Concrete Pavement Rehabilitation and Overlay: Ontario's Experience

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Currently, highway authorities are faced with the challenge of rehabilitating portland cement concrete (PCC) pavements on high-volume freeways. In 1989, the Ministry of Transportation of Ontario (MTO) initiated a demonstration contract to rehabilitate one such freeway using various PCC pavement repair techniques in one direction and an unbounded PCC overlay in the opposing direction. The site used to demonstrate these procedures is classed as a four-lane divided arterial with 30,000 average annual daily traffic, 10 percent classified as commercial. The existing pavement consisted of 230-mm mesh-reinforced dowelled PCC with a 21.3-m joint spacing constructed in 1963. The rehabilitation techniques used included full-depth repair, partial-depth repair, diamond grinding, and joint sealant replacement on the northbound lanes that had experienced moderate deterioration. The southbound lanes received a 180-mm-thick plain jointed unbonded PCC overlay to address the severe D cracking and spalling of all joints and cracks. Design and construction details and the performance of the pavement, before and after rehabilitation, are discussed in terms of load transfer efficiencies and pavement edge deflections based on falling weight deflectometer testing; roughness using the profilograph, the portable universal roughness device, and the automatic road analyzer; skid resistance using the ASTM brake force trailer; pavement condition ratings; and a crack survey. Observations of noise levels, traffic volumes, and surface texture are also presented.

Repair of portland cement concrete (PCC) pavement in Ontario has always posed a challenge. Traditionally, rigid pavements have been rehabilitated by removing severely distressed concrete full depth and spalls partial depth and then filling with asphaltic concrete. The patched PCC pavement was then generally overlain with varying thicknesses of hot mix depending on the serviceability level of the pavement and the road classification. This repair technique was used extensively and performed adequately in the short term; however, over time the hot-mix patches began to distort, which significantly reduced the pavement ride.

In order to improve on the Ministry's traditional PCC pavement repair methods, a number of alternative rehabilitation techniques have been tried over the last few years. Some of the techniques tried and proven successful included full-depth removal of distressed concrete and replacement with either normal or fast-track PCC (*1*). Subsealing of concrete pavement has also been used to stabilize slabs that were severely stepped or faulted (*2*). A demonstration contract using PCC pavement rehabilitation techniques, unique in Canada, was a project on Highway 126 in London, Ontario, undertaken during the summer of 1989.

This project used the most diverse PCC pavement rehabilitation techniques ever attempted by Ontario. The repair techniques ranged from partial- and full-depth repairs to diamond grinding on the northbound lanes (NBLs) and an unbonded concrete overlay on the southbound lanes (SBLs).

BACKGROUND

Highway 126 is located on the eastern limit of the City of London, Ontario. Classified as a four-lane divided arterial, this facility experiences traffic volumes ranging from 19,000 to 30,000 average annual daily traffic, and of that, approximately 3,000 are commercial vehicles. There is a high percentage of commuter traffic.

The existing pavement was constructed in 1963 with 225 mm of mesh-reinforced PCC on 300 mm of granular base and subbase materials. The pavement was constructed with a 21.3-m joint spacing and load transfer dowel bars. The joints were sealed with preformed neoprene seals.

The pavement serviceability varied dramatically between the NBLs and the SBLs. The pavement condition on the NBLs was relatively good considering the 26-year service life. The main distresses were three transverse cracks per slab with one of these being very severe, some spalling at joints and cracks, and a moderately polished surface. The joints exhibited minimal stepping and good load transfer. The joint seals were 80 to 90 percent intact, although significant bond failure was apparent throughout.

The pavement condition on the SBLs was considerably worse with numerous full- and partial-width transverse cracks in each slab, severe D cracking and spalling of all joints throughout, and moderate pavement edge distress. Deterioration had advanced to the stage where routine maintenance activities could no longer preserve a safe riding surface.

The variance in pavement performance was attributed to the two types of aggregate used on the opposing lanes. The NBLs were constructed using a pit run gravel source for the coarse aggregate, and the coarse aggregate for the SBLs came from a quarried limestone source. The quarried aggregate exhibited absorptive characteristics and was highly susceptible to D cracking under freeze-thaw conditions.

DESIGN

The design for this project included PCC rehabilitation methods on the NBLs and an unbonded concrete overlay on the

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SBLs. This option of concrete repairs with PCC, diamond grinding, and an unbonded concrete overlay was selected because it best addressed the actual performance deficiencies exhibited by the pavement and provided the longest anticipated service life.

NORTHBOUND LANE REHABILITATION

The work on the NBLs involved full-depth (1940 m^2) and partial-depth PCC repairs, diamond grinding of the surface (29 900 m^2) and sealing of all joints and cracks (5,450 m). One fairly significant revision was made to the earlier specification for full-depth repairs. These required that the contractor use mechanically mounted hydraulic drills (a gang drill) to cut holes for installation of dowel bars. This new requirement was made to ensure that the holes were drilled in line with the pavement axis and also that they were not elongated or out of round. Adequate load transfer at the patch interface is one of the most critical aspects of the design of full-depth repairs.

A plan view of the full-depth repair is shown in Figure 1. The standard repair size is 2 m long by either one or two lanes wide. General dowel bar layout and references to jointing are also provided on this drawing. Longitudinal tie bars were only used in repair sections greater than 2 m in length, and consisted of 15-mm deformed bars placed on 600-mm centers.

To provide load transfer between the existing and repaired slabs, 32-mm-diameter by 450-mm-long epoxy-coated smooth dowels were resin grouted into the existing pavement at 300-mm intervals, midheight in the slab. The exposed length of the dowel and the concrete face were coated with a bond breaker to ensure that a working contraction joint was provided. A 25-MPa portland cement was used in the repairs. Figure 2 shows the details of the full-depth repair and placement of the dowel bars.

