtained from hot-mix asphalt samples (relative to the job mix formula) shall meet the requirements shown on Table 410.11.

7.4 HOT-MIX ASPHALT - GENERAL

7.4.1 SAMPLING

A. The daily construction plan is shown on Table 410.12. This construction plan places three different hot-mix asphalt materials per day on eight to nine sections. The daily quality control plan is shown on Table 410.13 for the HMA at the plant and Table 410.14 for the HMA at the laydown site. This frequency of sampling will be used for the HMA placed in the trial lane, as well as the test lane.

B. The quality assurance sampling plan is shown on Table 410.15. This sampling will be performed on HMA placed on the test lane only.

7.4.2 TESTING

A. Testing shall be performed as shown on Tables 410.13, 410.14 and 410.15.

7.4.3 ACCEPTANCE FOR ASPHALT CONTENT

A. The asphalt content (relative to the job mix formula) shall meet the requirements shown on Table 410.11.

7.4.4 ACCEPTANCE FOR IN-PLACE AIR VOIDS

A. The in-place air void content shall meet the requirements shown on Table 410.16. The target air void contents shall be 4, 8 and 12 percent, as shown on the plans.

Table 410.10 Aggregate testing for HMA extracted samples and ignition samples.

Specification	Test Method		Sublots Per Lot	Lots Per Section	Comments
General	Gradation	C117,C136	1*,5**	1	
	Apparent Specific Gravity	C127,C128			
	Bulk Specific Gravity	C127,C128			
	Absorption Capacity	C127,C128			
	Absorption Capacity	D2041			
SUPERPAVE™	C.A. Angularity	PennDOT 621			
	F.A. Angularity	TP 33			
	Flat or Elongated	ASTM D4791			
	Sand Equivalent	AASHTO T176			
	L.A. Abrasion	AASHTO T96			
	Soundness	AASHTO T104			
	Deleterious Materials	AASHTO T112			
	Plasticity Index	D4319			

* Extraction samples
** Ignition samples

Table 410.11 Gradation and asphalt content acceptance requirements for solvent-extracted and ignition-oven-processed hot-mix asphalt.

Sieve Size and Asphalt Content	Tolerance	PWLs for Individual Lots	PWL for Project	Standard Deviation for Project
1 in.	100	100	100	---
3/4 in.	± 5	60	100	2.5
1/2 in.	± 5	60	85	2.5
3/8 in.	± 5	60	85	2.5
No. 4	±5	60	85	2.5
No. 8	±4	60	85	2.0
No. 16	±4	60	85	2.0
No. 30	±4	60	85	2.0
No. 50	±4	60	85	1.5
No. 100	±3	60	85	1.0
No. 200	± 1	60	85	0.5
Asphalt Content	± 0.3	65	85	0.2

Table 410.12 Daily construction plan.

Day	Morning or Afternoon	Lane	Lift	Block Numbers	Mixture Numbers	Aggregate Gradation	Asphalt Content
1	A.M. P.M.	Trial Trial	Bottom Bottom	1 2	1,2,3,4 5,6,7,8,9	DC DC	L,M L,M,H
2	A.M. P.M.	Trial Trial	Bottom Bottom	3 4	10,11,12,13 14,15,16,17,18	DSC DSC	L,M,H L,M,H
3	A.M. P.M.	Trial Trial	Bottom Bottom	5 6	19,20,21,22 23,24,25,26	DNC DNC	L,M,H L,M,H
4				Curves			
5	A.M. P.M.	Test Test	Bottom Bottom	1 2	1,2,3,4 5,6,7,8,9	DC DC	L,M L,M,H
6	A.M. P.M.	Test Test	Bottom Bottom	3 4	10,11,12,13 14,15,16,17,18	DSC DSC	L,M,H L,M,H
7	A.M. P.M.	Test Test	Bottom Bottom	5 6	19,20,21,22 23,24,25,26	DNC DNC	L,M,H L,M,H
8				Curves			
9	A.M. P.M.	Trial Trial	Top Top	1 2	1,2,3,4 5,6,7,8,9	DC DC	L,M L,M,H
10	A.M. P.M.	Trial Trial	Top Top	3 4	10,11,12,13 14,15,16,17,18	DSC DSC	L,M,H L,M,H
11	A.M. P.M.	Trial Trial	Top Top	5 6	19,20,21,22 23,24,25,26	DNC DNC	L,M,H L,M,H
12				Curves			
13	A.M. P.M.	Test Test	Top Top	1 2	1,2,3,4 5,6,7,8,9	DC DC	L,M L,M,H
14	A.M. P.M.	Test Test	Top Top	3 4	10,11,12,13 14,15,16,17,18	DSC DSC	L,M,H L,M,H
15	A.M. P.M.	Test Test	Top Top	5 6	19,20,21,22 23,24,25,26	DNC DNC	L,M,H L,M,H
16				Curves			

