A Method for the Investigation and Validation of Composite Pavement Performance Including the use of the Falling Weight Deflectometer

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Abstract

Engineers are frequently asked to develop detailed rehabilitation strategies and repair quantity estimates for the concrete portion of composite pavements based on visual condition assessments and Falling Weight Deflectometer (FWD) testing completed on top of the hot mix asphalt (HMA) layer. In some cases, once the HMA layer is removed, the condition of the concrete base is either better or worse than expected. It is always difficult to determine what type, and how much testing should be completed for composite pavement structural evaluation studies.

An innovative approach was developed by the Ministry of Transportation, Ontario (MTO) Southwestern Region, where pavement investigations were conducted as a part of a freeway shoulder paving contract. This preliminary, yet in-depth investigation was done to assess the underlying concrete for an entire corridor some 46 km in length. The method was considered to be cost effective as it encompassed several future construction contracts.

At each designated pavement investigation area within the project limits, the field investigation included coring of the asphalt overlay, a detailed surface distress survey of the concrete pavement after removal of the asphalt overlay, Falling Weight Deflectometer pavement load/deflection testing, coring of the concrete pavement, a test pit excavated at the edge of pavement through the shoulder, and laboratory testing of recovered concrete pavement, granular, and subgrade materials.

The paper presents the history of the pavement construction and maintenance activities, the investigation methodology, as well as the results of the field data collection. Recommendations are provided for cost-effective utilization of standardized composite pavement evaluation techniques.

INTRODUCTION

Highway 401 is a critical transportation corridor that provides a link between the United States and Canada at one of the busiest international border crossings in Windsor/Detroit. I-75 and Highway 401 form a major international trade and goods movement corridor, extending from the Ontario/Quebec border south to Miami, a distance of nearly 3,200 kilometres (km). The North American Free Trade Agreement (NAFTA) and 'just in time' delivery has resulted in this section of Highway 401 being the heaviest travelled corridor in Ontario for international truck traffic.

Truck volumes are in excess of 6,000 per day throughout the corridor from Toronto to Detroit. Trucks represent greater than 30 percent of the daily traffic on most interurban segments of the route. Truck traffic on I-75 and Highway 401 exceeds 9 billion vehicle-km annually. The total annual value of motor carrier operating expenditures in the corridor has been estimated to be more than $7 billion [1]. It is clear that Highway 401 is vitally important in the transportation of goods and services and is key to the prosperity of Ontario.

GENERAL DATA

Highway 401 was designated a Controlled Access Highway in the early 1950's and is considered a Class 1 Freeway with a Functional Classification of RFD 120 (Rural Freeway Divided, Design Speed 120 km/h). The limits of the pavement evaluation project described in this paper extend 45 km from immediately east of Highway 3, Windsor, easterly to Essex Road 42 (Interchange 56), just west of Tilbury.

This section of highway comprises 3.35 to 3.50 m wide lanes. The median shoulder is 1.0 m wide and paved, while the 3.0 m wide outside shoulder was fully paved in 2000. The depressed grass median is 9.1 m wide. Eight interchanges exist within the project limits.

Historical Data

Highway 401 within the project limits was originally constructed in four separate contracts in the mid 1950s as an exposed concrete pavement. This section of Highway 401 was originally built as a four lane divided facility with the following rigid pavement structure:

225 mm	Plain Concrete Pavement (6.1 m slabs, undowelled)
100 mm	Granular 'A' Base
125 mm	Granular 'B' or Granular 'C' Subbase

Due to stepping of all joints and centreline separation, the concrete pavement was overlain with a 30 mm thick HL2 (levelling mix) sand asphalt layer (SAL) in 1966/1967.

Around 1970, expansion joints were installed every 152 m (500 ft.). The expansion joints comprise skewed 100 mm wide, full depth slots, cut using a Vermeer machine and filled with timbers. Reflection cracking through the SAL led to the paving of an additional 130 mm hot mix asphalt (HMA) overlay in 1972/1973. The overlay comprised 50 mm of HL4 Modified (open graded base course mix), 40 mm of HL4 (base course mix) and a 40 mm HL1 surface course. Superelevation was built up on the curves with 100 to 225 mm of HMA. Ploughed in subdrains were installed around 1980.

