Challenges in Designing Pavements for Bus Rapid Transit Projects Experience in York Region, Ontario

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ABSTRACT

There are a number of challenges that require careful planning, investigation and design when adopting existing heavily travelled arterial roads to accommodate Bus Rapid Transit (BRT) lanes. These include the widening/strengthening old deteriorated pavements, staging, grade raises, as well as Agency requirements related to extended service lives, timing rehabilitation to coincide with that on adjacent lanes, coloured pavements, to name a few.

A section of Yonge Street in York Region that was originally built as a concrete pavement was subsequently realigned, overlain with asphalt and granular materials (the concrete was buried) and widened using flexible pavements. When designing the BRT lanes, one of the main challenges was to identify the locations where buried concrete could be encountered when excavating for the widening. Other challenges included variable pavement structures, and identifying the areas that require major strengthening/reconstruction to support the additional bus traffic.

On Highway 7, also in York Region, the proposed BRT will use the existing median lanes with the road platform widened to accommodate new outside lanes. The challenge was to design a pavement structure for the widening that can have its service life significantly extended so as to minimize down time due to future maintenance activities. In addition, the rehabilitation work on the BRT lanes in the existing median and the outside lanes designed to have a long service life had to be synchronized. Red coloured or brick pavement was stipulated for the BRT lanes to differentiate them from the adjacent general traffic lanes.

This paper summarizes the results of the field investigations which also included Ground Penetrating Radar (GPR) and Falling Weight Deflectometer (FWD) load deflection testing as well as the innovative pavement designs developed to address the design challenges.

INTRODUCTION

To reduce maintenance activities and the associated staging, user delay and social (increased carbon dioxide emissions, noise, and risk of accidents) concerns, a number of municipalities in Ontario are moving towards longer lasting pavements. These pavements typically do not require any major rehabilitation for a period of up to 50 years and only periodical resurfacing is needed [1]. This can be carried out quickly and cost effectively without closing lanes to traffic for extended periods of time. Perpetual pavement is an example of a pavement that can provide for a long service life with minimal maintenance on new highways. However, rehabilitation options that provide a long service life may be limited due to the poor quality or inadequate strength of the existing pavement structure. In addition, the goal of reducing future maintenance activities can be achieved only if the weakest sections of the pavement are clearly identified and addressed during rehabilitation.

York Region in Ontario is home to a well established service sector (engineering, computer sector, finance and insurance), has recreational areas that draw traffic from the surrounding regions and has one of the fastest growing populations in Canada. To meet its rapidly increasing needs for mass transit, the Region is constructing dedicated BRT lanes along Yonge Street, Highway 7 and Davis Drive, three of the most heavily travelled arterial roads in the Region.

The investigation and design challenges on Yonge Street included the following:

- Identifying the locations where the excavation for the widening will encounter old buried concrete pavements. This reduces claims/delays from contractor due to unexpected site conditions; and
- Identifying the areas that need strengthening to support the estimated traffic loading.

The design challenges on Highway 7 included the following:

- The existing road platform is being widened on the outside to accommodate two general purpose lanes in each direction and the BRT in the median. The challenge was to recommend a rehabilitation strategy for the existing lanes that will have the same service life as the perpetual pavement structure used to widen the highway;
- Identifying the areas that need strengthening to support the estimated traffic loading; and
- Visually differentiate the pavement for the BRT lanes from the adjacent general purpose lanes, without compromising performance.

FIELD WORK PROGRAM

The conventional field investigation methods consisting of a detailed pavement condition survey, to identify surface distresses, and coring and borehole investigations at discrete intervals can be used to develop a general rehabilitation strategy for a section of pavement but are not always successful in delineating the weakest areas that need specific treatments.

To address this issue, in addition to the traditional methods, Ground Penetrating Radar (GPR) surveys and Falling Weight Deflectometer (FWD) load deflection testing were carried out on Yonge Street and Highway 7. The use of GPR was critical on Yonge Street which had sections of buried concrete. GPR not only identified the areas with buried concrete but it also provided a continuous profile of the pavement structure which helps in identifying the thinner or more distressed sections of pavement [2].

