Innovative, Comprehensive Design and Construction Of Perpetual Pavement on the Red Hill Valley Parkway In Hamilton

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ABSTRACT

A comprehensive approach is required to design a perpetual pavement. This paper will present the innovative approach used to design a perpetual pavement on the Red Hill Valley Parkway in Hamilton, Ontario. This approach included a feasibility study including life cycle cost analysis, detailed pavement design and the development of paving specifications.

The conventional AASHTO 93 pavement design methodology used for the design was verified using mechanistic-based methodologies including PerRoad and other programs. However, the major step was to make sure that the constructed pavement layers will meet the desired performance characteristics. This required the development of six new paving specifications for this project including mix types, rich bottom mix, smoothness, segregation, use of steel slag in hot-mix asphalt and hot-mix asphalt paving (paving operations and innovative testing). The specified asphalt mix characteristics included dynamic modulus, resistance to fatigue and resistance to rutting. The specifications used the recent achievement in paving and materials technology in Ontario and the United States and reflected very extensive paving experience in the City of Hamilton.

The perpetual pavement was successfully completed on the Red Hill Valley Parkway in 2007. In addition, traffic monitoring and pavement response monitoring systems were also installed in this pavement.

1.0 INTRODUCTION

Conventional asphalt pavements are typically designed for 20-year life expectancies. The concept of extending the life well beyond this period mainly on high volume roads is gaining more interest and acceptance in Canada and the United States. With the ever increasing volumes on our road networks, agencies are looking for pavements that require less frequent rehabilitations. In order to do so, a rut-resistant, impermeable and wear-resistant surface course must be combined with a rut-resistant and durable intermediate layer and fatigue resistant and durable base layer.

Perpetual or long-life asphalt pavements are designed and constructed from the bottom up to provide a structure having very long useable life with a renewable asphalt surface [1 to 5]. The wearing surface can be resurfaced with minimal traffic disruption. Bottom-up design and construction recognizes that all the layers act in concert to determine the useful life and failure mode of a pavement. The key is to design a pavement structure that will effectively prevent bottom-up cracking.

Recent improvements in material technology include the Performance Graded Asphalt Cement system, better aggregates, use of polymers and fibers in asphalt mixes, Superpave mix design methodology and SMA mixes [6 to 9]. These improvements as well as more advanced pavement design methodologies allows obtaining a very long-term performance from asphalt pavement structures (greater than 50 years) while replacing periodically (approximately every 14 to 17 years) only the surface (top 25 to 50 mm) of the pavement [5].

A comprehensive approach is required to design a perpetual pavement. This paper presents the approach used to design an innovative perpetual pavement on the Red Hill Valley Parkway in Hamilton, Ontario. This approach included a feasibility study including life cycle cost analysis, detailed pavement design and the development of paving specifications, asphalt mixes mechanistic properties testing. Some construction related issues are also presented.

2.0 FEASIBILITY STUDY

The Red Hill Valley Parkway (RHVP) is a modern urban Expressway in the City of Hamilton, Ontario. It is the final leg of a longer Freeway project considered to be the largest municipal road project in Canada with an estimated final total cost of $430 Million. Initial opening volumes of 35,000 to 40,000 vehicles per day and full capacity volumes in excess of 90,000 vehicles per day are expected for this section of the City's crucial transportation artery. The 7.5 km long RHVP is located in an environmentally sensitive area in the City of Hamilton along the Red Hill Creek [10]. The City of Hamilton decided that, given the projected traffic volumes, the conventional deep strength pavement designed for a 20-year life might not be acceptable and that a perpetual pavement should also be considered. A feasibility study was completed comparing both pavement design alternatives.

The deep strength pavement designs, developed originally,, were compared with the initial perpetual pavement design. As part of the feasibility study, life-cycle costs, environmental benefits of the perpetual pavement design, pavement sustainability aspects and public satisfaction were analysed. More information about these analyses is provided in [10].

A perpetual pavement has two main attributes which are as follows [1 to 3]:

1. Total asphalt thickness of more than 200 mm. In theory, it has been shown that flexible pavements with more than 200 mm of hot mix can resist fatigue cracking (bottom-up cracking) regardless of the number of axle load repetitions. As such, damage to the pavement is limited to the surface which can be milled off and replaced periodically.
2. The asphalt content of the bottom lift of hot mix asphalt (Rich-bottom lift) is increased slightly and the air voids in the mix reduced to about 2 to 3 percent to further enhance the resistance to fatigue cracking. The increased hot mix asphalt thickness provides sufficient cover over the Rich-bottom lift to resist asphalt rutting.

