Pavement Rehabilitation Design for City of Ottawa OR-174 Composite Pavement Section

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Abstract

The OR-174 is major arterial highway in the City of Ottawa connecting the Blackburn Hamlet and Orleans communities to the rest of Ottawa. A 3.9 km four lane section (2 lanes each way) of the highway is a composite pavement consisting of a 1959 concrete pavement overlayed with asphalt pavement. This section of highway is experiencing a variety of maintenance issues including development of humps at joint and crack areas. Stantec Consulting Ltd. (Stantec) was contracted by the City to perform a detailed pavement evaluation on this section of the OR-174 to develop a pavement rehabilitation design strategy. As part of the evaluation process a variety of evaluation techniques were utilized to collect data on the roadway structure including Falling Weight Deflectometer (FWD) testing, Ground Penetrating Radar (GPR) surveys, Visual Condition Assessments and Subsurface Investigations.

This report provides background and a summary of the data collected and how it was analyzed to assist in the evaluation of six different rehabilitation / reconstruction alternatives for the OR-174 project area. Results of the evaluation of the various alternatives are provided in the paper including development of preliminary designs, maintenance and rehabilitation schedules, initial potential cost estimates and life cycle analysis on the three most promising options.

1.0 Introduction

Stantec Consulting Ltd. (Stantec) was retained by the City of Ottawa to develop pavement rehabilitation strategies for composite pavement section of the OR-174 between Highway 417 (City Limit) and Montreal Road / St. Joseph Boulevard. This section of OR-174 is functionally classified as a City Freeway and is approximately 3.9 km in length with the inside two lanes in each direction being concrete pavement with asphalt overlay. The project limits are presented below in Figure 1.1.

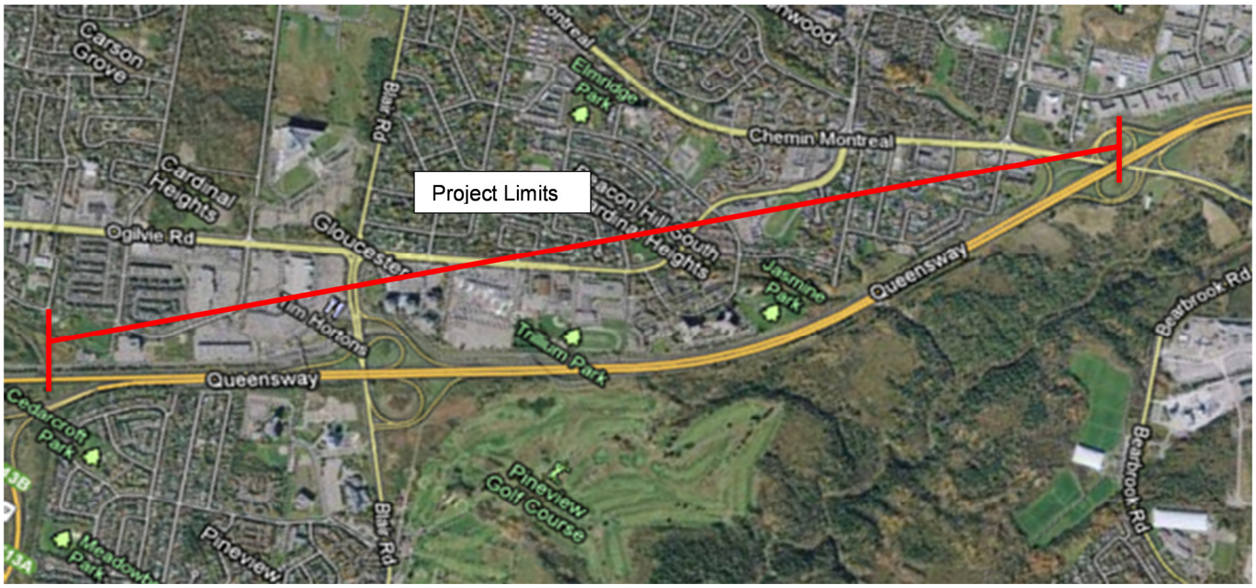

Figure 1.1: Project Limits

The inner two composite pavement lanes in each direction are currently exhibiting the following distresses; reflective transverse cracks; transverse humps at crack areas and longitudinal cracks aligning with the underlying concrete pavement. The City was concerned that the humps not only result in an uncomfortable ride, but could be possibly hazardous to the travelling public. Residents within the vicinity of the roadway also have expressed concern of vibration as a result of heavy vehicles passing over the humps. Road users have also expressed concern with the riding comfort of the pavement structure.

The scope of the project as identified in the project proposal was as follows:

- Perform a detailed analysis of the composite pavement and confirm the cause of transverse humps and other distresses in the composite pavement;
- Develop alternative strategies for rehabilitation of the composite pavement (inner two lanes in each direction) to rehabilitate the existing distress and provide a safe and smooth riding surface;
- Assess the impact of each strategy on the adjacent flexible pavement structure;
- Develop expected maintenance and rehabilitation schedules and conduct life cycle cost analysis for each strategy;
- Recommend a rehabilitation strategy that considers the results of the life cycle cost analysis, traffic impacts, constructability and advantages and disadvantages relative to other strategies; and

- Develop an urgent and short term maintenance strategy to minimize the impact of pavement humps until the rehabilitation strategy can be implemented. Note, this portion of the analysis is not included in the paper.

Details on the field investigation are presented in Section 2.0, Field Data Collection and Investigation Results.

2.0 Field Data Collection and Investigation Results

The following section reviews the various field data collected on OR-174 and additional information on the construction history. Notes taken during the field investigation are also presented as data collected.

Pavement evaluations were completed on OR-174 between November 6 and November 10, 2010. The pavement evaluation included Falling Weight Deflectometer (FWD) testing, Ground Penetrating Radar (GPR) surveys, Visual Condition Assessments, and Subsurface Investigations (i.e. pavement core and bore holes). Additional site visits were undertaken in September, October and December 2011 to assist in the analysis and development of potential rehabilitation and reconstruction strategies. All pavement evaluation activities were completed at night, off-peak hours, to minimize disruption to the traveling public.

