Three test roads were constructed for the Canadian Strategic Highway Research Program (C-SHRP) in 1991/92 for the purpose of evaluating the Canadian General Standards Board specification and the then-emerging SUPERPAVE binder specification. Samples of the binders used in the test roads were retained and later tested using the SUPERPAVE protocols by the Ministère des Transports du Québec (MTQ) under a co-operative agreement with C-SHRP. Warren Robertson was contracted by C-SHRP to assist MTQ with the laboratory program being performed for C-SHRP. This brief summarizes Mr. Robertson’s analysis of the early performance of the test roads compared to the performance predictions inherent in the SUPERPAVE binder specification. These results were originally presented at the Canadian User/Producer Group for Asphalt (CUPGA) session in November, 1994.

BACKGROUND

In 1990, the Canadian General Standards Board (CGSB) issued a new specification for asphalt cements. At the same time, a new specification for paving binders and new test methods were anticipated from SHRP. In contrast to the penetration graded CGSB specification, the SHRP system, now known as SUPERPAVE, is performance based. It contains requirements based on the rheological and physical properties of binders that are mechanistically related to pavement performance models. The three main pavement distress modes are addressed in SUPERPAVE; rutting at high service temperatures, load associated fatigue cracking, and low temperature transverse cracking.

To determine if the new specifications adequately classify asphalt cements according to their low temperature performance, C-SHRP carried out a research program entitled “Performance Correlation for Quality Paving Asphalts”. To provide field verification for the theoretical specifications, three test roads were constructed under the C-SHRP study. The test roads were constructed in regions with low winter temperatures using similar pavement structures and paving mix designs, and 14 different asphalt binders graded according to the CGSB specification. Recognizing that binder has the greatest influence in low temperature performance, the binders were se-
lected to provide the widest range of performance in this distress mode. Some binders which were expected to fail at low temperatures and some which would be resistant to thermal cracking were included in the test road construction. Each test site has instrumentation to monitor temperatures in the air and in the pavement structure, and to detect transverse pavement cracking. The test sites have been in service for three to four years, and significant cracking has occurred. This brief highlights the early thermal cracking performance of the three C-SHRP test roads (up to the end of the winter of 1993-94) and discusses the low temperature requirements of the SUPERPAVE specification.

DESIGN TEMPERATURES FOR SELECTING PAVEMENT BINDERS

The purpose of the SUPERPAVE binder specification is to enable the selection of a pavement binder which will perform satisfactorily in the climatic conditions at the pavement site. The two conditions at which the performance requirements are to be met are the high temperature, or summer design condition, and the low temperature, or winter design condition. The grade designation is expressed as a combination of those two design temperatures. For example, PG 58-22 is for use where the summer design temperature is 58°C and the winter design temperature is -22°C. Both the high and low temperature parameters change by increments of 6°C between grades.

The SUPERPAVE design system provides algorithms for determining the summer and winter design temperatures from a weather database containing observed extreme temperatures and the temperature variability at more than 6000 locations in the United States and Canada. The summer design temperature is the highest expected seven-day average pavement temperature, measured 20 mm below the surface. These conditions reflect observations that severe rutting may occur during periods of very hot weather, when the pavement mass becomes heated to temperatures where the binder stiffness is low. For very heavy or slow traffic, or on long grades used by heavy trucks, it is recommended that one grade higher than that given by the design equation be used.

The winter design temperature is the lowest expected pavement surface temperature. In the SUPERPAVE design system, it is taken as equivalent to the lowest air temperature at the pavement site during the design lifetime. This approach is rationalized on the basis that the coldest pavement temperatures occur at night, so that there is no solar radiation or other contributing factors to be considered. However, this aspect of the SUPERPAVE design process is in dispute. Historically, it has been demonstrated that the surface temperature will be warmer, and in some circumstances substantially warmer, than the air temperature. The difference in temperature is accounted for by the heat transfer from the relatively warmer pavement structure (the earth) to the colder air mass. Under this heat transfer process, colder climates have higher temperature gradients between the pavement and air, and hence higher heat flux. This results in a larger difference between the air and pavement temperatures in progressively colder climates. Air and pavement temperatures measured at the test roads were used to verify the new SUPERPAVE specifications and methods.

