CHAPTER 5

MATERIALS CHARACTERIZATION AND PERFORMANCE MODELS

5.1 INTRODUCTION

One of the major purposes of WesTrack was the development of performance models which define the influence of HMA variables on pavement performance. These models are central to the development of PRSs. HMA mixture variables included asphalt binder content, in-place air void content (degree of compaction), and aggregate gradation. The Pavement Research Center at the UCB developed performance models for permanent deformation (rutting) and fatigue cracking. Details of the UCB research effort are contained in WesTrack Technical Report UCB-1 (*62*).

The program to accomplish these objectives included the following:

- Testing of cores and beams (sawed from slabs) from the test sections, referred to as field-mixed/field-compacted (FMFC) specimens.
- Testing of cores and beams obtained from slabs mixed and compacted in the laboratory by rolling wheel compaction (LMLC).
- 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 (field-mixed/laboratory-compacted [FMLC], not discussed in this report).

The data obtained from these tests combined with performance measurements of deflection, rutting, and cracking were used to develop the performance models for rutting and fatigue cracking described in this part of the report and more extensively in Part II of this report and in WesTrack Technical Report UCB-1 (*62*).

This introductory section to Chapter 5 contains a brief description of the laboratory tests used and presents a framework for the performance models which have been developed.

5.1.1 Laboratory Tests

The laboratory tests program consisted of permanent deformation measurements on cores using the repeated simple shear test at constant height (RSST-CH) (*63*) and determination of stiffness and fatigue response on beam specimens using a flexural fatigue test (*64*).

5.1.1.1 Repeated Simple Shear Test at Constant Height

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. The RSST-CH was performed at three temperatures—40°C (104°F), 50°C (122°F), and 60°C (140°F)—with the majority of tests being performed at 50°C (122°F).

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. An equation of the form

$$\gamma_P = aN^b \quad (5)$$

is fit to the data, usually for values of N ≥ 100 after a zero correction has been made. In this expression, the coefficients *a* and *b* result from the regression analysis. Figure 122, after a zero correction has been made, illustrates a representative plot of the data in this form.

Shear stiffness, G, is also determined from the data according to the relation

$$G = \frac{\tau}{\gamma_{\text{recov}}} = \frac{\text{shear stress [69 kPa (10 psi)]}}{\text{recoverable shear strain at } N = 100} \quad (6)$$

Data obtained from this test are summarized in reference 62 and the WesTrack database discussed in Part III of this report.

5.1.1.2 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 (68°F), a limited number of specimens were tested at 5°C (41°F) and 30°C (86°F) to define the influence of temperature on fatigue behavior. The data provided a measure of both flexural stiffness and fatigue response, the latter 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 66 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:

$$N = K_1 \varepsilon_t^{K_2} \tag{7}$$

where

N = number of strain repetitions to 50 percent reduction in mix stiffness,
ε_t = tensile strain, repeatedly applied, mm/mm (in./in.), and
K_1, K_2 = experimentally-determined coefficients.

Test data used for the analyses presented herein are contained in summary form in reference 62 and the WesTrack database. Data include results for the 26 original and 8 replacement sections.

5.1.2 Performance Models

The performance models developed from the WesTrack data are of two general types: those based on direct regressions relating the specific performance measure (rut depth or fatigue cracking) to ESALs and mix characteristics; and those based on mechanistic-empirical (M-E) analyses assuming the pavement behaves as a multilayer elastic system. The first category has been termed level 1 and the second, level 2. The general framework is illustrated in Figure 123.

5.1.2.1 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 relating observed rutting or cracking to ESALs and mix characteristics (Figure 123). For rutting, the model uses performance data from the 26 original and 8 replacement sections while for fatigue, the model uses only the fatigue data for the 26 original sections.

The level 1B model was obtained using M-E analyses of the pavements. In the case of rut depth versus ESALs, relationships were developed for a 10-year period for 23 sections in which little or no fatigue cracking was observed during the 2½ years of truck loading. The 23 sections included both original and replacement sections. For the analyses, the traffic was uniformly distributed throughout a 24-hr 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 which occurred in some of the sections.

For fatigue, a Probit model has been used to define the probability of cracking.

As seen in Figure 123, the level 1 models are based on WesTrack-type mixes. The level 1B model for rutting can, however, be used for other traffic and environmental (temperature) conditions.

5.1.2.2 Level 2 Models

For rutting, two level 2 models have been developed—level 2A and level 2B. The level 2A model can be used for other traffic and temperature environments, but it is limited to mixes with aggregate gradings similar to those at WesTrack. The level 2B model can be used for other types of mixes so long as they are characterized by means of the RSST-CH tests.

While not shown in Figure 123, regression models are included in reference 62 relating rut depths to aggregate gradation [defined by the percent passing the No. 200 (0.075 mm) sieve and the percent of aggregate between the No. 8 (2.36 mm) and No. 200 (0.075 mm) sieves], as well as to ESALs, asphalt binder content, and in-place air void content. The regression equations use the results of RSST-CH tests on both FMFC and LMLC specimens. These regressions were developed using the level 2 approach. Models of this type are suitable for determining pay factors (PFs) for permanent deformation so long as the bounds of the regression are not exceeded.

The level 2 models for fatigue, a total of three, have not been characterized as have the rutting models. Rather, since the procedure is the same for the three categories shown in Figure 123, selection is based on the engineer's choice of mix fatigue and stiffness characteristics. Three options are available:

- Use of WesTrack mix data.
- Use of stiffness and fatigue data from published information.
- Use of laboratory-determined stiffness and fatigue response data obtained for the specific area in which the mix(es) are to be used.

These guidelines are also shown in Figure 123.

5.2 MODULUS DETERMINATION

5.2.1 Introduction

The purpose of this evaluation was to establish elastic moduli for the pavement components at WesTrack to allow simulation 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 PRS, a major WesTrack product.

The assumption used is that multilayer elastic analysis can produce sufficiently accurate estimates of stresses, strains, and deflections in the pavement structures. In turn, this forms the basis for the establishment of performance models for load-associated cracking (fatigue) and permanent deformation (rutting).

The sources from which the moduli were obtained include both field and laboratory measurements. The field data include an extensive series of FWD measurements taken at intervals throughout the traffic loading. Laboratory data include the following:

- *HMA*—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.

5.2.2 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. Microsoft® Excel's solver routine was used to determine the best-fit moduli.

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) at a radius of 150 mm (5.9 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 the following:

- Asphalt modulus, E_1, is related to the average surface temperature, T, (based on section 12 data):

  $$E_1 = \exp(A_0 + A_1 T) \tag{8}$$

  where A_0 and A_1 = regression coefficients.
- Base modulus, E_2, is independent of temperature and season.
- Foundation soil moduli are sensitive to seasonal but not temperature influences and were investigated as a discreet function of the measurement period and a sinusoidal function.

Figure 124 illustrates the framework used for the simulations. Modulus values for the three layers are summarized in reference 62.

FWD-determined moduli for the AC as a function of temperature are shown in Figure 125 for the sections evaluated in the south tangent and in Figure 126 for sections from the north tangent.

Table 148 compares mixes based on moduli at a temperature of 40°C (104°F) and examines the effects of asphalt binder content and air void content. It is noted that the influence of air void content is significant, with an increase in air void content resulting in a reduction in mix stiffness. It will also be noted 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 93.1 MPa (13,500 psi), respectively. The modulus for the south tangent is about the same as that for the foundation soil; whereas, in the north tangent the modulus for the base is less than that for the foundation soil. Considering other investigations which suggest that conventional backcalculation routines may underestimate base moduli, additional investigation appears warranted to determine suitable means for backcalculating untreated base moduli. That, however, was beyond the scope of this study.

The influence of season on foundation soil modulus is illustrated in Figures 127 and 128 for the south and north tangents, respectively. In these figures, it is 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-soil 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.

Sinusoidal functions applied to the foundation-soil moduli to define seasonal variations, as described in reference 64, appear reasonably well-suited to define the influence of seasonal variations on modulus for the WesTrack foundation (*64*).

5.2.3 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 tests 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 129.

Similarly, in the RSST-CH tests 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 130. For comparisons with the FWD estimates, the laboratory shear stiffnesses were converted according to the following expression:

$$E = G \cdot 2(1 + \nu) \quad (9)$$

For this conversion, the Poisson's ratio, ν, was assumed to be equal to 0.35 for the AC.

The correlations shown in Figures 129 and 130 were also used to determine moduli to use in the analysis of response of the replacement sections.

A brief comparison was also made between the FWD and laboratory-determined moduli for the base and foundation soils. These results are shown in Table 149.

5.2.4 Moduli Used for Permanent Deformation and Fatigue Analyses

The results presented in the previous sections established bases for selecting moduli for use in developing the performance models for both permanent deformation and fatigue.

For permanent deformation and fatigue, the subgrade moduli for the south and north tangents shown in Figures 128 and 129, respectively, were used in order to reflect seasonal variations in the subgrade stiffness.

It was noted in Section 5.2.2 that backcalculation procedures may, at times, result in estimated moduli for untreated bases which are lower than expected. This was assumed to be the case for the base moduli shown in Table 149. Based on the results of other studies (e.g., references 65 and 66), the WesTrack team decided to use a base modulus of 138 MPa (20,000 psi) for the level 1B and 2A analyses for permanent deformation and 172 MPa (25,000 psi) for the level 2 fatigue analyses.

For the HMA, moduli at 20°C (68°F) from the flexural fatigue tests and the temperature slope (A_1) from the backcalculation procedure were used.

5.2.5 Additional Stiffness Analyses

For the mechanistic analyses used to assess fatigue response, the mix stiffnesses obtained from the flexural fatigue tests were used (*62*). 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 (86°F).

Results of the analyses are represented by the following equations:

- *fine* and *fine plus* mixes (127 tests)

$$\ln Stiff = 11.4677 - 0.0827V_{air} - 0.2285P_{asp} - 0.0579T \qquad R^2 = 0.85 \quad (10)$$

- *coarse* mixes (59 tests)

$$\ln Stiff = 11.4707 - 0.0576V_{air} - 0.2142P_{asp} - 0.0606T \qquad R^2 = 0.79 \quad (11)$$

where

$Stiff$ = mix stiffness, MPa (1 ksi = 6.9 MPa),
V_{air} = air void content, percent,
P_{asp} = asphalt content, percent (by weight of mix), and
T = temperature, °C (°F = 1.8°C + 32).

Comparisons of the mix stiffnesses for the original sections with those predicted by the regression equations for specific asphalt binder content and in-place air void contents are shown in Figure 131.

5.3 PERMANENT DEFORMATION

5.3.1 Introduction

The purpose of this phase of the investigation was to develop models which can be incorporated in the PRS program to define the influence of asphalt binder content, in-place air void content, and aggregate gradation on the accumulation of permanent deformation (rutting) in the HMA layer.

Two levels of models were developed: those based on regressions between measured performance, rut depth,[1] and traffic loading and mix variables (termed level 1) and those based on M-E analyses using the same parameters (termed level 2).

Data used to develop these models are included in WesTrack Technical Report UCB-1 (*62*) and the WesTrack database and are summarized as follows:

- Measured downward rut depths (baseline to valley) and associated traffic (in terms of ESALs).
- RSST-CH data on FMFC specimens prior to the start of and at the conclusion (termed post mortem)[2] of traffic for the specific test sections.
- RSST-CH on LMLC specimens including the following:
  - Study of specimens representing sections 4 and 25 to determine effects of temperature and shear stress level on mix performance.
  - Aggregate gradation study at North Carolina State University (NCSU) to define the effects of aggregate grading variations on the performance of specimens; this was done over ranges in air void contents, asphalt contents, and aggregate gradations representing reasonable specification tolerances for both the fine and coarse gradings.

[1] 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 trough in each rut.
[2] For example, sections 7, 9, 13, 21, and 25 were rehabilitated and removed from consideration at about 1,460,000 ESALs.

To assist in the development of the M-E models, a special study of the effects of traffic wander on rut depth accumulations was also performed. This analytic 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 of reference 62. Details of the model development effort for permanent deformation are contained in Part II of this report and reference 62. A summary of this research effort is presented in the following section.

5.3.2 Summary and Recommendations for Permanent Deformation Models

A series of models have been developed 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 M-E modeling and regression.

For the level 1 analyses, equation 12 is recommended for use:

$$\begin{aligned}\ln(rd) = &-6.1651 + 0.30991\ \ln(ESAL)\\ &+ 0.00294305V_{air}^2 + 0.0688276P_{asp}^2\\ &- 0.0657803P_{asp} \cdot P_{200}\\ &+ 0.600498\ (\text{fine-plus}) - 1.59167\ (\text{coarse})\\ &+ 2.35276\ (\text{replace})\\ &+ 0.21327\ \ln(ESAL)\ (\text{coarse})\\ &- 0.140386\ \ln(ESAL)\ (\text{replace})\end{aligned} \tag{12}$$

where

rd = rut depth in mm (1 in. = 25.4 mm),
P_{200} = percent passing No. 200 (0.075 mm) sieve, and
fine plus, coarse, replace = variables which take the value of unity in the fine plus, coarse, or replacement mixes if the expression is used for one of these mixes. Otherwise, they have a zero value.

This recommendation is based on the fact that it tends to minimize the effects of some of the early rutting observed in some of the WesTrack sections.

The level 2 analysis, using an M-E procedure incorporating layered elastic analysis, permits the use of different temperature regimes and traffic distributions than those occurring at WesTrack.

In the M-E analyses, rutting in the HMA is assumed to be controlled by shear deformations. Accordingly, computed values for the shear stress, τ, and elastic shear strain, γ^e, at a depth of 50 mm (2 in.) beneath the edge of the tire are used for rutting estimates.

Permanent shear strain in the HMA is assumed to accumulate according to the expression:

$$\gamma^i = a \cdot \exp(b\tau)\gamma^e n^c \tag{13}$$

where

γ^i = permanent (inelastic) shear strain at a 50-mm (2-in.) depth,
τ = shear stress at the 50-mm (2-in.) depth determined from elastic analysis,
γ^e = corresponding elastic shear strain,
n = number of axle load repetitions, and
a,b,c = regression coefficients.

