Ontario's Experience in the Construction of Perpetual Pavement Trials

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ABSTRACT

As part of the on going effort to promote sustainability in the design, construction, and maintenance of highway infrastructure, the Ministry of Transportation, Ontario (MTO) has identified the need to construct perpetual pavements on major highways. It is anticipated that this approach will reduce major rehabilitation works and the associated green house gas emissions by reducing traffic delays associated with major construction. In 2006, the first perpetual pavement trial with Rich Bottom Mix (RBM) was constructed on Highway 406, near Thorold. Subsequently, two more perpetual pavement trial projects were identified for construction on Highway 7, Carleton Place and Hwy 401, Woodstock in Ontario.

The trial section on Highway 401 is divided into three segments: perpetual pavement section with RBM; perpetual pavement section without RBM; and conventional flexible pavement control section. All three segments will be instrumented in collaboration with the Centre for Pavement and Transportation Technology at the University of Waterloo, Ontario, to better understand the behaviour of the different layers in each section under various traffic loadings and environmental conditions. More specifically, the basic concept used in the perpetual pavement design will be evaluated through long-term monitoring of pavement performance through instrumentation as well as the traditional approach which includes manual distress surveys, and measurements of deflection, roughness and rutting.

This paper describes briefly the experience gained in the construction of perpetual pavement design test sections in Ontario focussing mainly on the design and construction of rich bottom mix, and the instrumentation of the test sections.

INTRODUCTION

Conventional pavement design does not consider the contribution of each pavement layer to resist fatigue cracking, low temperature cracking and rutting. Recent developments in technology for materials selection, mixture design, performance testing, and pavement design offer a methodology to design perpetual pavements, also known as long lasting asphalt pavements, by taking into account the contribution of each asphalt layer to enhance performance. A perpetual pavement is a flexible pavement designed from the bottom up to resist structural failure, minimize cracking and rutting, and expected to last for 50 or more years with only periodic renewal [1].

As part of the on going effort to promote sustainability in the design, construction, and maintenance of highway infrastructure, the Ministry of Transportation, Ontario (MTO) has identified the need to construct perpetual pavements on major highways to extend pavement service life and eliminate major structural rehabilitation. It is anticipated that this approach will reduce green house gas emissions by reducing traffic delays associated with major construction. In 2006, the first perpetual pavement trial with Rich Bottom Mix (RBM) was constructed on Highway 406, near Thorold. Subsequently, two more perpetual pavement trial projects were identified for construction on Highway 7, Carleton Place and Hwy 401, Woodstock in Ontario.

In 2007, Highway 401 between Oxford Road 2 and Oxford Road 29 was redesigned to accommodate a perpetual pavement trial sections. In collaboration with the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo, the Ministry plans to instrument the perpetual pavement trials and control sections to better understand how the different pavement structures react and perform under various traffic loadings and environmental conditions. The trial section on Highway 401 is divided into three segments: perpetual pavement section with RBM; perpetual pavement section without RBM; and conventional flexible pavement control section. More specifically, the basic concepts used in the perpetual pavement design will be evaluated through long-term monitoring of pavement performance which includes manual distress surveys, measurements of deflection, roughness and rutting annually, in addition to stress/strain, temperature, and moisture measurements under various traffic and environmental loadings.

OBJECTIVES

The main objective of this paper is to describe the experience of MTO in the design and construction of perpetual pavement trial sections in Ontario. This includes description of sensors such as moisture probes, temperature gauges, earth pressure cells, and asphalt strain gauges which would be installed at critical locations within the asphalt pavement structure by CPATT as part of partnership agreement with MTO. The purpose of the instrumentation is to:

- Understand the effects seasonal variation of temperature and moisture conditions on measured pavement stress and strains at critical locations

- Evaluate the benefit of rich bottom mix to mitigate fatigue crack initiation.
- Quantify the influence of individual layer contribution to the observed pavement response and the overall road performance under actual traffic loading conditions.
- Validate the perpetual pavement design concepts used for providing a long service life.

PERPETUAL PAVEMENT DESIGN CONCEPT

The approach used in the design of perpetual pavement is based on the concept that each layer in a three layer hot mix asphalt pavement could be designed to provide a life span of 50 years or more, with periodically scheduled renewal of the surface layer to minimize major construction delay and maintain optimum serviceability. The three layer hot mix pavement design concept to achieve the perpetual pavement objectives are described below:

1) Top Renewable Layer
   A low permeability, rut-resistant and wear-resistant surface layer which will be periodically renewed to prevent "top-down" cracks from propagating to the lower binder layers.
2) Middle Rut Resistant Layer
   Strong, rut-resistant and durable layers which remain in place during the full 50 year design life.
3) Bottom Fatigue Resistant Layer
   There are two approaches to designing flexible pavements to resist fatigue cracking [1]. One approach is to provide a sufficient thickness for minimizing the tensile strain at the bottom of the flexible pavement which contributes to fatigue crack initiation and the other is to design a flexible bottom layer to provide increased resistance to fatigue cracking. This layer is referred to as Rich-Bottom Mix (RBM) layer as described below.

