Selection, Evaluation and 5-Year Performance of Highway 1 Section Rehabilitated with Hot-In-Place Recycling Treatment

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ABSTRACT

Various maintenance and rehabilitation treatments are available to extend the life of a pavement structure depending on its position in the pavement life cycle. In today's age of depleting natural resources, shrinking maintenance budgets, increasing costs, and heightened awareness for environmentally friendly alternatives, owner agencies struggle to find alternatives that meet all of the criteria and keep the critics and public satisfied.

The British Columbia Ministry of Transportation and Infrastructure (BC MoTI) uses a Hot-In-Place Recycling (HIPR) strategy consistently to rehabilitate candidate segments of the highway system that are structurally adequate to support the design traffic, but exhibit surface distress.

Tetra Tech was retained by BC MoTI to develop the rehabilitation strategies for a section of Highway 1 from Summit Drive Overpass to Kokanee Way Overpass in Kamloops, BC. Upon completion of review and analysis of data, HIPR was selected as the preferred rehabilitation strategy for the project. The slow lanes in either direction were rehabilitated using HIPR in 2010. The fast lanes were not included in the rehabilitation treatments in 2010 as they were observed to be in relatively better condition at that time.

This paper looks at the pavement evaluation, quality control and quality assurance testing completed during construction and current condition of the 5–year old pavement.

RÉSUMÉ

Différents traitements d'entretien et de réadaptation sont disponibles pour prolonger la vie d'une structure de chaussée selon sa position dans le cycle de vie de la chaussée. Dans l'ère de l'épuisement des ressources naturelles, de la réduction des budgets de maintenance, des coûts et de la prise de conscience croissante de solutions de rechange écologiques, les donneurs d'ouvrage ont du mal à trouver des alternatives qui répondent à tous les critères et satisfont les critiques et le public.

Le Ministère des Transports et des Infrastructures de Colombie-Britannique (BC MoTI) utilise systématiquement une stratégie de recyclage à chaud en place (HIPR) pour réhabiliter les segments du réseau routier qui sont structurellement adéquats pour supporter le trafic de conception mais qui exhibent des défauts de surface.

Tetra Tech a été retenu par BC MoTI afin de développer les stratégies de réhabilitation d'une section de l'autoroute 1 entre le viaduc de Summit Drive et celui de Kokanee Way à Kamloops, en Colombie-Britannique. Une fois l'examen et l'analyse des données, HIPR a été choisi comme stratégie de réhabilitation préférée pour le projet. Les voies lentes dans les deux sens ont été réhabilitées en 2010 utilisant HIPR. Les voies rapides n'ont pas été incluses dans les traitements de réhabilitation en 2010 puisqu'elles étaient relativement en meilleure condition à cette époque.

Ce document se penche sur l'évaluation de la chaussée, le contrôle qualité et l'assurance de la qualité effectuées pendant la construction et de l'état actuel de la chaussée après 5 ans d'utilisation.

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1.0 BACKGROUND OF HIPR TECHNOLOGY

The Hot-In-Place Recycling (HIPR) technology was initially developed in late 1970s to the mid 1980s, but excessively visible black emissions to the atmosphere made the initial equipment / process unacceptable. Considering the depleting natural aggregate resources, the British Columbia Ministry of Transportation and Infrastructure (BC MoTI) continued with the process trials in the early 1980s and the equipment manufacturers and contractors continued to make modifications to the paving equipment to improve on the quality of emissions. Tetra Tech and BC MoTI published a paper entitled – "British Columbia's Success with Hot-In-Place Recycling – a 25 Year History" in the proceedings of 56th Annual Conference of the CTAA and presented the paper at the annual conference in Quebec City in 2011 [1].

The first HIPR project was tendered by the BC MoTI in 1987. Initially, BC MoTI proceeded with caution selecting the possible locations in the provincial network that appeared to be ideal candidates for HIPR. The heating and milling capabilities of the initial equipment were limited to 25 mm, limiting the candidate projects suitable for rehabilitation using HIPR to the pavements still in fair condition, and with low severity cracking. The first few projects rehabilitated using the HIPR technology had very short service lives and needed a follow up rehabilitation treatment in the form of mill and inlay or overlay. During the initial years of the development of the HIPR technology in late 1980s or early 1990s, the pavements rehabilitated with HIPR were either overlaid with Hot Mix Asphalt (HMA) or graded aggregate seal coat.

RW Blacktop produced BC's first designed/built two stage infrared HIPR processing equipment in 1987. This equipment allowed for the inclusion of up to a maximum of 25 percent virgin asphalt mix (admix) into the mix being recycled.

During the same time, the industry experimented with the additives introduced during the rehabilitation stage and the rate of addition of admix with an objective to increase the service life of the rehabilitated pavement so that the HIP recycled pavement could be used as a riding surface. Different rejuvenating agents at varying addition rates (Cyclogen L being the most common product used) along with varying admix addition rates were tried.

It was primarily believed that the exposure of the asphalt mix to heating during the HIPR process resulted in additional aging of the asphalt cement in the mix and the rejuvenating agent was added to compensate.

By early 2000s, most of the issues affecting the performance of HIPR were addressed. Issues surrounding in-place density, pavement smoothness, segregation, surface texture, centreline joints, longitudinal joints, mixing of the admix and rejuvenator with the recycled pavement were at the acceptable levels.

The HIPR study undertaken by the BC MoTI in 2001 reported that addition of admix (up to 20 percent) increased the service life of the pavement to 6 or 7 years while addition of rejuvenator further increased the service life by another 1 to 2 years. It was concluded that addition of both rejuvenator and admix to a project located in a Wet No-Freeze zone had an average service life of 9 or 10 years.

The key milestones of the equipment and process improvements over the years are presented in Figure 1.

