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Design, Construction, and Performance of Four Experimental Concrete Pavement Sections in Ontario

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Synopsis: Recent innovative developments in concrete pavement design methodology, material specification, construction techniques, and pavement drainage systems prompted Ontario's Ministry of Transportation and Communications to consider alternative rigid pavement designs.

In order to evaluate the relative performance of several concrete pavement designs, a 15.6 km (9.7 mi) long experimental rigid pavement was constructed in 1982 incorporating four different pavement designs, three shoulder designs and two types of surface textures.

A summary of the design and construction details, plus the initial performance results of an ongoing monitoring program are documented in this paper.

Early performance observations indicate superior performance of the free draining base materials. In addition, some anomalous behaviour based on pavement cracking and roughness suggest additional areas of process control are warranted.

Continuing performance verification of preliminary conclusions indicate the new designs have resulted in a significant saving in construction materials and costs plus increased durability and performance with a corresponding reduction in future maintenance costs.

Keywords: base courses; concrete construction; concrete pavements; deflection; drainage; load transfer; performance; skid resistance; structural design; surface roughness; test roads

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INTRODUCTION

In 1982, Ontario's Ministry of Transportation and Communications constructed a 15.6 km (9.7 mile) stretch of experimental concrete pavement which incorporated three thicknesses of plain jointed undowelled concrete pavement and two shoulder designs plus two surface textures.

The concrete pavement was constructed as part of Contract 82-01, Hwy. #3 (New) from Ruthven to Essex, refer to site plan Figure 1, and consisted of four sections varying in design and length:

(I) 4.8 kilometres (3 miles) of 305 mm (12 inch) thick plain jointed undowelled concrete with 76 mm (3 inch) thick hot mix shoulders

(II) 5.2 kilometres (3.2 miles) of 203 mm (8 inch) thick plain jointed undowelled concrete over 102 mm (4 inch) open graded drainage layer (bituminous treated permeable base) with 76 mm (3 inch) thick hot mix partially paved shoulders

(III) 0.8 kilometres (0.5 miles) of 203 mm (8 inch) thick plain jointed undowelled concrete over 127 mm (5 inch) lean concrete base with 203 mm (8 inch) tied-in plain concrete shoulders

(IV) 4.8 kilometres (3 miles) of 178 mm (7 inch) thick plain jointed undowelled concrete over 127 mm (5 inch) lean concrete base with 178 mm (7 inch) tied-in plain concrete shoulders

Transverse joints in all sections were skewed and randomly spaced at 4, 5.8, 5.5, 3.7 m (13, 19, 18, 12 ft), sawn to a width of 13 mm (0.5 inch) and a depth of 25 mm (1 inch), blown clean, and filled with a hot poured rubberized sealant.

Detailed sections of the four pavement designs are shown on Figures 2, 3, and 4.

The subgrade throughout was a silty clay.

A 100 mm (4 inch) diameter perforated plastic sub-drain wrapped with geotextile was installed 300 mm (12 inch) outside all pavement edges. The pipe invert was located 50 mm (2 inch) into the subgrade and backfilled with Granular 'A' base course materials. Refer to detail sketches on Figures 2 to 4.

In order to assess skid resistance and noise level characteristics, the pavement surface was textured by dragging either an astroturf or burlap mat behind the paver and then transversely tining the concrete surface.

Upon completion, the following performance features of the experimental pavement were measured and continually monitored:

Pavement Thickness
Roughness
Skid Resistance
Load/Deflection Characteristics
Pavement Condition Surveys
Crack Survey
Joint Movement (horizontal and vertical)
Subgrade Moisture Content
Noise Levels
Traffic Volumes

This paper summarizes these measurements, at the completion of construction and over the next 3 years, presents some observations about the performance of various design features, and points out lessons to be learned from the experiment.

BACKGROUND

Prior to 1968, heavy duty concrete pavements constructed in Ontario were generally 230 mm (9 inch) thick reinforced concrete slabs on 230 mm (9 inch) granular subbases, with dowelled joints at spacings which were successively reduced from 30 m (99 ft.) in 1958, 21.3 m (70 ft.) in 1960, 17 m (56 ft.) in 1963, to 8.8 m (29 ft.) in 1967. (1,2) The major problem encountered with these designs was the increasing incidence of transverse cracks and subsequent development of spalling and faulting at joints and cracks which caused deterioration in ride quality. No cost-effective maintenance treatment for these problems was then available, so thick asphalt overlays were used to rehabilitate these pavements at ages which varied from 12 to 16 years, with a few sections reaching 20 years. Between 1968 and 1971, concrete pavements were designed as plain 9 inch slabs with dowelled skewed joints at random spacings of 4, 5.8, 5.5 and 3.7 m (13, 19, 18 and 12 feet) placed on a 127 mm (5 inch) cement stabilized or weak concrete base. These latter designs are still performing remarkably well under extremely heavy truck traffic. However their high cost makes this design difficult to justify, and escalating construction costs during the ensuing years did not make justification easier. No new concrete pavements were built during the years 1971 to 1983.

