

**CPR TECHNIQUES IN ONTARIO
- 15 YEARS EXPERIENCE**

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Paper prepared for presentation at the

Very Long-Term Life-Cycle Analysis of Pavements –
Determining the True Value of Our Investment (B)

of the 2005 Annual Conference of the
Transportation Association of Canada
Calgary, Alberta

ABSTRACT

In the summer of 1989, the Ministry of Transportation of Ontario (MTO) undertook the rehabilitation of an exposed concrete pavement exhibiting various distress manifestations. Highway 126 in Southwestern Ontario is a four-lane divided arterial with 22,000 AADT and 9.6% commercial traffic in year 2000. The existing pavement, originally constructed in 1963, consisted of 230 mm mesh reinforced Portland Cement Concrete (PCC) pavement with dowelled joints at a spacing of 21.3 m.

The rehabilitation of the highway in the northbound lanes (NBL), which had experienced moderate deterioration, consisted of using the latest concrete pavement rehabilitation (CPR) techniques, material specifications and construction methods. The rehabilitation techniques included full depth repair, partial depth repair, diamond grinding and joint sealant replacement. The southbound lanes (SBL) received a 180 mm thick plain jointed unbonded PCC overlay to address the severe 'D' cracking and spalling at all the joints and cracks.

This paper will discuss the fifteen-year evaluation of this rehabilitated pavement in terms of roughness measurements using the Automatic Roughness Analyzer (ARAN), frictional resistance measured with the ASTM brake-force trailer, and Pavement Condition Ratings. Also included will be a discussion on subsequent localized concrete pavement repair work completed on the highway during the fifteen years.

Monitoring the performance of the pavement over the last fifteen years has indicated that locations for partial depth repairs must be chosen judiciously to ensure that they are not greater than one-third of the slab depth. Where existing pavement joints have seized and full depth repairs are constructed at mid-slab, further deterioration of secondary minor transverse cracks can occur. Consideration should be given to carrying out full depth repairs at these locations during initial construction. Although diamond grinding significantly improved the ride of the rehabilitated pavement, the initial improvement in skid resistance has dissipated so that after fifteen years, the average SN_{80} is 7 units lower than the burlap dragged/tined surface.

Overall, the rehabilitated concrete pavement, both NBL and SBL, is performing well, with acceptable levels of ride quality, frictional resistance and distress propagation.

1.0 INTRODUCTION

Until 1989 the traditional method of rehabilitating concrete pavements in Ontario was to remove the distressed concrete full depth or partial depth and replace it with asphaltic concrete. Although these repairs performed well in the short-term, in the long-term the hot mix patches would begin to distort and crack resulting in a rough ride. During the mid to late 1980's, significant advances in concrete pavement rehabilitation (CPR) techniques in North America were achieved allowing the restoration of rigid pavements

with concrete. This maintained the integrity of the PCC slabs and the long-term benefits of concrete. A site was selected in the late 1980's to demonstrate various restoration techniques, including methods that had not previously been utilized in Ontario.

At the time of construction, this project utilized the most comprehensive CPR techniques undertaken in Canada. The demonstration site is located on Highway 126, a 5 km urban arterial facility in London, Ontario. The highway has since been assumed by the City of London and is now known as Highbury Avenue. Rehabilitation techniques included partial and full depth repairs and diamond grinding on the northbound lanes and an unbonded concrete overlay on the southbound lanes. Construction was completed late in the summer of 1989.

2.0 BACKGROUND

2.1 General

Highbury Avenue is located approximately 200 kilometres west of Toronto. It is a four-lane divided arterial, with an AADT of 22,000, and 9.6% commercial vehicles in year 2000. According to the year 2000 traffic study data, the southbound commercial vehicle traffic is 11.3%, which is significantly higher than the northbound traffic of 7.9%.

The original pavement was constructed in 1963 with 225 mm of mesh reinforced PCC (JRCP) on 300 mm of granular base and subbase materials. The pavement was constructed with a 21.3 m joint spacing with dowel bars at the transverse joints. The joints were sealed with preformed neoprene seals.