Partial depth repairs with PCC had not previously been undertaken in Ontario, so new drawings and specifications for this work were developed. Typical drawings used for this work are shown in Figure 3. The specification required all unsound spalled concrete to be removed; an average removal depth of 75 mm was used for estimating. Where spalls extended deeper than half the slab thickness, a full-depth repair was specified. Following removal and immediately before placement of 25-MPa concrete, the exposed surfaces had to be abrasive blast–cleaned, and then coated with a PCC paste. Where the repair was adjacent to a crack or joint, a gap had to be formed in this area to allow for expansion at the joint or crack and to prevent spalling of the patch. Proper patch isolation is critical to minimize compression failure of the patch.

Following curing of full- and partial-depth repairs, the complete northbound pavement surface was retextured by diamond grinding. Diamond grinding was specified to improve skid resistance, restore a smooth surface profile and reinstate an acceptable ride to the pavement surface. The grinding specification required specialized equipment with a minimum 900-mm-wide grinding head, having at least 60 diamond blades per 300 mm of width. The final surface texture to be achieved was also specified.

Following texturing of the concrete surface, all existing joints and cracks were cleaned of old joint sealant and incompressibles. Before sealant application, all joints were sandblasted, cleaned, and dried with a hot-air lance. A bond breaker was placed at the bottom of the joint and then sealed with a hot-poured rubberized sealant. The joints between the full-depth repair areas and the existing concrete were treated similarly except a saw cut for the sealant was required.

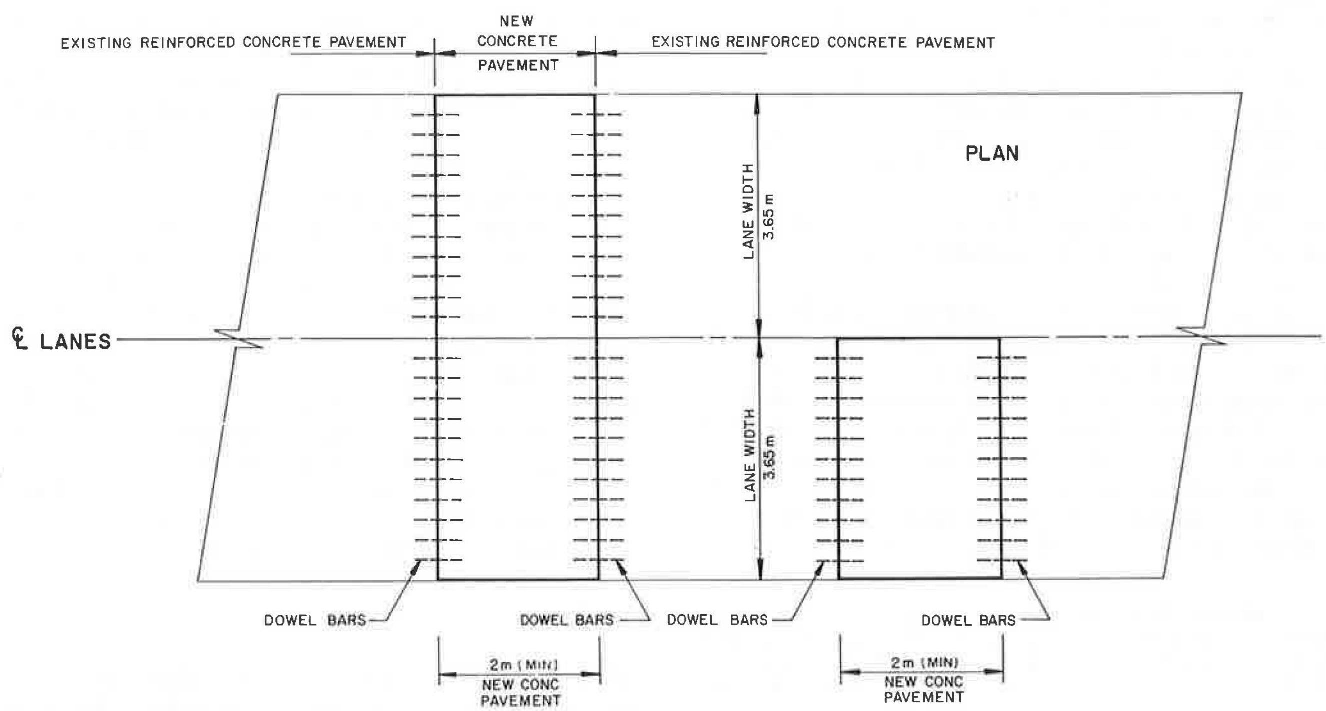


FIGURE 1 Full-depth concrete repairs plan view.

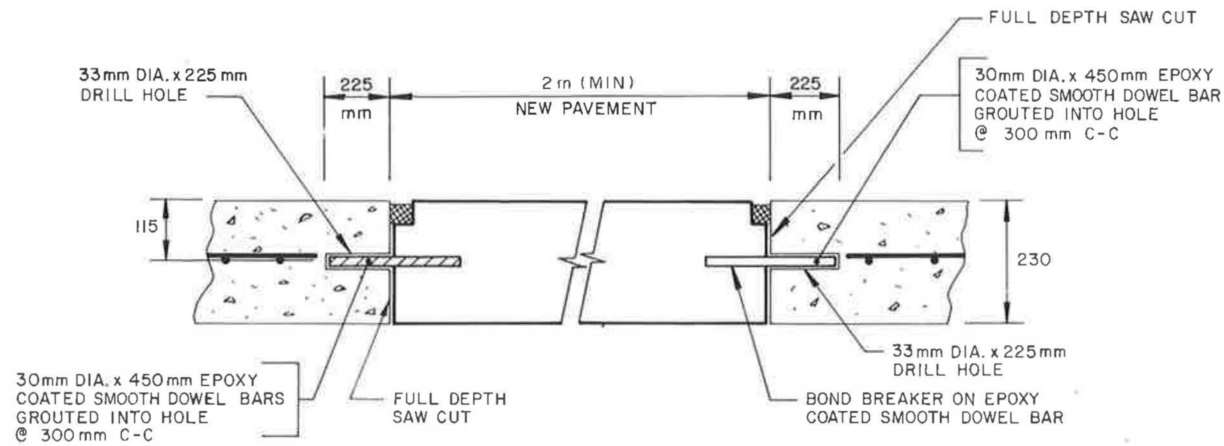


FIGURE 2 Full-depth concrete repair cross-section.

