Optimization of Concrete Maintenance to Extend Pavement Service Life

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ABSTRACT

The Highway 407 ETR concession in Ontario, Canada, is responsible for the management of a large highway network for a period of 99 years. As a part of that concession, 407 ETR manages over 600 lane-km (373 lane-mi) of exposed concrete highway. 407 ETR has a very active pavement maintenance and preservation program to maximize the life of the pavement. Also, as a private-sector concession, 407 ETR has the ability to act very quickly and actively partner with industry to promote innovation and to avoid the pitfalls of low-bid procurement.

407 ETR has an active pavement management and maintenance management system that is used for future needs planning but, more importantly, is also used to identify maintenance and rehabilitation needs early in their development so that they can be addressed using a less expensive preventive maintenance program. It is in the best interest of the concession to maximize the life of the pavement, to provide a high-quality riding surface for the paying public, and to avoid disruptions to traffic flow and revenue. To accomplish this, 407 ETR has employed many maintenance techniques including slab stitching, dowel bar retrofit, joint retrofit, diamond grinding, shot blasting, longitudinal grooving, underslab sealing and lifting, targeted slab replacement, microsurfacing, and other proprietary thin asphalt surfacings.

This paper reviews each of the concrete pavement maintenance and repair techniques used by 407 ETR over the past 10 years, discusses their performance, provides guidance on “what to do and what not to do” aspects of their use, and compares their life-cycle benefits.

INTRODUCTION

The Highway 407 ETR concession in Ontario, Canada, is responsible for the management of a highway network for a lease period of 99 years. As a part of that concession, 407 ETR manages over 600 lane-kilometres of exposed concrete highway. 407 ETR’s pavement maintenance and preservation program is designed to maximize the life of the pavement, provide a high-quality riding surface for the paying public, and avoid disruptions to traffic flow and revenue.

The pavement management and maintenance management system is used for future needs planning, but, more importantly, it is used to identify maintenance and rehabilitation needs early in their development so that they can be addressed using a less expensive preventive maintenance program. Also, as a private sector concession, 407 ETR has the ability to act very quickly and actively partner with industry to promote innovation in pavement preservation and to avoid some of the pitfalls of required low-bid procurement. This allows 407 ETR to test new pavement preservation technologies and procedures by working with in-

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dustry to quickly and effectively determine the applicability and usefulness of these technologies.

As a result of the active pavement maintenance and preservation program, 407 ETR has been able to maintain its pavement condition rating above a value of 90 out of 100 for the past 10 years.

PAVEMENT PRESERVATION

The key to cost-effective preservation of pavements is to have a toolbox that includes a variety of effective preventive maintenance techniques that can be effectively used to extend the service life of the pavement. Preventive maintenance treatments are applied to prevent premature deterioration of the pavement or to retard the progression of pavement defects. As a result, the pavement is maintained at a relatively high level of service. This type of approach is illustrated in Figure 1.

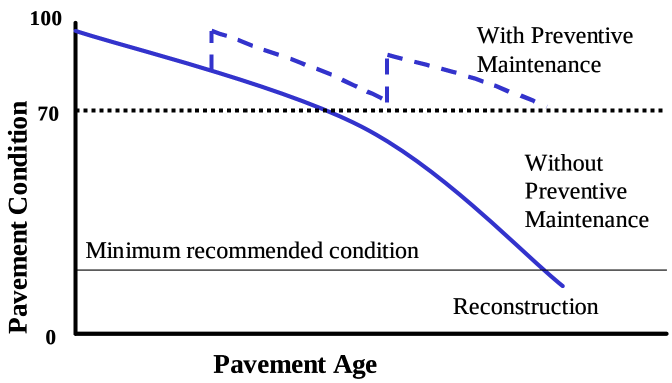

Figure 1. Pavement deterioration with and without preventive maintenance.

To accomplish this, 407 ETR has employed many maintenance techniques including slab stitching, dowel bar retrofit, joint retrofit, texturization (diamond grinding, shot blasting, longitudinal grooving), underslab sealing and lifting, targeted slab replacement, microsurfacing, and other proprietary thin asphalt surfacings.

