Concrete Pavement Rehabilitation Techniques and Canadian Based Case Studies

Rico Fung, P.Eng., LEED®AP, Director, Markets & Technical Affairs
Tim Smith, P.Eng., Director, Transportation & Public Works
Cement Association of Canada

Paper prepared for presentation

at the Pavement Evaluation, Performance and Management Session

of the 2010 Annual Conference of the
Transportation Association of Canada
Halifax, Nova Scotia

Abstract

The need for engineered rehabilitation of our transportation infrastructure has never been greater. There is increasing demand to make better use of shrinking resources for rehabilitation and maintenance of our highways and city streets. There are a number of concrete pavement restoration, resurfacing and reconstruction techniques, also known as CPR^3 (R^3 stands for restoration, resurfacing and reconstruction), to address the various distresses in the concrete pavements. Selecting the most cost-effective CPR^3 requires the transportation professionals to have knowledge of the various concrete pavement restoration techniques.

This paper focuses on the many restoration techniques available to extend the concrete pavements life including: full-depth/partial depth repairs, joint and crack resealing, slab stabilization/Jacking, diamond grinding, load transfer restoration, and cross stitching longitudinal cracks. These concrete pavement restoration (CPR) techniques will prolong and enhance the concrete pavement's service life in a cost effective manner. A pavement design engineer can easily adopt the proper CPR technique based on the local materials, environmental conditions, project distress conditions and costs.

The paper will also review several Canadian based case studies identifying various restoration techniques which have been successfully used including the following:

- dowel bar retrofit on Ontario's Highway 417,
- precast concrete panels installation on Ontario's Highway 427,
- slabjacking of concrete pavement at culvert area on Nova Scotia's Highway 104
- cross stitching of longitudinal cracks on Ontario's Highway 417 and Nova Scotia's Highway 101, and
- diamond grinding of city streets in Winnipeg, Manitoba.

Introduction

Concrete pavement restoration (CPR) is a series of engineered repair techniques, but non-overlay option, to manage the rate of deterioration in concrete pavements due to truck traffic. A timely and appropriate CPR program will maintain a concrete pavement's smooth, safe, and quiet condition, while extending its service life economically. CPR will repair isolated areas of pavement distress without affecting the grade. These rational, corrective/preventive techniques restore the pavement to a condition close to original and reduce the need for major and more costly repairs until later in the pavement's life, such as overlays or reconstruction. Reports from the Transportation Research Board state that for every dollar invested in appropriately timed preventive pavement maintenance, three to four dollars in future rehabilitation costs are saved. [TRB 1996]

Ideally, CPR is the first rehabilitation procedure applied to concrete pavement. Figure 1 shows where CPR fits into the overall CPR^3 sequence for concrete pavements. CPR techniques have been shown to add 12 to 15 years of service life to the concrete pavement. The key to any preservation strategy is timing and proper techniques(s). It is usually applied in an early stage when the pavement is in reasonably good condition with only minimal distresses. CPR is typically used to restore or replace isolated sections of deteriorated pavement, or to prevent or slow the overall deterioration, as well as to reduce the impact loadings on the pavement. If the truck traffic increases beyond the anticipated design value or the pavement has deteriorated to poorer conditions, then other techniques such as resurfacing (bonded or unbonded concrete overlay) can be applied to extend the pavement service life, or reconstruction.