YONGE STREET

The section of Yonge Street was initially constructed as a two lane Portland Cement Concrete (PCC) pavement. The original pavement was overlain with granular material and hot mix asphalt over the years and widened on both sides using flexible pavement construction. The road platform required widening to accommodate the proposed BRT lanes along the centre/median.

The field investigation consisted of a visual pavement condition survey, FWD testing, GPR survey, and coring and drilling about 140 boreholes. Figure 1 shows a typical pavement condition on Yonge Street.

Figure 1 – Overview of Yonge Street looking at the southbound lanes. Note the transverse cracks and the mid lane crack in Lane 2.

On this project, the sequencing of the field program was important to maximize the benefits from the different investigation techniques. The GPR survey was performed first using two ground coupled Sensors and Software systems with antenna centre frequencies of 500 MHz and 1000 MHz, respectively. A quick analysis of the results from the GPR survey was carried out to identify the sections with buried concrete and those with thinner or thicker pavement structures than the average or typical road section. The thinner pavement sections could have insufficient structural capacity while locations with thicker asphalt could be areas where past problems had been addressed by placing an additional overlay, or by localized patching. Figure 2 shows the GPR profile from a section of Yonge Street.

Figure 2 – GPR Profiles From a Section of Yonge Street
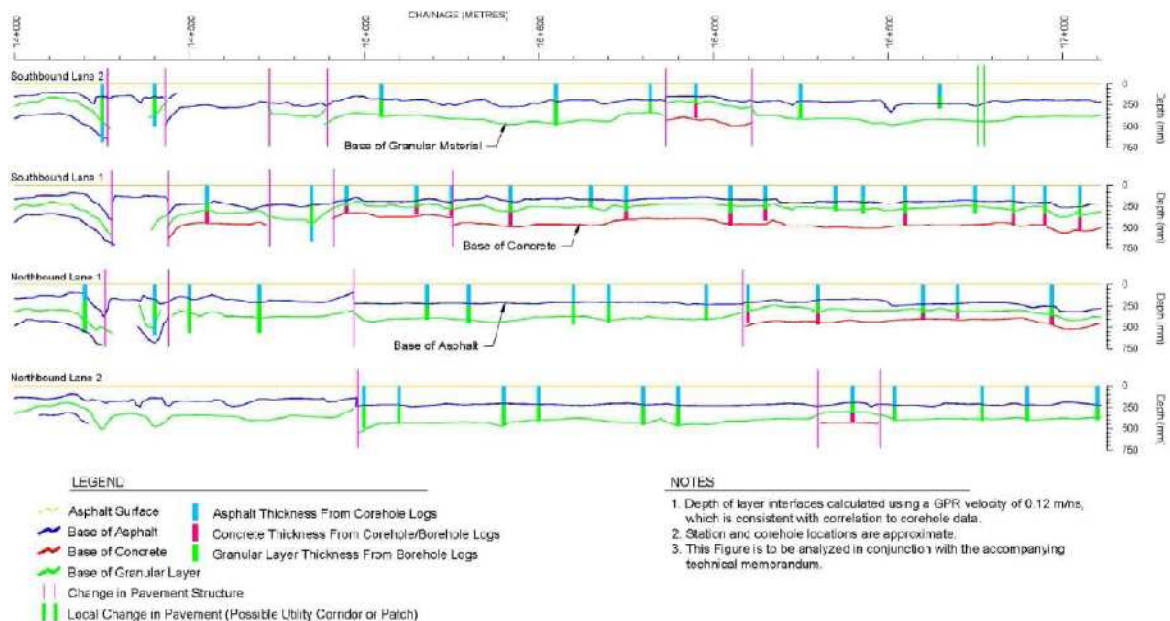
The GPR survey was followed by the detailed visual condition survey, the FWD testing and the coring/boreholes. In addition to testing at regular intervals, additional FWD test locations and cores/boreholes were targeted in the areas with thinner pavement or thicker asphalt (based on GPR) or in areas with poor condition based on the visual condition survey.

Table 1 below provides a summary of the pavement structure obtained from the boreholes and the GPR survey.