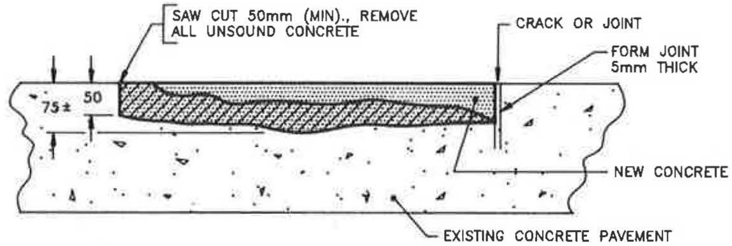


FIGURE 3 Concrete spall repairs.

SOUTHBOUND LANE REHABILITATION

The design of the unbonded concrete overlay on the SBLs included the removal of any loose spalled material from the existing badly cracked pavement. The spalled areas (427 m^2) were then patched with hot mix and a 20-mm asphaltic sand mix bond breaker (884 tonnes) was specified over the existing pavement surface. The sand mix was placed to prevent bonding between the new and old PCC pavements and minimize reflection cracking in the overlay. Following placement of the bond breaker, a 180-mm-thick unreinforced plain-jointed concrete pavement (38 200 m^2) was placed. A typical cross section showing these details is provided in Figure 4.

Slipforming of the unbonded overlay was carried out using Ontario's revised specifications and drawings for concrete pavement. The revisions were based on experience gained on the experimental concrete pavement sections on Highway 3N (*3,4*).

CONSTRUCTION

Generally, construction of the concrete repairs, diamond grinding, and the unbonded overlay went smoothly following the initial start-up difficulties.

During construction, the highway was closed to traffic, which simplified construction staging. Sawcutting for full-depth repairs was carried out in advance of slab removal and replacement.

Initially, during removal of the full-depth concrete some spalling of the existing concrete at the sawcut edge occurred where only two sawcuts were made. The contractor then elected to make a third sawcut on one side of the repair to remove a small 150-mm-wide slab before removal of the larger 2-m slab. This operation eliminated all spalling at the edge of the repair area. The contractor used a backhoe to remove the concrete slabs and disturbance of the underlying granular was negligible. Concrete removal was only undertaken where the placement of concrete could be completed on the same day. This minimized disturbance of the exposed granulars caused by construction activity and infiltrated water.

Following removal of concrete, drilling for dowel bars was completed using a Tamrock gang drill. This system worked well and increased production significantly over the single drills used on previous contracts.

After air cleaning of the holes, the dowel bars were epoxied into place using a two-part epoxy cartridge system. This method ensured that epoxy was uniformly distributed throughout the hole. The dowel bars were then inserted and rotated, and the grout was forced forward, enveloping the bar. The exposed ends of the dowel bars were then coated with grease (a bond-breaking agent) to allow for longitudinal movement of the pavement slabs.

Normal PCC, 25-MPa mix, was placed and finished flush with the existing slabs using a razor back screed. Matching of surface tolerances was not critical because the entire surface was to be diamond ground.

Spall repairs were undertaken following full-depth repairs. They involved sawcutting around the spalled area to a depth of 50 mm and removing all unsound concrete. Spall repairs located adjacent to existing cracks or joints were removed, leaving small sections of sound concrete between repairs. These small sound areas fractured and spalled off in a day or two