Aggregate Gradation
- DC = Dayton optimum gradation - critical
- DSC = Dayton high fines gradation - supercritical
- DNC = Dayton optimum gradation - non-critical

Asphalt Content
- L = Low of optimum
- M = Medium of optimum
- H = High of optimum

Table 410.13 Typical daily quality control test frequency and responsibility at hot-mix plant.

General Property	Method	Asphalt Content								
		Low (Lot A)			Medium (Lot B)			High (Lot C)		
		Tests/ Sublot	Sublots/ Lot	Test Respons.	Tests/ Sublot	Sublots/ Lot	Test Respons.	Tests/ Sublot	Sublots/ Lot	Test Respons.
Asphalt Content	Nuclear	1	3	BRE	1	3	FHWA	1	4	BRE,FHWA
	Extraction									
	Ignition	1	5	BRE	1	5	FHWA	1	5	NCAT
Gradation	Cold-Feed	1	2	UNR	1	2	UNR	1	1	UNR
	Extraction									
	Ignition	1	2	UNR	1	2	UNR	1	2	UNR
SHRP Gyratory Compaction	Bulk SP GR	1	3	BRE	1	3	FHWA	1	4	BRE,FHWA
	Air Voids & Volumetrics	1	3	BRE	1	3	FHWA	1	4	BRE,FHWA
	MR									
Marshall Compaction	Bulk SP GR				3	3	FHWA			
	Air Voids & Volumetrics				3	3	FHWA			
	Stability & Flow				3	3				
Hveem Compaction	Bulk SP GR									
	Air Voids & Volumetrics									
	Stability									
Theoretical Mix SP GR		2	1	BRE	2	1	FHWA	2	2	BRE,FHWA

Table 410.13 Typical daily quality control test frequency and responsibility at hot-mix plant (continued).

General Property	Method	Asphalt Content								
		Low (Lot A)			Medium (Lot B)			High (Lot C)		
		Tests/ Sublot	Sublots/ Lot	Test Respons.	Tests/ Sublot	Sublots/ Lot	Test Respons.	Tests/ Sublot	Sublots/ Lot	Test Respons.
Temp of HMA at Plant		1	5	UNR	1	5	UNR	1	5	UNR
Temp of HMA Laydown										
In-Place Air Voids	Nuclear									
	Cores									
Field Simple Shear		1	2	BRE	1	2	BRE	1	2	BRE
Sample & Split			Granite, UNR				Granite, UNR			Granite, UNR

Table 410.14 Typical daily quality control test frequency and responsibility at laydown operation.

General Property	Method	Section Number									Comments
		1	2	3	4	5	6	7	8	9	
Asphalt Content	Nuclear										
	Extraction										
	Ignition										
Gradation	Cold-Feed										
	Extraction										
	Ignition										
SHRP Gyratory Compaction	Bulk SP GR										
	Air Voids & Volumetrics										
	MR										
Marshall Compaction	Bulk SP GR										
	Air Voids & Volumetrics										
	Stability										
Theoretical Max. SP GR											
Temp of HMA at Plant											
Temp of HMA Laydown		HLA(5)*	HLA(5)	HLA(5)	HLA(5)	HLA(5)	HLA(5)	HLA(5)	HLA(5)	HLA(5)	
In-Place Air Voids	Nuclear	HLA(5)	HLA(5)	HLA(5)	HLA(5)	HLA(5)	HLA(5)	HLA(5)	HLA(5)	HLA(5)	
	Cores	HLA**	HLA	HLA	HLA	HLA	HLA	HLA	HLA	HLA	

Table 410.14 Typical daily quality control test frequency and responsibility at laydown operation (cont'd).