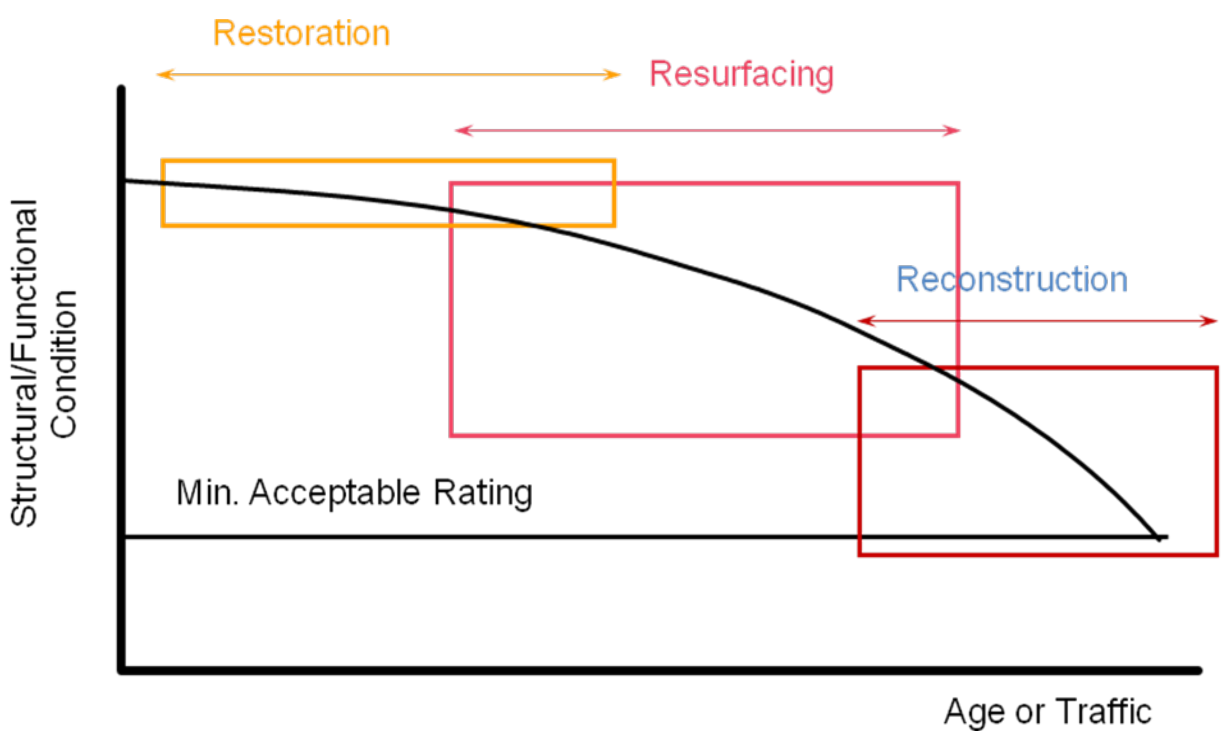

Figure 1 Rehabilitation Timing [Smith 2007]

Table 1 Concrete Pavement Restoration Techniques [ACPA-TB020P]

Concrete Pavement Restoration Technique	***Used to:***
Full-Depth Repairs	Repair cracked slabs and joint deterioration
Partial-Depth Repairs	Repair joint and crack deterioration and surface distress
Diamond Grinding	Extend serviceability; improve ride and skid resistance; reduce noise
Dowel-Bar Retrofit	Restore load transfer at transverse joints and cracks
Joint and Crack Resealing	Minimize infiltration of water and incompressible material into joint system & cracks
Slab Stabilization	Fill small voids underneath the concrete slab
Cross-Stitching	Repair low and medium severity longitudinal cracks
Grooving	Restore skid resistance and reduce wet weather accident potential and prevent hydroplaning
Retrofitting Edge Drains	Add a longitudinal drainage system
Retrofitting Concrete Shoulder	Decrease pavement edge stresses and slab corner deflections, reduce slab crack potential

Table 1 shows that each CPR technique is designed specifically to repair or prevent the recurrence of a distress or a combination of distresses. While each technique can be used to address one type of distress, typically several are used in combination to be more effective.

Although CPR does not increase structural capacity of a pavement structure in general, it does extend the pavement's service life. One example is the Interstate 475 near Macon, Georgia. This pavement has carried nine times its original design traffic because it has been maintained effectively with proper CPR techniques and procedures at the right time over the years. [Banasiak 1996]

Selection and Application of CPR techniques

1. Selection Considerations:

   Transportation agency must first look at all relevant pavement information systematically, in order to determine whether a project is a CPR candidate and select the best CPR technique(s). The relevant information must include existing pavement data; initial construction cost; past and anticipated future maintenance; future rehabilitation requirements; anticipated serviceability; experience; and constructability. Of these, the most important is the existing pavement data. The existing pavement data tells the pavement engineer which distresses are present, coupled with thorough site inspection, it helps to assess why the distresses happened. The pavement data can be grouped into the following 6 categories:
   - Original design data,

- Construction data,
- Current traffic data,
- Current environmental data,
- Previous CPR activities if any,
- Existing Pavement conditions.

2. Application Considerations:

CPR allows the pavement engineer to address specific distresses and develop a network wide CPR program that will provide different levels of improvements. For example, an engineer may use a complete CPR program to restore a pavement to a condition similar to a new pavement, or a partial program to extend a pavement's life for a few years until additional funding is available for resurfacing or reconstruction. Factors such as fiscal constraints, adjacent pavement conditions, and future agency-programming may make one approach more suitable than another at the time.

