

Long Term Performance of Sustainable Concrete Pavement Preservation Strategies in Canada

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Abstract

Rigid pavement preservation and rehabilitation strategies for high traffic volume roads are important sustainable methods of extending the life of our concrete roadways. In 1989, the Ministry of Transportation of Ontario (MTO) undertook the rehabilitation of an exposed concrete pavement exhibiting various distresses. 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 preservation strategies used on the northbound lanes, which had experienced moderate deterioration, consisted of using sustainable concrete pavement restoration (CPR) techniques, material specifications and construction methods, which included full depth repair, partial depth repair, diamond grinding and joint sealant replacement. The rehabilitation strategy selected for southbound lanes was 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 identify the sustainable concrete pavement preservation strategies using the pavement sustainability rating system – GreenPave. It will also discuss the pavement preservation strategies and their long term performance evaluation in terms of roughness measurements, frictional resistance measured, and pavement condition ratings. Overall, the 22 year performance of these preserved and rehabilitated concrete pavements has been good with acceptable levels of ride quality, frictional resistance and distress propagation.

1.0 Introduction

Highway 126 in Southwestern Ontario is a four-lane divided arterial with 32,000 AADT and 12.4% commercial traffic in year 2010. The existing pavement, originally constructed in 1963, was selected in the late 1980's to demonstrate various concrete pavement restoration techniques, including methods that had not previously been utilized in Canada. The demonstration site is located on a 5 km urban arterial facility in London, Ontario, Highway 126. The highway has since been assumed by the City of London and is now known as Highbury Avenue.

2.0 Background

The original pavement was constructed in 1963 with 230 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

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lanes (NBLs) 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.

The pavement on the southbound lanes (SBLs) 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.

Subsequently, concrete pavement restoration (CPR) techniques which included full depth repair, partial depth repair, diamond grinding and joint sealant replacement were elected as the rehabilitation strategies for NBLs. And SBLs was overlaid with a 180 mm thick plain jointed unbonded concrete overlay. See reference (Kazmierowski et al. 2009) for more details on design and construction of this demonstration site.

3.0 Sustainable Preservation Strategy

Pavement preservation is a proactive planned strategy that extends the life of the pavement while it is still in good condition, and maintains the pavement at a high level of service with reduced overall environmental impacts throughout the pavement life cycle. Subsequently, pavement preservation is one of the key practices to ensure pavement sustainability.

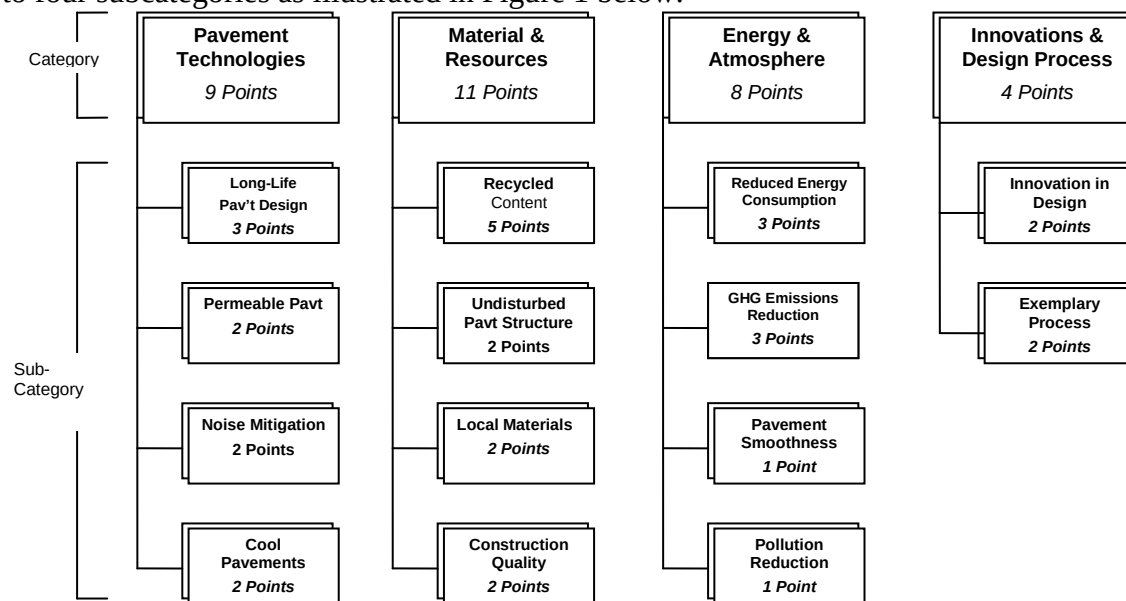
Recently, MTO has developed a green pavement rating system called GreenPave to promote pavement sustainability. GreenPave is an understandable and quantifiable methodology that promotes sustainable pavement technologies for the design and construction of new pavements, rehabilitation, reconstruction and preservation management of pavements. GreenPave was used to validate the pavement preservation strategies applied on Highway 126 are sustainable alternatives.