General Property	Method	Section Number									Comments
		1	2	3	4	5	6	7	8	9	
Water Sensitivity	T283	HLA	HLA	HLA	HLA	HLA	HLA	HLA	HLA	HLA	
Field Simple Shear											
Smoothness		FHWA	FHWA	FHWA	FHWA	FHWA	FHWA	FHWA	FHWA	FHWA	

*Testing responsibility and number of tests.
**Sufficient cores to establish correlation.

Table 410.15 Frequency of testing - conventional quality assurance.

General Property	Method	Tests/ Sublot	Sublots/ Lot	No. of Lots or Sections to be Tested	No. of Layers	Comments
Asphalt Content	Nuclear	1	5	26	2	
	Extraction	1	1	26	2	
	Ignition	1	5	26	2	
Gradation	Cold-Feed	1	5	26	2	
	Extraction	1	1	26	2	
	Ignition	1	5	26	2	
SHRP Gyratory Compaction	Bulk SP GR	3	5	26	2	
	Air Voids & Volumetrics	3	5	26	2	
	MR	3	5	26	2	
Marshall Compaction	Bulk SP GR	3	1	20	2	
		3	5	6*		
	Air Voids & Volumetrics	3	1	20	2	
		3	5	6		
	Stability & Flow	3	1	20	2	
		3	5	6		
Hveem Compaction	Bulk SP GR	3	1	20	2	
		3	5	6		
	Air Voids & Volumetrics	3	1	20	2	
		3	5	6		
	Stability	3	1	20	2	
		3	5	6		

Table 410.15 Frequency of testing - conventional quality assurance (continued).

General Property	Method	Tests/ Sublot	Sublots/ Lot	No. of Lots or Sections to be Tested	No. of Layers	Comments
Theoretical Max. SP GR		3	1	26	2	
Temp of HMA at Plant		1	5	26	2	
Temp of HMA Laydown		1	5	26	2	
In-Place Air Voids	Nuclear	2	5	26	2	
	Cores	1	5	26	2	
Water Sensitivity	T283	3	1	20	2	
		1	5	6		
Field Simple Shear		1	5	26	2	

*Replicate mixes only (i.e., MM1 and MM2)

Table 410.16 In-place air void or relative density requirements for hot-mix asphalt.

Measurement	Tolerance, Percent	PWLs for Individual Lot	PWLs for Project	Standard Deviation for Project, Percent
In-Place Air Voids	± 1	65	80	1.0
Relative Density	± 1	65	80	1

7.4.5 ACCEPTANCE FOR THICKNESS

The thickness requirement shall be 150 mm (6 in.) and shall meet the requirements shown on Table 410.17.

Table 410.17 Thickness requirements for hot-mix asphalt.

Measurement	Tolerance, (inches)	PWL for Individual Lot	PWL for Project	Standard Deviation for Project, Inches
Thickness, Inches	± 0.25	65	90	0.13

7.46. ACCEPTANCE FOR SMOOTHNESS

The smoothness requirements shall meet those shown on Table 410.18.

Table 410.18 Smoothing requirements for hot-mix asphalt.*

Measurement	Tolerance (inch/mile**)
Ride Quality	Less than 5 in./mi as measured after grinding

* California Profilograph Nevada Test Method T 446.

** Grind to smoothness of 3 inches per mile, grind all surface irregularities in excess of 0.3 inches as measured by the profilograph with a 25-ft. wheelbase.

PART 8 MEASUREMENT

A. All measurements will be made in accordance with Subsection 109.01 "Measurement of Quantities" of the Nevada DOT Specifications. Batch weights will not be permitted as a method of measurement unless plant scales are provided. Plant scales shall be accurate to five-tenths (0.5) percent of the maximum load that may be required. Poises shall be designed to be locked in any position to prevent unauthorized change or position. In lieu of truck scales, the Contractor may provide an approved automatic printer system which will print the weights of the material delivered, provided the system is used in conjunction with an approved automatic batching and mixing control system. Such weights shall be evidenced by a weigh ticket for each load. If plant scales meet these criteria, cumulative weight of all the acceptable batches will be used for payment.