PAVEMENT PRESERVATION TECHNIQUES

Highlights and lessons learned from the implementation of each of the concrete pavement maintenance and repair techniques used by 407 ETR over the past 10 years including performance on “what to do and what not to do” aspects of their use are provided below.

Crack Stitching

407 ETR has made extensive use of crack stitching over the past 10 years. Crack stitching typically includes the following steps:

- Drilling holes at a 35-to-45º angle so that they intersect the crack at about the slab middepth (Figure 2).
- Cleaning of holes by air blasting.
- Injecting epoxy into the hole (in sufficient volume to fill all the available space after a tie bar is inserted).

- Inserting a deformed tie bar into the hole, leaving about 25 mm (1 in.) between the pavement surface and the end of the tie bar (Figure 3).
- Removing excess epoxy and finishing it flush with the pavement.
- Sealing of the crack (Figure 4).

The objective of crack stitching is to prevent widening of the cracks and to assist in providing load transfer across the cracks. Narrow cracks maintain aggregate interlock, reduce the potential for stepping (or faulting), and are easier to seal. Good candidates for crack stitching are pavements in good condition with low severity longitudinal cracks.

Figure 2. Drilling holes for cross stitching.

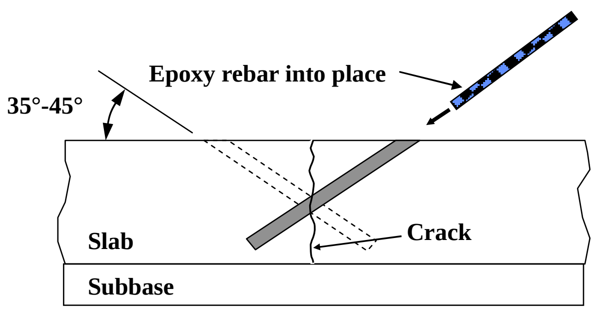

Figure 3. Stitched longitudinal crack.

Figure 4. Completed crack stitch.

407 ETR has completed cross stitching for over 350 cracks over the past 10 years. To date, the installation and performance has been excellent. The estimated service life for crack stitching is expected to be 10 or more years. Cracks stitched in 1998 still show excellent performance. The typical cost for crack stitching is in the order of US $60 per bar (2008 dollars). This is substantially less than the cost and user inconvenience if the concrete slabs were removed and replaced. Crack stitching is a cost-effective tool in extending the service life of a concrete pavement while minimizing the impact on traffic. A key lesson learned with respect to crack stitching is the early identification of cracking and immediate stitching of the crack before any secondary cracking occurs. If secondary cracking has occurred, the effectiveness of the treatment is reduced (Figure 5). While crack stitching has been used successfully for some transverse cracks, it is best suited to longitudinal or diagonal cracks.

Figure 5. Cracking at a stitch that was completed too late.

Transverse Joint/Crack Load Transfer Retrofit

Load transfer is the distribution of wheel loads across transverse joints in jointed concrete pavements. The distribution of loads across a joint (or crack) can be addressed in two ways; through aggregate interlock or through the use of mechanical devices. Poor load transfer can lead to a number of pavement deficiencies including faulting, pumping, and corner breaks. The occurrence of these distresses often leads to a reduced pavement service life. Load transfer retrofit is a procedure used to restore the load transfer efficiency of joints / cracks, which in turn improves pavement performance and ride quality.

The purpose of load transfer restoration (also called dowel bar retrofit) is to insert dowel bars across transverse cracks (Figure 6) or insert additional dowel bars across the transverse joints of jointed portland cement concrete (PCC) pavements. The objective is to increase load transfer and reduce potential for further progression of faulting (stepping of slabs), pumping (repeated deflections at transverse joints that can erode slab support), and slab cracking.

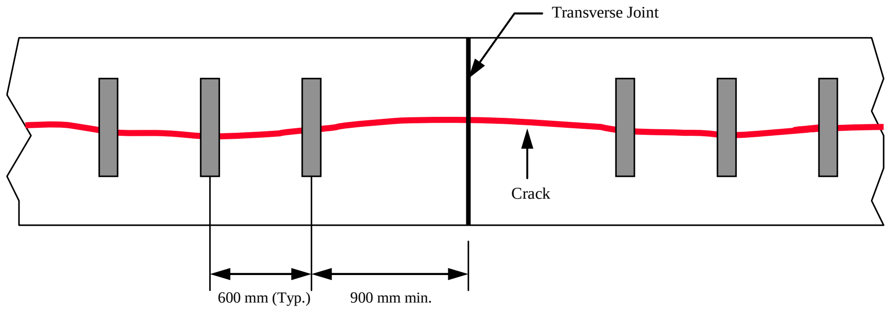

Figure 6. Typical spacing of dowels across a transverse crack.