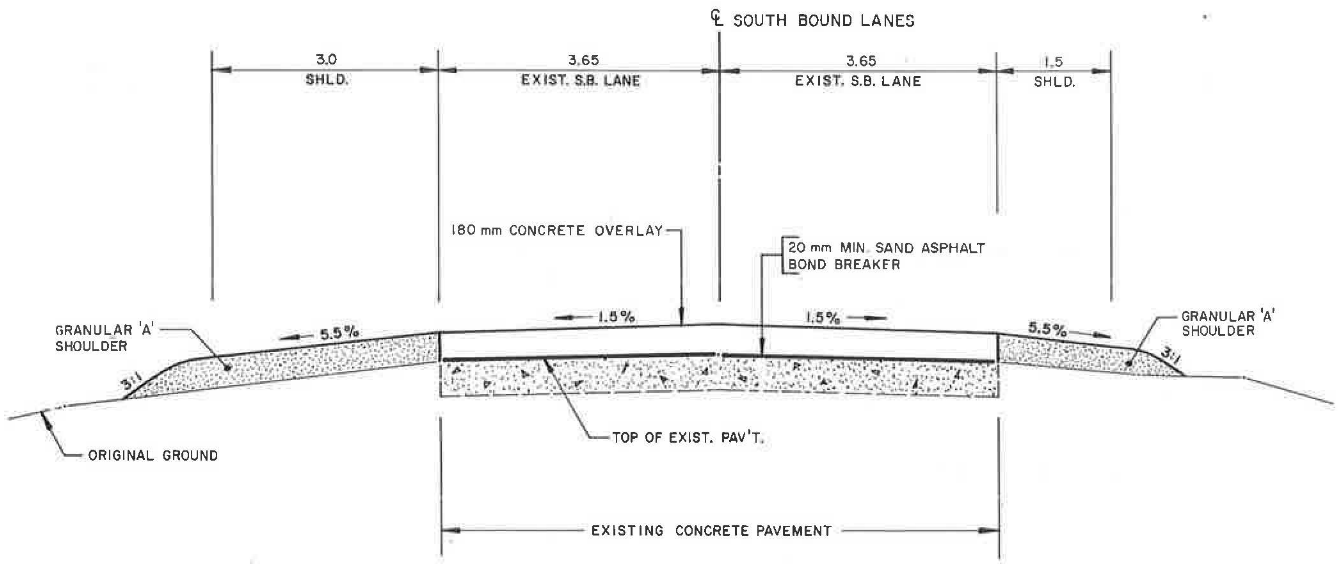


FIGURE 4 Unbonded concrete overlay.

as the pavement expanded. In order to avoid this problem, the entire joint width was repaired.

Following placement and curing of these repairs, the NBLs were diamond ground. The grinding equipment comprised a grinding head mounted between the forward and rear wheels of a weighted frame. This arrangement planed the surface for a minimum depth of 1.5 mm, both retexturizing and reprofiling the concrete surface. An integral vacuum system was used to pick up the cuttings. This slurry was stored in a mobile tank and disposed of at the local sewage treatment plant.

Once diamond grinding was completed, the cracks were routed, cleaned, and sealed with hot-poured rubberized asphalt. A short test section of silicone sealant was placed on the NBL cracks.

Construction of the unbonded concrete overlay on the SBLs went smoothly following a few initial breakdowns on the slipform paver. The two lanes were slipformed simultaneously with longitudinal tie bars being inserted every 600 mm on the centerline. The plastic concrete surface was dragged longitudinally with a burlap mat and tined transversely to achieve the specified surface texture. Speed change lanes were then slipformed and tied onto the outside of the core lanes where required.

Skewed joints were sawcut into the overlay at random intervals varying from 3.7 to 5.8 m. No uncontrolled cracking of the pavement occurred as sawcutting was not required within 12 hr after placement.

The pavement ride was somewhat better than the previous slipforming project, which was in part because of a requirement for stringline control on both sides of the slipform paver. Pavement ride is discussed in further detail in the following section.

PAVEMENT PERFORMANCE

Roughness Measurements

The ride of a pavement is the most visible sign of pavement condition to the traveling public, therefore the collection and analysis of the ride condition or roughness data were undertaken.

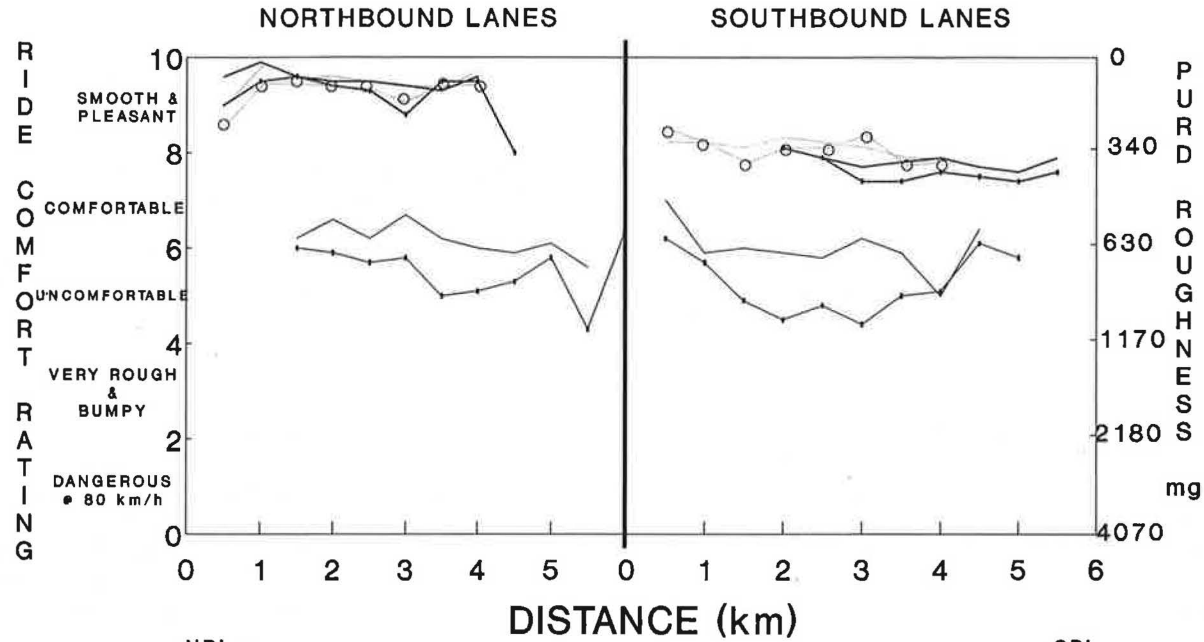
Just after construction and before opening to traffic, roughness was measured using the California profilograph. (SBLs only) and the portable universal roughness device (PURD).

The profilograph measurements were taken on the new concrete overlay with readings taken in both wheelpaths of the driving and passing lanes. The average profilograph reading, profile index, for the length of the project in the driving lane was 11.09 in. mi (10.66 in. mi in the passing lane). These readings were taken before grinding 21 locations at which the roadway did not meet the surface tolerance specifications of 3 mm in 3 m. These numbers compare reasonably well with those obtained by other authorities constructing considerably larger quantities of concrete pavement. Many of these agencies have performance specifications requiring a ride ranging from a high of 12 in./mi to as low as 7 in./mi with incentive bonuses for smoother pavements.