PART 9 PAYMENT

A. Payment will be as specified by the subcontract between Granite Construction and NATC.

END OF SECTION

SECTION 502
CONCRETE STRUCTURES

PART 1 GENERAL

1.1 SECTION INCLUDES

This work shall consist of furnishing and placing portland cement concrete in headwalls. The concrete headwalls shall be constructed to the lines and grades shown on the plans.

1.2 APPLICABLE PUBLICATIONS

A. American Association of State Highway Officials (AASHTO)

T 22-92	Compressive Strength of Cylindrical Specimens
T 23-93	Making and Curing Concrete Test Specimens in the Field
T 119-93	Slump of Hydraulic Cement Concrete
T 12 1-86	Weight Per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete
T 141-93	Sampling Freshly Mixed Concrete

B. AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM)

C 33-92a	Specification for Concrete Aggregates

1.3 RELATED SECTIONS

A. QA/QC DOCUMENT

B. SECTION 206 STRUCTURE EXCAVATIONS

C. SECTION 207 BACKFILL

D. SECTION 601 PIPE CULVERTS

PART 2 PRODUCTS

2.1 CONCRETE

A. Compressive Strength: Concrete mixtures shall be proportioned to obtain a minimum compressive strength in 28 days of 27.5 MPa (4000 psi), and shall be tested in accordance with AASHTO T 22.

B. Air Content: Total air content of the concrete shall be maintained at 6% ±1.5% percent by volume of concrete. Air content shall be determined in accordance with AASHTO T 121.

C. Slump: Slump shall be 20 to 100 mm, and shall be determined in accordance with AASHTO T 119.

2.2 AGGREGATES

Coarse aggregate shall be one maximum size the least of the following: 1/5 the narrowest dimension of the member or 3/4 the minimum clear spacing between reinforcing bars or between bars and forms, and shall comply with ASTM C 33.

2.3 REINFORCING STEEL

Steel shall be deformed, 414 MPa (Grade 60) billet steel and shall be placed as indicated on the drawings.

2.4 FORM MATERIALS

Plywood or hardboard especially made for concrete form use or other materials that will produce the specified finishes without adversely affecting the concrete surfaces.

2.5 STORAGE

Materials shall be stored so as not to deteriorate or become contaminated.

PART 3 EXECUTION

3.1 PREPARATION

A. Formwork shall be mortar tight, properly aligned and adequately supported to produce concrete conforming accurately to the indicated shapes, lines, dimensions, and with surfaces free of offsets, waviness or bulges. Surfaces shall be thoroughly cleaned and coated before each use. Forms shall be removed at a time and in a manner that will not injure the concrete.

B. Reinforcement: Reinforcement shall be fabricated to the shapes required.

B. Installation of Anchorage Items: Installation of anchorage items shall be as indicated or required to insure sufficient anchorage for purpose intended.

3.2 PLACING CONCRETE

Concrete shall be placed upon clean undisturbed surfaces free from frost, ice and water. Dry or pervious surfaces receiving concrete shall be covered with impervious sheet materials. Concrete may be placed directly on pervious surfaces that are thoroughly moistened, but not muddy. During cold weather, in-place concrete shall be protected from freezing throughout the curing period. Concrete to receive other construction shall be screeded to the proper level.

3.3 CONSOLIDATION OF CONCRETE

Concrete shall be consolidated in layers not to exceed 300 mm. Vibrating equipment shall be adequate to thoroughly consolidate the concrete.

3.4 FINISHING CONCRETE

A. Formed Surfaces: Fins and loose materials shall be removed. Unsound concrete, voids over 13 mm in diameter, and tie-rod and bold holes shall be cut back to solid concrete, reamed, brush coated with cement grout and filled with a stiff portland cement and sand mortar mix. Patchwork shall finish flush with adjoining concrete surface and, where exposed, shall match adjoining surface in texture and color. Patchwork shall be cured for 72 hours. White portland cement shall be used as needed to attain color match.

