INNOVATION TO MINIMIZE THE IMPACT OF ROAD WORK IN CANADA

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ABSTRACT

Highway and municipal traffic in Canada, particularly in the major urban areas, continues to rise. In the Toronto area, Highway 401 is the major east/west corridor and has annual average daily traffic levels exceeding 400,000. While an express toll route that opened in 1996 was expected to ease traffic on Highway 401, traffic levels on the toll route are also quite high. With increasing heavy vehicle traffic, the highway infrastructure is deteriorating more rapidly than expected which has resulted in the need to renew and repair the highway infrastructure. In order to minimize the impact of the road construction on the highway users, both the highway and toll road agencies have turned to innovation in design, construction and traffic management. This has included the use of advanced warning systems for construction, provision of the same number of lanes during construction, performance incentives and penalties, use of police presence, pavement construction innovations such as fast track concrete, pre-cast concrete panels, thin surface restoration techniques such as micro-surfacing and texturization, dowel bar retrofit, foaming injection to stabilize concrete slabs, slab stitching, etc. This paper provides an overview of the innovations to minimize the impact of road construction on the traveling public and surrounding home owners and businesses.

Keywords: Highway maintenance, innovation, minimization of impact of construction.

1. INTRODUCTION

Highway 401 (Macdonald-Cartier Freeway) extends slightly more than 800 kilometres across southern Ontario in Canada. Highway 401 is considered to be the world's busiest highway with an estimated annual average daily traffic of more than 450,000 vehicles in the section through the City of Toronto [1]. The highway is heavily used by the more than 6 million people who live and work in the Toronto area as well as servicing the just-in-time inventory systems of the auto industry in the Ontario/Michigan/Ohio areas. Highway 401 also includes the busiest multi-structure bridge system spanning Hogg's Hollow in Toronto. Until 1998, Highway 401 was the only major freeway crossing the City of Toronto in an east/west direction. In 1996, construction began on toll highway 407 which was intended to relieve some of the traffic pressure on Highway 401 and provided an alternate route to cross the City of Toronto.

Highway 401 was originally constructed with an exposed concrete surface with the sections in the Toronto area opened to traffic in 1938 and the entire length of the roadway opened in 1947. Since that time, the roadway has undergone some major widening and rehabilitation with the majority of the highway sections resurfaced with asphalt concrete. The Ontario Ministry of Transportation (MTO) is now in the final stages of a 10 year maintenance and rehabilitation program through the Toronto area with over $100 million being spent on pavement works.

Given the very high traffic on this highway, the MTO is very cognizant of the impact of construction on the road users and surrounding home and business owners. Closing the highway for any significant duration would be next to impossible. Construction work during the day time periods is also out of the question. Therefore, nearly all construction work on Highway 401 must take place at night during relatively short 6 hour road closures/restrictions and the MTO heavily promotes innovation to minimize the impact of construction. The operator of the toll road also completes pavement maintenance and rehabilitation work to minimize its impact as traffic delays could result in reduced revenue for the highway.

2. ASSESSING CONSTRUCTION IMPACT ON TRAFFIC

In 1997, the MTO initiated an incentive/disincentive program to minimize user delay costs during construction. Under this program, a contractor is rewarded for an early completion of work and penalized for a late completion. The amount of incentive and disincentive payments was based on expected user delay costs that were estimated by a formula taking into account site-specific conditions. The costs in this lane rental type program were based on the expected site-specific user delay costs during the construction periods.

2.1 Late Opening Due to Construction

Ontario Contract Special Provision No. 100F08 outlines the restrictions on construction operations and the penalties for late opening of the roadways. On each occasion when the contractor fails to reopen the traffic lanes by the specified time, the contractor is assessed an initial penalty of $ 5,000. If traffic lanes are not open within 15 minutes of the specified time, a further penalty of $ 2,500 is assessed against the Contractor. Thereafter, a further penalty of $100 per minute is assessed against the Contractor for every minute that the traffic lanes are not open to traffic.

2.2 Lane Rental

Incentive-disincentive payments are used for important projects that need to be completed by a set date. For example, they are used if a section of a highway needs to be open by a particular long weekend, or work needs to be done overnight. The amount of incentives and disincentives is determined by the Regional Managers using engineering judgement. That is, it is not determined by a set procedure used to calculate road user costs.