The time-hardening principle is used to accumulate the inelastic strains in the HMA considering in situ temperatures and applied traffic. Rut depth in the HMA is then determined from:

$$rd_{\text{HMA}} = \kappa\gamma_j^i \tag{14}$$

where

rd_{HMA} = rut depth and
κ = coefficient relating rut depth to inelastic strain and dependent on HMA layer thickness (*63*).

Contribution to surface rutting from the untreated pavement components is determined using a similar approach and is based on the elastic vertical compressive strain at the subgrade surface (*65*). The framework for rut depth estimation is shown in Figure 132.

The level 2A procedure requires the direct use of mix parameters in the models to define the *a* and *c* parameters for the specific mix under consideration so 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 which is intended for use in the pavement system and the use of the regression equations for the parameters *a* and *c* contained in reference 62.

Finally, a procedure has been developed whereby mix variables, including asphalt binder content, in-place air void content, and aggregate gradation (as defined by both the P_{200} and the No. 8 [2.36 mm] to No. 200 [0.075-mm] fractions), can be combined to develop a performance relation suitable for use in determining PFs by Monte Carlo simulations so 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 does make use of the RSST-CH data from both the field cores (FMFC) and from the laboratory-prepared specimens (LMLC) tested at NCSU. This procedure is also described in detail in reference 64 but has not been included in the framework of Figure 123.

5.4 FATIGUE CRACKING

5.4.1 Introduction

As with permanent deformation, the objective was to provide models which could be incorporated in the PRS program to define the influence of asphalt binder content, in-place air void content, and aggregate gradation on the development of fatigue cracking in the HMA layer.

Two levels of models were developed: those based on regressions between fatigue cracking, traffic loading, and mix variables (level 1); and those based on M-E analyses to predict performance based on laboratory-measured fatigue response and stiffnesses of the pavement layers (level 2). Appendix H of WesTrack Technical Report UCB-1 (*62*) and the WesTrack database contain a summary of the fatigue test and flexural stiffness data for FMFC specimens obtained from slabs from both the original and the replacement sections.

5.4.2 Regression Modeling

Linear regression approaches were 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. Accordingly, two models were developed: a Probit model for crack initiation; and a continuous model for crack propagation in which the dependent variable is the expected value of wheelpath cracking. For crack initiation, the Probit model was selected because it permits the use of observed field performance data for all 26 original test sections. In this model, the dependent variable is the indication of cracking termed INDCR. For each condition survey, if cracking is observed, INDCR = 1; otherwise it has a zero value.

For a 10 percent probability of cracking,[3] the following is the model for fine and fine plus mixes from the original sections:

$$\begin{aligned}\text{Prob}(INDCR = 1) = \Phi &- 49.502 + 4.788 \cdot \ln(ESAL) \\ &- 5.245 \cdot P_{asp} + 1.148 \cdot V_{air} \\ &- 2.301 P_{200}\end{aligned} \tag*{(15)[4]}$$

where Φ is the cumulative density function of the normal distribution.

For the coarse mixes in the original sections, the model is as follows:

$$\begin{aligned}\text{Prob}(INDCR = 1) = \Phi &- 47.151 + 5.293 \cdot \ln(ESAL) \\ &- 5.996 \cdot P_{asp} + 0.450 \cdot V_{air}\end{aligned} \tag{16}$$

[3] This level for probability of cracking was selected since it provided a better discrimination of performance among the sections than either the 5 or 2 percent levels.

[4] An alternative relation is:

$\text{Prob}(INDCR = 1) = \Phi -75.832 + 5.234 \cdot \ln(ESAL) - 3.072 \cdot P_{asp} + 1.050 \cdot V_{air}$

It should be noted that both asphalt content and degree of compaction (as measured by in-place air void content) have a significant influence on fatigue performance.

For crack propagation, a continuous regression model has been used in which the dependent variable is the expected value, $|E|$ of wheelpath cracking (CRX):

$$|E| = [\log(CRX)\,|\,INDCR = 1] \tag{17}$$

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, fine plus, and coarse mixes are contained in reference 64.

5.4.3 Mechanistic-Empirical Modeling

The approach used to predict fatigue cracking within the M-E framework is similar to that described in reference 65. The approach includes two components: flexural fatigue testing of the fine, fine plus, and coarse mixes and performance predictions based on the models developed as part of SHRP (*68*) but extended to efficiently treat in situ temperatures; (*69*) and calibrated to the Caltrans flexible-pavement design methodology (*67*). The refined models have been used previously in interpreting the results of the California heavy vehicle simulator (HVS) testing from pavement sections in the Caltrans Accelerated Pavement Testing (CAL/APT) program.

As with the permanent deformation analyses, the pavement is treated as a multilayer elastic system. Modulus values for the HMA, base, and subgrade are those reported in this chapter and in reference 62.

The principal tensile strain, ε_t, at the underside of the asphalt-bound layer is used as the damage determinant of fatigue. Results of laboratory fatigue tests on the three FMFC mixes from the original sections are as follows:

Fine mixes

$$\begin{aligned}\ln N_f = &\underset{(1.5343)}{-27.0265} - \underset{(0.0230)}{0.1439} V_{air} + \underset{(0.1245)}{0.4148} P_{asp} \\ &\underset{(0.1632)}{-4.6894} \ln \varepsilon_t \qquad R^2 = 0.88\end{aligned} \tag*{(18)[5]}$$

Fine plus mixes

$$\begin{aligned}\ln N_f = &\underset{(1.5658)}{-27.3409} - \underset{(0.0231)}{0.1431} V_{air} + \underset{(0.1247)}{0.4219} P_{asp} \\ &\underset{(0.0126)}{-0.0128} \ln T - \underset{(0.1632)}{4.6918} \ln \varepsilon_t \qquad R^2 = 0.88\end{aligned} \tag*{(19)[5]}$$

Coarse mixes

$$\begin{aligned}\ln N_f = &\underset{(2.3308)}{-27.6723} - \underset{(0.0299)}{0.0941} V_{air} + \underset{(0.2853)}{0.6540} P_{asp} \\ &\underset{(0.0174)}{+0.0331} T - \underset{(0.1878)}{4.5402} \ln \varepsilon_t \qquad R^2 = 0.92\end{aligned} \tag*{(20)[5]}$$

[5] The numbers in parentheses are "p" values for each of the terms indicating the significance of each of the parameters.

where

N_f = fatigue life;
V_{air} = air void content, percent;
P_{asp} = asphalt content, percent;
T = temperature at 150 mm (6 in.), °C (°F = 1.8°C + 32); and
ε_t = maximum tensile strain.

The framework for analyzing mix performance for the various sections is shown in Figure 133 and represents the level 2 procedure shown in Figure 123.

5.5 LOW TEMPERATURE CRACKING

5.5.1 Introduction

Two approaches were used to define the low temperature cracking potential at WesTrack: 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. At the onset of the project, the WesTrack team was hopeful that the IDT data could be used with the performance prediction models incorporated in the Superpave mix design and analysis system; accordingly, the original test plan included comprehensive IDT.

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 150, which made extensive use of the TSRST, evolved. For all low temperature cracking testing, FMLC and FMFC cores and slabs were taken from the top lift of the AC. A summary of the IDT and TSRST test results is included in Appendixes A and B of WesTrack Technical Report OSU-1 (*70*). More detailed information on the IDT and TSRST results is contained in the WesTrack database.

5.5.2 Test Results

Typical TSRST and IDT results are shown in Figures 134 and 135, respectively. Low temperature cracking test results are summarized in Figures 136 through 139. TSRST results are shown in Figures 136 and 137; IDT results in Figures 138 and 139.

Observations made about the IDT results are qualitative in nature because the limited number of tests conducted precluded a rigorous statistical analysis. As expected, and as is evident from Figure 138, 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 (–4°F) and –10°C (14°F), though it does not appear to be consistent. At –20°C (–4°F), section 1 (fine gradation with optimum asphalt content and medium air voids) has the highest stiffness, whereas at –10°C (14°F) and 0°C (32°F), section 25 (coarse gradation, high asphalt content and low air void content) has the highest stiffness. Since section 25 has a higher stiffness than any section tested but section 1 at –20°C (–4°F), one might conclude that low temperature stiffness is dependent to some degree on asphalt binder content. Recall that section 25 was a high asphalt content section, sections 1, 11, and 24 were optimum asphalt content sections, and section 26 was a low asphalt content. This conclusion is supported by the tensile (i.e., fracture) strength data shown in Figure 139. 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 136 indicates that there is little difference in fracture temperature between FMFC at time = 0 and FMLC, though there is greater scatter in the former because of variability in air void content. The average fracture temperatures for FMFC at time = 0 and FMFC post mortem specimens were –22.8°C (–9°F) and –20.6°C (–5°F), respectively. Extending the logic of AASHTO's MP1 (binder classification) to mixes, a "significant" difference in fracture temperature would be 3°C (5°F). In addition, the data shown in Figure 136 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 (–1°F) and –15.2°C (5°F), respectively, whereas all the coarse mixes (sections 24, 25, 26, and 35 through 39) had average fracture temperatures ranging from –20.8°C (–4°F) to –28.7°C (–20°F).

The TSRST results from the aging study are shown in Figure 137. The short-term oven-aged (STOA) specimens had an average fracture temperature of –27.3°C (–17°F). The long-term oven-aged specimens (LTOA) had an average fracture temperature of –25.4°C (–14°F), approximately a 2°C (4°F) difference. Interestingly, this 2°C (4°F) difference between STOA and LTOA is virtually identical to the difference in fracture temperature between the FMFC at time = 0 and FMFC post mortem specimens, –22.8°C (–9°F) and –20.6°C (–5°F), respectively.

To assess the difference between the various TSRST data sets, t-tests were conducted. The results, shown in Table 151, indicate that there is a statistically significant difference between the STOA and LTOA specimens. For all other data sets, there is no statistically significant difference in the mean fracture temperature. Also interesting to note is that the average fracture temperature for all the TSRST data sets was lower than –22°C (–8°F), the low temperature grade of the binder used at WesTrack (PG 64-22). The fact that no low temperature cracking was observed at WesTrack may be interpreted in two ways: (1) pavement temperature did not reach –22°C (–8°F) so the binder selection criterion was not tested or (2) pavement temperature dropped to or below –22°C (–8°F) such that the binder selection criterion was appropriate or perhaps somewhat conservative as explained below. The overall mean fracture temperature for TSRST specimens made with plant-mixed material, that is, FMFC or FMLC, was –21.8°C (–7°F). This is a conservative estimate of the fracture temperature of the mix because it is well documented that fracture temperature increases with cooling rate. The TSRST cooling rate of 10°C/hour (18°F/hour) exceeds the typical 2°C/hour (4°F/hour) cooling measured in the field such that a more realistic estimate of the fracture temperature might be 3°C (5°F) to 5°C (9°F) cooler than that measured in the TSRST, that is, –25°C (–13°F) to –28°C (–18°F). This suggests that the binder selection is in fact somewhat conservative, that is, that it should provide low temperature cracking resistant to temperatures of –25°C (–13°F) to –28°C (–18°F).

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. Because none of the models yielded an explained variation in excess of 20 percent, this rigorous analysis is not included herein.

5.5.3 Performance Models

As previously noted, the Superpave low temperature cracking performance prediction model was not available at the time the WesTrack results were analyzed. Accordingly, other analytical tools were used to extend the WesTrack results to other materials and climatic regions. Specifically, the Computations of Low-Temperature Damage (COLD) program with Mn/Road 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 behavior, 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. COLD equates the thermal stress assuming the pavement to be a pseudo-elastic beam or slab, infinite and longitudinally restrained. The following is the general form of the equation of stress as a function of depth:

$$\sigma_x(t) = -\alpha(T)\int_{t_0}^{t} S(\Delta t, T)\, dT(t) \tag{21}$$

where $S(\Delta t, T)$ is the time and temperature dependent stiffness, or creep modulus, and α is the coefficient of thermal expansion, assumed to be temperature independent. The method assumes the following: the induced stress is elastic, uniaxial, and uniformly distributed within a given depth increment; and the pavement is homogeneous and initially uncracked. 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 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.

Two separate pavement test tracks, WesTrack and Mn/ROAD (sited roughly 65 km (40 mi) northwest of St. Paul, Minnesota) were selected as the basis for all field verification of performance predictions made from laboratory data sets. 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 be desirable to examine a wider variety of binder types in mixes, but only two binders were used at Mn/ROAD. Therefore, investigating the performance of more than two sections at Mn/ROAD 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 would fail in thermal cracking, conventional wisdom dictates that it should be 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. Thereby, a "hybrid" pavement was conceived: one with properties that would mimic the binder contribution from WesTrack and all other mix properties and structural specifications of a Mn/ROAD pavement.

5.5.3.1 Mn/ROAD

COLD predicted pavement temperatures which resulted in a visible qualitative difference in cracking levels between the pavements of sections 14 and 15. The AC-120/150 asphalt mix of section 14 was predicted to fail first during the morning of February 2, 1996. COLD makes no predictions about the extent of cracking due to repeated episodes of failure, that is, on February 3 and 4, 1996, although intuition leads one to equate the area between the stress and strength curves with cracking density. The AC-20 mix of section 15 was predicted to crack first on January 20, then remain intact until January 30, when another episode of cracking was predicted to commence. A state of failure persisted throughout the entire period of January 31 through February 4.

On February 13, 1996, a pavement condition survey recorded 15 cracks in each lane of section 14 (Table 152). The combined length of these cracks was 53 m (174 ft) in the passing lane and 55 m (175 ft) in the driving lane. The same survey reported 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 section 15. Not only is this total length approximately 100 percent to 109 percent greater than that for the AC-120/150 section, but the cracks are more numerous, forming a much more jagged, irregular pattern. While the higher distress levels in the driving lane of both sections suggest that traffic loading contributes to transverse cracking, the difference is 3 percent to 7 percent and is, thus, arguably, a minor effect.