As encouraging reports of improved performance of other rigid pavement designs with tied concrete shoulders and non-erodable bases were received from the USA and Europe, it was decided that Ontario needed to explore these new ideas, in combination with their own experiences, to find promising new lower-cost designs. Subsequently, the decision was made to construct and monitor four experimental concrete pavement sections on Hwy. 3N.

DESIGN DETAILS

The experimental pavement was designed as a 7.3 m (24 feet) wide, two lane new facility project with 0.6 m (2 feet) partially paved shoulders, located some 24 kilometres (15 miles) south west of Windsor in the Township of Gosfield North and South, County of Essex. Refer to site plan, Figure 1. All pavement tapers, speed change lanes, connected sideroads, etc., were designed as conventional hot mix pavement. The majority (95%) of the test sections were constructed on fill typically the parent silty clay indigenous to the area. Physiographically, the site is located on a glacio-lacustrine clay plain, with the southern limit located on a sand plain. The topography is flat over most of the alignment with some relief at the south end. The subgrade soils consist predominately of silty clays of low to intermediate plasticity (CL-CI) overlain by sands, silty sands and gravels in the southern 1.6 kilometres of the alignment.

The average annual daily traffic (AADT) anticipated in 1978 was 4,400, with 20 year projected AADT of 8600. Thirteen percent of this traffic is classified as commercial traffic.

Typically, frost penetration in this area ranges from 760 to 910 mm (30 to 36 inches), with a freezing index of 400-500 degree days.

In consideration of these parameters a benchmark design of 203 mm (8 inch) thick plain jointed undowelled concrete pavement over 127 mm (5 inch) lean concrete base was selected as an alternative to the initially approved 305 mm (12 inch) full depth bituminous design. The alternatives selected represent variations in design strategy utilizing different erodible bases and subbases (3) while maintaining similar strength equivalences.

In consideration of the light truck traffic condition, sufficient load transfer between slabs would be achieved through aggregate interlock by closely spaced undowelled joints. To insure a smoother ride over the joints and improved joint performance a randomized pattern of 4-5.8-5.5-3.7 m (13-19-18-12 ft) for transverse joints skewed at 1:6 was recommended.

MATERIALS AND CONSTRUCTION

In general, current M.T.C. specifications for grading, granular base, hot mix, lean concrete base and concrete pavement were applied, without change. The following special provisions were included in the contract to deal with specialized construction materials, methodology and test procedures as required for the experimental pavements:

To insure the subgrade would perform uniformly and allow rapid drainage flow into the subdrain systems, the use of an impermeable selected clay borrow was specified between Sta. 34+00 and Sta. 160+00.

Upon final shaping and compaction of the subgrade, construction haul was restricted to shoulder use.

All lean concrete base and concrete pavements were to be placed by slip-forming techniques only.

The surface tolerance for earth grades receiving lean concrete or open graded bituminous base was specified as $\pm$ 12 mm (0.5 inch) from the theoretical grade elevation and cross-section. Prior to laying the second or subsequent base lane width, the subgrade was scarified, reshaped and compacted using an approved 8 ton roller to standard M.T.C. compaction requirements.

The coarse aggregate for the bituminous treated Open Graded Drainage Layer (O.G.D.L.) was specified as 100% crushed material. The O.G.D.L. was designed as a modified HL 8 asphaltic concrete with a 90/10 coarse aggregate/fine aggregate split and 2% by weight of an 85-100 penetration asphalt cement binder. This ratio was slightly modified during construction to improve stability.

The O.G.D.L. is basically an open textured, uniformly graded coarse aggregate with 2% A.C. content which was placed in a 100 mm (4 inch) lift directly on the clay subgrade using conventional paving techniques. This free draining bituminous treated permeable base course material is designed to expedite internal drainage of the pavement structure while providing sufficient stability to resist densification and shear distortion under construction traffic.

Typical gradation curves for the O.G.D.L. mix are shown on Figure 5, adapted after Cedergren (4).

