Impacts of Increased Loading Due to Heavy Construction Traffic on Thin Pavements

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ABSTRACT

Heavy construction traffic was anticipated to cause accelerated deterioration or damage of pavements in the area of watermain construction in the City of Ottawa and the Township of Russell in Ontario. A monitoring program was implemented to determine if construction traffic caused accelerated deterioration or damage to the pavement. The agencies involved wanted to quantify the damage caused by the increased loading during construction to allow an equitable sharing of costs to restore the pavement to preconstruction conditions.

Potential damage was quantified using visual pavement condition assessments and Falling Weight Deflectometer (FWD) testing. The pavement condition was assessed pre and post construction, and the information was used to quantify the pavement damage caused by construction. Pavement deflections were measured using the FWD. The measured deflections were used to determine the in-situ structural condition of the pavement pre and post construction through backcalculation analysis which included establishing the subgrade soil conditions. Detailed visual distress surveys were also completed on representative 100 m sections to document a change in distress severity and frequency. The type, severity and extent of the distresses were recorded, and digital images were taken to document the condition.

The pre construction results were compared to the post construction results to assess the extent of the pavement damage caused by construction traffic. The FWD testing indicated that no significant structural damage had been caused by construction traffic. The visual monitoring did show an increase in the extent and severity of surface distresses; however, this increase in distress did not significantly impact the structural performance of the pavement.

INTRODUCTION

It was anticipated that heavy construction traffic may cause accelerated deterioration or damage to the pavements in areas of watermain construction on seven streets in the City of Ottawa and the Township of Russell in Ontario. The agencies involved wanted to quantify the damage caused by the increased loading during construction to allow an equitable sharing of costs to restore the pavement to pre-construction conditions. Subsequent to construction the Township of Russell and the City of Ottawa agreed that Parkway Road from Bank Street to Boundary Road was the pavement section that was at greatest risk of pavement deterioration as it was identified to have the weakest pavement structure of the seven streets. It was agreed that post construction testing would be limited to Parkway Road, and the other roads would not be tested.

Excavation for the watermain was generally located within the shoulder or ditch of the existing pavement requiring the operation of heavy construction traffic on the adjacent paved road for an extended period of time. This heavy construction traffic could result in accelerated deterioration of the pavement, especially in areas where the existing strength of the pavement was low. The Township of Russell retained Stantec Consulting Ltd. (Stantec) to implement a pavement monitoring program of the seven street segments located within the Township of Russell and the City of Ottawa where the new watermain was constructed. The monitoring program was developed to quantify or identify the damage resulting from the construction of the watermain.

Deflection testing was selected to be the primary evaluation method used to assess the condition of the existing pavement. As pavements deteriorate, the strength of the pavement decreases and deflections increase. This loss of strength can be quantified by comparing deflection or pavement strength prior to construction, to the deflection or strength following construction. This differential in strength can then be equated to the thickness of the asphalt required to restore the pavement back to its original strength. Pavement deflection testing was used to determine the structural strength of the pavement before and after construction. A Falling Weight Deflectometer (FWD) was used to measure pavement deflection and the resulting deflections were measured. The amount of deflection and the area affected by the imposed load provide measurable methods of assessing the strength of a pavement structure. The pre construction data was compared to the post construction results to assess the extent of the pavement damage caused by construction traffic or activities, if any.

A secondary evaluation technique was used to monitor the pavement, visual assessments of the surface distresses were completed at each FWD test location. In addition, more detailed visual distress assessments were completed on 100 m long representative sections of the pavement. Logging of distresses included extent and severity for each 100 m section.

The pavement monitoring activities including FWD testing and visual condition assessments were completed on May 1 and 2, 2008 prior to construction and on May 6, 2009 and July 7, 2009 subsequent to construction.

METHODOLOGY USED FOR FWD TESTING AND CONDITION ASSESSMENT

Deflection testing was completed using a LTPP-SHRP calibrated FWD to determine the in-situ structural capacity of the pavement structure (and subgrade soil conditions). Testing was completed in accordance with the FWD Testing Guidelines by the Ontario Ministry of Transportation (MTO) (MERO-019). For general project level work, this procedure recommends testing every 50 m to 200 m or a minimum of 15 test points per uniform pavement section.

For this project, testing was completed at an approximate 100 m interval in each direction with the test points staggered between directions to ensure maximum coverage, as depicted in Figure 1.