5.5.3.2 WesTrack Pavements

COLD predicted no thermal cracking distress for sections 24 and 25. WesTrack did not experience thermal cracking. Very close agreement was obtained for pavement temperatures, with the measured value being no higher than 3.5°C (6°F) above the value predicted by COLD. Pavement temperatures were nearly identical for both sections.

5.5.3.3 Hybrid Pavement

The hypothetical hybrid mix constructed with the WesTrack binder and all other Mn/ROAD mix properties, and subjected to Mn/ROAD climatic conditions, that is, the period January 18, 1996, through February 6, 1996, showed cracking to occur by a smaller margin than the Mn/ROAD AC-20 mix, but significantly more than the AC-120/150 mix. The hybrid performed most like the AC-20 mix. In principle, one would expect failure at a pavement temperature of –22°C (–8°F), 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 (–10°F). This agrees closely with the low temperature grade suggested by AASHTO MP1. The measured temperature at that time was –26.4°C (–15.6°F), approximately 3°C (5°F) lower than COLD estimated. Agreement between measured and calculated temperature was very good for this time increment, but inconsistent throughout the analysis period.

5.5.4 Conclusions

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 mix fracture temperature and binder stiffness, which is directly linked to low temperature mix stiffness and, thus, 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 the information required to judge a pavement's low temperature performance is adequately captured by knowledge of the following: laboratory-measured material rheological properties, climatic conditions, and application of a suitable pavement temperature prediction model.

Since the WesTrack experiment was structured to minimize or preclude problems with low temperature cracking, no performance prediction model or PFs are included in the PRS at this time. However, it is anticipated that refinements to the PRS would include the low temperature cracking model incorporated in Superpave.

5.6 MOISTURE SENSITIVITY

5.6.1 Introduction

Although the annual precipitation of the WesTrack site is typically less than 180 mm (7 in.), the climate is quite harsh. Nevada DOT has reported moisture-related problems in AC due to water vapor rising from underlying layers and as a result of freeze-thaw cycling. Moreover, the aggregate used for track construction was reportedly a low to moderate "stripper," hence, the inclusion of limited moisture susceptibility testing.

One objective of the WesTrack experiment was the early field verification of Superpave volumetric mix design; therefore, moisture sensitivity testing was included in accordance with AASHTO Test 283 (T283) using 150-mm (6-in.) diameter samples as described in the Superpave mix design method. Laboratory-fabricated specimens were approximately 95 mm (3.7 in.) in height whereas field cores were approximately 50 mm (2 in.) in height. For moisture sensitivity testing, field cores, that is, FMFC, were taken from the bottom lift of the HMA. Table 153 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 of WesTrack Technical Report OSU-2 (*71*). More detailed information on the T283 test results is contained in the WesTrack database.

5.6.2 Test Results

Moisture sensitivity test results are summarized in Figures 140 through 143. Shown in Figures 140 and 142 are T283 test results from specimens taken immediately after construction and before traffic loading, that is, time = 0. Post mortem test results are shown in Figures 141 and 143. There is tremendous scatter in the T283 data for the FMFC specimens taken immediately after construction, that is, 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 one-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, that is, FMFC and FMLC, were lower than the TSR for specimens made in the laboratory, that is, LMLC. 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.

Shown in Table 154 are results from t-tests conducted on various pairs of data (e.g., FMFC versus FMLC). As is evident from the results shown in Table 154, the mean TSR for the plant mixed material (FMFC and FMLC) is statistically different from the mean TSR for the laboratory 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 laboratory-fabricated specimens suggest exactly the opposite. There is no statistically significant difference between the results from the time = 0 and post mortem specimens. Finally, there is a statistically significant difference between the OSU and UNR results from the FMFC specimens.

Figure 144 shows the relationship between air void content and indirect tensile strength 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 disconcerting. Though several states report some degree of confidence in T283 results, recently completed research (*NCHRP Report 444*, “Compatibility of a Test for Moisture-Induced Damage with Superpave Volumetric Mix Design”) tends to reinforce the observations reported herein.

5.7 OTHER TEST RESULTS

During the conduct of the WesTrack project, a number of other testing programs were performed to support the material characterization program and the QA programs previously described. These testing programs were directed to defining the following properties:

- Theoretical maximum specific gravity — WesTrack Technical Report UNR-25 (*72*)
- Resilient modulus — WesTrack Technical Report UNR-26 (*73*)
- Tensile strength — WesTrack Technical Report UNR-26 (*73*)
- Recovered asphalt binder properties — WesTrack Technical Report UNR-27 (*74*)

A discussion of the WesTrack Technical Reports that contain this information are briefly summarized below.

5.7.1 Theoretical Maximum Specific Gravity

An extensive laboratory testing program was conducted on replacement section mixtures to determine if mixture aging prior to the determination of the theoretical maximum specific gravity (Rice specific gravity) would affect the test results and might explain the differences between mixture design volumetrics (LMLC) and FMLC sample volumetrics. Samples that had been prepared in the laboratory and subjected to both the Superpave STOA and LTOA for mixtures as well as samples that were mixed in the field were tested. Theoretical maximum specific gravity, asphalt absorption, and effective aggregate specific gravity were measured or calculated.

The differences in volumetric properties, due to the different laboratory aging conditions, were within the single-operator precision of the Rice specific gravity test method. Properties of the laboratory-aged samples correlated well with those of the field-aged samples. Comparison of laboratory and field data show that the Superpave STOA procedure induced aging similar to the aging which occurred during construction when measured in terms of Rice specific gravity and other related volumetric properties. Thus, it is appropriate to perform process control tests on field mixtures immediately after sampling for comparison with mix design properties.

5.7.2 Resilient Modulus and Tensile Strength

An extensive laboratory testing program was conducted on WesTrack mixtures to define the resilient modulus and tensile strength properties. This program was conducted as part of the water sensitivity study and is reported in WesTrack Technical Report UNR-26 (*73*) and reference 75. The resilient modulus was determined at different pavement ages on core samples for two lifts. The sensitivity of the HMAs at WesTrack to asphalt binder content, in-place air voids, and time after construction as measured by the resilient modulus and tensile strength is illustrated in the report.

5.7.3 Recovered Asphalt Binder Properties

The properties of asphalt binder extracted and recovered from core samples of HMA were determined. Conventional viscosity and penetration measurements were made as well as Superpave asphalt binder characterization tests. Mixtures were sampled from pavement sections placed as part of the original construction as well as replacement section mixtures. 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 in the coarse-graded mixtures was greater than in the fine-graded mixtures. WesTrack Technical Report UNR-27 (*74*) and reference 33 contain detailed asphalt binder data from core samples obtained over time.

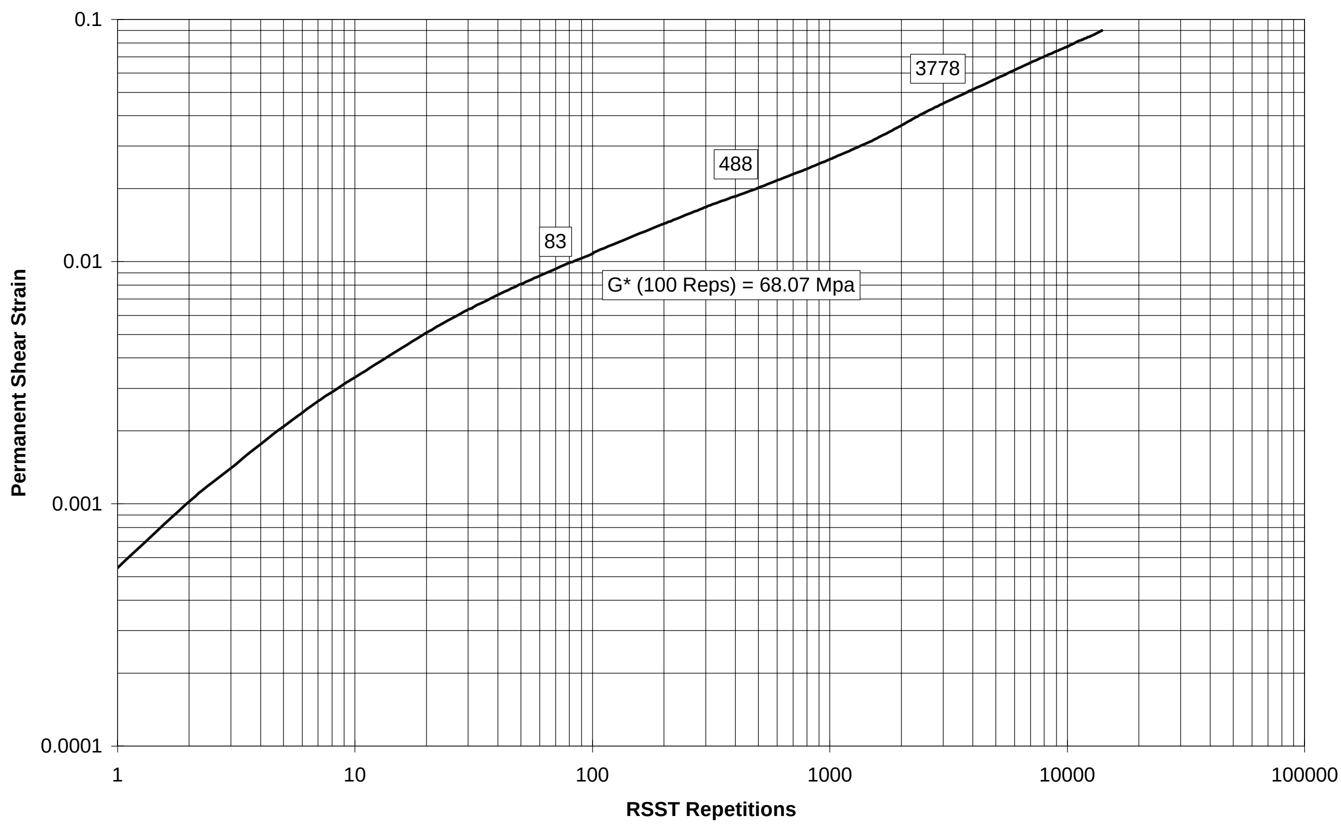


Figure 122. Shear strain, γ_p, versus load repetitions, N (1 ksi = 6.9 MPa).

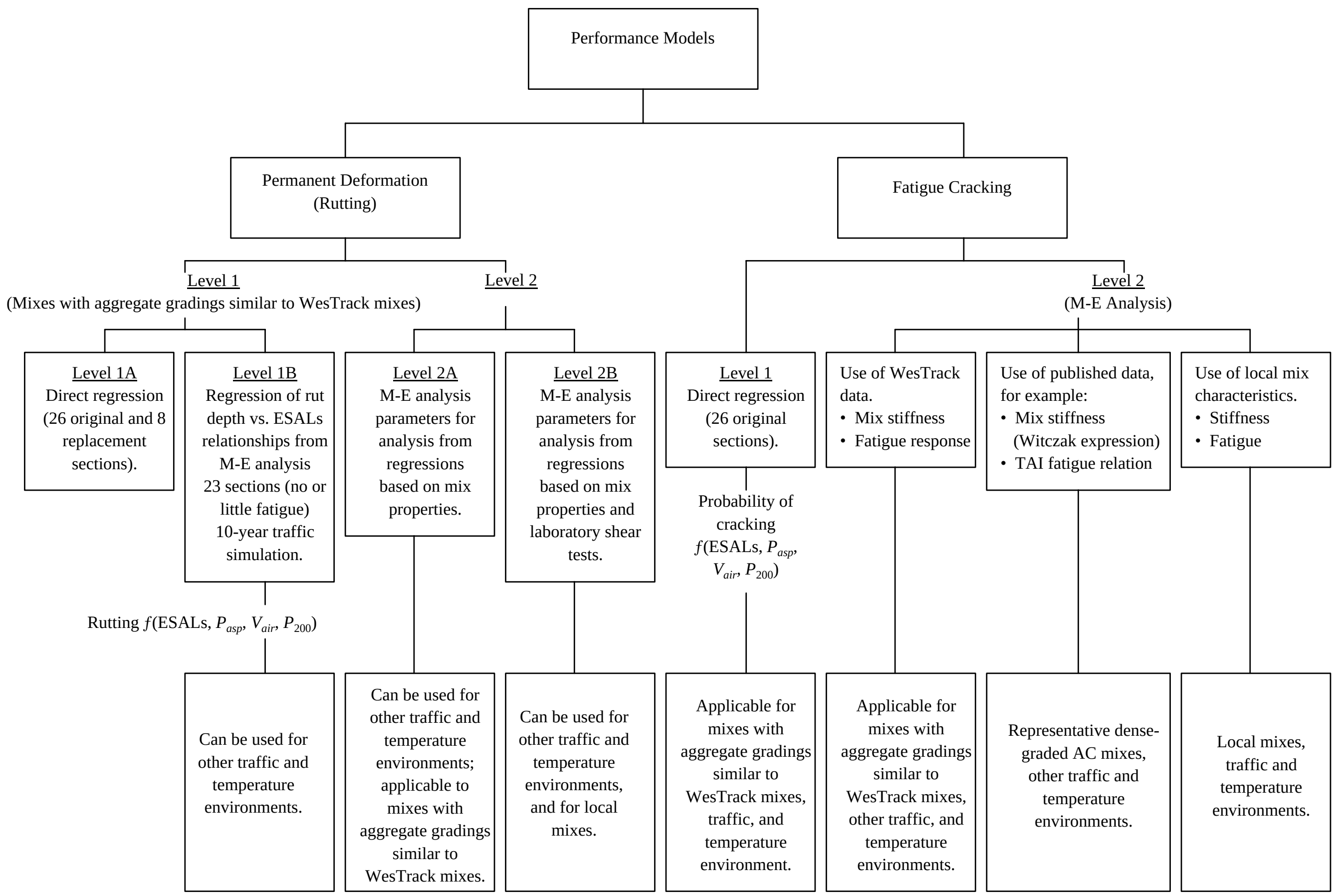


Figure 123. Performance model framework.