The pavement serviceability in 1989 varied dramatically between the northbound and southbound lanes. The general pavement condition of the northbound lanes was considered better than average considering the 26-year service life. The distresses on these lanes consisted of approximately three transverse cracks per slab, with one being a severe working crack and two slight cracks, occasional spalling at joints and cracks, and a moderately polished surface. Typically the transverse contraction joints had seized, leading to the severe mid-slab working cracks. Minimal faulting (stepping) was exhibited at the joints. The joint seals were approximately 85% intact, although there was significant bond failure between concrete and sealant throughout.

The pavement on the southbound lanes was in much poorer condition, with full and partial width transverse cracks in each slab, severe D-cracking, spalling of all joints throughout, and moderate pavement edge break-up.

The variance in the 26-year pavement performance was attributed to the different aggregate types used in the concrete on the opposing lanes. The quarried aggregate used on the southbound lanes exhibited absorptive characteristics and was highly susceptible to D-cracking under freeze/thaw conditions. A pit run gravel source was

used for the coarse aggregate on the northbound lanes, which did not exhibit this D-cracking performance characteristic.

Three rehabilitation strategies were considered:

- crack and seat with an asphalt overlay;
- repair of the PCC pavement with hot mix and a multiple lift asphalt overlay; and
- full depth repairs and spall repairs with concrete plus diamond grinding on the northbound lanes; and placement of an unbonded concrete overlay on the southbound lanes.

The estimated initial construction costs for the three options varied from \$1.5 to \$1.8 million, however, the total life cycle costs over 30 years were similar. The option of concrete repairs with PCC, diamond grinding and an unbonded concrete overlay was selected, as it best addressed the actual performance deficiencies exhibited by the pavement and provided the longest anticipated service life.

2.2 Design

The PCC rehabilitation techniques utilized on the northbound lanes incorporated the latest designs and construction procedures. The design of the full depth repairs included a minimum repair width of 2.0 m with epoxy coated dowel bars epoxied into drilled holes spaced at 300 mm on both transverse faces. Also, the existing concrete had to be removed in such a manner as not to disturb the underlying granular base. See Figure 1 below for the full depth repair operation.



Figure 1. Typical Full Depth Repair in NBL

The partial depth repair requirements included sawcutting the perimeter to a depth of 50 mm, removal of loose concrete, and sandblasting of the final exposed surfaces. A cement paste was applied immediately prior to concrete placement. The designs used are fully detailed in [1].

The design of the unbonded concrete overlay on the southbound lanes included the placement of a 20 mm asphaltic sand hot mix bondbreaker over the existing pavement surface. Then overlain by a 180 mm thick unreinforced plain jointed concrete pavement. Slipforming of the concrete overlay used revised specifications based on experience gained on an earlier MTO demonstration project on Highway 3N, which placed and monitored four types of experimental concrete pavements [2, 3]. Skewed randomized joints were utilized with no effort made to avoid matching the underlying joints. See Figure 2 below for the slipform paving of the unbonded concrete overlay.



Figure 2. Slipforming Unbonded Concrete Overlay in SBL

2.3 Construction

There were some initial difficulties with the removal of the existing concrete for the full depth repairs without disturbing the granular base. Once this was resolved, the construction of the concrete repairs, diamond grinding, and the unbonded overlay went smoothly. Details of the construction procedure and material testing have been published in the earlier report [1].

2.4 Maintenance

Routine maintenance is required to prolong the pavement structure. Maintenance activities included resealing of cracks and joints, as well as some full depth and partial

depth concrete repairs performed in the NBL in years 1995 and 2000. SBL activities included resealing of cracks and joints plus minor full depth and partial depth concrete repairs in 1997.

The remedial work carried out on both NBL and SBL after the last major rehabilitation in 1989 were summarized in Table 1 below:

Table 1. Remedial Works Carried Out after Major Rehabilitation

Year	Location	Types & Quantities of Repair
1994	Northbound lanes	<ul style="list-style-type: none"> • Full depth repair - 800 m² • Partial depth repair - 35 m²
1995	Northbound lanes	<ul style="list-style-type: none"> • Resealing of joints and cracks - 375 m
1997	Southbound lanes	<ul style="list-style-type: none"> • Full depth repair – 535 m² • Partial depth repair 10 m² • Resealing of joints and cracks – 110 m
2000	Northbound lanes	<ul style="list-style-type: none"> • Full depth repair – 1300 m² • Partial depth repair – 20 m² • Resealing of joints and cracks – 810 m

3.0 PAVEMENT PERFORMANCE

3.1 Pavement Distress Survey

The visible distresses in the pavement surface were surveyed using the ministry's Rigid Pavement Evaluation Procedure [4] to provide an overall indication of pavement performance.