To satisfy the above two criteria, the asphalt thickness was increased from 160 mm for the conventional pavement design to 240 mm for the perpetual pavement design. The pros and cons of the two designs are compared in Table 1.

Table 1. Pros and Cons of Deep Strength and Perpetual Pavement Designs

Pavement Design	Pros	Cons
Deep Strength	Lower initial cost. Pavement structure typical of those used on main arterial roads in Ontario. Technology well established in Hamilton.	Maintenance costs are higher. Higher Life Cycle Costs. The time required to complete maintenance activities will be more and hence, user delay costs will be more. Lower Structural Number and GBE. Will likely be prone to fatigue cracking (bottom-up cracking) in 20 to 30 years of service. This could increase future rehabilitation costs (investigations, design and additional lifts of overlay) and user delay costs. A detour will be required during pavement rehabilitation/repair work.
Perpetual	Lower Life Cycle Costs. Lower maintenance costs. The time required to complete maintenance activities will be less and hence, public inconvenience and user delay costs will also be less. Higher Structural Number and GBE. No detour will be required for pavement rehabilitation work. Multi-layer analysis indicates that asphalt pavements with more than 200 mm of hot mix will not be prone to fatigue cracking. In addition, the Rich-bottom mix contains a higher asphalt content that is more resistant to fatigue failure while the increased hot mix thickness makes the pavement less susceptible to rutting due to compressive stress in the subgrade. This should result in reduced rehabilitation costs (investigations, design and additional lifts of overlay) and user delay costs in the future.	Higher initial (construction) costs. New technology with some uncertainties.

In addition, the availability of experienced contractors, pavement and materials and project management consultants, and the availability of high quality materials were also considered. The City of Hamilton has extensive experience with asphalt technology and is one of the leaders in Ontario in implementing innovations in pavement and materials engineering.

A flexible pavement satisfying the requirements for perpetual pavement design was recommended for the Red Hill Valley Parkway in Hamilton.

3.0 PAVEMENT STRUCTURE DESIGN

The Red Hill Creek Expressway is projected to sustain about 30 million ESAL's over a 20 year period. The originally selected deep strength pavement design, based on geotechnical investigation completed in 1999 to 2004 for various sections of the Parkway, was to support the conventional 20 year traffic loading. When the change to a Perpetual Pavement was decided, designs were completed for all sections to support about 90 million ESAL's over a period of 50 years. The selected pavement designs for both alternatives are summarized in Table 2 and shown in Figure 1. The perpetual pavement incorporates an 80 mm thick layer of a Rich Bottom Mix, RBM, which will protect against the initiation of load induced fatigue cracking. The perpetual pavement was initially designed using the AASHTO 93 methodology [11 and 12] and verified using the PerRoad software [13]. More information on the perpetual pavement design and verification using these methodologies is described in [5].

Table 2. Summary of Pavement Designs

<table>
<tr><th rowspan="4">Pavement Type</th><th rowspan="4">Design Period</th><th rowspan="4">Traffic Loading (Million ESAL's)</th><th colspan="6">Pavement Structure</th></tr>
<tr><th colspan="5">Layer Thickness (mm)</th><th rowspan="3">Total Thickness (mm)</th></tr>
<tr><th colspan="3">HMA</th><th rowspan="2">Granular Base</th><th rowspan="2">Subbase[4]</th></tr>
<tr><th>Surface Course[1]</th><th>Binder Course[2]</th><th>RBM[3]</th></tr>
<tr><td>Deep Strength</td><td>20</td><td>30</td><td>40</td><td>60
60</td><td>-</td><td>150</td><td>450</td><td>760</td></tr>
<tr><td>Perpetual</td><td>50</td><td>90</td><td>40</td><td>50
70</td><td>80</td><td>150</td><td>370</td><td>760</td></tr>
</table>

1 SMA 12.5
2 Superpave 19 mix for upper binder and Superpave 25 mix for lower binder.
3 Superpave 19 mix modified to meet Rich Bottom Mix requirements.
4 Crusher run limestone to be used for subbase.

