Early Pavement Life Cracking Performance of Asphalt Concrete Overlays in Saskatchewan

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Abstract

Based on network level asset management data, cracking is the most prevalent asphalt pavement distress observed on Saskatchewan's provincial highway network. Thermal transverse cracks typically reflect through new paved asphalt mats within two years of repaving, and in some cases as early as after the first winter. Applying preservation treatments on newly rehabilitated asphalt pavements takes funds away from other roads and impacts the overall level of service of the pavement network. In 2019, the Saskatchewan Ministry of Highways (ministry) implemented the use of polymer-modified asphalt binders for highways with high truck traffic, with the objective of using softer grade base asphalt to help mitigate cracking of newly constructed asphalt pavements. In addition, polymer-modified asphalt binders were mandated on repaving projects for higher volume highways.

This paper compares the cracking performance of asphalt concrete pavement test sections constructed on Highway 7 rehabilitation project in 2019, with dense-graded asphalt mixes using 150-200A binder and PG 58-37P binder, both containing 1% hydrated lime. Visual crack assessments were conducted, and automated cracking data collected with a Laser Crack Measurement System (LCMS) was compared over time. LCMS data was also compared over selected segments of the pavement outside the official test sections for a more comprehensive analysis. Further assessment included laboratory testing of pavement cores from the test sections for evaluation of cracking resistance of the asphalt mixes using the I-FIT test (AASHTO TP 124) and the Indirect tensile cracking test, IDT N_{flex} (AASHTO TP 141).

Background

The Saskatchewan Ministry of Highways (ministry) maintains 12,559 centerline kilometers of asphalt concrete pavement highways. Cracking is the most common pavement surface distress on the highway network. Specifically of interest for this case study is the significant amount of early/reflective cracking that is observed after asphalt concrete rehabilitation projects.

The ministry employs automated pavement data collection equipment to capture network level cracking data as part of its Asset Management System. Cracking information is binned into distinct categories, the definitions of which are as follows:

- Block Cracking - Cracks that are interconnected and tightly spaced. Block cracking is identified by a cracked tile density model. It is important to note that fatigue cracks are binned into the block cracking distress and are referred to as "wheel path block cracking". The pavement area is divided into tiles. The length of each crack passing through each tile is calculated. The total length of cracks passing through a tile is divided by the area of the tile to get tile density. The crack density for each crack relative to the tile area(s) it occupies is calculated. If a crack is completely contained within the tile, then the tile density is the crack density. If the crack passes through multiple cells, crack density is the weighted average of the tile density.
- Transverse Cracking - Cracks that run across the width of the pavement. Transverse cracks are identified as any crack that is oriented ≤ 30° from perpendicular to the direction of travel and is greater than 3 meters in length.
- Longitudinal Cracking - Cracks that run lengthwise, parallel to the direction of travel. Longitudinal Cracks are identified as any crack that is oriented ≤ 20° from the direction of travel.
- Meandering Cracking - Cracks that wander from edge to edge of the pavement. Single cracks that are not transverse, longitudinal, or block cracks, are classified as meandering cracks.

All cracks are reported in units of length, and in terms of crack width severity, which ranges from slight to extreme. The crack width and severity ranges are as shown in Table 1.

Table 1. Crack Severity Ranges used for Asset Management by Saskatchewan Ministry of Highways

Crack Severity	Crack Width
Slight	≤ 4 mm
Low	>4 mm to ≤ 12 mm
Moderate	>12 mm to ≤ 25 mm
Severe	>25 mm to ≤ 50 mm
Extreme	>50 mm to ≤ 100 mm

Most recent condition data collected on the pavement network in 2022 indicates that 55% of the pavement network is in fair cracking condition, while 18% of the pavement network is in poor cracking condition, as shown in Table 2.

Table 2. Saskatchewan Asphalt Pavement Network Cracking Conditions (2022)

Cracking Rating	Centerline Length %	Centerline Length (km)
Good	23%	2,877
Fair	55%	6,905
Poor	18%	2,311
Not Assessed in 2022	4%	466

Finding economically feasible ways to prevent or reduce the amount of early/reflective cracking in asphalt pavements would help the ministry optimize its maintenance and rehabilitation spending on the highway system. The intent of this study is to analyze the potential benefits to reflective cracking performance using SBS polymers in the ministry's asphalt mixes containing hydrated lime.

Early Cracking of Asphalt Pavements

To highlight the network issue of early cracking on newly rehabilitated asphalt pavements, annually collected Laser Crack Measurement System (LCMS) pavement network condition cracking data from randomly selected 150 m highway segments from four repaving projects completed in 2019 was investigated. The asphalt concrete overlay thickness varied from 90 mm to 110 mm for these four projects. Each segment had no recorded cracks in 2019, immediately after repaving was completed. The sum of all cracking, including block cracking, meandering, longitudinal and transverse cracking, within a 150-meter segment of each repaving project, is presented in Figure 1, for 2019 pre-construction, and for each of the first three years after construction. As can be seen, cracking increased each year for all four pavement segments, and in year three (2022), cracking increased more than 50% from the previous year (2021), for each of the pavement segments.

The same data is illustrated in Figure 2 to show the total cracking observed in 2022 as a percentage of cracks recorded prior to the repaving activity. After three years of field performance, the total cracking recorded ranges from 10% to 17% of the cracking recorded prior to repaving.

Figure 1. Pre- and Post-Construction Cracking on 150-m Segments of Four Repaving Projects from 2019

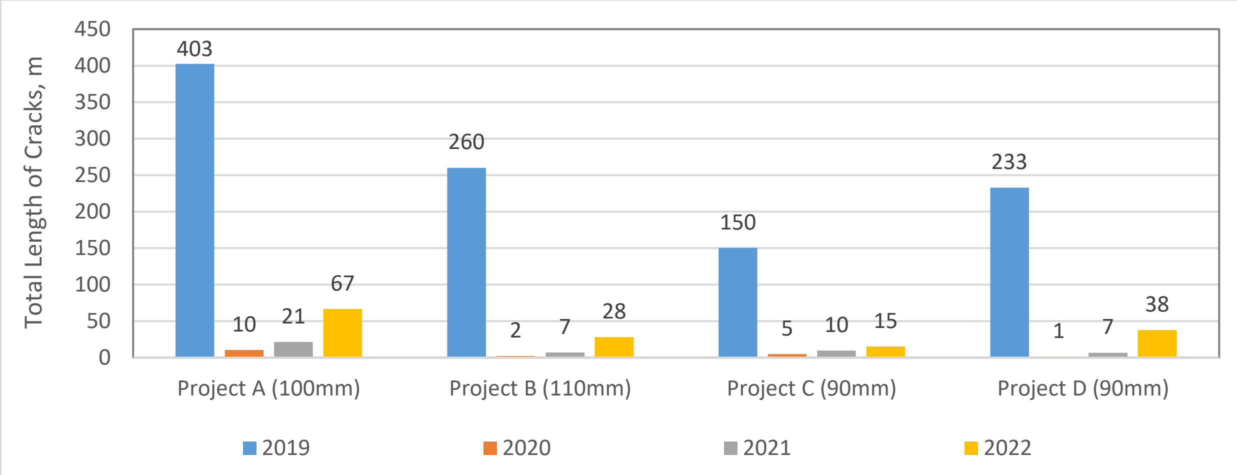
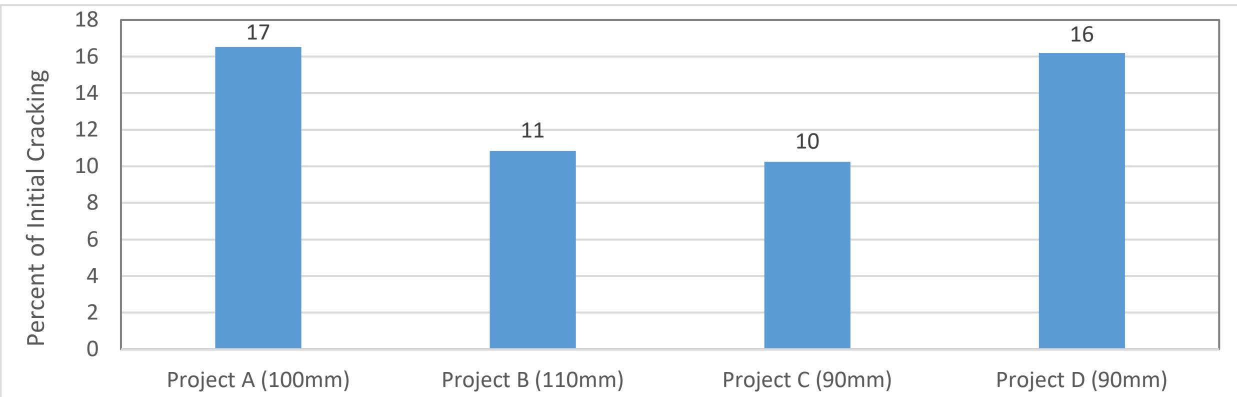