The MTO administers incentive-disincentive payments, as Special Provisions No. 100F09 and 100F10. These special provisions contain clauses requiring contractors to complete highway rehabilitation work by a certain date or to pay "*liquidated damages for each and every calendar day's delay in finishing the Work in excess of the number of Working Days prescribed*". The contractor is not rewarded for finishing the work at an earlier date. The amount of liquidated damages is determined by engineering judgement.

2.3 Evaluation of the Impact of Road Construction during the Design Stage

In 2004, MTO developed a Priority Economic Analysis Tool (PEAT) [2] to facilitate benefit-cost analysis of highway infrastructure investments using a standardized procedure. PEAT incorporates MTO user cost models and their recommended default values. PEAT calculates the costs to the road user including travel time costs, travel time delays during construction and operating costs including items such as vehicle depreciation, insurance, fuel, tire wear, etc. Most recently, in the pavement area, PEAT has been used to prioritize recommendations for upgrading a 350 km network of surface-treated pavements to asphalt concrete pavements in Sault Ste. Marie area [3]. In general, PEAT is suitable for the estimation of benefit-cost ratio at the design and planning stages of highway infrastructure investments and to calculate the user costs over the life-cycle of the pavement.

2.4 Application of Road User Costs

The importance of road user costs is highlighted on high traffic volume roadways like Highway 401 where the potential for delays is large and contractors must meet specific requirements to minimize user delays. These requirements may include, for example, night work only or construction of detours (e.g., paving or widening of shoulders) to keep open a specific number of traffic lanes. The cost of these requirements is part of the contract bid price and is thus included in construction costs. Consequently, a part of the "soft" road user costs is transformed into agency costs.

2.5 Types of Road User Costs

User costs belong to the category of indirect costs that may be considered when comparing factors and consequences associated with the selection of alternative pavement investments. The indirect costs include the following items:

- Construction zone delay costs.
- Vehicle operating costs.
- Collision costs.
- Environmental costs.

2.5.1 Construction Zone Delay Costs

Construction zone delay costs are incurred as the result of additional travel time spent by motorists driving through construction zones or detours as the result of scheduled maintenance and rehabilitation activities. The maintenance and rehabilitation activities for the two pavement types differ in terms of their type, duration, and frequency. Although the MTO is not using time delay costs to obtain bids for construction work explicitly, time delay costs are included in construction costs for the maintenance and rehabilitation of major highways by including contact provisions that are intended to minimize user costs. These provisions include requirements for keeping a specified number of lanes open at different times, and requirements for completing construction by set dates.

2.5.2 Vehicle Operating Costs

Vehicle operating costs (VOC) include costs of owning, operating, and maintaining a vehicle. PEAT [2] provides separate VOC calculations for fuel, oil, tire, maintenance and repair, and depreciation costs. VOC depend on pavement smoothness and on operating condition of the traffic flow. VOC will depend mainly on pavement smoothness and are typically only considered when analyzing the impact of using different pavement surface types and rehabilitation activities. At present, VOC are not utilized on a regular basis in Ontario.

2.5.2 Collision Costs

Differences in collision rates (for fatal collisions, injury collisions, and property damage only collisions) may arise because differing pavement types may not have identical characteristics that may influence, however marginally, collision rates. These characteristics include pavement friction during the analysis period and under a variety of pavement conditions (e.g., dry, wet, and icy), visibility of traffic control lines, visibility of geometric features under adverse weather conditions, level of illumination at night, and perhaps other characteristics such as the likelihood of ice forming on the pavement surface. At present, collision costs are not being used on a regular basis in Ontario.

2.5.3 Environmental Costs

Environmental costs include the cost of air, noise, and water pollution.

Air pollution – Air pollution costs are concerned with differences in air pollution costs, such as costs of green house gas emissions. According to a Canadian National Research Council study, there are indicators of the possible lower consumption rates of trucks operating on PCC pavements compared to AC pavements [4]. The most recent study concluded that a statistically significant fuel savings ranging from 0.8 to 3.9 percent could be realized for a typical heavy vehicle operating on a rigid pavement surface compared to a flexible pavement surface. The difference energy consumption rates caused by differences in pavement smoothness are typically captured as part VOC.