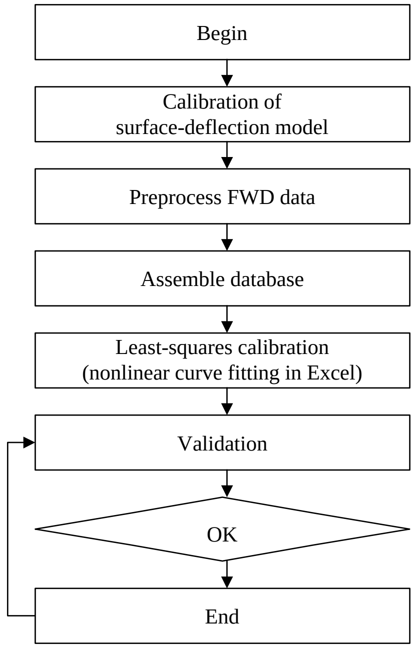


Figure 124. Framework for moduli determination.

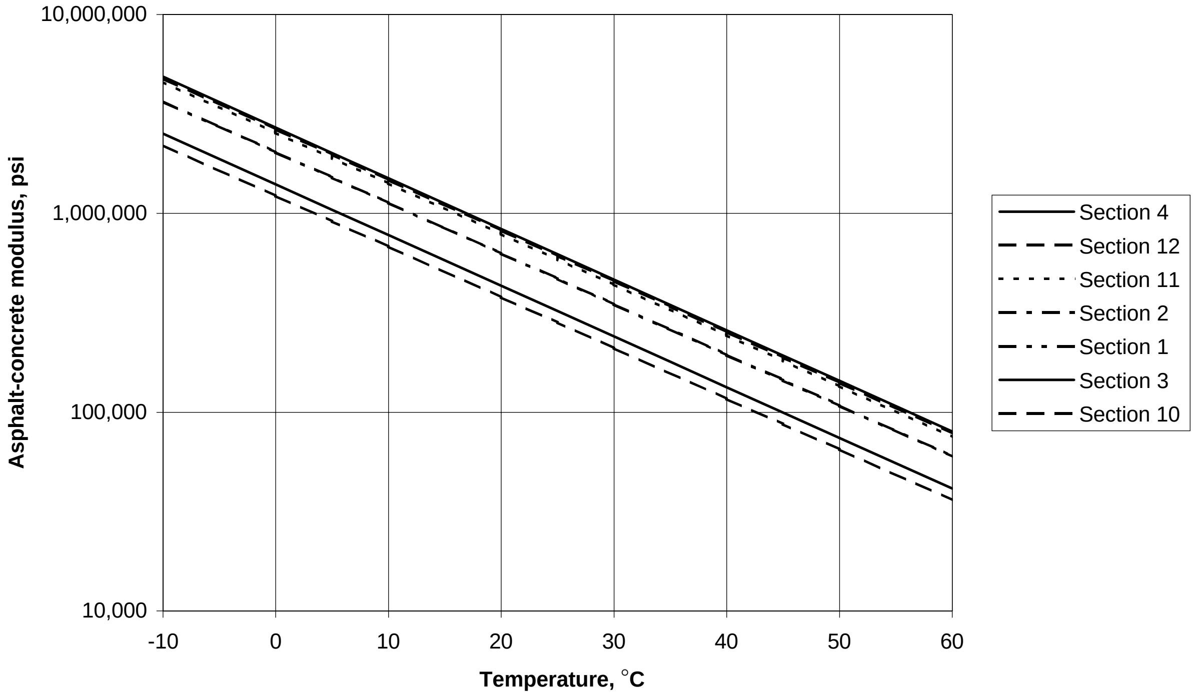


Figure 125. FWD-determined moduli for asphalt mixes, south tangent. (Note: 1 MPa = 145 psi, °F = 1.8°C + 32).

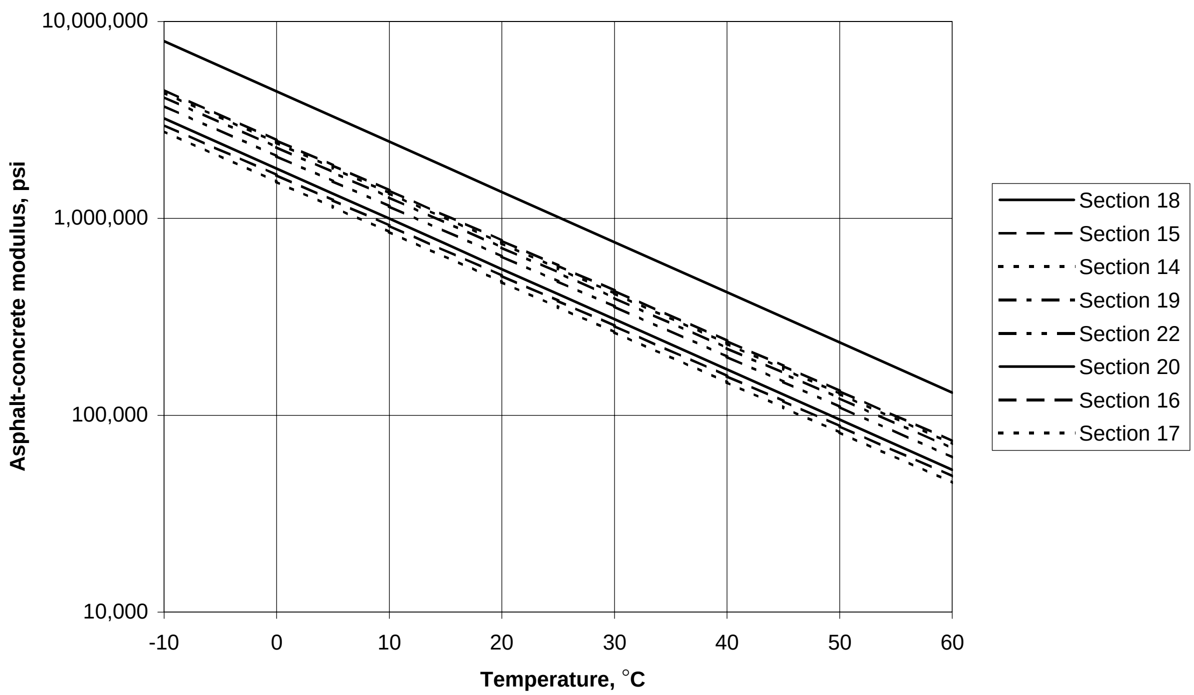


Figure 126. FWD-determined moduli for asphalt mixes, north tangent. (Note: 1 MPa = 145 psi, °F = 1.8°C + 32).

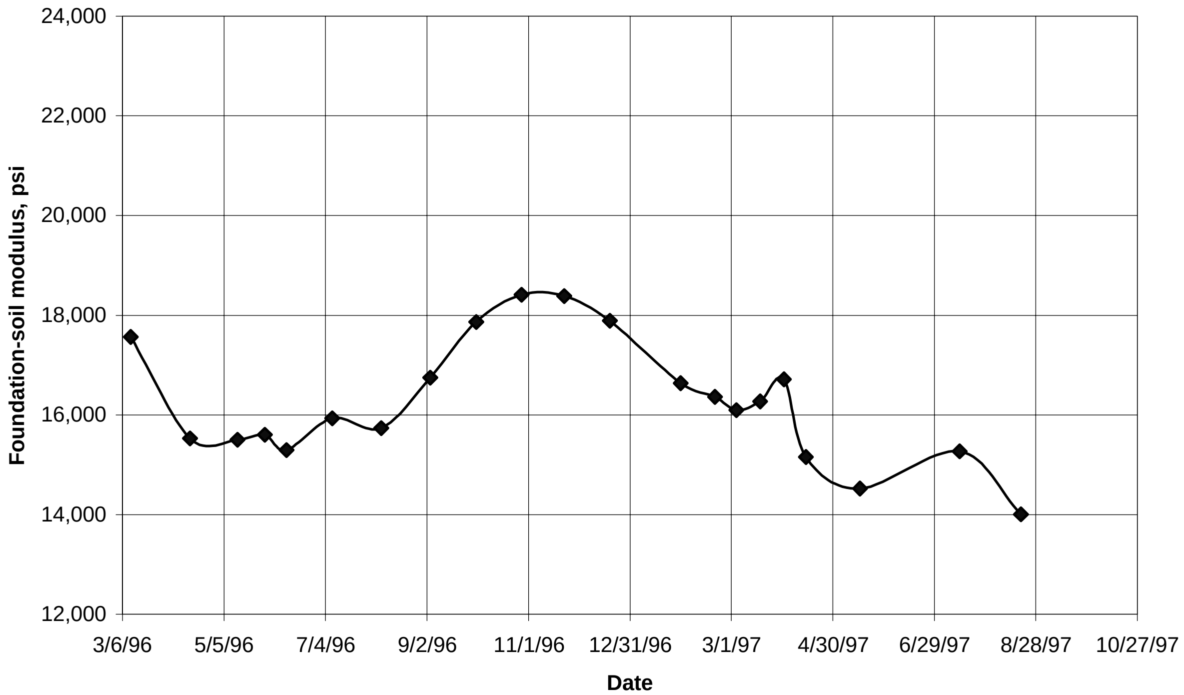


Figure 127. Seasonal variations of foundation-soil modulus, south tangent. (Note: 1 MPa = 145 psi).

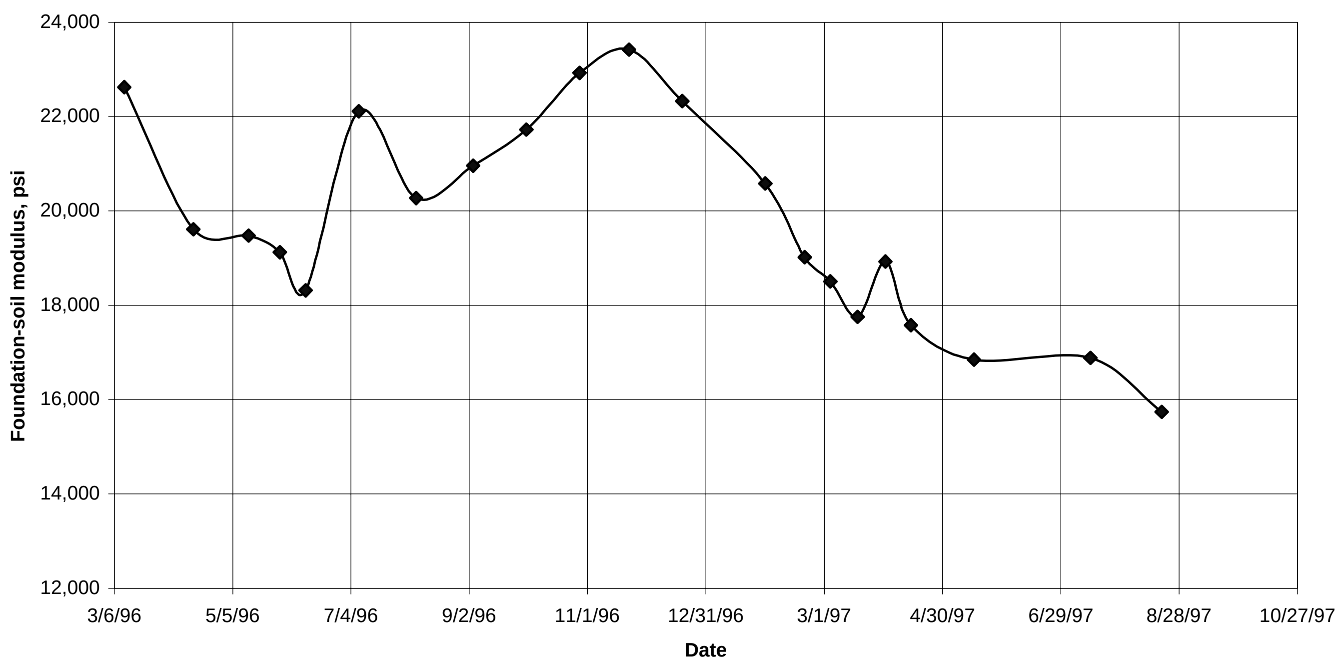


Figure 128. Seasonal variations of foundation-soil modulus, north tangent. (Note: 1 MPa = 145 psi).