Each lane within both sections was identified with a unique lane identification number. The lane IDs are presented below in Figure 2.1. It is important to note that all pavement evaluation and investigation data collected as a part of this project were referenced to the lane IDs for consistency. Chainage for all data collected are based on the following:

- Eastbound:
  - Section A: 0+000 is at Highway 417 City limit and 1+000 is centerline of Blair Road overpass.
  - Section B: 0+000 is centreline of Blair Road overpass and 2+900 is centerline of Montreal Road overpass.
- Westbound:
  - Section B: 0+000 is centreline Montreal Road overpass and 2+900 is centreline of Blair Road overpass.
  - Section A: 0+000 is centreline of Blair Road overpass and 1+000 is Highway 417 City limit.

Deflection testing was completed in November 2010 with a Falling Weight Deflectometer (FWD) to determine the structural capacity of the pavements including the Load Transfer Efficiency (LTE) across the transverse joints/cracks and also layer modulus of the pavement layers. In total, 1,645 deflection tests were completed. A continuous Ground Penetrating Radar (GPR) survey was also completed to identify the pavement layer profiles using an air coupled antenna. In total, 24.3 lane-km of GPR testing was performed. A visual condition assessment was completed to document the severity of each observed transverse crack/joint. Fifty-nine (59) cores and bores were advanced to determine the pavement material types and condition, layer thicknesses and subgrade condition.

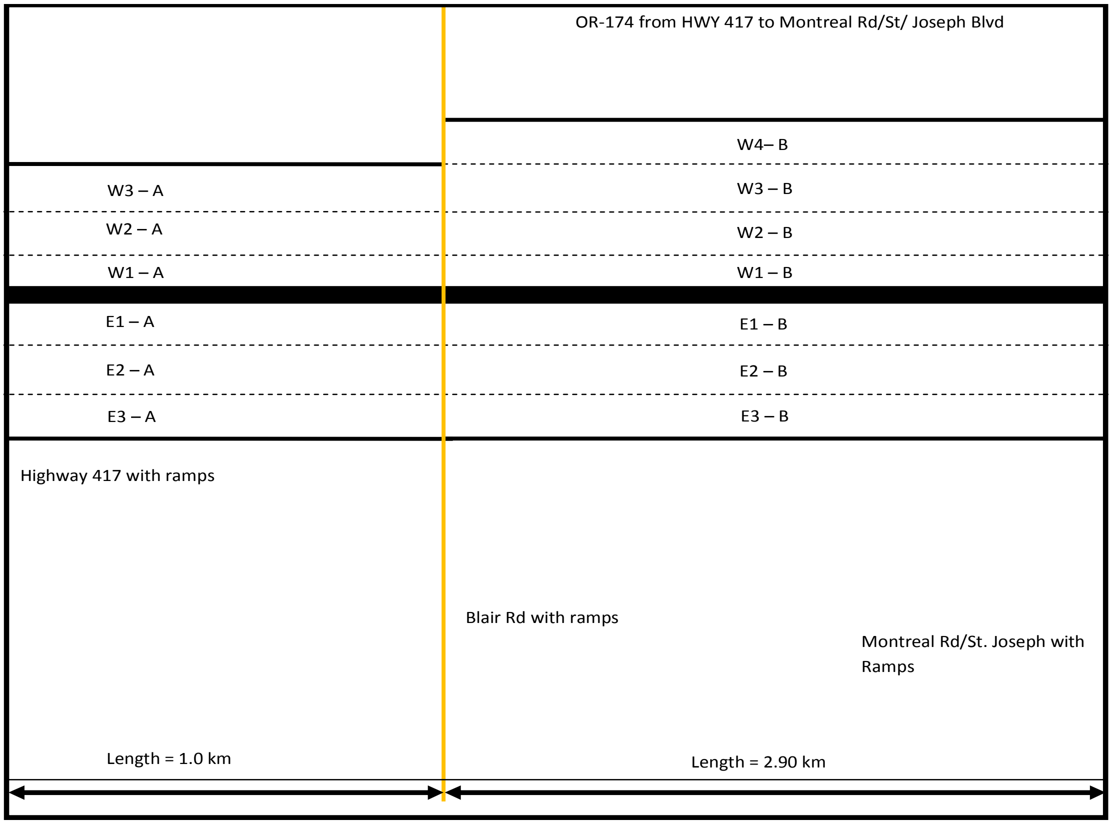

Figure 2.1 Project Section and Lane IDs on OR-174

Note: W3-A and E3-A were not included in Stantec's 2010 investigation. The cross section of section B varies from four lanes wide to seven lanes wide.

2.1 Falling Weight Deflectometer (FWD) Testing Procedures

The deflection testing was completed using a Stantec LTPP-SHRP calibrated Dynatest FWD equipped with a differential GPS. It passed calibration (load cell and geophones) at the Harrisburg, Pennsylvania SHRP FWD Calibration Center in February, 2010. A relative sensor calibration was completed in late October 2010 prior to the start of testing. The FWD unit is equipped with thermo sensors that automatically monitor air and pavement surface temperature at each test location and store them in the FWD data file. It is also equipped with a Trimble satellite receiver that is linked to the FWDwin software.

In general, FWD testing was completed in the outer right wheel path at an approximate 100 m interval in each lane and was referenced linearly to an initial starting point on the highway using a DMI and spatially with GPS coordinates. A nine-sensor configuration was used to record the pavement deflections. The FWD sensor configuration used is presented in Table 2.1. The loading sequence consists of a seating drop followed by three load applications at three target heights. The standard loading sequence is presented in Table 2.2 and the total number of FWD tests in each lane is presented in Table 2.3.