Figure 2. Cracking as Percent of Initial Cracking on 150-m Segments of Four Repaving Projects from 2019



Quantifying the Effects of Asphalt Binder on Cracking Performance

The effects of polymer-modification on asphalt binders have been widely studied in North America, with conclusions that asphalt binder, and the resulting asphalt concrete pavement performance can be improved by the addition of polymers [1-4]. Specifically, the addition of elastic polymers, such as Styrene-Butadiene-Styrene (SBS), improves performance at elevated temperatures and reduces pavement rutting potential, which in turn allows for the use of softer asphalt base binder, to improve pavement cracking performance. Although polymer modification increases the initial construction cost, previous Canadian studies found that using polymer-modified asphalt improved pavement performance and increased pavement services life by two to six years when compared to conventional asphalt concrete pavements [5,6].

Prior to 2019, the ministry primarily relied on straight run asphalt binder grades for repaving projects, except for the infrequent use of crumb rubber modified asphalt. The most common binders in use were penetration-viscosity system grades 150-200A and 200-300A. Historically, these binders have been locally sourced, and of high quality, and coupled with mandatory addition of hydrated lime for all asphalt concrete mixes, the overall performance of asphalt concrete in Saskatchewan was satisfactory.

The ministry relies on hydrated lime as an additive to asphalt concrete mixes, not only for its superior anti-stripping qualities, but also due to its many other benefits to asphalt concrete performance. An extensive literature review of existing research, a jurisdictional scan, and internal ministry studies, including mechanistic testing and field performance evaluation, confirm that the addition of hydrated lime results in better, longer lasting pavements. Saskatchewan, along with several other transportation agencies in North America and Europe, have reported improved asphalt cement and aggregate adhesion, less cracking, lower rut depths, reduced age hardening, and overall reduced maintenance costs in pavement maintenance, when hydrated lime is added to asphalt concrete mix [7-14].

In 2019, the ministry implemented the use of a new asphalt binder type for high traffic volume and high truck traffic highways. The new binder is a Performance Graded (PG) Polymer-Modified Asphalt that is specified to be made by adding Styrene-Butadiene-Styrene (SBS) polymer to a softer (Pen-Vis A grade) asphalt binder to achieve PG 58-37P. The specification requires conformance with AASHTO M320 *Performance Graded Asphalt Binder*, with the exception for testing temperature modifications to account for the -37°C Low Temperature split grade. There is also a requirement for Multiple Stress Creep and Recovery (MSCR) testing with a minimum required percent elastic recovery of 40%.

At the time of implementation in 2019, the incremental costs of the PG 58-37P binder constituted an increase of approximately eight to ten percent to the price per tonne of asphalt concrete in place. Even though it was understood that the most benefit from polymer-modified asphalt binders in terms of cracking performance would occur on new construction, a decision was made to also use it on high traffic repaving projects. To verify whether these higher expenses are warranted, the ministry proceeded to construct and monitor test sections on a repaving project on Highway 7 near Rosetown, and to monitor the overall network level performance of other similar projects.

Cracking of asphalt pavements is complex and can be caused by varied factors including stresses from traffic loading, cold temperature induced stresses and other environmental conditions, age hardening, and poor construction practices. Key factors that can enhance the cracking resistance of asphalt pavement relate to the asphalt mix properties, including asphalt binder type and properties, and the amount of asphalt binder [15,16]. The intent of the Highway 7 test sections was to change the asphalt binder type and leave all other variables as consistent across test sections as possible.

Highway 7 Test Sections Setup

The Highway 7 test sections were constructed as part of a pavement rehabilitation project West of Rosetown. Highway 7 is an important highway corridor in Saskatchewan and serves as a part of the National Highway System, connecting Saskatoon and Calgary. In 2017 the Average Annual Daily Traffic was estimated to be 3040 vehicles per day, and of those, 680 being trucks.

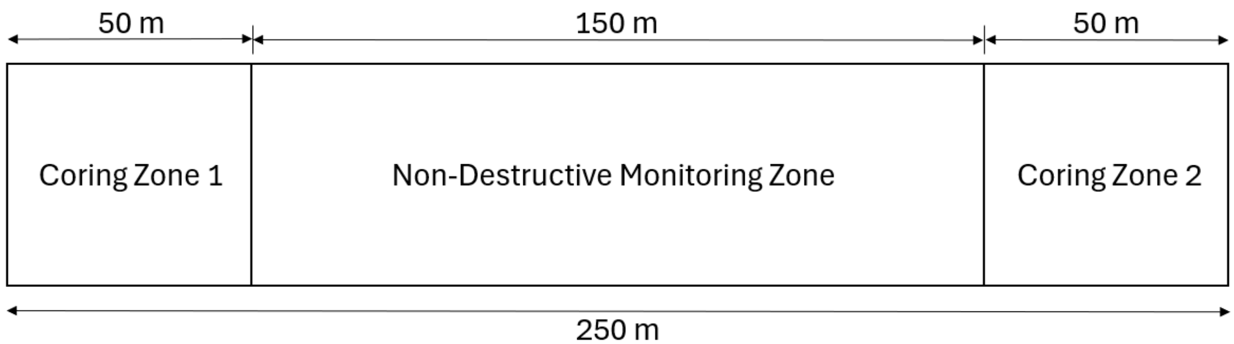
The test sections were constructed to compare the performance of two asphalt mixes: one made with 150-200A asphalt binder, and the other with PG 58-37P asphalt binder, each containing hydrated lime (1 % by weight of dry aggregate), under similar traffic loading and environmental conditions. The following are pavement structure details for the test sections prior to repaving:

- Highly Plastic Clay Subgrade (CH), Soaked CBR of 3.1
- 200 mm thickness of Granular Sub-base Course
- 150 mm thickness of Granular Base Course
- 150 mm thickness of Asphalt Concrete

The rehabilitation design consisted of a mill 50 mm/fill 50 mm and overlay 50 mm treatment with dense graded asphalt concrete, to provide the required 15-year pavement design life. The asphalt concrete included 150-200A asphalt binder and 1% Hydrated Lime (150-200A+HL) from km 0.00 to km 9.05. For the remaining distance, from km 9.05 to km 29.88, the asphalt concrete included PG 58-37P asphalt binder and 1% Hydrated Lime (PG 58-37P+HL). A test section area was selected within each of these two different project sections in the Westbound Lane.