B. Unformed Surfaces: Surfaces shall be finished to a true plane with no deviation exceeding 8 mm when tested with a 3-meter straightedge. Surfaces shall be pitched to drains. Surfaces shall be screened and floated to the required finish level with no coarse aggregate visible before finishing as specified below.

3.5 CURING

Curing shall start as soon as free water has disappeared from concrete surface after placing and finishing. Curing materials shall be applied and maintained so as to protect the concrete from moisture loss for 7 days. Curing shall be accomplished by moist curing impervious sheet or membrane-forming curing compound. Unformed surfaces shall be covered with absorptive materials wetted before placing. Absorptive materials or forms used during curing shall be thoroughly wetted before covering with impervious-sheet materials. Membrane-forming curing compound shall be applied with mechanical spraying equipment at a coverage of not more than 70 square meters per liter. Surfaces of compound damaged during curing shall be resprayed.

3.6 WEATHER LIMITATIONS

A. The concrete shall have a temperature of at least ten (10) degrees Celsius and not more than thirty (30) degrees Celsius at the time of placing. Heating equipment or methods which alter or prevent the entrainment of the required amount of air in the concrete shall not be used. The equipment shall be capable of heating the materials uniformly. Aggregates and water used for mixing shall not be heated to a temperature exceeding 63 degrees Celsius. Concrete containing frost or lumps at the time of placing shall not be used.

B. Stockpiled aggregates may be heated by the use of dry heat or steam. Aggregates shall not be heated directly by gas or oil flame or on sheet metal over fire. The use of live steam on or through binned aggregates will not be permitted.

C. Reinforcing steel shall be free of ice, snow, or frost during placement of concrete. Concrete shall not be placed on frozen ground.

D. Fire retardant and waterproof insulating blankets or artificial heat applied inside an enclosure may be used to protect concrete from low temperatures.

E. Hot Weather. The maximum temperature of cast-in-place concrete shall not exceed 30 degrees Celsius immediately before placement.

3.7 TESTING

A. One concrete test cylinder will be taken for the entire amount of concrete placed, and used to

determine the compressive strength of the concrete at 28 days.

B. One slump test will be taken for the entire amount of concrete placed.

PART 4 MEASUREMENT AND PAYMENT

4.1 MEASUREMENT

The structures to be measured for payment will be the actual number of structures placed, having the properties specified in this section.

4.2 PAYMENT

The accepted quantities of structures measured as specified in subsection 4.1, will be paid for at the contract unit price bid per each for the concrete having the properties as specified in this section, and such payment shall include installation of canal gates (shown on plans), structure excavation, backfilling, forming, placing and finishing concrete to the lines and grades shown on the plans.

END OF SECTION

SECTION 601
PIPE CULVERTS

PART 1 GENERAL

1.1 SECTION INCLUDES

A. This work shall consist of furnishing and installing pipe culverts, and headwalls as may be required to complete the work shown on the plans.

1.2 APPLICABLE PUBLICATIONS

A. American Association of State Highway and Transportation Officials (AASHTO)

M 36/M 36M-91 Corrugated Steel Pipe, Metallic Coated, for Sewers and Drains

1.3 RELATED SECTIONS

A. QA/QC DOCUMENT

B. SECTION 201 CLEARING AND GRUBBING

C. SECTION 203 EXCAVATION AND EMBANKMENT

D. SECTION 206 STRUCTURE EXCAVATION

E. SECTION 207 BACKFILL

F. SECTION 502 CONCRETE STRUCTURES

1.4 DELIVERY AND STORAGE

A. Materials delivered to site shall be inspected for damage, unloaded, and stored with a minimum of handling. Materials shall not be stored directly on the ground. The inside of pipes and fittings shall be kept free of dirt and debris.

B. Materials shall be handled in such a manner as to insure delivery to the trench in sound, undamaged condition. Pipe shall be carried to the trench not dragged.

PART 2 PRODUCTS

2.1 PIPE MATERIALS

A. Pipe shall have a thickness of 1.6 mm (16 gauge) and shall have a corrugation size of 68 by 13, (2-2/3 inch by 1/2 inch). The size of pipe shall be as indicated on the plans. Corrugate Metal Pipe shall conform to the specification of AASHTO M 36M (M 36).