CPR may also correct design or construction deficiencies before any distresses develop, or repair a concrete pavement before an overlay is placed. Repairing a design defect or repairing the pavement before an overlay minimizes future distresses and maintenance headaches.

Finally, it is feasible to repair a concrete pavement that has been previously overlaid with asphalt. In the past, many transportation agencies overlaid roughened concrete pavements with asphalt to restore smoothness. This does not correct the cause of roughness, and the asphalt overlays often deteriorate soon after, requiring a second overlay. In many cases, overlays have to be replaced many times within a short period. With the proper CPR, it is possible to remove an asphalt overlay and repair an underlying concrete pavement to close to its original condition, even to meet the smoothness requirement.

CPR Techniques

CPR techniques are divided into three categories:

- Corrective repairs,
- Preventive repairs,
- Corrective and Preventive repairs.

Corrective repair is to improve the serviceability of the pavement, including full-depth and partial-depth repair. Preventive repairs are proactive measures to slow or prevent the occurrence of distresses that would reduce the desired serviceability, which include joint and crack resealing, retrofitting concrete shoulders, and retrofitting edge drains. While the diamond grinding, dowel-bar retrofit, slab stabilization/Jacking, cross-stitching and grooving are both corrective and preventive repair techniques.

1. <u>Corrective CPR Techniques:</u>

- Full-Depth Repairs — full-depth repairs (FDRs) fix cracked slabs and joint deterioration by replacing a portion of or the entire existing slab with new concrete. This will maintain the structural integrity of the existing slab and pavement structure. This technique also repairs shattered slabs, corner breaks, punchouts in CRCP, and some low-severity durability problems. Figure 2 shows the placement of a full depth new concrete slab. It involves marking the distressed concrete, saw cutting around the perimeter, removing the old concrete, providing load transfer bars, and placing new concrete. Each repair must be large enough to replace all significant distress and resist rocking under the traffic.

  Advantages are fast, easy, and inexpensive, can be done under traffic and precast concrete panels are an option for a 6 to 8-hour short closure period.

<u>Figure 2: Placing concrete in full-depth repair [ACPA-TB020P]</u>

- Partial-Depth Repairs — partial-depth repairs (PDRs) correct surface distress and joint/crack deterioration in the upper third (1/3) of the concrete slab. When the deterioration is greater than one-third the slab depth or in contact with the embedded steel, a full-depth repair must be used instead. Placing a PDR involves removing the deteriorated concrete, cleaning the patch area, placing new concrete, and reforming the joint system.

2. <u>Preventive CPR Techniques:</u>

- Joint and Crack Resealing — joint and crack resealing minimizes the infiltration of surface water and incompressible material into the transverse and longitudinal joints or cracks. Advantages are:

- To reduce subgrade softening,
- To slow pumping and erosion of subbase or subgrade fines,
- Limit dowel-bar corrosion caused by deicing chemicals,
- Minimizing incompressibles reduces the potential for spalling, joint lock up and blow-ups,
- Especially critical to reseal the longitudinal joint along the pavement/shoulder edge to prevent most of the surface water from entering the pavement system at this joint.

- Retrofitting Concrete Shoulders — adding a tied concrete shoulder to the free edge of the existing concrete pavement, helps to decrease the critical edge stresses, corner deflections and the potential for transverse cracking, pumping, and faulting. In CRCP, retrofitting the concrete shoulders will decrease the outside pavement edge deflection and cantilever action, thus reduces the potential for punchouts. For retrofitted concrete shoulders to be effective, good design and construction practices are essential to the success.

- Retrofitting Edge Drains — adding a longitudinal drainage system to a pavement structure aids in the rapid removal of water and prevents pumping, faulting, and durability distresses from developing, at the same time, may reduce wet pavement incident potential. For fine grained subgrade soils, the adding of the edge drain may accelerated the loss of fines from underneath the pavement, resulting with loss of support and increase the slab cracking potential.

