CONCRETE HIGHWAYS

A CASE STUDY OF PCCP SECTION OF HIGHWAY 417 EAST IN ONTARIO

Yasser Hassan
Associate Professor
Carleton University

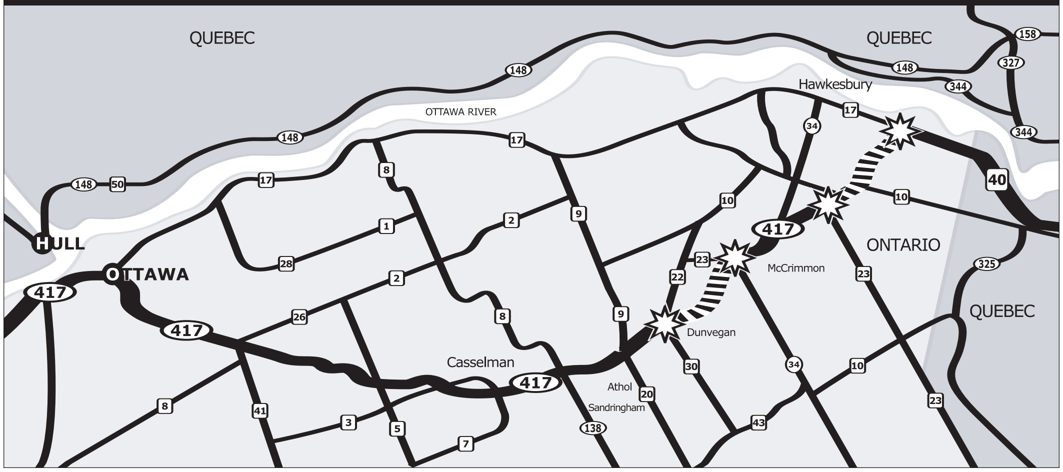
August 2004

CONCRETETHINKING
in transportation **solutions**

Introduction

For the first time in its history, the Ontario government tendered an alternate bid road construction contract (concrete or asphalt structure) based not only on the initial construction cost but also on a 50 year life cycle costs (LCC) of maintaining the highway as well[1]. The project was for a total of 34.4 km of the eastbound lanes of Highway 417, which is part of the Trans-Canada Highway. As shown in Figure 1, this section is in east Ontario about 9 km to the west of the Ontario-Québec provincial borders and extends from County Road 30 (of the United Counties of Stormont, Dundas, and Glengarry) to Interchange IC9 at the intersection with County Road 17 (of the United Counties of Prescott-Russell). The section is a divided highway with two lanes in each direction. The low bid for the construction of the highway including initial cost plus LCC value was awarded to the portland cement concrete pavement (PCCP) option. The tender recognized the longer life of the PCCP structure compared to an equivalent designed asphalt by giving the PCCP option a $433,321 LCC advantage over the asphalt structure[1]. A $23.6-million contract was awarded in Spring 2001 to Dufferin Construction of Oakville. Construction started in Summer 2001. The first phase of the construction for 25 km was completed in September 2001 and the second phase was completed in 2002.

Fig. 1. Location of Section with Concrete Pavement.



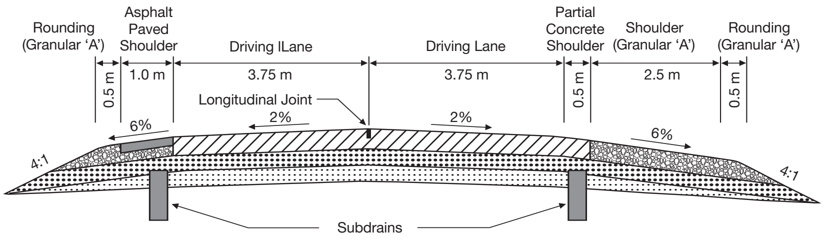
Pavement Design

Design of this rigid pavement was performed by a consulting firm using *DARWin* software, which is a computer implementation of the 1993 AASHTO *Guide for Design of Pavement Structures*[2]. The results were then checked against the Portland Cement Association (PCA) design method using the PCAPAV design program. A 50-year period was used for the analysis of life cycle costs with an initial design life of 27 years.