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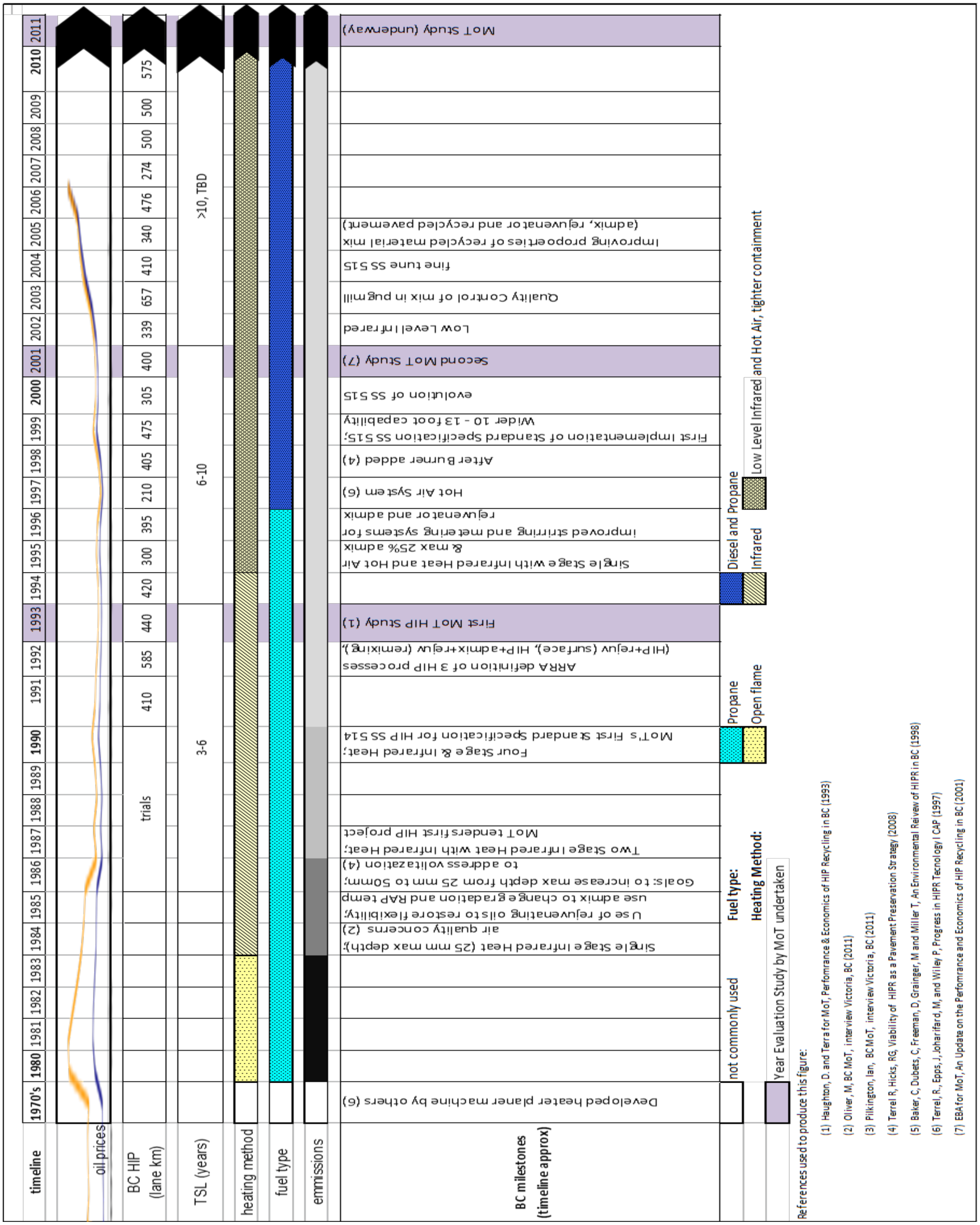

Figure 1. History of Success with Hot In-Place Recycling in British Columbia

The findings from the MoTI's HIPR study of 2011 as documented on Figure 1 are not available. The new advancements in the available technologies and improvements in the construction equipment have resulted in significant improvements in the HIPR processes and better end results. HIPR is considered as a pavement rehabilitation strategy in its own right by the BC MoTI. The improved process used today is referred to as a multi-stage process as it consists of a heater/miller first stage that heats and mills the first layer of asphalt typically to a depth of 12.5 to 25 mm.

The subsequent stage consists of an identical heater/miller that sequentially heats and mills the asphalt typically to a total depth of 50 to 60 mm. This is followed by the remixer unit, which consists of equipment to bring together the admix, rejuvenator and recycled asphalt mix prior to laying down the recycled mix with a conventional paver and compaction, using conventional rollers.

Ecopave Systems Inc. developed a new three stage HIPR train in 2014 that uses infra-red heaters to heat the pavement (Photograph 1), which results in significantly lower fumes when compared with the use of the propane heaters, and improved end product. As a result of the improvements in the equipment and processes over the last decade, up to 4 lane-kilometres of the roadway could be recycled in a single shift.

Photograph 1. Latest Hot-In-Place Recycling Train

Some of the projects initially constructed using this strategy have already been rehabilitated, whereas, some projects rehabilitated using the HIPR technology have been in service for more than 10 years and are still performing well. The BC MoTI has recently completed a second round of HIPR of some projects that were previously rehabilitated using the HIPR technology. The performance of those projects is being evaluated and monitored.

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As part of its support to the HIPR industry, the BC MoTI is always looking for suitable candidate projects to rehabilitate using HIPR and completes approximately 500 lane-km of provincial highways annually using HIPR. Nearly 11,000 lane-km of the provincial highways have been rehabilitated using HIPR in total.

Review of some of the past rehabilitation projects completed using HIPR indicated that the pavements rehabilitated using HIPR have better rut resistance and very minimal low severity rutting was evident for such projects. Similarly, the HIPR technology and the processes have improved such that the HIPR projects generally result in a smooth pavement surface and the contractors earn close to maximum bonus payments available for pavement smoothness.

2.0 HIGHWAY 1 (SUMMIT DRIVE O/P TO KOKANEE WAY O/P, KAMLOOPS)

2.1 Project Location

The project section of Highway 1 extended from approximately 1.3 km east of the junction with Highway 5A at Summit Drive Overpass to the Kokanee Way Overpass in Kamloops, BC and was approximately 17.88 km long. The roadway is a 4-lane divided highway. The general alignment of the roadway is shown in Figure 2. Kamloops is located about 500 km northeast of Vancouver on the Trans-Canada Highway.

The BC MoTI retained Tetra Tech in 2009 to evaluate the conditions of the pavement within the project limits to develop the rehabilitation design options. The BC MoTI expressed interest in evaluating the use of HIPR as a rehabilitation strategy for the project.

As part of the assignment, Tetra Tech completed review of the BC MoTI Roadway's Pavement Management Systems (RPMS) data, Visual Condition Survey (VCS), pavement strength testing using a Falling Weight Deflectometer (FWD), asphalt pavement coring, and laboratory testing of the asphalt mix from the extracted cores.

2.2 Construction History

Most of the roadway sections within the project limits were rehabilitated around 1991. Overlay and HIPR strategies were used to rehabilitate the pavement at that time. Therefore, the majority of the pavement surface within the project limits was about 18 years old.

2.3 Pavement Condition

The pavement surface was observed to be in fair condition with several localized poor areas at the time of pavement evaluation in 2009. Low severity rutting and bleeding were observed in the eastbound slow lane for majority of the project length. Moderate severity ravelling in the form of loss of surface fines was noted to exist throughout the project limits. Several localized areas with high severity alligator cracking in the wheel paths were also noted. High severity rutting with bleeding was noted in the eastbound slow lane adjacent to the intersection with the Vicars Road.