Load transfer restoration is suitable for pavements with deflection load transfer of 60 percent or less in cool weather that show early signs of faulting (more then 2 mm [0.08 in.] but less than 6 mm [0.24 in.]). The pavement should have adequate PCC slab thickness. To ensure proper selection of transverse joints that would benefit from load transfer restoration, evaluation of the load transfer efficiency should be carried out using falling weight deflectometer (FWD) testing. The basic design and construction steps of load transfer restoration method include the following:

- Cutting slots perpendicular to the transverse crack / joint. The slots must be large enough to place the dowel at middepth of the slab and allow for the backfill grout to flow below and around the dowel.

- Removal of the concrete within the slot using light hammers. The slot must be properly cleaned by sand blasting followed by air blasting.

- Installation of the load transfer devices, which are typically smooth, epoxy-coated dowel bars. The size of the dowel bars depends on the slab thickness and anticipated loads. For the concrete pavement on 407 ETR, which is 280 mm (11 in.) thick, a dowel bar 32 mm (1.3 in.) in diameter and 450 mm (18 in.) long is used (Figure 7). One half of the dowel bar is coated with a bond-breaking compound (grease-based) and equipped with an expansion cap. A spacer is inserted in the middle to preserve transverse crack opening.

- Backfill of the slots using materials that develop adequate early strength gain to facilitate early opening of the area to traffic and exhibit little or no shrinkage. Polymer concretes and high-early-strength PCC materials have been used in most installations to date.

Load transfer retrofit techniques are very rapid to complete, require minimal disruption to traffic, and can cost-effectively extend the life of a concrete pavement. A completed load transfer retrofit treatment for a mid-panel transverse crack is shown in Figure 8.

To date, 407 ETR has completed over 100 load transfer retrofit installations primarily at mid-slab transverse cracks. The performance to date has been excellent and a life expectancy of at least 8 to 10 years is anticipated. The cost to install eight bars per lane is in the order of US $1,300 (2008 dollars).

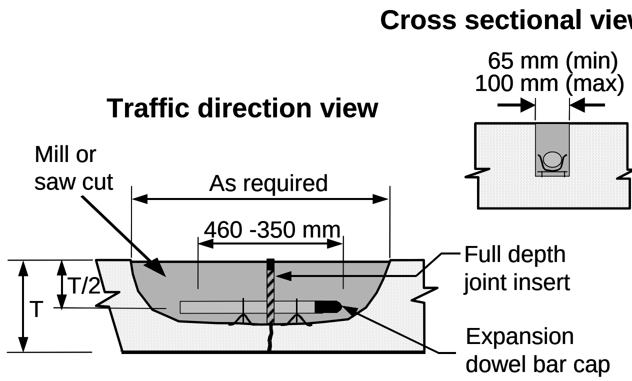

Figure 7. Dowel bar placement for load transfer retrofit.

Figure 8. Load transfer retrofit for a mid-panel transverse crack.

Expansion Joint Retrofit

Expansion joint retrofit is an extension of the load transfer retrofit outlined above. Bridge inspections completed in 2007 indicated that there were some problems with cracking of ballast walls on some of the bridges. A detailed visual inspection indicated that there were some shear cracks in the corners of the ballast walls where the reinforcing steel forms the cleat with the wing wall.

Typically, the bridges and approach slabs are constructed in advance of the pavement. The pavement is then slipformed to within four or five slabs from the approach slab depending on jointing details and bridge skew. The remaining concrete pavement is then formed and placed with an expansion joint at the tie-in to the concrete pavement. The expansion joint typically includes compressible expansion joint material (fibre board) covered with hot-poured rubberized crack sealant. In some cases, the expansion joint is insufficient to accommodate the expansion of the concrete pavement.