At each test location, a series of four load applications were applied to the pavement surface in the right wheelpath. The first load application consisted of a "seating" drop of 40 kN (9,000 lbf) to ensure that the FWD loading plate was firmly resting on the pavement surface. The next three load applications consisted of three drops applied at approximately 40 kN, 55 kN, and 70 kN at each test location. Pavement deflections at each load were measured by nine sensors (geophones) placed at the fixed distances as depicted in Table 1. The distances are referenced from the center of the approximate 300 mm (12 inch) diameter load plate. Pavement surface and air temperature readings were automatically recorded at each FWD test location.

A general condition assessment of the pavement surface was completed at each FWD test point to document the observed pavement distresses and the overall pavement condition. The visual distress survey was completed using a modified SHRP-LTPP manual pavement distress protocol; digital images of the pavement surface were taken to document the existing pavement condition. As noted above, 100 m long control sections representative of the pavement segment were selected for detailed visual examination and documentation. The distress survey was completed by documenting the distress types and severity levels within the control section.

ANALYSIS METHODOLOGY FWD TESTING

The FWD test data was analyzed using backcalculation procedures detailed in the AASHTO 1993 Guide for the design of pavement structures. Backcalculation was used to determine the effective structural number (pavement strength) and the in-situ subgrade soil resilient modulus. The following subsections summarize and highlight the AASHTO 1993 Design Methodologies.

Maximum Normalized Deflection

The maximum normalized deflection (D_o), measured at the center of the load plate was used as an indicator of the overall pavement stiffness (strength). The deflection at this location is a function of the pavement layer stiffnesses, including the support capacity of the subgrade soil beneath the pavement structure. The normalization of the deflection under the load plate is used to equalize the effect of the load variation during FWD testing between different test locations and to normalize the deflection collected at different FWD load levels to a common standard load level of 40 kN (9000 lbf), at a standard temperature of 20^{o}C. The AASHTO 1993 temperature correction methodology was used to normalize the deflection to a standard temperature of 20^{o}C.

Backcalculation & Evaluation of the In-situ Pavement Conditions

Pavement layer thicknesses used for the backcalculation analysis were established from trench excavations through the pavement during construction. The pavement structure was documented at each of the road crossings and a summary of the pavement layer thicknesses is summarized in Table 2.

Backcalculation uses analytical pavement response models to predict deflections based on a set of given layer thickness values and moduli. With pavement thickness held constant, based on GPR thickness scans, coring results and/or as-built construction records, the response models identify the set of subgrade and pavement layer moduli that produce deflections that are very similar to those measured during FWD field testing. The backcalculated moduli are examined to draw conclusions about the degree of structural deterioration in the pavement layers and the expected remaining life of the pavement structure. In addition, the backcalculated moduli can be used for the design of future structural overlays for the existing pavement (i.e. for rehabilitation design). The outputs of the backcalculation analysis are as follows:

Effective Pavement Modulus (E_P), the modulus of elasticity of the pavement structure
Effective Structural Number (SN_{eff}) of the pavement layers
Subgrade Soil Resilient Modulus (M_R)

The Effective Pavement Modulus (E_P) is representative of the overall pavement stiffness (the combined stiffness of all pavement layers above the subgrade layer). Typical values of E_P for new flexible pavement structures usually range between 1,035 to 1,735 MPa depending on the overall pavement thickness. High values of E_P indicate a stronger pavement structure.

The Effective Structural Number (SN_{eff}) is the effective strength or structural capacity of the existing pavement structure. Low SN_{eff} values indicate low structural capacity of the pavement structure; while high SN_{eff} values indicate high structural capacity of the pavement structure.

The Subgrade Soil Resilient Modulus (M_R) provides an indicator of the strength of the pavement subgrade. A high subgrade resilient modulus provides better support for a pavement structure and helps to resist permanent deformation of the pavement due to repeated traffic loading. A low subgrade resilient modulus is indicative of a weak subgrade soil which would require construction of a thicker pavement structure to support similar traffic loads for a similar service life. For typical sandy subgrade soils, AASHTO 1993 Pavement Design Guide identifies M_R values less than 24 MPa to be low and may be attributed to the deterioration of the subgrade.

The coefficient of variation (COV) of pavement deflection was also determined within the various pavement sections. The AASHTO 1993 design guide indicates a COV for deflection ranging from less than or equal to 15% for a pavement section indicates uniform pavement conditions within that pavement section. A COV between 15% and 30% generally indicates moderate variation with less uniformity of the pavement section. COV values greater than 30% indicate a variable (non uniform) pavement section with high variability, most likely a reflection of pavement distress.