Photograph 2 shows the condition of the pavement surface prior to rehabilitation in 2009.

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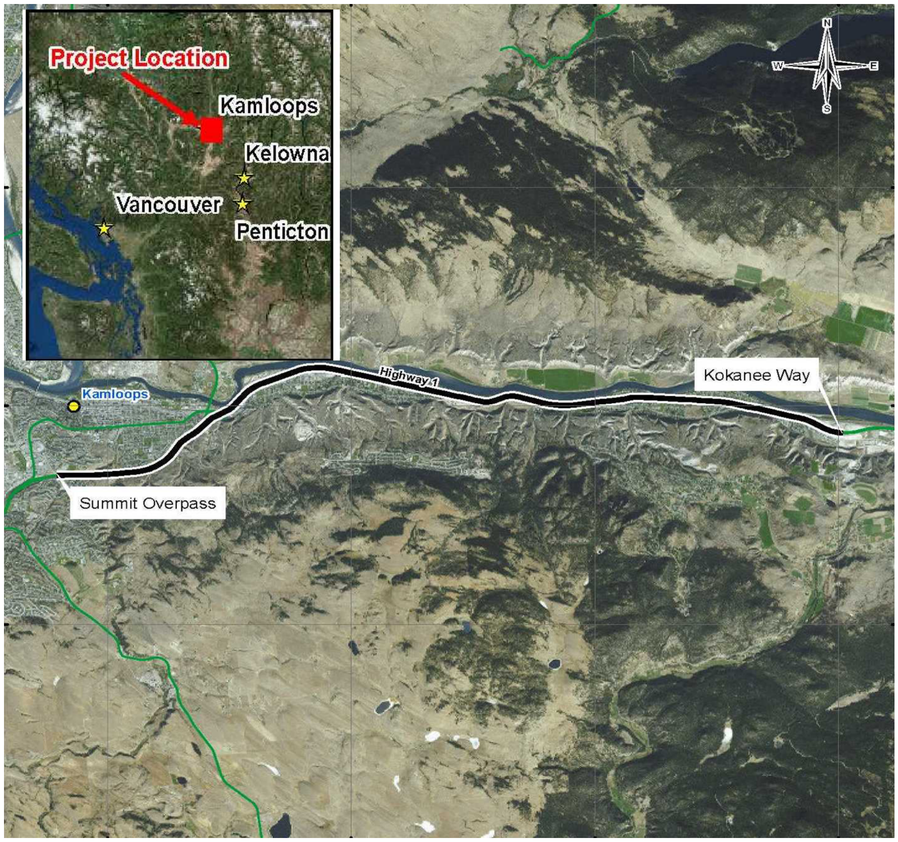

Figure 2. Site Plan of the Project

Photograph 2. Pavement surface exhibiting wheelpath cracking and rutting in the eastbound slow lane at Station 14.37.

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3.0 FIELD INVESTIGATION

The field investigation completed for this project included a Visual Condition Survey, Asphalt Concrete Pavement (ACP) thickness survey, strength testing by FWD, and asphalt pavement coring.

3.1 Visual Condition Survey

A limited visual condition survey of the pavement surface was completed using the methodology as outlined in BC MoTI's Pavement Surface Condition Rating Manual (2009) and included assessing the overall pavement condition, identifying areas of potential localized repairs, areas of predominant high severity distresses, and areas with poor drainage.

During the visual condition survey, the pavement surface was observed to be in fair condition with several localized poor areas. Low severity rutting and bleeding were observed in the eastbound slow lane. Moderate severity ravelling in the form of loss of surface fines was noted to exist throughout the project limits. Several localized areas with high severity alligator cracking in the wheel paths were also noted. High severity rutting with bleeding was noted in the eastbound slow lane adjacent to the intersection with the Vicars Road.

Drainage along the roadway was judged to be acceptable within the project.

3.2 Asphalt Pavement Coring

A total of twelve 150 mm diameter cores were extracted from the center of the slow lanes within the project limits to determine the properties of the existing asphalt mix. The thickness of the asphalt cores varied from 145 to 265 mm as shown in Table 1.

Table 1. Asphalt Pavement Thickness from Cores

Lane	No. of Cores	Minimum (mm)	Maximum (mm)	Average (mm)	Standard Deviation
Eastbound Slow Lane	6	145	225	185	30
Westbound Slow Lane	6	175	265	215	35

3.3 Pavement Thickness Evaluation

An ACP thickness survey was undertaken in conjunction with FWD testing. A small diameter (~25 mm diameter) drill was advanced into the ACP at the center of the slow lanes to create probe holes to measure the pavement thickness at 55 test locations. Maximum, minimum and average pavement thickness values measured for the slow lane in each direction are summarized in Table 2.

Table 2. Asphalt Pavement Thickness

Lane	No. of Cores / Probe Holes	Minimum (mm)	Maximum (mm)	Average (mm)	Standard Deviation
Eastbound Slow Lane	28	125	225	155	24
Westbound Slow Lane	27	135	265	160	34

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3.4 FWD Testing Program

Pavement strength testing was completed for the outside lanes in both directions. The FWD tests were located in the outer wheel path and were spaced at approximately 200 m intervals in either direction to give a nominal centerline spacing of 100 m between the tests. The pavement was tested using a Dynatest Model 8000 FWD with 9 active sensors. To simulate standard 80 kN single axle load, the target load during testing was 40 kN.

4.0 LABORATORY TESTING PROGRAM

A laboratory testing program was developed to determine the suitability of the existing asphalt mix for reuse in a HIPR pavement rehabilitation project. The asphalt mix sample from the top 50 mm of each core was tested. The testing program included:

- Cutting the top 50 mm of each core and determining the in-place Bulk Relative Density (BRD); and
- Grouping of the cores into five sets based on the direction of travel, density of the cores and chainage to determine the properties of the existing asphalt mix.

The combined mix samples for each set were tested to determine the properties of the existing asphalt mix. The Maximum Theoretical Relative Density (MTRD) for the combined mix sample for each set was used to calculate the in-place air voids for each core. These test results are summarized in Table 3.

