

# PERPETUAL PAVEMENTS: THE ONTARIO EXPERIMENT

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**ABSTRACT**

A Perpetual Pavement is a flexible pavement designed from the bottom up to resist structural failure, minimize cracking and rutting, and last for 50 years or more with only periodic renewal of the wearing surface. In 2006, the Ministry of Transportation Ontario (MTO) will begin reconstruction of 11.3 km of Highway 402, near Sarnia, Ontario. The project will be constructed in three sections: a 4 km trial section of Perpetual Pavement with rich bottom mix as the lower binder layer; a 4 km trial section of Perpetual Pavement with Superpave 25 mm as the lower binder layer; and a control section of conventionally designed flexible pavement constructed with Superpave mixes. The Perpetual Pavement trials and control section will be instrumented by the Centre for Pavement and Transportation Technology (University of Waterloo, Ontario), to better understand how the different pavement structures react and perform under various traffic loadings and environmental conditions. This long term monitoring and instrumentation is a three way partnership with the Ministry of Transportation Ontario, Ontario Hot Mix Producers and Centre for Pavement and Transportation Technology.

This paper describes the philosophy of the pavement design for each trial section and the specification requirements for the rich bottom mix. The instrumentation design plan and methodology is explained in the paper, including details on the instrumentation and the description of the long-term monitoring program. The intent of the work is to examine how the various trial sections perform under various loading and environmental conditions. In-situ measurements will be supplemented by Falling Weight Deflectometer Testing, roughness and rutting measurements, and manual distress surveys.

## 1 INTRODUCTION

The concept of Perpetual Pavements was originally developed in the United States in response to observations on the long life performance of deep strength or full depth pavement designs constructed in the 1960s. Increased pressure to extend pavement service life and reduce delays to the travelling public has lead transportation agencies worldwide to explore these lessons in constructing pavements today. A perpetual pavement is a flexible pavement designed from the bottom up to resist structural failure, minimize cracking and rutting, and last for 50 or more years with only periodic renewal (Newcomb, 2002). Extending the life of flexible pavements cannot occur without regular preventive maintenance, applied at the right time and in the right location. Mitigating deterioration early in the life will allow the extension of the ultimate service life of the pavement.

The concept of perpetual pavements is not new in Ontario. In 2003, The Asphalt Pavement Alliance (APA) presented awards for perpetual pavements in North America. The awards were judged by the National Center for Asphalt technology (NCAT) and recognized asphalt pavements that are a minimum of 35 years old, have never had a structural failure, have not been overlaid more frequently than an average of 12 years, and demonstrate the qualities expected from long-life asphalt pavements. One of the 8 inaugural winners of the award was the City of Toronto for the Don Valley Parkway.

In the next two years, four new perpetual pavements will be constructed to further explore the concept of perpetual pavements in Ontario. A summary of the perpetual pavement trials scheduled in Ontario is shown in Table 1.

This paper details the design methodology and the instrumentation and monitoring plan for one of these pavements; namely the reconstruction of the 30 year old composite pavement forming the eastbound and westbound lanes of Highway 402, east of the City of Sarnia. The total length of the project is 11.3 km.

## 2 PROJECT DESCRIPTION

Highway 402 is part of Ontario's freeway 400 series network and is a key transportation corridor linking Southwestern Ontario and the north-central United States. This project is the final phase of the re-construction/rehabilitation of Highway 402 from the Bluewater Bridge in Sarnia to Highway 401 interchange at London.

The project will be constructed in three sections: a 4 km trial section of perpetual pavement with rich bottom mix as the lower binder; a 4 km trial section of perpetual pavement with Superpave 25 mm as the lower binder; and a control section of conventional flexible pavement.

In addition, the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo, with industry support, will work with the Ministry to instrument both perpetual pavement trial sections as well as the control section in order to gain a better

understanding of how the different pavement structures react and perform under various traffic loadings and environmental conditions.