For low temperature performance, limits on the creep stiffness (S) and the absolute value of the slope of the stiffness master curve (m) are set in SUPERPAVE at less than 300 MPa and greater than 0.3, respectively, at the design temperature. The parameters were originally set based upon a loading time of 7200s, but for ease of testing measurements are made at 10°C warmer than the design temperature with a loading time of 60s. For the purpose of analyzing test road performance, Robertson defined a critical temperature for the binder which is 10°C colder than the lowest temperature at which the stiffness (S(60)) is less than 300 MPa and the slope of the stiffness master curve (m) is greater than 0.3. Due to the stepwise nature of the SUPERPAVE low temperature grades, the critical temperature is between 0 and 6°C below the low temperature in the SUPERPAVE grade.

C-SHRP TEST ROADS

Test roads were constructed in 1991 near Lamont, AB, east of Edmonton and near Hearst in north-western Ontario, and in
1992 near Sherbrooke, QC, south-east of Montreal. All of these locations experience severe winter climates, with temperatures as low as -50°C. The test roads were all new construction on granular base courses, to eliminate reflection cracking and to minimize the effect of subgrade variation on thermal cracking.

The binders for the three test roads were selected to evaluate the low temperature performance of various grades of asphalt cements. The binders used represent a wide range of commercial asphalt binders available at the time that the roads were constructed. Grading was based on the CGSB specification which was available at the time. Several are of the same low temperature grade as defined by the SUPERPAVE specification. Table 1 includes both the CGSB grade and SUPERPAVE grade for each test section as well as observations of cracking frequency and temperatures at the time of fracture, as recorded after the winter of 1993-94.

### Lamont, AB

The Lamont test road is the main test road and was constructed in the summer of 1991. The pavement consists of two 50 mm lifts, for a total thickness of 100 mm. Both lifts have the same aggregate composition and binder content. The same binder was used in both lifts of each section. There are seven test sections, each containing a different binder. Two oxidized asphalts were included. Four of the sections were expected to crack before the others because of the characteristics of the binders used. These were instrumented to enable monitoring of temperatures in the pavement structure and to detect transverse cracking.

Five of the Lamont test sections have cracked, with cracking severity ranging from insignificant to severe. The winter of 1991-92 at the test site was milder than usual, with a minimum air temperature of only -30°C, and a minimum surface pavement temperature of -24°C. No thermally induced cracking occurred during that winter. The second winter (1992-93) was much colder and four of the sections cracked. Cracks were detected both by the crack detector instrumentation and by visual observation during very cold periods. Minimum air and pavement temperatures during this winter were -46°C and -34°C, respectively. The winter of 1993-94 was the most severe, and considerably more severe than typical of the region; air and pavement surface temperatures fell to -50°C and -37°C, respectively. One more section cracked, and additional cracking of previously cracked sections also occurred.

### Table 1 – Low Temperature Performance of CGSB and SUPERPAVE Graded Pavement Binders

<table>
<thead>
<tr>
<th>Test Section</th>
<th>CGSB Grade</th>
<th>SUPERPAVE Grade</th>
<th>Critical Temp at Fracture °C</th>
<th>Air Temp at Fracture °C</th>
<th>Surface Temp at Fracture °C</th>
<th>Cracks/ km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamont, AB</td>
<td>1 80/100 B</td>
<td>PG 58-22</td>
<td>-26.1</td>
<td>-43.3</td>
<td>-32.4</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>2 120/150 B</td>
<td>PG 52-28</td>
<td>-29.9</td>
<td>-44.6</td>
<td>-33.3</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>3 300/400 A</td>
<td>PG 46-34</td>
<td>-38.4</td>
<td>-50.0</td>
<td>-38.2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4 80/100 C</td>
<td>PG 58-22</td>
<td>-24.9</td>
<td>-38.5</td>
<td>-28.9</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>5 80/100 A</td>
<td>PG 64-28</td>
<td>-33.8</td>
<td>-41.3</td>
<td>-31.3</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>6 150/200 A</td>
<td>PG 52-28</td>
<td>-33.8</td>
<td>-50.0</td>
<td>-38.2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>7 200/300 A</td>
<td>PG 52-34</td>
<td>-35.8</td>
<td>-50.0</td>
<td>-38.2</td>
<td>0</td>
</tr>
<tr>
<td>Hearst, ON</td>
<td>AA 200/300 A</td>
<td>PG 46-34</td>
<td>-37.0</td>
<td>-35.9</td>
<td>-26.1</td>
<td>5</td>
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<tr>
<td></td>
<td>A 150/200 A</td>
<td>PG 52-28</td>
<td>-33.5</td>
<td>-31.1</td>
<td>-21.6</td>
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</tr>
<tr>
<td></td>
<td>B 120/150 A</td>
<td>PG 52-28</td>
<td>-33.0</td>
<td>-39.6</td>
<td>-31.1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>BB 120/150 A</td>
<td>PG 52-28</td>
<td>-33.0</td>
<td>-36.4</td>
<td>-27.1</td>
<td>3</td>
</tr>
<tr>
<td>Sherbrooke, QC</td>
<td>A 150/200 A</td>
<td>PG 52-34</td>
<td>-34.9</td>
<td>-37.0</td>
<td>-28.2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>B 80/100 A</td>
<td>PG 58-22</td>
<td>-27.1</td>
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<td>8</td>
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<tr>
<td></td>
<td>C 80/100 A</td>
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<td>-29.7</td>
<td>-37.0</td>
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<td>D 150/200 B</td>
<td>PG 52-28</td>
<td>-31.2</td>
<td>-37.0</td>
<td>-28.2</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes:
1. ‘Critical Temperature’ is 10°C colder than the lowest temperature at which S(60) ≤ 300 MPa and m(60) ≥ 0.3.
2. Temperature shown is the lowest observed; section has not cracked.
These observations are shown in Table 1.