3.1 Overview of GreenPave. GreenPave is primarily based on the Green Roads (Washington State) and GreenLITES (New York State) rating systems, but customized for Ontario. The LEED® certification program and Alberta's rating system were also assessed during the development. The main difference between GreenPave and other rating systems is that it focuses specifically on the pavement component rather than the entire road. GreenPave is a point based system that was developed to assess the "Greenness" of pavement designs or constructed pavements, both flexible and rigid structures. Assigning a rating to the pavement design will enable MTO to incorporate more sustainable technologies in pavements and encourage industry to do the same. Assigning a rating to constructed pavements eliminates design assumptions and allows for incorporation of construction components and contractor innovation that cannot be estimated at the time of design. In the proposed rating system, pavements will be assessed within four categories (Table 1).

Table 1. Four Categories of MTO GreenPave Rating System

Category	Goal	Points
Pavement Design Technologies	To optimize sustainable designs. These include long life pavements, permeable pavements, noise mitigating pavements, and pavements that minimize the heat island effect	9
Materials & Resources	To optimize the use/reuse of recycled materials and to minimize material transportation distances	11
Energy & Atmosphere	To minimize energy consumption and greenhouse gas (GHG) emissions	8
Innovation & Design Process	To recognize innovation and exemplary efforts made to foster sustainable pavement designs	4
	Maximum Total:	32

Each category is further broken down to address specific objectives, with corresponding points assigned to each subcategory. Each category is divided into two to four subcategories as illustrated in Figure 1 below.

**Figure 1.** Categories and Subcategories of GreenPave

Specific objectives within these subcategories must be met in order to achieve the maximum points available. Proposed rating levels for the GreenPave projects are bronze (10-14 points), silver (15-19 points), and gold (20+ points). Any project that rates lower than 10 points is not certified.

3.2 Evaluation of Concrete Preservation Strategies using GreenPave.

Evaluating the pavement rehabilitation techniques using GreenPave can quantify the sustainability level of these preservation strategies. In this case study, concrete pavement restoration (CPR) techniques were applied to NBLs, which included full depth repair, partial depth repair, diamond grinding and joint sealant replacement. The rehabilitation strategy selected for SBLs was an unbonded PCC overlay.

For NBLs, the GreenPave evaluation case study was focused on diamond grinding and SBLs was focused on the unbonded overlay. The evaluation indicated

diamond grinding and unbonded overlay are sustainable pavement preservation treatments with GreenPave rating of 18 and 17 respectively. These treatments were both GreenPave certified as Silver. Therefore, the rehabilitation techniques selected for both NBLs and SBLs are considered sustainable preservation strategies.

4.0 Life Cycle Analysis of Preservation Strategy

Pavement preservation is “a program employing network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations.” (FHWA 2005) The key to a successful pavement preservation program is to apply the right treatment to the right road at the right time in order to extend the pavement life.

Based on the guideline published by MTO (Lane and Kazmierowski, 2005) on life cycle costing analysis on MTO freeway projects, the recommended concrete pavement rehabilitation schedule is presented below (Figure 2):

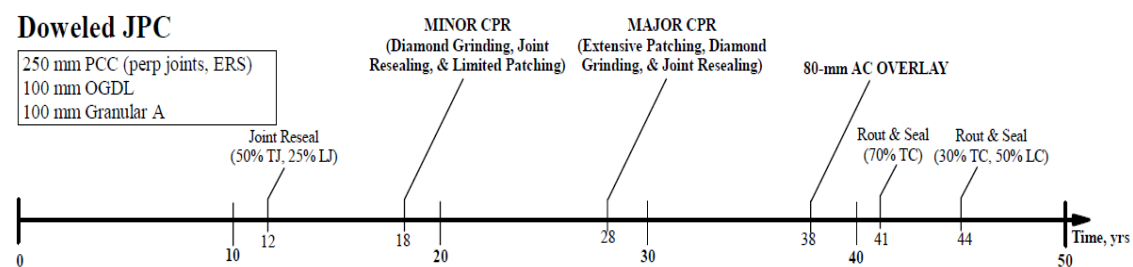


Figure 2. Recommended Rehabilitation Schedule for Concrete Pavement (Lane and Kazmierowski, 2005)

In this Highway 126 case study, the pavement preservation strategy applied on NBLs and SBLs are illustrated below:

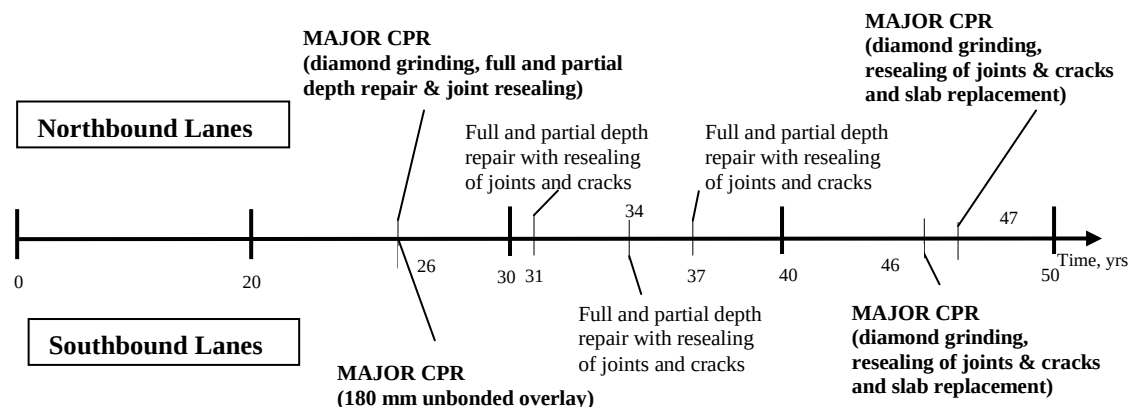


Figure 3. Pavement Preservation Schedule on Highway 126

Based on the actual preservation strategies performed on Highway 126 (Figure 3), both NBLs and SBLs administered their first major CPR at year 26. This is very close to the recommended schedule (Figure 2) where the first major CPR should happen at year 28. The recommended schedule indicated the next major rehabilitation will be asphalt overlay. But this project elected to use a sustainable concrete pavement preservation strategy to prolong the pavement life. Minor concrete pavement restoration techniques were completed by full and partial depth repairs and resealing of cracks and joints. The second major CPR has been applied to NBLs in

2009 and SBLs in 2010 to restore the ride. The pavement has now reached 48 years and still performing acceptably and within the anticipated life cycle parameters. This case study shows when pavement preservation strategy applied at the right time can extend the pavement life and lead to sustainable pavement. Pavement evaluation and performance of the road is detailed in the following sections.

5.0 Pavement Performance

5.1 Overview of Pavement Preservation Treatments. The pavement preservation activities performed on Highway 126 included resealing of cracks and joints, some full depth and partial depth concrete repairs as well as diamond grinding to restore the ride. The remedial work carried out on both NBLs and SBLs after the last major rehabilitation in 1989 is illustrated in Figure 3 above.

5.2 Pavement Distress Survey. The visible distresses in the pavement surface were surveyed using the ministry's Rigid Pavement Evaluation Procedure (Chong et al. 1995) to provide an overall indication of pavement performance. A Pavement Condition Rating (PCR) is also used to indicate the overall pavement condition. PCR is a composite pavement serviceability index ranging from 0 to 100; with the higher rating indicating a better pavement condition. Below is a summary of the pavement condition throughout the 22 years of services (Table 2 and Table 3). For more detailed pavement condition, see reference (Kazmierowski et al. 2009).

Table 2. NBL Pavement Condition after Major CPR in 1989

Year	Year after Rehab	Pavement Condition / Remarks
1992	3	Seven of the 266 full depth repairs were exhibiting a very slight longitudinal cracking. Investigation revealed failure of the partial depth repairs had extended beyond the general practice of not exceeding 1/3 of slab depth.
1994	5	Distress survey indicated more full depth repair is required due to cracking slabs.
1994 and 1995 - Full depths (800 m²) and partial depth repairs (35 m²); resealing of joints and cracks (375 m)		
1999	10	A few of the new repairs have slight in severity cracked in the wheelpath of the driving lane. Also some slight spalling of the repairs and original concrete at the joints and cracks.
2000 - Full depths (1,300 m²) and partial depth repairs (20 m²); resealing of joints and cracks (810 m)		
2004	15	The pavement was in fair to good condition, with a PCR of 63 in the driving lane, and 70 in the passing lane. A few moderate faulted joints and intermittent moderate joint and crack spalling. In addition, extensive severe pavement edge drop off was identified.
2008	18	The pavement was in fair condition with an average PCR of 55. A few moderate longitudinal and meandering cracks; frequent severe to very severe transverse cracking; moderate faulting throughout; intermittent moderate joint and crack spalling.
2009 - Diamond grinding, replacing slabs, resealing of cracks and joints (146 m² of slab replacement by conventional method)		
2011	22	The pavement is in good condition with good ride since the major CPR in 2009. Few slight meandering cracks and few slight joint spalling. No major distress identified.