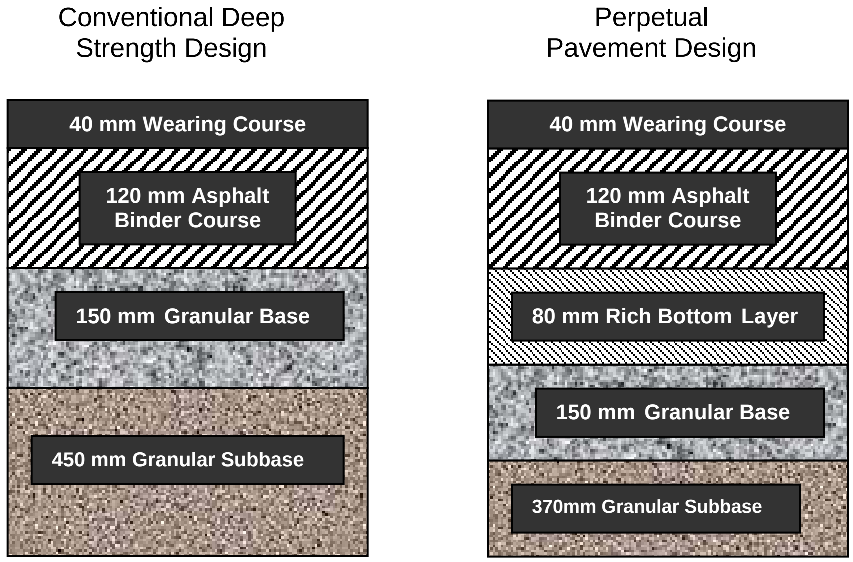


Figure 1. Comparison of conventional deep strength and perpetual pavement structures designed for the Red Hill Valley Parkway.

As part of the perpetual pavement mix designs, the mechanistic properties of the SMA 12.5, Superpave 19 and Superpave 25 and RBM mixes were determined. When these mechanistic properties were available, the perpetual pavement design was verified using elastic theory and the Bisar [14] program. Figure 2 shows the asphalt part of the pavement structure constructed on the Red Hill Valley Parkway and used in the analysis.

Photograph 2. The asphalt pavement structure on the main line of the Red Hill Valley Parkway.

4.0 DEVELOPMENT OF NEW SPECIFICATIONS

There were six special provisions developed for asphalt paving on the RHVP project. Although the special provisions were generally based on the Ontario Provincial Standard Specifications [15 to 17], they were modified to reflect the City of Hamilton extensive experience in asphalt paving, available materials, experienced contractors and equipment, and the state of asphalt technology used for perpetual pavement design and construction [1 to 3].

1. Mix types – detailed the type of hot-mix asphalt (HMA) mixes that shall be used on the Red Hill Valley Parkway mainline, ramps, mainline shoulders, ramp shoulders full and partial depth, other roads and asphalt pavement on structures. The mix types included Rich Bottom Mix (RBM), Superpave 12.5 FC2, Superpave 19, Superpave 25 and HL 1. For low volume roads, HL 8 and HL 3 mixes were specified. No Reclaimed Asphalt Pavement (RAP) material was allowed in the SMA, Superpave 12.5 FC2 and RBM mixes.

2. Rich bottom mix (RBM) – RBM was specified as a modified Superpave 19 mix designed using the procedures described in the AASHTO PP28 standard and on the basis of 4.0 percent air-void criteria. The asphalt cement content in the mix was increased by 0.5 percent of the original Superpave 19 mix design designed for traffic category E (more than 30 million ESAL's). The special provision included the gradation and volumetric requirements. Initially, a PG 64-28 asphalt cement was specified. The performance requirements for the RBM mix included dynamic modulus, rutting resistance and fatigue endurance testing and criteria.

3. Hot-mix asphalt paving – covered the requirements for HMA paving on the Red Hill Valley Parkway, in addition to the OPSS 310 standard specification [15]. The main objective was to avoid potential damage to the pavement caused by the construction traffic and equipment. It required that asphalt paving on the mainline should be done in echelon using a Shuttle Buggy® material transfer vehicle (Photograph 3). No construction traffic was allowed on the RBM and Superpave 19 layers with the exception of the pavers and rollers. The lower binder course median lane should be paved using a Shuttle Buggy® driving on the median shoulder and the delivery trucks using the shoulder only. When the median lane is completed, the Shuttle Buggy® was allowed to move on the median lane to feed the pavers. The delivery tracks were also allowed on the median lane; however, the maximum length of the Superpave 25 layer opened to construction traffic was limited to 500 m. The application of tack coat was required only on the surface of the Superpave 19 layer.