PAVEMENT CONDITION ASSESSMENT

The results of the visual pavement condition assessments on Parkway Road are summarized below.

On the eastbound lane, the pavement distresses observed pre and post construction were similar; however, in a few locations the severity and extent of the distress had increased slightly. The following distresses were observed:

- Medium to high severity transverse cracking throughout
- Medium to high severity edge cracking and alligator cracking throughout
- Longitudinal and transverse cracking throughout
- Infrequent slight potholes throughout

Images from the pre and post construction detailed visual condition assessments completed on the three 100 m long representative sections of the eastbound lane of Parkway Road are presented in Figures 2, 3, 4 and 5.

On the westbound lane, similarly to the eastbound lane the pavement distresses observed pre and post construction were similar. However, in a few locations the severity and extent of the distress had increased slightly. The following distresses were observed:

- Medium to high severity transverse cracking throughout
- Medium to high severity edge cracking and alligator cracking throughout
- Longitudinal and transverse cracking throughout
- Infrequent slight potholes throughout

Images from the pre and post construction detailed visual condition assessment completed on the three 100 m long representative sections of the westbound lane of Parkway Road are presented in Figures 6, 7, 8, and 9.

A visual assessment of the surficial drainage was completed pre and post construction. Drainage on Parkway Road was provided by grassed ditches. The ditches in the area of watermain construction were regraded following construction; and this resulted in an improved drainage condition following construction.

RESULTS OF FWD ANALYSIS

The major findings of the pavement evaluation and back calculation analysis results are presented in the following subsections. The results are presented in terms of normalized pavement deflection (D_o) under the load plate, in-situ subgrade resilient modulus (M_R), effective pavement modulus (E_P) and effective structural number (SN_{eff}).

Normalized FWD Deflections

Table 3, 4, and 5 summarizes the maximum, minimum, and average normalized maximum deflections for each direction for the data collected in May 2008, May 2009 and July 2009 respectively. Figures 10 and 11 present the variation of the normalized maximum deflection (D_o) data on the eastbound and westbound lanes of Parkway Road for all three sets of data.

The maximum normalized deflection (D_o) on the eastbound lane generally ranged between 245 µm to 1,632 µm for May 2008 testing, between 253 µm to 1,490 µm for May 2009 testing and between 228 µm to 1,211 µm for July 2009 testing. The D_o values on the westbound lane ranged between 310 µm to 2,045 µm for May 2008 testing, between 235 µm to 1,623 µm for May 2009 testing and between 276 µm to 1,596 µm for July 2009 testing. The maximum, minimum and average values of the maximum normalized deflection (D_o) for both directions are presented in Tables 6, 7 and 8 for the three cycles of testing.

Subgrade Resilient Moduli (M_R)

The calculated M_R values on the eastbound lane varied from 9.94 MPa to over 480 MPa for testing in May 2008, from 8.36 MPa to 1,134 MPa for May 2009 and from 12.50 MPa to 646 MPa for July 2009. The calculated M_R values in the westbound lane varied from 9.54 MPa to over 1,377 MPa for testing in May 2008, from 7.61 MPa to 320 MPa for May 2009 and from 8.86 MPa to 729 MPa for July 2009. The average M_R values for eastbound lane were:
47.71 MPa for May 2008,
87.35 MPa for May 2009 and
58.65 MPa for July 2009.

For the westbound lane, the average M_R values were;
57.90 MPa for May 2008,
40.91 MPa for May 2009 and
41.87 MPa for July 2009.

The calculated subgrade soil resilient moduli (M_R), for the eastbound and westbound lanes of Parkway Road are presented graphically in Figures 12 and 13 respectively.

Effective Pavement Modulus (E_P)

The E_p values in the eastbound direction varied from 82 MPa to 1573 MPa for May 2008, from 92 MPa to 635 MPa for May 2009 and from 134 MPa to 1063 MPa for July 2009. The E_p values on the westbound direction varied from 63 MPa to 922 MPa for May 2008, from 94 MPa to 1034 and from 92 to 1569 MPa. The average E_P values for eastbound lane were;
255 MPa for May 2008,
300 MPa for May 2009, and
310 MPa for July 2009.

The average E_P vales for westbound lane were;
236 MPa for May 2008,
263 MPa for May 2009, and
249 MPa for July 2009.