Table 2.1: FWD Sensor Configuration

FWD Sensor Number	1	2	3	4	5	6	7	8	9
Offset from FWD Load Plate [mm]	0	200	300	450	600	900	1,200	1,500	-300

Table 2.2: FWD Standard Loading Sequence

FWD Drop Sequence	FWD Target Height	FWD Load Level (kN)
Seating Drop	1	40 kN
1	1	40 kN
2	2	55 kN
3	3	70 kN

Table 2.3: FWD Tests per Lane

Direction	Lane ID	Number of FWD Tests	Direction	Lane ID	Number of FWD Tests
East Bound (EB)	E1-A	113	West Bound (WB)	W1-A	125
	E1-B	208		W1-B	247
	E2-A	107		W2-A	118
	E2-B	262		W2-B	210
	E3-A	N/A		W3-A	25
	E3-B	71		W3-B	86
				W4-B	73
	Total	**761**		**Total**	**884**

2.1.1 Review of FWD Data

Stantec completed a detailed analysis on the FWD data to review the Load Transfer Efficiency (LTE) of the existing concrete pavement.

To calculate the load transfer efficiency for all joints tested on OR-174, the American Association of State Highway and Transportation Officials (AASHTO) 1993 equation was used:

$$\Delta LTE = 100 \times \left(\frac{\Delta ul}{\Delta l}\right) \times B$$

Where:

ΔLTE = deflection load transfer efficiency, percent
Δul = unloaded side deflection, μm
Δl = loaded side deflection, μm
B = slab bending correction factor

A slab bending correction factor of 1.0 was used in the analysis as recommended by MTO MI-183 document "Adaptation and Verification of AASHTO Pavement Design Guide for Ontario Conditions".

When reviewing the results of the above noted analysis it was noted that many of the joints and cracks have LTE values lower than 50 %and some even below 20 %. The LTE values should be in the 90 to 70 % range. In fact, the American Concrete Pavement Association (ACPA) literature identifies 60% load transfer or less as a time when dowel bar retrofitting should be considered to restore load transfer capability. This confirmed the importance of observing the concrete joint / crack areas to see the amount of deterioration in the underlying concrete pavement to help provide information for the selection of short term and long term pavement rehabilitation strategies.

Due to the complexity of composite pavements, Stantec used the ELMOD Dynatest program for the FWD data backcalculation analysis to determine normalized deflections, surface moduli, voids, layer moduli, modulus of subgrade reaction, and modulus at joint. This information was reviewed in detail and used in the development of feasible pavement rehabilitation design strategies. The AASHTO equation was used to verify the resilient modulus (M_R) of the subgrade and calculate the modulus of the subgrade reaction (k_{static}). The surface layer is 100 mm – which is the minimum thickness to backcalculate a modulus. The asphalt layer appears to have a low modulus about ~2000 MPa indicating that the asphalt is deteriorating. The normal range for HMA is 3,000MPa to 7,000MPa @ 20°C. The concrete modulus was not in the normal range of 28,000 to 30,000 MPa (i.e. approximately 25 % of the values were below 20,000) an indication of deteriorated concrete pavement. This is consistent with the findings from the joint / crack investigations performed in late November and December. Ground Penetrating Radar Survey

2.2 Review of GPR Data

Ground penetrating radar (GPR) data was collected continuously in each lane and direction of OR-174 within the project limits. The GPR system was manufactured by Geophysical Survey Systems Inc. (GSSI). It consists of a SIR-20 data acquisition, a model 4105 2.0-GHz air coupled horn antenna, wheel-mounted distance measuring instrument (DMI). The GPR vehicle is equipped with a Trimble GPS system that will simultaneously collect GPS coordinates along the road sections. The quality of the GPS data depends on the satellite coverage within the area.

In order to collect high resolution GPR data for the asphalt concrete, concrete and granular layers, the antenna was set to collect at 15 nanoseconds. The transmission rate for the GPR data collection was set to 100 kHz. Data was collected at a scan rate of 6 scans per metre. The collected GPR data was saved to the laptop and backed up on an external drive.

At the beginning of testing, the GPR antenna and DMI were calibrated. During data collection, the operator "flagged" the start and end of all sections within the data file. It is important to note that several factors can influence signal penetration and the quality of the collected data. For example, pavements or base/subbase materials with high moisture contents will adversely affect GPR signal penetration. To limit or eliminate this problem, data was not collected during or immediately after a rain event. High frequency radio interference caused by overhead wires, cell phone towers, transmission lines, etc. can cause significant "noise" within a data file making it difficult to interpret. This problem is hard to avoid or prevent as these items are "fixed" and cannot be "removed" from the vicinity of the test section.

GPR data was checked for quality and processed using RADAN 6.5, GPR data reduction software developed by GSSI. GPR data processing involves identifying reflections caused by changes in the electrical properties (dielectric, electrical conductivity, etc.) of a material. The data technician digitizes the reflection and the software converts the digitized reflection into layer thicknesses. Once the layers have been identified with RADAN 6.5, the layer and thickness data was exported as an ASCII file. GPR layer statistics including the minimum, maximum, average and standard deviation are reported.

The GPR data was calibrated using ground truth information obtained by cores and boreholes that were extracted or advanced on OR-174. This process involves inputting a known layer thickness (core and borehole information) at a given point along the GPR survey, into the RADAN software to allow it to calculate the electrical properties for the specific asphalt material that is present on site. By default, the RADAN software will use an assumed average value for the electrical properties of the pavement materials if no ground truth information is available.

In total, 59 cores were used to calibrate the GPR layer data. RADAN selects the nearest core to calculate the electrical properties at each GPR scan. A summary table of the GPR results is presented in Table 2.4. The GPR layer profiles and results are shown in the CD which is included with this report.