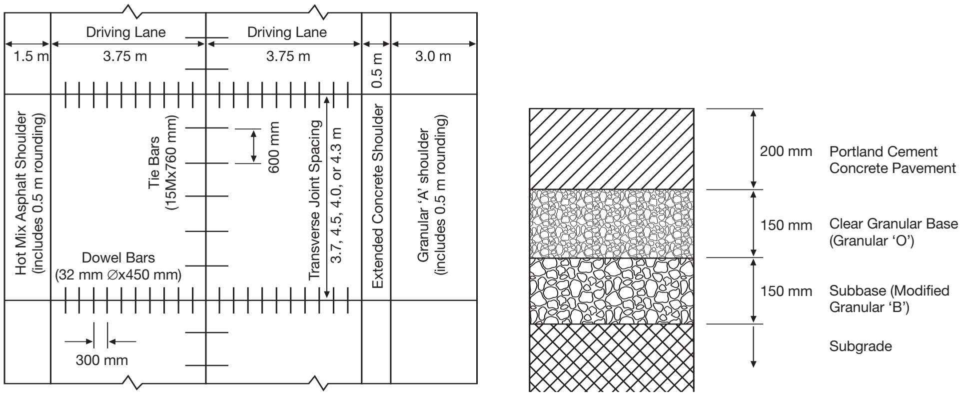
A typical cross section, plan view, and the final structure of the pavement section are shown in Figure 2. As shown in the figure, the pavement is a jointed plain concrete pavement (JPCP) with dowels. The pavement structure is 200 mm (8 inch) slab thickness on top of a 150 mm (6 inch) clear granular base (known as Granular 'O') for drainage and 150 mm (6 inch) subbase consisting of recycled asphalt pavement structure blended with new granular B material (known as modified Granular 'B').

The subgrade soil is uniform and is of good quality consisting of silty sand till with some gravel and frequent cobbles. In addition, no Leda clays (which are unstable, sensitive marine clays) are present at the site. Therefore, geotextiles were not needed to prevent contamination of the subbase and base layers by fines or to help in drainage. The modulus of subgrade reaction (K) was estimated as 54.29 MN/m^3 (200 pci), and the composite subgrade-subbase K was 108.57 MN/m^3 (400 pci). Drainage is provided using sub-drains.

Fig. 2. Typical Cross Section of PCCP Section.



Typical Cross Section of Roadway



Plan View

Final Pavement Structure

The total concrete pavement width is 8.0 m: consisting of two 3.75 m wide lanes and a 0.50 m extended concrete pavement shoulder on the right hand side. An additional 2.5 m of granular 'A' was placed to give a total right hand shoulder width of 3.0 m. The inside shoulder, on the other hand, is a hot mix asphalt of 1.0 m width. A 0.5 m wide rounding of Granular 'A' is used at the end of both the inside and outside shoulders, and the side slope on both sides is 4:1. It should be noted here that the right hand side driving lane and the partial concrete shoulder were built as a one-piece widened slab (3.75 m + 0.50 m) without a joint in between. Studies have shown that the widened slab would improve the fatigue cracking and faulting performance of JPCP by keeping the truck axles away from the free edge and corners where they cause critical stress and deflections[3,4,5]. However, the same studies have also shown that use of widened slabs at some sections could have increased the tendency to develop longitudinal cracking in the wheel path.

Transverse contraction joints were created using saw cuts perpendicular to the road centerline at intervals alternating from 3.7, 4.5, 4.0, and 4.3 meters so that the total length of each four successive slabs is 16.5 m. According to Ontario Provincial Standards Specification (OPSS 350), depth of the saw cut is 1/3 of the concrete slab depth. Load transfer along the transverse joints is enhanced by using smooth, epoxy coated dowel bars with a 32 mm diameter and a 450 mm length. The bars were inserted by an automatic dowel inserter at every transverse contraction joint at 300 mm spacing. In addition, tie bars were inserted along the longitudinal joints to tie adjacent lanes together and eliminate separation between parallel lanes. The tie bars are deformed, epoxy coated with 15M diameter, 760 mm length, and 600 mm spacing. Hot poured liquid sealant was applied at the joints according to OPSS 369. Burlap drag was used to provide a pavement microtexture followed by transverse tining with 3 mm thick tines to a 4 mm depth on a 16 mm spacing of centers to provide macrotexture for good skid resistance (OPSS 350).