Photograph 3. Echelon paving of the SMA surface course using a Material Transfer Vehicle (MTV).

The construction tolerances for all asphalt mixes were specified; generally the requirements were tighter than in the OPSS standard specifications, particularly on gradations, asphalt cement content and particularly compaction. The RBM had to be compacted to 97.0 to 99.0 percent of the maximum relative density, Superpave 19 and Superpave 25 to 93.0 to 96.5 percent and SMA 12.5 to 93.0 to 97.5 percent. These compaction requirements were much tighter than in the OPSS specification [15] typically used on paving projects in Ontario. Compaction at longitudinal joints should not be less than 91.5 percent.

This special provision also defined the mechanistic properties to be determined for the SMA, Superpave 25, Superpave 25 and RBM mixes.

4. Surface smoothness – modified the OPSS standard to local conditions. The owner shall conduct QA measurements on a minimum of 10 percent of the surface course and measured by the contractor.

5. Acceptance of hot-mix by visual inspection of segregation – modified the OPSS standard to meet the local conditions. The special provision defined the severity of segregation and the required methods of repair.

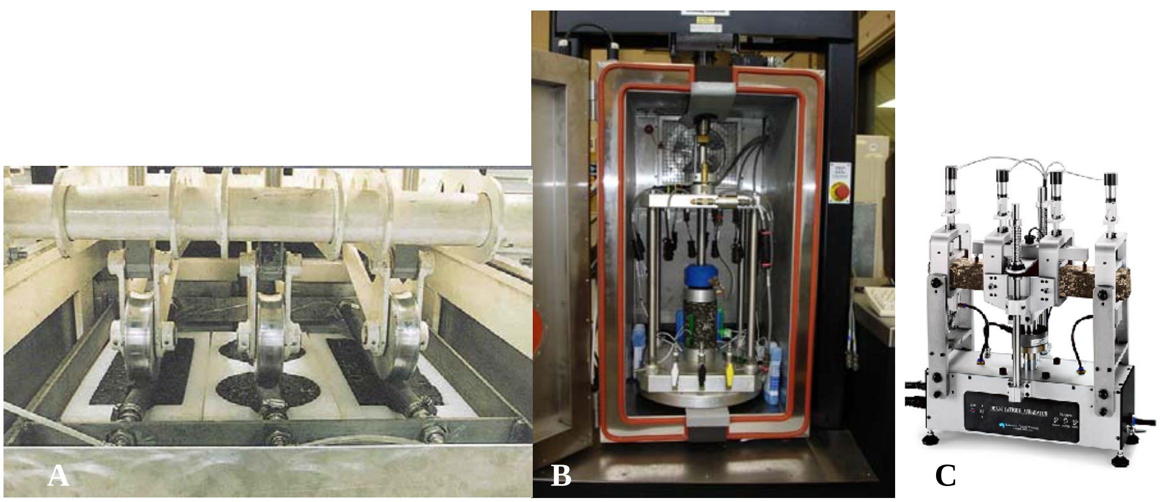
6. Use of steel slag in HL 1 mix – the contractor was given the option of supplying either HL 1 (OPSS) or HL 1 Steel Slag surface course mixes at locations allowed by the project specifications. The criteria of steel slag acceptance were specified. This special provision reflected City of Hamilton's extensive experience in using good quality steel slag in their asphalt mixes.

5.0 MECHANISTIC CHARACTERISTICS OF ASPHALT MIXES

The design of the perpetual pavement on the Red Hill Valley Parkway was based on extensive literature research [1 to 5] and consultations with academia (University of California, Berkeley, for instance) and agencies such as the National Asphalt Pavement Association (NAPA), National Center for Asphalt Technology (NCAT), Asphalt Institute (AI). At the time of the design, the experience with the design and construction of perpetual pavements in the United States was still somewhat limited. It was decided that, besides specifying the conventional requirements such as mix gradations, asphalt cement content and volumetrics, the mix performance characteristics should also be determined. In order to verify the pavement design, it was required that the mechanistic properties of the mixes used in the mainline be determined at the mix design stage. They included the following: dynamic modulus; rutting resistance testing using the Asphalt Pavement Analyzer (APA) or the Hamburg Wheel Rut Tester (HWRT); and fatigue endurance testing (Photograph 4). The specified criteria for the mechanistic properties are listed in Table 3.