Roughness measurements using the PURD were also taken. The PURD is a trailer-mounted accelerometer-based mechanical measuring device operated at constant highway speed, which measures and calculates the root-mean-square vertical acceleration, in thousandths of *g*, of the trailer axle as an indicator of pavement roughness. PURD measurements are converted into a ride rating, RCR, using a transfer function for use in pavement management applications.

Both pavements were tested for roughness using the PURD before rehabilitation, after rehabilitation just before opening to traffic, and in the spring of 1990. All four traffic lanes were tested.

The ride was improved significantly following rehabilitation with a reduction in roughness from an average of 800 m*g* for all lanes (RCR of 5.8) to 230 m*g* (RCR of 9.2) for the NBLs and 360 m*g* (RCR of 7.8) for the SBLs. See Figure 5 for the details. The 8-month postconstruction PURD testing does not indicate any significant change in ride except on the SBLs where the ride has improved slightly. This effect is probably because of wearing of coarse projections on the tined surface. The detailed PURD measurements are shown in Figure 5 and summarized in Figure 6.



NBL LEGEND AVG RCR / TEST DATE	BEFORE MAY 89	AFTER NOV. 89	AFTER MAY 90	SBL LEGEND AVG RCR / TEST DATE	BEFORE MAY 89	AFTER NOV. 89	AFTER MAY 90
DRIVING	5.4	9.1	9.1	DRIVING	5.1	7.7	7.9
PASSING	6.5	9.3	9.2	PASSING	6.1	7.8	8.0

FIGURE 5 PURD roughness survey.

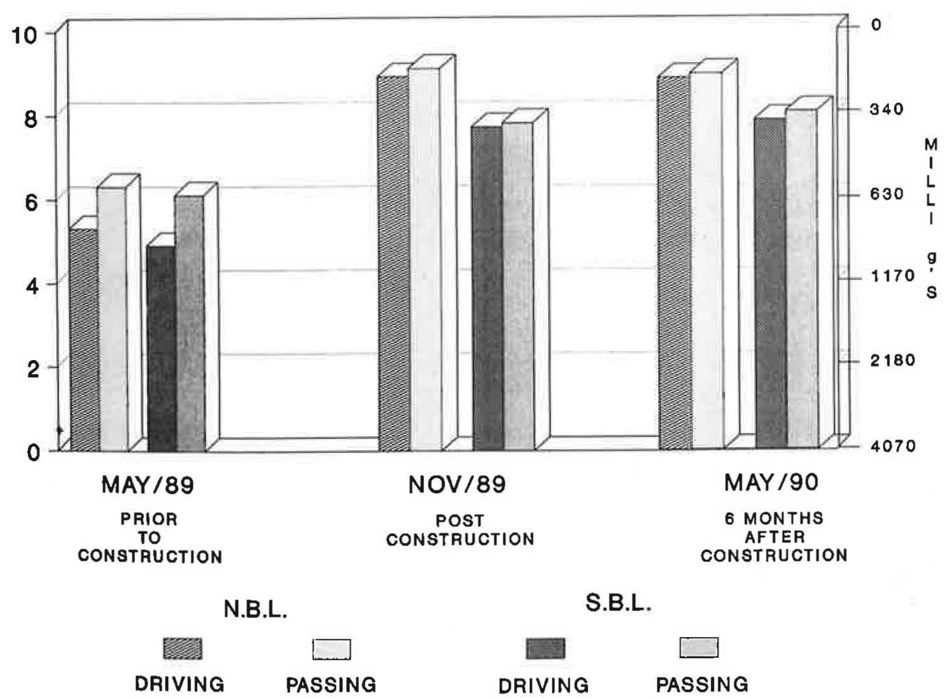


FIGURE 6 Summary of PURD survey.

The roughness numbers for the diamond-ground surface indicate a very smooth surface was obtained. The slipformed concrete, which averages 360 mg, is somewhat rougher than the diamond-ground surface; however, it is only slightly rougher than the ride achieved on a new asphalt surface.

Skid Testing

In North America, the most commonly accepted method for measuring skid resistance is the skid trailer conforming to ASTM Standard E274. The test unit consists of a towing vehicle and a brake force trailer on which a wheel locks. The horizontal and vertical forces that are required to pull the locked wheel over wet pavement are measured. Water is applied to the pavement directly in front of the locked wheel. The measured friction force is described as a skid number (SN) at a specific speed, for example SN80 at 80 km/hr.

Skid resistance testing was completed before construction and twice after construction and the data are detailed in Figure 7 and summarized in Figure 8. The test results immediately after construction indicate there was a substantial increase in skid resistance on both the NBLs and SBLs, as expected. The skid numbers in the SBLs increased to an average of 55 for both lanes from 18.3 and 28.9 in the driving and passing lanes, respectively. On the diamond-ground surface, the skid numbers improved from an average of 24.8 and 35.1 to 48.0 and 50.4 for the driving and passing lanes, respectively.

Skid numbers of this magnitude indicate a good friction factor and are similar to numbers obtained on premium hot-mix surface courses (*5*). The corduroy type of texture developed by grinding visually indicates high frictional resistance. The ridges improve the surface macrotexture and provide an escape route for moisture under a tire. The broken peaks, concrete fractured between the blades, improve microtexture.