In 1986 to 1990 cupped severe transverse cracks were repaired and sections of the driving lane were milled and resurfaced with Recycled and Virgin HL1. Subsequently, all but the westernmost 4 km were resurfaced from 1992 to 1996. This work consisted of additional transverse crack repairs, milling and a 40 mm Heavy Duty Binder Course (HDBC) and 40 mm Dense Friction Course (DFC) overlay. Portland cement concrete (PCC) repairs were also carried out under Contract 93-04, in the EBL from Essex Road 27 to Essex Road 42. Transverse crack repairs were undertaken in the westernmost 4 km of the project in 1999.

Maintenance has consisted primarily of routing and sealing cracks and hot mix patching. Hot mix patching is more frequently undertaken in the vicinity of structures where reflection cracking is relatively severe due to thinner HMA.

Pavement Performance

The study area had been previously divided into four Pavement Management Sections. The Pavement Condition Rating (PCR) used by MTO is a subjectively derived rating of serviceability based on an evaluation of pavement riding comfort and of pavement surface distress. PCR is an assessment of overall pavement performance, both functionally and structurally, as related to actual observable pavement characteristics – roughness and various distress manifestations. The procedures for conducting the condition ratings are outlined in the *Manual for the Condition Rating of Rigid Pavements* [2]. The PCRs of the study area, as assessed by MTO in August 1999, are summarized in Table 1.

Table 1. 1999 Pavement Condition Ratings.

Description	Length	PCR	Last Contract
Essex Road 42, IC 56 (Old Hwy 2) to Essex Road 27, IC 34 (Belle River Road)	22.2 km	79 EBL 71 WBL	93-04 EBL 92-03 WBL
Essex Road 27 , IC 34 to Essex Road 25, IC 28 (Puce Road)	6.3 km	81 EBL 82 WBL	94-01
Essex Road 25, IC 28 to Sandwich S Twp Con. Road 8	13.3 km	86 EBL 85 WBL	96-27
South Sandwich Twp Con. Road 8 to Highway 401 Ends	4.3 km	60 EBL 61 WBL	73-172

In general, the performance and ride of the easterly three pavement sections is good. The typical distresses are variable and comprise intermittent to extensive slight transverse and centreline cracking as well as moderate ravelling, very slight coarse aggregate loss and frequent to intermittent slight distortions. Pavement edge cracks, midlane cracking and very slight wheel track rutting were also noted locally. A few blowups are also noted as well as concrete failures in the easternmost section. A photograph illustrating the typical pavement condition in the eastern PMS sections is provided in Figure 1.

Figure 1. Typical pavement condition in eastern PMS sections

The performance and ride of the westernmost section is only fair. The primary distresses in this section are frequent severe transverse cracks, a few moderate centreline cracks, slight wheel track rutting throughout and a few areas of slight coarse aggregate loss and ravelling. An illustration of the typical pavement condition in the eastern PMS sections is provided in Figure 2.

Figure 2. Typical pavement condition in western PMS section

INVESTIGATION

Although Highway 401 within the study limits was designed as an exposed concrete pavement, it has been a functional composite pavement for the last 35 years. As is typical with most composite pavements, defining an investigation program that will evaluate the condition of both the HMA and the underlying concrete road base is problematic. Complete removal of the HMA within the study section to allow for a complete concrete base inspection would be cost prohibitive and cause excessive user delay.

In an effort to evaluate the existing conditions of the total pavement structure, MTO Southwestern Region developed an innovative evaluation procedure and delivery method. A special provision was written into a 2000 highway shoulder paving contract whereby the paving contractor was responsible for retaining an MTO shortlisted specialty pavement consultant. The special provision defined the pavement study methodology and the deliverables to be submitted on completion of the assignment.

Study Methodology

A detailed pavement evaluation and geotechnical investigation was completed at 16 geotechnical investigation areas identified in the Contract drawings. Each investigation area was approximately 50 m in length and located in the driving lane of the highway. The geotechnical investigation at each of the 16 investigation areas consisted of:

- Detailed surface condition survey of the exposed concrete pavement (after removal of the HMA overlay) to determine the type, severity and extent of any observable pavement surface distresses. In addition, photographs of representative areas of the pavement and associated features were taken;

- Pavement load/deflection testing of representative joints/cracks using a Dynatest 8081 High Capacity Falling Weight Deflectometer (FWD);

- Asphalt and concrete pavement coring;

- Test pits at the pavement edge (located at a joint) advanced perpendicularly through the shoulder; and

- Laboratory testing of recovered samples of the concrete pavement, granular base/subbase, and subgrade for classification purposes.