Table 2.4: GPR Results Summary

Direction	Lane	AC Layer Thickness (mm)				PCC Layer Thickness (mm)				Granular Layer Thickness (mm)			
		Min	Max	Avg	Stdev	Min	Max	Avg	Stdev	Min	Max	Avg	Stdev
EB	E1-A	42	392	191	146	206	245	227	9	116	256	192	27
	E1-B	47	284	110	41	97	386	256	40	105	248	171	37
	E2-A	45	386	97	78	218	282	251	14	134	338	169	28
	E2-B	55	317	111	39	120	293	224	25	70	233	149	37
	E3-A	N/A											
	E3-B	93	175	133	16	N/A	N/A	N/A	N/A	267	357	305	20
WB	W1-A	59	363	111	83	183	258	223	14	119	287	192	38
	W1-B	38	260	87	26	198	363	252	34	141	256	190	23
	W2-A	42	402	110	68	203	304	251	24	92	193	154	19
	W2-B	54	280	103	32	192	295	244	22	94	376	158	56
	W3-A	102	237	189	25	NA	NA	NA	NA	193	304	257	25
	W3-B	189	287	240	15	N/A	N/A	N/A	N/A	163	309	225	25
	W4-B	148	318	231	21	N/A	N/A	N/A	N/A	144	316	216	44

2.3 Subsurface Investigation Results

Pavement cores and boreholes were extracted from all lanes (excluding E3-A and W3-A) on OR-174 within the project limits. Representative samples of the granular base, granular subbase and subgrade material were retained and submitted to the laboratory for testing. The results of the subsurface investigation confirmed that the inner two lanes in each direction were a composite pavement structure with an asphalt concrete surface layer over a Portland cement concrete. This structure was placed on top of a granular base/subbase. The outer lanes which were added as a widening were a flexible pavement structure comprised of an asphalt concrete surface layer on granular base/subbase layers. Table 2.5 presents a summary of the subsurface investigation including a statistical summary of each encountered layer within the project.

Table 2.5: Subsurface Investigation Layer Thickness Summary

Direction	Lane	# of Boreholes	AC Layer Thickness (mm)				PCC Layer Thickness (mm)				Base Layer Thickness (mm)				Sub Base Layer Thickness (mm)			
			Min	Max	Avg	Stdev	Min	Max	Avg	Stdev	Min	Max	Avg	Stdev	Min	Max	Avg	Stdev
EB	E1-A	4	60	380	213	166	225	230	228	4	130	205	171	31	390	550	465	70
	E1-B	6	70	155	109	37	215	250	231	12	135	210	175	26	370	600	436	94
	E2-A	4	70	350	148	135	220	350	267	72	170	230	197	31	370	850	560	204
	E2-B	6	75	170	121	37	205	235	224	11	90	170	128	29	190	490	310	113
	E3-A	N/A																
	E3-B	6	110	135	122	11	N/A	N/A	N/A	N/A	285	360	310	27	470	790	627	144
WB	W1-A	3	75	95	85	8	210	225	220	9	130	230	195	56	420	510	453	49
	W1-B	6	55	230	99	65	215	240	227	9	160	245	189	34	270	470	366	80
	W2-A	5	80	185	109	43	160	240	213	36	150	245	191	47	460	570	500	45
	W2-B	6	70	120	98	20	100	235	211	54	115	150	133	15	450	630	525	76
	W3-A	N/A																
	W3-B	6	220	255	238	14	N/A	N/A	N/A	N/A	180	260	218	26	370	550	428	75
	W4-B	6	215	255	233	13	N/A	N/A	N/A	N/A	160	275	228	44	350	520	432	59

2.4 Visual Condition Assessment

Site visits were completed in November 2010 to assess the current pavement conditions to help understand the potential causes of the pavement distresses. A visual condition assessment was competed to identify the number and severity of the transverse cracks and joints within the project limits. The cracks were rated at three severity levels (low, medium and high) based on the FHWA Distress Identification Manual [FHWA 2003]:

- Low severity is an unsealed crack with a mean width ≤ 6 mm; or a sealed crack with sealant material in good condition and with a width that cannot be determined.
- Moderate severity is any crack with a mean width > 6 mm and ≤ 19 mm; or any crack with a mean width ≤ 19 mm and adjacent low severity random cracking.
- High severity is any crack with a mean width > 19 mm; or any crack with a mean width ≤ 19 mm and adjacent moderate to high severity random cracking.

The numbers of cracks were grouped into intervals of 100 m in each lane. In addition, the number of "humps" at the transverse joint and crack locations was also documented as a part of this survey. "Humps" can be defined as large asphalt patch repairs placed over deteriorated joints and cracks.

A site review was also undertaken on September 1, 2011 to visually assess the extent and severity of the pavement distresses within the project limits compared to the 2010 observations. During this visit it was noted that there were some depressed areas in portions of the roadway and potential drainage issues in another portion. On October 24, 2011 Stantec staff took part in a night time site visit to observe the precision milling of humps on OR-174 with City of Ottawa staff. A few observations were as follows:

- Transverse cracks were observed in the asphalt at the each location where the asphalt humps were milled off; and
- Extensive cracking was observed in the underlying asphalt at one hump area following milling.

2.4.1 Concrete Joint and Crack Observations

On November 30 and December 7 and 8, 2011 site visits were made by Stantec and City of Ottawa staff to observe the condition of the concrete surface at several locations where the asphalt surface was cracked. The asphalt was removed to the concrete surface in nine different locations to observe the condition of the concrete surface. Listed below is a summary of the observations made during the site visit:

- Wire mesh and steel dowels were observed at the surface of the concrete pavement in several locations. Rust spots in the concrete surface were also observed, this suggests the wire mesh was close to the surface of the concrete. The wire mesh should be at 1/3 of the depth of the concrete pavement and the steel dowels should be at mid slab;
- Delamination of the concrete was observed at the crack locations suggesting the wire mesh is corroding and fracturing the concrete in that area. The delamination area varied at each crack location and extended up to 1.2 metres at some joints.
- An asphalt patch/plug was observed in the most easterly removal area in the eastbound lanes. In addition, the concrete was observed to have some delamination. The longitudinal crack in the asphalt pavement was observed to have severe deterioration along the edge of the concrete pavement. It was observed that the underlying concrete pavement at the longitudinal crack in the asphalt pavement was in good condition except for some delamination in one location;
- In a few locations, the concrete was deteriorated to such a degree that it could be broken by kicking it with safety boots. In other areas a slight application of a hammer could break up the concrete. This was evident at the location between the Blair Road Interchange and the Transitway interchange adjacent to a depression in the adjacent lane. The concrete was observed to be severely deteriorated and could be punctured with a slight application of a hammer;
- The asphalt pavement varied in thickness from 40 mm to less 100 mm.
- Vermeer (wooden) joints were observed at two of the investigated cracks and one area that was not part of the investigation. Vermeer joints may exhibit tenting of the asphalt surface in the summer as the concrete compresses into the joint due to thermal expansion. Lateral compression of the wood causes vertical expansion creating a bump in the pavement surface;
- A longitudinal crack was observed in the westbound lane between the shoulder and edge of the lane near City of Ottawa station 1 + 400 (this chainage differs from that used by Stantec in the 2010 data collection process). The concrete appeared to be cracked and raised approximately 25 mm to 40 mm;
- A joint spacing of 21 metres was confirmed (based on three measurements); and

- Mid panel cracking typically occurred at an approximate 7-8 m interval between joints (based on three measurements).

A review of historic documents indicated that the 225 mm concrete pavement was constructed in 1959 with 32 mm dowels, wire mesh placed at 1/3 the depth and a joint spacing of 21 metres. This is greater than the presently recommended 4.5 to 5 metres today. Therefore, there is a high probability that one or more mid panel cracks have developed over time. The joint and crack field investigations in 2010 and 2011 support this as many transverse cracks currently exist in the asphalt surface at spacing's in the order of 21 metres. One investigation area confirmed a crack in a mid-panel location was severely deteriorated like the joint locations. This confirms that deteriorated mid-panel cracks exist in the underlying concrete. Another issue on the jointing side is that Vermeer (wooden) joints were used at some joints (frequency not known but several were observed during the joint / crack investigation as follows). This type of joint cause's performance issues over time.

3.0 Review of Potential Rehabilitation Options for Ottawa OR-174 Roadway

There are several potential strategies to address the rehabilitation of the City of Ottawa OR-174 composite pavement structure. The options reviewed in this analysis were as follows:

1) **Option A: Routine maintenance**; Continue to perform yearly routine maintenance consisting of milling off the transverse bumps and patching the depression areas. Rutting would be addressed by milling and replacing the asphalt.
2) **Option B: Thick asphalt overlay**; One potential repair method would be to overlay the existing asphalt, as is, with a thick asphalt overlay.
3) **Option C: Concrete pavement restoration and asphalt overlay**; This option involves removal of asphalt to the concrete surface, rehabilitation of the concrete pavement and then overlaying with asphalt to match the existing grade of adjoining asphalt only lanes. The existing asphalt is milled off the concrete and the joints / cracks are evaluated to decide if they need to be repaired. Based on the joint and crack investigation, there is a high probability that all joints will need full depth repairs and at least one mid-panel crack per panel will be requiring repair. Leaving an exposed concrete surface will not be possible due to having to meet the elevation of the adjacent asphalt only lanes. Therefore, an asphalt overlay will be required. Repairs should be able to be done one lane at a time thereby minimizing the impacts on the travelling public.
4) **Option D: Concrete pavement rubblization and asphalt or concrete overlay**; the existing concrete is rubblized and used as a base material for a new asphalt or concrete pavement surface. The asphalt surface is milled off to expose the underlying concrete pavement surface for rubblizing. Two types of processes can be used to rubblize concrete pavement - resonant pavement breaker and multi-head breaker. It is very important to ensure there are no water issues with the pavement structure prior to commencing the rubblization process to ensure proper rubblization of the pavement. The resonant pavement breaker is especially sensitive to water issues. The existence of subdrains was not investigated under the scope of this work. If not present, subdrains should be installed in the pavement structure to allow water to drain from the granular base and subbase layers. This process could take several months if the granular material is in a saturated state. Vermeer (wooden) joints will also need to be removed and replaced by asphalt.

- **Option E: Unbonded concrete overlay**; The existing asphalt is removed from the underlying concrete pavement to review its condition. Severely deteriorated joints / cracks are repaired with concrete pavement restoration technique such as full depth repairs (FDR) and partial depth repairs (PDR). This involves removing and replacing of the damaged concrete at the joint and crack locations to provide continuity of support for the concrete overlay. Ontario Provincial Standard Specifications (OPSS) and the American Concrete Pavement Association (ACPA) have technical documents that address these types of repairs. A thin layer of asphalt (50 mm) is placed over the older concrete pavement and a new concrete pavement is then placed over the asphalt layer. As with the other alternatives, any drainage issue will need to be addressed to prevent possible future issues. New lanes will be in the passing lanes instead of the bus lane where concrete properties such as non-rutting surface would be more beneficial. And,
- **Option F: Reconstruction with asphalt or concrete pavement**: This option involves the reconstruction of the total pavement structure. The existing composite pavement is removed and disposed of followed by removal of granular to the depth of the required new structure. A new granular subbase / base and asphalt or concrete pavement structure is then placed in the excavated area designed to handle the anticipated traffic Table 3.1 summarizes the six potential options to rehabilitate the OR -174 composite pavement and several evaluation criteria. Based on the analysis of the options, several were eliminated from more detailed analysis.