**Hearst, ON**

The Hearst satellite test road was paved in the summer of 1991. It has four test sections incorporating three different binders. Three of the sections are 50 mm thick and were laid in a single lift. The fourth has two 50 mm lifts to accommodate crack detector and temperature monitoring instrumentation. One of the binders used in the Hearst road was from the same source as one used in the Lamont test road. Another binder was a chemically modified premium binder. As per normal practice in this region, all of the binders used in the Hearst road had an anti-stripping agent added to them.

After three winters, cracking of the Hearst test sections has been minimal. The instrumented test section has one partial crack which has not severed the embedded crack detector. One full width crack has been observed visually in three of the four test sections. The first cracks occurred during the first winter of service, 1991-92. The time of occurrence of these cracks and the pavement temperatures at the time of cracking cannot be determined precisely because none of them have occurred in the instrumented portion of the test road. Although visual inspections were made during cold periods when cracking was expected, detection of cracks was hampered by the presence of snow and ice cover, and by sand applied to the road surface to improve traction. In Table 1, the fracture temperatures have been taken as the lowest temperature occurring in the cold period immediately preceding visual detection of the crack.

The initial fracture temperatures for the Hearst sections are all higher than expected from the binder stiffness measurements. The 50 mm thick Hearst sections cracked at significantly higher temperatures than the 100 mm thick section. Although the 100 mm thick Hearst section cracked at a higher temperature than the Lamont or Sherbrooke sections, its fracture temperature is reasonably close to them. All the 100 mm thick sections form a group for which the mean fracture temperature is about 1.5°C below the binder critical temperature.

It was also noted that the cracking observed at Hearst occurred at temperatures warmer than the lowest temperatures observed, and that additional cracking did not occur at subsequent colder pavement temperatures. This suggests that the Hearst pavement is significantly different from that at Lamont. Two differences are known. The first difference is the thickness. Second, all the Hearst binders contained an anti-stripping additive. The effect of this is not known. However, all the rheological measurements were made on samples containing the additive, which should have accounted for its effect.

The small number of cracks that have developed so far does not permit a reliable assessment of the performance of these sections to be made.

**Sherbrooke, QC**

The second satellite test road was constructed in the fall of 1992. There are four test sections incorporating four different binders, two of which were chemically modified premium asphalts. All sections are 120 mm thick, laid in two lifts. The two sections which were expected to crack at warmer temperatures were instrumented.

At the time of observation, the Sherbrooke pavement had been in service for only two winters, compared to three for the others. The minimum air and pavement surface temperatures at the Sherbrooke site were -37°C and -32°C, respectively. Cracking has occurred in only one of the four sections, and this happened during the second winter at the lowest observed temperature. However, none of the cracks has progressed to the edge of the pavement where the crack sensors are located, so the reported fracture temperature is not precise. The number of cracks is small, but the performance of this section appears to be consistent with that of the Lamont sections made with the same low temperature grade of binder.