Existing Conditions

In general, the investigation confirmed the historical records. The existing pavement structure at the exposed areas typically consisted of 230 mm of HMA over 230 mm of PCC over an average 275 mm of granular base/subbase which sometimes includes a fine aggregate levelling (screenings) layer. No reinforcing (dowels or mesh) was encountered in the PCC. The slab lengths were measured to be 6.1 m.

The subgrade was relatively uniform comprising a silty clay with a Plasticity Index, I_p of around 20 percent. The insitu moisture content is usually around or drier than the plastic limit. This type of subgrade generally exhibits a low susceptibility to frost heave.

The HMA overlay was found to be of variable thickness ranging from some 125 to 260 mm. The notable features of the HMA overlay was the use of an HL-4 modified open graded base course interlayer intended to mitigate reflection cracking. Further, many of the reflection cracks that had propagated through the overlay were skewed rather than perpendicular from the bottom of the overlay to the top.

On removal of the asphalt overlay, the existing condition of the Highway 401 concrete base was found to be variable. The concrete base was assessed to be relatively sound near Essex County Road 46 (Windsor) and deteriorating to poor near Essex County Road 42 (Tilbury).

The majority of the concrete base surveyed was found to be in relatively good condition from the perspective of overall concrete quality. The predominant distress features consisted of joint/crack faulting, joint/crack spalling and mid-slab transverse cracking (Figure 3).

Figure 3. Typical concrete road base condition in western PMS sections (near Windsor). Note evidence of previous crack repair.

However, at the eastern end of the study area the joints and cracks were found to have deteriorated significantly resulting in a poor concrete road condition (Figure 4).

The occurrence of faulting at joints and cracks was noted throughout the study area. The severity of faulting varied from very slight to very severe (barely noticeable to in excess of 80 mm) but was predominately slight to moderate (5 to 10 mm). The most severe example of faulting was noted near the middle of the study area where the approach slab was some 80 mm higher than the leave slab. We refer to Figure 5 illustrating the very severe faulting. For an exposed concrete pavement, the severity and frequency of faulting would result in poor ride quality. The very severe sections would be dangerous at posted highway speeds.

Along with faulting, spalling of joints and cracks was observed as a predominant defect in the concrete base. Spalling varied from slight to moderate in the better performing western PMS sections to severe to very severe at the eastern end of the study area.

Figure 4. Typical concrete road base condition in eastern PMS sections (near Tilbury).

Figure 5. Severe concrete road base faulting.

The shoulders are for the most part comprised of granular with earth fill at the shoulder rounding at many locations. Shoulder trenches encountered a negative crossfall on the subgrade in several locations. The subdrains were usually in good condition but were sometimes full of water.

Pavement Load/Deflection Analysis

The FWD testing was completed in the outer wheel path of the driving lane for the joint/crack testing. At each joint/crack, two FWD tests were completed. The first was completed with the FWD loading plate positioned on the ‘approach’ side of the joint/crack and the second was completed with the FWD loading plate positioned on the ‘leave’ side of the joint. At each of the test locations, a series of four load applications were applied to the pavement surface. The first application was a "seating" load to ensure the FWD load plate was firmly resting on the pavement surface. The next three loads were approximately 40, 55 and 70 kN. The field results were analysed in accordance with the procedures outlined by *Crovetti* [3].

The normalized dynamic deflection values were variable within the Investigation Areas. Values ranged between about 90 and 720 μm with the majority of the tests between 100 and 300 μm. Values in this range would indicate a relatively good pavement structural capacity.

The load transfer exhibited by the concrete joints/cracks in the western end of the study area were generally consistent with values ranging from 71 to 100 percent with the majority of the values measured to be greater than 90 percent. At the eastern end of the study area, the load transfer was typically fair to poor with the majority of the values below 50 percent. The results of the load transfer analysis were generally consistent with the overall visual condition of the concrete base.

The results of the loss of support analysis were somewhat more variable than the load transfer analysis. Approximately 30 percent of the FWD tests indicated the presence of potential voids beneath the joint/crack. Where a concrete road base core was extracted from a location where the loss of support analysis indicated the potential for voids, the presence of voiding was confirmed.

Conclusion

Summarizing the investigation results, the existing pavement structure consisted of some 230 mm of HMA over 230 mm of PCC over an average 275 mm of granular base/subbase. No reinforcing (dowels or mesh) was encountered in the PCC. The slab lengths were measured to be 6.1 m. The concrete base was assessed to be relatively sound near Essex County Road 46 (Windsor) deteriorating to poor near Essex County Road 42 (Tilbury).

