REHABILITATING URBAN PAVEMENTS WITH CONCRETE: A MUNICIPAL CASE STUDY

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ABSTRACT
Municipal agencies are challenged to provide high quality pavements, despite aging infrastructure and shrinking budgets. However, the nature of heavy urban traffic can be extremely damaging to asphalt pavements.

Despite the preference of many municipalities for hot mix asphalt as a paving material, Portland cement concrete has numerous technical and economic benefits that make it an excellent choice for rehabilitating urban pavements.

This paper focuses on urban pavement maintenance and rehabilitation considerations, and presents a case study of two types of rehabilitation strategies using concrete pavement materials. The performance of these pavements during their first ten years of service is discussed and the future maintenance and rehabilitation needs of these sections are considered, based on current performance trends.

The City of Toronto was observing the rapid deterioration of the pavements at an urban intersection with high volumes of transit bus traffic. In order to mitigate the frequent rutting and shoving problems that were recurring despite regular maintenance and rehabilitation interventions, the City elected to rehabilitate the troublesome intersection using Portland cement concrete materials. As part of this project, the city constructed its first unbonded concrete overlay and reconstructed an adjacent area as with conventional Jointed Plain Concrete Pavement inlay.

The results of this case study show that concrete overlays and inlays are excellent rehabilitation options for urban pavements subjected to high volumes of heavy traffic. Both the unbonded overlay and Jointed Plain Concrete Pavement sections have demonstrated excellent performance to date. The pavements are in very good condition visually, ride quality remains excellent and the recurrence of the regular rutting and shoving problems that were being observed prior to rehabilitation has been mitigated. Significant remaining life is expected from the concrete pavement sections at Bloor and Aukland. Frequent maintenance interventions have no longer been required.

Keywords: unbonded concrete overlays, concrete pavements, pavement rehabilitation, pavement preservation, urban pavements, municipal pavements, performance evaluation, case study

INTRODUCTION
Functional and effective pavement infrastructure is paramount in urban areas. People and goods must be able to quickly and safely move around, in order to ensure societal and economic development. However, existing municipal infrastructure is aging and the amount of available fiscal resources is shrinking. Meanwhile, growth and development demand better and more durable roadways. The consequence of not providing safe and functional road transportation has numerous negative social, economic and environmental impacts, imparting unique challenges on all municipalities.

In Ontario, most municipalities prefer to construct hot mix asphalt pavements, due to their long history of use and significant experience with their design, construction, and maintenance and rehabilitation.
However, typical urban traffic can be very damaging to asphalt pavements. Asphalt is a viscoelastic material, and is particularly susceptible to the severe stresses imparted by braking, standing, accelerating and turning traffic. The stresses induced by static and slow-moving urban vehicles, such as trucks and buses, frequently cause asphalt pavements to deteriorate prematurely. This damage manifests typically itself as rutting and shoving.

Rutting and shoving are most prevalent in intersections, in bus bays and on bus and truck routes (1). The rutting of asphalt pavements creates numerous safety concerns. Pavement rutting can reduce frictional characteristics due to flushing or water ponding. Lane changes can potentially become dangerous and vehicles can hydroplane and lose control, particularly during periods of poor weather (2). The ruts can also make snow removal more difficult (1). It is recommended that these safety concerns be addressed as soon as possible to mitigate the possible impacts on the safety of drivers, vehicles and pedestrians (2). These types of pavement failures often become a costly, recurring maintenance issue for the local transportation department.

Despite many municipalities’ preference for asphalt, concrete pavements also have a place on city streets and local roads. The selection of pavement materials is one of the more challenging engineering decisions facing transportation agencies. The technical benefits of the material must be weighed against the initial construction costs and the life-cycle (maintenance and rehabilitation) costs, as well as the sustainable and social benefits.

Many factors influence these types of decisions involving municipal pavements. Examples of these factors include: municipal policies, previous local experience, traffic volumes, vehicle types, road geometry, availability of funds, qualified engineering support, local availability of materials, availability of qualified and experienced contractors, sustainability goals, stimulus of competition, winter and summer maintenance impacts and road user safety and comfort.