In the late spring/early summer of 2008, expansion joint retrofits were installed at several bridge structures. The expansion joint retrofit is similar to the load transfer retrofit for transverse cracks except, the existing dowel bars at the joint are cut using a diamond saw. A second cut is then completed to widen the joint to a width of between 40 and 50 mm (1.6 and 2.0 in.). Slots are cut for new dowel bars in between the existing now cut dowel bars. A fibre expansion board is then placed in the joint to the bottom of the slot cuts and dowel placed in the slots. Dowel bars with expansion caps on one end are then placed within the slots with a plastic grout retention shield on either side of the bar at each slot to ensure that the grout is in the slots and does not flow into the joint. The grout is then placed in the slots to the top of the pavement, followed by additional expansion board, which is then topped with hot-poured rubberized asphalt sealant. A photograph of a typical installation is shown in Figure 9. Shortly after the expansion joint installation, the sealant was noted to be squeezing out of the joint, indicating that pressure is being relieved at the joint and the installation is working as designed.

Figure 9. Expansion joint retrofit at bridge approach.

In 2008, 407 ETR installed these expansion joint retrofits at six bridge locations. It is hoped that they will protect the bridge ballast walls from further damage and have a service life of at least 15 to 20 years. The cost to install each expansion joint is in the order of US $ 4,200 per lane (2008 dollars). Additional installations are planned for the spring of 2009. However, prior to completing the new installations, each of the existing retrofit expansion joints will be scanned using an MIT Scan (magnetic imaging tomography) device to evaluate the alignment of the dowel bars in the slots. It is critical that they be aligned properly to ensure that there is free movement across the slabs at the joint.

To maximize the efficiency of the expansion joint installation, it is critical that the joints be installed during relatively cool weather conditions (< 20 ^{o}C [< 68 ^{o}F]). At higher temperatures, the stress due to the expansion of the concrete makes it very difficult to cut the slots and could result in the saw blade binding within the cut. The cut should be completed using several passes to ensure that any built-up stress in the concrete is gradually relieved. It is also important to maintain parallel cuts to ensure a consistent joint width. As shown in Figure 9, concrete barrier walls and concrete shoulders are present at the approach to many of the bridges. To facilitate free movement of the pavement, it may also be necessary to cut the concrete barrier wall. Finally, as many of the bridges have skewed approaches, it was decided to not install any expansion joints in skewed slabs but rather to move back to the first slabs that allow for the installation of the expansion joint perpendicular to the direction of the pavement. It was felt that this would assist in accommodating any expansion while facilitating easier joint installation.

Texturization

Texturization techniques include conventional milling, fine milling, micromilling, diamond grinding, longitudinal and transverse grooving, precision milling, surface abrading and other techniques that remove unevenness from the pavement surface or improve its texture, and leave an abraded surface that is used as a driving surface. While milling techniques have been used for concrete pavements in some jurisdictions, they tend to be very aggressive causing joint damage as shown in Figure 10. As such, 407 ETR has limited its use of texturization techniques to diamond grinding and grooving and surface abrading.

Figure 10. Difference between micro-milling (left) and diamond grinding (right).

Diamond grinding of PCC pavements is a rehabilitation technique that removes a shallow depth of pavement surface material by sawcutting closely spaced grooves into the pavement surface using diamond-tipped blades. The purpose of diamond grinding is to improve pavement smoothness and improve pavement surface friction. When used to improve pavement smoothness, diamond grinding can be used only for selected areas of the pavement, for example to remove slab stepping (faulting) at selected transverse joints. When used to improve pavement surface friction, diamond grinding is used over the entire pavement area. Diamond grinding can remove up to 20 mm (0.8 in.) from the pavement surface and can remove surface defects and irregularities such as polished or scaling surface and faulting, and restore pavement surface smoothness.

Grooving of the pavement is not intended to improve pavement smoothness but rather to provide channels for the removal of surface water thus potentially improving the frictional properties of the pavement. Longitudinal grooving is shown in Figure 11.

Figure 11. Longitudinal grooving completed perpendicular to the transverse tines.

Surface abrading can be completed using a number of proprietary techniques such as Blastrac and Skidabrader. An example of Blastrac texturization is shown in Figure 12.

