REFLECTIVE CRACKING ON C-SHRP LONG TERM PAVEMENT PERFORMANCE SITES

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Abstract
Reflective cracking is associated with the premature occurrence of cracks on overlays at positions and orientations that correspond to locations of cracks in lower pavement layers. The paper reports on a study commissioned by the Canadian Strategic Highway Research Program (C-SHRP) to evaluate reflective cracking trends on the Long Term Pavement Performance (C-LTPP) test sections. The C-LTPP sites have been in operation since 1989 and 1990. The paper outlines the data available to the study and in detail discusses three examples of the twenty-four test sites. The three selected sites are located in Manitoba, Ontario and Quebec. These sites provide an insight into reflective cracking under varying climatic conditions and traffic volumes.

At each C-LTPP site, two to four side-by-side test sections were constructed with the purpose of studying and optimizing rehabilitation strategies. One of the sections represented the provincial agency’s typical design while other alternatives considered a different overlay thickness or another design factor such as the use of recycled or modified binders. The results included comparison of cracking extents in original and overlaid pavements and the annual progression of cracking. Since reflective cracking appears early in the pavement life, the comparisons were based on the first five years of operation. The study provides essential information on the performance of the test sections to C-SHRP and Canadian highway agencies.

1. Introduction

1.1 Reflection Cracking
Reflective cracking is associated with the premature occurrence of cracks on overlays at positions and orientations that correspond to locations of cracks in lower pavement layers. Historically, pavement distresses have been classified into three major groups including rutting, thermal cracking and fatigue cracking, and a cluster of minor distresses that mainly focus on surface characteristics, i.e. raveling, polishing, and
With the rising percentage of rehabilitation projects compared to new construction and the prevalence of premature cracking, pavement practitioners are viewing reflective cracking as the logical fourth major distress mode.

The mechanistic analysis of reflective cracking is complex. Vertical and horizontal movements caused by traffic loads and climatic variations are critical to the spread of reflective cracks. These displacements contribute also to thermal and fatigue cracking. The overlap between the distress modes emphasizes the importance of a unified analytical approach to studying pavement cracking whereby all the interactions between failure modes can be accounted for, Shalaby (1997), Shalaby et al. (1998).

Reflection cracks are initiated at discontinuities in the underlying pavement layer. The source of these discontinuities are usually existing cracks in older pavement layers but can also include pavement joints or weak spots in the original pavement. Through the combined effects of thermal contraction of the asphalt concrete and traffic loading, tensile stresses are concentrated at these discontinuities. When the stresses exceed the tensile strength of the asphalt concrete overlay, a crack will advance from the bottom surface of the overlay. Under thermal cycling, the crack will propagate upwards through the overlay towards the pavement surface. The cracking pattern on the overlay surface resembles that on the old pavement surface.

1.2 Canadian Long Term Pavement Performance (C-LTPP) Experiment
The C-LTPP project was designed to examine the practices of asphalt concrete overlays of asphalt concrete pavements in ten Canadian provinces. At each of the twenty-four experiment sites, the local agency overlay design was compared with one to three design alternatives, differing mainly in overlay thickness and the use of reclaimed materials or polymer-modified binders. Crack maps for the original pavements and for each year after rehabilitation are collected and stored in the C-LTPP database. The creation of this detailed database made the evaluation of reflective cracking possible. In 1995, with five years of collected performance data, C-SHRP completed a data insight study on reflection cracking. The final report of the study is in Fréchette (1998). A detailed discussion of the performance of three typical C-LTPP test sites located in Manitoba, Ontario and Quebec is presented in part 3 of this paper.

2. Specific Site Characteristics

The C-LTPP database contains records of original pavement condition and overlay construction and performance. The monitoring will continue until the end of the service life of the overlays, estimated to be 15 years. The following data types were utilized in this study of reflective cracking.

2.1 Climatic data
The C-LTPP project relies on climatic data collected by Environment Canada at the weather stations nearest to the pavement sites. The data includes hourly temperature,
precipitation, wind and solar radiation. The number of freeze-thaw cycles at each site is computed and shown in Table 1. A cycle is counted when the hourly air temperature drops below and then rises above the freezing point. Because the temperatures are recorded every hour, the minimum observed duration of a freeze-thaw cycle is two hours.