Noise pollution – The noise pollution generated from a highway construction operation is typically overshadowed by the sound levels emitted by highway vehicles during normal operation of the highway. There is an extensive body of knowledge, concerning noise generated by the interaction between the tires of highway vehicles and pavement surface texture. Most of the literature describes noise measurement studies that provide relative comparison of the potential of different pavement surfaces to generate tire-pavement noise for a variety of simplified situations. Examples of such studies are sound measurements in the close proximity of a passenger tire, or measurements of sound emitted by a single vehicle passing at the distance of 7.5 m from the microphone. Noise generated during construction includes the operation of heavy equipment, backup alarms on construction vehicles and banging of the tail gates of dump trucks. While these noises are not specifically controlled during construction activities, is has started to become a significant issue on Highway 401 in Toronto where nearly all of the construction takes place during the night time hours. It is expected that restrictions on noise during night construction operations will work their way into Ontario construction specifications in the near future.

Water pollution – The impact of construction on water pollution is governed by environmental laws and regulations in Canada. These regulations strictly control runoff from construction sites and the impact of construction on local water courses.

3. METHODS OF REDUCING THE IMPACT OF CONSTRUCTION

In order to assist in mitigating the impact of construction on the road users and surrounding environment the Ontario government has embraced design and construction innovation to either reduce the time necessary to complete construction or to increase the time periods between maintenance and rehabilitation activities. Several proven technologies include:

- Precast prestressed concrete panels for full-depth repair.
- Load transfer retrofit.
- Fast track concrete repair.
- Slab stabilization.
- Micro-surfacing.

Each of these pavement maintenance and rehabilitation methods and their impact on road users is discussed in the following sections.

3.1 Precast Prestressed Concrete Panels for Full-Depth Repair

Full depth repair of Portland cement concrete (PCC) pavements 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 PCC material. Precast concrete panel (PCP) replacement is mature technology, but a relatively new concrete pavement restoration (CPR) technique for full depth PCC pavement repairs. The technique can take advantage of short term overnight lane closures and can be open to traffic the following rush hour. The technique has been used for rapid repair of local PCC slab distresses as well as for construction/replacement of longer sections of roadway.

3.1.1 Purpose and Selection Criteria

The purpose of full-depth repairs is to replace PCC slabs that contain working cracks through the slab and can not be repaired using partial-depth repairs. This includes slabs with deteriorated concrete (particularly near joints), mid-slab cracking, slabs damaged by frost heaving and subgrade settlement and slabs where dowels are exposed. The objective of the repair is to restore smoothness and structural integrity of the pavement, and to arrest further deterioration.

Full-depth repairs are often done together with other maintenance treatments, such as partial depth repairs, slab stabilization, and crack and joint sealing as part of a pavement rehabilitation project.

3.1.2 Materials and Construction

PCP offers a number of material property advantages over cast in place PCC repairs. The PCP sections are manufactured under controlled conditions that can significantly reduce the variations that can occur with cast in-place construction. This can include stricter control over batching, curing, thickness, temperature and moisture gradients, etc.

Pre-cast repairs can provide a good alternative to cast-in-place repairs when the duration of repairs must be minimized. A new pre-fabricated concrete slab is placed into the prepared repair area in one piece. The restoration of the load transfer can be accomplished by installing dowels before or after the slab placement.

For the most common installation method, holes are drilled into the existing concrete at either end of the repair and dowels are inserted and the second half of the dowel slides into a slot in the pre-cast slab (Figure 1). Once the slab is in place, the slab is pressure injected with a cement grout to fill the dowel slots and any voids underneath the slab.

Figure 1 - Installation of pre-cast slab.

3.1.3 Performance

MTO has recently completed demonstration projects to evaluate construction techniques for precast concrete slab repairs in concrete pavement [7]. The trial was carried out on Highway 427, a heavily trafficked freeway in Toronto. The trial project required demonstrations of three precast concrete pavement full-depth repair methods. Each method involves designing and fabricating precast concrete slabs to replace deteriorated concrete pavement. The methods differ in how the base is prepared and how the precast slab is installed and connected to the existing concrete pavement. The overall assessment of the Ministry is that the precast trials went well. The precast slabs did not crack, spall, or rock. Other than workmanship issues, the work was carried out within the required timeframes, and seems to be performing well. The workmanship issues were largely attributed to a Contractor carrying out precast repairs for the first time and under difficult conditions, including night work, in cold wet weather, with a 6-hour work window.

A Texas study [5] concluded that precast concrete panels are a viable method for expediting construction of PCC pavements. Curing time delays for opening to traffic are eliminated. Prestressing can allow for the use of a thinner pavement section. A Texas DOT trial section shows virtually no signs of distress after 15 years of service.