**Table 1: Scheduled Perpetual Pavement in Ontario**

Route	Hwy 402	Hwy 406	Hwy 7	Red Hill Creek Expressway
Location	Sarnia	Thorold	Carlton Place	Hamilton
Authority	MTO	MTO	MTO	City of Hamilton
AADT	20,400	25,470	21,900	70,000
Percent Truck Traffic	25%	7%	10%	
Design ESALs (millions)	38 (18 years) 146 (50 years)	42 (50 years)	28 (30 yrs)	40 (20 years) 90 (50 years)
Designer	Ontario Ministry of Transportation (MTO)	MTO / Golder Associates	MTO / Jacques Whitford	Golder Associates
Design Methodology	AASHTO '93 DARWin / PerRoad 2.4	AASHTO '93 DARWin	AASHTO '93 DARWin	AASHTO '93 DARWin / PerRoad 2.4
Performance Period	50 years	50 years	50 years	50 years
Total HMA Thickness (mm)	340	250	230	240
Rich Bottom Mix in Total HMA	Trial 1 – 80 mm Trial 2 – None	Yes 80 mm	Yes 80 mm	Yes 80 mm
Total Granular Base (mm)	550	400	500	540

## 2.1 Pavement History

This section of Highway 402 will be 31 years old in 2006 and was originally constructed in 1975 as a four-lane divided freeway. The composite pavement structure consists of 80 mm of hot mix asphalt (HMA), over 200 mm of plain concrete base, over 150 mm of cement treated granular base (CTB), on subgrade soil.

The CTB was designed to extend 600 mm wider than the concrete base, and on the shoulders, earth was placed flush with the top of the CTB. Subdrains were retrofitted along the outside and median edge of the CTB in 1981.

## 2.2 Existing Pavement Condition

The Ministry reports pavement serviceability in terms of Pavement Condition Rating (PCR), a composite performance index combining IRI and distress data measured on a scale of 1 – 100,

where 100 is a pavement in excellent condition (MTO, 1989). In 2004, the MTO Southwestern Region Geotechnical Section assessed the Highway 402 pavement condition as PCR = 60 in the eastbound lanes and PCR = 54 in the westbound lanes.

Highway 402 is in fair condition. The 31 year old asphalt surface is slightly to moderately ravelled with slight wheel track rutting throughout. A few joint failures are moderate to severe. There are a few moderate longitudinal cracks and extensive moderate centreline cracks. A few edge crescent cracks are severe and there are a few severe transverse cracks and severe reflective transverse joints throughout.

### **2.3 Physiographic Region**

This section of Highway 402 travels through relatively flat terrain. According to Chapman and Putnam, this portion of Highway 402 is located on a drumlinized bevelled till plain known as the Huron Fringe. The major soil types are the Brookston and Perth clays, consisting of medium clay tills.

## **3 FIELD INVESTIGATION**

A field investigation was carried out in October of 1998. The field investigation determined that the existing pavement structure consisted of an average of 86 mm of hot mix asphalt, over an average of 205 mm of concrete base, over an average of 140 mm of CTB. The subgrade consisted of brown silty clay and brown clayey silt of low to intermediate plasticity (ML–CL). The in-situ moisture content of the silty clay ranged from 21 to 28%. The subgrade samples were determined to be of low frost susceptibility.

The investigation included trenches across the shoulders to examine the earth shoulder construction, and removal of the asphalt overlay to determine the condition of the underlying concrete base.

The original Pavement Design Report, dated February 16, 1999 (MTO, 1999), recommended excavation of the shoulders, concrete slab repairs and a new asphalt riding surface. It was later determined that the rate of concrete deterioration was such that a large number of slab failures were anticipated. Rehabilitation was no longer a feasible alternative and the decision was made to reconstruct.

## **4 DESIGN CONSIDERATIONS**

Since publication of the original Pavement Design Report in 1999, where rehabilitation was recommended, a more rapid deterioration of Highway 402 has occurred resulting in an increase in the number of joint and slab repairs required in 2006. The same rapid deterioration occurred on the adjacent project which was tendered in 2003, where the decision was made to re-construct rather than rehabilitate. The advantages of reconstruction (longer pavement life, reduced user costs and lower potential for overruns and claims) outweighed the disadvantages of reconstruction (higher initial cost). For these reasons, it was decided to re-construct the 30 year

old composite pavement (MTO, 2005). It was then determined that this project is a good candidate for a perpetual pavement trial.