Rich Bottom Mix

The rich-bottom mix was designed as a flexible layer by increasing the asphalt content of a standard Superpave 25.0 mm or Superpave 19.0 mix by 10% (about 0.4% additional asphalt cement), which in turn, reduces the air voids content to about 3% to optimize the flexibility of the mix. To date, all ministry RBM's have been Superpave 25.0 RBM. Care is required with this approach in selecting the mix, as there is a potential for the air voids to collapse with some aggregate structures. Hence, Ontario's specification which bases placed mix acceptance on percent within limits of air voids with a lower limit of 1.5% less than the mix design air voids (4.0%), includes an air void lower limit of not less than 1.5% (1.5% less than 3.0%). Alternately the mix could be designed to a lower air void requirement of 3.0% instead of directly specifying the higher asphalt cement content.

The City of Hamilton in Ontario constructed a perpetual pavement using the Superpave 19 RBM mix on the Red Hill Valley Parkway in Hamilton using 0.5% extra asphalt cement.

Originally designed with PG 64-28 it was determined that a PG 70-28 was required to meet dynamic modulus, rutting resistance and fatigue endurance testing criteria in the laboratory [2].

PAVEMENT DESIGN PROJECT DETAILS

Highway 406, Thorold

Highway 406 near Thorold was the first perpetual pavement trial in the summer of 2004. This is a four-lane divided freeway with annual Equivalent Single Axle Load (ESAL) of 450,000.

Initially, Highway 406 was constructed as a concrete pavement in 1969, consisting of 230 mm plain concrete over 150 mm cement treated base (CTB), and subsequently rehabilitated and resurfaced with 90 mm HMA in 1998. This Highway 406 project was originally designed as a conventional deep strength flexible pavement, and the perpetual pavement concept was incorporated into the project at its 90% design stage. As a result, many challenges were encountered to complement the perpetual design with the existing geometric constraints and various design and pre-construction issues.

Two pavement design software, AASHTO 1993 – DARWin [3] and OPAC 2000 [4], were used to verify the structural adequacy of this long-life pavement.

The final design of the Highway 406 project (Table 1) was modified to accomplish the perpetual pavement concept by adding 80 mm of rich-bottom base HMA. The total thickness of the pavement structure was adjusted to achieve the same profile grade as the original design.

A Superpave 25.0 RBM was specified for this contract. The original Superpave 25.0 mix design called for 4.3% asphalt cement, and the Superpave 25.0 RBM design with 4.7% asphalt cement content and only 2.6% air voids. Although there was some initial concern that it might be difficult for the Contractor to meet the air void mix properties during construction, actual quality control and quality assurance testing both reported mean air voids of 3.2%.

The RBM was placed under night closures, and although there was some concern that it may be unstable, the contractor did not find this to be the case, and obtained full pay incentives for compaction.

Highway 7, Carleton Place

Highway 7 expansion from Carleton Place to Ottawa began construction in summer 2008. The ministry selected this project to implement a perpetual pavement design.

Highway 7 is a flexible pavement and the most recent rehabilitation contract prior to this perpetual pavement reconstruction occurred in 1982 with 80 mm HMA overlay. The existing condition of this section of Highway 7 has been performing well. The ride within the project limits is good and no poor performing areas were identified.

Two pavement design software, AASHTO 1993 –DARWin [3] and PerRoad 3.2 [5], were used to verify the structural adequacy of this long-life pavement. Table 1 provides the design thickness of each layer.

Again the RBM was designed as a Superpave 25.0 mix, with 0.4 % more asphalt cement (AC), for a total design AC content of 4.4%, which resulted in design air voids of 2.8 % from 4.4 %. This contract is currently under construction and although initial observations have been made, it is premature to comment on the material placed to date.

Highway 401, Woodstock

Highway 401 located in the County of Oxford from 1 km east of Oxford Road 2 easterly to 4.1 km east of Drumbo Road is a perpetual pavement design. The project is the last in a series of expansion projects on Highway 401 between Woodstock and Kitchener/Waterloo. This project will add two new lanes in the median and a median barrier/storm sewer system.

This portion of Highway 401 was originally constructed as a flexible pavement structure with a four lane cross-section in the late 1950's. It was resurfaced in the mid 1970's and in 1998.