The Colorado DOT [6] used several different methods of precast concrete panels and installation techniques including polyurethane foam injection for underslab stablization and fibreglass joint ties. The failure rate for relatively thin panels (160 mm of less) was quite high with 24 percent of the panels showing ‘significant’ failure within a few years of service. Panels cast at least 185 mm in thickness experienced a much lower failure rate of 1.5 percent. Colorado experience indicates that proper preparation for the work is very important. They also conclude that using precast panels for concrete repairs significantly reduces disruption of traffic and reduces road user costs.

3.1.4 Service Life and Cost

In Ontario, a slab replacement trial project using precast concrete panels has been completed and to date, the short term performance has been good, however, cracking of the parent concrete has been noted at the dowel insertion locations. There have been no long term applications in the Province for assessment of performance.

Based on the Ontario experience, precast panel slab replacement would cost in the range of US $10,000 per slab. Based on the Colorado experience, the typical cost of a full-depth repair is about US $9,000 per slab. The Colorado study also demonstrated a significant user delay cost savings in the order of US $100,000 per day of work by using the precast slab repair method compared to conventional cast in place slab replacement methods where the lane is closed to allow the concrete to cure.

3.1.5 Summary

The use of precast concrete panels for rapid repair of local PCC slab distresses as well as for construction/replacement of longer sections of roadway has been successfully used in Texas for over 15 years. The success of the technique in Texas has prompted trial sections in Ontario, Michigan, New York, etc. The technique can take advantage of short term overnight lane closures and can be open to traffic the following rush hour. The cost of the technique is significantly more than conventional full depth repair methods, however, the reduced time to complete a slab replacement may result in life-cycle cost competitiveness with conventional methods.

3.2 Joint/Transverse 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.

3.2.1 Purpose and Selection Criteria

The purpose of load transfer restoration (also called dowel bar retrofit) is to insert dowel bars or insert additional dowel bars across the transverse joints of jointed PCC pavements. The objective is to increase load transfer across transverse joint 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.

Load transfer restoration is suitable for pavements with deflection load transfer of 60 percent or less in cool weather, which show early signs of faulting (more then 2 mm but less than 6 mm), or pumping. 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. Load transfer restoration is typically carried out concurrently with other rehabilitation treatments such as resealing of joints and full depth repairs. It is also used prior to overlays.

3.2.2 Materials and Construction

The basic design and construction steps of transfer restoration method include:

The selection of joints should be based on Falling Weight Deflectometer (FWD) testing. Some joints may not require any repairs, and some joints may require full depth repair rather than load transfer restoration.

A diamond-tipped slot cutting saw is the most common equipment for slot cutting although modified milling machines have been used. Slots should be perpendicular to the transverse joint. The slots must be large enough to place the dowel at mid-depth of the slab and allow for the backfill to flow below and around the dowel. The concrete within the slot is removed using light hammers and the slot must be properly cleaned by sand blasting followed by air blasting.

The most common type of load transfer device is smooth epoxy-coated dowel bars. Some agencies are now using stainless steel bars or stainless steel clad bars. The size of the dowel bars depends on the slab thickness and anticipated loads. Typically, dowel bars have the diameter of 30 to 40 mm and the length of 350 to 460 mm (Figure 2). One half of the dowel bar is coated with a bond-braking compound (grease-based) and equipped with an expansion cap. A spacer is inserted in the middle to preserve transverse crack opening (Figure 3).

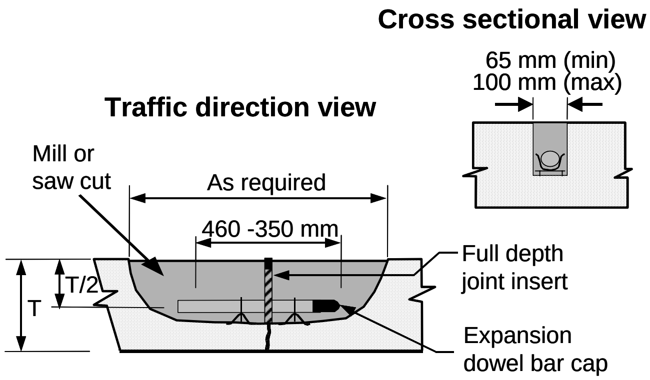

Figure 2 - Dowel bar placement for load transfer retrofit.

Figure 3 - Insertion of a spacer into a slot with dowel bar.