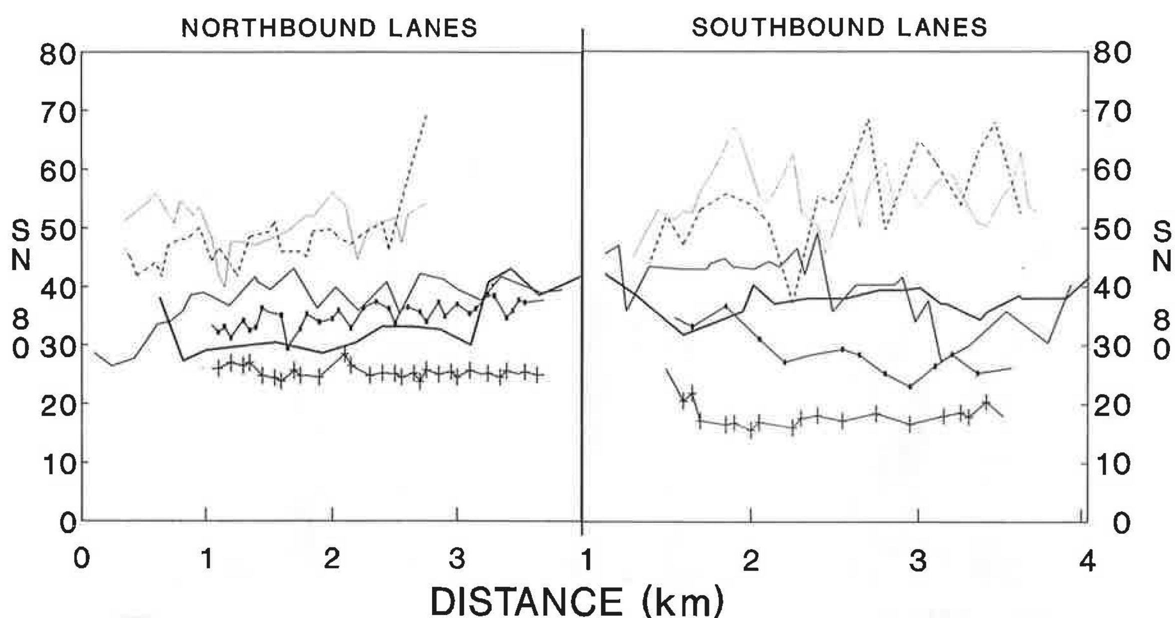
Testing in the spring of 1990 has shown a fairly significant reduction in skid number from the initial postconstruction number and confirmed expectations. The 1990 skid tests provided average numbers of 37 and 40 in the passing lanes and 35 and 36 in the driving lanes for NBLs and SBLs, respectively. These numbers are somewhat lower than those ranging from 48 to 55 obtained in the immediate postconstruction tests.

Visual observations indicate that the microtexture in the wheelpaths on both the NBLs and SBLs has undergone some polishing.

On the basis of previous experience, this decrease was anticipated as the initial sharp projections of both the ground and drag-tined surfaces were worn or sheared by traffic and snow removal operations. This elimination of sharp projections reduces skid resistance, particularly in the short term. The rate of friction loss in the long term is heavily dependent on traffic volume, abrasion of maintenance activities, and the aggregate mineralogy.

Sound Level Measurements

Sound level measurements were undertaken on Highway 126 before and following rehabilitation. Because highway noise



NBL

LEGEND / AVG SKID — TEST DATE	BEFORE MAY 89	AFTER NOV. 89	AFTER MAY 90
DRIVING	25	48	35
PASSING	35	50	37

SBL

LEGEND / AVG SKID — TEST DATE	BEFORE MAY 89	AFTER NOV. 89	AFTER MAY 90
DRIVING	18	55	36
PASSING	29	55	40

FIGURE 7 Skid resistance survey.

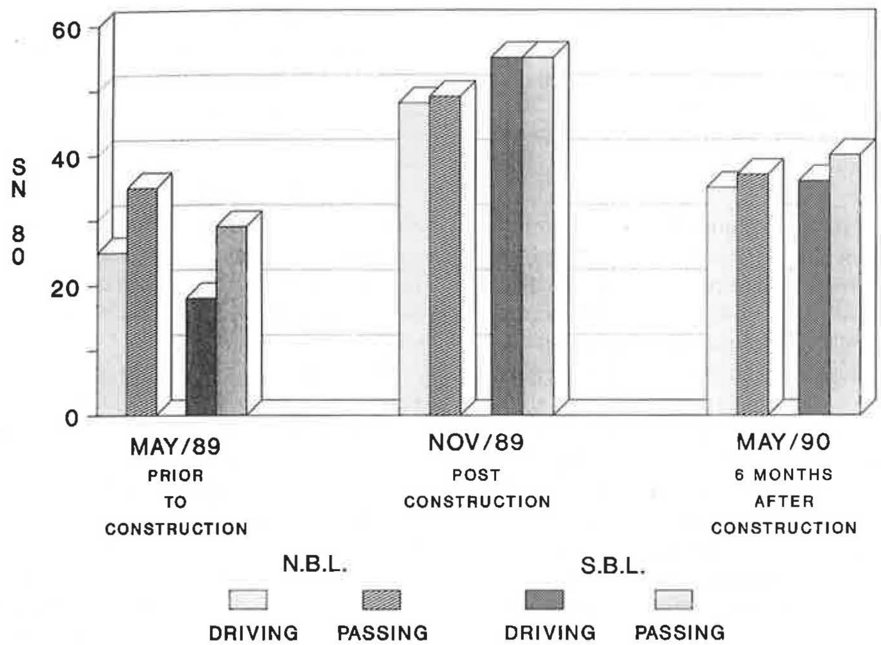


FIGURE 8 Summary of skid survey.

is becoming an ever-increasing environmental concern to the public, it is important to collect and maintain this information.

The procedure used to evaluate pavement noise on this project was to measure sound emissions from individual vehicle passbys at a 15-m distance from the traveled lane. The results are plotted on Figure 9 and indicate that the diamond-ground surface was approximately 1 dBA quieter than the old worn concrete and the MTO sample. The ground surface is only 1 dBA louder than the open-graded friction course used for its low noise and good skid resistance characteristics. The MTO sample was provided by Jung et al. (*6*) and was derived by testing several hundred vehicles on a variety of pavement surfaces across the province.