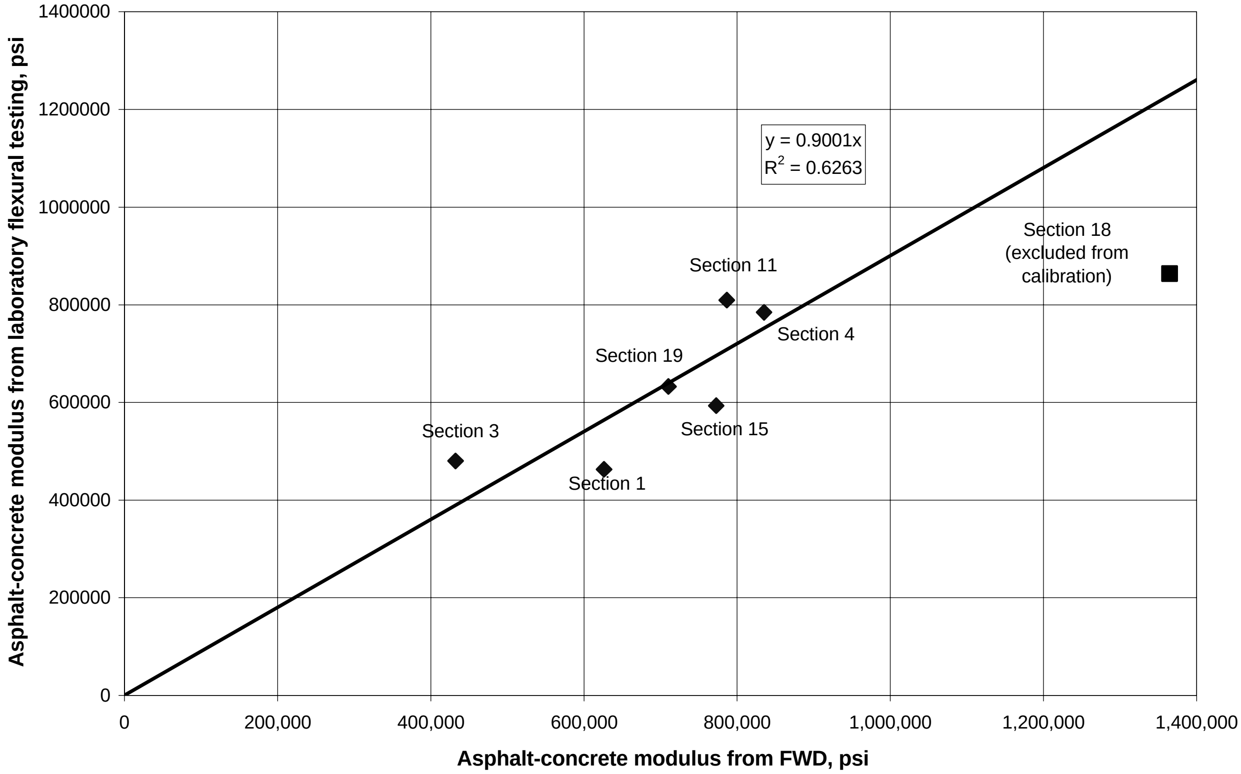


Figure 129. Comparison of laboratory-determined flexural stiffness moduli at 20°C (68°F) and moduli determined from FWD measurements (1 MPa = 145 psi).

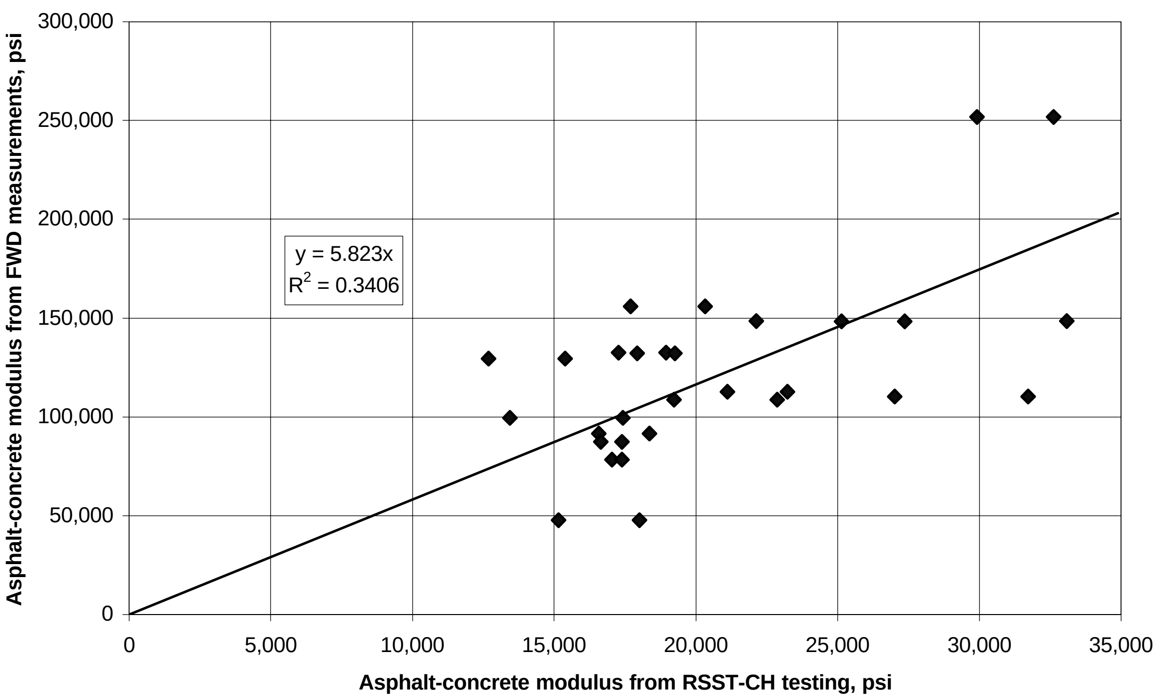
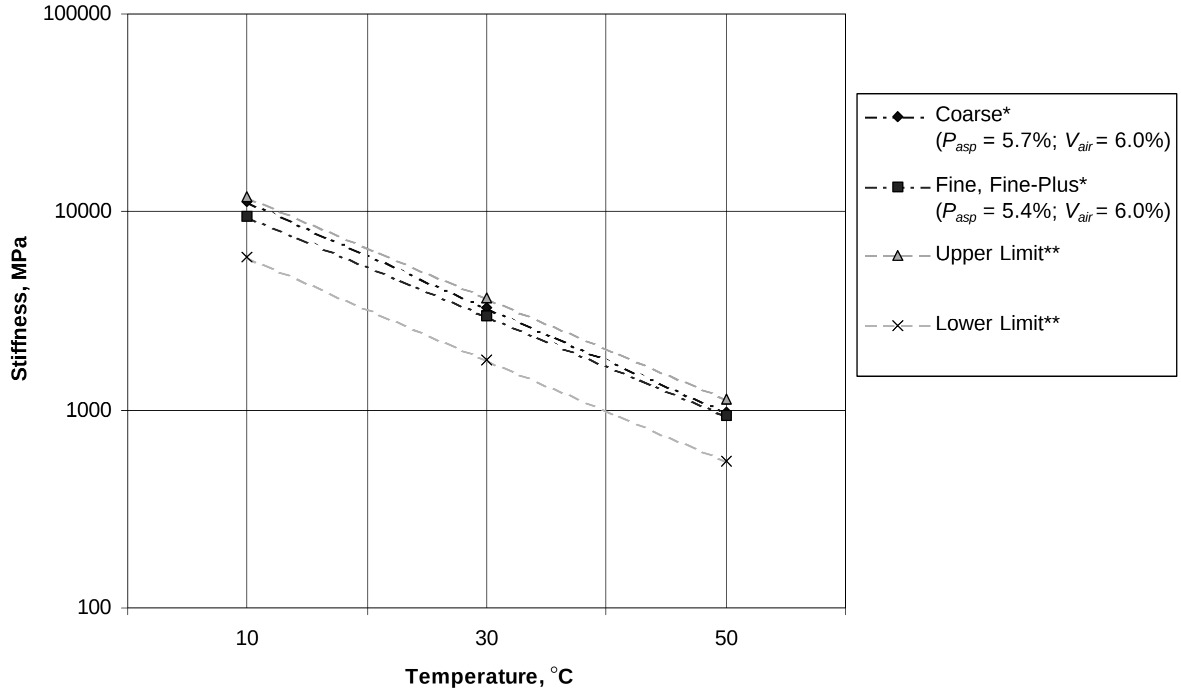


Figure 130. Comparison of laboratory-determined stiffness values determined from the RSST-CH tests at 50°C (122°F) and moduli determined from FWD measurements (1 MPa = 145 psi).



*According to equations 10 and 11
**Range in stiffness used in permanent deformation analyses; equation 8

Figure 131. Comparison of moduli used in permanent deformation analyses with moduli from equations 10 and 11 and those used in fatigue analyses, original sections (1 ksi = 6.89 MPa, °F = 1.8°C + 32).

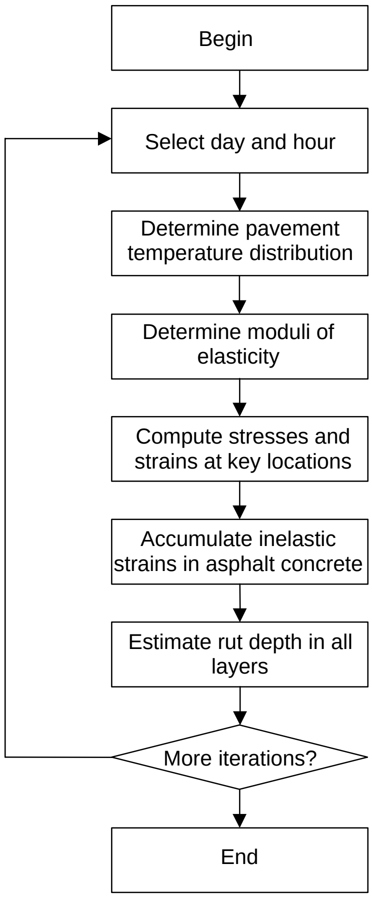


Figure 132. Framework for rut depth estimates.

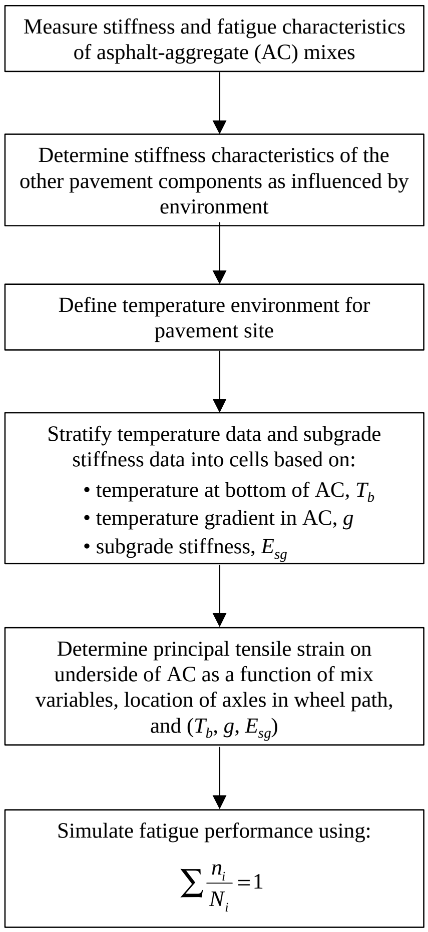


Figure 133. Framework for simulation of fatigue performance of 26 WesTrack sections.

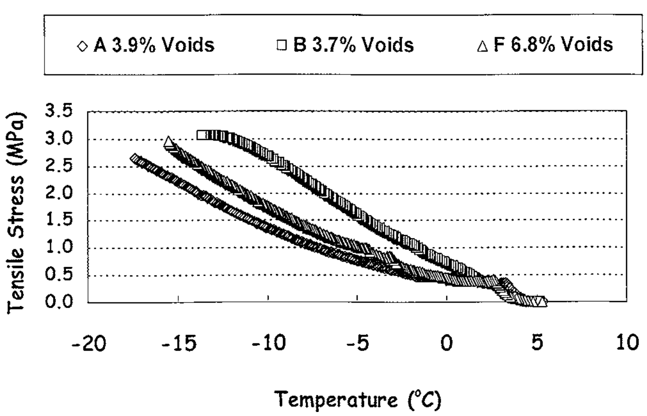


Figure 134. TSRST results—section 11 (FMFC) (1 ksi = 6.89 MPa, °F = 1.8°C + 32).

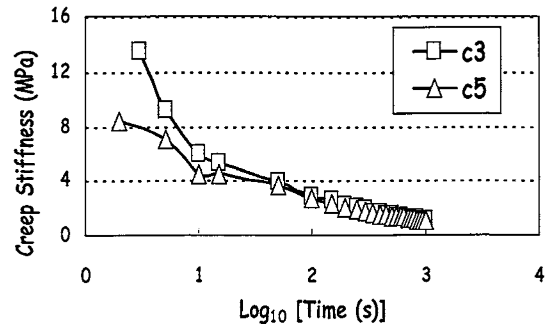


Figure 135. Creep stiffness at 0°C (32°F)—section 1 (FMFC) (1 ksi = 6.89 MPa).

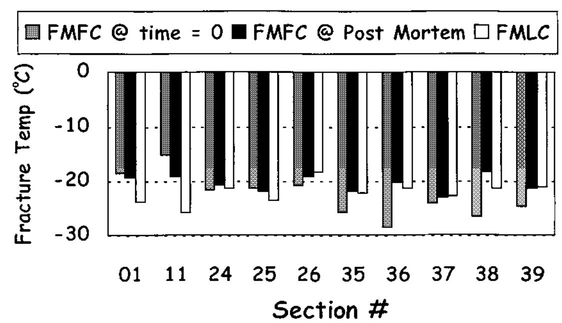


Figure 136. TSRST data (°F = 1.8°C + 32).

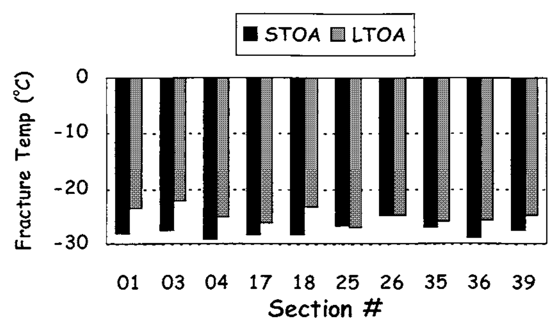


Figure 137. TSRST data—LMLC (°F = 1.8°C + 32).

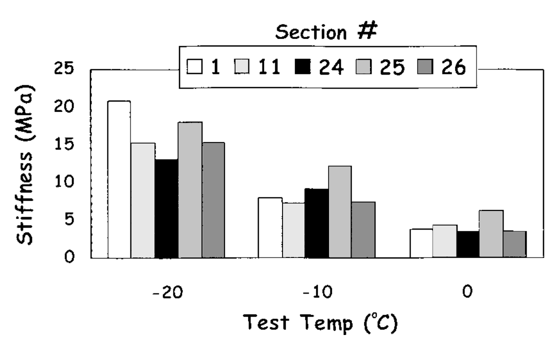


Figure 138. IDT creep stiffness (1 ksi = 6.89 MPa, °F = 1.8°C + 32).