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

3.2.3 Summary

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.

3.3 Crack Stitching

There are two methods for stitching cracks, slot stitching and cross stitching.

Stitching of cracks using slot stitching is very similar to load transfer restoration with the following main exceptions:

- Stitching is done to repair longitudinal cracks and joints (not at transverse cracks).
- Instead of smooth dowel bars, deformed tie bars are used (with a smaller size placed further apart than dowel bars).
- The tie bars are not coated with a bond-breaking agent.

Cross stitching includes the following steps:

- Drilling holes at an 35 to 45º angle so that they intersect the longitudinal crack or joint at about the slab mid-depth (Figure).
- 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 between the pavement surface and the end of the tie bar (Figure 5).
- Removing excess epoxy and finishing it flush with the pavement.

Figure 4 - Drilling holes for cross stitching.

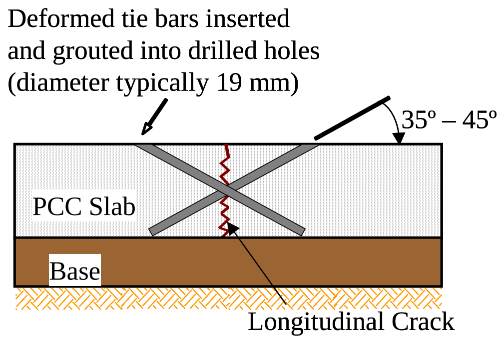

Figure 5 - Stitched longitudinal crack.

3.3.1 Synthesis of Performance

The purpose of crack and joint stitching is to repair longitudinal cracks or strengthen longitudinal joints by inserting tie bars across cracks or joints. The objective is to prevent widening of longitudinal cracks and joints (slab migration). Narrow longitudinal cracks and joints 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 where longitudinal cracks and joints show signs of slab migration. If longitudinal cracks and joints perform well simply by sealing them, crack and joint stitching may not be advisable or necessary.

Crack stitching has been extensively used with great success for the Highway 407 toll road north of Toronto. The Washington State Department of Transportation has completed over 350 lane kilometres of dowel bar retrofit projects [8]. WSDOT has concluded that dowel bar retrofit is an appropriate technique for rehabilitating faulted concrete pavements. Dowel bar retrofit is appropriate for pavements with less than 10 percent slab replacement and average faulting between 3 and 13 mm.

Harvey and Brian completed a study [9] using accelerated pavement testing using the Heavy Vehicle Simulator (HVS) to evaluate the performance of dowel bar retrofit (DBR) joints and cracks as measured by deflections and load transfer efficiency (LTE). The study found dowel bar retrofit significantly improved the load transfer efficiency and reduced deflections from both loads and environment compared to the un-doweled pavement. Three dowels per wheel path was found to have significantly lower LTE than four dowels per wheel path.

3.3.2 Service Life and Cost

In Ontario, load transfer retrofit of joints with poor load transfer has been successfully completed on Highways 407 and 417. To date, the installation and short term performance has been good and as expected. There have been no long term applications in the Province for assessment of performance.

The estimated service life for load transfer restoration is between 7 to 15 years, and for crack stitching 10 or more years. The typical cost of a load transfer restoration or crack stitching is in the order of US $50 per bar. For a complete joint retrofit, i.e. 4 bars in each wheel path, the cost is estimated to be US $400 per joint.

3.3.4 Summary

Load transfer retrofit is a viable procedure for restoring the load transfer efficiency of joints/cracks which in turn improves pavement performance and ride quality. The success of the application is dependant on the quality of the installation and on the quality of the existing concrete.

If the joint is retrofitted prior to the progression of significant joint distress, the method can reduce the potential for further progression of faulting (stepping of slabs), pumping (repeated deflections at transverse joints that can erode slab support), and slab cracking resulting from poor load transfer.

Load transfer retrofit is a cost-effective tool in extending the service life of a concrete pavement while minimizing the impact on traffic.

3.4 Fast Track Concrete Repair

Full depth repair of PCC pavements (Figure 6) 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 PCC material.

Figure 6 - 2 m repair area prepared for concrete placement.

3.4.1 Purpose and Selection Criteria

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

Full-depth repairs are often done together with other maintenance treatments, such as partial depth repairs, slab stabilization, and crack and joint sealing as part of a pavement rehabilitation project. Full-depth repairs using PCC are also done before overlays.