Test section locations were selected to provide similar existing pavement structures, traffic loading, environmental conditions, existing cracking amount, and other surface distress conditions. The 150-200A+HL test section was located at km 8.70 to km 8.95 and the PG 58-37P+HL test section was located at km 9.15 to km 9.40. Each test section area consisted of 150-meter non-destructive monitoring area and 50-meter coring zones at each end of the non-destructive monitoring area, as shown in Figure 3. A short 200-meter transition area was located between the two test section areas, which allowed for a transition between the two different asphalt concrete mixes.

Figure 3. Typical Test Section Layout



Pre-Construction Pavement Cracking Condition of the Test Sections

The predominant types of cracking observed on the test sections prior to milling and paving included fatigue cracking, block cracking, longitudinal cracking, and transverse cracking. There was high extent and high severity cracking on both test sections with spalling at many of the cracks. Cracking condition of the test sections and the post-milling pavement surfaces are shown in Figure 4 and Figure 5.

Figure 4. Highway 7 150-200A+HL Test Section, Pre- and Post-Milling

Figure 5. Highway 7 PG 58-37P+HL Binder Test Section – Pre- and Post-Milling

Construction of Test Sections

The repaving consisted of removing a 50 mm deep trench of the old asphalt concrete on the main lane through cold milling, paving 50 mm of asphalt concrete in the trench, and then a final overlay of 50 mm of asphalt concrete on both the main lane and shoulder. Cross-sections showing the cold milling/reclaiming asphalt trench and the required new asphalt thickness are presented in Figure 6. The milling and first lift of asphalt concrete to backfill the trench was completed on June 13, 2019, for both test sections. The second lift of asphalt concrete was placed on June 26, 2019, for the 150-200A+HL section and June 27, 2019, for the PG 58-37P+HL section.

The asphalt mix type used was a 12.5mm (top size and NMAS), dense-graded mix, designed to 75 Marshall blows. A separate asphalt mix design was completed for each of the two binder types used for the project. Both mix designs called for the same aggregate proportions, asphalt binder content, and used 1% hydrated lime. Table 3 shows the key mix design properties and composition of each asphalt mix used.

Figure 6. Design Cross-Sections and Asphalt Concrete Lift Thickness for Highway 7 Repaving Project

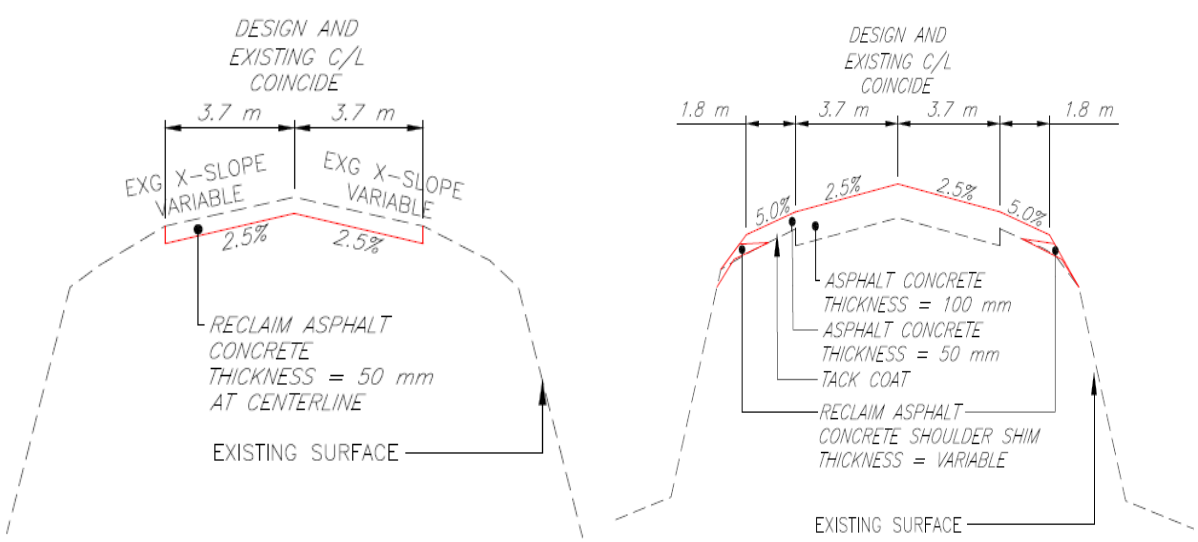


Table 3. Properties of Asphalt Mix Designs used on Highway 7 Paving

Mix Property	Asphalt Mix with 150-200A+HL	Asphalt Mix with PG 58-37P+HL
Marshall Blows	75	75
Density of Mixture (kg/m^3)	2386	2388
Maximum Theoretical Density (kg/m^3)	2475	2474
Marshall Air Voids (%)	3.6	3.5
Voids in Mineral Aggregate (%)	14.6	14.5
Voids Filled (%)	75.1	75.7
Marshall Stability (N)	14492	12176
Marshall Flow (mm)	2.10	2.25
Retained Tensile Strength STP 204-15 (%)	87.9	77.4
Design Asphalt Content (% of aggregate mass)	5.4	5.4
Reclaimed Asphalt Pavement Content (%)	15	15
Crushed Coarse Aggregate (%)	33	33
Crushed Fines Aggregate (%)	31	31
Natural Fines Aggregate (%)	20	20
Hydrated Lime (%)	1.0	1.0
Coarse Aggregate Fracture, 2 or more faces (%)	87.7	87.7
Fine Aggregate Angularity	44.5	44.5

There were no pavement compaction cores assessed directly within the test section limits, however the Lot average compaction for the 150-200A+HL test section for bottom and top lifts was 94.8% and 95.1%, respectively (based on Maximum Theoretical Density). The PG 58-37P+HL test section compaction Lot average of bottom and top lifts was 95.3% and 94.3%, respectively.

For the 150-200A binder, eight samples obtained directly from delivery trucks were tested for random quality assurance checks. The average results for penetration were 156 (0.1mm), and for viscosity 78.8 (Poise). Another 2019 sample of 150-200A binder from this supplier was tested and graded using the Performance Grading system, and was graded as PG 58-28, with an actual High Temperature Grade of 60.1°C and Low Temperature Grade of -31.8°C.

For the PG 58-37P binder, 34 samples were obtained directly from delivery trucks and tested for quality assurance. Four samples exceeded the 300 MPa maximum allowable Creep Stiffness, S value, however those four samples passed the Direct Tension Test requirements. One sample did not meet the Creep Stiffness, m-value, minimum requirement of 0.3. The supplier's certificate of analysis on the material provided indicated an actual High Temperature Grade of 64.4°C and a Low Temperature Grade of -38.4°C. Six samples were tested for additional binder properties of DENT and extended BBR for informational purposes. Details of the quality assurance results for the PG 58-37P binder are shown in Table 4.