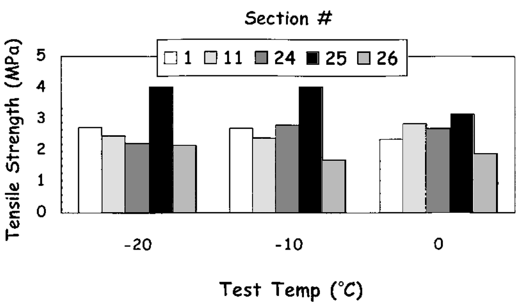


Figure 139. IDT tensile strength (1 ksi = 6.89 MPa, °F = 1.8°C + 32).

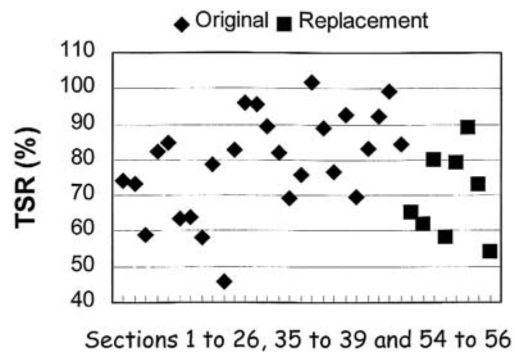


Figure 142. T283 results (FMFC)—UNR.

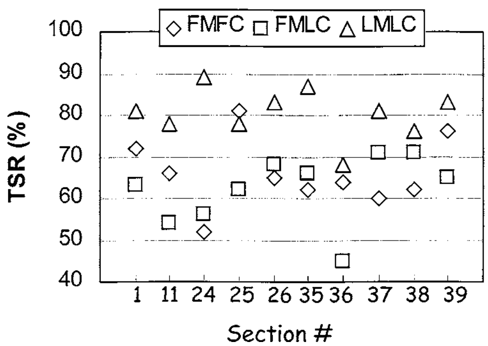


Figure 140. T283 results—OSU (time = 0).

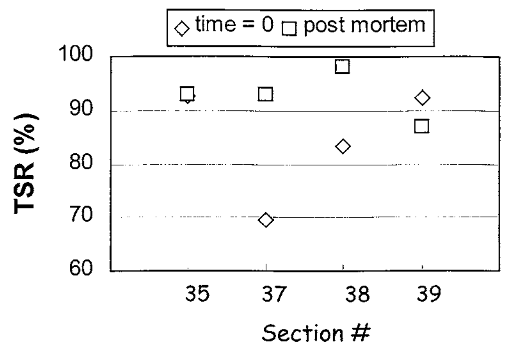


Figure 143. T283 results (FMFC)—UNR.

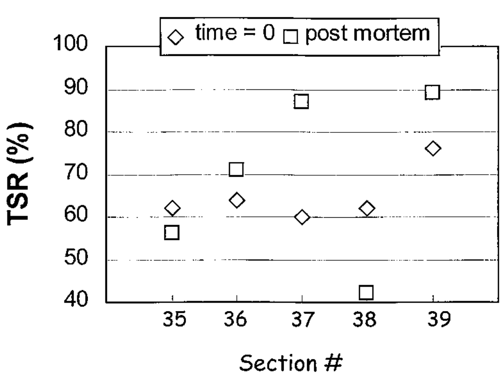


Figure 141. T283 results (FMFC)—OSU.

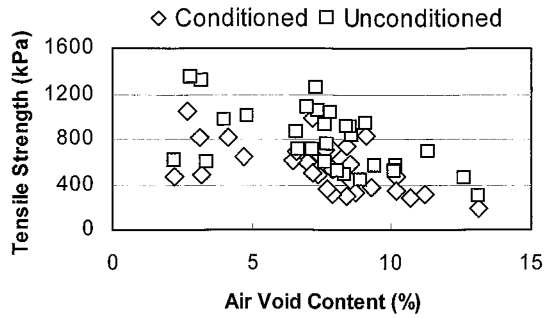


Figure 144. T283 results (1 psi = 6.9 kPa).

TABLE 148 Stiffness ranking of asphalt concrete

Gradation	Section	Asphalt Content	Air Void Content	Modulus at 40°C, psi[d]
South Tangent				
	12	Medium	Low	253,073
Fine plus	11[a]	Medium	Medium	243,064
	10	Low	High	116,834
	4	Medium	Low	258,119
Fine	2	Low	Medium	194,654
	1[b]	Medium	Medium	193,549
	3[c]	Low	High	133,659
North Tangent				
	19[a]	Medium	Medium	219,565
Fine plus	22	Low	Medium	198,222
	20	Medium	High	171,201
	18	High	Low	421,795
	15[b]	Medium	Medium	238,794
Fine	14	High	Medium	231,007
	16[c]	Low	High	158,222
	17	Medium	High	146,852

[a]Sections 11 and 19 are duplicates.
[b]Sections 1 and 15 are duplicates.
[c]Sections 3 and 16 are duplicates.
[d]1 psi = 6.9 kPa, °F = 1.8°C + 32

TABLE 149 Comparison of laboratory and FWD moduli, psi, for base and foundation soil (monitoring session 12)

Layer	South Tangent		North Tangent	
	Laboratory	**FWD**	**Laboratory**	**FWD**
Base	13,000	15,100	12,100	13,500
Engineered fill, top	14,100		6,800	
Engineered fill, bottom	20,000	16,700	20,400	21,000
Foundation soil	11,000		16,800	

1 psi = 6.9 kPa

TABLE 150 Low temperature cracking test plan

	Section Number	
	TSRST	**IDT**
FMFC: time = 0	1, 11, 24, 25, 26, 35 - 39	1, 11, 24, 25, and 26
FMFC: post mortem	1, 11, 24, 25, 26, 35 - 39	
FMLC	1, 11, 24, 25, 26, 35 - 39	1, 11, 24, 25, and 26
LMLC	1, 3, 4, 17, 18, 25, 26, 35, 36, and 39**	

FMFC: field-mixed/field-compacted
FMLC: field-mixed/laboratory-compacted
LMLC: laboratory-mixed/laboratory-compacted

** short-term oven aging and long-term oven aging

TABLE 151 Results of t-tests from TSRST data (fracture temperature)

Data Set	t - Statistic	t - Critical	Means Different?
FMFC time = 0 vs. post mortem	1.577	2.101	no
FMFC @ time = 0 vs. FMLC	0.446	2.101	no
FMFC post mortem vs. FMLC	1.900	2.101	no
LMLC STOA vs. LTOA	4.529	2.101	yes

TABLE 152 Pavement condition survey: Mn/Road cells 14 and 15

Cell	Lane	Survey Date	Transverse Cracks	
			Number	Combined Length (ft)
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	590
	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

1 ft = 0.305 m

TABLE 153 Moisture sensitivity testing

	Section Number	
	OSU	**UNR**
FMFC: time = 0	1, 11, 24, 25, 26, 35 - 39	1 - 26 35 - 39 54 - 56
FMFC: post mortem	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 154 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 @ post mortem	0.416	2.160	no
FMFC (OSU) vs. FMFC (UNR)	2.826	2.032	yes

CHAPTER **6**

REPORTS AND PUBLIC INFORMATION ACTIVITIES

A number of reports have been prepared and public information activities conducted during the WesTrack project. These reports and activities are summarized below.

6.1 REPORTS

The WesTrack project and its products are documented in this four-part report, several WesTrack Technical Reports, various papers and articles that have appeared in the literature, and a series of graduate student theses. The following is a description and list of the reports.

6.1.1 WesTrack Report

The WesTrack report has been developed in four parts:

- Part I: Project Overview.
- Part II: Performance-Related Specification.
- Part III: WesTrack Database.
- Part IV: Observations and Lessons.

Part I, Project Overview, provides an overview of the entire project. It discusses some historic background of the project, introduces the WesTrack research team, defines the various preconstruction activities (experiment design, site evaluation, geometric design, etc.), summarizes the construction operations, discusses the operation of the track, and outlines the materials characterization and performance modeling activities.

Part II, Performance-Related Specification, contains the background information for the PRS including the performance models, discussion of PRS development issues, and a guide specification. This part also includes a PRS software user's guide.

Part III, WesTrack Database, describes the database developed to record the project files. The database is available from the FHWA; it includes materials properties, performance monitoring results, and weather data for the project. The structure of the database allows data from one file to merge with a second file to produce the desired table of plots of information. The WesTrack database user's guide is also included in Part III of this report.

Part IV, Observations and Lessons, discusses general observations and findings resulting from the WesTrack research effort and identifies additional analysis possibilities.

6.1.2 PRS Software and WesTrack Database

An alpha version of the PRS software and a beta version of the WesTrack database were prepared by the WesTrack team along with respective user's manuals.

6.1.3 WesTrack Technical Reports

Some 44 individual WesTrack Technical Reports have been prepared to provide detailed discussion of key elements of the WesTrack project. These reports provide the details on preconstruction, construction, and postconstruction work activities. Table 155 is a listing of these technical reports and all have been listed as references, where appropriate, in this report. The WesTrack Technical Reports are available on CD-ROM from the FHWA and TRB.

6.1.4 Published Papers and Articles

More than 25 papers and articles have been published by the WesTrack team and others on the WesTrack project. These range from papers published in journals and proceedings at the international level to brief articles in trade magazines. Table 156 lists these papers and articles.

6.1.5 Graduate Student Theses

Ten graduate student theses have been prepared based on the WesTrack data and information. Eight masters and two Ph. D. students were active on the WesTrack project at the UCB, OSU, and UNR. Table 157 lists these theses.

6.2 PUBLIC INFORMATION ACTIVITIES

The WesTrack public information activities primarily consisted of the preparation of a video, an "open house" for the public and industry, and presentations at various venues. These activities are briefly discussed below.

6.2.1 Video

A 7-min video providing background information on WesTrack, the experimental design, trafficking considerations, and anticipated results was prepared and distributed. The video has the title “WesTrack” and a copy is available from the FHWA.

6.2.2 Open House

An open house was held at WesTrack in June 1995 for public officials, interested citizens, engineers and technicians, material suppliers and contractors, and consultants and project staff. The program featured speakers from the FHWA, AASHTO, Nevada DOT, Granite Construction, NATC, and the American Trucking Industry.

6.2.3 Tours

Numerous tours were conducted at WesTrack during the conduct of the project. Table 158 contains a list of the tours conducted by the WesTrack team.

6.2.4 Presentations

More than 70 presentations were made on the WesTrack project during the life of the project. These presentations provided briefings of the project and results from the project to technical and trade association meetings throughout the United States. All members of the research team were involved in these presentations. Table 159 contains a list of the presentations made on WesTrack at various meetings and conferences.

6.3 FUTURE ACTIVITIES

NCHRP is sponsoring further research projects to build on results of the WesTrack project. These projects will conduct beta testing for the PRS software and trial use of and calibration and validation of the WesTrack performance models with field performance data in selected states. The WesTrack facility is available for additional accelerated pavement performance testing.

TABLE 155 WesTrack technical activity reports

Title	Primary Authors	Report Number	Date
"WesTrack Driverless Vehicle Integration"	Ashmore, C.	NATC-1	November 2000
"WesTrack Pavement Surface Distress Collection and Data Reduction"	Ott, W., Alavi, S., and Mactutis, J.	NCE-1	November 2000
"Geometric Design"	Welsh, J.	NCE-2	November 2000
"WesTrack Longitudinal Profile Data Collection and Level 1 QC/QA Data Analysis"	Mactutis, J., Alavi, S., and Ott, W.	NCE-3	November 2000
"Evaluation of Laboratory and Field Tests Used to Determine Pavement Structural Support from the WesTrack Experiment"	Ott, W., Alavi, S., and Mactutis, J.	NCE-4	November 2000
"WesTrack Post Mortem Investigation of Sections: 05, 06, 08, 24, and 26 on May 23, 1997"	Ott, W., Alavi, S., and Mactutis J.	NCE-5	November 2000
"WesTrack Traffic Wander"	Mactutis, J., Alavi, S., and Ott, W.	NCE-6	November 2000
"Rut Depth Data and Equipment for WesTrack Original and Replacement Sections"	Ott, W., Alavi, S., and Mactutis, J.	NCE-7	November 2000
"WesTrack Site Investigation and Track Layout"	Ott, W., Alavi, S., Mactutis, J., and Seeds, S.	NCE-8	November 2000
"*HMA Spec* User's Guide"	Scholz, T.	NCE-9	November 2000
"Low Temperature Cracking – Testing and Performance Prediction"	Leahy, R. and Waters, C.	OSU-1	March 2000
"Moisture Sensitivity Testing"	Leahy, R. and James, D.	OSU-2	March 2000
"WesTrack: Performance Models for Permanent Deformation and Fatigue"	Monismith, C., Deacon, J., Harvey, J.	UCB-1	June 2000
"WesTrack Asphalt Binder Properties Original Construction"	Epps, J., Ashour, M., Hand, S., and Sebaaly, P.	UNR-1	July 2000
"WesTrack Asphalt Binder Properties Replacement Sections"	Epps, J., Hand, A., and Sebaaly, P.	UNR-2	July 2000
"WesTrack Hydrated Lime Properties Original Construction"	Epps, J., Hand, A., and Sebaaly, P.	UNR-3	July 2000
"WesTrack Aggregate Properties Original Construction"	Epps, J., Hand, A., and Sebaaly P.	UNR-4	July 2000
"WesTrack Aggregate Properties Replacement Sections"	Epps, J., Hand, A., and Sebaaly, P.	UNR-5	July 2000
"Original Construction Mix Designs for the WesTrack Project"	Hand, A., Epps, J., Sebaaly, J., and D'Angelo, J.	UNR-6	July 2000
"Hot-Mix Asphalt Mixture Design Replacement Sections"	Epps, J., Hand, A., and Sebaaly, P.	UNR-7	July 2000
"WesTrack Quality Control Volumetrics Original Construction"	Gordon, C., Killingsworth, B., Epps, J., Hand, A., and Sebaaly, P.	UNR-8	July 2000
"WesTrack Quality Assurance Volumetrics Original Construction"	Hand, A., Epps, J., and Sebaaly, P.	UNR-9	July 2000
"WesTrack Quality Control Volumetrics Replacement Sections"	Epps, J., Hand, A., and Sebaaly, P.	UNR-10	July 2000
"WesTrack Replacement Construction HMA Quality Assurance Superpave Volumetric Properties"	Hand, A. and Epps, J.	UNR-11	July 2000
"In-Place Air Void Content and Thickness Original Construction"	Epps, J., Hand, A., and Sebaaly, P.	UNR-12	July 2000
"In-Place Air Void Content and Thickness Replacement Sections"	Epps, J., Hand, A., and Sebaaly, P.	UNR-13	July 2000
"Quality Control Asphalt Binder Contents Original Construction"	Gordon, C., Killingsworth, B., Epps, J., Hand, A., and Sebaaly, P.	UNR-14	July 2000
"WesTrack Original Construction Quality Assurance Asphalt Contents"	Hand, A., Epps, J., and Sebaaly, P.	UNR-15	July 2000