Photo 1. Recent Photo on Northbound Lanes

Table 3. SBL Pavement Condition after Unbonded Concrete Overlay in 1989

Year	Year after Rehab	Pavement Condition / Remarks
1997 - Full depths (535 m²) and partial depth repairs (10 m²); resealing of joints and cracks (110 m)		
1999	10	The only distress observed in the SBLs was slight longitudinal cracking in 11 of the driving lane slabs. This can probably be attributed to inadequate longitudinal joint construction.
2004	15	The pavement was in good condition with a PCR of 70 in the driving lane and 78 in the passing lane. A few moderate joint and crack spalling, localized slight faulting at the joints, and intermittent very severe pavement edge drop off. The longitudinal cracks identified earlier are of moderate severity. In addition, a few severe reflection diagonal cracking and frequent moderate transverse cracks were identified.
2008	18	The pavement was considered to be in fair condition with an average PCR of 52. There were a few to intermittent crescent cracks; intermittent severe longitudinal cracks; moderate longitudinal and meandering cracks; frequent slight to moderate transverse cracking; moderate faulting throughout; few moderate joint and crack spalls; few areas of moderate raveling/coarse aggregate loss. See Photo 2 below for the typical southbound driving lane condition showing a moderate transverse crack. Note that the surface still has a tined macro-texture.
2010 - Diamond grinding, replacing slabs, resealing of cracks and joints (100 m) (1,300 m² of slab replacement by conventional method)		
2011	22	The pavement is in good condition and good ride since the major CPR in 2010. Few slight diagonal corner & edge crescent cracks. No major distress identified.



Photo 2. Recent Photo on Southbound Lanes

5.3 Roughness Measurements. The Portable Universal Roughness Device (PURD) was initially used for ongoing roughness monitoring on a yearly basis. In year 2001 the Automatic Road Analyzer (ARAN) replaced the PURD to collect International Roughness Index (IRI) based measurements. The IRI scale starts from 0 m/km which represents absolute smoothness to an unlimited scale. The lower the IRI value, the smoother the pavement. See reference (Kazmierowski et al. 2009) for more details on PURD and ARAN pavement evaluation devices.

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 previously collected using PURD are converted from RCI to IRI.

5.3.1 Roughness Measurement Northbound Lanes. Roughness in the NBLs improved significantly after the concrete pavement surface was diamond ground in 1989, with an improvement in IRI from initially 3.9 to 0.9 m/km and 2.6 to 0.9 m/km in the driving and passing lanes respectively, see Figure 4. The ride data for the diamond ground surface indicates that the initial roughness values deteriorated to an approximate value of 1.8 after two years and has remained fairly constant over the following three years. These IRI values are in the comfortable range of the ride categories. The ride quality levels (smooth, comfortable, uncomfortable) indicated on the graph are converted based on the established ride comfort index (RCI). RCI between 10 to 8 is smooth (IRI = 0.76 to 1.60 m/km); 8 to 6 is comfortable (IRI = 1.60 to 3.36 m/km); and below 6 (IRI > 3.36 m/km) is considered to be uncomfortable ride (Chong et al. 1995).

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

The ARAN surveys from 2001 to 2004 indicates the roughness remained constant over these years, with an average IRI of 2.3 and 1.8 m/km for the driving and passing lane respectively. From 2005 to 2008, the driving lane roughness data shows a mild trend of deterioration with an average deterioration rate of 0.1 IRI every year. The roughness data for the passing lane are still fairly constant between 2005 to 2008, with an average IRI of 1.9 m/km.

The second CPR was applied to the NBLs in 2009, and the IRI values then significantly improved from 2.8 to 1.8 m/km and 1.9 to 1.6 m/km in the driving and passing lanes respectively.

Overall, the first CPR techniques used on the NBLs are performing well within the comfortable category even before applying the second round of CPR in 2009. The CPR techniques used are well within the anticipated life cycle parameters.