Table 3. Mechanistic Properties Requirements

Mechanistic Property	Standard	Specified Limit
1. Dynamic Modulus	AASHTO TP62-03	NA
2. Rutting Resistance Asphalt Pavement Analyzer Hamburg Wheel Rut Tester	 AASHTO TP-63-03 Colorado L5112 Standard	 Max 5.0 mm after 8,000 cycles Maximum 4.0 mm after 10,000 passes and maximum 10.0 mm after 20,000 passes
3. Fatigue Endurance	AASHTO TP8-94	Minimum 7,000,000 repetitions



Photograph 4. The Asphalt Pavement Analyzer was used for the rut resistance testing (A); the Interlaken Soil and Asphalt Testing System for the dynamic modulus testing (B); and the Four Point Bending Beam Test for fatigue endurance testing (C).

A summary of the mechanistic properties of the mixes used in the mainline paving is given in Table 4. In order to improve the fatigue endurance of the RBM mix, a PG 70-28 asphalt cement with significantly higher polymer content was used. The dynamic modulus of the mixes was then used in the Bisar analysis for pavement performance analysis.

Table 4. Summary of Asphalt Mix Mechanistic Properties Testing

Mix Type	Dynamic Modulus* (MPa)	Rutting Resistance Rut Depth in APA (mm)	Fatigue Endurance (number of repetitions)
SMA	3,000	3.80	**
Superpave 19	5,100	4.89	-
Superpave 25	7,700	4.49	-
RBM	3,200	4.64	-

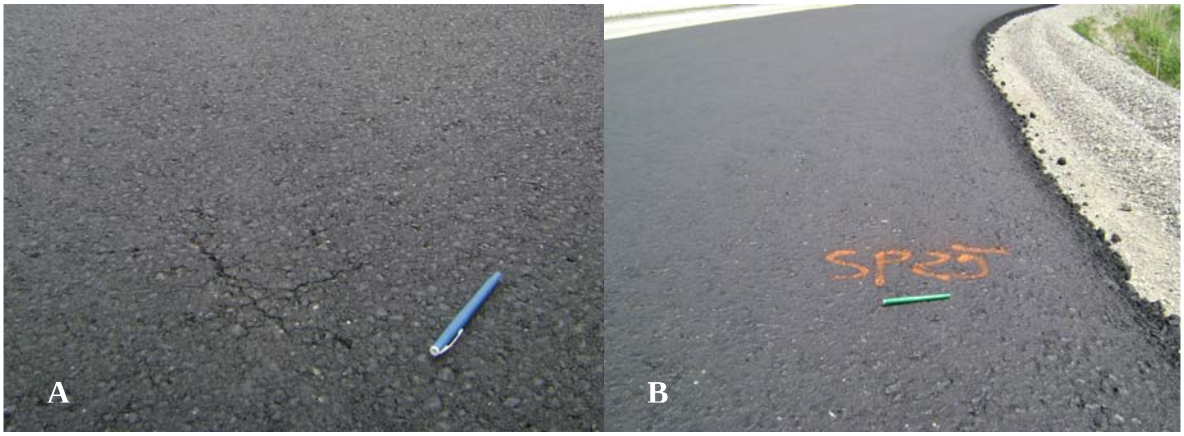
* The test was completed at 5 temperatures and 6 loading frequencies. This table shows only the dynamic modulus at 21 °C and 1 Hz frequency.
** Testing stopped after a day of testing.

6.0 CONSTRUCTION

As usual on a large asphalt paving project, there were number of issues that had to be addressed quickly. They mainly concern four aspects of construction: asphalt check cracking; quality control (QC)/quality assurance (QA); compaction; and construction methodology. An experienced project management, paving consultant and contractor team working together allowed these issues to be addressed efficiently and effectively.

1. Asphalt Check Cracking

There was check cracking observed initially during the paving of the RBM, Superpave 25 and Superpave 19 layers. As the mixes in the mix designs were considered to be very fine, it was agreed that the mix design adjustments were necessary. After the increase of the stone content by about 2 percent and reducing the amount of sand, the issue of check cracking was resolved and they were no longer observed during paving. Photograph 5 shows the check cracking in the Superpave 25 mat before the mix adjustment and then the mat free of any check cracking after the gradation adjustment. Photograph 6 shows the surface of the RBM and Superpave 19 after the gradation adjustments.



Photograph 5. Check cracking observed in the original Superpave 25 mix (A). After the mix gradation was adjusted, no check cracking was observed (B).