Table 4. Quality Assurance Test Results for PG 58-37P Binder

Tested Property	Mean (SD)	Minimum	Maximum	Specification
Rotational Viscosity (Pa. s)	0.507 (0.024)	0.490	0.640	Max 3
Dynamic Shear (G*/sinδ, kPa)	1.74 (0.09)	1.65	2.12	Min 1.00
Mass Change (%)	-0.657 (0.074)	-0.765	-0.472	Max 1.00
Dynamic Shear (G*/sinδ, kPa)	4.05 (0.36)	3.23	4.79	Min 2.20
Dynamic Shear (G*sinδ, kPa)	2527 (278)	2090	3430	Max 5000
Creep Stiffness, S (MPa)	278 (27)	214	345*	Max 300
Creep Stiffness, m-value (slope)	0.326 (0.013)	0.270	0.348	Min 0.3
MSCR, 3.2kPa, $R_{3.2}$ (%)	54.5 (4.8)	49.0	71.3	Min 40.0
Ash Content (%)	0.048 (0.018)	0.033	0.100	N/A
DENT Test, CTOD (mm)	29.8 (5.1)	24.2	38.9	N/A
xBBR, Low Temp. Limiting Grade (°C)	-35.3 (0.3)	-35.9	-35.0	N/A
xBBR, Grade Loss (°C)	-2.3 (0.4)	-2.9	-1.7	N/A

*For samples with Creep Stiffness results >300MPa, Direct Tension Test criteria were achieved

Highway 7 Test Sections Cracking Performance

Visual Crack Mapping

During the pre-construction visual crack mapping (in June 2019) seven full transverse cracks (crossing the entire lane width) were recorded on the 150-200A+HL test section. On the PG 58-37P+HL test section seven full transverse cracks were also found. Both test sections were recorded as having a high density of fatigue cracking in both wheel paths, as well as block cracking, and longitudinal cracking.

During the post-construction visual crack mapping performed in February 2021, three full transverse cracks were noted on the 150-200A+HL test section. Two of the transverse cracks were of low severity (4 to 12 mm crack width) and the other crack was of moderate severity (12 to 25 mm crack width). The winter seasonal variations contributed to the width of cracking observed. Two full transverse cracks of low severity were observed on the PG 58-37P+HL test section. Two transverse cracks that were beginning to reflect through the asphalt layer were observed to extend partially into the driving lane from the shoulder were of slight severity (less than 4 mm wide).

The most recent visual inspection of the test sections was completed in May 2024. Prior to the inspection, a maintenance treatment consisting of routing and placement of rubber asphalt crack sealant (RACS) was applied in September 2022. Some transverse cracks visible during the May 2024 inspection had not been treated with RACS and are assumed to have either appeared or widened since the RACs treatment was applied. With the spring temperatures the cracks were narrow and were slight (≤ 4mm crack width) in both test sections. Counting both the treated and untreated cracks, four full transverse cracks were recorded in the 150-200A+HL test section (length of 14.8 m), and five full transverse cracks were recorded in the PG 58-37P+HL test section (length of 18.9 m). For both test sections, a small amount of longitudinal joint cracking was observed at the centreline, and some sections of these had been treated with RACS. These cracks were not included in the analysis because they are related to the construction issues with the longitudinal joint. Figure 7 presents pre-construction and post-construction transverse cracking length through visual crack mapping, with the total amount of linear meters in each inspection.

Figure 7. Transverse Cracking Length Recorded During Visual Inspections of Highway 7 Test Sections

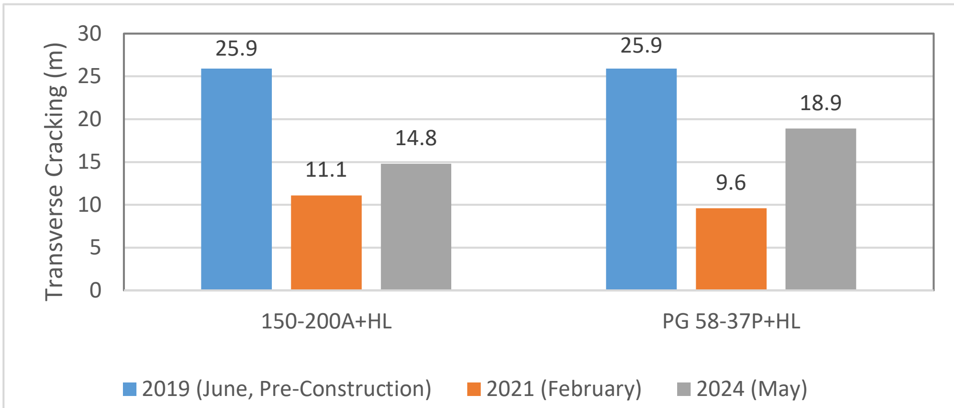
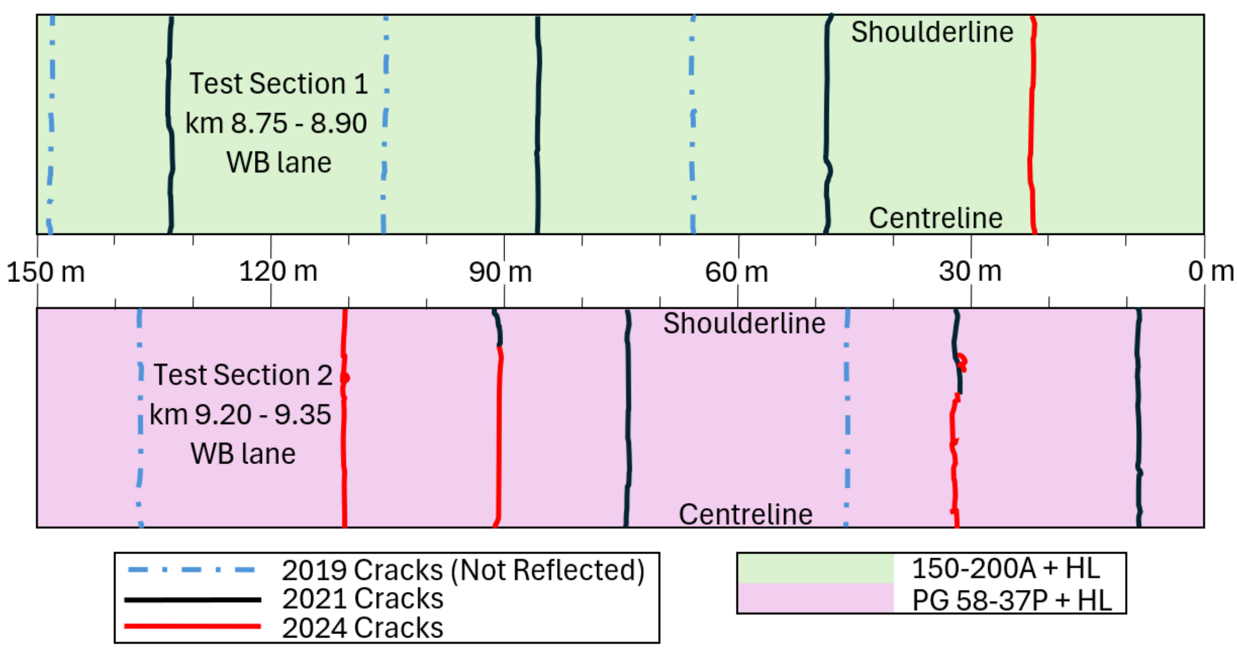


Figure 8 shows the progression of the transverse cracks occurring over time, with new cracking mapped out in each visual inspection. Progression of cracking after five years can be considered similar between the test sections, with the PG 58-37P+HL test section having one more transverse crack reflected through than the 150-200A+HL test section.

Figure 8. Highway 7 Test Sections Visual Crack Mapping Results of Non-Destructive Monitoring Zones



Within the test section areas, the post-construction cracking to date has been limited to reflective transverse cracking. Based on the physical inspections and visual monitoring to date, there are no significant differences in the cracking performance of the two test sections.