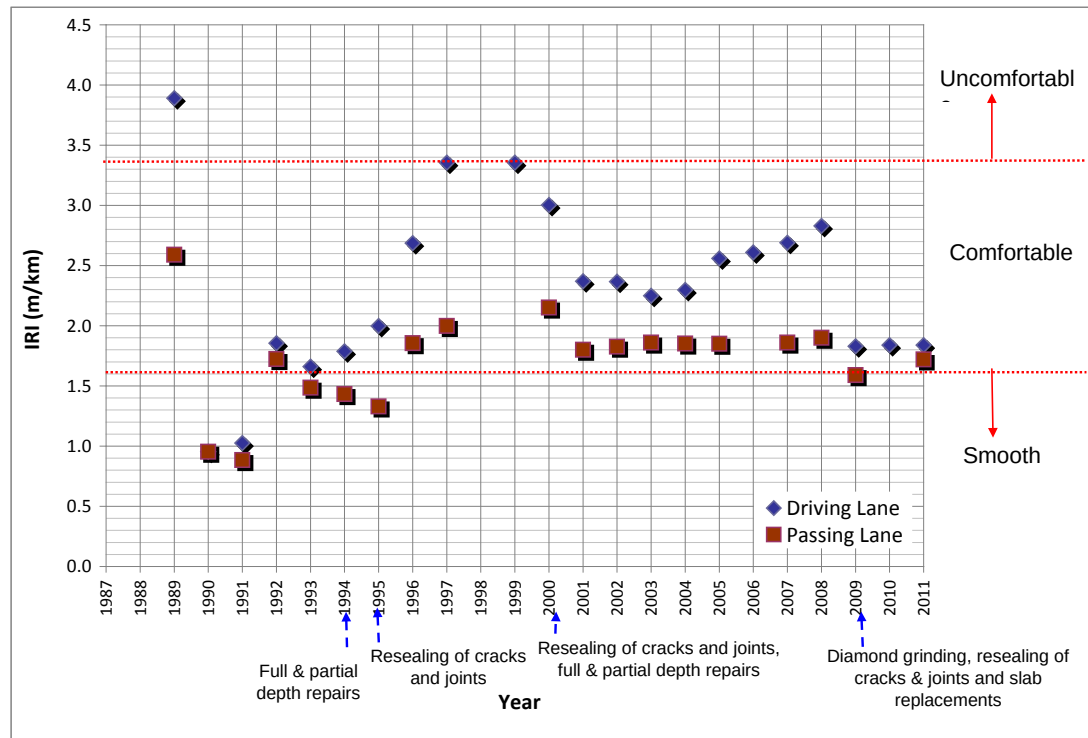


Figure 4. Summary of Roughness (IRI) in Northbound Lanes

5.3.2 Roughness Measurement Southbound Lanes. The unbonded overlay rehabilitation on the SBLs in 1989 resulted in an improvement in roughness (IRI) from 3.9 to 1.7 m/km and 2.8 to 1.6 m/km in the driving and passing lanes respectively; see Figure 5.

The newly tined surface texture on the unbonded overlay was very aggressive and had contributed to some of the initial roughness. The roughness in both the passing and driving lanes in the southbound direction demonstrate fairly constant IRI values from 1990 to 1995, with an average IRI of 1.8 and 1.7 m/km in the driving and passing lane respectively.

Incorrectly correlated transfer function used to convert PURD data to RCI coupled with several additional cycles of remedial work resulted in the survey data from 1996 to 2000 being out of trend.

The surveys from 2001 to 2010 indicate the roughness has slowly deteriorated over these years, with an average deterioration rate of 0.1 m/km IRI every year. The passing lane is still within the comfortable range, and the driving lane just bordering into the uncomfortable range.

The second CPR was applied to the SBLs in 2010, and the IRI values then significantly improved from 2.93 to 1.54 m/km in the passing lane.

Overall, the unbonded concrete overlay on the southbound lanes is performing at an acceptable level of ride quality even before applying the second round of

pavement preservation treatment in 2010. The unbonded concrete overlay treatment is performing well within the anticipated life cycle parameters.