This paper focuses on urban pavement maintenance and rehabilitation considerations, and presents a case study of two types of rehabilitation strategies using concrete pavement materials. The performance of the pavements during their first ten years of service is discussed and the future maintenance and rehabilitation needs of these sections are considered, based on current performance trends.

WHY CONCRETE?
Portland cement concrete has many technical and economic benefits that make it an excellent choice for municipal pavements.

First off, concrete is a rigid material. This rigidity makes it virtually immune to the rutting and shoving observed in asphalt pavements in areas subject to heavy, slow-moving traffic (3).

Concrete pavements also typically have design lives 1.5 to 2 times the service life of equivalent asphalt sections (4). The service lives of concrete pavements can exceed forty years without major rehabilitation. Concrete pavements typically deteriorate slower than asphalt pavements and require less maintenance to maintain an acceptable level of service. The long-term durability and low maintenance costs of concrete pavements can be highly attractive to municipal agencies (4).

Concrete pavements also have additional societal and environmental benefits, stemming from its higher albedo and reflectivity. Concrete surfaces have reduced lighting needs at night and remain cooler when exposed to sunlight, reducing the urban heat island effect (5).
Rising oil prices are resulting in higher asphalt prices. These increases are making Portland cement concrete solutions much more competitive economically. In the past, concrete pavements were subject to higher initial costs, but lower overall lifecycle costs compared to asphalt pavements. However, in recent years, concrete pavements are much more competitive due to lower initial and lifecycle costs than competing asphalt designs.

In spite of these numerous benefits, the shortcomings of Portland cement concrete must also be considered in the material selection process. For example, the cement manufacturing process produces high levels of carbon dioxide emissions, which are detrimental to the environment and human health.

PAVEMENT REHABILITATION WITH PORTLAND CEMENT CONCRETE

Various innovative solutions involving concrete materials are available for pavement rehabilitation. Examples include bonded overlays, unbonded overlays and inlays. The selection of the proper treatment requires careful consideration of factors such as existing pavement condition, anticipated future traffic levels and geometric constraints, e.g. curb and gutter.

Unbonded concrete overlays, typically 150 to 275 mm thick, have been used as an effective rehabilitation solution for moderately to severely distressed pavements. This type of overlay can be constructed over existing concrete, asphalt or composite pavements. The existing pavement structure, albeit having some structural deterioration, serves as a base layer for the new concrete pavement placed on top. The concrete overlay restores ride quality and serviceability, while also providing the additional structural capacity required for future traffic loads. The Transportation Association of Canada’s new Pavement Asset Design and Management Guide suggests that 25+ years of service can be expected from unbonded concrete overlays.

Unbonded overlays over existing concrete pavements require a separation interlayer to prevent reflective cracking and premature failures. The interlayer, commonly a thin lift of asphalt concrete, provides a shear plane for differential movements and prevents the different concrete layers from becoming bonded together, providing stress relief. With the inclusion of the interlayer, only minimal pre-overlay preparation is required. Significant cost savings can be incurred by avoiding the need to remove the existing pavement and the earlier investment in the original pavement remains intact.

Concrete inlays provide another rehabilitation option where the existing asphalt or concrete pavement has failed. Inlays involve the removal of the existing pavement and the placement of a full depth concrete slab. Inlays are designed and constructed as conventional concrete pavements, such as a jointed plain concrete pavement.