3.4.2 Materials and Construction

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.

Typical full-depth cast-in-place repair of jointed PCC pavement with dowels consists of the following steps:

Selection of Repair Boundaries – A detailed investigation is required to properly identify the areas requiring repairs. Visual examination is not sufficient (Figure 7). Full-depth repairs should be done on the full width of the lane and should have the minimum width of 2.0 m. The maximum width should be such that at least 2.0 m of the original slab remain in place. If the remaining slab is less then 2.0 m wide, the entire slab should be replaced (Figure 8). Consideration should be given to combining repairs in close proximity.

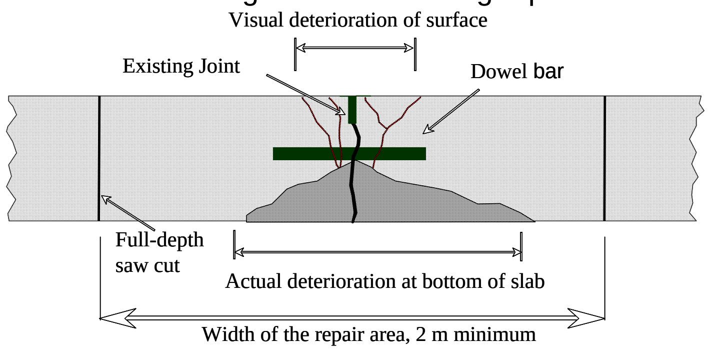

Figure 7 - Cross section of deteriorated transverse joint.

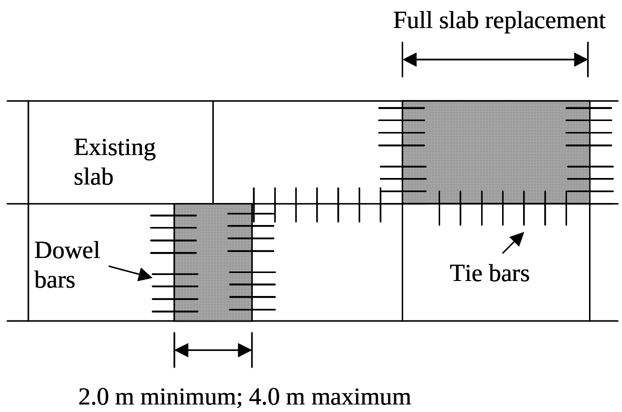

Figure 8 - Example layout for full-depth repairs for a 2-lane roadway.

Subgrade and Base Preparation – After the removal of the deteriorated concrete, the base course, subgrade and subdrains should be restored. Any disturbed material should be re-compacted.

Dowel and Tiebar Placement – All load transfer across the transverse repair joints must be re-established. Typically, epoxy-coated dowel bars are inserted half-way into the existing slab. This requires drilling holes into the exposed face of the slabs, grouting the holes with epoxy or cement-based grout, and inserting the dowel bars. A similar procedure is used for installing tie bars. Tie bars are thinner then dowel bars and are used for longitudinal joints.

Placement of Concrete – Before placing concrete, exposed dowel and tie bars should be coated with a bond breaker to prevent a bond between the bars and patch concrete. The concrete placement techniques should follow standard procedures.

Finishing and Texturing — Unless a grinding operation of the entire pavement section is to follow, the patch should be textured to resemble the finish on the rest of the pavement.

Curing – Curing should start as soon as the texturing is carried out. A white pigmented curing compound is typically used.

Joint Resealing – All longitudinal and transverse joints should be resealed. The steps include, saw cutting as soon as possible, thorough cleaning of the joint, and sealing the joint with a hot-poured rubberized compound.

3.4.3 Synthesis of Performance

These types of concrete repairs have been extensively used throughout Ontario with excellent success. Yu, et al [10], found through their review of the Strategic Highway Research Program (SHRP) 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, however, is not advisable because of the risk of random failures caused by single heavy load at early age.

NCHRP Project 18-04B, *Early Opening-to-Traffic Portland Cement Concrete for Pavement Rehabilitation* [11], evaluated fourteen different high-early strength full-depth repair mixtures designed for a 6 to 8 hour opening to traffic window and tested. The study found that high-early strength mixtures of adequate strength could be produced, but that interactions between the various constituents could result in durability problems in some mixtures. The study authors recommended that durability-related testing be conducted on such mixtures to ensure longevity of the repair.