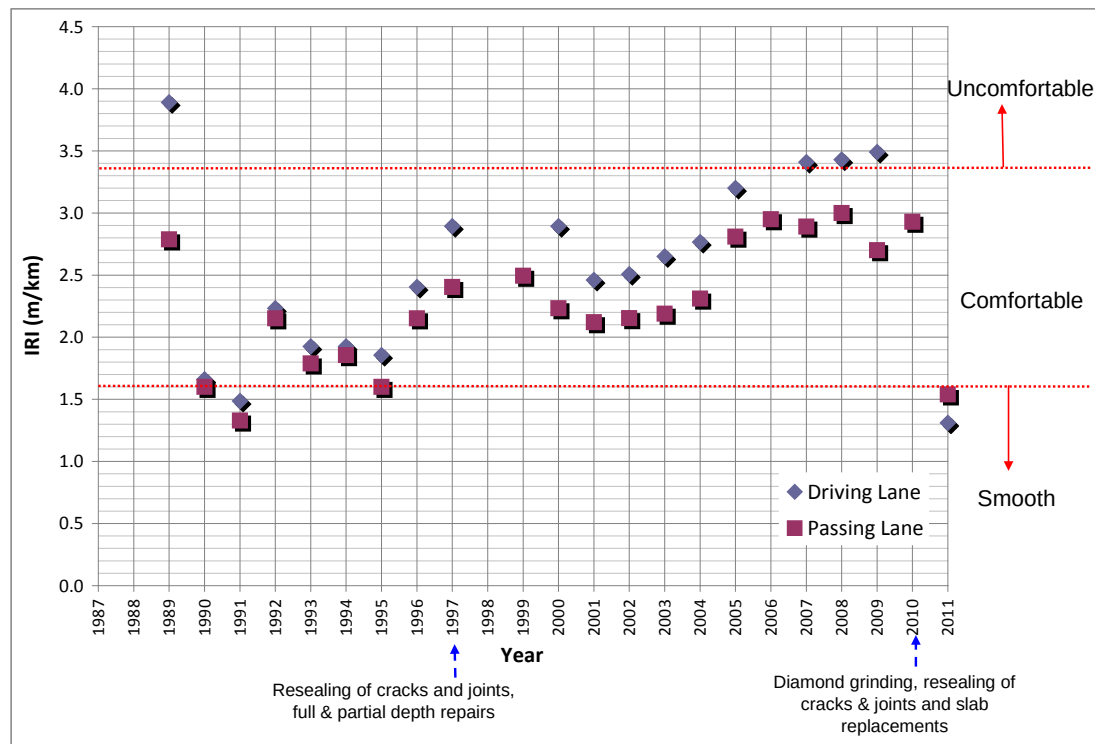


Figure 5. Summary of Roughness (IRI) in Southbound Lanes

5.4 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 (higher the better).

5.4.1. Skid Testing on Northbound Lanes. For the diamond ground surface on the NBLs, the skid numbers improved immediately after construction in 1989, from an average of 25 to 33 and 35 to 38 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 (Ryell et al. 1978).

As shown in Figure 6, the skid resistance has stayed fairly constant since 1990 to 2000, with the driving lane ranging from 24 to 33 (average of 28) and the passing lane ranging from 30 to 39 (average of 35). From 2001 to 2008, the skid resistance starts to decline slowly, from 26 to 22 in the driving lane; and from 32 to 28 in the passing lane. After the second CPR in 2009, the skid resistance that was collected soon after the diamond grinding application has improved from 22 to 34 in the driving lane and 28 to 37 in the passing lane.