Photograph 6. Completed mats of the RBM layer (A) and Superpave 19 layer (B). No check cracking was observed after the mix adjustment.

2. Quality Control/Quality Assurance

As the QA field laboratory was located in an environmentally sensitive area, no solvents were allowed for extraction and an ignition oven was used for the gradation and asphalt cement testing (Photograph 7). However, the contractor used the conventional extraction/gradation method at the plant. In order to correlate the QC/QA, additional testing of the asphalt mixes was carried out. The correlation was generally very good, within the required tolerances. The aggregates used in the SMA 12.5 surface course mix exhibited significant degradation at a very high temperature in the ignition oven; therefore, the gradation and asphalt cement testing of the SMA mix was completed in the Golder main asphalt laboratory in Whitby using the extraction/gradation method. This change in testing procedure resolved any discrepancy in correlation issues. The flexibility of the owner and the consultant to move past the costs involved allowed the issue to be resolved.

Photograph 7. The ignition oven was used for the gradation and asphalt cement testing of the mixes on the Red Hill Valley Parkway with the exception of the SMA mix.

3. Compaction

As mentioned in Section 4, Development of New Specifications, the compaction requirements were tighter than on conventional asphalt paving projects in Ontario. Therefore, the compaction operation required a special care [15] and was always one of the main concerns of the contractors. The compaction was generally achieved by using increased number of rollers (6 rollers were used for SMA paving, for instance), careful control of the mix temperature during compaction, and following the effective compaction operation procedure such as keeping the rollers close to paver screed (Photograph 8) and avoiding excessive water, etc. Paving in echelon contributed to the successful achievement of the compaction requirements and mitigated problems with longitudinal joints.

Photograph 8. In order to achieve compaction of the SMA layer, the rollers were kept very close to the paver screed (A). Application of tack coat on the surface of the Superpave 25 layer (B).

4. Construction Methodology

Originally, it was intended to limit construction traffic to the paver and rollers on the surface of the RBM. Given the observed performance of the RBM and the desire to pave the Sp 25 in echelon, it was decided to allow a limited construction traffic on the surface of the RBM layer. This facilitated paving of the Superpave 25 layer in echelon and avoided construction of longitudinal joints in this layer. However, the length of the RBM opened to the HMA delivery trucks was limited to 300 m and the number of trucks allowed to wait in front of the paver was also limited.

The project specifications required that the tack coat should only be applied on the surface of the Superpave 19. However, as a limited construction traffic was allowed on the Superpave 25 layer, it was also decided during construction that a layer of tack coat should be applied on the surface of this layer as well.(Photograph 8).

It was agreed during the course of the project that good communication and team work between the City of Hamilton, the contractor (Dufferin Construction), and paving consultant (Golder) and project management consultant (Philips Engineering) was of critical importance. This allowed any pavement design, mix design or construction issues to be resolved almost immediately with obvious benefit to the quality of the constructed pavement.

The perpetual pavement was constructed successfully on the Red Hill Valley Parkway in 2007. Photograph 9 shows the completed perpetual pavement.

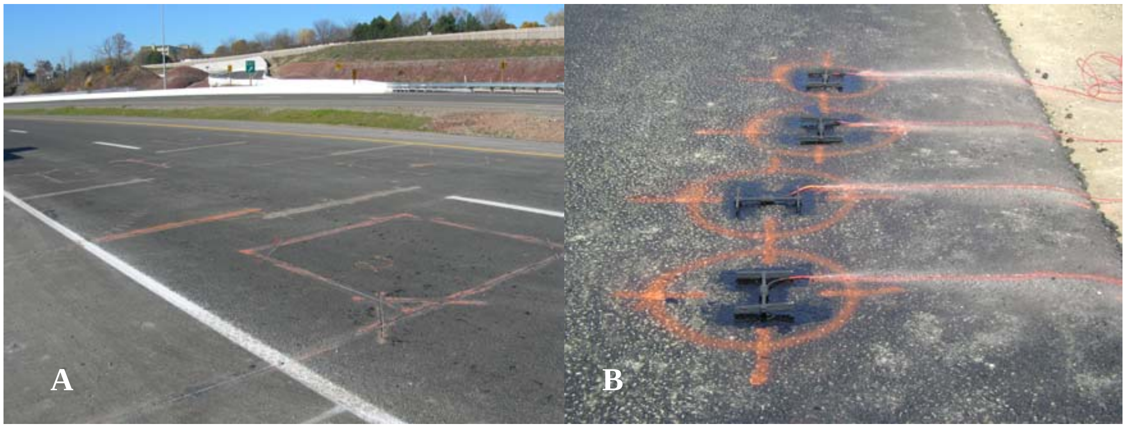
Photograph 9. Completed perpetual pavement on the Red Hill Valley Parkway.