Table 3.1: Evaluation of Potential Long-Term Rehabilitation Options below is a summary of the various evaluation criteria including estimated service life, feasibility of option, construction cost, construction staging, reflective cracking, grade change, salvage of existing materials, and recommendation for further analysis. Based on this comparison four options were chosen to perform a more detailed analysis on them including the following:

1) Option C - Concrete Pavement Restoration (CPR) & Asphalt Overlay
2) Option E - Unbonded Concrete Overlay
3) Option F – Reconstruction with Asphalt Pavement
4) Option F – Reconstruction with Concrete Pavement

4.0 PAVEMENT ANALYSIS AND DESIGN OF PREFERRED ALTERNATIVES

Based on the results of the rehabilitation Options evaluated in Section 3, a more detailed analysis was completed on the selected rehabilitation alternatives. Preliminary pavement designs are presented for four rehabilitation alternatives to allow for an initial cost and life cycle cost analysis (LCCA) comparison. The four alternatives are as follows:

- Alternative 1 - Concrete Pavement Restoration (CPR) and Asphalt Overlay 100 mm;
- Alternative 2 - Concrete Overlay;
- Alternative 3 - Reconstruction with Asphalt Pavement Structure; and
- Alternative 4 - Reconstruction with Concrete Pavement.

Table 3.1: Evaluation of Potential Long-Term Rehabilitation Options

Evaluation Criteria	Option A Maintain Existing	Option B Thick Asphalt Overlay	Option C Concrete Pavement Restoration and Asphalt Overlay	Option D Rubblization	Option E Unbonded Concrete Overlay	Option F Reconstruction
Service Life	Shortest **service** life	Difficult to access as the causes of distress are not addressed	18 year design based on MTO Composite pavement	20 year design	25 year design	20 year design asphalt 25 year design concrete
Feasibility of option	General public is concerned with condition of OR-174 so need to address pavement distress issues	Grade raise will affect the adjacent asphalt lanes Potential overhead clearance issues	Joint / crack investigation revealed substantial deterioration at the nine cracks which were investigated full depth	Grade raise will affect the adjacent asphalt lanes Potential overhead clearance issues	Grade raise will affect the adjacent asphalt lanes Potential overhead clearance issues	Longest timeline to construct, Greatest construction impact to the public
Construction Cost	Lowest short term cost	Grade raise increases cost. Asphalt must be added to adjacent lanes	Slightly lower cost for rehabilitation options	Grade raise increases cost, as asphalt must be added to adjacent lanes	Grade raise increases cost, as asphalt must be added to adjacent lanes	Higher cost
Construction Staging	Continued yearly maintenance and traffic disruption	One lane at a time possible	One lane at a time	One lane at a time	Highest production requires closing one direction of traffic	Highest production requires closing one direction of traffic
Reflective Cracking	Reflective cracking will continue and new cracks will also reflect through new cracks?	Cracks in underlying asphalt will reflect	Joints in underlying concrete will reflect	Reflective cracks eliminated	Reflective cracks eliminated	Reflective cracks eliminated
Grade Change	No change	125 to 150 mm	No grade change	425 mm for asphalt overlay 300 mm for concrete overlay	200 mm	No grade change
Salvage of Existing Materials	Will continue to need mill and replace asphalt	Utilizes existing pavement structure	Utilizes existing pavement structure	Concrete pavement recycled into base material	Use existing structure as good base material	Potential to use old concrete as subbase material after crushing
Other	Does not address frost heave.	Does not address frost heave.	Sustainable option as use existing structure	Does not address frost heave.	Check overhead clearance	Least sustainable option
Recommendation for Further Analysis	Eliminate from further evaluation. Additional detail provided in section 4.1	Eliminate from further evaluation. Additional detail provided in section 4.2	Recommend for further analysis	Eliminate from further evaluation. Additional detail provided in section 4.4	Recommend for further analysis	Recommend for further analysis

4.1 Review of pavement condition

To develop a pavement design, it is necessary to understand the condition of the existing pavement to see if it can be utilized as part of the new pavement structure. The information in Section 2 was used to assist in the review of the pavement structure. More detailed analysis was performed on the data collected in November of 2010 to provide a better understanding of the current pavement structure and performance.

4.2 Traffic Analysis

Based on information supplied by the City of Ottawa the AADT of 21,318 and 6.3 percent trucks values were then used to help determine the estimated amount of ESALs to be carried on the asphalt and concrete pavements over their 20 and 25 year design lives respectively. A compound growth factor of 1.1 percent was used.

4.3 Subgrade Analysis

The results of the boreholes taken by Stantec in November of 2010 were compared to the Ontario Geological Survey borehole logs and were found to have similar results. The subsurface data collected during the field investigations in November of 2010 was analyzed to determine the subgrade condition. Based on the review of the borehole information, see Appendix D - borehole logs and lab results, there appears to be three subgrade conditions in the project area: glacial till from the split to just beyond Blair Road; grey silty clay in the remainder of the project except in the cut area where weaker higher water content soil conditions exist. The exact locations of the different types of soils are not known.

Using the MTO Recommended M_R values from MTO document, Adaptation and Verification of AASHTO Pavement Design Guide for Ontario Conditions the recommended subgrade resilient modulus would be as follows: 30 MPa for glacial till; 25 MPa for grey silty clay and; and 20 MPa for the subgrade in the cut area. [ERES 2008]

For construction projects of this length, 3.9 kilometer, it is common practice to design for only one and possibly two soil conditions. Therefore, it was decide to run preliminary designs for both the 20 MPa and 25 MPa subgrade resilient modulus.

4.4 Asphalt Pavement Design

OR-174 design parameters were selected using the information presented in the MTO document Adaptation and Verification of AASHTO Pavement Design Guide for Ontario Conditions, and in consideration of the results of the current field investigation program and the results of the laboratory test program. These design parameters were used in the evaluation of the pavement using the AASHTO 1993 Guide for the Design of Pavement Structures.