Table 3. Asphalt Core Test Results

Core Set	Core ID	Project Stationing (km)	Direction	Asphalt Pavement Thickness (mm)	MTRD (kg/m^3)	Mix Properties of Top 50 mm Lift		
						In-Place Density (kg/m^3)	In-Place Air Voids (%)	Average In-Place Air Voids (%)
1	8	11.00	Eastbound	225	2,586	2,472	4.4	5.6
	10	13.20		170		2,429	6.1	
	12	15.40		160		2,424	6.3	
2	6	6.40	Eastbound	205	2,561	2,437	4.8	4.6
	7	8.00		205		2,448	4.4	
3	3	2.00	Eastbound	145	2,522	2,432	3.6	3.6
4	9	13.78	Westbound	185	2,544	2,491	2.1	2.1
	11	16.58		175		2,489	2.2	
5	1	2.28	Westbound	190	2,556	2,438	4.6	4.3
	2	3.68		240		2,447	4.3	
	4	4.68		265		2,467	3.5	
	5	7.48		225		2,428	5.0	

Note: MTRD is Maximum Theoretical Relative Density.

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5.0 FWD DATA ANALYSIS

5.1 Pavement Design Inputs

The American Association of State Highway and Transportation Officials (AASHTO) flexible pavement design methodology, outlined in the 1993 Guide for Design of Pavement Structures [2], was used for the analysis of FWD data. The design parameters required by the AASHTO methodology and used in the analysis of the FWD test data are summarized in Table 4.

Table 4. AASHTO Pavement Design Inputs

Criteria	Value	Rationale
Reliability	85%	Based on engineering judgment, the roadway classification, 20-year design ESALs, and BC MoTI
Initial Serviceability Index (P_i)	4.2	In accordance with generally accepted pavement engineering principles and AASHTO practice. (BC MoTI Technical Circular T-01/04)
Terminal Serviceability Index (P_t)	2.5	
Serviceability Loss (ΔPSI)	1.7	
Overall Standard Deviation (S_o)	0.45	
Resilient Modulus Reduction Factor	0.33	This factor is required to adjust the back calculated subgrade resilient modulus to be consistent with the values used to represent the AASHO Road Test subgrade. As recommended in the AASHTO Guide, a value of 0.33 has been selected.
20-Year Design Equivalent Single Axle Loads (ESALs) in the Design Lane (millions)	20.4	Based on analysis of BC MoTI traffic data

The ACP thicknesses used in the analysis of the FWD data were based on the average ACP thickness information from the ACP probe survey and asphalt core thicknesses, as summarized in Tables 1 and 2.

The analysis of the pavement structure was conducted using DAPAv99 (Design and Analysis of Pavements using AASHTO) software developed by Tetra Tech. The software analyzes FWD data in accordance with the methodology outlined in the 1993 AASHTO Guide for Design of Pavement Structures [2] and provides point-by-point analysis at each FWD test location. The output consists of back-calculated Subgrade Resilient Modulus (M_R), Pavement Modulus (E_P), and strengthening requirement presented as an equivalent thickness of ACP in millimetres.

The results of the FWD data analysis are presented in Figure 3.

5.2 Pavement Strengthening Results

Review of the analyzed FWD data indicated that majority of the pavement structure within the project limits was adequate to support the 20-year design Equivalent Single Axle Loads (ESALs) with the exception of a few localized areas. It was recommended that the pavement areas with the strengthening requirement in excess of 25 mm be reviewed for signs of fatigue cracking and the areas exhibiting localized failed areas be considered for deep patch repairs prior to carrying out the HIPR treatment.

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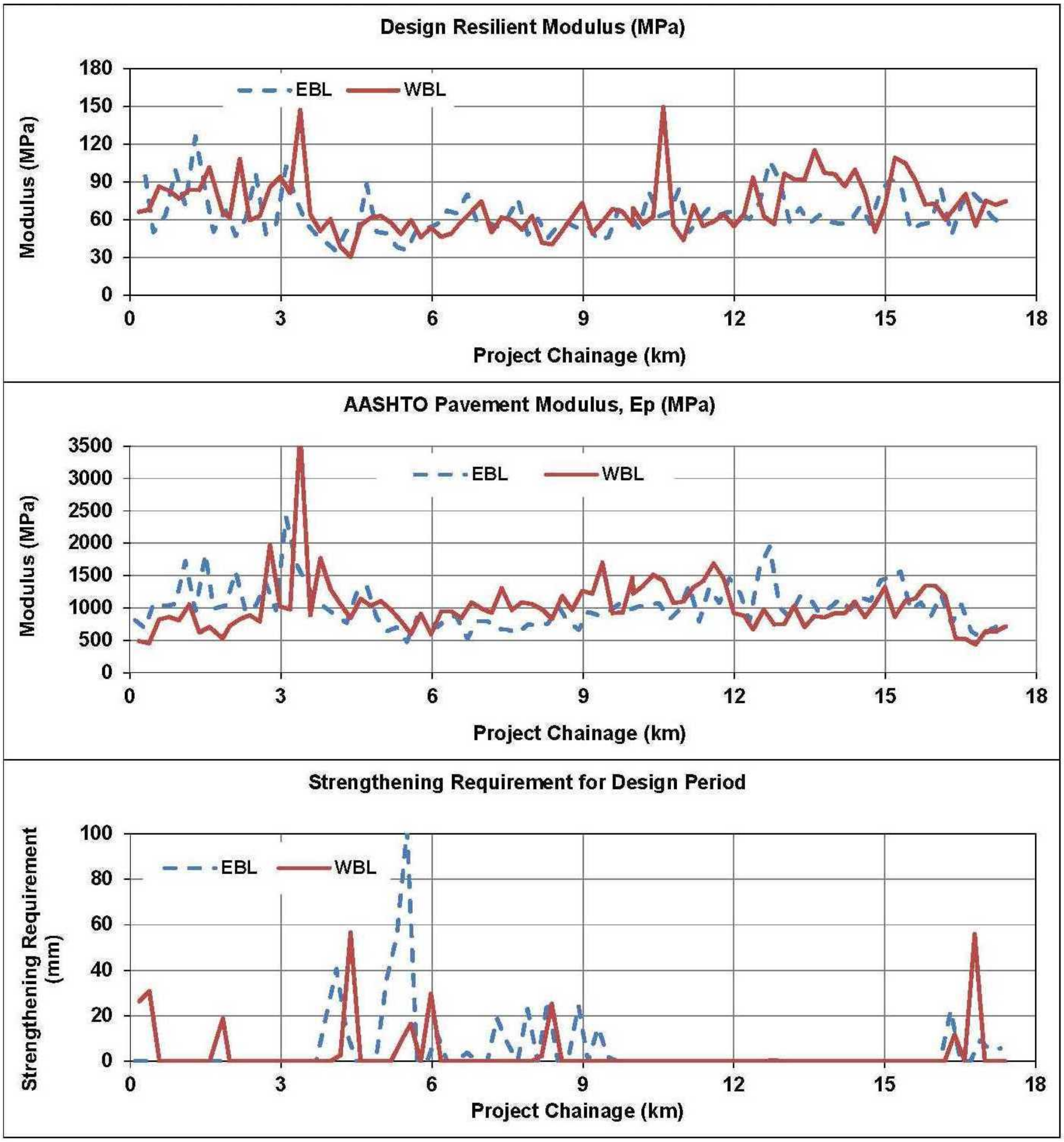

Figure 3. Summary of Analyzed Falling Weight Deflectometer (FWD) Data

6.0 LABORATORY TEST RESULTS

The cores were combined to have sufficient mix quantity for the laboratory tests. The combined asphalt mix for each set was tested for:

- Asphalt Cement (AC) Content;
- Abson Recovered Penetration @25^{o}C;
- Gradation;
- Fracture Count; and
- MTRD.