7.0 PAVEMENT INSTRUMENTATION

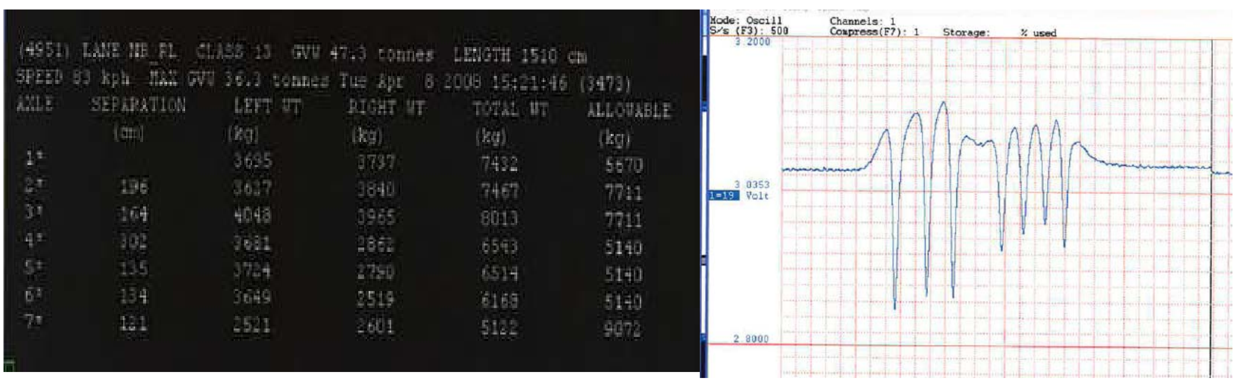
In order to verify the performance on the pavement materials in the Hamilton conditions and to verify the perpetual pavement design and predict the performance of the pavement, the City decided to install a pavement response system. This system includes the pressure and moisture gauges in the subgrade, asphalt strain gauges in the RBM, Superpave 25 and SMA layers and temperature sensors in the subgrade, granular and asphalt layers (Photograph 10) and is based on the systems used for pavement monitoring of test tracks in the United States [16 to 18].

As the Red Hill Valley Parkway is one of the main routes in Hamilton, the City decided to install a traffic monitoring system in the pavement as well. The traffic monitoring system included traffic loops and weigh in motion (WIM) sensors.

The number of vehicles, speed, spacing and loading of the vehicles is recorded and stored in the pavement monitoring system. The traffic data is synchronized with the pavement response data (Photograph 11). The combination of these two systems not only allow for the anaylsis of the strains in the pavement but also the relationship with the induced stresses and loads causing these strains. The methodology of the analysis of the traffic loading and pavement response is still under development.



Photograph 10. Traffic loops and Weigh in Motion sensors installed in the pavement (A) and the tensile asphalt gauges on the top of the Superpave 19 layer ready to be covered with the SMA surface course layer (B).



Photograph 11. Example of traffic data and pavement response monitoring on the Red Hill Valley Parkway. The strain in the asphalt shown on the right is caused by the passing of a seven-axle 47.3 tonnes track which data is shown on the left.

8.0 SUMMARY

The design of the perpetual pavement on the Red Hill Valley Parkway required an innovative, comprehensive approach. The major aspects of this approach include:

1. Extensive feasibility study including life-cycle cost analysis, environmental benefits and pavement sustainability analysis, considering the availability of experienced contractors, consultants, materials and equipment, and the asphalt pavement technology aspects;
2. Pavement structure design and structural analysis;
3. Development of six new paving specifications; and
4. Testing of the mechanistic properties of asphalt mixes including dynamic modulus, resistance to rutting and fatigue endurance.

There were number of issues during construction that had to be addressed on site. They included asphalt mix designs adjustment to avoid check cracking, QC/QA issues, some aspects of the asphalt compaction operation to meet very tight specification requirements, and some necessary modifications to the paving operation specifications.

The traffic monitoring and pavement response systems were installed in the pavement on the Red Hill Valley Parkway in order to verify the perpetual pavement design and the performance of the materials in the Hamilton conditions.

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