Table 1 – Results from Boreholes and GPR Survey

Pavement Component	Borehole Data		GPR Survey Data	
	Range (mm)	Average (mm)	Range (mm)	Average (mm)
Asphalt	100 – 490	230	90 – 515	200
Granular Base*	190 – > 910	400	160 – 670**	400**
Granular Subbase	0 – > 1,000	100		

∗ - Includes thickness of granular materials as well as buried asphalt and concrete

∗∗ - The GPR did not differentiate between granular base and subbase materials and did not identify the granular materials below the concrete.

Generally, there was a good correlation between the asphalt thicknesses obtained from the boreholes and the thickness of the asphalt at an adjacent point from the GPR survey. However, the average thickness for the coring was about 230 mm while for the entire GPR survey was only about 200 mm. Relying on the average thickness from cores for design analysis would have resulted in an overestimation of the existing asphalt thickness. An accurate knowledge of pavement thickness is essential for determining rehabilitation strategies [3]. With adequate calibration, the GPR provides better estimates of asphalt thickness since it yields continuous profile data. The GPR survey also identified six sections in the southbound direction totalling about 900 m in length and three sections along the northbound direction totalling about 1,100 m in length where the contractor would encounter buried concrete when excavating for the widening.

The FWD testing was carried out using a JILS Heavy Weight Deflectometer with sensors offset from the load plate as listed in Table 2:

Table 2 – Spacing of FWD Sensors From Load Plate

Sensor #	Distance From Load Plate (mm)
1	0
2	200
3	300
4	450
5	600
8	900
7	1,200

The applied loading pulses were about 30, 40 and 50 kN. The results from the FWD testing indicated that the structural capacity of the pavement was generally good with an average Pavement Surface Modulus of over 1,300 MPa. However, the FWD testing identified seven locations where the structural capacity of the pavement was poor. The Pavement Surface Modulus at five of these locations, ranged from 420 to

530 MPa, compared to 800 to 900 MPa on the adjacent lanes while at the other two locations, the Pavement Surface Modulus was 740 and 790 MPa, compared to over 1,200 MPa on the adjacent lanes. Table 3 presents the information obtained from the closest borehole, the visual condition survey and the GPR survey at these seven locations:

Table 3 – Comparison of the Data from the Different Investigation Techniques

Locations with Low Pavement Modulus (FWD)	Visual Condition Survey	Closest Borehole Data	GPR Survey Data	Remarks
Sta. 17+490 NBL 1 (790 MPa)	Good, few cracks	Sta. 17+500 NBL 2 280 mm asphalt 530 mm Gran. Base	Sta. 17+490 NBL 1 270 mm asphalt 530 mm Gran. Base/Subbase	FWD results relatively low but sufficient. Pavement in good condition. Good correlation between borehole and GPR data
Sta. 18+260 SBL 2 (740 MPa)	Fair, some cracks	Sta. 18+150 SBL 2 290 mm asphalt 510 mm Gran. Base	At St. 18+245 150 mm asphalt 500 mm Gran. Base/Subbase	FWD results relatively low but sufficient. No boreholes close by. GPR readings show lower asphalt
Sta. 19+713 SBL 2 (420 MPa)	Fair, some cracks	Sta. 19+750 SBL 2 100 mm asphalt 250 mm Gran. Base, wet 310 mm Subbase	Sta. 19+715 SBL 2 130 mm asphalt 325 mm Gran. Base/Subbase	Low Pavement Modulus correlates with low asphalt thickness (borehole and GPR), wet base (borehole) and low pavement thickness (GPR)
Sta. 19+913 SBL 2 (500 MPa)	Good, some cracks	Sta. 19+850 SBL 2 170 mm asphalt 430 mm Gran./Conc. Base	Sta. 19+915 SBL 2 120 mm asphalt 220 mm Gran. Base/Subbase	Low Pavement Modulus correlates with low asphalt thickness and low total pavement thickness (GPR)
Sta. 20+017 NBL 1 (530 MPa)	Fair, close to water main trench, cracks	Sta. 19+950 NBL 2 150 mm asphalt 270 mm Gran. Base 430 mm Subbase, wet	Sta. 20+015 NBL 1 115 mm asphalt 325 mm Gran. Base/Subbase	Low Pavement Modulus correlates with presence of trench, low asphalt thickness (borehole and GPR) and low total pavement thickness (GPR)
Sta. 20+217 NBL 1 (520 MPa)	Fair, slight distortion, edge breaks	Sta. 20+200 NBL 2 120 mm asphalt 160 mm Gran. Base 470 mm Subbase	Sta. 20+215 NBL 1 115 mm asphalt 275 mm Gran. Base/Subbase	Low Pavement Modulus correlates with distortion, low asphalt thickness (borehole and GPR) and low total pavement thickness (GPR)
Sta. 21+017 NBL 1 (460 MPa)	Fair, slight distortion, map cracks	Sta. 21+000 NBL 2 220 mm asphalt 210 mm Gran. Base 440 mm Subbase, wet	Sta. 21+015 NBL 1 170 mm asphalt 400 mm Gran. Base/Subbase	Low Pavement Modulus correlates with distortion, wet subbase (borehole)