The existing pavement has many full depth cracks at frequent intervals. Due to the extensive nature of crack repairs required in the existing pavement, it was more cost effective approach to remove and replace the pavement layers instead of undertaking crack repairs and overlay.

A consistent granular base thickness was recommended throughout to ensure comparative evaluation of a conventional flexible pavement design with two perpetual pavement designs under similar sub layer conditions. As well, 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.

The RBM Superpave 25.0 mix was designed with 5.1 % AC, up 0.5% from the Superpave 25.0 mix AC of 4.6%. This resulted in a drop from the Superpave 25 air voids of 4.0% to 2.4 %, lower than both the two previously constructed mixes. The mix was placed at night, October 2008 and as can be seen in photo A, the compacted mat was tight, with a very rich asphalt cement appearance, but no areas of flushing were observed.

Table 1 provides the thickness of each layer selected for the perpetual pavement design. Three pavement design software, AASHTO 1993 –DARWin [3], OPAC 2000 [4], and PerRoad 3.2 [5] were used to verify the structural adequacy of this long-life pavement. The life cycle costs of a rigid or flexible pavement are similar for this project. There is potential for differential settlement in the new median lanes and re-aligned horizontal curves; therefore a flexible pavement is recommended.

INSTRUMENTATION PLAN

The test sections on Hwy 401 would be instrumented in collaboration with CPATT 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 [7]. Figures 1 and 2 show the locations of the sensors installed on Hwy 401.

Installation of Moisture Probes

Moisture probes were installed in the subgrade at each test section. The probes were 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 were filled with sieved subgrade material (passing 4.75mm) in three 25 mm lifts, and compacted to ensure density. Cables were 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.

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 were placed in the outside wheel path of the driving lane. The pressure cell cavities were excavated in the subgrade, 275 mm in diameter and 50 mm deep. Cavities 100 mm wide by 625 mm long by 100 mm deep were 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 were filled with loose sand (passing 2.36 mm) to promote proper levelling of the cell plate, in addition to preventing any air voids under the plate. This is critical for obtaining accurate readings. The cells were 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 were excavated, running from the cavities to the edge of the pavement. The trenches were partially filled with clear stone.

Installation of Asphalt Strain Gauges on the Granular Base Course

Asphalt strain gauges (ASGs) would 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 leveled 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.

Installation of Asphalt Strain Gauges on the Rich Bottom Mix

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. Figure 3 shows the RBM layer placed on Hwy 401

Installation of Temperature Probes and Data Loggers

Temperature probes will be installed at the pavement edge after completion of hot mix paving. The probes will be inserted into the HMA pavement, the granular base, and the subgrade. 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.

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 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.

CONCLUSION

In 2006, MTO began construction of its first perpetual pavement with the extension of Hwy 406 near Thorold and subsequently, two more perpetual pavement trial projects were identified for construction on Highway 7, Carleton Place and Hwy 401, Woodstock in Ontario.

The Hwy 401 project will be constructed in three sections: a trial section of perpetual pavement with RBM as the lower binder; a 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, 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. Overall, the results of performance monitoring and data analysis will assist in resolving some of the following uncertainties associated with perpetual or long life pavement designs [8]:

- 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
- Adopting perpetual pavement concepts for the Canadian environment.

REFERENCE

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Table 1: Summary of Perpetual Pavement Design in Ontario

Location	**Highway 406 Thorold [1]**	**Highway 7 Carleton Place [2]**	**Highway 401 Woodstock [3]**
AADT	25,470	22,000	48,000
% Truck Traffic	7%	9.5%	30%
Design ESALs (millions)	42 (50 years)	23 (30 years)	97.5 (20 years)
Designer	MTO / Golder Associates	MTO / Jacques Whitford	MTO Geotechnical Section
Design Methodology	DARWin / OPAC	DARWin / PerRoad 3.2	DARWin / OPAC / PerRoad 3.2
Design Life	50 Years	50 Years	50 Years
HMA Thickness (mm) (RBM = Rich Bottom Mix)	40 mm SP 12.5FC 2 50 mm SP 19.0 80 mm SP 25.0 80 mm SP 25.0 (RBM)	40 mm SP 12.5FC2 55 mm SP 19.0 55 mm SP 19.0 80 mm SP 25.0 (RBM)	40mm SP12.5 FC2 50mm SP19.0 60mm SP19.0 70mm SP19.0 100mm SP25.0 100mm SP25.0 (RBM)
Total HMA Thickness	250 mm	230 mm	420 mm
Total Granular Base (mm)	400 mm	500 mm	750 mm