3.1.1 Northbound Lanes – At 3 years of service

In 1992, after three years, seven of the 266 full depth repairs were exhibiting a very slight longitudinal cracking in the right wheelpath of the driving lane. In a few locations, these cracks began to propagate into the adjacent slabs. No signs of movement or faulting of the repairs were observed.

At that time, approximately half of the 75 partial depth repairs were exhibiting distress. The majority of the failures were in the driving lane and in the outside third of the slab.

In 1992 a limited investigation of a few partial depth repairs was undertaken. The investigation revealed that the partial depth repairs had extended to the level of the dowel bars, with associated joint movements resulting in rapid deterioration (cracking and spalling) occurring at the repairs. This reaffirms the generally accepted practice of

not undertaking partial depth repairs for depths greater than one third the slab depth or where shallow dowel bars/reinforcing meshes are encountered [5]. Cores were taken through some slabs where the partial depth repairs did not exhibit any cracking. In these uncracked repairs, the replacement did not exceed a third of the slab depth and bond between the old and new concrete was excellent. In the deteriorated repairs, bond between the old and new concrete was also very good, indicating the weakness or spalling in the slab extended below the repair level. These findings confirm the importance of critical assessment of where partial depth repairs should be used.

3.1.2 Northbound Lanes – At 5 years of service

In 1994 a detailed distress survey was also carried out indicating that further full depth repairs were required. A total of 96 areas requiring full depth repairs (including 13 of the original repairs) and 16 new partial depth repairs were identified. Pavement monitoring has revealed that where existing pavement joints are seized (non-working), and full depth repairs are constructed at mid-slab working cracks, future deterioration of secondary minor transverse cracks, requiring full depth repairs, may occur. Consideration should be given to carrying out full depth repairs at the time of initial rehabilitation or scheduling them at a future date. The majority of the full depth repair locations required the minimum one lane width by 2.0 m long repair. The partial depth repairs were all one-half a square meter in size. An additional 46 cracks identified that need to be removed and replaced did not exist or were not wide enough to require full depth repairs at the time of original construction.

In the summer of 1994, the City of London completed 96 full depth and 16 partial depth repairs along with limited joint and crack resealing. The repairs were completed in the same manner as the original repairs as detailed in [1], except that the surface of the repairs was not diamond ground but tined longitudinally by hand, while the concrete was plastic.

3.1.3 Northbound Lanes – At 10 years of service

In 1999, the survey of the northbound lanes indicated that a few of the new repairs have cracked in the wheelpath of the driving lane, as happened with the original repairs. These cracks are slight in severity. There was also some slight spalling of the repairs and original concrete at the joints and cracks.

3.1.4 Northbound Lanes – At 15 years of service

A recent survey of the northbound lanes in Fall 2004 indicates the pavement is in fair to good condition, with a Pavement Condition Rating (PCR) of 63 in the driving lane, and 70 in the passing lane. MTO's Pavement Condition Rating (PCR) is a composite pavement serviceability index ranging from 0 to 100; with the higher rating indicating a better pavement condition. Routing and sealing of cracks and joints, plus additional full depth and partial depth concrete repairs was carried out in early 2000. Most of the

joints and cracks are performing well. There were a few moderate faulted joints and intermittent moderate joint and crack spalls. In addition, extensive severe pavement edge drop off was identified. See Figure 3 below showing the typical northbound lanes performance in 2004 adjacent to full depth repair.



Figure 3. Typical NBL Pavement Condition

3.1.5 Southbound Lanes – At 10 years of service

There were minimal distresses identified in southbound lanes for the first 9 years, until 1999 the only distress observed in the southbound lanes is slight longitudinal cracking in 11 of the driving lane slabs. This can probably be attributed to inadequate longitudinal joint construction (i.e., delayed saw cutting) as the cracks were visible soon after construction. No transverse or reflection cracking has been observed, which correlates with other agencies' experience [6].