CASE STUDY PROJECT BACKGROUND

The intersection of Bloor Street and Aukland Road, located in west Toronto, is subjected to heavy traffic loadings. Bloor Street is a four-lane major east-west arterial road with an Average Annual Daily Traffic (AADT) of over 30,000 vehicles and high peak hourly volumes (approximately 1000 vehicles and in excess of 15 buses). It meets Aukland Road, a short north-south major collector road, at a T-intersection. Aukland Road leads directly into the nearby Toronto Transit Commission’s (TTC) Kipling subway station, located approximately 500 metres south, as indicated in Figure 1. Many TTC and MiWay (formerly Mississauga Transit) bus routes travel along Bloor St. and turn onto Aukland Rd to travel to and from the subway station.
The City of Toronto was observing the rapid and repeated deterioration of the asphalt pavements at this busy urban intersection. The high volumes of heavy, slow moving bus traffic were leading to frequent pavement deterioration beyond acceptable levels. Furthermore, since many of the vehicles travelling through the intersection were slowing to turn or stopping for the traffic signal, the damage imparted to the pavement was greater.

The recurring performance issues forced the City of Toronto to intervene with “mill and patch” treatments every 2-3 years to address safety concerns. It was apparent that traditional maintenance and rehabilitation treatments were not addressing the underlying issues and a more permanent solution was required.

In collaboration with the Cement Association of Canada, the City of Toronto elected to rehabilitate the high traffic intersection of Bloor Street and Aukland Road using Portland cement concrete materials in attempt to mitigate the recurring problems. As part of this project, the city constructed its first unbonded concrete overlay on Bloor Street West and placed a full depth Jointed Plain Concrete Pavement inlay on the adjacent area on Aukland Road (9). This rehabilitation work was completed in the summer of 2003.

**DESIGN**
A local engineering consultant was retained to carry out an evaluation of the existing pavements and a geotechnical investigation and develop pavement designs for the intersection rehabilitation project.

The visual condition survey indicated moderate rutting and shoving in the curb lanes on Bloor Street, near the stop bars. Frequent, severe reflective cracking was also present. Very severe rutting (up to 150 mm in depth) was observed on Aukland Road. Shoving was also occurring at the stop bars on Aukland Road. Furthermore, numerous asphalt patches (utility cuts)
along both roadways were found to be very poor condition and were negatively impacting ride quality (9).

The results of the field program revealed that the existing pavement on Bloor Street consisted of a composite structure (asphalt over concrete). It comprised of 80 mm of HL1 hot mix asphalt concrete (HMA), 200 mm of Portland cement concrete (PCC) base and 100-150 mm of granular base over a poorly draining silty clay subgrade. The existing pavement on Aukland Road was a flexible structure, consisting of 190 mm of hot mix asphalt concrete (40 mm HL1 over 150 mm HL8) over top of a 250 mm granular base on a similar silty clay subgrade.

Rehabilitation alternatives using Portland cement concrete materials were developed. Based on the existing conditions and anticipated traffic loadings, the recommended alternative was a 150 mm unbonded concrete overlay of the existing concrete base for an 85 metre long section of Bloor Street. A 63 metre long section of Aukland Road was reconstructed as a conventional Jointed Plain Concrete Pavement (JPCP), 225 mm thick. The existing and new pavement designs are illustrated in Figure 2.

As part of the University of Waterloo’s involvement, instrumentation to assess the long-term performance of the rehabilitation strategies was embedded in the new pavement layers. An instrumentation plan was devised to monitor the pavement responses of interest associated with the bus traffic and environmental effects and assist with the validation of the pavement designs. Twelve vibrating wire strain gauges were placed at various locations on both Bloor Street and Aukland Road. The sensor locations were strategically selected to capture the effects of accelerating, slowing and turning traffic, as well as the overall effects due to environmental changes.

CONSTRUCTION
From start to finish, the rehabilitation activities were completed in stages over the course of a one month period. Construction needed to be staged in order to maintain partial access to traffic through the busy intersection and reduce delays for the travelling public. In order to minimize delays, the placement of the concrete pavement took place over the course of two weekend closures.

On Bloor Street, the existing asphalt layer was removed by milling. Cracking in the underlying concrete base were routed and sealed and the deteriorated utility cuts were repaired with full depth concrete patches. Once the concrete base was prepared, a slow-setting asphalt emulsion tack coat was placed, followed by a 25 mm thick lift of high stability HL3 asphalt.
Concrete, prior to placement of the new concrete overlay. Once the asphalt had sufficiently cooled, formwork was installed and the 150 mm thick concrete slab was placed on top.