Additional investigations (boreholes and FWD) testing will be carried out during detail design to delineate the areas with low strength and develop a suitable rehabilitation strategy to address the observed conditions.

HIGHWAY 7

This 7.5 km section of Highway 7 from Yonge Street to Warden Avenue is a major arterial road in the Region of York. It was originally constructed as a two-lane highway with flexible pavements and has been widened to six through lanes over the years, except at the east end (~ 1km) where there are only four lanes. The field investigation consisted of a visual pavement condition survey, FWD testing, GPR survey and about 75 cores and 180 boreholes.

The visual condition survey identified the main forms of pavement distresses to be intermittent, slight to moderate longitudinal, transverse, pavement edge, map and alligator cracking; extensive, slight wheel track rutting; slight to moderate ravelling; intermittent slight flushing, and shoving, distortion and potholes at a few locations (Figure 3).

Figure 3 - Section of Highway 7 showing typical distresses; transverse, longitudinal and pavement edge cracks, ravelling and rutting.

The borehole investigation indicated that the pavement structure along Highway 7 was a relatively uniform flexible pavement, with about 190 mm of asphalt overlying about 200 mm of granular base and 500 mm of sandy subbase. The GPR survey results indicated an average asphalt thickness of about 200 mm but the inferred total granular thickness was much less at 450 mm. This is probably due to the high moisture content of the granular materials, and the GPR survey results being sensitive to significant variations in moisture. Figure 4 shows the excellent correlation between the thickness of the asphalt cores and the asphalt thickness inferred from the GPR survey at the same location. As shown on the figure, the average thickness of the cores and the GPR results at the same location were 195 and 196 mm, respectively while the thicknesses of the individual cores and GPR data at the corresponding location were generally within 15 percent.
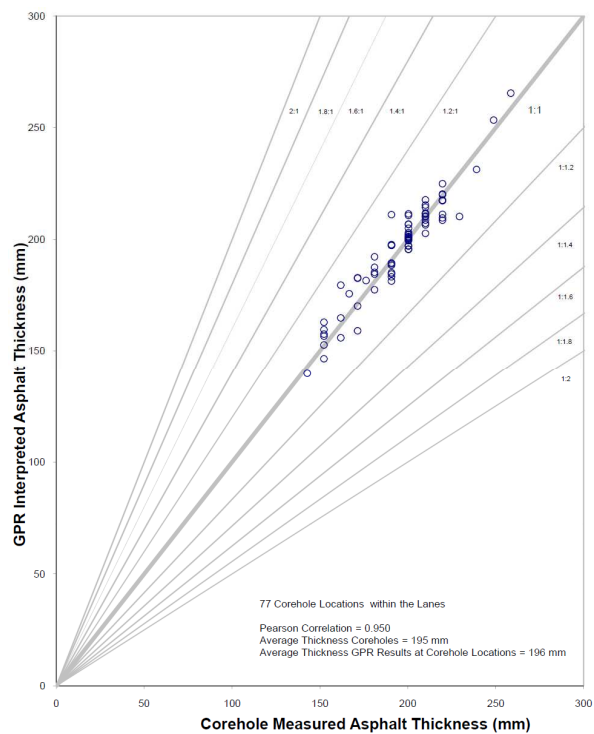

Figure 4 – Correlation: Thickness of Asphalt Cores and GPR inferred Thickness at the same Locations

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The results from the FWD testing indicated that the structural capacity of the pavement was generally good with an average Pavement Surface Modulus of about 950 MPa, except on the 4 lane section at the east end where the Pavement Surface Modulus was only about 650 MPa. The likely reason for the lower pavement strength at the east end was poor drainage caused by an undersized culvert resulting in a saturated base and subbase. To address this problem, the drainage through this area is being improved by increasing the size of the culvert and raising the road grade by about 200 mm. The FWD testing also indicated that strengthening of the pavement structure was required throughout the project limits to support the estimated traffic loads over the design period.