The predominant distress features consisted of joint/crack faulting, joint/crack spalling and mid-slab transverse cracking. The results of the load transfer analysis were generally consistent with the overall visual condition of the concrete base. Areas in which the joint/crack appeared in good visual condition typically had corresponding high load transfer efficiencies with no evidence of voiding beneath the slab.

From the perspective of predicting the condition of the concrete road base on the visual condition of the HMA surface, there was no correlation. With over 200 mm of HMA over the concrete road base, the pavement would more accurately be considered as HMA over concrete rather than a composite pavement. While reflection cracking through the HMA overlay was certainly a predominate distress feature, other features such as, faulting, spalling, etc, were effectively hidden from view. The use of open graded HMA interlayers do not appear to mitigate reflection cracking and have been determined by MTO to be mixes of poor durability.

Pavement Condition Ratings established based solely on the HMA surface do not, in this study section, reflect the condition of the HMA and concrete pavement layers. Rather, the PCI ratings largely identify only the deterioration/age of the HMA surface. This finding would not have been ascertained had the HMA overlay(s) not been removed as the overlay had effectively hidden the underlying distress features in the concrete road base.

Although the majority of the pavement is considered to be in good condition, the MTO has found that the expected overlay service lives are generally shorter than what would be expected on other sections of highway within the Province. This premature deterioration would be primarily due to significant reflection cracking from the concrete base.

The selection of effective potential rehabilitation alternatives for this section of highway would need to identify and address the distress features contributing to the actual condition of the pavement. With conventional composite pavements incorporating thinner HMA overlays, typically in the order of 100 mm, the MTO rehabilitation methodology has been to remove all HMA overlays during the initial stages of the construction Contract, conduct condition surveys on the exposed concrete pavement, conduct FWD testing on transverse joints and cracks, and based on this information, modify their decision matrices for concrete pavement restoration (CPR). On completion of the CPR, the pavement is resurfaced with two or three lifts of new HMA. Repair quantities for Contract tendering purposes are estimated based on the visual distresses of the HMA overlay (FWD testing may or may not be undertaken at this stage) and then revised using the established unit rates and the quantities determined from a combination of the distress survey/FWD testing (after removal of the HMA overlay) and the MTO established decision matrices for joint/crack repair. As would be expected, tender quantities and actual repair quantities can differ considerably.

Recommendations

Developing detailed rehabilitation strategies and repair quantity estimates for the concrete road base portion of composite pavements based on visual condition assessments and Falling Weight Deflectometer (FWD) testing completed on top of the hot mix asphalt (HMA) layer is problematic. While reflection cracking through the HMA overlay will manifest as a predominate distress feature, other features such as, faulting, spalling, etc, of the concrete road base are effectively hidden from view. PCI ratings established based solely on the HMA surface typically do not reflect the condition of all of the bound pavement layers. Rather, the PCI ratings reflect mostly the deterioration/age of the HMA surface. In this study, the areas with the highest HMA surface visual condition rating were often associated with the worst concrete road base conditions highlighting our observation that PCI ratings of the overlay typically do not reflect the condition of the underlying layers.

Although FWD testing of the HMA surface was not undertaken in this study, the observation that many of the reflection cracks were skewed through the HMA overlay would indicate that had the field data been collected, the results would likely not be representative of the actual joint/crack condition. Nevertheless, developing a correlation between the FWD load transfer tested on the HMA surface with the FWD load transfer on the concrete base would be a useful tool in predicting the condition of the underlying concrete road base and would provide significant benefits towards estimating meaningful repair quantities during the tendering stage.

Clearly, it is difficult to determine the level and type of testing that should be completed for composite pavement structural evaluation studies. However, detailed design field investigations should allow for a thorough examination of the underlying concrete road base. A suggested composite pavement investigation would include; a detailed surface distress survey of the HMA surface, FWD testing of the HMA surface at joints/cracks, a detailed surface distress survey of the concrete pavement after removal of the asphalt overlay, FWD testing of the concrete road base, and a test excavation at the edge of pavement through the shoulder to allow for examination of random joint/crack profiles. This type of investigation can be cost effective, if undertaken as part of a network level investigation within a corridor (i.e. several construction contracts or PMS Sections) to assess similar vintage concrete road base.

References

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[3] Crovetti, J.A. and M.I. Darter, *Void Detection for Jointed Concrete Pavements*, *Transportation Research Record 1041*, Transportation Research Board, Washington DC, 1985.