Contraction joints were cut in a grid pattern at a short spacing of 1.5 metres. Joints were cut as soon as the concrete had set (within four to twelve hours) using a wet concrete saw to a depth of one-fourth of the thickness of the new concrete slab. Although not required in all overlay projects, dowel bars (25 mm in diameter by 400 mm long) were placed in turning locations and stopping areas to provide additional reliability from slow-moving or static vehicles. The first 25 meters west of Aukland Road were dowelled to accommodate the slow-moving bus traffic. Dowel baskets, spaced at 300 mm intervals, were installed on the asphalt interlayer prior to the placement of the concrete. Both the transverse and longitudinal joints were dowelled.

On Aukland Road, the existing distressed asphalt concrete was removed, as was the top 150 mm of the existing granular base. The removed base material was replaced with fresh granular material, compacted and re-graded. The new 225 mm concrete slab was then placed. Full lane width transverse contraction joints were cut at a 4.5 metre spacing. The joints between the first two slabs at both the north end and the south end of the concrete section of Aukland Road were dowelled as well. In the same fashion as Bloor Street, dowel baskets, spaced at 300 mm intervals, were installed across the full lane width.

During the first weekend closure, the eastbound lanes of Bloor Street West were paved, along with the centre lane of Aukland Road. This stage was constructed using fast track methods using high early strength concrete (24 MPa in 72 hours). The newly constructed lanes were re-opened to traffic on Monday morning. The following weekend, the westbound lanes of Bloor Street West and the outside lanes of Aukland Road were constructed using conventional concrete with a minimum strength of 32 MPa.

The rehabilitation of the Bloor Street West and Aukland Road intersection was completed at a cost of 369,700 Canadian dollars. The overlay on Bloor Street West amounted to $228,900 and the full depth concrete inlay on Aukland Road totalled $140,800.

STRAIN DATA ANALYSIS AND EVALUATION
Sensor data is recorded hourly and has been regularly collected since construction was completed. As of 2013, only seven of the twelve gauges originally installed remain operational. Some of the non-functional sensors started providing erroneous readings soon after construction, whereas others became defective in later years. The erroneous or missing data has been excluded from any analyses. The loss of working strain gauges makes a complete analysis more difficult, because some comparisons of possible interest are no longer possible. Nevertheless, the embedded instrumentation continues to provide valuable information relating to the behaviour of the concrete under environmental and vehicular loadings.

The vibrating wire type strain gauges reliably capture the long-term effects of environmental loads, e.g. thermal expansion/contraction, shrinkage, curling and warping, as well as the cumulative effects of repeated traffic loadings.

Strain data from the first, third and ninth years of service is presented in this paper. A similar number of datapoints from each year, collected equally across all twelve months, was used in the analysis.

The most obvious trend observed in the strain data is a clear daily variation in strain, corresponding with a daily temperature cycle. The measured strains increase as the concrete
heats up and expands with rising temperatures and exposure to solar radiation during the day and
decrease as the pavement cools and contracts overnight.

Seasonal trends have been observed from year to year as well. The largest strains are
observed in the winter season, which is likely due to the drastic changes in temperatures. Although Toronto’s average daily temperature in January is -4.5°C, the city can experience
temperatures ranging from -33°C to 16 ºC (10). The measured strains continue to decrease
throughout the year, with the lowest strains being observed in the fall.

Throughout the ten year period, a general trend of increasing compressive strains has
been observed in the wheelpaths of the unbonded overlay on Bloor Street, both at the top and
bottom of the overlay layer. This trend is illustrated in Figure 3, which compares strain data from
the first, third and ninth years of service. The boxplots present the maximum, third quartile,
median, first quartile and minimum strain values for each year. Strain values greater than zero
are tensile; those less than zero are compressive. The zero strain condition was established prior
to the installation of the gauges in the concrete at an ambient temperature of 25°C.