3. <u>Corrective and Preventive CPR Techniques:</u>

- Diamond Grinding and Grooving — diamond grinding (DG) improves the pavement's ride quality by creating a smooth, uniform, corduroy-like longitudinal grooved profile and removing faulting, slab warping, studded tire wear, and patching unevenness (Figure 3). DG reduces the impact loadings, resulting with less cracking and pumping potentials, leading to longer pavement service life. DG also decreases the undesirable tire/pavement noise, improves skid resistance, corrects poor drainage caused by inadequate cross slope, and thus reduces hydroplaning potential.

- Grooving — Grooving restores skid resistance to concrete pavements. It increases the surface friction and surface drainage capabilities by creating small longitudinal or transverse channels that drain water away from underneath the tire, reducing the hydroplaning potential. The only caution is that the deeper the grooving, the nosier the pavement. It should be a balance between the width/depth/spacing of the groove and the skid resistance/noise.

Figure 3: Diamond Ground Surface [ACPA-TB020P]

- Dowel-Bar Retrofit — dowel-bar retrofit increases the load transfer efficiency at transverse joints/cracks in jointed plain concrete and jointed reinforced concrete pavements by linking the slabs together across the saw cut transverse joint so the wheel load is distributed evenly across the joint, reducing the edge stress. As a result, it increases the pavement's structural capacity and reduces the potential for faulting by decreasing the stresses and deflections in the pavement. Dowel-bar retrofit consists of cutting horizontal slots in the pavement across the transverse joint or crack, removing the concrete, in particular the cracked concrete, cleaning the slot, placing the smooth dowel bars centered horizontally at the joint/crack and in mid depth with proper alignment, then backfilling the slots with new concrete/high strength grout and curing to design strength before opening for traffic (Figure 4). Figure 5 shows recommended orientation, slot size and details for retrofit dowel bars.

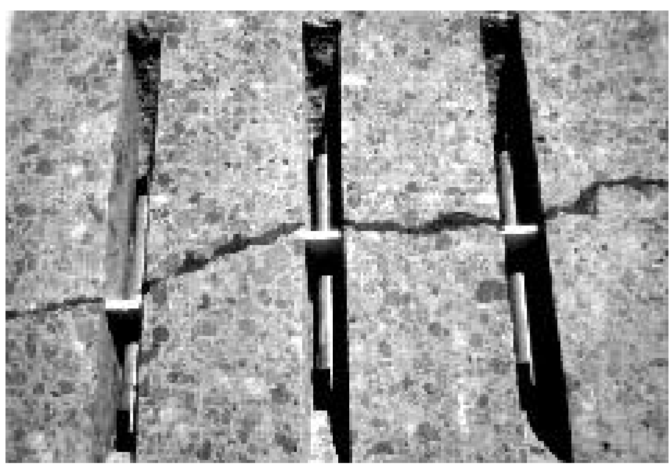

Figure 4: Dowel-Bar Retrofit [ACPA-TB020P]