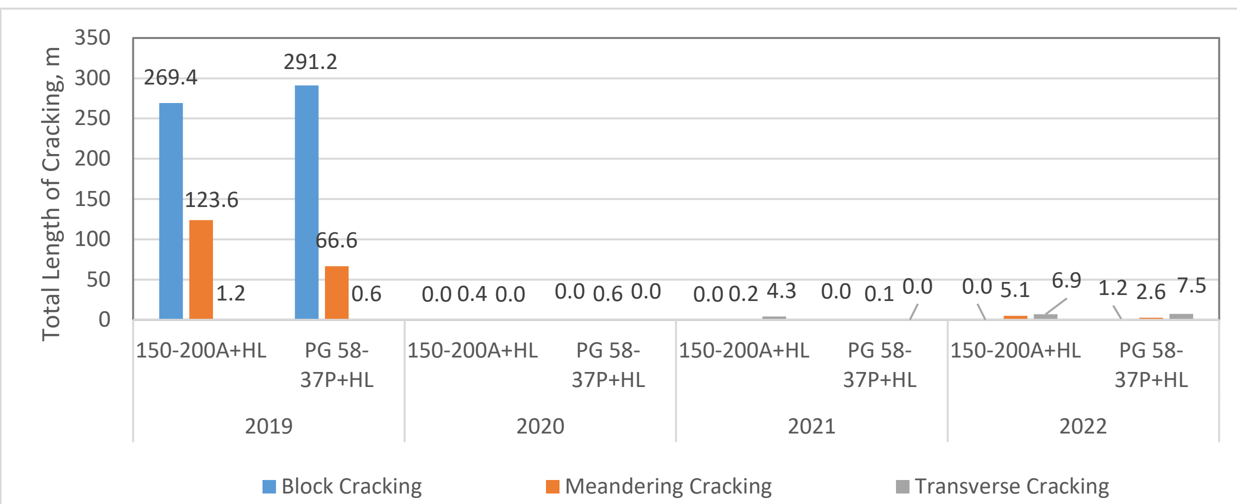
LCMS Cracking Data Analysis for Highway 7 Test Sections

Pavement management (LCMS) data was collected in the test section locations prior to the milling and paving operations in 2019. Subsequent LCMS data was collected in 2020, 2021, and 2022. Table 5 and Figure 9 presents a summary of total cracking length observed during each of these assessments.

Table 5. Highway 7 Annual LCMS Cracking Data for the 150-m Test Sections

Year	Test Section	Crack Type			
		Block Cracking (m)	Meandering Cracking (m)	Transverse Cracking (m)	Total Cracking (m)
2019	**150-200A+HL**	269.4	123.6	1.2	**394.2**
	PG 58-37P+HL	291.2	66.6	0.6	**358.4**
2020	**150-200A+HL**	0.0	0.4	0.0	**0.4**
	PG 58-37P+HL	0.0	0.6	0.0	**0.6**
2021	**150-200A+HL**	0.0	0.2	4.3	**4.5**
	PG 58-37P+HL	0.0	0.1	0.0	**0.1**
2022	**150-200A+HL**	0.0	5.1	6.9	**12.0**
	PG 58-37P+HL	1.2	2.6	7.5	**11.3**

Figure 9. Highway 7 Test Sections Pre-Construction and Post-Construction Cracking Progress



Although LCMS did not detect and count any transverse cracks in either test section in 2020, and only a small amount in 2021, it was evident and visible on the digital images obtained as part of the LCMS data collection that some transverse cracks had reflected through the new asphalt layers in both test sections. These cracks were also noted during the visual inspections summarized in the previous section. The factors that contributed to the LCMS not detecting all the transverse cracking include the sensitivity setting for crack detection of the LCMS, and the seasonal timing of data collection. The first transverse crack, on either test section, was detected by the LCMS on the 150-200A+HL test section in 2021. In 2022, the LCMS only detected 12.0 m of total cracking in the 150-200A+HL test section, and 11.3 m in the PG 58-37P+HL test section. There was no block cracking (wheel path or otherwise) detected on either test section until 2022, when 1.2 metres of non-wheel path block cracking was detected on the PG 58-37P+HL test section. This block cracking was not evident during visual field inspection in May 2024.

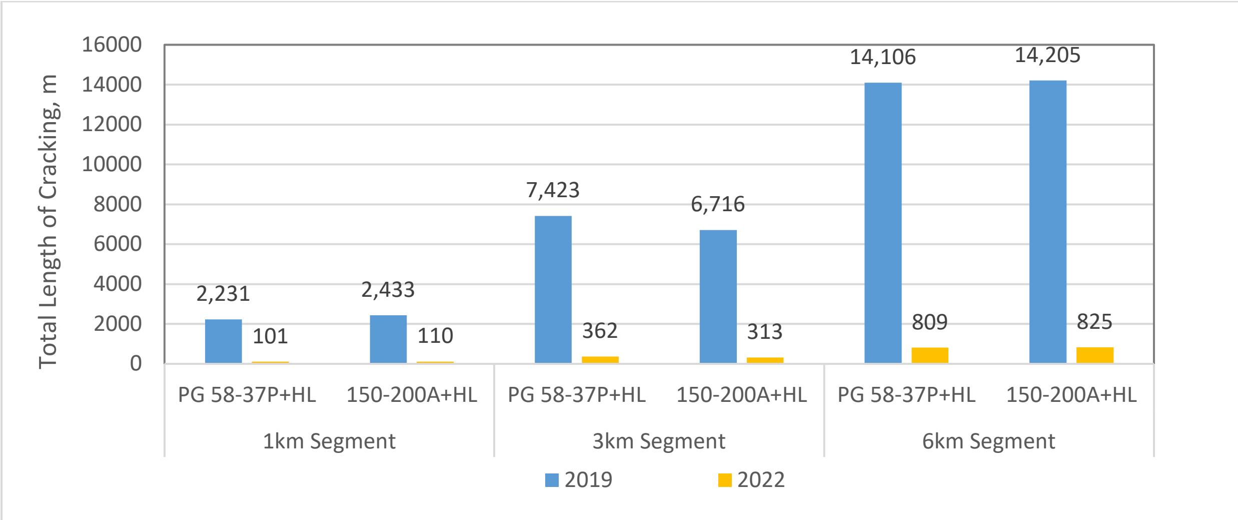
Highway 7 Network Level Cracking Analysis

Annual LCMS data was also compared for longer segments of Highway 7 paved with the two different asphalt concrete mixes. The short 150-m monitoring test sections are small samples of the network, and LCMS is most effectively used for network-level analysis. To compare performance of the two different asphalt concrete mixes on a larger scale, pavement segments of one, three, and six kilometres in length (each including the original 150-m test sections) were compared for pre-construction and post construction cracking. The total length of individual cracks (meandering, longitudinal, transverse, block, and fatigue cracks) for these segments is summarized in Table 6 and Figure 10. In addition, Table 6 shows the total length of cracks for 2022 (three years after paving) as a percentage of the initial total length of cracks recorded in 2019.