3.1.6 Southbound Lanes – At 15 years of service

A recent survey of the southbound lanes in Fall 2004 indicates the pavement is in good condition with Pavement Condition Rating (PCR) of 70 in the driving lane, and 78 in the passing lane. In 1997, southbound lanes maintenance activities included routing and sealing of cracks and joints, as well as a few full depth and partial depth concrete repairs. There were a few moderate joint and crack spalls, localized slight faulting at the joints, and intermittent very severe pavement edge drop off. The longitudinal cracks

identified in 1999 are now of moderate severity. In addition, a few severe reflection diagonal cracking and occasional moderate transverse cracking were identified. See Figure 4 below for the typical southbound lanes condition showing localized slight faulting at the joint.



Figure 4. Typical Condition of Unbonded Concrete Overlay, SBL

3.2 Roughness Measurements

Roughness was measured just after construction, prior to opening to traffic, using the California Profilograph. The Portable Universal Roughness Device (PURD) was initially used for ongoing roughness monitoring on a yearly basis. In 2001, the Automatic Road Analyzer (ARAN) replaced the PURD to collect International Roughness Index (IRI) based measurements.

The profilograph measurements were taken on the new concrete overlay with readings taken in both wheelpaths of the driving and passing lanes. For details on the function and operation of a profilograph, refer to [7]. The average profilograph reading (profile index) for the length of the project in the driving lanes was 175 mm/km and 169 mm/km in the passing lanes. These readings were taken prior to diamond grinding the 21 locations where the roadway did not meet the surface tolerance specifications of 3 mm in 3 m. For this demonstration project, the initial ride measured with the profilograph indicated that it met the smoothness requirements expected of a new exposed concrete pavement.

Roughness measurements using the PURD were taken until 2000. The PURD is a trailer-mounted, accelerometer-based mechanical measuring device operated at constant highway speed that uses the root mean square vertical acceleration of the trailer axle to measure roughness. PURD measurements are converted into a ride comfort index (RCI) using a transfer function for application in Ontario's Pavement Management System. RCI is based on a scale from 0-10, with 10 considered a smooth and pleasant ride.

Since 2001, the ARAN is used to collect roughness data. The ARAN consists of a van, equipped with various testing and data logging systems traveling at highway speed. Rutting is measured (in mm) by a series of ultrasonic sensors that are mounted to an aluminum 'smart' bar at the front of the van. Roughness is measured in the wheelpaths and converted into an International Roughness Index (IRI) value. IRI is a roughness measure with scale of mm/m (or m/km). The IRI scale starts from 0 mm/m which represents absolute smoothness. The lower the IRI value, the smoother the pavement.

Testing for roughness was undertaken prior to rehabilitation, after rehabilitation just prior to opening to traffic, and on an annual basis since. For ease of comparison and consistency, all roughness measurements collected using ARAN are converted from IRI to RCI.

3.2.1. Northbound Lanes

The roughness improved significantly after the concrete pavement surface was diamond ground in 1989, with an improvement in RCI from initially 5.6 to 9.4 and 6.7 to 9.4 in the driving and passing lanes respectively. The ride quality levels (smooth, comfortable, uncomfortable) indicated on the graph are converted based on the established RCI. The ride data for the diamond ground surface indicates that the initial roughness value deteriorated to an approximate value of 7.7 after two years and has remained fairly constant over the next three years. These RCI values are in the comfortable range of the ride categories.

The maintenance history indicated the northbound lanes were rehabilitated in 1995 and 2000 with resealing of cracks and joints, as well as some full depth and partial depth concrete repair. Due to an incorrectly correlated transfer function used to convert PURD measurement to RCI coupled with several additional cycles of remedial work, roughness results from 1996 to 2000 are out of trend, see Figure 5.