The design parameters noted above were inputted into the Stantec AASHTO 1993 asphalt pavement design spreadsheet to develop an asphalt pavement structural design. Table 4.1 provides a sensitivity analysis for the asphalt structure noting the effect of varying the percentage of trucks, truck type percent, subgrade resilient modulus, and thicknesses of asphalt and granular layers. For the probable cost estimates the following design was used:

Table 4.1: Asphalt Pavement Structure Sensitivity Analysis

Evaluation Criteria	Design A	Design B	Design C	Design D
ESALs	21,445,325	21,445,325	25,530,149	25,530,149
Percent Truck	6.3	6.3	7.5	7.5
% Truck type - 2 & 3 axles	30	30	30	30
% Truck type - 4 axles	10	10	10	10
% Truck type - 5 axles	45	45	45	45
% Truck type - 6+ axles	15	15	15	15
Resilient Modulus	20	25	20	25
SN required	188.3	176.5	192.4	180.5
SN provided	189	175	193.2	182
ACP thickness	200	200	210	200
Base Thickness	150	150	150	150
Subbase Thickness	600	500	600	550

Design A (Design based on MTO truck distribution):

- 200 mm of asphalt,
  - 50 mm SP12.5 FC2 (PG 70-34) Cat D
  - 150 mm SP19 (PG 70-64) Cat D (2 lifts at 75 mm each)
- 150 mm of Granular A,
- 600 mm of Granular B Type II

4.5 Concrete Pavement Design

OR-174 design parameters were selected using the MTO Adaptation and Verification of AASHTO Pavement Design Guide for Ontario Conditions as noted in the asphalt write-up above. These design parameters were used in the evaluation of the pavements using the AASHTO 1993 Guide for the Design of Pavement Structures. The ACPA StreetPave concrete pavement thickness design program was used to check the AASHTO design due to the knowledge that the AASHTO 1993 thickness design procedure over designs concrete pavements. This fact is supported by the research done by ACPA and the lower pavement thickness outputs being produced with the new AASHTO Darwin ME software.

The Stantec AASHTO 1993 concrete pavement design spreadsheet was used to develop concrete pavement structural design using the above data. Table 4.2 below provides a sensitivity analysis for the concrete structure noting the effect of varying the percentage of trucks, truck type percent, subgrade resilient modulus, drainage coefficient, and concrete strength. Based on the results in the table the following concrete pavement design was chosen for the probable cost estimate:

- 250 mm of concrete pavement with 32 mm dowels and 4.5 metre joint spacing
- 300 mm of Granular A

Table 4.2: Concrete Pavement Structure Sensitivity Analysis

Evaluation Criteria	Design A	Design B	Design C	Design D	Design E	Design F	Design G	Design H	Design I	Design J
ESALs (AASHTO)	27,281,372	27,281,372	27,281,372	21,555,284	21,555,284					
AADTT two-way (StreetPave)						2,700	2,686	2,686	2,800	3,000
Percent Truck	6.3	6.3	6.3	6.3	6.3	6.33	6.3	6.3	6.6	7.0
% Truck type 2 & 3 axles	30	30	30	30	30	Major Arterial Category	Major Arterial Category	Major Arterial Category	Major Arterial Category	Major Arterial Category
% Truck type 4 axles	10	10	10	10	10					
% Truck type 5 axles	45	45	45	45	45					
% Truck type 6+ axles	15	15	15	15	15					
Resilient Modulus	20	20	20	20	20	21	21	21	21	21
Load Transfer	2.7	2.7	2.7	2.7	2.7	Yes	Yes	Yes	Yes	Yes
Drainage Coef. Or Edge Support	1	1.1	1.1	1.1	1	No	Yes	No	No	No
Strength	5	5	4.85	5	5	5	5	4.85	5	5
Concrete Thickness	278	264	268	255	268	241	216	254	241	241
Base Thickness	300	300	300	300	300	300	300	300	300	300

5.0 ESTIMATE OF PROBABLE COST OF EACH ALTERNATIVE

An estimate of probable cost was calculated for each of the preferred alternatives. Table 5.1 summarizes the various alternatives noting the activities which need to be performed for each alternative, the unit cost used to calculate the activity cost and the cost of the individual activities. Additional information related to the alternative is provided in the paragraphs following the table. It should be noted that these costs are based on current information and changes in oil prices and energy costs can have a substantial effect on the actual costs. In addition, the actual thickness of the asphalt portion of the composite pavement can also affect the cost.

Table 5.1: Estimate of Probable Cost of Each Alternative

Activity	Unit Price ($)	Alternative 1 CPR &Asphalt Overlay ($)	Alternative 2 Unbonded Concrete Overlay ($)	Alternative 3 Asphalt Reconstruction ($)	Alternative 4 Concrete Reconstruction ($)
Milling asphalt	3.55/m^2	$200,000	$200,000	$200,000	$200,000
Full depth repairs of concrete	2,110/repair	$3,120,000	$1,055,000		
Asphalt surface course	100/tonne	$560,000		$700,000	
Asphalt base course	84/tonne	$700,000		$1,760,000	
50 mm Asphalt separation layer SP 12.5	101/tonne		$700,000		
PCCP 250mm	67.25/m^2		$3,850,000		$3,850,000
Overlay adjacent ACP lanes to match concrete grade	100/tome 84/tonne		$270,000 $910,000		
Removal of concrete slabs	7.00/m^2			$400,000	$400,000
Excavation of 510 mm of granular	15.00/m^3			$530,000	
Excavation of 150 mm of granular	15.00/m^3				$200,000
Granular A	24.50/tonne			$460,000	$920,000
Granular B	22.50/tonne			$1,700,000	
Total cost		**$4,600,000**	**$7,000,000**	**$5,800,000**	**$5,600,000**

Note: values are rounded to the nearest $100,000.

The costs noted above exclude traffic control which can have a significant impact on the cost depending on what is performed. The following are a few comments on the traffic control:

- Cost of cross over and traffic staging, etc. is approximately $45,000 for each end of the project;
- Night time work will increase labour and equipment charges by approximately 10 percent; and

- Probable cost to close lanes is approximately $1,000 per shift.