2.2 MATERIALS FOR DRAINAGE STRUCTURES

A. Concrete: Concrete shall be in accordance with Section 502 CONCRETE STRUCTURES

B. Reinforcing Steel: Steel shall be deformed, 414 MPa (Grade 60) billet steel and shall be placed as indicated on the drawings.

PART 3 EXECUTION

3.1 INSTALLATION OF PIPE

A. Excavation of trenches and of appurtenances and backfilling for culverts shall be in accordance with the applicable portions of Section 203 EXCAVATION AND EMBANKMENT, Section 206 STRUCTURE EXCAVATION and Section 207 BACKFILL.

B. The interior of the pipe shall be kept free of dirt and other foreign material as the pipe laying progresses, and left clean at the completion of the work.

C. The bedding surface for the pipe shall provide a firm foundation of uniform density throughout the entire length of the pipe. When no bedding class is specified or detailed on the drawings, the pipe shall be bedded carefully in a soil foundation accurately shaped and rounded to conform to the lowest one-fourth of the outside portion of circular pipe for the entire length of the pipe. When necessary, the bedding shall be tamped. Depressions for joints shall be only of such length, depth and width as required for properly making the particular type of joint.

D. Where wet or otherwise unstable soil incapable of properly supporting the pipe, as determined by the Principal Investigator, is unexpectedly encountered in the bottom of a trench, such material shall be removed to the depth required and replaced to the proper grade with select granular material, compacted as provided in Section 207 BACKFILL. When removal of unsuitable material is due to the fault or neglect of the Contractor in his performance of shoring and sheeting, water removal, or other specified requirements, such removal and replacement shall be performed at no additional cost to the Owner.

E. Each pipe shall be carefully examined before being laid, and defective or damaged pipe shall not be used. Pipelines shall be laid to the grade and alignment indicated. Pipe shall be laid from low elevation to high elevation. Proper facilities shall be provided for lowering sections of pipe into trenches. Lifting lugs in vertically elongated metal pipe shall be placed in the same vertical plane as the major axis of the pipe. Under no circumstances shall pipe be laid in water, and no pipe shall be laid when trench conditions or weather are unsuitable for such work. Diversion of drainage or dewatering of trenches during construction shall be provided as necessary. All pipe in place shall be inspected before backfilling, and those pipes damaged during placement or which is not true to alignment shall be removed and replaced.

F. Joints shall be coupling type. Before installing joints the ends of the pipe must be clean. All joints must be tight to prevent excessive leakage of drainage water.

3.2 MOVEMENT OF CONSTRUCTION MACHINERY

A. Movement of construction machinery over a pipe at any stage of construction shall be at the Contractor's risk. Any damaged pipe shall be repaired or replaced.

3.3 HEADWALLS

A. Where shown on the plans, flared ends and outlet headwalls shall be constructed in connection with culvert pipes. Where such headwalls are constructed, the ends of the pipes shall be placed flush or shall be cut off flush with the headwall face. Headwalls are to be constructed to conform to the applicable requirements of Section 502 CONCRETE STRUCTURES.

PART 4 MEASUREMENT AND PAYMENT

4.1 MEASUREMENT

A. The quantity of corrugated metal pipe to be measured for payment will be the actual number of lineal meters of pipe, of the type and size specified complete in place.

4.2 PAYMENT

B. The accepted quantities of corrugated metal pipe measured as specified in subsection 4.1, will be paid for at the contract unit price bid per lineal meter for corrugated metal pipe of the type and class specified, and such payment shall include trench excavation, joints and installation, and backfill.

END OF SECTION

SECTION 603

REINFORCED CONCRETE PIPE

PART 1 GENERAL

1.1 SECTION INCLUDES

A. This work shall consist of furnishing and installing circular reinforced concrete pipe of the size, kind, and dimension and the location shown on the plans and in accordance with these specifications.