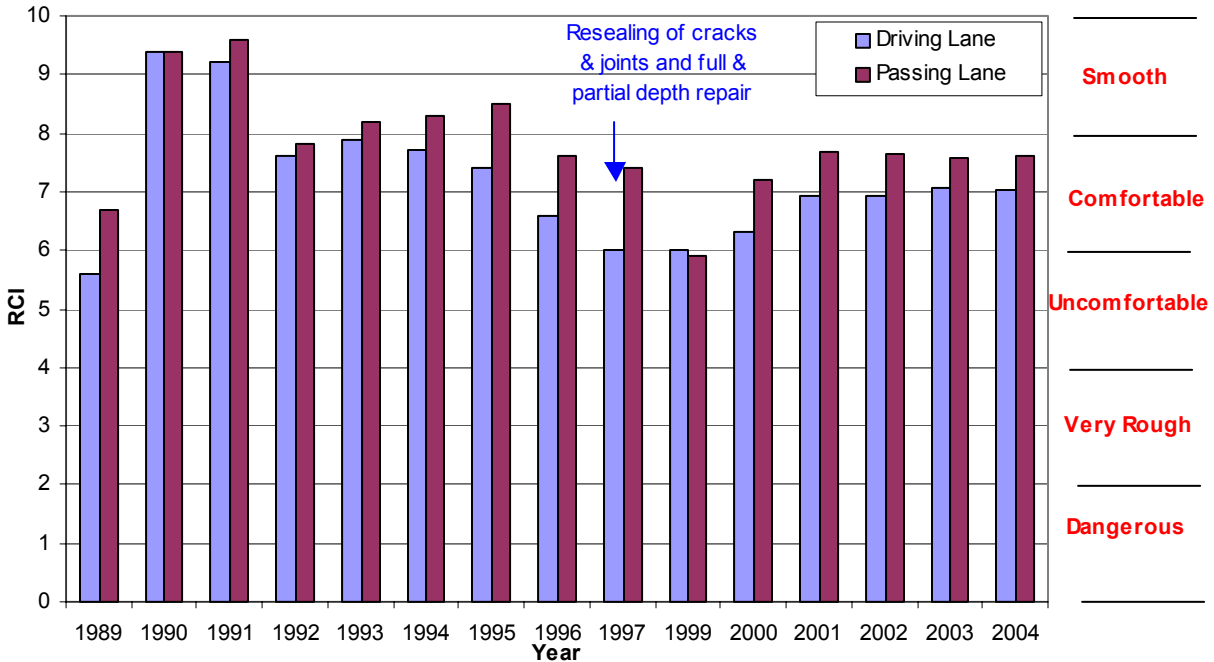


Figure 5. Summary of Roughness (RCI) in NBL

The ARAN surveys from 2001 to 2004 indicates the roughness remained constant over these years, with an average RCI of 7.0 and 7.6 for the driving and passing lane respectively. Overall, the northbound lanes rehabilitated using full CPR techniques are still performing within the comfortable range, after 15 years of service.

3.2.2 Southbound Lanes

The unbonded overlay on the southbound lanes resulted in an improvement in roughness in RCI from 5.6 to 7.9 and 6.5 to 8.0 in the driving and passing lanes respectively; see Figure 6. The newly tined surface texture on the unbonded overlay was very aggressive and may have contributed to some of the initial roughness. The roughness in both the passing and driving lanes in the southbound direction have had fairly constant RCI values from 1990 to 1995, with an average RCI of 7.6 and 7.8 in the driving and passing lane respectively.

The RCI roughness values between 1996 to 2000 appear elevated as a result of an erroneous transfer function used in converting PURD measurements into RCI values. The conversion was based on limited correlation data.

The survey from 2001 to 2004 indicates the roughness remained fairly constant over these years, with an average RCI of 6.7 and 7.2 for the driving and passing lane respectively. Overall, the southbound lanes are in the comfortable category, indicating that after 15 years service, the unbonded concrete overlay treatment is performing well within anticipated life cycle parameters.