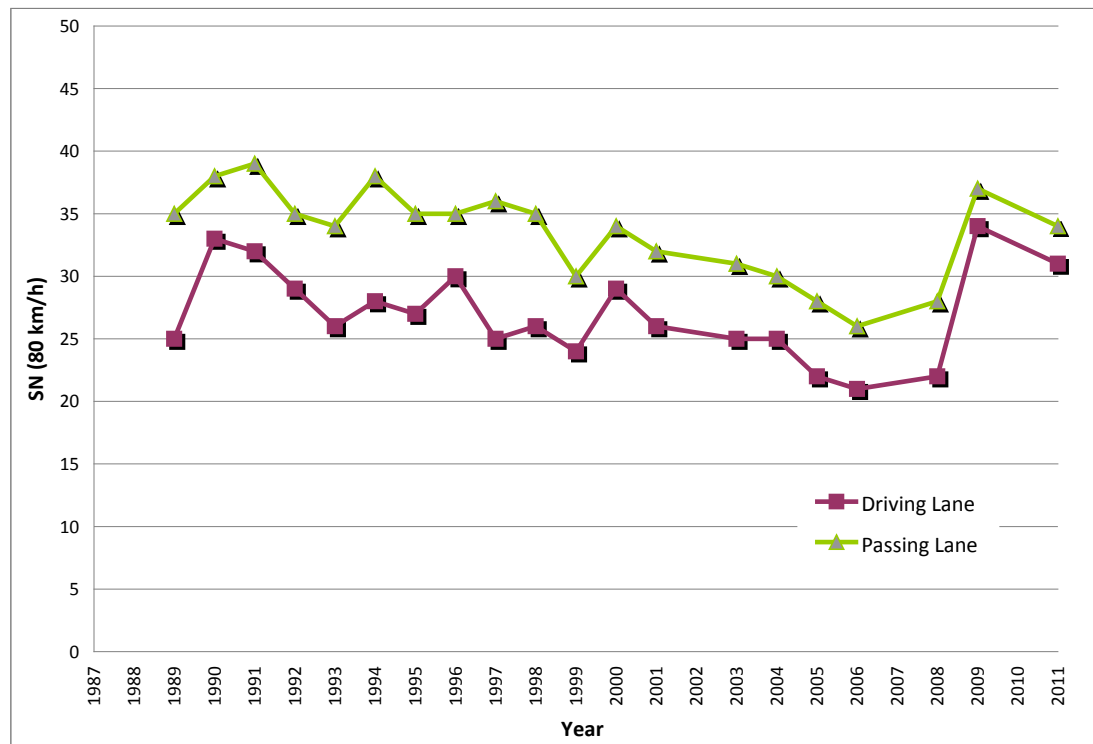


Figure 6. Summary of SN_{80} in Northbound Lanes

5.4.2. Skid Testing on Southbound Lanes. The skid numbers in the SBLs increased from SN_{80} of 18 to 36 (driving lane) and 29 to 40 (passing lane) immediately after the overlay in 1989. See Figure 7 for an annual summary of the skid resistance in the SBLs.

The skid resistance has stayed fairly constant since 1990 to 2000, with the driving lane ranging from 34 to 39 (average of 37) and the passing lane ranging from 37 to 45 (average of 43). From 2001 to 2008, the skid resistance starts to decline slowly, from 33 to 28 in the driving lanes and from 40 to 35 in the passing lane. The skid resistance starts to improve a little in 2009 and 2011. The second CPR which includes diamond grinding was applied to SBLs in 2010. The skid resistance for 2011 was 32 for the driving lane, 37 for passing lane.

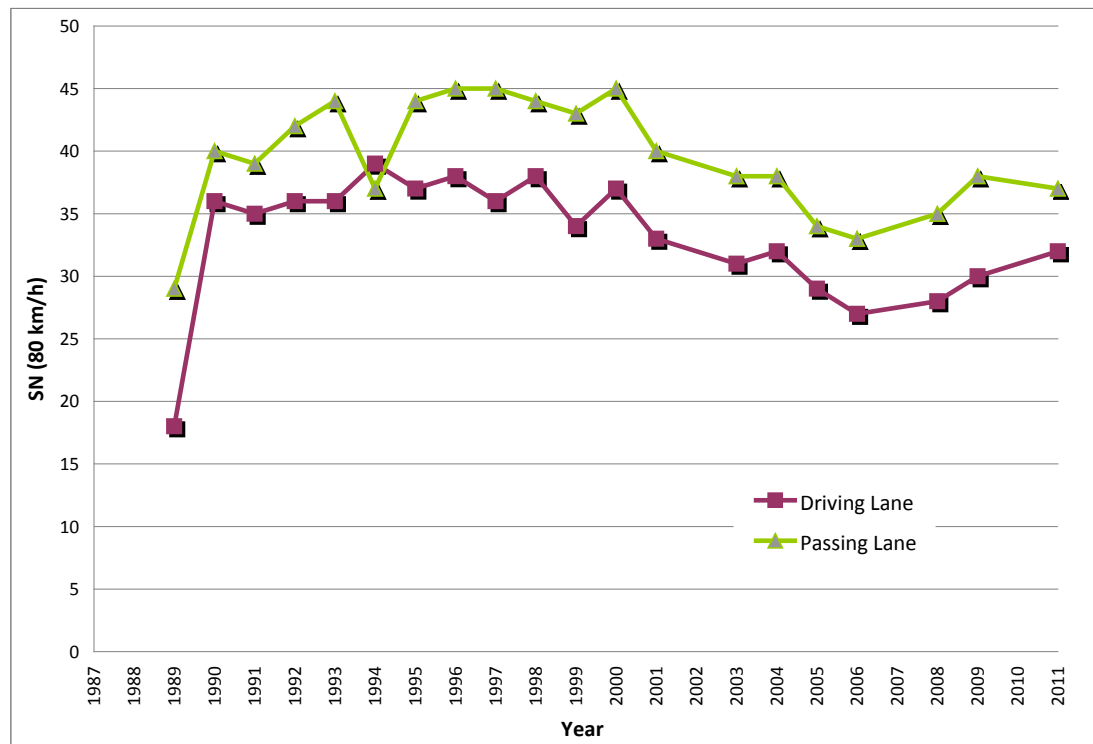


Figure 7. Summary of SN₈₀ in Southbound Lanes

5.4.3. Skid Testing Comparison on Northbound and Southbound Lanes. The average skid numbers for NBLs from 1990 to 2008 (prior to the second diamond grinding application) are 27 for driving lane and 33 for passing lane. The average skid numbers for SBLs from 1990 to 2009 (prior to the second diamond grinding application) are 34 for driving lane and 40 for passing lane. Focusing on the skid resistance performance prior to the second round of diamond grinding for both directions, these average skid numbers indicated NBLs with diamond ground texture are approximately 7 units lower than the SBLs with a burlap drag and tine texture.