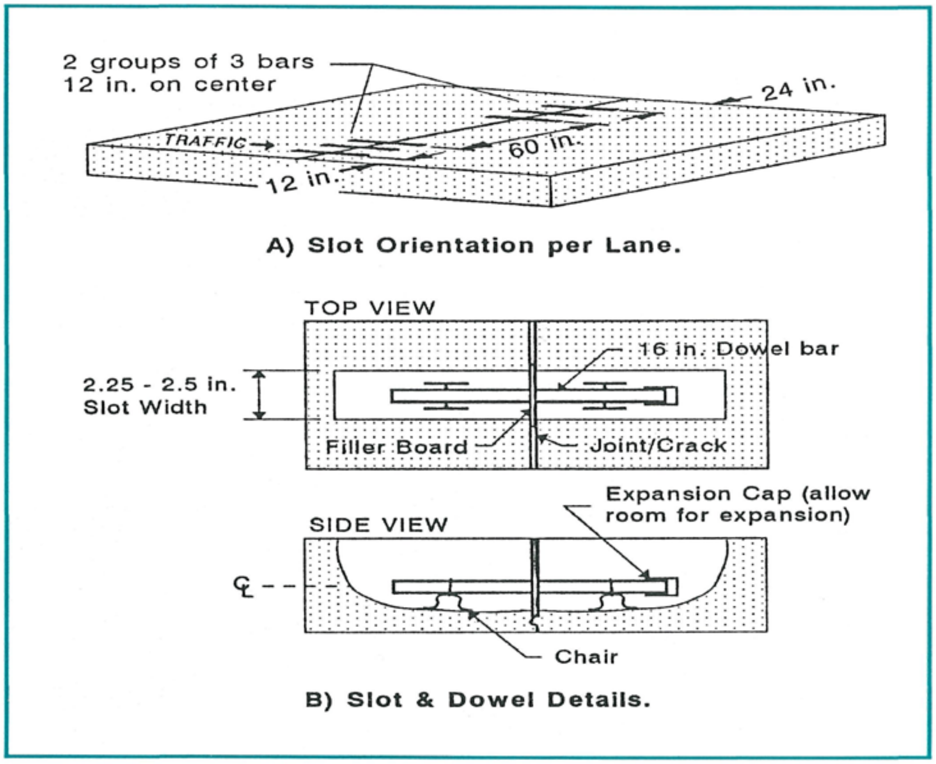

Figure 5: a) Recommended orientation for retrofit dowel bars (per lane)
b) Slot size and details for each retrofit bar [ACPA-TB012P]

- Slab Stabilization/Jacking — Slab stabilization/jacking restores base/subgrade support to the concrete pavement slabs by filling small voids with foam/grout that develop underneath the concrete slab at joints, cracks, or the pavement edge (Figure 6). The voids are caused by pumping or consolidation of the subgrade from high corner deflections. Without proper support, the pavement will develop faulting, corner breaks, and extensive cracking, reducing the structural capacity and service life. This CPR Technique is sensitive to the construction practices and care should be taken by the crew when injecting foam or grout, so as not to cause other problems such as accidentally sealing the transverse joints.

Figure 6 Slab Stabilization/Jacking [ACPA-TB020P]

- Cross-stitching — cross-stitching repairs longitudinal cracks not joints that are in fair (low-severity) condition. It increases load transfer across the crack by adding steel reinforcement to hold the crack together tightly (Figure 7). This limits the crack's horizontal and vertical movement and prevents it from widening. Cross-stitching will not repair severely deteriorated cracks that are functioning as a moving joint. At severely deteriorated cracks, there is too much deterioration to re-establish effective load transfer; other CPR techniques such as partial or full depth repair may be warranted. Cross-stitching transverse joints/cracks may restrain the pavement slab movement in the direction of traffic and will cause a new transverse crack to form not too far away. In these cases, dowel-bar retrofit is the proper CPR technique to address the distresses.

Figure 7: Cross-Stitching [ACPA-TB012P]

Relating CPR Techniques to Concrete Pavement Distresses

In any CPR program, an understanding of the relationship between the available CPR techniques and the distress or combination of distresses, is essential to the success of the program. A thorough investigation of the distresses and their root causes narrows the choice of viable CPR solutions substantially. In most cases, more than one CPR technique may have to be considered, but depending upon the condition of the distress, one technique may be more suitable than another. For example, transverse cracks that are "working cracks" can be sealed early and may perform for many years, then followed with dowel-bar retrofit or full-depth repair to restore the pavement structural integrity if the cracks develop severe spalling, pumping, or faulting.

The sequence of work is very important in a CPR program also. Figure 8 shows a flow chart to facilitate the CPR technique sequence maximizing the results, such as slab stabilization/jacking and retrofit edge drains preceded full and partial depth repairs or full- and partial-depth repairs, dowel-bar retrofit, retrofit concrete shoulders, and cross-stitching preceded diamond grinding.