Lee and Choi [12] reported a California case study of an innovative approach to fast track reconstruction. A 4.5-km stretch of badly damaged concrete truck lanes was rebuilt over two 215 hours (about 9-day) periods using one-roadbed full closures with counter-flow traffic and around-the-clock (24/7) construction operations. Rapid set concrete was used for the project. The same project would have taken 10 months using traditional nighttime closures. The approach utilized an automated work zone information system and proactive public outreach. Advantages of using this method of fast-track accelerated highway reconstruction included less traffic disruption for the traveling public, longer (30-plus years) pavement life expectancy, improved safety for motorists and workers, and reduced agency cost when compared to the traditional approach using repeated nighttime closures.

3.4.4 Service Life and Cost

Full depth repairs can last 20 years or more. A typical cost of a full depth repair using conventional concrete is in the range of US $200 per m^2. Using fast track concrete, the cost is in the order of US $500 per m^2.

3.4.5 Summary

The use of fast track concrete for rapid repair of local PCC slab distresses has been successfully used in Ontario for over 10 years. With emphasis on adequate controls during placement and curing to ensure that temperature gradients are within acceptable ranges, the performance of fast track concrete should be similar to that of conventional concrete. The fast track method has been used to complete these types of repairs within the typical 5 to 6 hour nightly closure of the highways in the Toronto area.

3.5 Micro-Surfacing

Micro-surfacing 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 micro-surfacing consists of high-quality interlocking crushed aggregate particles. Consequently, it is possible to place micro-surfacing in layers thicker than the largest aggregate size, or in multiple layers, without the risk of permanent deformation.

3.5.1 Purpose and Selection Criteria

Micro-surfacing is typically used on top of a bituminous layer, such as hot mix asphalt concrete or surface treatment. When applied to the hot mix asphalt concrete pavement, micro-surfacing is used to correct surficial distresses such as slight block cracking, ravelling and segregation, flushing, and loss of pavement friction. Because micro-surfacing contains high-quality crushed aggregate, it is also used to fill-in ruts and surface deformation to the depth of up to 40 mm. As a preventive maintenance treatment, it has been used to seal the surface of the asphalt concrete pavement protecting the pavement from water infiltration and greatly reducing the rate at which the existing bituminous surface oxidizes. Oxidization of the bituminous surface material leads to ravelling and cracking. Micro-surfacing can also be used to extend the service life of the pavement until a more permanent restoration can be completed.

3.5.2 Service Life and Cost

When used to protect the existing asphalt concrete pavement structure as a preventive maintenance treatment, micro-surfacing can prolong pavement life span by 4 to 6 years. When used to restore or improve pavement surface, for example, to restore pavement friction, or to repair wheel track rutting, micro-surfacing can last 5 to 8 years. The cost of micro-surfacing is about US $3 to $5 per square metre.

3.5.3 Materials and Construction

The construction of micro-surfacing using a self-propelled continuous feed mixing machine. Micro-surfacing mix is always designed by a contractor or an emulsion supplier, and consists of the following three main ingredients:

Polymer-modified asphalt emulsion contains 60 to 65 percent of asphalt cement. Polymers, typically latex, represent about 3 to 5 percent of the weight of the asphalt cement. Altogether, micro-surfacing contains about 8 to 9 percent of residual asphalt binder. The addition of polymers improves bonding properties of asphalt cement and reduces its temperature susceptibility.

Aggregate used for micro-surfacing is manufactured high-quality crushed stone, typically dense graded. Open-graded aggregate is not commonly used in North America.

Typically, open-graded micro-surfacing mix contains cellulose or mineral fibres to increase consistency of the mix and prevent draining of the emulsion.

The International Slurry Surfacing Association recommends two types of gradations, Type II and Type III. The Type II gradation is finer, with 90 to 100 percent passing 4.75 mm sieve, and is typically used on residential streets. The surface shows the stony character of the texture typical for micro-surfacing. The Type III gradation is coarser with 70 to 90 percent of aggregate passing 4.75 mm sieve size, and is typically used on high traffic volume facilities. A minimum thickness of micro-surfacing mix using Type III gradation is 10 mm for a single course.

Mineral filler, typically Portland cement or hydrated lime, is used to control curing time of the mix with the amount of mineral filler typically less than 1 percent of the dry mix weight.