407 ETR has used each of the above techniques on a trial basis since 2002 to monitor their longevity in improving the frictional properties of the pavement. To date, 1,875 m^2 (2,242 yd^2) of diamond grinding, 158,000 m^2 (188,966 yd^2) of grooving, 11,625 m^2 (13,903 yd^2) of Blastrac, and 3,500 m^2 (4,186 yd^2) of Skidabrader texturization have been completed. Each of the techniques has been very effective in improving the initial frictional properties of the pavement. The various technology test sites continue to be monitored so that in the future, when more extensive action may be needed to address friction, 407 ETR will have a good understanding of the most optimal technique to use to address any pavement frictional issues. The cost of the treatments varies between about US \$ 2 and \$ 8 per m^2 (2008 dollars). Based on the performance of the various texturization techniques to date and the experience reported by others (*2*), it is expected that texturization will have a service life of some 4 to 6 years.

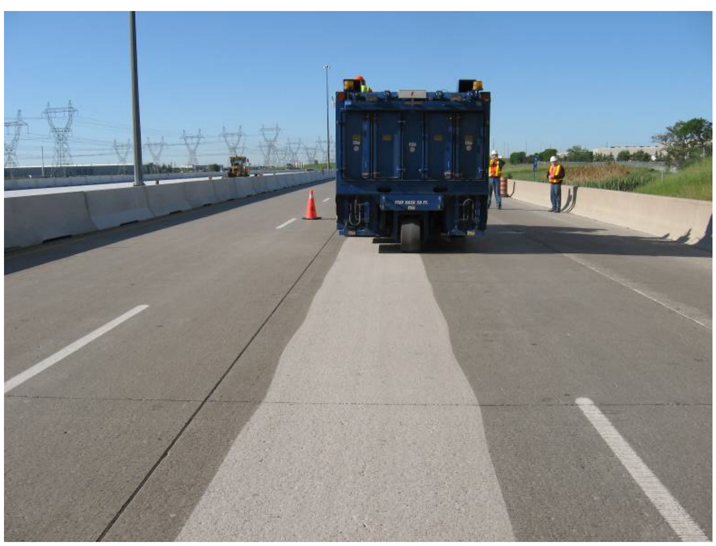

Figure 12. Blastrac concrete pavement surface texturization.

Under-Slab Sealing and Jacking

Slab stabilization is a rehabilitation technique that fills voids underneath a PCC slab with grout or foam without raising the slabs. Slab jacking fills voids underneath PCC slabs and raises the grade of the slabs. Slab stabilization is also called slab subsealing and under slab grouting (Figure 13).

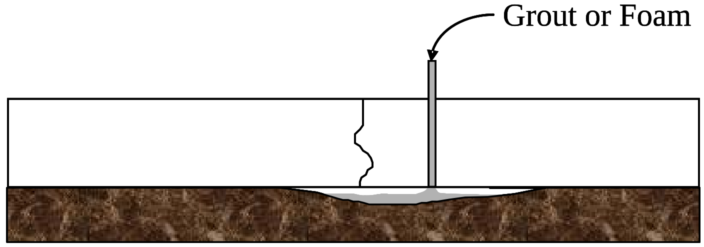

Figure 13. Concept of under-slab sealing and jacking.

The purpose of slab stabilization is to stabilize the pavement slab by pressurized injection of a material such as grout underneath the slab. The objective is to fill existing voids and restore full slab support, particularly at transverse joints and cracks. The main benefit of sub sealing is slowing down the erosion of base and subgrade materials caused by excessive pavement deflections through pumping action of traffic.

The purpose of slab jacking is to raise pavement slabs permanently to a desired grade by pressurized injection of grout underneath the slab. At the same time, slab jacking will also stabilize the slab. The objective is to improve rideability (pavement smoothness) and to fill voids underneath the pavement. Slab jacking can raise PCC slabs by up to about 50 mm (2 in.).