**LOW TEMPERATURE PERFORMANCE AND SUPERPAVE SPECIFICATION PARAMETERS**

At Lamont and Sherbrooke, air temperatures at the time of fracture were well below the critical temperatures of the binders in the cracked sections. At Hearst, the fracture temperatures were much
higher, and about the same as the binder critical temperatures. The relationship between the air temperature at fracture and the binder critical temperature for those test sections which cracked is shown in Figure 1. There is no mechanistic reason that the pavement should crack when the air temperature falls to the binder critical temperature. It is the temperature of the material which cracks that is important. Hence, the large difference between the air temperature at fracture and the binder critical temperature should not be surprising.

Pavement temperatures depend not only on the air temperature, but also on the subgrade temperature. The air temperature history also has an effect. For test sections that cracked, the minimum pavement temperature at the time of fracture was usually below the critical temperature of the binder. This is shown in Figure 2. One Lamont section which has developed only one crack, and the three cracked Hearst sections had pavement surface temperatures at fracture above the binder critical temperature. For the Lamont section, the difference was only 2.5°C, but at Hearst, minor cracking occurred at up to 11.8°C above the binder critical temperature.

For one section at Lamont, the minimum observed pavement temperature was slightly below the binder critical temperature, but no cracking has been observed.

Three Hearst test sections developed minor transverse cracking at surface temperatures well above the critical temperatures of the binders. The mean difference for the 50 mm thick sections was 11.3°C, while the 100 mm thick section cracked at 5.9°C above the critical temperature. This suggests the mechanism for cracking of the Hearst sections is different from that at Lamont and Sherbrooke. The most obvious difference between the Hearst pavements and the others is the smaller thickness of the two sections which cracked at warmer
temperatures. Thinner pavements are known to be more susceptible to thermal cracking.

There is relatively good correlation between the critical temperature of the binder derived from the SUPERPAVE low temperature performance criteria and the pavement fracture temperature. Therefore, the SUPERPAVE low temperature criteria of $S(60) \leq 300$ MPa and $m(60) \geq 0.3$ are reasonable predictors of performance. The use of a limiting stiffness criterion is not mechanistically correct. However, it is probably reasonable because most of the stress that develops in pavements during cooling is accumulated at temperatures just above the fracture temperature, where the binder stiffness is high and relatively insensitive to the temperature and loading time.

**SUMMARY AND CONCLUSIONS**

The conclusions drawn from the early results of the C-SHRP test roads are summarized in the following statements.

✦ The present SUPERPAVE low temperature design algorithm, which selects the minimum expected air temperature as the winter design temperature, is too conservative. It is not consistent with experience in regions with very low winter temperatures which show that pavement temperatures in winter are significantly warmer than air temperatures.

✦ The minimum expected pavement surface temperature is a more realistic design temperature, and is consistent with the mechanism of thermal cracking.

✦ The critical temperature of the binder, determined using the SUPERPAVE criteria and BBR tests correlates with the pavement fracture temperature.

✦ The SUPERPAVE low temperature performance criteria for asphalt binders, taken together, are a good predictor of resistance to thermal cracking at low temperatures. The mean pavement surface temperature at fracture was about 1.5°C colder than the binder critical temperature.

✦ The anomalous behaviour of the Hearst test sections may be due to the thinner pavements. However, the amount of cracking which has occurred so far is insufficient to allow firm conclusions to be drawn about this.

In response, in part, to the C-SHRP test road results and Canadian experience with low temperature performance of asphalt binders, the US Federal Highway Administration adopted an interim guideline in the spring of 1995. **Interim Guideline:** SUPERPAVE Binder Selection for Low-Temperature Performance acknowledges discrepancies between Canadian experience and the SUPERPAVE design process. When the performance data collected from numerous ongoing studies is compiled and analyzed a new algorithm will be developed to accurately determine the critical pavement cracking temperature. Until then, an alternative system should be used. The interim guideline proposes that, for northern climates when the air temperature is colder than -28°C, the reliability of the temperature prediction should be reduced from 98% to 50%. This has the effect of specifying a less restrictive grade and will prevent unreasonable recommendations for extremely low temperatures.

It should be emphasized that although the approach recommended by FHWA may provide more realistic numbers, it is not the final solution to the problem with low temperature design in SUPERPAVE. Recommending 50% reliability could result in unsatisfactory design and an algorithm relating pavement temperature to air temperature with 98% reliability is required. Experiments to produce data for such an algorithm are in progress and results are anticipated in two to three years.