2.2 Traffic data
Although all C-SHRP sites are instrumented with weigh-in-motion equipment (WIM) and vehicle classifiers, issues such as the interpretation and accuracy of traffic data remain unresolved. To date, C-SHRP relies on the agency estimates of traffic volumes, weigh stations, and manual counts. Nevertheless, these counts were found to be influenced by the results of the WIM monitoring and the growth of experience in WIM operation and outputs. In a way, the agencies have narrowed the gaps between manual and WIM counts. Table 1 shows summary of traffic information for the selected sites.

2.3 Original Pavements
The C-LTPP experiment involves asphalt concrete overlay built on original pavements that have been in service for five to thirty years. The sites were selected from a roster of rehabilitation projects that were commissioned in the 1989 and 1990 construction seasons. The reasons for rehabilitation differed from site to site but usually involved severe rutting, thermal cracking or roughness. The data included information on all layer thicknesses, material characterization, and deflections before and after rehabilitation.

2.4 Cracking data
The C-LTPP database classified groups of cracks according to location and orientation into four categories of crack types; wheel path, transverse, centerline, and edge. Crack maps are routinely collected during annual site visits. To identify reflective cracks, a comparison of crack maps prior and after the construction of the overlays was conducted. Cracks in the overlays, which are close in position and orientation to cracks in original layers, were considered reflective. Since crack maps are drawn on a metric grid of approx. 1 m grid spacing, cracks were considered reflective if they have a similar orientation and occur at an offset of less than one metre from cracks in the original layers. The complete documentation of distress data is available in the C-LTPP database and associated user’s guide, C-SHRP (1997).

2.5 Construction Cost data
The highway agencies reported the pavement overlay construction cost of their respective test sections from contract documents for each project. Discrepancies were found between the costing methods of different agencies due to inclusion of fixed cost components such as engineering and supervision, and due to the proximity or size of the projects. As the C-SHRP sections are relatively short (150m each) and experimental in nature, the actual costs for constructing the overlays and QA/QC on the materials often exceeded costs of typical projects. Nevertheless, the relative cost of the 150m sections at the same site remains a useful indicator for comparing the different overlay strategies.
within each site. Cost comparison of test sites across Canada is not possible in this limited and experimental program.

3. Pavement Monitoring and Performance

The C-LTPP project included the side-by-side comparisons of reflective cracking on adjacent 150 metre sections at twenty-four locations across Canada. The performance of the following three sites is examined in further detail. The parameters of each site are illustrated in Table 1 and the as-built information of the overlay is provided in Table 2.

3.1 Manitoba Site No. 830403

This site, which comprises 3 test sections, is located in the Southwest part of Manitoba on the Provincial Trunk Highway PTH-2 (a 2-lane facility), in the westbound lane. The region falls within a dry-freeze zone. The overlay was placed on top of a severely cracked 91mm asphalt concrete pavement. The underlying structure comprises a granular base layer of approximately 140mm built directly over a stiff brown silty clay subgrade.

The 113mm thick HMAC overlay placed on Section 2 is the outcome of the conventional overlay design method used by Manitoba Highways & Transportation. For comparative performance evaluation, a thinner overlay was used in Section 1 and a thicker design in Section 3. Manitoba Highways & Transportation estimated the unit cost per tonne of asphalt concrete to be $23.28 at this site, which includes material and construction costs from the July 1990 rehabilitation project. Given asphalt concrete bulk densities of 2.273, 2.267, and 2.260 for Sections 1, 2, and 3, respectively, the estimated overlay cost for the three 150 metre test sections were:

<table>
<thead>
<tr>
<th>Section</th>
<th>Thickness (mm)</th>
<th>Cost ($)</th>
<th>Cost per Lane km ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1</td>
<td>100mm Virgin HMAC</td>
<td>2,937</td>
<td>19,580</td>
</tr>
<tr>
<td>Section 2</td>
<td>113mm Virgin HMAC</td>
<td>3,310</td>
<td>22,067</td>
</tr>
<tr>
<td>Section 3</td>
<td>148mm Virgin HMAC</td>
<td>4,322</td>
<td>28,813</td>
</tr>
</tbody>
</table>

The preceding costs exclude the engineering design and project management costs.