Mix properties as determined from the laboratory tests on the combined core samples are summarized in Table 5.

Table 5. Asphalt Mix Properties of Combined Core Samples

Direction	**Eastbound**	**Eastbound**	**Eastbound**	**Westbound**	**Westbound**
Core Set No.	**1**	**2**	**3**	**4**	**5**
Asphalt Content (% by Mix)	3.8	4.7	4.8	4.6	4.8
Fracture (%, 2+ faces)	82	100	100	83	98
Penetration @ 25^{o} C(dmm)	20	24	28	74	41
Air Voids (Average, %)	5.6	4.6	3.6	2.1	4.3
MTRD (kg/m^3) for Combined Sample	2,586	2,561	2,522	2,544	2,556
Sieve Size (mm)	**Percent Passing by Mass**				
19.0	100	100	100	100	100
12.5	87	96	94	92	97
9.5	72	83	85	79	83
4.75	44	50	63	55	55
2.36	32	32	48	42	38
1.18	26	23	37	33	28
0.600	20	18	25	25	20
0.300	14	13	14	16	14
0.150	9.0	10.0	9.0	10.0	10.0
0.075	6.0	7.5	6.7	7.3	7.4

Note: MTRD is Maximum Theoretical Relative Density.

Review of the laboratory test results as compiled in Table 5 indicated that:

- Gradation for most of the sets was similar to BC MoTI's Class 1 Medium Mix specifications [3].

- The in-place air voids for Sets 3 and 4 were lower than the in place air voids for the rest of the mix samples. Although the in-place air voids were relatively lower than the remainder of the sets, it was considered acceptable for rehabilitation using HIPR.

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- Percent fracture for Sets 1 and 4 do not meet the minimum requirement of 85 percent for BC MoTI's Class 1 Medium mix.

- The asphalt content in the asphalt mix was 5.0 percent (by weight of mix) or less, which is considered slightly lower than normal.

- Review of the penetration of the recovered asphalt cement values indicated that the penetration values ranged from 20 to 74 dmm. Penetration of 74 dmm was considered as an anomaly as the asphalt mix samples were obtained from a newer maintenance patch and not from the original pavement.

7.0 CONSIDERATIONS FOR SELECTING HIPR AS A REHABILITATION STRATEGY

Typically, the mix properties reviewed for assessing the HIPR feasibility include aggregate gradation, penetration of the asphalt cement, asphalt cement content, and in place air voids. Presence of higher amount of material passing the 0.075 mm will make the rehabilitation using HIPR difficult as more fines are generated during the rehabilitation process, which could lead to lower air voids and potential bleeding of the asphalt pavement. Similarly, lower in-place air voids in the existing pavement is likely to cause further lowering of the air voids in the recycled mix and poor performance from the recycled mix. Recycling of the asphalt mix with penetration lower than 20 dmm is considered unsuitable for HIPR as the asphalt cement in the recycled mix is hard enough to shorten the service life.

Other properties such as asphalt cement content (high or low) and percent of fractured aggregates can be improved by the incorporation of a properly designed admix to address the inappropriate mix properties of the existing asphalt mix.

8.0 REHABILITATION RECOMMENDATIONS

Review of the laboratory test results summarized in Table 5 and discussed in Section 6 indicated that the asphalt mix in the existing pavement was suitable for rehabilitation using HIPR and that the properties of the recycled asphalt mix could be altered by the incorporation of the admix to meet the asphalt mix specifications for BC MoTI's Class 1 Medium Mix.

Hot-In-Place Recycling of the pavements was recommended as a rehabilitation strategy for the project roadway. It was also recommended that the condition of the pavement surface at locations identified in need of strengthening from FWD testing be reviewed and deep patch repairs completed prior to undertaking HIPR for areas exhibiting high severity fatigue cracking.

9.0 ADMIX RECOMMENDATIONS

9.1 Admix Objectives

The admix is selected such that the resulting recycled mix (after its incorporation at the desired addition rates during rehabilitation) will result in the gradation and asphalt mix properties of the Class 1 medium mix normally specified by the BC MoTI for similar projects. Owing to higher fines content, HIP recycled mixes tend to have lower mix air voids than non-recycled mixes. Air voids of 2.5 to 3.0 percent are considered optimum for HIP recycled mixes. This results in a mix that provides tighter pavement surface and prevents

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the ingress of moisture into the pavement. The admix is designed to modify any of the deficiencies in the existing mix such as asphalt content, gradation, percent of fractured aggregates, fines content, and air voids.

A softer asphalt cement is used to compensate for the hardened asphalt cement in the existing mix. A rejuvenating agent is also added during rehabilitation to help with the recycling process and improve the penetration of the hardened asphalt cement in the existing pavement.

9.2 Admix Selection for the Project

A modified mix gradation similar to 19 mm Class 1 Medium Asphalt Mix (with a maximum of 3 percent material passing the 0.075 mm sieve) was recommended. A Group A 150-200 asphalt cement was recommended for the admix to offset the hardened binder in the existing pavement. The use of Cyclogen L or an equivalent rejuvenating agent at a rate of approximately 0.2 to 0.3 percent was recommended for use during the rehabilitation process.

The use of aggregates with higher percent fractured faces was recommended for the admix to increase the percentage of fractured aggregates in the recycled asphalt mix and improve the performance of the pavement.

The recommended gradation for the admix and the target gradations for the recycled asphalt mix are presented in Table 6. Although two of the five sets had a coarser gradation than the other sets, one admix gradation was recommended for the admix to simplify the construction process. The average gradation from the five sets was used to develop the recommendations for the admix.

It is estimated that approximately 1.5 percent fines (i.e., material passing 0.075 mm) are generated during the recycling process. This was taken into account by adding 1.5 percent fines to the measured gradation of the existing asphalt mix in Table 6.

It was also recommended that the Contractor perform detailed mix designs prior to construction to establish the actual addition rates and compliance to the target mix properties. The laboratory test results from Set 4 (from the westbound slow lane) indicated presence of softer asphalt cement than the samples from the eastbound slow lane. This was to be accommodated during pavement rehabilitation by lowering the addition rate of the rejuvenating agent. Similarly, higher addition rates of rejuvenating agent (0.2 to 0.35 percent) were suggested to be used during the rehabilitation process of the eastbound lanes to improve the relatively hardened binder in the existing pavement.