407 ETR has used both slab-sealing and slab-jacking techniques. Slab sealing has typically been used where voids are present beneath concrete slabs due to settlement of the underlying base and subgrade materials. Ground-penetrating radar has been used to evaluate the presence and extent of voids. In one case, slab sealing was used to stabilize the subgrade beneath the pavement due to a partial washout caused during a pipe-jacking operation to install a utility service beneath the pavement. Slab jacking has also been used extensively during the widening of the pavement. From 2004 through 2008, much of the existing concrete pavement was widened with two or more lanes installed to the inside of the existing lanes. Prior to the widening, pavement settlement areas were raised using slab-jacking techniques to improve the longitudinal profile of the pavement so that when the widening lanes were installed, they could be matched to the new profile instead of the settled profile. A total of almost 10,000 kg (22,046 lb) of foam were injected beneath the pavement to lift the slabs (Figure 14). The cost for foam injection is in the order of US $ 15 per kg (6.82 per lb) (2008 dollars), and the service life of the technique would depend on the extent and severity of the initial problem.

While foam injection has been used extensively by 407 ETR, care must be taken in the amount of foam injected and its location. The concrete pavement on Highway 407 has an asphalt cement treated, open-graded drainage layer (OGDL) directly below the concrete. If foam is injected into the OGDL as shown in Figure 14, the permeability of the OGDL will be substantially reduced in the area of foam injection. This was accepted for the slab jacking as it provided the best layer to inject to lift the slabs. Also, it is very important to monitor the lifting of the slabs during the jacking operation. Lifting the slabs by more than about 50 mm (2 in.) can result in cracking of the slabs. In these situations, a load transfer retrofit treatment was used across any of the cracks to assist in stabilizing the slabs.

Figure 14. Slab jacking using foam.

Full-Depth Concrete Slab Replacement

Full-depth repair of PCC pavements (Figure 15) is a rehabilitation method that involves the removal of an entire slab, or a substantial portion of the entire slab (full depth), the installation of load transfer devices, and the replacement of the PCC material.

The purpose of full-depth repairs is to repair slabs that can no longer be repaired using other less expensive techniques. This includes slabs with broken concrete, midslab cracking, slabs damaged by frost heaving and subgrade settlement, slabs with poor load transfer, and slabs where dowels are exposed, etc. The objective of the repair is to restore smoothness and structural integrity of the pavement and to arrest further deterioration.

Depending on the requirement to open the area to traffic, PCC repair materials can be a regular PCC paving mix using normal portland cement or "fast-track" early-strength cement. Modified cement mixtures with the addition of accelerating admixtures, polymers, or specialty proprietary cement materials are also used.

Full-depth repairs should be done on the full width of the lane and should have the minimum length of 2.0 m (6.6 ft). The maximum length should be such that at least 2.0 m (6.6 ft) of the original slab remain in place. If the remaining slab is less then 2.0 m (6.6 ft) long, the entire slab should be replaced (figures 16 and 17).

Figure 15. A 2-m full-depth repair area prepared for concrete placement.

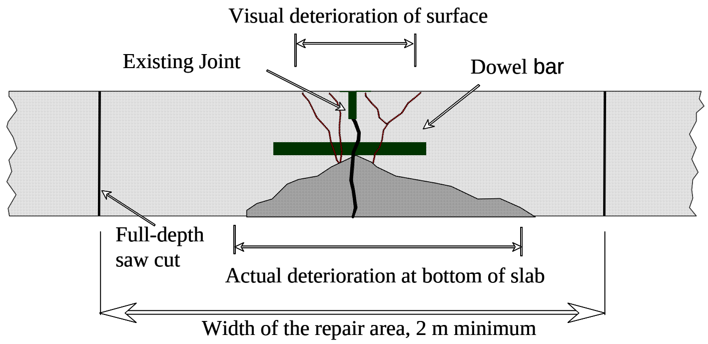

Figure 16. Cross section of deteriorated transverse joint.

Given the relatively young age of the Highway 407 ETR pavement (10 years), full-depth slab repairs have only been necessary on a limited basis. Yu et al. (*1*) found through their review of the Strategic Highway Research Program C206 test sites, that high-early-strength PCC can provide good long-term performance, however, adverse temperature conditions during installation can cause premature failures. If the difference in the average PCC temperature during curing and overnight low temperatures is large, longitudinal cracking is possible, as the thermal contraction in the transverse direction is restrained by dowel. The results of this evaluation showed that in terms of fatigue damage or faulting performance, the repairs could be opened to traffic at much lower strengths than those typically recommended. However, opening at strengths much less than those recommended is not advisable because of the risk of random failures caused by a single heavy load at early age. Therefore, 407 ETR has completed all full-depth repairs to date during the summer and on weekends when traffic is reduced and conventional curing can be completed for at least 48 hours.