Field permeability testing indicated a lateral flow velocity of 2.8 X 10^{-1} cm/sec (804 ft/day). Based on laboratory permeable testing of cored field samples the average vertical permeability = 1.2 X 10^{-1} cm/sec (350 ft/day). The permeability of the base course was such that water poured on to the surface drained instantaneously into the mat and did not have time to flow over the surface.

Provision was made for two days of evaluation and testing upon completion of the initial kilometre of concrete pavement, to insure material quality, surface tolerance, and texture had been achieved.

The 100 mm subdrain was installed to the required grade and location by ploughing (5,6) and reinstating the displaced granular material in one continuous operation.

In order to insure long term performance and minimize 'D' cracking, high quality aggregates with low absorption characteristics were used in all concrete pavement and bases. Aggregate sources whose material met acceptance criteria for freeze-thaw testing (maximum-0.04% expansion at 350 freeze-thaw cycles) as per ASTM C666, Procedure A were specified. The coarse aggregate used on site was a Manitoulin Island Dolomite.

Complete details of the materials and methodology used in construction of the experimental sections are described in Reference 9.

The specification requirements and results of quality assurance acceptance testing for lean concrete base and concrete pavements are summarized in chart form on Figure 6.

The lean concrete base was constructed by conventional methods using slipform paving equipment to a total width of 7.6 m (25 feet), ie. 150 mm (6 inches) beyond the edge of concrete pavement. The lean concrete was centrally mixed on site, transported by end-dump and belly-dump trucks, and placed on the prepared base by a mechanical spreader.

The concrete wearing course was constructed using conventional slipform paving techniques. Additional ready mix concrete was used for the full depth slab, Section I, to supplement the production of the site plant. Concrete placement commenced on 82-09-08 and continued to completion on 82-10-21 with an average production rate of 1530 cubic metres (2000 cubic yards) per day. The sequence of pour consisted of beginning at the east end (Sta. 0+11), slipforming both 305 mm full depth section and the 200 mm of O.G.D.L. (both with 0.6 mm asphalt shoulders) for the full 7.3 m (24 ft.) width. The final two sections with tied-in concrete shoulders were slipformed in one lane plus shoulder (3.7 m + 0.6 m) width, starting with W.B.L. travelling westerly and then shifting to the E.B.L. and travelling easterly.

COST COMPARISON

Section	Length KM (miles)	Pavement Structure	Cost (1981) $/Km ($/mile)
I	4.8 (3.0)	-305 mm Plain Concrete	$ 220,300 (354,600)
II	5.2 (3.2)	-203 mm P. Concrete 100 mm O.G.D.L. 76 mm Asphalt Shoulder	$ 218,700 (351,900)
III	0.8 (0.5)	-203 mm P. Concrete 127 mm Lean Concrete Base 203 mm Concrete Shoulder	$ 272,600 (438,700)
IV	4.8 (3.0)	-178 mm P. Concrete 127 mm Lean Concrete Base 178 mm Concrete Shoulder	$ 260,600 (419,400)

INSTRUMENTATION AND MONITORING

Profilograph Measurements

Immediately upon setting of the concrete, a California Type Profilograph was walked through the pavement wheelpaths in the direction of paving. For a description and operation details of a profilograph, refer to Reference 7. A summary of the profilograph test results for 1,000 and 4,000 feet sections plus each day's paving is presented in Figure 7. A complete breakdown of the profile index data measured is given in the appendix of reference (7).

Roughness Measurements

A commonly used technique for measuring pavement roughness is the Mays Ride Meter (MRM).

This unit comprises a full-sized station wagon with or without a trailer which has been instrumented to measure the vertical movement of the axle in relation to the vehicle or trailer's body. The chart recorder provides a continuous recording of the vertical movement of the unit's body and the distance travelled by the unit. The chart recorder paper feed is dependent upon the vehicle axle/body movement and advances 1/64 inch for every 0.1 inch of axle/body movement. The measured movement of the vehicle is expressed as inch of axle/body movement per distance or inch per mile (I.P.M.). The Mays Ride Meter accumulates the axle/body movement of the unit through a photocell and celluloid vernier measure.

Each pavement section was tested three times during the initial 2 years of service. These measurements were completed immediately after construction and subsequently on an annual basis. Tests were carried out in each lane at 80 km/hr. and the average of 3 tests per pavement type are summarized graphically in Figure 8.