## **5 PAVEMENT DESIGN**

### **5.1 Traffic Calculations**

This section of Highway 402 has a 2002 AADT of 20,400 and a projected 2006 AADT of 22,950 with 25.0% commercial vehicles. A truck factor of 2.3 was used for design purposes. The long-term truck volume growth rate for this corridor was estimated to be 3% per year. A lane distribution factor of 0.7 was used. Traffic loadings for an 18-year design life (conventional flexible design) were determined to be 38.1 million 80-kN equivalent single axle loads (ESALs). Traffic loadings for a 50-year design life (perpetual pavement design) were determined to be 146.3 million ESALs.

### **5.2 Granular Base and Subbase Considerations**

Large quantities of crushed granular base material will be produced by recycling the existing composite pavement structure (asphalt surfacing over a concrete slab). Natural sources of granular base are limited and natural sources of granular subbase material are of poor quality in this part of Ontario. The price differential between base and subbase does not warrant the use of granular subbase, therefore the flexible pavement designs will utilize a crushed aggregate base produced by on-site crushing of the existing composite pavement structure. For the purposes of the pavement design, the reclaimed material has been assigned typical values for aggregate base in southern Ontario (AASHTO structural coefficient of 0.14).

### **5.3 Frost Depth**

For design purposes, the frost penetration depth for the project area is 1.0 m.

### **5.4 Flexible Pavement Design**

The flexible pavement designs were carried out using the American Association of State Highway and Transportation Officials (AASHTO, 1993) using the DARWin software package. The AASHTO design method and input parameters have been adapted and verified for use in Ontario (MTO, 2000).

Using AASHTO 1993, the required structural number (SN) determined by DARWin for the conventional flexible pavement was 180 mm. This analysis was calculated using the parameters shown in Table 2.

**Table 2: AASHTO 1993 Flexible Design (DARWin) Inputs for a Conventional Flexible Pavement**

<b>Parameter</b>	<b>Value</b>
80-kN ESALs over initial Performance Period	38.1 Million
Initial Serviceability	4.5
Terminal Serviceability	2.6
Reliability Level	90%
Overall Standard Deviation	0.49
Roadbed Soil Resilient Modulus	27,000 kPa
Performance Period	18 years
% Trucks in Design Lane	70
% Heavy Trucks (of ADT) FHWA Class 5 or Greater	25
Average Initial Truck Factor (ESALs/truck)	2.3
Annual Truck Volume Growth Rate	3.0%

The required SN determined by DARWin for the perpetual pavement was 213 mm. This analysis was calculated using the parameters shown in Table 3.

**Table 3: AASHTO 1993 Flexible Design (DARWin) Inputs for a Perpetual Pavement**

<b>Parameter</b>	<b>Value</b>
80-kN ESALs over initial Performance Period	146.3 Million
Initial Serviceability	4.5
Terminal Serviceability	2.6
Reliability Level	90%
Overall Standard Deviation	0.49
Roadbed Soil Resilient Modulus	27,000 kPa
Performance Period	50 years
% Trucks in Design Lane	70
% Heavy Trucks (of ADT) FHWA Class 5 or Greater	25
Average Initial Truck Factor (ESALs/truck)	2.3
Annual Truck Volume Growth Rate	3.0%

## 5.5 Flexible Pavement Design Considerations

Since this project is a trial project to compare a conventional flexible pavement design to two perpetual pavement designs, a consistent granular base thickness was recommended throughout.

Likewise, the two perpetual pavement designs will have the same asphalt layer thickness, the difference being that one will have a Rich Bottom Mix (RBM) as the lower binder and the other will have a conventional Superpave 25 mm as the lower binder.

An RBM is a fatigue resistant hot mix asphalt with an increased asphalt cement content that is placed as the bottom layer in a perpetual pavement. In this case, the standard Superpave 25 mm mix used at other locations in the contract will be modified by increasing the asphalt content of the mix by 10% (about 0.5% additional asphalt cement) which in turn is expected to reduce the air voids content to about 3%. The result is a flexible mix that is more resistant to bottom up cracking.