Table 6. Annual LCMS Data on 1, 3, and 6 Km Long Segments of Highway 7

Type of Crack	Initial 2019 (m)	2020 (m)	2021 (m)	2022 (m)	2022 Cracking (% of Initial)	Initial 2019 (m)	2020 (m)	2021 m)	2022 (m)	2022 Cracking (% of Initial)
	PG 58-37P+HL (1 Km Segment)					**150-200A+HL (1 Km Segment)**				
Meandering	321.1	2.9	4.3	9.7	3.0	572.1	1.4	5.1	16.9	3.0
Longitudinal	141.2	0.0	0.2	10.6	7.5	158.6	0.0	0.0	22.2	14.0
Transverse	10.6	0.0	1.8	58.6	552.1	23.9	0.0	10.5	67.2	281.6
Block	877.6	8.7	91.8	21.9	2.5	887.3	1.6	9.0	3.4	0.4
Fatigue	880.9	0.0	0.0	0.5	0.1	791.1	0.0	0.0	0.3	0.0
Total	**2231.3**	**11.6**	**98.1**	**101.2**	**4.5**	**2432.9**	**2.9**	**24.6**	**110.1**	**4.5**
	PG 58-37P+HL (3 Km Segment)					**150-200A+HL (3 Km Segment)**				
Meandering	1484.6	5.8	8.0	23.3	1.6	1393.5	1.9	8.4	37.1	2.7
Longitudinal	577.9	0.0	1.2	45.1	7.8	528.4	0.4	8.1	86.4	16.3
Transverse	15.9	0.0	4.0	175.9	1106.3	70.7	0.0	14.3	163.4	231.0
Block	2690.5	71.5	302.1	117.1	4.4	2603.1	3.9	19.6	24.1	0.9
Fatigue	2654.3	0.0	0.2	0.9	0.0	2119.9	0.0	0.3	1.6	0.1
Total	**7423.2**	**77.3**	**315.5**	**362.2**	**4.9**	**6715.7**	**6.2**	**50.6**	**312.6**	**4.7**
	PG 58-37P+HL (6 Km Segment)					**150-200A+HL (6 Km Segment)**				
Meandering	3205.7	10.9	22.4	69.5	2.2	2255.1	4.7	13.0	71.9	3.2
Longitudinal	1286.2	0.7	1.5	112.7	8.8	2949.0	18.5	63.1	327.4	11.1
Transverse	98.0	0.0	41.1	380.2	388.0	164.3	0.0	16.6	344.8	209.9
Block	5146.0	126.9	421.3	244.2	4.7	4497.5	5.7	35.2	47.0	1.0
Fatigue	4369.9	0.0	0.6	2.0	0.0	4338.7	0.0	0.3	34.2	0.8
Total	**14105.7**	**138.5**	**486.9**	**808.5**	**5.7**	**14204.5**	**28.9**	**128.2**	**825.4**	**5.8**

Figure 10. Total Cracking Observed by LCMS on 1, 3, and 6 Km Long Segments of Highway 7

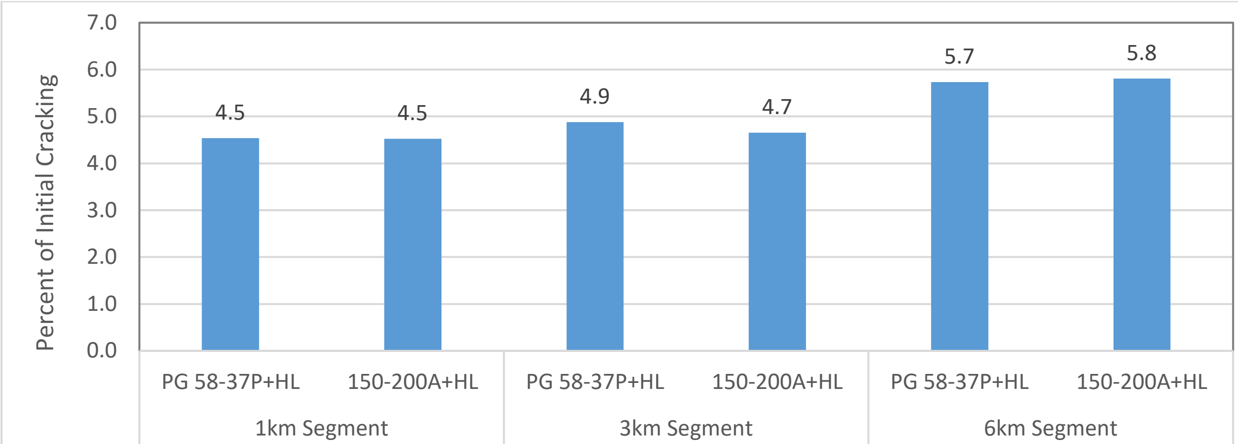


The length of transverse cracks in 2022 recorded by the LCMS was greater than the length of transverse cracks recorded prior to construction in 2019 for both asphalt binder types and all three pavement segment lengths. This result was contrary to what was physically observed in the test section locations, and to the expected pavement performance. The increase in length of transverse cracks three years after paving is attributed to the binning of cracks in the LCMS software. The high density of cracks on the old pavement led to most transverse cracks being detected and counted as part of block cracking or fatigue cracking. In the absence of high-density block cracking and fatigue cracking in 2022, transverse cracks were detected by the LCMS, and this time, they were binned correctly. Due to binning inconsistencies with the initial 2019 LCMS data, total cracking is used as the most comparable measure with the current data.

Pre-construction total cracking was similar for both asphalt mixes, as shown by the small differences between PG 58-37P+HL and 150-200A+HL segments of pavement of one kilometre (202 m), three kilometres (707 m) and six kilometres (99 m). This indicates that the pre-existing conditions were very similar for most of the project length, confirming this project as a good candidate for this type of investigation. After three years of field performance, the 2022 total cracking is also similar for both asphalt mixes, as shown by the small differences between PG 58-37P+HL and 150-200A+HL asphalt concrete across segments of one kilometre (9 m), three kilometres (49 m) and six kilometres (16 m).

Figure 11 shows a comparison of total cracking in 2022 expressed as a percentage of the initial total cracking observed in 2019 (pre-construction). The percentage of cracking three years after paving was similar between the PG 58-37P+HL and 150-200A+HL asphalt materials for all three segment lengths. When analysing the cracking data for these larger segments of the repaving project, it was encouraging to see that only a small percent of pre-existing cracks is present, ranging from 4.5 to 5.8%.

Figure 11. Total Cracks Observed by LCMS Expressed as Percentage of Initial Cracks



Highway 7 Test Sections 2022 Laboratory Investigation

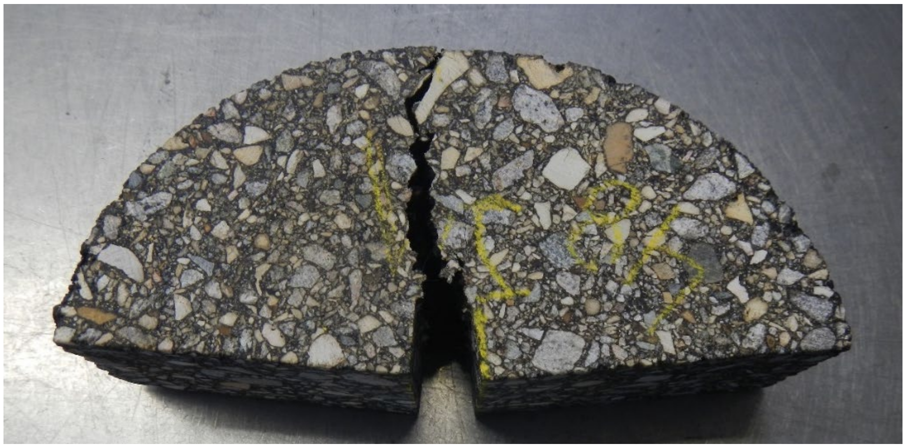
In March 2022, after nearly three years in service, pavement cores were obtained from the inside (IWP) and outside (OWP) wheel path locations, as well as from between wheel paths (BTW), for the two coring areas of both test sections. Laboratory testing and investigation of the cores included the I-FIT test (AASHTO TP124) and IDT N_{flex} (AASHTO TP141), to evaluate the cracking resistance of the asphalt mixes. These tests were selected based on a review of cracking tests available at the time and considering future practical aspects of implementing cracking tests for the ministry's asphalt mix design standards and/or quality management program.