Skid Testing

In North America the most commonly accepted technique for measuring pavement skid resistance is based on the use of a skid trailer conforming to ASTM Standard E274. The test unit consists of a towing vehicle and a Brake-Force Trailer. The test measures the steady friction force generated when the locked left test wheel standard tire slides over the wetted pavement at a constant travelling speed. During the test a specified quantity of water from the on-board supply system is discharged through a nozzle in front of the test tire to produce a water film thickness of 0.5 mm. The standard (ASTM 501) tire on the brake-force trailer has seven plain ribs on the tread. The measured friction force is described as the skid number (SN) at a specific speed, SN80 at 80 kph for example.

Each pavement section was tested three times during the first 2 years of service and twice in 1985. Initial measurements were completed immediately after construction and subsequently on an annual basis. Tests were carried out in the left wheelpath of each lane at 80km/hr and the average of 20 tests per surface type are summarized in and plotted on Figure No. 9.

Load Deflection Testing

In order to compare the load/deflection characteristics and the joint load transfer efficiencies of the four pavement sections, a non-destructive load testing program was conducted. For each pavement section, ten slabs were randomly selected for load testing using the Dynatest 8000 falling weight deflectometer (FWD). This FWD consists of a mass that can be dropped onto the pavement from several heights to simulate varying axial loadings, an electrical load cell to measure the transmitted load to the pavement, and seismic sensors to measure the displacement of the pavement at seven locations (deflection basin). This instrumentation is mounted on a trailer and the data signals are fed to a HP 85 computer mounted in the tow vehicle. The deflection measurements required to calculate load transfer for the approach and leave sides of the joint were obtained simultaneously with the corner slab measurements by "straddling" the joint using a trailing sensor. The majority of the testing was performed early in the day to minimize the influence of slab curl resulting from differential slab temperatures. No change in the transverse joint opening (13 mm) was apparent at the time of testing.

Typically, the test sequence consisted of the mass being dropped four times; initially to seat the load plate, and then from three different heights corresponding to three load levels, resulting in three sets of deflection readings for each sensor. These were then used to plot the load/deflection characteristics of each pavement type.

Sound Level Measurements

In order to assess relative sound level characteristics of the burlap versus astroturf drag surface texture, sound level measurements were taken by our Research and Development Branch. Three testing procedures were utilized for comparison purposes:

The first procedure is a near tire method comparing noise from pavements. A microphone is placed 10 cm behind the tire of a testing trailer and the sound pressure level, in dBA, is measured while the vehicle is travelling 80km/h. The advantage with this method is, that the sound levels are repeatable with different vehicle runs on different days. The ambient temperature will affect the absolute sound levels but not the relative levels measured between different pavements. The disadvantage of this method is that the sound levels are only measured behind the tire and underestimate the sound being generated by the tire side walls.

The second method measures the maximum sound level of a vehicle passing by 15 m from the centre of the travelled lane. A single vehicle is tested on several different pavements at the same speed (80 km/h) and any differences should be simply due to different pavement/tire noise. The disadvantage is, that only one particular vehicle is considered and there may be differences between different types of vehicles.

The third method measures noise due to the total traffic flow at two different locations adjacent to different pavement types. If there are a large number of heavy vehicles the differences in pavement type can be masked by noise from the truck engines and the vehicles may not operate the same as when they pass the different microphone positions.

The results are expressed in the following table:

Summary of Results

Testing Method	Pavement Type	Date	Sound Level (dBA)
1	Astroturf Concrete	83 10 06	102.3
1	Burlap Concrete	83 10 06	102.5
1	Old Hot Mix	83 10 06	101.8
1	New Hot Mix	83 10 06	102.1
1	Astroturf Concrete	84 06 13	103.3
1	Burlap Concrete	84 06 13	103.2
1	Old Hot Mix	84 06 13	102.5
1	New Hot Mix	84 06 13	102.7
2	Burlap Concrete	84 06 13	74.8
2	Old Hot Mix	84 06 13	75.3
3	Burlap Concrete	83 10 07	66.3
3	Old Hot Mix	83 10 07	67.3

Horizontal Reference Pins

In order to assess horizontal joint movement for the various pavement sections, four sets of pins were embedded in each section across two joints. These pins were placed across the joints between the 5.8 m and 3.7 m panels. Four sets of readings were taken in the first year following construction and two sets in every subsequent year.

At present, only seasonal variations are apparent in the data, no discussions on trends relating to horizontal joint movement are possible due to the short elapsed time since construction.

Vertical Slab Movements

To monitor vertical slab movements, a series of pins were placed in the outer wheel path at 0.6 metre intervals for approximately 20 metres in all four pavement sections.