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TABLE 155 (Continued)

Title	Primary Authors	Report Number	Date
"Quality Control Asphalt Binder Contents Replacement Sections"	Epps, J., Hand, A., and Sebaaly, P.	UNR-16	July 2000
"WesTrack Replacement Construction Quality Assurance Asphalt Contents"	Hand, A. and Epps, J.	UNR-17	July 2000
"WesTrack Original Hot-Mix Asphalt Preconstruction, Construction, and Postconstruction Material Sampling and Testing Plan"	Hand, A. and Epps, J.	UNR-18	February 2000
"WesTrack Replacement Hot-Mix Asphalt Preconstruction, Construction, and Postconstruction Material Sampling and Testing Plan"	Hand, A. and Epps, J.	UNR-19	February 2000
"Coarse Aggregate Angularity of the WesTrack Project Aggregates"	Hand, A., Epps, J., and Sebaaly, P.	UNR-20	February 2000
"Quality Control Aggregate Gradations Original Construction"	Epps, J., Hand, A., and Sebaaly, P.	UNR-21	July 2000
"Quality Assurance Aggregate Gradations Original Construction"	Epps, J., Hand, A., and Sebaaly, P.	UNR-22	July 2000
"Quality Control Aggregate Gradations Replacement Sections"	Epps, J., Hand, A., and Sebaaly, P.	UNR-23	July 2000
"Quality Assurance Aggregate Gradations Replacement Sections"	Epps, J., Hand, A., and Sebaaly, P.	UNR-24	July 2000
"Effect of Aging Conditions on Hot-Mix Asphalt Theoretical Maximum Specific Gravities WesTrack Replacement Sections"	Hand, A., Epps, J., and Sebaaly, P.	UNR-25	July 2000
"Resilient Modulus and Tensile Strength Properties of WesTrack Hot-Mix Asphalt Mixtures"	Epps, J., Dewan, S., Hand, A., and Sebaaly, P.	UNR-26	July 2000
"Recovered Asphalt Binder Properties WesTrack Hot-Mix Asphalt Mixtures"	Epps, J., Ashour, M., Hand, A., and Sebaaly, P.	UNR-27	July 2000
"Costs Associated with Pavement Construction, Rehabilitation, and Maintenance Activities"	Hicks, R. and Epps, J.	UNR-28	July 2000
"Subgrade, Base Course, and Hot-Mix Asphalt Construction Variability"	Epps, J., Hand, A., and Sebaaly, P.	UNR-29	July 2000
"Guide Performance-Related Specification for WesTrack"	Epps, J. and Hand, A.	UNR-30	July 2000
"WesTrack Construction Specifications"	Epps, J., Welsh, J., Hand, A., and Sebaaly, P.	UNR-31	July 2000

TABLE 156 Published papers and articles on WesTrack

Title	Authors	Publication	Date
"WesTrack Performance-Interim Findings"	Epps, J., Monismith, C., Seeds, S., Alavi, S., Ashmore, C., Leahy, R., and Mitchell, T.	Journal Association of Asphalt Paving Technologists	March 1998
"WesTrack Full-Scale Test Track: Interim Findings	Epps, J., Monismith, C., Seeds, S., Ashmore, C., and Mitchell, T.	Proceedings, Eighth International Conference on Asphalt Pavements, Vol. III, August 1997	August 1997
"WesTrack - The Road to Performance-Related Specifications"	Epps, J., Leahy, R., Mitchell, T., Ashmore, C., Seeds, S., Alavi, S., and Monismith, C.	International conference on Accelerated Pavement Testing	October 1999
"Development of a Pavement Rutting Model from Experimental Data"	Archilla, R. and Madanat, S.	Journal of Transportation Engineering, ASCE	July 2000
"An Econometric Model of Pavement Rutting in Asphalt Concrete Mixes"	Archilla, A. and Madanat, S.	Submitted for publication in the International Journal of Pavement Engineering	
"Development of Distress Progression Models Using Panel Data Sets of In-Service Pavements"	Madanat, S. and Shin, H.	Transportation Research Record 1643, Transportation Research Board, National Research Council	1998
"Smoother, Sturdier, High-Tech Highways at WesTrack	Brown, S. and Mitchell, T.	Fortune Magazine	December 21, 1998
"It's a Wrap"	- - -	FOCUS	August 1999
"WesTrack: Putting ITS to Work"	Ashmore, C. and Mitchell, T.	Public Roads Magazine	July/August 1997
"WesTrack: The Road to Solutions"	Mitchell, T.	Public Roads Magazine	Autumn 1996
"WesTrack Full-Scale Test Track: Interim Findings	Epps, J., Seeds, S., Leahy, R., Alavi, S., Mitchell, T., Monismith, C., and Ashmore, C.	Paper for International Symposium on Asphalt Pavement (ISAP)	August 1997
"Superpave Volumetric Designs of the WesTrack Project"	Epps, J., Seeds, S., Leahy, R., Alavi, S., Mitchell, T., Monismith, C., and Ashmore, C.	Draft paper prepared for TRB	1997
"Team Evaluates Rutting Problems at WesTrack Performance of Course - Graded Mixes at WesTrack - Premature Rutting	Mitchell, T., Brown, R., Michael, L., Dukatz, E., Scherocman, J., Huber, G., and Sines, R.	FOCUS Analysis conducted by an independent team, final report on FHWA web site	October 1997 June 1998
"Potential Role of Structural Thickness in the WesTrack Mixture Performance"	Huber, G., Scherocman, J., and Dukatz, E.	Written opinion by members of the WesTrack Forensic Team USDOT FHWA web site	June 1998
"Superpave Advances with Opening of Western Regional Center and WesTrack"	Sheriff, M. and Mitchell, T.	"Pavements" "Research and Technology Transporter On-Line"	August 1996
"WesTrack: Performance Testing for Quality Roads"	- - -	FHWA Publication No. FHWA-SA-97/038	1997
"More Work, Changes Ahead for Highway Paving Sector Intelligent Roads for Driverless Vehicles"	Flynn, L.	Roads and Bridges	September 1998
"More Work, Changes Ahead for Highway Paving Sector Intelligent Roads for Driverless Vehicles"	Siuru, B.	Electronics Now	December 1997
"Where the Rutting Meets the Pavement"	Hecht, J.	Technology Review	November/December 1998
"Driverless Trucks Earn Good Safety Record at WesTrack"	Mitchell, T.	FOCUS	January 1997

(*continued on next page*)

TABLE 156 (Continued)

Title	Authors	Publication	Date
"WesTrack: The Road to Tomorrow"	Ashmore, C. and Mitchell, T.	FOCUS	September 1996
"FHWA Project Running Four Driverless Trucks"	Siegel, S.	Fleet Owner	November 1996
"Rutting at WesTrack: Final Report Due Out Next Month"	D'Angelo, J. and Williams, C.	FOCUS	March 1998
"WesTrack Update: Rutting - As Expected"	Mitchell, T.	FOCUS	December 1996
"Test Track Rutting as Expected"	Mitchell, T.	Roads and Bridges	December 1996
"Superpave Test Track Takes a Beating"	Avera, L.	Asphalt Contractor	October 1996
"Team Investigating Cause of Premature Deformation at WesTrack"	Mitchell, T. and D'Angelo, J.	FOCUS	September 1997
"Experimental Test Track Takes Shape in Nevada - Where's the Driver?"	Mitchell, T. Yelton, R.	FOCUS The Concrete Producer	October 1995 April 1997
"Test Roads Key to Tomorrow's Pavements"	Churilla, C.	Roads and Bridges	June 1996
"Safety First Trucking's First Concern"	Tiffany, B.	Inside Trucking	August 1996
"WesTrack Team Combines Industry's Expertise and Resources for Pavement Research"	- - -	FHWA Publication No. FHWA-SA-97/054	- - -
"Road Tests Going High Tech"	O'Driscoll, B.	Reno Gazette Journal	May 31, 1996
"Super Pavement Being Developed with Involvement of Local Firm"	- - -	The Fernley Leader—Dayton Courier	June 12, 1996
"UNR Joins National Effort to Create Better Asphalt"	Kellogg, A.	Daily Sparks Tribune	June 5, 1996
"Brave New Road - New Technology Could Lead to an End to Reno's Roadway Hassles"	Summerhill, B.	Reno News and Review	June 12, 1996
"Reno Center Aims to Build Better Asphalt"	Chereb, S.	The Modesto Bee	June 6, 1996
"UNR Engineering School Unveils 'Superpave Center'"	Sion, M.	Reno Gazette Journal	June 9, 1996
"Test Track to Improve Roads"	Szoke, A.	Appeal	- - -
"'Superpave Pavement' Being Developed with Involvement of Local Firm"	- - -	The Leader-Courier (Fernley, Dayton)	June 12, 1996
"Evaluation of Laboratory and Backcalculated Moduli from the WesTrack Experiment"	Mikhail, M., Seeds, S., Alavi, S., and Ott, W.	Draft paper prepared for TRB	1998
"Evaluation of Laboratory-Determined and Nondestructive Test Based Resilient Modulus Values From WesTrack Experiment"	Seeds, S., Alavi, S., Ott, W., Mikhail, M., and Mactutis, J.	"Nondestructive Testing of Pavements and Backcalculation of Moduli" ASTM STP 1375	1999
"Investigation of the Relationship Between Roughness and Pavement Surface Distress Based on the WesTrack Experiment"	Mactutis, J., Alavi, S., and Ott, W.	Transportation Research Record 1699	2000

TABLE 157 Graduate student theses on WesTrack

Title	Author	University	Degree	Date
"Asphalt Cement Characterization of the WesTrack Project"	Moetaz El Ayed Ashour	University of Nevada	Master of Science	August 1997
"Analysis and Development of Performance Models for WesTrack"	Stephen P. Healow	University of Nevada	Master of Science	May 1998
"Mechanical Properties of HMA Mixtures Used in WesTrack Project"	Shameem Ahmed Dewan	University of Nevada	Master of Science	August 1988
"The Use of the Ignition Oven in Testing NDOT and WesTrack HMA Mixes"	M. Osama	University of Nevada	Master of Science	May 1998
"Comparison of Asphalt Content Measuring Methods - Ignition and Reflux"	Sivaranjan Sivasubramaniam	University of Nevada	Master of Science	August 1998
"Relationships Between Laboratory Measured HMA Material and Mixture Properties and Pavement Performance at WesTrack"	Adam J.T. Hand	University of Nevada	Doctor of Philosophy	August 1998
"Development of Pavement Rutting Progression Models by Combining Multiple Data Sources"	Adrian Ricardo Archilla	University of California	Master of Science	January 2000
"Joint Econometric Models of Pavement Cracking Initiation and Progression"	Hee-Cheol Shin	University of California	Doctor of Philosophy	May 2000
"Characterization of Low Temperature Cracking Potential for WesTrack Paving Materials"	Tom Walker	Oregon State University	Master of Science	December 1998
"A Discussion of Low Temperature Cracking and the Stiffness of Bituminous Materials"	Chris Waters	Oregon State University	Master of Science	December 1999

TABLE 158 WesTrack tours

Date	Tour Group	No. of People
8/8/95	Chrysler Corporation	?
9/20/95	Public Relations Photo Tour	?
9/27/95	FHWA/Nevada DOT	?
9/29/95	FHWA/Nevada DOT/UNR	?
12/12/95	Reno/Sparks business and civil leaders	Over 200
12/14/95	National Academy of Sciences	1
1/96	Allied Transportation Research	1
5/2/96	Asphalt Institute	13
5/7/96	WASHTO Conference visitors	12
5/8/96	Rose/Glenn Advertising Agency	5
6/4/96	FHWA, Washington, D.C./FHWA, Carson City, NV	5
6/11/96	FHWA, Washington, D.C./Asphalt Institute	2
6/14/96	Berlogar Geotechnical Consultants	1
6/15/96	FHWA, Lakewood, CO	1
6/21/96	FHWA, Carson City, NV/U.T. Space Institute/Shell Development Co./Alcoa Wheel Products Division/East Pennsylvania Mfg./student from Trace, TN, Byron Lord, and Vince Russel	8
7/18/96	Visitors	3
8/16/96	Knight Trailer/Bobell Northwest Transport Ltd.	2
8/26/96	FHWA, Olympia, WA	1
9/9/96	People attending a tire blowout-training course at NATC: Michelin/Ryder/Volvo Trucks/Fleet Owners Magazine, etc.	20
9/12/96	Auburn University/Electrical Engineering Department	3
9/13/96	FHWA hosted a Federal Lands Highway Meeting for various western divisions	12
9/16/96	Attendees of the Pavement Rehabilitation Course	65
11/13/96	Pavement Stress ETG Group/MinnRoad/NCAT	26
11/13-14/96	Heritage Research Group	1
12/10/96	Koch Material Company	53
12/10-14/96	FHWA	1
1/28/97	Incheron International Airport in Korea	5
1/29/97	National Automated Highway Consortium/FHWA	11
3/3/97	Division of Roads and Transportation Technology (Transportek)	3
3/14/97	FHWA/NDOT	35
3/17-19/97	Deabon Engineering	2
3/19/97	Association of Asphalt Paving Technology	4
3/20/97	Association of Asphalt Paving Technology	1
3/31/97	Virginia Polytechnical Institute/VDOT	2
4/3/97	WesTrack Technical Panel Meeting members	16
4/7/97	LTPP Regional meeting people/Koch Material Company	?
4/9/97	FHWA	1
4/23/97	Triaxial Institute	20
4/24/97	Western FHWA Federal Land Division	20
4/28/97	TRB Subcommittee A2D05	20