Concrete Properties

The concrete pavement mix design was a zero slump mix, w/c ratio ranging from 0.41 to 0.44 (mix design changes), and air content ranging from 4.5 to 7.5%. No slag or other supplementary cementing materials were added to the mix. The flexural strength of the concrete was 5.0 MPa (730 psi). No additional information is available on the mix design for public release.

Environmental Conditions

According to Environment Canada data at the National Climate Data and Information Archive[6], the normal air temperature range for this highway section is 26.4 to –14.8°C with the most extreme high and low temperature recorded being 37.8 and -38.9°C, respectively. Normal annual precipitations are 733.2 mm of rain plus 202.7 cm of snow adding up to an annual precipitation of 914.2 mm of water equivalent. Frost depth is estimated as 1.8 m below the pavement surface. For the purposes of controlling ice and snow accumulation of the pavement surface, road salts (Sodium Chloride) are typically applied to this section as required with Calcium Chloride used as a prewetting agent. Between November 1, 2003 to February 29, 2004, approximately 14 tonnes of road salts per two-lane-km on this section of concrete have been applied. It should be noted that the rate of application of salt is constant regardless of the pavement type. Therefore, the salt applied to the neighbouring asphalt pavement section was almost equal to that applied to the concrete pavement section. However, the operator might add more salt at odd areas during a second pass. It is the judgement of the MTO engineers that slightly more salt was added to the concrete pavement section but the difference was not significant enough to warrant special monitoring.

Traffic Conditions

The design average annual daily traffic volume (AADT) for the 1995 design year was estimated to be 12,700 vehicles/day of which 10.2% were commercial vehicles. More specifically, the breakdown of the design AADT was: 11,400 passenger vehicles (89.8%), 420 light trucks (3.3%), 840 heavy trucks (6.6%), and 40 buses (0.3%). A 2% annual growth rate was projected; however, according to the Pavement Management System (PMS) data, the actual AADT was 11,202 vehicles/day for 1995 and 14,033 vehicles/day for 2002. The actual design equivalent single axle load (ESAL) information was not available but the most recent estimate for ESAL's in 1999 on this section is 2.5 to 3.15 million. Assuming that the 2% annual growth rate was the actual growth rate over the period of 1999-2003, the total ESAL's on the section for the first year of operation (September 2001 to August 2002) would range from 2.60 to 3.28 million. Similarly, the total ESAL's on the section for the second year of operation (September 2002 to August 2003) would range from 2.65 to 3.34 million.

Pavement Performance

As the highway section has only been recently constructed, limited distress data are currently available and no maintenance activities have taken place. Expected future maintenance activities include joint sealant replacement, diamond grinding for re-texturing, and concrete joint repairs. Relevant pavement condition data were collected in the summers of 2002 and 2003, and were used to calculate the following major pavement condition indices:

- Distress Manifestation Index (DMI): an index calculated based on the severity and extent of individual distresses surveyed for pavement management sections. Scale ranges from 0 (worst condition) to 10 (condition of new pavement).
- Pavement Condition Index (PCI): an index for evaluating the pavement surface condition. Scale ranges from 0 (very poor) to 100 (excellent).
- Riding Comfort Index (RCI): an index to measure pavement roughness in terms of the number of metres per kilometre (or inches per mile) that a laser, mounted in a specialized van, jumps as it is driven across the road. Scale ranges from 0 (very poor) to 10 (very smooth).
- International Roughness Index (IRI): a scale for roughness defined as a property of the true profile, and therefore can be measured with any valid profiler. An IRI of 0.0 corresponds to perfectly flat profile. Although no theoretical upper limit exists, pavements with IRI above 8 m/km are nearly impassable except at reduced speeds.