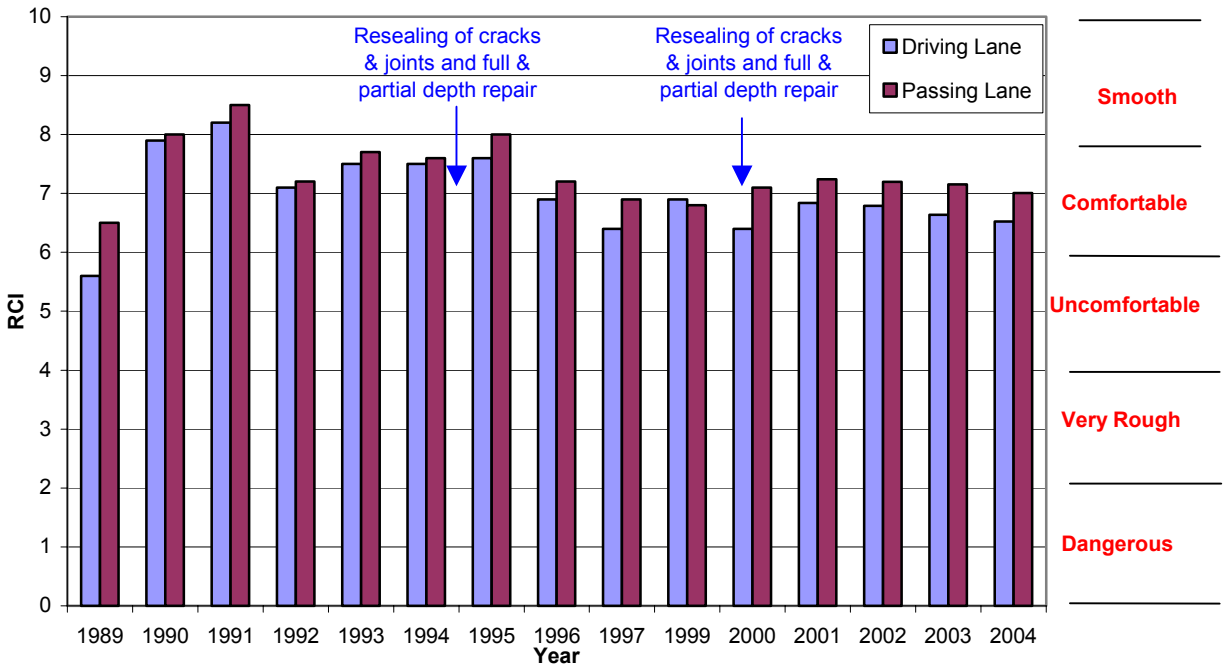


Figure 6. Summary of Roughness (RCI) in SBL

3.3 Skid Testing

The skid resistance of the pavement was measured with a brake-force trailer conforming to ASTM Standard E274. The measured friction force is described as a skid number (SN) at a specific speed; for example, SN₈₀ is the skid number at 80 km/h. A skid number is the average coefficient of friction across the test interval with a practical range from 10 to 60 (the higher the better).

3.3.1 Northbound Lanes

On the diamond ground surface, the skid numbers improved just after construction in 1989, from an average of 25 and 35 to 48 and 49 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 in Ontario [8]. Over the last fifteen years, the skid resistance appears to be consistent in the range of 24 to 33 (average of 27) for driving lane, range of 30 to 39 (average of 35) for the passing lane, see Figure 7.

These values are approximately 7 units lower than the results of the burlap dragged and tined texture on the southbound lanes. The fractured ridges in the diamond ground surface have worn away fairly quickly under high traffic and heavy winter maintenance activities. The micro-texture created with diamond grinding may not be as durable as

that created by the burlap drag/tined texture resulting in an earlier reduction in measured frictional properties.