1.2 APPLICABLE PUBLICATIONS

A. American Association of State Highway and Transportation Officials (AASHTO)

M 170-93 Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe

M 170M-93 Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe (Metric)

M 198-75 Joints for Circular Concrete Sewer and Culvert Pipe Using Flexible Watertight Gaskets

1.3 RELATED SECTIONS

A. QA/QC DOCUMENT

B. SECTION 201 CLEARING AND GRUBBING

C. SECTION 203 EXCAVATION AND EMBANKMENT

D. SECTION 206 STRUCTURE EXCAVATION

E. SECTION 207 BACKFILL

1.4 DELIVERY, STORAGE, AND HANDLING

A. Materials delivered to site shall be inspected for damage, unloaded, and stored with a minimum of handling. Materials shall not be stored directly on the ground. The inside of pipes and fittings shall be kept free of dirt and debris. Gasket materials shall be protected from exposure to the direct sunlight over extended periods.

B. Materials shall be handled in such a manner as to insure delivery to the trench in sound, undamaged condition. Pipe shall be carried to the trench, not dragged.

PART 2 PRODUCTS

2.1 MATERIALS

A. Circular reinforced concrete pipe shall conform to the specifications of AASHTO designation M 170-93 or M 170M-93 for the specified diameters and strength classes.

B. Flared end sections (precast) shall conform to the details and dimensions shown on the plans and, except for shape, shall conform to the requirements of this section for reinforced concrete pipe.

C. Rubber gaskets shall conform to the requirements of AASHTO M 198.

D. Joint mortar shall be composed of one part Portland cement and two parts sand by volume.

PART 3 EXECUTION

3.1 INSTALLATION OF PIPE

A. Excavation of trenches and for appurtenances and backfilling for culverts shall be in accordance with the applicable portions of Section 203 EXCAVATION AND EMBANKMENT, Section 206 STRUCTURE EXCAVATION, and Section 207 BACKFILL.

B. The Contractor shall determine his source of supply of sand for use in mortar a sufficient time in advance of pipe laying operations to permit sampling and testing before use, and no mortar shall be used until the sand has been approved by the Principal Investigator.

C. The consistency of joining mortar shall be such as to adhere to the ends of the pipe while being laid and may be easily squeezed out of the joint when the pipe sections are pressed together.

D. In advance of joining sections of pipe, the ends of each section shall be washed clean with a wet brush and immediately prior to placing mortar and joining the sections, the ends shall be thoroughly wetted.

E. Pipe sections shall be checked for alignment and grade at the time of joining the sections. If an adjustment in alignment or grade is necessary after making the joint, additional mortar shall be firmly pressed into the joint, the internal and external surfaces of the joint shall be brushed.

F. The interior of the pipe shall be kept free of dirt, excess mortar, and other foreign material as the pipe laying progresses, and left clean at the completion of the work. Any pipe which is not in true alignment or which shows any undue settlement after laying, or is damaged, shall be taken up and relaid at the Contractor's expense.

G. The first section of pipe to be laid shall be firmly placed to the designated line and grade at the outlet end with the groove end or bell end pointing in the direction to be followed by the pipe laying.

H. Abutting ends of the sections of pipe to be jointed shall then be cleaned and wetted, after which joining mortar shall be firmly placed into the lower half of the groove end of the previously laid section. Joining mortar shall be firmly placed on the top half of the tongue

end of the section to be jointed which shall then be inserted truly and snugly into the groove end of the section previously laid so as to completely fill the joint.

I. The interior joint shall then be either brushed or pointed and all surplus mortar removed from the pipe. The external space between the ends of the jointed pipe shall be firmly filled from the outside with laying mortar.

J. When pipe with self-centering joints and without an inside pointing recess is furnished, the inside shoulder of the groove end of each section shall first be lightly plastered or buttered with joining mortar after which the pipe ends shall be firmly fitted together in such a way that the tongue end of each section fits snugly into the groove end of the preceding section in order to center the joint and form a true flow line. The inside joints shall be troweled or brushed smooth and excess mortar removed from the pipe. The outside joint recesses shall then be filled with mortar, after which backfilling shall be performed as specified.