I-FIT Test (AASHTO TP 124)

The testing procedure for the I-FIT test is defined in AASHTO TP 124 *The Standard Method of Test for Determining the Fracture Potential of Asphalt Mixtures Using the Illinois Flexibility Index Test (I-FIT)*. This test method determines cracking resistance properties of asphalt mixtures at intermediate test temperatures. The test simulates Mode I, which is the tensile opening mode during crack propagation. Specimens are tested using the semicircular bend geometry, which is a half disc with a notch parallel to the direction of load application. The fracture energy (Gf) and post peak slope (m) of the load-load line displacement (LLD) curve are used to calculate a Flexibility Index (FI) to predict the fracture resistance of an asphalt mixture at intermediate temperatures. A high FI value over 6.0 can be associated with good cracking performance [17]. Figure 12 is an example of an I-FIT test specimen after testing is completed, showing the mode of failure.

The two binder type test sections each had two separate coring zones. Within each of the four coring zones, three cores were obtained, one from each of the distinct lane locations: inner wheel path (IWP), between wheel paths (BWP), and outer wheel path (OWP). A total of 12 cores were taken for this testing. The pavement cores were sawed into bottom lift and top lift sections, prior to being sawed in half into two specimens, according to the test procedure. Each of the specimens was then notched and tested at 25°C test temperature using a monotonic loading rate of 50 mm/minute until failure. The two specimens from each lift were averaged to produce the FI value. This testing regime generated a total of 24 unique FI values.

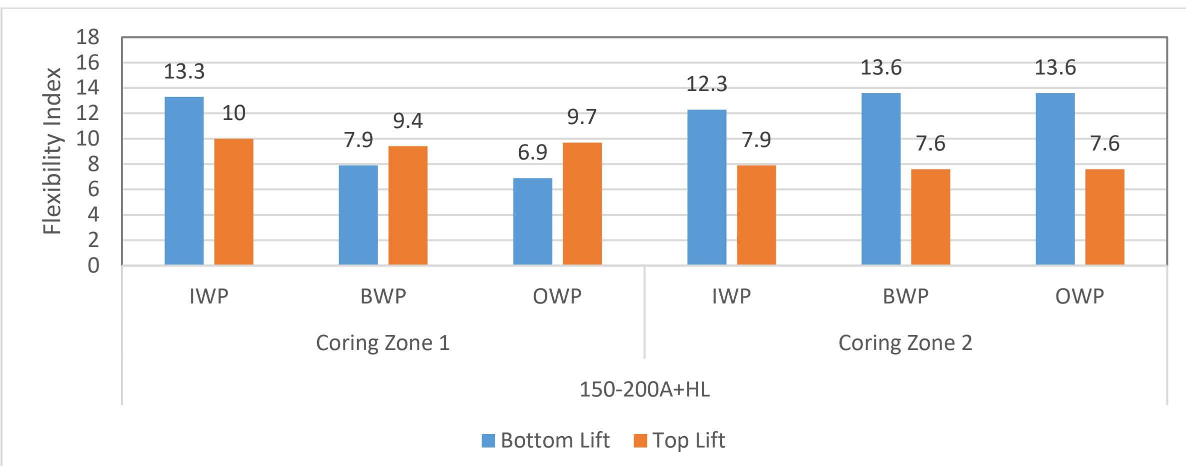
Figure 12. Example Photo of an Asphalt Concrete Core Specimen after I-FIT Testing



Although variability was observed in the FI results within each test section, the FI values were above 6.0 for all test samples, which is an indication of overall good cracking performance for each of the two test sections. The FI data showed an average 10.7, a standard deviation of 2.6, and an overall range in FI of 6.9 to 17.2. The I-FIT test results are presented in Figure 13 and Figure 14.

Variability within the FI values may be attributed to the level of repeatability of the I-FIT test, differences in the asphalt mat compaction, asphalt mix variations between the paving lifts and coring zone locations, and different environmental aging effects in the different lifts of the asphalt mat.

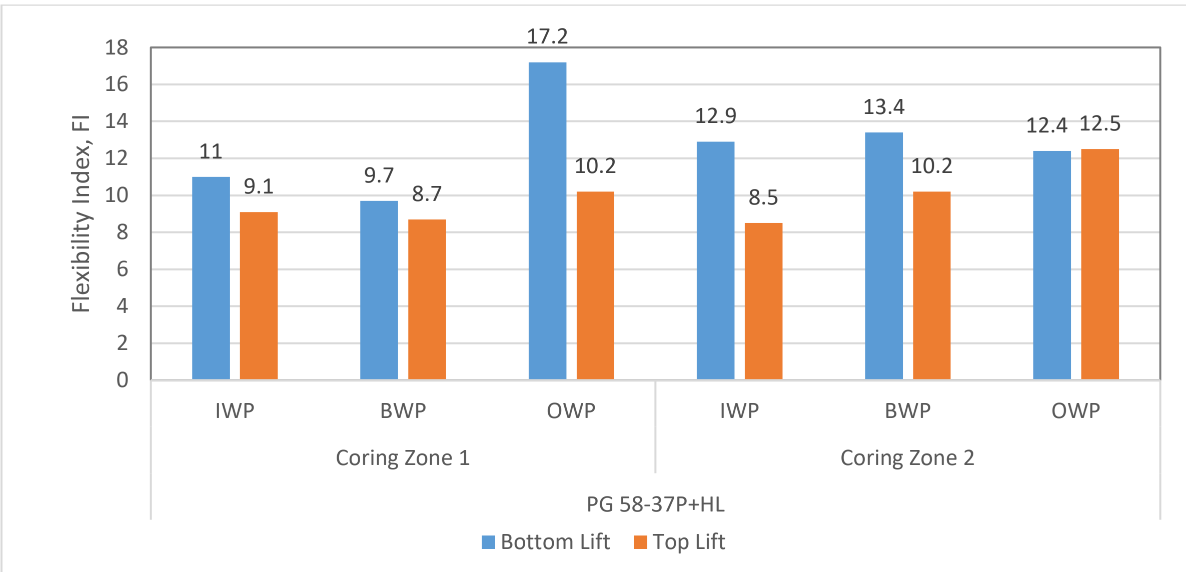
Figure 13. I-FIT Flexibility Index Results in 150-200A with Hydrated Lime Test Section



When performing the statistical analysis on the data set (single and multi-factor ANOVA across all variables, with alpha = 0.05), it was observed that there was no significant difference in the FI values between the two test sections attributed to asphalt binder type. The most statistically significant trends were the differences in FI values between top lift and bottom lift specimens. These differences most likely relate to the fact that each asphalt concrete lift was paved on a different day (13 days apart for 150-200A+HL, and 14 days apart for PG 58-37P test section). The bottom lift specimens had a higher FI value than top lift specimens. In addition to mix production and asphalt mix materials variability between lifts, another potential factor contributing to the better cracking resistance in the bottom lift materials could be the reduced aging of the asphalt binder located lower in the asphalt concrete surface.