Pavement Design for the Widening of Highway 7:

Highway 7 is a major arterial road with an AADT of about 65,000 vehicles anticipated to increase to a maximum of 83,500 within the design period. The percentage of commercial traffic is about 6.5 per cent (4,000/day increasing to 5,000/day). To minimize maintenance and the associated traffic problems, York Region wanted a long lasting pavement that could be rehabilitated cost effectively and quickly with minimal disruption to traffic flow during the design life. Using AASHTO design analyses and a detailed cost analysis, the following perpetual (flexible) pavement with a design life of 40 years was selected as the preferred strategy for the widening of Highway 7:

New Hot Mix Asphalt	-	240 mm
New Granular A, Base	-	200 mm
New Granular B Type I, Subbase	-	600 mm
Total Thickness	**-**	**1,040 mm**
Structural Number	-	183 mm

The recommended asphalt mix types are as follows:

40 mm	Superpave 12.5 FC2	Surface Course
50 mm	Superpave 19.0	Upper Binder Course
75 mm	Superpave 25.0	Intermediate Binder Course
75 mm	**Rich Bottom Mix**	Lower Binder Course

After the perpetual pavement design was selected as the preferred design for the widening, York Region expressed its concern that having a different timing for maintenance on the widened section when compared to the existing lanes will result in more frequent disruptions to traffic flow. As such, based on a detailed analysis, a compatible rehabilitation strategy that can provide the same service life as the perpetual pavement was developed for the rehabilitation of the existing lanes:

The rehabilitation will involve milling 50 mm and overlaying as follows:

40 mm	Superpave 12.5 FC2	Surface Course
50 mm	Superpave 19.0	Upper Binder Course
60 mm	Superpave 19.0	Intermediate Binder Course
70 mm	**Rich Bottom Mix**	Lower Binder Course

This strategy will provide for a similar service life over the full width of the roadway while the thicker asphalt is expected to significantly delay or prevent existing cracks from reflecting through to the surface.

Coloured Pavement

One of the challenges was to help the public visually distinguish the BRT lanes from the adjacent lanes used for general traffic. A red coloured surface course and paving bricks are being tried out on an 800 m section to evaluate the effectiveness of the two methods.

A number of options including red coloured aggregates, synthetic colourless asphalt cements and red pigments were evaluated. The synthetic asphalt cement was not cost effective and as such, a mix with coloured aggregates and red pigment was used on the trial section. The challenge was to balance the

percentage of the pigment and air voids in the mix against the appearance. Increasing the percentage of pigment made for better contrast with the normal mixes but resulted in lower air voids that would reduce performance.

Figures 5 shows that the red asphalt surface is clearly visible when travelling away from the sun (left photograph) but is not as clear when travelling in the direction of the sun (right photograph). The other option that is being trialed is brick pavers, shown on Figure 6. The brick pavers were more visible when viewed in the direction of the sun as seen on the photograph to the right on Figure 6.

Figure 5 – Red Asphalt surface looking away from the Sun (left) and in the direction of the Sun (right)

Figure 6 – Surface with Paving Bricks looking away from the Sun (left) and in the direction of the Sun (right)

RICH BOTTOM MIX (RBM)

The inclusion of a RBM is critical when designing longer lasting flexible pavements. This layer, located at the transition from an unbound layer (granular base) to the bound layers (asphalt layers), is designed to be fatigue resistant. The RBM is also designed to be highly resistant to the intrusion of any moisture. In addition, an effective bond must be achieved between the RBM and overlying rut-resistant asphalt layers. As such, the proper design and construction of the RBM is very critical for long lasting pavements.