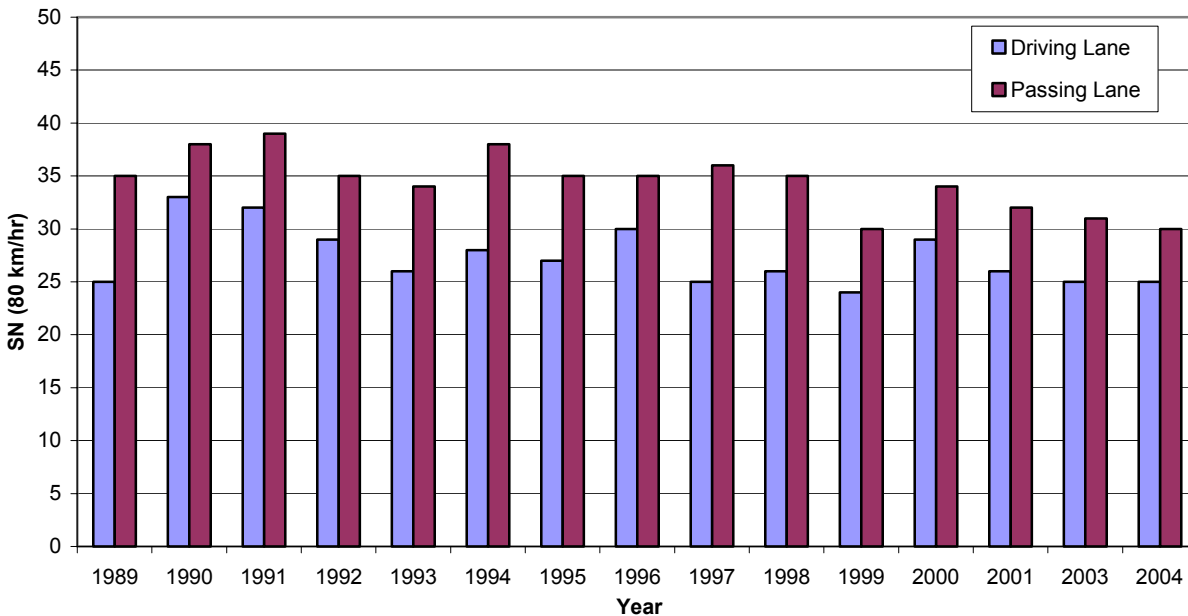


Figure 7. Summary of Average SN₈₀ in NBL

3.3.2 Southbound Lanes

The skid numbers in the southbound lanes increased to an average SN₈₀ of 55 for both lanes after the overlay in 1989, from an SN₈₀ of 18 and 29 in the driving and passing lanes respectively. The skid resistance has stayed fairly constant since construction with the driving lanes ranging from 31 to 39 (average of 34) and the passing lanes ranging from 37 to 45 (average of 41). See Figure 8 for a summary of the skid resistance in the southbound lanes.

As anticipated, in the first year the initial sharp projections of the burlap drag/tined surface have been worn, polished and sheared off by traffic and snow removal operations.