The asphalt content of the admix and the addition rate of the rejuvenating agent is monitored and adjusted on an ongoing basis by the contractor during construction. The rejuvenator addition rate sometimes needs to be reduced/increased during production to accommodate variable dust and field conditions.

9.3 Predicted Penetration of Asphalt Cement in the Recycled Mix

The penetration of the asphalt cement in the recycled admix was estimated using the Nomographs provided by the manufacturer of Cyclogen products as presented in Figure 4. Based on the review of the Nomograph plots, the penetration of the asphalt cement in the recycled asphalt mix was estimated to be about 70 dmm based on an average recovered penetration in the cores of 28 dmm.

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Table 6. Suggested Admix Gradation and Target Mix Properties

	Existing Mix		Admix		Target
	In Place Average	Contribution to Total Mix (80%)	Proposed	Contribution to Total Mix (20%)	100%
Asphalt Content (% by Mix)	**4.54**	**3.63**	**5.66**	**1.13**	**4.76% + 0.3% Cyclogen**
Sieve Size (mm)	**% Passing by Mass**				**Average**
19	100	80	100	20	**100**
12.5	93	74	90	18	**92**
9.5	80	64	82	16	**80**
4.75	53	42	63	13	**55**
2.36	38	30	46	9	**39**
1.18	29	24	36	7	**31**
0.600	22	17	26	5	**22**
0.300	14	11	18	4	**15**
0.150	9.6	8	12	2	**10**
0.075	8.5*	6.8	5.0	1.0	**7.4**

*This includes 1.5 % fines estimated to be generated during HIP recycling

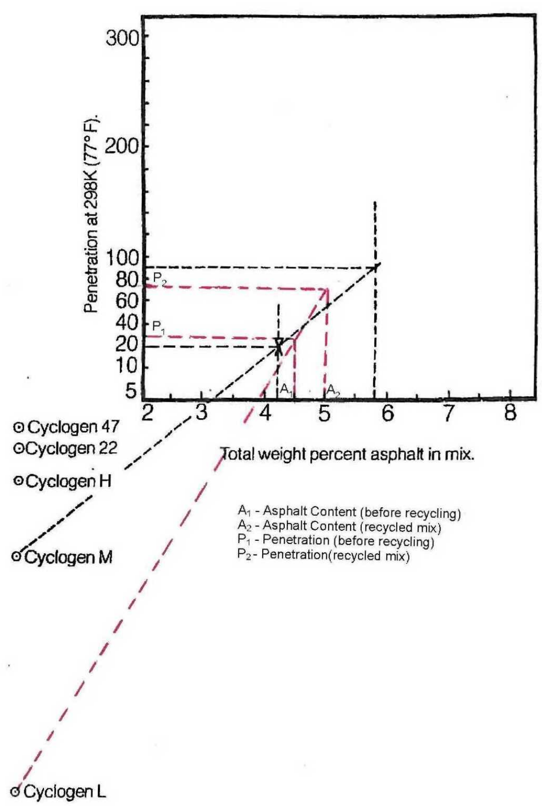

Figure 4. Nomograph for Estimating Penetration of Asphalt Cement in Recycled Mix

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10.0 PAVEMENT REHABILITATION

Rehabilitation of the project section of Highway 1 was undertaken by the BC MoTI in the summer of 2010. Considering that the fast lanes within the project limits were in relatively better condition than the slow lanes, the BC MoTI decided to complete the rehabilitation of the slow lanes only and defer the rehabilitation of the fast lanes. Prior to rehabilitation, the BC MoTI reviewed the condition of the pavement surface and decided to mill and inlay the eastbound slow lane approaching the signalized intersection with decelerating and accelerating truck traffic at Vicars Road that was exhibiting high severity rutting using a mill and inlay strategy. Similarly, BC MoTI decided to skip some sections from rehabilitation.

10.1 Construction

Green Roads Recycling Limited of Fernie, BC completed an asphalt mix design conforming to 19 mm Superpave mix requirements [4] for use as admix during the rehabilitation process. 150-200 Group A asphalt cement was used for the admix. The aggregate gradation for the admix used by the Contractor was similar to that proposed by Tetra Tech and resulted in aggregate gradation of the recycled similar to the proposed target gradation. The paving for the project was completed in July 2010 over 13 shifts without any major issues / concerns.

10.2 Quality Control / Quality Assurance

Quality Control (QC) testing was completed by the contractor and Quality Assurance (QA) testing was completed by the Field Services Branch of the BC MoTI. Review of the QC/QA test results indicated that the majority of test results met the gradation requirements and all of the lots were in bonus for payment adjustments. Summary of the QC/QA results for various performance parameters is presented in Table 7.

Table 7. Summary of Quality Control and Quality Assurance (QC/QA) Test Results

No.	Property	Average	Specification / Target
1	Asphalt Cement Content (in Admix)	5.08	5.1 $\pm$ 0.3
2	Compaction (Cores, based on Marshall Density), %	96.9	93.9*
3	Air voids (in recycle mix), %	1.9	n/a
4	Lift Thickness (mm)	57	60 **
5	Addition Rate of Cyclogen (l/m^2)	0.3	n/a
6	Smoothness (m/km)	0.85	< 1.4 *

* For no bonus no penalty payment adjustment.
**Based on 50 mm treatment depth and 20% addition rate for admix.

The QC / QA results summarized in Table 7 indicate that the majority of the asphalt mix properties met the specifications / acceptance criteria for an HIPR asphalt mix.

The smoothness of the pavement was 0.85 m/km, which is significantly lower than 1.4 m/km (for no bonus penalty payment adjustments). The compaction of the asphalt mix was also significantly better than the minimum specified compaction requirements. Average Marshall air voids in the recycled mix of 1.9 percent and average compaction of 96.9 percent resulted in average in place air voids of 5.0 percent, which is considered optimum for HIPR. This results in a tighter asphalt pavement surface, which deters the infiltration of water into the pavement surface and improves its performance.

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11.0 2015 PROJECT STATUS

11.1 Visual Condition Assessment

Visual condition assessment of the pavement surface was completed in April 2015 by Tetra Tech and BC MoTI. A windshield survey was completed at the highway driving speeds with occasional stops to review the condition of the pavement surface.

The pavement surface within the areas rehabilitated using HIPR in 2010 were observed to be in fair condition and was exhibiting slight raveling, and few reflective cracks. The longitudinal joints were observed to be performing well and there was no open longitudinal crack at the construction joint. The pavement surface offered a good ride quality at the posted highway speeds.