The burlap-dragged and transversely tined concrete surface was approximately 1 dBA noisier than the worn concrete and MTO sample. The new concrete on the SBLs should become quieter as some of the very coarse tining wears off.

Load Response Characteristics

In order to compare the load-deflection characteristics and the joint load transfer efficiencies of the rehabilitated pavement, a nondestructive load testing program was conducted. Deflection testing was completed using the Dynatest 8000 falling-weight deflectometer (FWD). The FWD simulates various axle loadings by dropping a mass onto the pavement from various heights. A load cell is used to measure the transmitted load to the pavement and seven seismic sensors are used to measure displacement of the pavement.

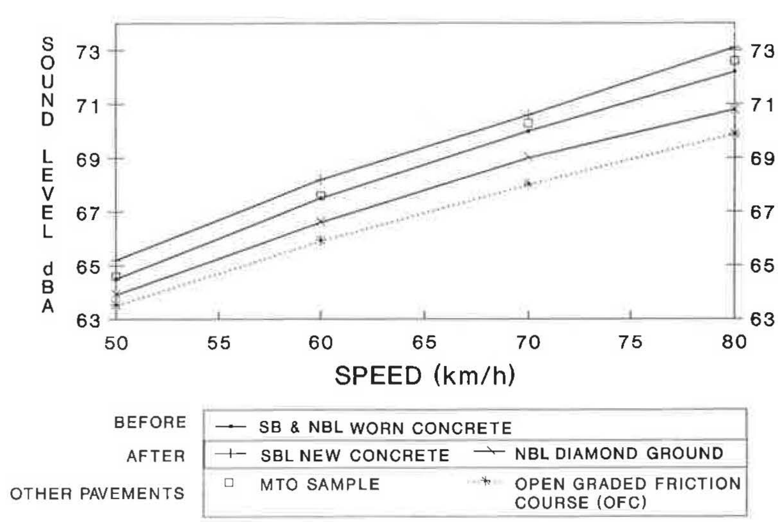


FIGURE 9 Pavement noise emission of automobiles.

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.

Before rehabilitation, slabs were randomly selected for testing of corner to center deflection ratios and load transfer efficiency across joints. This information was used for design to determine whether voids existed below the slabs and to establish the need for stabilization of the joints by subsealing.

Overall deflection testing indicated that the existing pavements, both NBLs and SBLs were in a stable condition before rehabilitation. Load transfer across joints or cracks tested varied from a mean value of 78 to 89 percent on the NBLs and from 67 to 83 percent on the SBLs. Load transfer efficiency of 70 to 100 percent is generally observed in relatively new pavements and is considered acceptable (*7*). These test values also indicated that voids beneath the slabs were very small or nonexistent. The corner to center deflection ratio testing on the old pavement verified acceptable slab support on the basis of mean values ranging from 3.3 to 5.9 in the NBLs and from 4.4 to 4.8 in the SBLs. Following rehabilitation, and before opening to traffic, deflection testing was undertaken at the same locations or at the nearest point to the preconstruction testing. This work was undertaken to evaluate the performance of the repairs and to provide a general comparison on the overall performance of the rehabilitation work.

Testing on the unbonded concrete overlay indicated a substantial improvement in both load transfer and corner to center deflection ratios, as expected. The postconstruction load transfer testing indicated mean values ranging from 88 to 91 percent, an increase of 5 to 24 percent over mean preconstruction levels. The load transfer was also more uniform among the joints tested as evidenced by the reduction in the range and standard deviation of test values. The corner to center deflection ratios were also substantially improved after rehabilitation with similar trends to those observed for load transfer. This information is shown graphically in Figure 10.

On the NBLs, postconstruction tests for load transfer and corner to center deflection ratios were carried out on unrepaired joints and slabs as well as repaired sections. The results for the unrepaired sections were very similar to preconstruction results with some minor changes within normal test variations.

The results of FWD testing across the full-depth repair joints indicated load transfer had been reduced in areas where improvements were anticipated. A general pattern of lower load transfer values, in the order of 20 percent, was observed when loads were applied on the repair itself versus loading on the old concrete. These data are shown graphically in Figure 11a.

This pattern may be explained by surficial loosening and softening of the granular base in the repair area during full-depth repair activities. These activities may create a thin loosened zone susceptible to deformation. The mechanism for the reduction of load transfer is inconclusive and will require further investigation.

The use of grease as a bond-breaking agent on the dowel bars in the repair has also been suggested as a possible contributor to reduced load transfer. The grease may create a small void around the dowel bar. Further investigation will also be required in this area.

Previous studies (*8*) have found that reduced load transfer is usually observed when the load is applied on the unrepaired concrete. This pattern was found to be a result of voids above the grouted bar in the existing concrete pavement. Results on this project are opposite to these previous studies.