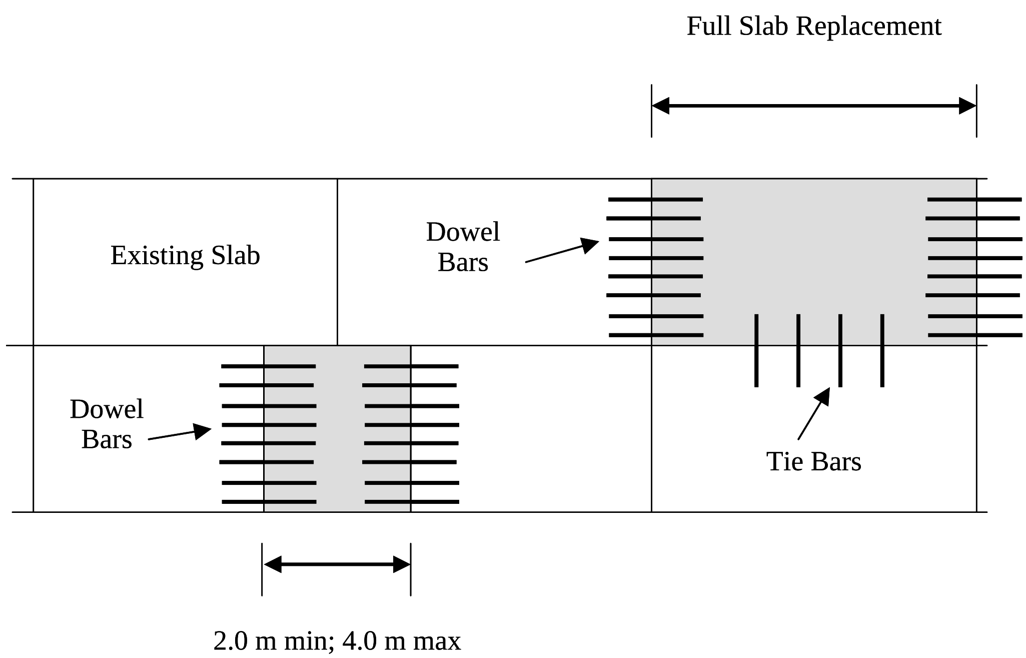

Figure 17. Example layout for full-depth repairs for a two-lane section.

To date, about 400 m^2 (478 yd^2) of full-depth repairs using conventional concrete have been completed on the highway at a cost of about US $ 375 per m^2. This translates to a cost of about US $ 2,800 (2008 dollars) for a 2-m (6.5-ft) repair or about US $ 5,500 (2008 dollars) for a typical full slab. The performance of the full-depth repairs to date has been excellent, and a service life of at least 20 years is expected (*1*).

Thin Surface Restoration Techniques

An overlay of PCC pavements is a rehabilitation technique that may include repairs of structural deficiencies in the existing PCC slabs, application of a bonding agent (tack coat) or a layer intended to mitigate the propagation of reflection cracking, and placement of an overlay. The purpose of an overlay is to improve functional deficiencies of the PCC pavement, such as low pavement surface friction, excessive pavement–tire noise, inadequate cross-slope, and roughness.

407 ETR has utilized thin surface restoration techniques such as microsurfacing and thin specialty overlays (Novachip) on a trial basis to determine their effectiveness. While these techniques are typically used for flexible pavements, experience with their use on concrete pavements is somewhat limited.

Microsurfacing is an unheated mixture of polymer-modified asphalt emulsion, high-quality frictional aggregate, mineral filler, water, and other additives, mixed and spread over the pavement surface as a slurry. The aggregate skeleton used for microsurfacing consists of high-quality interlocking crushed aggregate particles. Consequently, it is possible to place microsurfacing in layers thicker than the largest aggregate size, or in multiple layers, without the risk of permanent deformation (Figure 18).

Figure 18. Micro-surfacing over a concrete pavement.