The values of all four indices are shown in Table 1 along with the total ESAL's on the section since construction based on the assumptions stated in the previous section. Regarding the data collected in 2002, with most of the section only one year old, no single type of distress was observed and the result is reflected in high DMI and PCI values. As for roughness indices, the low value of IRI and the high value of RCI indicate a very good roughness levels. One year later, in 2003, only slight polishing and scaling with intermit densities was observed. As shown in Table 1, this has translated into very slight drop in DMI and PCI. As for roughness, a slight improvement was reflected in the IRI and RCI values. Such an improvement in roughness is commonly reported in concrete pavement due to the action of traffic wheels removing the concrete displaced by the tining operation.

Table 1. Summary of Pavement Condition Data.

Year	ESAL (millions)	DMI	PCI	IRI (m/km)	RCI
Sep 2001 – Aug 2002	2.60 – 3.28	10	85.50	1.30	7.70
Sep 2002 – Aug 2003	2.65 – 3.34	9.69	83.46	1.17	7.82
Total	**5.25 – 6.62**				

Pavement Condition

It should be mentioned that longitudinal cracking has been identified in early 2004 on less than 1% of the pavement surface. The Ministry of Transportation of Ontario (MTO) has collected and evaluated data to determine the potential cause of the cracking. The early age longitudinal cracking occurred likely due to a combination of: (1) improper saw cut of joints; (2) excessive curling and warping stress due to extreme weather conditions; and (3) widened slab increased the frictional restraint from slab-base interface. MTO selected cross-stitching as the repair method for the cracking and have already completed repairs on all the identified longitudinal cracking.

Conclusions

Based on the facts presented in this case study, it is evident that considering the life cycle cost of the pavement structure instead of just the initial cost recognizes the long-term performance benefits of portland cement concrete pavement (PCCP). Evidently, this is more of a trend than an isolated incident. At the time of preparing this report, it was announced that the westbound lanes of the same section of pavement would be re-constructed in PCCP possessing the same pavement design. However, the PCCP section was the lowest tender even before considering the life cycle cost advantage given to the concrete pavement option, which was $860,719.

Available pavement condition data indicate excellent performance to date. It should be mentioned, however, that at the time of preparing this report, the pavement section is relatively new. Therefore, continuous monitoring of the pavement performance is strongly recommended.

Acknowledgements

Assistance by the MTO Pavements & Foundations Section in preparing this case study is gratefully acknowledged.

References

1. Cement Association of Canada. *Highway 417 Reconstruction Project – A First for Highways in Ontario.* http://www.cement.ca <Accessed March 23, 2004>
2. AASHTOWare®. *DARWin®: Pavement Design, Analysis and Rehabilitation for Windows.* http://darwin.aashtoware.org/ <accessed April 1, 2004>
3. *Key Findings from LTPP Analysis 2000-2003.* Research Report FHWA-HRT-04-032, http://www.tfhrc.gov/pavement/ltpp/reports/04032/index.htm <accessed August 18, 2004>.
4. Selezneva, O.I., Jiang, Y.J., and Tayabji, S.D. *Preliminary Evaluation and Analysis of LTPP Faulting Data – Final Report.* Research Report FHWA-RD-00-076, Long-Term Pavement Performance Program, Federal Highway Administration, Washington, DC, September 2000.
5. Jiang, Y.J. and Darter, M.I. *Structural Factors of Jointed Plain Concrete Pavements: SPS_2_Initial Evaluation and Analysis.* Research Report FHWA-RD-01-167, Long_Term Pavement Performance Program, Federal Highway Administration, Washington, DC, November 2001.
6. National Climate Data and Information Archive, http://www.climate.weatheroffice.ec.gc.ca/ <accessed April 1, 2004>

Cement Association of Canada
Association Canadienne du Ciment

www.cement.ca

Canada
Government of Canada
Action Plan 2000 on
Climate Change

Headquarters
Ottawa, ON
(613) 236-9471
headquarters@cement.ca

Ontario Region
Toronto, ON
(416) 449-3708
ontario@cement.ca

Western Region
Calgary, AB
(403) 250-3535
western@cement.ca

Western Region
Vancouver, BC
(604) 269-0582
western@cement.ca

Atlantic Region
Halifax, NS
(902) 423-7317
atlantic@cement.ca

Quebec Region
Montreal, QC
(514) 739-2722
quebec@ciment.ca