It was observed that the pavement areas exhibiting reflective cracking were the areas identified for deep patch repairs in 2009. The deep patch repairs were not completed prior to HIPR and the pavement surface at those locations are exhibiting reflective cracking now.

11.2 Asphalt Pavement Coring

Asphalt pavement coring was completed to obtain the asphalt mix to determine the current properties of the asphalt mix recycled with HIPR in 2010. The asphalt cores were extracted at approximately 20 m in the direction of travel from the locations where the cores were extracted in 2009 to compare the current properties of the asphalt mix from those determined in 2010. This was done based on the anticipation that the HIPR train picks up the existing asphalt mix, mixes it with admix and deposits it approximately 20 m ahead in the direction of travel.

The asphalt cores were combined in groups as done previously in 2009 and the combined mix was tested in Tetra Tech's laboratory to determine various asphalt mix properties.

11.3 Laboratory Testing

Laboratory testing was completed on three sets of cores to determine in-place density, asphalt content, MTRD, in-place air voids, penetration of the abson recovered asphalt cement, gradation and percentage of fractured aggregates in the mix. The results from the laboratory testing are summarized in Table 8.

11.4 Comparison of Current Asphalt Mix Properties with Pre–HIPR Asphalt Mix Properties

11.4.1 Overview

The asphalt mix properties as determined from the laboratory testing and summarized in Table 8 were compared with the properties of the asphalt mix (for the cores extracted from the same locations) as determined during preliminary engineering evaluation in 2009 (summarized in Table 6).

The comparison of the two sets of test results is summarized in Table 9.

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Table 8. 2015 Laboratory Test Results

Core Set No.	A	B	C
Asphalt Content (% by Mix)	5.09	4.84	5.21
Fracture (%, 2+ faces)	91	97	94
Penetration @ 25C (dmm)	46	44	35
Air Voids (Average, %)	1.5	4.4	2.2
MTRD (kg/m^3) for Combined Sample	2,586	2,550	2,556
Sieve Size (mm)	Percent Passing by Mass		
19.0	100	100	100
12.5	94	95	97
9.5	81	80	84
4.75	56	56	58
2.36	43	42	43
1.18	34	33	32
0.600	25	24	23
0.300	17	15	16
0.150	11	10	11
0.075	7.7	7.2	8.3

Note: MTRD is Maximum Theoretical Relative Density.

Table 9. Comparison of Pre-HIPR and Post-HIPR Asphalt Mix Properties

Core Set No.	1 (2009)	A (2015)	3 (2009)	B (2015)	5 (2009)	C (2015)
Asphalt Content (% by Mix)	3.8	5.09	4.8	4.84	4.8	5.21
Fracture (%, 2+ faces)	82	91	100	97	98	94
Penetration @ 25^o C (dmm)	20	46	28	44	41	35
Air Voids (Average, %)	5.6	1.5	3.6	4.4	4.3	2.2
MTRD (kg/m^3) for Combined Sample	2,586	2,586	2,522	2,550	2,556	2,556
Sieve Size (mm)	Percent Passing by Mass					
19.0	100	100	100	100	100	100
12.5	87	94	94	95	97	97
9.5	72	81	85	80	83	84
4.75	44	56	63	56	55	58
2.36	32	43	48	42	38	43
1.18	26	34	37	33	28	32
0.600	20	25	25	24	20	23
0.300	14	17	14	15	14	16
0.150	9.0	11	9.0	10	10.0	11
0.075	6.0	7.7	6.7	7.2	7.4	8.3

Note: HIPR is Hot In-Place Recycling and MTRD is Maximum Theoretical Relative Density.

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11.4.2 Gradation

Comparative plots of the aggregate gradations from the extracted aggregates samples from the asphalt mix are shown in Figure 5.