K. When pipe is furnished, with self-centering joints, with both inside and outside pointing recesses, the pipe shall be firmly fitted together in such a way that the tongue end of each section fits snugly into the groove end of each preceding section in order to center the joint and to form a true flow line, after which the inside joint recess shall be firmly filled with pointing mortar and then troweled or brushed smooth and excess mortar removed from the pipe, after which backfilling shall be performed as specified.

L. Backfilling of the trench shall not be commenced within sixteen (16) hours of jointing the pipe sections.

M. Free water shall not be allowed to come in contact with the pipeline until the mortar in the joints has set at least twenty-four (24) hours.

N. Concrete pipe with elliptical reinforcing shall be suitably marked to clearly indicate the top and bottom of the pipe.

O. Prior to placing backfill material, all handling holes in concrete culverts shall be completely filled with grout.

3.2 RUBBER GASKET JOINTS

A. Reinforced concrete culvert pipe, connected by flexible, watertight, rubber or plastic gasketed joints, may be used in lieu of other types of joints.

B. All rubber gaskets shall be stored in as cool a place as practicable, preferably at 20 degrees Celsius or less, and in no case shall the rubber gaskets be exposed to the direct rays of the sun for more than 72 hours.

C. Rubber gaskets of the type requiring lubrication shall be lubricated with the lubricant recommended and supplied by the manufacturer of the pipe.

D. After the pipe has been laid, the outer and inner annular space between pipe sections shall be completely filled with cement mortar, except that no mortar shall be required if the space is 5 mm or less in width. Where reinforced concrete collars or bells with rubber gaskets are used at the pipe joints, mortar will not be required in the outer annular space. Where pipes are used with exposed metal surfaces at the joint, may be jointed by brushing smooth and removing all surplus mortar. The rubber gasket shall be the sole element depended upon to make the joint watertight for the purposes intended.

3.3 MOVEMENT OF CONSTRUCTION MACHINERY

A. In compacting by rolling or operating heavy equipment parallel with the pipe, displacement of or injury to the pipe shall be avoided. Movement of construction machinery over a pipe at any stage of construction shall be at the Contractor's risk. Any damaged pipe shall be repaired or replaced.

3.4 COMPACTION

A. Compactions shall be in accordance with Section 207 BACKFILL.

PART 4 MEASUREMENT AND PAYMENT

4.1 MEASUREMENT

A. The quantity of reinforced concrete pipe to be measured for payment will be the actual number of linear meter of pipe, of the class and size specified complete in place exclusive of precast end sections.

B. Precast end sections will be measured for payment on an each basis.

4.2 PAYMENT

A. The accepted quantities of reinforced concrete pipe measured as specified in subsection 4.1, will be paid for at the contract unit price bid per lineal meter for reinforced concrete pipe of the class and size specified, arid such payment shall include mortar, joints and installation and compaction of backfill.

B. End sections will be paid for at the contract unit price bid per each for the kind and sizes specified complete and in place, which payment shall include structure excavation and backfill for precast end sections.

END OF SECTION

SECTION 610

RIPRAP

PART 1 GENERAL

1.1 SECTION INCLUDES

A. This work shall consist of furnishing and placing riprap. The type of riprap shall be as indicated on the plans and shall conform to the applicable requirements of these specifications.

1.2 RELATED SECTIONS

A. QA/QC DOCUMENT

B. SECTION 203 EXCAVATION AND EMBANKMENT

C. SECTION 206 STRUCTURE EXCAVATION

PART 2 PRODUCTS

2.1 RIPRAP

A. Riprap shall be 150 mm to 200 mm in size.

PART 3 EXECUTION

3.1 PREPARATION OF SURFACE

A. The bed for the riprap shall be properly trimmed and shaped.

3.2 INSTALLATION

A. Riprap may be placed by mechanical means that will produce a well graded, uniform rock blanket in close conformity with the typical section shown on the plans. Interstices between stones shall be chinked with spalls firmly rammed into place.

PART 4 MEASUREMENT AND PAYMENT

4.1 MEASUREMENT

A. The quantity of riprap measured for payment will be the number or cubic meters complete and in place.

4.2 PAYMENT

A. The accepted quantities of riprap measured as provided in subsection 4.1 will be paid for at the contract unit price bid per cubic meter.

END OF SECTION