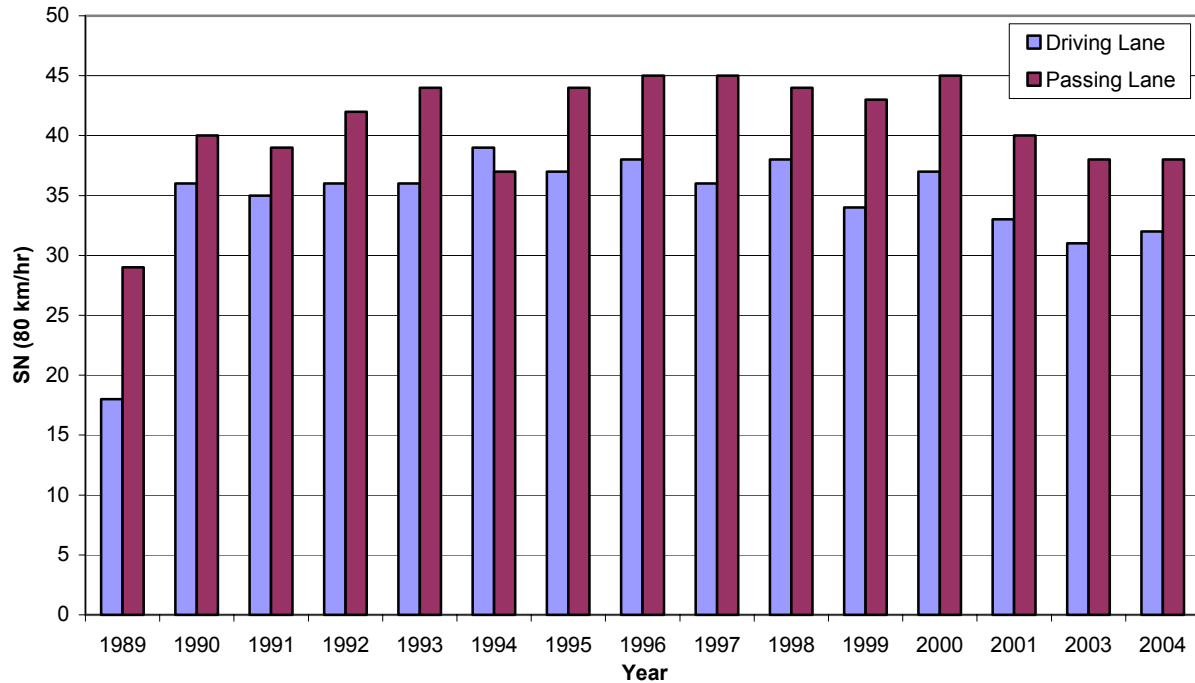


Figure 8. Summary of Average SN₈₀ in Southbound Lanes

3.4 Sound Level Measurements

Sound level measurements were undertaken prior to and following rehabilitation to provide data for future projects. The procedure used to measure pavement noise on this project was to measure noise from individual vehicle pass-bys at a 15 m distance from the travelled lane. The results indicated that the diamond ground surface was approximately 1 dBA quieter than the old worn concrete surface and the MTO sample. The diamond ground surface was only 1 dBA louder than an open graded asphalt friction course, which is used for its low noise characteristics and good skid resistance. The MTO sample was obtained from [9] was derived by testing several hundred vehicles on a variety of pavement surfaces, predominantly asphaltic concrete, across the province.

The burlap dragged and transversely tined concrete surface was approximately 1 dBA noisier than the old worn concrete and MTO sample. For further details on the sound emission measurements see [1].

4.0 CONCLUSIONS

1. Diamond grinding has significantly improved and restored the ride quality of an old unfaulted concrete pavement over the fifteen-year monitoring period. Initially, diamond grinding of the northbound lanes was also very effective in restoring

pavement skid resistance. However, after a few years the beneficial effect of diamond grinding on skid resistance has dissipated. After 15 years of service, average measured SN_{80} values of the diamond ground surface were approximately 7 units lower than that of the burlap drag/tined surface.

2. Visual observations of partial depth repairs in the northbound lanes, in conjunction with core analysis, confirms the importance of both construction quality and judicious selection of repair locations on the effectiveness and durability of partial depth concrete repairs. The partial depth repairs that extended to the level of dowel bars resulted in rapid deterioration (cracking and spalling) of the repairs.
3. Pavement monitoring of the northbound lanes has revealed that where existing pavement joints are seized (non-working), and full depth repairs are constructed at mid-slab working cracks, ongoing deterioration of secondary minor transverse cracks, requiring subsequent full depth repairs, may occur. Consideration should be given to carrying out additional full depth repairs at the time of initial rehabilitation or scheduling them at a future date.
4. The 15-year performance of the unbonded 180 mm thick overlay on the southbound lanes has been good with acceptable ride quality and skid resistance, and with occasional reflection cracking and slight faulting at the joints.
5. As anticipated, due to less truck traffic, the overall performance of the passing lane for both northbound and southbound is better than the driving lane.
6. The PCR for the southbound lanes is higher than for the northbound lanes; however, the corresponding RCI values show the opposite trend. The northbound lanes are experiencing greater distress features which have not, as of yet, been reflected in the ride quality. See Table 2 below for a summary of the pavement performance.
7. To add to the body of knowledge on concrete pavement rehabilitation (CPR) techniques and to obtain data on life cycle costing of CPR strategies, the monitoring of pavement performance and pavement maintenance on this project will continue.

The serviceability of this concrete pavement, after 15 years since major rehabilitation, has been good with acceptable levels of ride, frictional resistance, and distress propagation. The knowledge gained on this project has been successfully used on numerous rigid pavement rehabilitation contracts in Ontario.

Table 2. Summary of Pavement Performance after 15 Years

PERFORMANCE AT YEAR 15	NORTHBOUND	SOUTHBOUND
Distress	<ul style="list-style-type: none"> • Intermittent, moderate joint and crack spalls • Few, moderate faulting along the joints • Extensive, edge of pavement drop off (25 mm) 	<ul style="list-style-type: none"> • Few, moderate joint and crack spalls • Intermittent, slight faulting along the joints • Occasional, moderate transverse cracking • Frequent pavement edge drop off (25 to 50 mm)
PCR*	67	74
RCI*	7.3	6.8
SN ₈₀ *	28	35
Ride Quality	Comfortable	Comfortable

* These values are the average of driving and passing lanes readings.

5.0 REFERENCES

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