The evolution of cracking since placement of the overlay is shown in Figure 1. The extent of existing cracks on the original pavement prior to rehabilitation is shown as the first point to the left of the zero age mark on the time axis. An illustration of the percentage of original cracks that have reflected through the overlay after five years is provided in Figure 2. The original pavement surface was heavily cracked with an average of 400 metres of transverse cracks (in an alligator pattern) on each of the three test sections which is equivalent to an average crack spacing of about 1.4 metres. There was also a considerable extent of wheel path cracks (20 metres on Section 1, 100 metres on Sections 2 and 3), centreline cracks (120 metres on Section 1, 150 metres on Section 2, and 70 metres on Section 3), and edge cracks (40 metres on Section 1, about 15 metres on Sections 2 and 3). As Figure 2 demonstrates, all of the centreline cracks have reflected to the overlay surface, with “new” cracks having likely been formed on Section
3. Ten to twenty percent of the transverse cracking has reflected while the original wheel path and edge cracks have not yet resurfaced.

The progression of transverse cracking was retarded with the increase of overlay thickness. While the 100mm overlay cracked after the first year, the 148mm overlay resisted cracking for four years.

3.2 Ontario Site No. 870102
The test site is located in the westbound lane of Highway 80, approximately 25 km south of Sarnia in Ontario. The site is in a wet freeze environment and the subgrade is classified as silt/clay. The structure underneath the overlay consisted of 179 to 227 mm of hot mix asphalt concrete on 465 mm of granular base and 112 mm of subbase. The agency design is compared to an overlay of twice the thickness as shown in Table 2.

According to the Ministry of Transportation of Ontario, the asphalt concrete unit cost during the construction of the overlay in 1989 was $70 per tonne including the milling of 35mm. Bulk specific gravity tests conducted on cores retrieved after compaction resulted in densities of 2.405 and 2.402 kg/m³ for Sections 1 and 2, respectively. Using the preceding information and the as-built overlay thicknesses, the rehabilitation costs were computed to be:

| Section 1 (95mm Virgin AC) | $8,156 | ($54,373/lane km) |
| Section 2 (46mm Virgin AC) | $3,945 | ($26,300/lane km) |

The preceding costs exclude the engineering design and project management costs.

As illustrated in Figures 1 and 2, the two sections exhibited high amounts of reflective and overall cracking, however it appears that the thicker overlay Section 1 has resisted reflective cracking to a higher extent. Based on these results and the fact that the site is subjected to a large number of freeze and thaw cycles, it can be concluded that both designs are inadequate in resisting reflective cracking.

3.3 Quebec Site No. 890503
Site #890503 is located on Autoroute 40, West of Québec City on the westbound travelling lane. The pavement is built on a silty sand subgrade underneath approximately 1.1 metres of coarse sand subbase and 450mm of crushed stone base material.

The Section 1 overlay was designed according to the standard practice of the Ministère des transports du Québec (MTQ). Section 2 was built to compare the effect of adding a polymer additive to the AC mix. Section 3 will provide a means to determine whether or not increasing the overlay thickness to 106mm yields significantly better performance. The design of Section 4 will allow a performance comparison of doubling the overlay thickness, and using a polymer modified mix.
According to MTQ, the rehabilitation costs of the conventional AC mix and the polymer-modified mix were $34.62 per tonne and $42.08 per tonne, respectively. Based on the AC overlay thickness and density at each 150-metre section, the total rehabilitation costs for the four sections were computed to be:

<table>
<thead>
<tr>
<th>Section</th>
<th>Thickness</th>
<th>Cost</th>
<th>Cost/lane km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1</td>
<td>40mm Virgin AC</td>
<td>$1,790</td>
<td>$11,933/lane km</td>
</tr>
<tr>
<td>Section 2</td>
<td>51mm Polymer-Modified AC</td>
<td>$2,780</td>
<td>$18,533/lane km</td>
</tr>
<tr>
<td>Section 3</td>
<td>106mm Virgin AC</td>
<td>$4,790</td>
<td>$31,933/lane km</td>
</tr>
<tr>
<td>Section 4</td>
<td>83mm Polymer-Modified AC</td>
<td>$4,470</td>
<td>$29,800/lane km</td>
</tr>
</tbody>
</table>

The preceding costs exclude the engineering design and project management costs.

As shown in Figure 1, the original pavement had less than 20 metres of transverse cracks, and since no wheel path or pavement edge cracks existed on the original AC pavement, the percent reflection could not be computed for these crack types. It is interesting to note that new wheel path cracks not caused by reflection of existing cracks through the overlay began appearing as early as 1 year after rehabilitation and 3 years for the edge cracks. Overlays on Sections 1 and 2 exhibited extensive wheel path cracking after a few years indicating that these sections were under-designed for the given traffic and environmental conditions. The thicker polymer-modified overlay has no wheel path cracks after 4 years whereas the thin polymer-modified section has approximately 50 metres of cracking.