Using AASHTO 1993 for the conventional flexible design and the perpetual pavement design, the structural requirements (structural number and granular base equivalency or GBE (MTO, 1990)) are shown on Table 4.

**Table 4: AASHTO 1993 (DARWin) Structural Requirements**

	<b>Conventional Flexible Design</b>	<b>Perpetual Pavement Design</b>
Total HMA Thickness (mm)	240	340
Total Granular Thickness (mm)	550	550
Total Pavement Structure Depth (mm)	790	890
Structure Number (mm)	180	220
Granular Base Equivalence (mm)	1,030	1,230

## 5.6 PerRoad Design Validation

PerRoad 2.4 is a mechanistic perpetual pavement design tool developed by NCAT (Timm, 2004). The program can perform two levels of analysis, a deterministic analysis using nominal design values and a reliability analysis, which predicts the amount of risk associated with a particular design. Design inputs include pavement structure information (number of layers, material types, material properties, variability and thresholds), seasonal information (duration of seasons/climates, associated material properties), and loading condition (anticipated axle loading, loading configurations). The PerRoad 2.4 program probabilistic execution uses Monte Carlo simulation, therefore random results are expected every time the analysis is run. As a result, the analysis is repeated and the results averaged.

The PerRoad 2.4 perpetual pavement design software was used to verify the perpetual pavement design. The program requires input in imperial units for the parameters as follows:

- ESALs (per day) = 4695.21 [assume axle growth rate is 2%];
- Specified asphalt bottom layer with horizontal strain of -70 microstrain (transfer function [fatigue]  $k_1 = 2.83e-006$ ;  $k_2 = 3.148$ );
- Specified subgrade top layer with vertical strain of 200 microstrain (transfer function [rutting]  $k_1 = 6.026e-008$ ;  $k_2 = 3.87$ );
- Seasonal information (from Environment Canada - climate online) –
  - Summer 16 weeks (Summer temperature = 66.3°F / 17.3°C)
  - Fall 9 weeks (Fall temperature = 43°F / 6.1°C)
  - Winter 18 weeks (Winter temperature = 25°F / -3.8°C)
  - Spring 9 weeks (Spring temperature = 50°F / 10°C);
- Traffic loading – imported “Rural Interstate.lsf”; and
- Based on previous FWD data, typical asphalt concrete summer modulus is 3,000 MPa (435,113 psi). However, the default modulus with revised summer temperature is 595,633 psi = 4,107 MPa.

The results of the validation runs carried out using the above parameters and performing three software runs are shown in the Tables 5 and 6.

**Table 5: PerRoad Design Iterations Using Winter Modulus E = 4,107 MPa**

Parameter	Run 1a	Run 1b
<b>HMA Thickness</b>	13 in. (330 mm)	12 in. (305 mm)
<b>Granular Thickness</b>	22 in. (558 mm)	22 in. (558 mm)
<b>Average Estimated HMA Life (years)</b>	89.9 years (82.6 to 91.8)	57.3 years (55.3 to 60.5)
<b>Average Estimated Granular Life (years)</b>	155.3 years (137.8 to 175.5)	135.8 years (103.9 to 166.1)
<b>Comments</b>		Reduced HMA

**Table 6: PerRoad Design Iterations Using Summer Modulus E = 3,000 MPa**

Parameter	Run 2a	Run 2b	Run 2c
<b>HMA Thickness</b>	13 in. (330 mm)	13 in. (330 mm)	13.39 in. (340 mm)
<b>Granular Thickness</b>	22 in. (558 mm)	20 in. (508 mm)	21.65 in. (550 mm)
<b>Average Estimated HMA Life (years)</b>	58.1 (54.2 to 60.8)	53.9 (50.6 to 57.9)	62.5 (56.2 to 70.5)
<b>Average Estimated Granular Life (years)</b>	118.9 (98.5 to 150.3)	126.3 (124.5 to 128.5)	135.4 (106.6 to 178.5)
<b>Comments</b>		Reduce granular	Design thickness

## 5.7 Recommended Pavement Structure

The recommended pavement structures for the conventional flexible pavement, perpetual pavement without RBM, and perpetual pavement with RBM used in the trial sections are shown in Table 7.