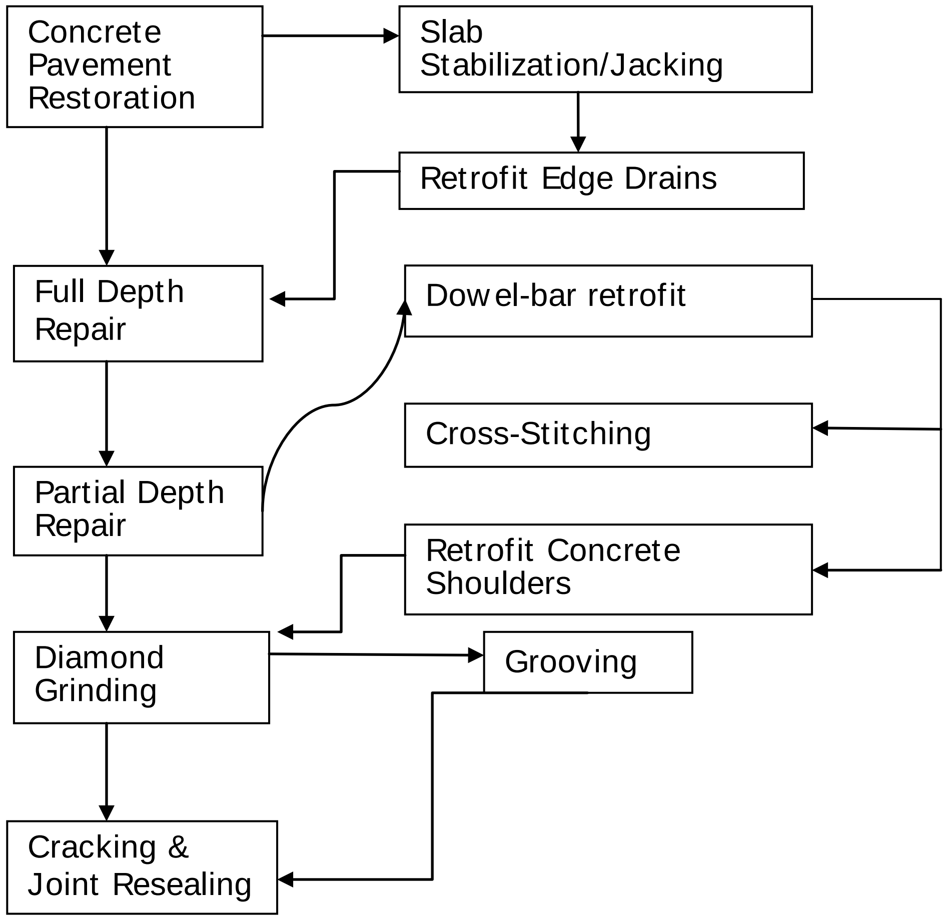

Figure 8: Sequence of CPR techniques

Canadian Based Case Studies

Dowel-Bar Retrofit on Ontario Highway 417 Westbound Lanes

Highway 417 Westbound was tendered by Ontario Ministry of Transportation (MTO) in 2004. It was the 2nd alternate bid with Life cycle cost adjustment factors and concrete pavement is the lowest bid. The 2 westbound lanes were constructed in 2004/2005. The concrete slab is 200 mm thick and built with slipform paver equipped with automated dowel-bar and tie-bar inserters. During construction, the alignments of dowel bars were found to be not in accordance with MTO's specification. Significant numbers of dowel bars were replaced with dowel-bar retrofit technique.

First MIT (Magnetic Imaging Tools) scan was deployed to identify misaligned dowel bar locations, then these bars were cut and adjacent slots were cut for new dowel bars. In some transverse joints, only a few bars were replaced but there were instances where the dowel bars were replaced for the entire joint. Figure 9 shows pictures depicting the installation process. As of today, the retrofit appears to work with minimal problems.

Figure 9 Highway 417 Westbound Dowel-Bar retrofit

Cross-Stitching on Ontario Highway 417 Eastbound Lanes

Highway 417 Eastbound was the 1st alternate bid tendered by MTO in 2000 and was won by concrete pavement and built over 2 years. There was no cracking indentified prior to December 2003. Between December 2003 and April 2004, approximately 523 metres of uncontrolled longitudinal cracks were found, about 0.72% of lane kilometres constructed. The concrete pavement slab is 200 mm thick and the cracks are predominately located in the driving lane between the wheel paths. MTO's investigation indicates that these cracks were already formed but tight until December 2003, they were widened and opened up due to higher than normal November precipitation causing temporary saturated conditions beneath the pavement edge and unpaved shoulder, coupled with sudden freezing temperature, resulted in differential slab support. [MTO 2004]

Cross-stitching was used for the first time by MTO to repair these cracks and was successful with 19.5 mm diameter tie bar, 250 mm long inserted at 35º angle to stitch the slab together. The procedure involved drilling the hole, air blast cleaning followed by inserting the bar with epoxy. [MTO 2004]

Full Depth Repair on Ontario Highway 427 with Precast Slab

In November, 2004, MTO initiated the first precast concrete pavement project on Highway 427 which is an exposed concrete pavement since the late1960. "Fort Miller Super-Slab™" and "Michigan DOT" precast pavement technologies were tried. The existing pavement structure consists of 230 mm of dowelled jointed plain concrete pavement over 150 mm of cement treated base and 150 mm of crushed granular base.