On Sections 2, 3 and 4, the transverse cracking extent, although insignificant on all sections at this time, represents 100% reflection from the original pavement. Given that Sections 3 and 4 are performing reasonably well, suggests that Section 4 is the most cost-effective design alternative.

### 4. Conclusions

The paper reviewed the results of five years of monitoring AC overlays in Canada. The paper presented the relevant information in C-LTPP database that has been collected for each site. Many of the overlays exhibited unusual premature cracking, and upon inspection it was determined that most of the cracking is of reflective nature.

The identification of reflective cracks was performed manually and proved to be a subjective and lengthy task. Overlays constructed on coarse subgrade or in wet environments showed higher amounts of cracking than those on fine subgrade or in dry environments. Sites having a freezing index higher than 1500 °C.days (e.g. Manitoba), or were subjected to a large number of freeze thaw cycles also showed a marked increase in cracking.

The results suggest that the mitigation of reflective cracking in cold areas is not necessarily controlled by the overlay thickness. Other variables such as milling, recycled AC mix and polymer modified binders proved to be more effective in resisting reflective cracking.
cracking. As reflection cracking is but one cause of failure, the evaluation of other distress modes is required to determine the appropriate rehabilitation strategy. The experiences gained from this study and similar studies dealing with roughness and rutting will assist C-SHRP in building a decision support system for selection of overlay alternatives.

5. Acknowledgements

The authors are grateful to the Canadian Strategic Highway Research Program for making the C-LTPP database available and for sponsoring the data insight project on reflection cracking on all sites. This research was also supported by a grant from the Natural Science and Engineering Research Council (NSERC) to the first author.

6. References

Table 1: Site conditions and existing pavement data prior to overlay.

<table>
<thead>
<tr>
<th>Site</th>
<th>Year of Original Construction</th>
<th>Average Pavement Thickness</th>
<th>Average No. of Cracks per km</th>
<th>AADT</th>
<th>ESALs</th>
<th>Freezing Index °C days</th>
<th>Avg. No. of Freeze thaw cycles</th>
<th>Annual Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>1962</td>
<td>91 mm</td>
<td>780</td>
<td>1200</td>
<td>28000</td>
<td>1882</td>
<td>147</td>
<td>513 mm</td>
</tr>
<tr>
<td>ON</td>
<td>1967</td>
<td>203 mm</td>
<td>710</td>
<td>1400</td>
<td>24000</td>
<td>376</td>
<td>114</td>
<td>873 mm</td>
</tr>
<tr>
<td>QC</td>
<td>1977</td>
<td>148 mm</td>
<td>22</td>
<td>16180</td>
<td>46667</td>
<td>1144</td>
<td>115</td>
<td>1027 mm</td>
</tr>
</tbody>
</table>

Table 2: Overlay design and relative costs between sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Test Section¹</th>
<th>Surface Preparation</th>
<th>Overlay Material</th>
<th>Overlay Thickness²</th>
<th>Relative Cost at Site</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>1</td>
<td>minimal</td>
<td>HMAC</td>
<td>100 mm</td>
<td>88%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>minimal</td>
<td>HMAC</td>
<td>113 mm</td>
<td>100%</td>
<td>agency design</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>minimal</td>
<td>HMAC</td>
<td>148 mm</td>
<td>131%</td>
<td></td>
</tr>
<tr>
<td>ON</td>
<td>1</td>
<td>Mill 35 mm</td>
<td>HMAC</td>
<td>95 mm</td>
<td>206%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Mill 35 mm</td>
<td>HMAC</td>
<td>46 mm</td>
<td>100%</td>
<td>agency design</td>
</tr>
<tr>
<td>QC</td>
<td>1</td>
<td>minimal</td>
<td>HMAC</td>
<td>40 mm</td>
<td>100%</td>
<td>agency design</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>minimal</td>
<td>AC Polymer modified</td>
<td>51 mm</td>
<td>155%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>minimal</td>
<td>HMAC</td>
<td>106 mm</td>
<td>267%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>minimal</td>
<td>AC Polymer modified</td>
<td>83 mm</td>
<td>250%</td>
<td></td>
</tr>
</tbody>
</table>

¹ Manitoba site was overlaid in 1990, and Ontario and Quebec sites were overlaid in 1989.
² Average of as-built thickness
Figure 1: Progression of transverse cracking on C-LTPP site.