**Table 7: Recommended Pavement Structure**

Description	Conventional Flexible Thickness (mm)	Perpetual Pavement Thickness (mm)	Perpetual Pavement with RBM Thickness (mm)
Superpave 12.5 FC2 Surface Course	40	40	40
Superpave 19.0 Binder Course	120 (2 lifts)	120 (2 lifts)	120 (2 lifts)
Superpave 25.0 Lower Binder Course	80	180 (2 lifts)	80
Superpave 25.0 Rich Bottom Mix	–	–	100
Total HMA	240	340	340
Granular Base	550	550	550
Note: Superpave 12.5 FC2 refers to a premium surface course mix. FC2 indicates a friction course where both coarse and fine aggregates are 100% crushed.			

## 6 INSTRUMENTATION PLAN

Working with the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo with the support of the Ontario Hot Mix Producers Association (OHMPA), the Ministry proposes to instrument the perpetual pavement trials and control section, to better understand how the different pavement structures react and perform under various traffic loadings and environmental conditions. Three test sections will be established: one in the perpetual pavement with RBM, one in the perpetual pavement without RBM, and one in the conventional flexible pavement control section (Ponniah, 2005).

The instrumentation of the three sections will consist of the following elements:

- vertical compressive stress in the subgrade will be evaluated with earth pressure cells;
- moisture probes will be installed at the pressure cell locations to evaluate the effect of moisture condition on the vertical stress;

- a nest of three asphalt strain gauges (ASGs) will be installed in the wheel paths at the bottom of the hot mix layers in each test section (two longitudinal and one transverse) to evaluate the strain at the base of the HMA;
- in the RBM section, an additional nest of three ASGs (two longitudinal and one transverse) will be installed in the wheel path on top of the RBM to evaluate the strain differential across this lift of material;
- each ASG will be equipped with a temperature probe; and
- a data logger connected to a telephone line will be installed at each test section.

### **6.1 Installation of Moisture Probes**

Moisture probes will be installed in the subgrade at each test section. The probes will be placed in the outside wheel path of the driving lane. Cavities 200 mm by 200 mm by 150 mm deep will be excavated to accommodate the moisture probes at a depth of 375 mm in the subgrade. Cavities will be filled with sieved subgrade material (passing 4.75 mm) in three 25 mm lifts, and compacted to ensure density.

Cables will be routed through trenches excavated 75 mm wide by 50 mm deep, running from the cavities to the edge of pavement. The trenches will be partially filled with clear stone.

### **6.2 Installation of Earth Pressure Cells**

The earth pressure cell gauges consist of two parts, a cell and a transducer. The cell is connected via a stainless steel tube to the transducer, forming a closed hydraulic system. The gauges will be placed in the outside wheel path of the driving lane. The pressure cell cavities will be excavated in the subgrade, 275 mm in diameter and 50 mm deep. Cavities 100 mm wide by 625 mm long by 100 mm deep will be excavated for the pressure transducer. The bottom half of the 50 mm deep cavities will be filled with sieved granular base material and compacted.

Approximately 20 mm of the remaining depth of the cavities will be filled with loose sand (passing 2.36 mm) to promote proper levelling of the cell plate and to prevent air voids under the plate. This is critical for obtaining accurate readings. The cells will be placed on top of the loose sand and additional clear stone will be placed around the transducer and compacted.

Cable trenches 75 mm wide by 50 mm deep will be excavated, running from the cavities to the edge of the pavement. The trenches will be partially filled with clear stone.

Once all the moisture probes and pressure cells have been placed, the gauges will be protected from potential damage caused by the heavy construction equipment using a thick layer of granular base material placed over the sensor and cable trench.

### **6.3 Installation of Asphalt Strain Gauges on the Granular Base Course**

Asphalt strain gauges (ASGs) will be installed once the contractor has completed construction of the granular base course. ASGs will be installed in the outside wheel path of the driving lane. Cavities are not required for the ASG installation.

Cable trenches 75 mm wide and 50 mm deep will be excavated in the granular base, running from the gauges to the edge of the pavement. The trenches will be partially filled with clear stone.