Three sections were constructed in the northbound lanes as follows:

- Michigan Intermittent Method – 3 individual full depth precast concrete slab repairs, 2 m x 3.65 m in size,
- Fort Miller Intermittent Method – 3 individual full depth precast concrete slabs, 2 m x 3.65 m in size,
- Fort Miller Continuous Method – a continuous 25 m x 3.65 m trial section, consisting of 6 individual slabs.

Each section was saw cut the night before and the removal of old concrete and precast slab placement were done the following overnight. Michigan Method involved dowel bar retrofit technique to tie the new to existing concrete pavement. For the "Super-Slab™" sections, the dowel/tie bars were drilled and grouted into the existing to tie the two together.

The observations at the time were as follows:

- Fort Miller Intermittent Method is acceptable in ride quality as compared to Michigan Method,
- Fort Miller Continuous Method was uneven and needed diamond grinding to restore the ride quality. This was due to the contractor's own leveling screed for base preparation was not as effective and created unevenness in the base material.

The sections are still in service today and MTO continues to monitor the performance. Another precast concrete pavement project was tendered in 2007 for Highway 427 involving over 100 plus precast slabs for both north and southbound lanes. Below are pictures depicting the 2004 trials (Figure 10).

Figure 10 Highway 427 Full Depth Repair-Precast Concrete

 

Figure 10 (cont'd): Highway 427 Full Depth Repair-Precast Concrete

Slabjacking Nova Scotia Highway 104 Concrete Pavement

An example of utilizing slabjacking as a concrete pavement maintenance technique can be found on the concrete pavement section on Highway 104 in Nova Scotia, Cumberland County. Here two culvert areas settled over a two year period after the placement of the concrete pavement. Slabjacking techniques were used to bring the pavement sections back up to grade. A series of strategically located holes were cored in the pavement to allow the injection of a flowable grout underneath the concrete pavement. The grout filled the gaps under the pavement and gradually lifted the settled pavement back to grade without damaging the pavement. The core holes were then filled with a durable concrete grout. The cost of slabjacking the two sections back in 1996 was $13,433. [NSTPW 1999]

Diamond Grinding of Winnipeg City Street, Manitoba

In the summer of 2008 the City of Winnipeg, Manitoba, did its first diamond grinding (DG) project. The City did the project to access diamond grinding as a pavement preservation treatment. A total of 119,500 square meters of diamond grinding was performed on the following three city streets:

1) Brookside Boulevard a 250 mm plain doweled concrete pavement constructed in 1995
2) Kenaston Boulevard a 250 mm plain concrete pavement constructed in 1997
3) Plessis Road a 230 mm plain dowelled concrete pavement constructed in 2007

Prior to diamond grinding, the streets were generally in good condition and had full depth and partial depth repairs.

The initial and final average, after DG, International Roughness Index (IRI) smoothness values were as follows for the three street sections:

1) Brookside Boulevard initial IRI 2.31 m/km and final IRI after DG 1.09 m/km
2) Kenaston Boulevard initial IRI 1.59 m/km and final IRI after DG 0.74 m/km
3) Plessis Road initial IRI 2.93 m/km and final IRI after DG 1.45 m/km

The total cost of the diamond grinding sections was $566,250 and was completed in 22 working days. It is anticipated the pavement service life will be extended by at least 15 years. See Figure 11 below for picture of the diamond grinding operation. Ken Boyd, Support Services Engineer for the Winnipeg Public Works Department, stated the following on the diamond grinding projects:

"In our city, more than 90 percent of the street infrastructure is concrete pavement, so we are looking for a means to restore and maintain our concrete pavement surfaces," said Boyd. "I was very satisfied with the results as taxpayers are receiving smoother pavements that will last longer. Additionally, the experience gained from the project will be used to develop future projects. In fact, we are already planning preservation treatments on some streets for 2010." [IGGA January 2010]

Figure 11: Diamond Grinding Test and Trial Project in Winnipeg, Manitoba [IGGA January 2010]

Concrete Pavement Rehabilitation and Diamond Grinding, Winnipeg, Manitoba

Provincial Trunk Highway 75, a main route between Winnipeg and the U.S. border, had a 25.4 km section of undoweled concrete pavement and is 17 to 18 years old with an average IRI of 2.53 mm/m and panel faulting of 10 to 15 mm. The faulting was caused by the lack of aggregate interlock and load transfer capability as no dowels were used in the initial design to assist with load transfer. Over time this lead to tire thumping and a very rough ride which needed to be corrected. Other issues were also present in the roadway including: dips at most of the through grade culverts, some randomly cracked panels, many transverse joints were spalled in the wheel path and many corners were cracked or chipped at the junction of the transverse and centerline joints. [IGGA March 2010]