For the diamond ground lanes, the fractured ridges in the retextured surface have worn away fairly quickly under high traffic and heavy winter maintenance activities. The micro-texture created with diamond grinding does not appear to be as durable as that created by the burlap drag tine texture in the southbound lanes, resulting in an earlier reduction in measured frictional properties.

Although the SBLs did not have a significant improvement in skid resistance after diamond grinding, the skid resistance values for both NBLs and SBLs are similar after receiving the diamond grinding application in 2009 and 2010 respectively. The 2011 skid resistances in NBLs are 31 for the driving lane and 34 for the passing lane; and 32 for the driving lane and 37 for the passing lane in SBLs.

6.0 Conclusions & Recommendations

The highway 126 pavement, constructed in 1963, has provided commendable service for almost 48 years. The main reason for its good performance was the application of sustainable pavement preservation strategies – both timely maintenance and rehabilitation treatments.

Monitoring the serviceability of the pavement over the last twenty-two years has indicated the concrete pavement rehabilitation techniques used have exhibited acceptable performance on both the northbound (diamond grinding, full and partial depth repairs) and southbound (180 mm unbonded concrete overlay) lanes. The skid

resistance in NBLs (diamond ground) has deteriorated at a faster rate than SBLs (tined texture). The 2nd generation of CPR is then applied to NBLs in 2009 and SBLs in 2010 which included diamond grinding, slab replacement and resealing of joints and cracks. This 2nd generation of CPR has enhanced the surface texture and friction characteristics and reduced tire/pavement noise emissions. The skid resistance for both NBLs and SBLs are comparable after applying the 2nd generation of CPR. Table 4 below summarizes the performance of the pavement after twenty-two years of service:

Table 4. Summary of Pavement Performance after 22 Years of Rehabilitation

PERFORMANCE AT YEAR 22	SOUTHBOUND (SBL) (Unbonded Overlay)	NORTHBOUND (NBL) (Major CPR)
Distresses	• Few slight meandering cracks • Few slight joint spalling • No major distress identified	• Few slight diagonal corner & edge crescent cracks • No major distress identified
IRI*	1.4 m/km	1.8 m/km
Skid Number*	35	33
Ride Quality	Smooth	Comfortable

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

The NBLs, which were originally treated with diamond grinding, full depth and partial depth repairs are performing acceptably. The diamond grinding significantly restored ride quality of the old concrete pavement for 20 years prior to the 2nd generation of CPR in 2009. Initially, diamond grinding at the NBLs was also very effective in restoring pavement skid resistance. However, after a few years the beneficial effects of diamond grinding for skid resistance has dissipated. After 20 years of service, measured skid resistance of the diamond ground surface was approximately 7 skid units lower than that of the burlap drag/tined surface on the SBLs. Therefore, diamond grinding was done again in 2009 to restore the ride and the average skid units increased from 25 to 36.

Monitoring the long-term pavement performance, associated with each type of concrete pavement restoration (CPR) technique, has been crucial in order to model CPR performance and obtain data on life cycle costing of these sustainable CPR strategies. The serviceability of this concrete pavement after 48 years has been fair to good, with acceptable levels of ride quality and frictional resistance.

In conclusion, the concrete pavement restoration techniques utilized on this project has significantly extended the life of the pavement and proven to be effective long term sustainable pavement preservation alternatives. The knowledge gained on this project has been successfully used on numerous subsequent rigid pavement rehabilitation contracts in Ontario.

7.0 Acknowledgement

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8.0 References

- Chong, G.J., Wrong, G.A., Prakash, A. (1995). "Manual for Condition Rating of Rigid Pavements". Ministry of Transportation of Ontario Report SP-026.
- Federal Highway Administration (FHWA). Action Pavement Preservations, Federal Highway Administration. 2005.
<http://www.fhwa.dot.gov/pavement/preservation/091205.cfm> (July 8, 2011)
- "GreenPave: Ontario's First Pavement Sustainability Rating System". Road Talk – Ontario's Transportation Technology Transfer Digest, Winter 2010, Volume 16, Issue 1.
- Kazmierowski, T.J., Chan, S., Uzarowski, L. (2009) "CPR Techniques in Canada – 18 Years Performance Experience", Proceedings of the 9th International Conference on Concrete Pavements, San Francisco, California, USA.
- Lane, B. And Kazmierowski, T.J. (2005) "Guidelines for the use of Life Cycle Costing Analysis on MTO Freeway Projects", Ministry of Transportation of Ontario, Material Engineering Research Office, Report number: MERO-18., Downsview, Ontario.
- Ryell, J., Corkill, J.T., and Musgrove, G.R. (1978) "Skid Resistance of Bituminous Pavement Test Sections-Highway 401, Toronto Bypass". Ministry of Transportation of Ontario Report IR67.