Generally, improved resistance to fatigue can be achieved by increasing asphalt cement content and reducing the air voids in the mix. However, it is also critical that the aggregates and asphalt cement used in the RBM satisfy specific properties. Generally, premium aggregates and polymer modified performance graded asphalt cement are required. They required mix performance testing is shown in Table 4.

Table 4 – Mix Performance Testing Required for RBM

Mechanistic Properties	Standard	Specified Limit
Dynamic Modulus	AASHTO TP62-03	N/A
Rutting Resistance in the Asphalt Pavement Analyzer	AASHTO TP63-03	Maximum 5.0 mm after 8,000 cycles
Rutting Resistance in the Hamburg Wheel Rut Tester	Colorado L5112 Standard	Maximum 4.0 mm after 10,000 passes and 10.0 mm after 20,000 passes
Fatigue Endurance	AASHTO TP8-94	Minimum 7 million repetitions

More detailed information on the design of and specifications for Rich Bottom Mixes is provided in a paper by Uzarowski et al. entitled "From Theory to Practice: Rich Bottom Layer Design" [4].

DISCUSSIONS

When developing pavement rehabilitation options, it is possible to overestimate the strength of the existing pavement by assuming an average thickness for the asphalt and total pavement structure based on a limited number of cores and boreholes. This will result in a shorter service life, more frequent maintenance and unexpected increases in maintenance costs. The use of GPR to supplement the field data reduces the number of cores and boreholes required and increases accuracy.

The GPR provides a continuous profile of the road, and this makes it possible to identify the areas with potential deficiencies so that they can be addressed during the design stage. Similarly, the FWD can identify areas with weaker pavement [5]. When analysing the FWD results, it is important to not only look at the absolute values but also compare the individual results with those from adjacent points to check whether the results are significantly lower or different. This can help identify areas that are performing well at the present time but with the potential to cause problems in the future, especially with increased traffic.

The sections of Yonge Street and Highway 7 selected to have BRT lanes are in heavily built-up and populated areas. The existing lanes are quickly approaching capacity, with no room for additional lanes. Any major pavement rehabilitations that would require prolonged lane closures were not considered acceptable. Therefore, York Region considered it critical to have a long lasting pavement that will require minimal intervention and maintenance work in the future so as to reduce delays, traffic backups, pollution, etc. Perpetual pavements, which consist of a Rich Bottom Mix to provide excellent cracking/fatigue resistance, and three additional asphalt lifts to support the estimated traffic loading, were the optimum solution for both the widening and the rehabilitation of existing lanes.

Two different methods, red coloured surface course asphalt and paving bricks are being tried out on an 800 m section of new pavement to differentiate the BRT lanes from the lanes used for general traffic. The initial results show that the contrast between the red asphalt and the adjacent lanes is dependent on the time of day and direction of travel (in the direction of or away from the sun). The paving bricks have a more distinct appearance but no information is available yet regarding the ride quality and user acceptance.

CONCLUSIONS

The investigations carried out on Yonge Street and Highway 7 show that the use of techniques such as GPR and FWD can significantly enhance the quality of the information available and reduce risks when developing suitable pavement rehabilitation strategies for major arterials, especially when being retrofitted for BRT usage. This is critical when rehabilitating existing pavements as any weak sections that are not

identified and addressed during the detail design stage can cause problems and require increased levels of maintenance and associated lane closures throughout the pavement's service life. GPR and FWD testing not only help identify the weaker areas that can cause problems during the pavement's service life but can also help avoiding potential claims from contractors arising from the presence of buried concrete, asphalt or utilities.

When cost benefit analyses are carried out over 40 years or more, perpetual flexible pavements with a Rich Bottom Mix are considered to be an excellent long term investment, both for new lanes as well as for the rehabilitation of existing lanes.

Two pavement surface types are being evaluated to differentiate the BRT lanes from the adjacent all purpose lanes. As the allowable minimum limit for air voids in the asphalt surface course had to be decreased slightly to achieve the desired red colour using pigments, the performance of the red coloured asphalt pavement is being monitored carefully for signs of rutting, flushing etc. Red brick pavements may represent an acceptable alternative.

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