The Manitoba Infrastructure and Transportation analyzed the issues and decided to choose concrete pavement restoration (CPR) techniques to address the roadway issues. An asphalt overlay was considered by Manitoba Infrastructure and Transportation but CPR was chosen as the rehabilitation method due to its projected cost being half the asphalt overlay cost. The CPR techniques selected to rehabilitate the concrete pavement were dowel bar retrofit, partial and full depth repairs, transverse joint sealing and diamond grinding. Other work performed under the construction contract were upgrade of the shoulders from granular to asphalt, addition of rumble strips to two sections of the southbound lanes and temporary detours were constructed for future projects.

This was the first project for Manitoba Infrastructure and Transportation utilizing dowel bar retrofitting and diamond grinding pavement restoration techniques. Helping to compound the use of these unfamiliar CPR techniques, the project was bid during the occurrence of the second largest flood on record in 100 years in Manitoba. The normal level of the river is 6.5 feet (1.98 m), but at one point, the flood waters threatened to push that level past 22.6 feet (6.89 m). During the bidding period, the highway was under water and closed to all traffic which actually caused the bidding period to be extended. The excessive flooding created many challenges such as soft shoulders and other unscheduled delays. Some of the operations were completed during night shifts while maintaining traffic, including the cutting of the dowel bar slots and diamond grinding. [IGGA March 2010]

Figure 12 below shows a full depth repair being done on the roadway. Upon completion of the restoration work, Gary Dyck, Maintenance Superintendent for the area, noted that “Highway 75 is finally smooth and the difference for the snow plows and their operators is unbelievable. The smooth pavement should dramatically reduce wear and tear on the equipment for years to come.” [IGGA March 2010]

The rejuvenated highway now boasts a smooth riding surface with an expected life span increase of 10 to 15 years. This result will not only save the taxpayers money, but will provide a smooth ride for years to come due to the addition of retrofitted dowel bars. With a project value of $9,000,000, the final cost of the dowel bar retrofit, partial and full depth repairs and diamond grinding was $360,000 per kilometre. [IGGA March 2010]

It is understood that Manitoba Infrastructure and Transportation has plans for another project in 2010 or 2011.

Figure 12: Highway 75 Full Depth Repair Winnipeg, Manitoba [IGGA March 2010]

References

1) [Smith 2007] Tim Smith, "MIT Workshop-Concrete Pavement Restoration, 2007", Cement Association of Canada.
2) [ACPA-TB012P] Joint and Crack Sealing and Repair for Concrete Pavements, 1995, American Concrete Pavement Association.
3) [ACPA-TB020P] The Concrete Pavement Restoration Guide, 1997, American Concrete Pavement Association.
4) [ACPA-RT3.02] Factors for Pavement Rehabilitation Strategy Selection, February 2002, American Concrete Pavement Association.
5) [ACPA-QD011P] Concrete Pavement Restoration & Preservation, A Guide to Maintaining Concrete Streets and Local Roads, 2006, American Concrete Pavement Association.
6) [Banasiak 1996] Banasiak, D., "Concrete Pavement Restoration: The Georgia Story," *Roads and Bridges*, Scranton-Gillette, Des Plaines, IL, April 1996.
7) [TRB 1996] "Transportation Overview: A Report by TRB Technical Activities Staff 1995-1996," *TR News*, Number 186, Transportation Research Board, National Research Council, Washington, D.C., September-October 1996, pp. 11-25.
8) [IGGA January 2010] Diamond Grinding Test and Trial Project in Winnipeg, Manitoba, International Grooving and Grinding Association, Case Study January 2010.
9) [IGGA March 2010] Infrastructure Rehabilitation in Winnipeg, Manitoba – Canada, International Grooving and Grinding Association, Case Study March 2010.
10) [NSTPW 1999] Nova Scotia Transportation and Public Works, "Asphalt Concrete Pavement and Portland Cement Concrete Pavement, Highway 104, Cumberland County, Year 5 of 5 Year Study", October 1999.
11) [MTO 2004] "Highway 417 EBL Investigation and Repairs" Presentation to CAC, June 2004, Ontario Ministry of Transportation.