The trend of increasing compression at the top surface is no surprise; however, the
bottom sensors are expected to be measuring tensile strains. Unbonded overlays are designed to
have the overlay slab and existing slab bend separately under traffic and environmental loads due
to the placement of a separation layer, shown in Figure 4.

**FIGURE 3** Comparison of strains in unbonded overlay after 1, 3 and 9 years of service.
However, preventing a bond between the two concrete layers cannot always be accomplished. It is possible that this may be the case with the Bloor Street overlay. The evidence of compressive strains throughout the thickness of the overlay may indicate that both slabs (old and new) are behaving monolithically and that the neutral axis falls in the old slab. The bonding of the layers can add additional structural capacity to the pavement, but is generally undesirable because it may allow reflective cracking to occur (3). By and large, the strains measured in the overlay section remain fairly low, i.e. well below cracking thresholds. The threshold for flexural (tensile) crack formation in a 30 MPa concrete is approximately 100-200 microstrain (12). The results suggest that considerable remaining pavement service life can be expected.

In the Jointed Plain Concrete Pavement (JPCP) section on Aukland Road, the average strain reading for sensor eight (southbound lane, top of concrete) saw a slight decrease between years one and three, and remained fairly consistent through the ninth year of service, not showing much change over time, as seen in the boxplots in Figure 5. The same trend of decreasing strain was observed in sensor nine (southbound lane, bottom of concrete) between years one and three. However, between years three and nine, a significant increase in strain, that is a growth in tensile strains, was observed, also seen Figure 5. The increase in tensile strains is expected at the bottom of the slab as vehicular loads will induce tensile stresses and the damage accumulates with repeated loadings. However, the year nine strain magnitudes are somewhat suspect since they are very high.

Strains of this magnitude exceed the tensile cracking limit of concrete and would have likely resulted in the development of cracking on the surface. However, no distress is visible in the vicinity of the sensor. The probable explanation is the degradation of the sensor over time or damage to the sensor or its wiring. The development of zero drift is also a possible source of error. Zero drift is a condition where the measured strain values changes for reasons other than actual changes in strain, such as creep of the vibrating wire (13). Although the magnitude of some of the measured strains observed in sensor nine exceeds probable ranges, the general trends in changes in strain observed in the JPCP section satisfy expectations.
FIGURE 5 Comparison of strains in JPCP after 1, 3 and 9 years of service.

VISUAL CONDITION SURVEY AND PAVEMENT PERFORMANCE EVALUATION

Visual condition surveys of the concrete sections have been performed regularly. The results of the most recent condition survey, performed in July 2013, show that both rehabilitated pavements remain in very good condition after ten years of service. Distresses are infrequent and generally low in severity.

In the Bloor Street overlay, some transverse joints exhibit ravelling and minor spalling. The joints between the overlay layer and the curb and gutter display occasional spalling, as well as the interface between the adjacent composite pavement and the overlay. This damage is likely attributable to edge restraint effects.

The settlement and movement of catchbasins has resulted in some cracking in the adjacent concrete, as shown in Figure 6. Improved isolation of the drainage appurtenances and better joint detailing would have likely prevented this damage. The most significant distress is two cracked slabs near the north-south crosswalk on the east side of the intersection, seen in Figure 7. This area has experienced a localized loss of support and settled. Nevertheless, the ride quality of this section remains excellent. The narrow width of the sawcuts in the overlay prevents the occurrence of “joint slap” noise, despite the short joint spacing, which results in a much greater joint frequency than most conventional concrete pavements. Despite the marginal surface condition of the overlaid concrete base, the overlay itself in structurally in good condition. The asphalt interlayer appears to provide the necessary stress relief to prevent the pre-existing cracks or other distresses from reflecting upwards into the overlay layer.
The Aukland Road inlay is also in excellent surface condition. However, moderate joint faulting is observed, most noticeably in the northbound lanes, as seen in Figure 8. This faulting results in some “joint slap” noise from the tire-pavement interaction. The greater use of dowel bars at the transverse joints should be considered for future similar projects to prevent this issue. The unsealed transverse joints on Aukland Road have also opened up significantly, leaving a large gap between adjacent slabs, in which vegetation has begun to grow. It is recommended that the joints should be sealed so that vegetative matter and other incompressible material do not enter. Locked up joints can lead to future performance issues including cracking.
Most significantly, it must be noted that the recurring rutting and shoving problems that were being observed prior to rehabilitation have been mitigated. The implementation of Portland cement concrete, a rigid material, as the pavement material in this area has eliminated their recurrence.