A few other points to consider are as follows:

- The prices for the Granular A and B obtained seem high so this will need to be verified;
- Shoulder material is not included in the analysis;
- Cost of subdrains are not included in the estimate and would be approximately $22.00 per linear meter for 150 mm subdrains; and
- Asphalt costs have recently exhibited high variability due to the fluctuation in crude oil costs and could change in the future. Concrete costs are typically more stable.

6.0 LIFE CYCLE COST ANALYSIS

A detailed 50 year life cycle cost analysis (LCCA) was performed based on the following alternatives:

- Alternative 1 - Concrete Pavement Restoration (CPR) and Asphalt Overlay 100 mm;
- Alternative 2 - Concrete Overlay;
- Alternative 3 - Reconstruction with Asphalt Pavement Structure; and
- Alternative 4 - Reconstruction with Concrete Pavement.

The maintenance and rehabilitation (M&R) schedules used in the analysis are based on the MTO 50 year LCCA process with some modifications. [ARA 2007] For example, instead of using an asphalt overlay at year 34 for the concrete M&R schedule concrete pavement restoration techniques such as full depth and partial depth repairs, diamond grinding and dowel bar retrofitting were proposed and calculated to ensure there was no need to raise the grade of the adjacent asphalt only lanes. Table 6.1 below summarizes the results of the life cycle analysis performed on the four alternatives noted above.

Table 6.1: Life Cycle Cost for Various Alternatives

Alternative	Initial Cost ($)	Maintenance and Rehabilitation Cost ($)	Salvage Value ($)	Total Net Present Worth Cost ($)
Alternative 1 – CPR and Asphalt Overlay	4,600,000	1,900,000	35,000	6,500,000
Alternative 2 – Concrete Overlay	7,000,000	1,000,000	100,000	7,900,000
Alternative 3 – Reconstruction Asphalt Structure	5,800,000	1,500,000	100,000	7,200,000
Alternative 4 – Reconstruction Concrete Structure	5,600,000	1,000,000	100,000	6,500,000

Note: values are rounded to the nearest $100,000.

It should be noted although Alternative 1, concrete pavement restoration with an asphalt overlay, has the lowest initial cost it has a life cycle cost higher than the concrete reconstruction alternative and close to the asphalt reconstruction option. In addition, based on the advanced age of the concrete (1959 construction) and condition of the concrete pavement at the nine locations observed in the joint and crack investigation there is a potential for even further deterioration of the concrete. Due to the risk of accelerated deterioration of the existing concrete, this rehabilitation strategy is not recommended for long term performance. Table 6.3 provides a comparison of the alternatives for several key evaluation criteria.

Table 6.3 Summary of Rehabilitation and Reconstruction Alternatives

Evaluation Criteria	Alternative 1: Concrete Pavement Restoration and Asphalt Overlay (Option C)	Alternative 2: Unbonded Concrete Overlay (Option E)	Alternative 3: Reconstruction Asphalt (Option F)	Alternative 4: Reconstruction Concrete (Option F)
Service Life	12 year design	25 year design	20 year design	25 year design concrete
Feasibility of Option	Condition of underlying concrete is not known so higher level of uncertainty with this option	Grade raise required which will affect adjacent asphalt only lanes and potentially overhead clearance issues	Longest construction period. Affects public the most	Longest construction period. Affects public the most
Probable Construction Cost	$4,600,000	$7,000,000	$5,800,000	$5,600,000
Probable Life Cycle Cost	$6,500,000	$7,900,000	$7,200,000	$6,500,000
Construction Staging	single lane construction possible	single lane construction possible	Highest construction production if one direction is closed	Highest construction production if one direction is closed
Reflective Cracking	Cracks in underlying asphalt will reflect over time	No Reflective cracks	No Reflective cracks	No Reflective cracks
Grade Change	No grade change	200 mm grade raise	No grade change	No grade change
Salvage of Existing Materials	Utilizing existing pavement structure	Use existing structure as good base material	Potential to use old concrete as subbase material after crushing	Potential to use old concrete as subbase material after crushing
Other	Will continue to need mill and replacement of asphalt does not address potential subgrade issue	Sustainable option as use existing structure	Least sustainable option from a materials point of view	Second least sustainable option from a materials point of view

Note: values are rounded to the nearest $100,000.

7.0 SUMMARY OF RECOMMENDATIONS

Based on the field investigations, pavement designs and probable costs / LCCA Stantec recommended the following for OR-174 roadway:

- **Long term Rehabilitation / Reconstruction Strategy** – Based on the analysis presented in summary of rehabilitation and reconstruction alternatives it is recommended the 3.9 km section of the OR-174 be reconstructed in either concrete pavement or asphalt pavement. The concrete pavement alternative has the lowest initial cost and life cycle cost but the initial cost of the asphalt pavement alternative is very close so either alternative is a viable solution.

- **The recommended asphalt and concrete pavement structures** are as follows:

Asphalt Pavement Structure	Concrete Pavement Structure
50 mm SP12.5 FC2 (PG 70-34) Cat D	250 mm of concrete pavement
150 mm SP19 (PG 70-64) Cat D (2 lifts at 75 mm each)	- 32 mm dowels
150 mm of Granular A,	- 4.5 m joint spacing
600 mm of Granular B Type II	300 mm of granular A

- **Drainage** - Although the lack drainage does not appear to be affecting the current pavement structure's performance ditching work should be considered as part of the rehabilitation strategy.

8.0 REFERENCES

[FHWA 2003] Federal Highway Administration, "Distress Identification Manual for the Long-Term Pavement Performance Program", Publication No. FHWA-RD-03-031, June 2003.

[ARA 2007] Applied Research Associates, Inc. "Life Cycle Costing 2006 Update Report, Final Report" submitted to Ministry of Transportation of Ontario, Cement Association of Canada and Ontario Hot Mixed Producers Association, August 23, 2007

[ERES 2008] ERES Consultants, "Adaptation and Verification of AASHTO Pavement Design Guide for Ontario Conditions", Submitted to Ministry of Transportation of Ontario, Final Report (Revised March 19, 2008).