On high traffic volume facilities, and/or when the surface of the pavement has minor distortions and/or has ruts exceeding about 6 mm, two courses of micro-surfacing are recommended. The first (scratch) course is intended to improve the profile of the pavement and the second course provides the wearing surface. Ruts exceeding 13 mm should be filled with micro-surfacing material using a rut-filling spreader box.

Some agencies rout and seal active cracks (e.g., transverse cracks) shortly before micro-surfacing is applied. However, micro-surfacing may not bond well to the new crack sealant resulting in the loss of material.

The MTO specifies the application of tack coat before micro-surfacing to ensure good adhesion between the existing pavement surface and the micro-surfacing mix. MTO has used micro-surfacing for many major highways (Figure 9) to cost effectively extend the service life of the pavement.

Figure 9 - Pre-treating of moderate alligator cracking at the centerline.

Micro-surfacing is applied prior to applying a regular course of micro-surfacing on the entire surface. After the micro-surfacing application, traffic can use the pavement without restrictions in about 45 to 120 minutes, depending on setting time of the asphalt emulsion, weather, and traffic conditions. Micro-surfacing should be carried out only during the warmer, dryer months. Cooler temperatures and wetter conditions can result in long curing times during which the micro-surfacing can be damaged by traffic.

3.5.4 Usage and New Developments

Based on the survey of provincial transportation agencies carried out in 2001/2002 [13], 60 percent of the agencies have used micro-surfacing on top of asphalt concrete pavements and reported very good or good performance.

3.5.5 Summary

The use of micro-surfacing both as a pavement maintenance and rehabilitation treatment continues to expand in Ontario. A properly designed and placed micro-surfacing treatment can be completed with minimal impact on the travelling public and cost-effectively extend the service life of the pavement.

4. REFERENCES

1. Wikipedia, http://en.wikipedia.org/wiki/Highway_401_(Ontario), 2007
2. Cambridge Systematics, Inc., Peat User Manual – Priority Economic Analysis Tool, Cambridge, Massachusetts, November 2004.
3.. Applied Research Associates, Inc, Surface Type For Low Volume Roads, Phase II, Report prepared for the Ministry of Transportation, Ontario, Northeastern Region, Geotechnical Section, December 2006.
4. Taylor, G.W. and Patten, J.D., 2006. Effects of Pavement Structure on Vehicle Fuel Consumption – Phase III. Report prepared for the Cement Association of Canada.
5. Merritt, D., McCullough, F.B., Burns, N.H., 2001. Feasibility of Using Pre-cast Concrete Panels to Expedite Construction of Portland Cement Concrete Pavements. 2001 Annual Meeting of the Transportation Research Board, Washington, D.C.
6. De Witt, G.L., 2006. Precaset Concrete Paving Panels: The Colorado Department of Transportation Region 4 Experience, 2000 to 2006. Colorado Department of Transportation Research Branch, Denver, Colorado, 2006.
7. Lane, B. and Kazmiereowski, T., An Evaluation of Three Methods of Pre-Cast Concrete Slab Repairs For Concrete Pavement, th International Conference on Concrete Pavements, which will be held in Colorado Springs, CO, USA on August 14-18, 2005.
8. Pierce, L.M., Uhlmeyer, J., Weston, J., Lovejoy, J., Mahoney, J.P., 2003. Ten-Year Performance of Dowel Bar Retrofit – Application, Performance, and Lessons Learned. 2003 Annual Meeting of the Transportation Research Board, Washington, D.C.
9. Harvey, J.T., Bian, Y., 2006. Evaluation of Dowel Bar Retrofit Alternatives using Accelerated Pavement Testing. 2006 Annual Meeting of the Transportation Research Board, Washington, D.C.
10. Yu, H.T., Mallela, J., Darter, M.I., 2002. Long-Term Performance of Fast-Track Full-Depth Repairs. 2002 Annual Meeting of the Transportation Research Board, Washington, D.C.
11. Bush, N., Van Dam, T.J., Peterson, K., Sutter, L., 2006. Evaluation of High Early Strength PCC Mixtures used in Full Depth Repairs. 2006 Annual Meeting of the Transportation Research Board, Washington, D.C.
12. Lee, E.B., Choi, K., 2006. California Experience with Fast-track Construction for Concrete Pavement Rehabilitation on an Urban Highway Network. 2006 Annual Meeting of the Transportation Research Board, Washington, D.C.
13. National Guide to Sustainable Municipal Infrastructure, Timely Preventive Maintenance for Municipal Roads, A Best Practice, 2002, www.infraguide.ca.