It should also be mentioned that no maintenance or rehabilitation has been required for the Bloor St. and Aukland Rd. sections since construction. In fact, the recommended maintenance plans in the Street Smart Report released by the Cement Association of Canada and the Ready Mixed Concrete Association of Ontario indicate the concrete pavements on arterial roadways should not require any treatment before 12 years of service (14). At 12 years, joints should be resealed and partial depth repairs should be completed where required. Prior to rehabilitation, this intersection was requiring maintenance intervention every two to three years.

SUMMARY AND CONCLUSIONS
The results of this study demonstrate that concrete pavement rehabilitation solutions, including overlays and inlays, are technically feasible options for distressed urban pavements subjected to high volumes of traffic.

The Bloor Street section, earning the distinction of the first unbonded overlay in Toronto, has proven itself as a feasible rehabilitation treatment for distressed concrete or composite pavements. The overlay section has shown excellent performance in its first ten years of service, with no major functional or structural issues of note to date. The recurring issues prior to rehabilitation, e.g. frequent rutting and shoving, have also been mitigated. It is anticipated that the expected service life of 25+ years (7) will be met and potentially exceeded, improving the return on investment.

The performance of the Aukland Road pavement also shows that the use of concrete inlays, such as this short section of JPCP, is a viable technique for mitigating the rutting and
shoving of asphalt pavements at intersections, which is frequently observed in areas high volumes of heavy traffic, such as bus routes. The concrete pavement, which does not deform under static or slow moving vehicles, maintains the safety characteristics of the roadway and averts the need for inconvenient and expensive maintenance work.

The embedded instrumentation has contributed much valuable information to the evaluation of these sections. For the most part, the measured strains remain low in both the unbonded overlay and the jointed plain section. The low measured strains being recorded are indicative of significant remaining life for both sections.

The concrete options implemented have greatly reduced the maintenance requirements for this intersection. Concrete pavements require intervention much less frequently than asphalt pavements.

With anticipated service lives of greater than 25 years, concrete overlays and inlays have the potential to be long-term pavement rehabilitation solutions for municipal pavements. These are proven technologies with excellent technical qualities and economic advantages. Solid research and technology transfer efforts are leading to greater implementation of these solutions. The City of Toronto is content with the results of this pilot project and is actively seeking new candidate projects for rehabilitation with concrete overlays. Other Canadian municipalities are also taking advantage of the City of Toronto’s experience and seeking projects where they can apply these solutions.

**RECOMMENDATIONS**

Continued monitoring of the experimental sections described herein is recommended. Ongoing data collection and evaluation will continue to provide additional valuable information for researchers as the test sections enter their second decade of service. The sensor data can be used to mechanistically model the behaviour of unbonded concrete overlays. This type of model can be used to predict future overlay performance and remaining life. Furthermore, the validation of the results obtained from the sensor data using the Mechanistic-Empirical Pavement Design Guide (MEPDG), now distributed as the AASHTOWare Pavement ME Design software, is also recommended.

Falling Weight Deflectometer (FWD) testing is also suggested to evaluate the current structural condition of the rehabilitated pavements. One round of deflection testing was performed prior to rehabilitation. This additional testing will help quantify the pavement’s current structural capacity and assist with evaluating remaining life.

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