LIST OF FIGURES

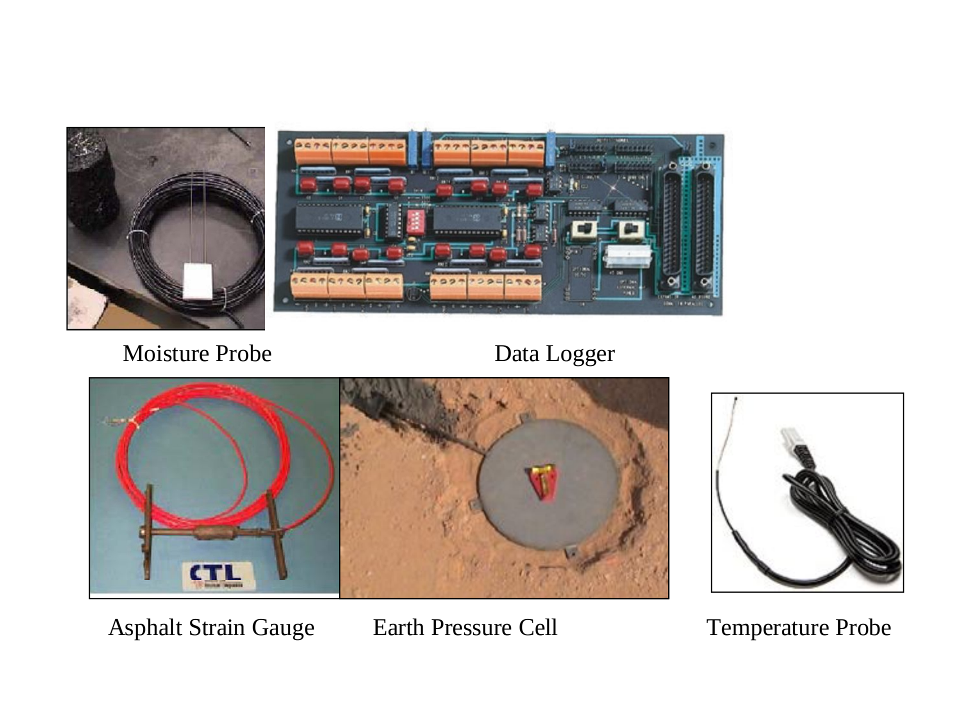

Figure 1 Sensors installed on Hwy 401

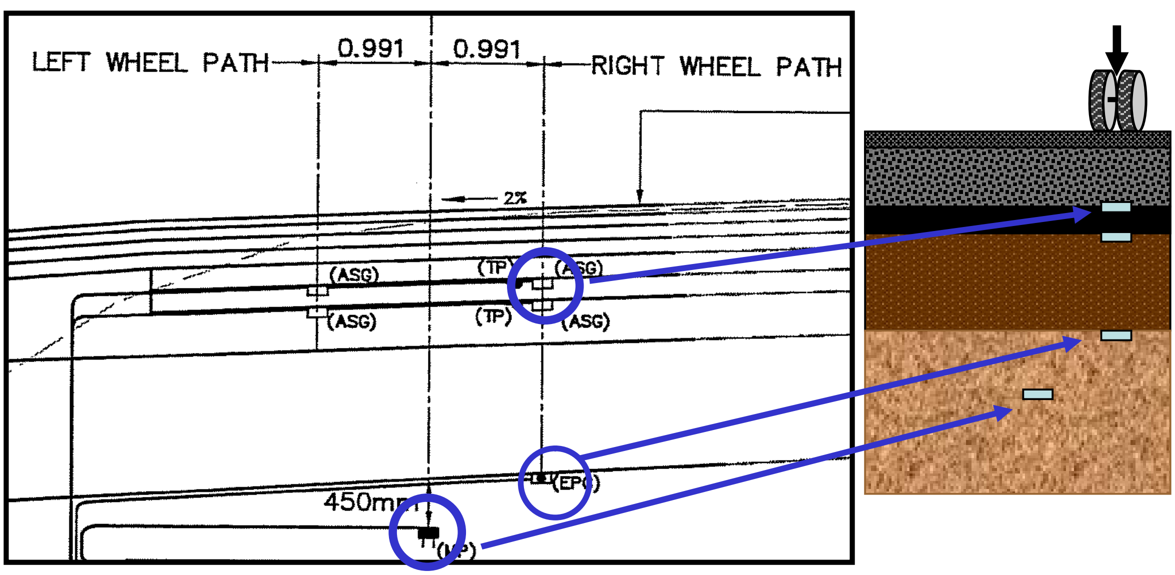

Figure 2 Locations of sensors installed underneath the pavement

Figure 3 Rich bottom mix placed on Hwy 401