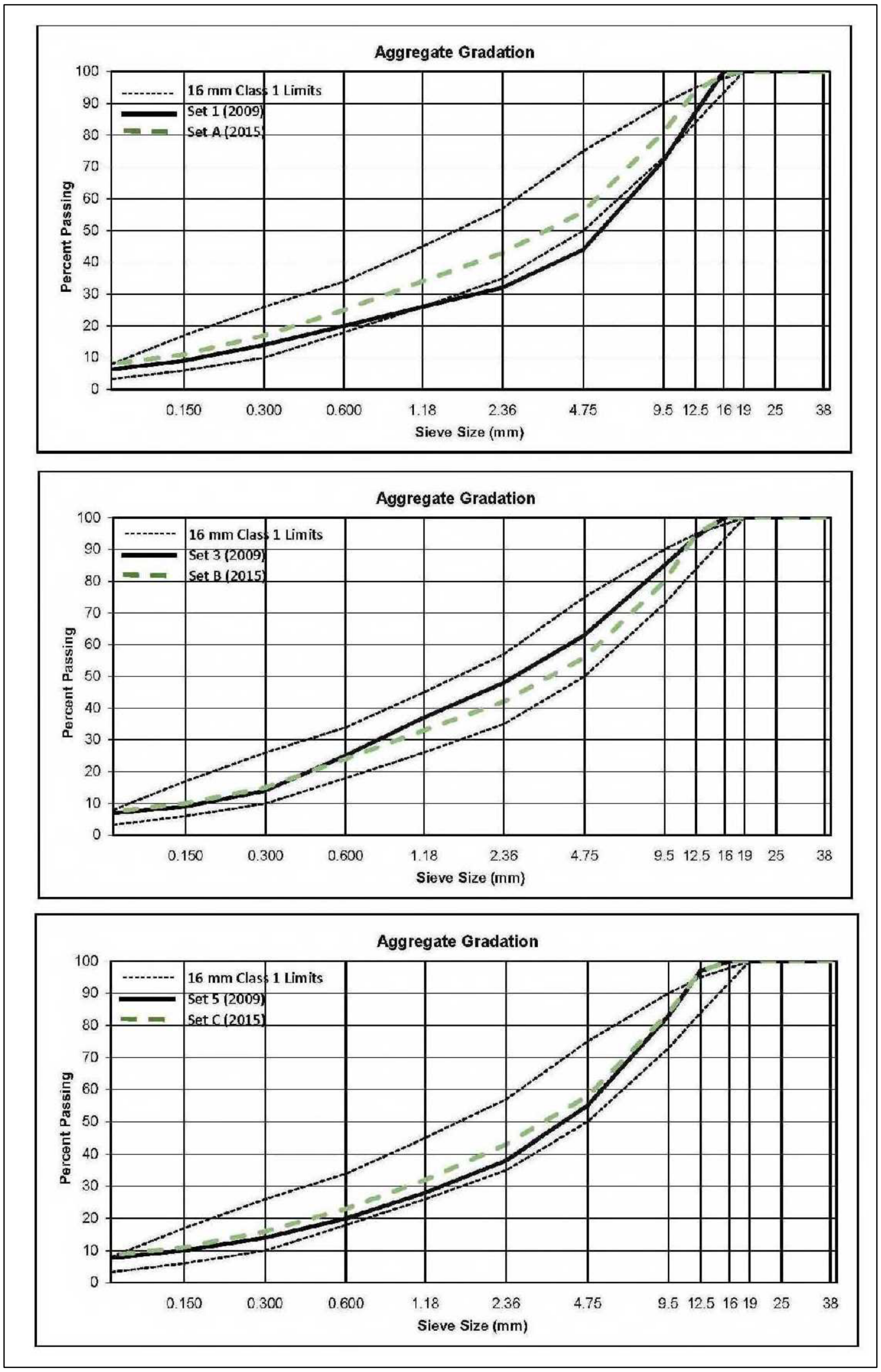

Figure 5. Comparative Gradation of Pre-HIPR and Post-HIPR Mixes

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Review of the aggregate gradations for Set 1 and Set A indicate that while the gradation of the original asphalt mix didn't meet the BC MoTI's gradation requirements for Class 1 Medium mix, addition of the admix resulted in the correction of the aggregate gradation for the recycled mix and its conformance to specifications. Similarly, comparison of the material passing the 0.075 mm sieve for pre-recycling and recycled asphalt mix indicated that the recycling process generated an average of approximately 1 percent fines.

11.4.2 Asphalt Content

Comparison of the asphalt content results from pre-HIPR and post-HIPR test results indicated that the asphalt cement content was more consistent in the post-HIPR asphalt mix. Post-HIPR testing completed in 2015 indicated improvement in the asphalt cement content for the test samples identified with lower asphalt cement content during pre-HIPR testing in 2009.

11.4.3 In-Place Air Voids

As expected, the HIPR treatment resulted in a lowering of the in-place air voids for the asphalt pavement. The test results summarized in Table 8 indicated significantly lower in-place air voids for two of the three sets and marginal improvement in the in-place air voids for the third set.

11.4.4 Penetration

The asphalt cement hardens with time as indicated by lower penetration values. Two of the three tests completed had higher penetration values in 2015 (post-HIPR) than those recorded in 2009 (pre-HIPR) confirming that the addition of admix and rejuvenating agent during the HIPR process improved the properties of the hardened asphalt cement in the mix and prevented hardening during heating and mixing.

11.4.5 Pavement Condition Data

The BC MoTI collects pavements condition data every 2 years on major highway networks. The data collected by the BC MoTI in 2011 and 2013 following the rehabilitation of the pavement was obtained and reviewed to evaluate the deterioration in the condition of the pavement. The pavement performance parameters reviewed and reported are – International Roughness Index (IRI), Pavement Distress Index (PDI) and Rutting. In addition to this, IRI and rutting data was also collected in April 2015 by Tetra Tech. The IRI data collected in 2011 and 2015 is plotted in Figure 6.

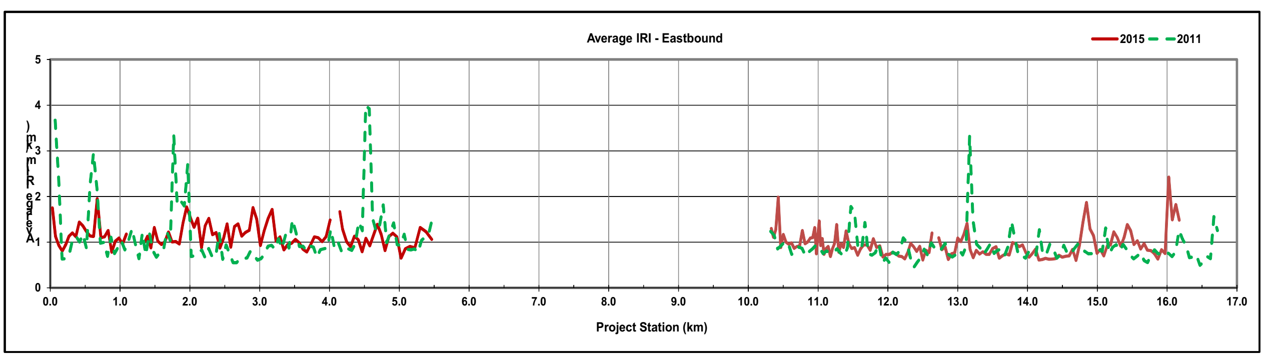

Figure 6. International Roughness Index (IRI) Progression since Hot In-Place Recycling

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The comparison of the progression in pavement roughness and rutting from prior to HIP recycling and through to five years after completion of rehabilitation is summarized in Table 10.

Table 10. Comparison of International Roughness Index (IRI) and Rutting before and after Hot In-Place Recycling (HIPR) Treatment

Performance Criteria	2007 (Pre - HIPR)			2011 (1 yr. After Rehabilitation)			2015 (5 yr. After Rehabilitation)		
	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.
Rutting (mm)	8	18	2	2	9	1	4	15	1
IRI (m/km)*	1.45	5.01	0.60	1.01	3.99	0.45	0.94	2.43	0.60

*IRI data was collected by three different agencies using different equipment.

Review of the data presented in Table 10 indicates that the progression of roughness and rutting has been slow and that the pavement surface offered very smooth ride five years after completion of rehabilitation.

12.0 CONCLUSIONS

Based on a review of the information as discussed and summarized, the HIPR rehabilitated pavement within the project limits is performing well after 5 years and the following conclusions were drawn:

- The HIPR asphalt mix has good rut resistance properties. Considering high traffic volumes (20-year design traffic of 20.4 million ESALs), traffic patterns (urban environment with signalized traffic intersections and stop and go slow moving traffic) and shallow treatment depths, the fact that very minimal low severity rutting was observed within the project limits, the recycled mix has performed well.

- The results of penetration testing completed on recovered asphalt cement from the recycled asphalt mix indicate that the properties of the asphalt cement improved with HIPR owing to addition of softer asphalt cement in admix and addition of rejuvenating agent.

  Average abson recovered penetration of 43 dmm after 5 years of completing HIPR indicate that the asphalt cement is soft enough and will likely perform well for another 5 to 7 years before rehabilitation will be required (penetration of around 25 dmm).

- Average in-place air voids of around 3 percent on HIP recycled pavement (as determined in 2015) that has been in service for five years is considered normal.

- Average IRI of 0.85 m/km was measured after completion of HIPR for the project roadway, which is very smooth considering 50 mm treatment depth of the HIPR treatment.

- Visual condition and the distresses exhibited by the pavement surface indicate that the pavement surface is in fair condition.

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