For the top lift of the 150-200A+HL test section, there was a significant difference in FI values between the two coring sections. The FI results from coring zone 1 were higher than coring zone 2. This difference between the two coring sections of the same lift and same asphalt mix likely indicates high variability in asphalt mix properties during plant production or in the level of asphalt concrete compaction between these two areas of the same asphalt concrete lift.

Figure 14. I-FIT Flexibility Index Results in PG 58-37P with Hydrated Lime Test Section



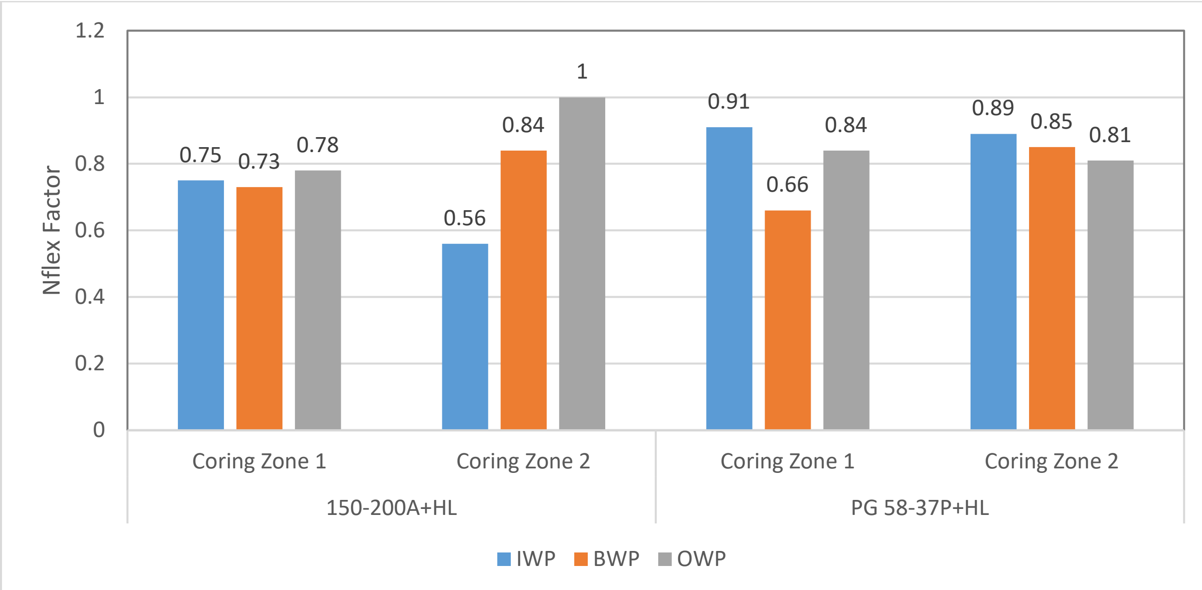
The impacts of the different coring locations within the lane (IWP, BWP, and OWP) were determined to be statistically insignificant.

IDT N_{flex} Factor (AASHTO TP 141)

Asphalt pavement core samples were also tested using the AASHTO TP 141 test procedure for *The Standard Method of Test for Determining the Indirect Tensile N_{flex} Factor to Assess the Cracking Resistance of Asphalt Mixtures (IDT N_{flex})*. The IDT N_{flex} uses fracture mechanics to determine the fatigue cracking resistance of asphalt mixes. Pavement core samples of 150-mm diameter were loaded at a rate of 50 mm/minute until failure. The N_{flex} Factor is a parameter for fatigue cracking resistance and is calculated by dividing toughness by the brittleness slope. A higher N_{flex} Factor is associated with good cracking resistance, and the test results have been shown to be sensitive to changes in asphalt binder grade, asphalt binder content, reclaimed asphalt pavement content, and in place air voids [18].

IDT N_{flex} specimens were prepared by saw-cutting the top lift of asphalt concrete from pavement cores obtained from IWP, BTW, and OWP, from coring areas 1 and 2, for each of the test sections. A total of 12 specimens were tested. After performing statistical analysis (ANOVA single factor and multi factor, with alpha = 0.05), it was determined that no statistically significant trends were found, and the test sections performed comparably. IDT N_{flex} test results are presented below in Figure 15.

Figure 15. IDT - Highway 7 Test Sections N_{flex} Factor Results from 2022 Cores



Summary of Observations

The analysis completed on the Highway 7 repaving project and the test sections that were constructed to monitor the two different asphalt binder types used has yielded the following observations:

- Based on visual inspections of the test sections, the transverse reflective cracks occurred early in the pavement life for both asphalt binder types. During the 2021 visual inspection 11.1 m of transverse cracks were noted in the 150-200A+HL test section, and 9.6 m of transverse cracks were observed in the PG 58-37+HL test section.
- In 2024, there were 4 out of 7 transverse cracks that reflected through the 100 mm overlay in the 150-200A+HL test section, and 5 out of 7 in the PG 58-37P test section.
- Despite the large amount of pre-existing block and fatigue cracking, none of these are currently present in the test sections.
- While the LCMS is proven as an excellent network level tool, it is not well suited for analysis of shorter pavement segments.
- The LCMS did not detect all transverse cracks in the test sections due to their very low severity, despite them being detected by visual inspection.
- Cracking analysis of segments of varying length resulted in similar conclusions with respect to cracking. The two asphalt binders are performing the same in terms of cracking.
- For the longer segments of 1, 3 and 6 km length, the percentage of cracking detected by LCMS in 2022 is quite low for all the segments, ranging from 4.5 to 5.8% of pre-existing cracking.
- I-FIT test results completed on cores from the 2022 sampling program indicate that both asphalt mixes should have good cracking performance (all FI results were greater than 6.0).
- There was no statistical difference when comparing I-FIT cracking resistance test results between the two asphalt binder types.

- I-FIT test results were significantly different between top and bottom lift for both test sections, and between coring area locations within the 150-200A+HL test section in the top lift. These differences are most likely related to the asphalt mix production and laydown variability. Environmental aging of the top lift of the asphalt concrete may also have contributed to these differences. Variability in asphalt concrete production may be obscuring any small differences between the two asphalt mix types used.
- IDT N_{flex} test results also did not yield any significant differences between the two asphalt binders.
- Based on ministry studies, the use of hydrated lime results in improved pavement performance and is contributing to the overall good performance observed with the 150-200A asphalt binder.
- Based on the first five years of service life, the cracking performance for both asphalt concrete mixes used on the Highway 7 repaving project is the same. The PG 58-37P asphalt binder did not demonstrate any improvement in cracking resistance when compared to the 150-200A asphalt binder.
- The visual inspections and LCMS data analysis of the test sections and the larger segments of the Highway 7 repaving project support the I-FIT and IDT N_{flex} test results, with both indicating no noticeable differences in performance to date.

Conclusions and Future Work

The ministry objective was to analyze SBS polymer addition in the presence of hydrated lime in the asphalt mix. SBS polymers have successfully been used to improve pavement performance over the pavement life cycle. However, as anticipated, to date in early service life there has been no visible improvement in reflective cracking from selecting PG 58-37P binder grade for the Highway 7 repaving project. Based on the results of this study, the ministry may want to review its approach to using polymer modified binders in pavement rehabilitation applications.

Future work recommended for the Highway 7 test sections includes:

- Continued monitoring of the test sections for detailed distress mapping to monitor the progression of all pavement distresses further into the pavement service life.
- Continued use of LCMS data monitoring over the test sections and network level analysis and extend to all distresses, including rutting.
- Further coring of the test section areas with cracking performance testing to quantify any changes in performance over time, and to explore other commonly used cracking procedures.
- Extend the analysis to include laboratory rutting performance and bond strength tests on field core samples.

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