407 ETR has used microsurfacing extensively for flexible pavements to extend the service life of hot-mix asphalt concrete exhibiting early signs of ravelling, in particular on bridge decks. 407 ETR has also used microsurfacing over concrete pavement on a trial basis with 1,125 m^2 (1,436 yd^2) of microsurfacing placed on a freeway-to-freeway ramp in 2006. Prior to placing the microsurfacing, one lane of the pavement was swept and the other sand-blasted to determine if there would be any difference in the adhesion of the microsurfacing to the pavement. To date, the performance of the microsurfacing has been quite good with no difference in performance between the lanes. However, as can be seen in Figure 18, the microsurfacing has cracked over the underlying joints, which are 12 mm (0.5 in.) wide in the concrete pavement and been lost from the pavement surface. This is likely due to the

relatively high stiffness of the microsurfacing material. These relatively wide joints will need sealing in the future. Although the microsurfacing was only recently placed, a service life of about 5 to 7 years is anticipated. The cost for microsurfacing is in the order of US \$ 4/m^2 (2008 dollars).

Proprietary thin asphalt concrete overlays are typically 15 to 20 mm (0.6 to 0.8 in.) thick and include an open-graded, high-quality aggregate passing the 13.2-mm (0.5-in.) sieve size. The mix is applied by a specialized paver with built-in application of a tack coat. The tack coat assists to ensure that there is a good bond between the concrete pavement and hot-mix overlay. Thin hot-mix overlays such as this can improve pavement friction and provide a quiet pavement surface because of their porosity (Figure 19).

Thin asphalt concrete overlays were placed directly over the exposed concrete pavement for three ramps and 500 m (1,640 ft) of the mainline pavement in 2004. While the thin overlays exhibited reflection cracking at each of the joints, the thin overlay material is more flexible than the microsurfacing and did not exhibit any raveling of the joints. To date, the performance of the thin overlays has been good, although there has been some snowplow damage to the asphalt concrete, particularly at the transition from the exposed concrete to the overlaid pavement. Based on its current performance, a service life of about 8 to 10 years can be expected. The cost for the thin overlay is in the order of US \$ 7 per m^2 (2008 dollars).

Figure 19. Thin asphalt concrete overlay over a concrete pavement.

SUMMARY AND CONCLUSIONS

In summary, through the use of a very aggressive pavement preservation program, 407 ETR is able to maintain its exposed concrete pavements at a very high level of service for a relatively modest cost. A variety of pavement preservation techniques such as crack stitching, dowel bar retrofit, expansion joint retrofit, surface texturization, slab sealing and jacking, full-depth slab replacement, micro-surfacing and thin overlays are being used and evaluated for their performance and cost-effectiveness. A summary of the techniques, expected performance and costs is shown in Table 1.

Table 1
Summary of Pavement Preservation Techniques, Performance and Cost

Treatment	Expected Benefit (life-span), years	Typical Unit Cost	
		Unit	Cost (US $)
1. Crack stitching	> 10	Each	70
2. Dowel bar retrofit	8–10	Lane	1,300
3. Expansion joint retrofit	15–20	Lane	4,200
4. Texturization	4–12[1]	m^2	2 to 8
5. Slab sealing and jacking	>10[2]	kg	15
6. Full-depth slab replacement	> 20	m^2	375
7. Microsurfacing	5–7	m^2	4
8. Thin hot-mix asphalt overlay	8–10	m^2	7

1. Based on current performance. Long-term effectiveness still unknown.
2. Depends on the extent and severity of the initial problem.

While there are many techniques available to assist in extending the performance of concrete pavements, their application is not uniform from agency to agency. In other words, what works for one agency may not be as effective for another as the performance of individual techniques will likely depend on local practice, experience, and conditions.

The ideal way to approach pavement preservation is through the life-cycle economic analysis that takes into consideration the initial construction as well as all subsequent maintenance and rehabilitation treatments. The objective is to have a pavement structure that provides the most cost-effective service through the combination of initial construction and subsequent maintenance and rehabilitation treatments.

407 ETR has taken a proactive approach in using and evaluating treatments for more widespread use including the installation of trial sections and engineering monitoring of their performance. With continued experience, decision trees and other tools for selecting the optimum pavement preservation treatments will be developed and implemented. Although cost must be considered, it is not always the decisive factor in the treatment selection process, which is particularly the case for toll facilities where disruptions to traffic can impact revenue.

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