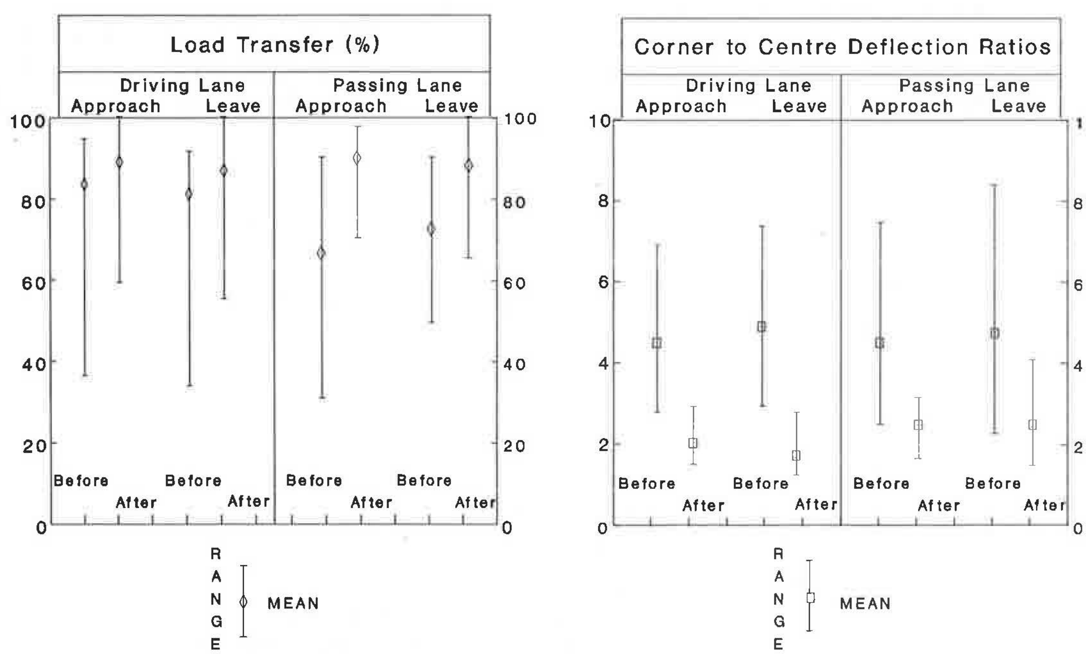


FIGURE 10 Load deflection results, SBLs.

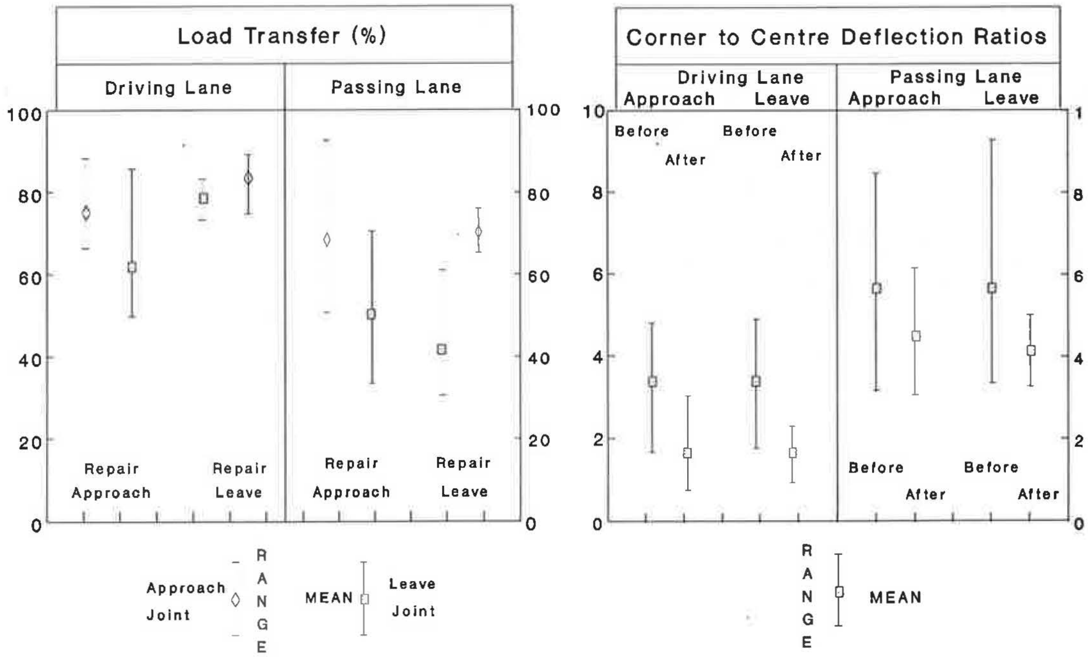


FIGURE 11 Load deflection results, NBLs.

Generally corner to center slab deflection ratios were improved following rehabilitation, as anticipated. The most significant improvement was in the reduction of the range of values obtained for corner to center deflection ratios. This result indicates that the weakest locations were improved and the entire length of the pavement has experienced an increase in stiffness and slab support, as shown in Figure 11b.

CONCLUSIONS

This report summarizes the successful design and construction of one of the most innovative PCC pavement rehabilitation projects undertaken in Ontario. It also provides an overview of the initial performance of these rehabilitated PCC pavements. Monitoring and data collection is continuing and future performance results will be documented.

The following general conclusions are based on short-term postconstruction results:

1. A significant improvement in ride and skid resistance is attainable using diamond grinding techniques. Postconstruction ride and skid resistance measurements were as good as, if not better than, those values obtained with premium hotmix surface course.
2. The integrity and continuity of the overall pavement structure was improved by undertaking full-depth repairs and the unbonded concrete overlay.
3. Noise level testing indicates that immediate postconstruction pavement noise levels are slightly lower for the diamond-ground surface when compared to preconstruction levels and marginally higher for the unbonded overlay.
4. The actual construction costs for this project were virtually identical to those obtained in estimates.
5. As an overall conclusion, the Highway 126 project has proven that full PCC pavement rehabilitation can be successfully and economically carried out in Ontario. These techniques provide an alternative methodology for addressing the rehabilitation of Ontario's aging highway infrastructure.

Several aspects of PCC pavement rehabilitation requiring further developmental work include the following:

1. Improvements in retrofitting load transfer devices to minimize subbase disturbance for full-depth repairs;
2. Improved methods of detecting and removing deteriorated concrete and replacement with economical high early strength patch materials;
3. Investigate and monitor the long-term skid resistance of diamond-ground pavements; and
4. Develop an end result surface tolerance specification for burlap dragged-tined and diamond-ground pavement surfaces in Ontario.

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