(*continued on next page*)

TABLE 158 (Continued)

Date	Tour Group	No. of People
4/29/97	FHWA, Montana	9
5/5/97	Pavement Distress Identification and Techniques for Rehabilitation and Design Class	60
5/12/97	E.J. Coley & Associates/a research engineer	2
5/20/97	Chrysler/Goodyear	3
5/29/97	Granite Construction	1
6/18/97	Caltrans/CA DOT/NATC/NCE	6
6/28/97	NDOT/NATC	4
7/8/97	TRW Summerlin/IRG	3
8/1/97	UNR/Swiss Federal Institute of Technology/person from Pretoria, Russia	3
8/4/97	NCE	2
8/7/97	People from Pretoria, Russia/Johannsburg, South Africa	2
8/9/97	NDOT	1
8/11/97	People that attended National Automated Highway System	10
8/18/97	Daimler-Benz AG, Germany	2
8/19/97	WesTrack Forensic Team	13
8/20/97	Person from Walkerville, South Australia	1
8/21/97	People from Christchurch, New Zealand	3
8/27/97	FHWA/NCE/University of Nottingham	4
9/25/97	FHWA, Montana	12
11/17/97	North California Asphalt Producers Association	25
12/10/97	Texas DOT	1
1/20/98	People from Pretoria, South Africa	2
2/98	Caltrans/David Newcomb	2
2/25/98	Tennessee Road Builders	?
3/9/98	University of Mississippi	1
3/13/98	Pavement Design Class held at UNR	40
4/1/98	FHWA	1
4/27/98	UNR	1
5/11/98	University of Illinois	1
5/12/98	Mack Truck/Renault	2
5/19/98	Construction Engineering Labs, Inc.	1
5/29/98	NDOT/JWA Consulting Engineers/Lumos & Associates	5
6/4/98	FHWA Division	9
7/14/98	Washington, D.C. DOT/National Academy of Sciences/Michigan DOT/Caltrans	5
8/19/98	Anchorage DOT/WADOT/City and County of San Francisco/Sully-Miller Contracting in California	6
8/26/98	City of Sparks	5
10/20/98	University of Costa Rica	2
10/24/98	California State University at Chico	5
11/3-4/98	Fortune Magazine/US Roads	4
11/6/98	Cal Poly	10
11/10/98	Swedish Asphalt Institute	6

(*continued on next page*)

TABLE 158 (Continued)

Date	Tour Group	No. of People
11/17/98	Northern California Asphalt Producers Association	25
12/19/98	Boy Scout Troop 150	3
1/25/99	FHWA, Olympia, WA	12
2/1/99	NDOT	1
3/12/99	ID DOT/UNR/FHWA UT, FHWA, Washington, D.C./FHWA Maine Division/NY SDOT/FHWA PA/FHWA, Olympia, WA/ADOT, Kingman, AZ, Toronto, Canada	27
3/26/99	CHEC Engineering Consultants	14
10/19/99	International Conference on Accelerated Pavement Testing attendees	129
Annual	FHWA/NHI Materials Engineers Course	30

TABLE 159 Presentations on WesTrack at conferences and meetings

Date	Conferences and Meetings	Location	Presentor(s)	Approximate Attendance
January 16, 1995	Transportation Research Board "University Contributions to Performance-Related Specifications"	Washington, D.C.	J. Epps	150
May 23, 1995	Pacific Coast Conference on Asphalt Specifications "WesTrack"	Berkeley, CA	J. Epps C. Monismith	75
October 5, 1995	Rocky Mountain User/Producer Group "WesTrack Construction"	Denver, CO	J. Epps	200
October 26, 1995	Idaho Asphalt Conference "Performance-Based Specifications"	Moscow, ID	J. Epps	200
October 31, 1995	AASHTO Annual Meeting "Superpave Regional Center and WesTrack"	Norfolk, VA	J. Epps	300
January 4, 1996	Twenty-Third Annual Colorado Asphalt Paving Seminar "WesTrack"	Ft. Collins, CO	J. Epps	125
January 7, 1996	Transportation Research Board "WesTrack Experiences: Construction and Operations"	Washington, D.C.	J. Epps	150
January 7, 1996	TRB - State SHRP Coordinators' Meeting "WesTrack"	Washington, D.C.	J. Epps	100
February 7, 1996	Asphalt Emulsion Manufacturers' Association "WesTrack - What it Means to the Maintenance Industry"	Phoenix, AZ	J. Epps	100
April 2, 1996	Nevada Street and Highway Conference "WesTrack"	Reno, NV	J. Epps	150
April 16, 1996	Alaska Transportation Week "Reno Test Track Facility - WesTrack"	Anchorage, AK	J. Epps	100
June 18, 1996	Ohio Strategic Highway Research Program "Instrumentation and Early Performance of WesTrack"	Delaware, OH	J. Epps	75
August 27, 1996	Superpave 2000 Conference "WesTrack Pavement Performance Update"	Indianapolis, IN	J. Epps	200
September 25, 1996	NAPA Mid-Year Meeting "WesTrack Status Report"	Reno, NV	J. Epps	150
October 4, 1996	Rocky Mountain User/Producer Group Annual Meeting "WesTrack Update"	Salt Lake City, UT	J. Epps	150
October 29, 1996	U.S. Hot-Mix Asphalt Conference "WesTrack"	E. Rutherford, N.J.	J. Epps	300
January 14, 1997	TRB Committees A2D02 and A2F02 "Distress at WesTrack"	Washington, D.C.	J. Epps	70
January 25, 1997	NAPA Annual Convention "WesTrack Update"	Orlando, FL	J. Epps	100

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TABLE 159 (Continued)

Date	Conferences and Meetings	Location	Presentor(s)	Approximate Attendance
February 20, 1997	Region 4 Superpave Conference "WesTrack Early Results"	Auburn, AL	J. Epps	200
March 6, 1997	22nd Annual Utah Asphalt Conference "WesTrack Progress Report"	Provo, UT	J. Epps	150
April 8, 1997	Western Regional LTPP Meeting "Tying it All Together - WesTrack"	Reno, NV	J. Epps	50
April 15, 1997	Nevada Street and Highway Conference "WesTrack"	Las Vegas, NV	J. Epps.	175
April 21, 1997	Annual Symposium, International Center for Aggregate Research "WesTrack Status"	Austin, TX	J. Epps	200
August 12, 1997	Eighth International Conference on Asphalt Pavements "WesTrack: Full Scale Test Track Interim Findings"	Seattle, WA	Team	400
August 27, 1997	Texas Hot-Mix Asphalt Pavement Association "WesTrack Performance"	Corpus Christi, TX	J. Epps	250
July 31, 1996	Asphalt Paving Association of Iowa's Mid-year Meeting "WesTrack"	Okoboji, IA	T. Mitchell	125
December 4, 1996	SHRP Asphalt Technical Working Group "WesTrack Update"	Phoenix, AZ	J. Epps T. Mitchell	50
September 3, 1997	FHWA Workshop on PRS "Performance-Related Specification Based on WesTrack"	Arlington, VA	J. Epps	50
October 8, 1997	Rocky Mountain Asphalt User/Producer Group Annual Meeting "WesTrack Performance"	Reno, NV	J. Epps	200
October 30, 1997	U.S. Hot-Mix Conference and Superpave Workshop "Update on WesTrack"	Phoenix, AZ	J. Epps	350
November 5, 1997	ASCE Transportation Conference "WesTrack Operation and Performance"	Ames, IA		100
December 3, 1997	Wisconsin Asphalt Pavement Association	Madison, WI	J. Epps	150
January 11, 1998	Transportation Research Board "Effect of Mix Variables on Pavement Performance"	Washington, D.C.	J. Epps	100
January 12, 1998	TRB Committee A2B05 "Performance of WesTrack Test Sections"	Washington, D.C.	J. Epps	50
October 7, 1998	Rocky Mountain Asphalt User/Producer Group "WesTrack Update"	Denver, CO	J. Epps	200

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TABLE 159 (Continued)

Date	Conferences and Meetings	Location	Presentor(s)	Approximate Attendance
October 22, 1998	Symposium on Transportation Practice "Accelerated Pavement Testing - Results and Applications"	Sacramento, CA	J. Epps	50
January 10, 1999	TRB Conference on WesTrack "Overview"	Washington, D.C.	T. Mitchell	250
January 10, 1999	TRB Conference on WesTrack "Traffic Operations and Vehicle Costs"	Washington, D.C.	C. Ashmore	250
January 10, 1999	TRB Conference on WesTrack "Laboratory Rut Testing"	Washington, D.C.	C. Williams	250
February 25, 1997	Illinois International Conference "WesTrack and Accelerated Pavement Testing"	Champaign, IL	T. Mitchell	200
October 1, 1997	Northeast States Materials Engineers Association "WesTrack"	MA	T. Mitchell	100
January 10, 1999	TRB Conference on WesTrack "Materials Characterization and Performance Prediction Models"	Washington, D.C.	C. Monismith R. Leahy	250
January 10, 1999	TRB Conference on WesTrack "Forensic Team"	Washington, D.C.	R. Brown	250
January 10, 1999	TRB Conference on WesTrack "LESSONS LEARNED"	Washington, D.C.	J. Epps	250
February 9, 1999	NAPA Annual Meeting "Superpave: Lessons We Have Learned"	San Diego, CA	J. Epps	100
March 23, 1999	WASHTO Subcommittee on Construction/Materials "WesTrack Update"	Scottsdale, AZ	J. Epps	75
May 11, 1999	Pacific Coast Conference on Asphalt Specifications "WesTrack"	Berkeley, CA	J. Epps	70
December 1, 1999	Southeast User/Producer Group "WesTrack Performance-Related Specification"	Panama City, FL	J. Epps	150
December 8, 1999	Pennsylvania Asphalt Pavement Association "WesTrack"	Hershey, PA	J. Epps	125

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TABLE 159 (Continued)

Date	Conferences and Meetings	Location	Presentor(s)	Approximate Attendance
January 9, 2000	TRB Conference on WesTrack "Project Overview and Products"	Washington, D.C.	T. Mitchell E. Harrigan	300
January 9, 2000	TRB Conference on WesTrack "Performance-Related Specifications for HMA	Washington, D.C.	S. Seeds T. Scholz	300
January 9, 2000	TRB Conference on WesTrack "Performance Models"	Washington, D.C.	C. Monismith R. Leahy	300
January 9, 2000	TRB Conference on WesTrack "WesTrack Database"	Washington, D.C.	S. Alavi	300
January 9, 2000	TRB Conference on WesTrack "From the Pavement Up"	Washington, D.C.	C. Ashmore	300
January 9, 2000	TRB Conference on WesTrack "Future of Full Scale APT"	Washington, D.C.	C. Monismith R. Leahy	1000
February 3, 2000	Rocky Mountain Asphalt Conference and Equipment Show "WesTrack - The Final Chapter"	Denver, CO	J. Epps	200

ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ABS	Anti-Lock Brake System
AC	Asphalt Concrete
ALF	Accelerated Load Facility
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
COLD	Computations of Low-Temperature Damage
DDEC	Detroit Diesel Electronic Control
DGPS	Differential Global Positioning System
ESAL	Equivalent Single-Axle Load
FA	Fine Aggregate
F/A	Filler to Asphalt
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIRM	Flood Insurance Rate Map
FMFC	Field-Mixed/Field-Compacted
FMLC	Field-Mixed/Laboratory-Compacted
FWD	Falling Weight Deflectometer
GPS	General Pavement Studies
HLA	Harding Lawson and Associates
HMA	Hot-Mix Asphalt
HVS	Heavy Vehicle Simulator
IDT	Indirect Tensile
IRI	International Roughness Index
JMF	Job Mix Formula
LMLC	Laboratory-Mixed/Laboratory-Compacted
LTOA	Long-Term Oven Aged
LTPP	Long-Term Pavement Performance
M-E	Mechanistic-Empirical
MRL	Materials Reference Library
NATC	Nevada Automotive Test Center
NCE	Nichols Consulting Engineers
NCHRP	National Cooperative Highway Research Program
NCSU	North Carolina State University
NDOT	Nevada Department of Transportation
NOAA	National Oceanic and Atmospheric Administration
OSU	Oregon State University
PCC	Portland Cement Concrete
PFT	Pay Factor Table
PFR	Pay Factor Relationship
PID	Proportional Integral Differential
PRS	Performance-Related Specification
PWL	Percent Within Limits
QA	Quality Assurance
QC	Quality Control
QC/QA	Quality Control/Quality Assurance
RAP	Recycled Asphalt Pavement
RF	Radio Frequency
RQL	Rejectable Quality Level
RSST-CH	Repeated Simple Shear Test at Constant Height
SHA	State Highway Agency
SHRP	Strategic Highway Research Program
SPS	Specific Pavement Studies
STOA	Short-Term Oven Aged
STRS	Strategic Transportation Research Study
TDR	Time Domain Reflectometry
TSR	Tensile Strength Ratio
TSRST	Thermal Stress Restrained Specimen Test
UCB	University of California, Berkeley
UNR	University of Nevada, Reno
VFA	Voids Filled with Asphalt
VMA	Voids in the Mineral Aggregate

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