Lead wires from each gauge will be routed through the cable trench leading to the shoulder edge. ASGs will be secured in place by first applying a thin layer of asphalt primer (CSS1) to the levelled base course surface. The primer should cover an area of 150 mm by 250 mm. Once the primer has cured, a mastic mix consisting of CSS1 bitumen and sand passing the 1.18 mm sieve in a 1:2 ratio will be applied in a thin layer (6 mm) to each gauge location. The gauges will be gently pressed into the mastic until the strain gauge comes into full contact with the mix. Approximately 50 mm of hot mix asphalt will be placed over and around each gauge immediately prior to paving to protect the gauge.

### **6.4 Installation of Asphalt Strain Gauges on the Rich Bottom Mix**

To monitor the strain differential in the RBM, after placement of the RBM, ASGs will be placed directly on the surface of this lower binder course. In this case, no cable trenches are needed, as the cables will be placed directly on the RBM surface. The cables will be protected with approximately 50 mm of hot mix.

ASGs will be adhered to the RBM surface using the same procedures described above for placing ASGs on the base course.

### **6.5 Installation of Data Loggers**

Data loggers will be installed at each trial location. The data loggers will be placed inside cabinets mounted to a 50 mm diameter galvanized pipe. All instrumentation will be connected to the data loggers which will in turn be connected to a telephone line to allow for the remote retrieval of the data at any time.

## **7 MONITORING**

CPATT will acquire data from the data loggers and conduct data analysis for a minimum four year period. This will include analyzing results and developing a procedure for the evaluation of the concepts used in perpetual pavement design and promoting the selection of the most cost effective pavement materials on future projects. Detailed analysis of strain measurements, temperature and various other measurements will be carried out. CPATT will also be submitting progress reports to the Ministry as needed and will prepare a final report summarizing all project results, data analysis and findings including recommendations and conclusions.

The primary goal of the instrumentation on Highway 402 is to better understand how the environment and traffic impact the long term performance of the perpetual pavement design. The intent is to provide full scale monitoring and testing of the perpetual pavement section. We would also hope to compliment the instrumentation with thorough structural testing in the CPATT laboratory.

The Ministry will carry out annual roughness and rutting surveys using the Automated Road Analyser (ARAN). Manual distress surveys will be carried out annually by the Regional Geotechnical Section. Falling Weight Deflectometer testing will also be carried out annually by the Ministry to compare the structural response of the three trial sections over time and to compare the responses to the data collected by the in situ monitoring program.

## **8 DISCUSSION**

In 2006, MTO begins reconstruction of 11.3 km of Highway 402, near Sarnia, Ontario. The project will be constructed in three sections: a 4 km trial section of perpetual pavement with RBM as the lower binder; a 4 km trial section of perpetual pavement with Superpave 25 mm as the lower binder; and a control section of conventional flexible pavement. In partnership with CPATT and OHMPA, the perpetual pavement trials and control section will be instrumented, to better understand how the different pavement structures react and perform under various traffic loadings and environmental conditions.

The technological challenges in pavements are particularly acute and it is essential that there is a better understanding to in situ performance. The primary mandate of a unique new pavement research initiative, based at the University of Waterloo, Centre for Pavement and Transportation Technology (CPATT), consists of a comprehensive research program which involves a field testing program and construction of a test track and satellite test facilities and a state-of-the-art pavement materials testing laboratory. The project described in this paper would be part of this satellite test program.

CPATT intends to monitor in situ strain as a function of load and environment and to monitor performance of the mix over the long term. The results of performance monitoring and data analysis will assist in resolving some of the following uncertainties (University of Waterloo, 2004) associated with perpetual or long life pavement designs:

- Design criteria and methodology;
- Failure mechanisms of these types of pavements;
- How the asphalt material properties relate to the long life behaviour;
- The optimum maintenance strategy for perpetual pavements;
- How to fully assess the life cycle costing, economic and sustainability benefits of these long life pavements;
- Impacts of material and construction variability; and
- Adapting long-life pavement concepts being researched in other locations to the Canadian environment.

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