The backcalculation results for the Effective Pavement Modulus of Elasticity (E_p) are provided in Figures 14 and 15.

Effective Structural Number (SN_{eff})

The average SN_{eff} values for the eastbound lane were;

3.39 for May 2008,
3.63 for May 2009, and
3.64 for July 2009.

The average SN values for the westbound lane were:

3.37 for May 2008,
3.51 for May 2009, and
3.41 for July 2009.

The SN_{eff} values for the eastbound and westbound lanes of Parkway Road are presented in Figures 16 and 17.

The maximum normalized deflection (D_o) and the backcalculation results (M_R, E_P and SN_{eff}) for the east and westbound lanes along Parkway Road are summarized in Tables 9, 10 and 11.

DISCUSSION AND CONCLUSIONS

As noted above, pavement strength testing was completed pre and post construction using a FWD. In addition, distress surveys were completed on representative 100 m sections. By comparing the visual distresses on the representative sections before and after construction, it was observed that there were some minor changes. Observed differences included minor increases in extent and severity of the pavement distresses, primarily related to severity and extent of pavement edge cracking. It was also noted that there was extensive patching at the edge of pavement. This patching is assumed to be related to construction activities having caused some failures in the pavement surface which were subsequently repaired.

In addition to observation of the pavement patches, it was noted that the ditches had been regraded in the area of watermain construction, and there was no standing water in the regraded ditches.

As presented in the various graphs noted above, the deflections generally decreased following construction of the watermain. A few specific observations include:

- There was no reduction in the strength of the pavement structure as presented graphically in Figure 18.
- The average pavement deflection decreased post construction in both the eastbound and westbound lanes and is presented graphically in Figure 19.
- The average effective structural number was marginally higher in May 2009 and July 2009 than it was in May 2008. This indicates the pavement was marginally stronger in 2009 than it was in 2008, and is presented graphically in Figure 18.

To confirm the interpretation of the data and results noted, a Student's t-test was performed. The t-test was completed on FWD deflections (D_1) and structural strength (SN_{eff}) for the pre and post construction pavement conditions. The t-test indicated there was an increase in structural strength post construction (at the 95% confidence level). It should be noted that this increase in strength was relatively small.

In summary, the FWD deflection testing and the backcalculated pavement strengths indicated there were no degradation of the pavement structurally. The visual assessments indicate there was a minor increase in severity and extent of the distresses; however, that had not negatively impacted the strength of the pavement. This was interpreted to be a function of the relatively thin asphalt surface and the extent of cracking prior to construction resulting in a limited contribution from the asphalt surface to the overall pavement strength. In addition, improvements to the ditches post construction may have contributed to better drainage of the pavement structure contributing to a marginal improvement in strength.

References:

Falling Weight Deflectometer (FWD) Testing Guideline, Materials Engineering and Research Report MERO-019, August 9, 2005, Ministry of Transportation of Ontario (MTO)

AASHTO Guide for Design of Pavement Structures, 1993, American Association of Transportation and Highway Officials (AASHTO), Washington, DC.

Table 1: FWD Sensor Configuration

Sensor Number	1	2	3	4	5	6	7	8	9
Offset from Center of the Load Plate (mm)	0	300	450	600	900	1,200	1,500	1,800	-300

Table 2: Summary of Pavement Layer Thickness

Material	Maximum [mm]	Minimum [mm]	Average [mm]	Standard Deviation
Asphalt	100	35	63	17
Granular Base	530	145	214	68
Granular Subbase	440	180	318	47

Table 3: Summary of Normalized Deflections Pre Construction (May 2008)

Direction	Lane	Maximum Deflection [μm]	Minimum Deflection [μm]	Average Deflection [μm]
East	1	1,632	245	732
West	1	2,045	310	781

Table 4: Summary of Normalized Deflections Post Construction (May 2009)

Direction	Lane	Maximum Deflection [μm]	Minimum Deflection [μm]	Average Deflection [μm]
East	1	1,490	253	630
West	1	1,623	235	724

Table 5: Summary of Normalized Deflections Post Construction (July 2009)

Direction	Lane	Maximum Deflection [μm]	Minimum Deflection [μm]	Average Deflection [μm]
East	1	1,211	228	602
West	1	1,596	276	734

Table 6: Summary of FWD Testing and Analysis Results Pre Construction (May 08)

Direction	Lane	Maximum Normalized Deflection [μm]	Subgrade Resilient Modulus M_R [MPa]	Effective Pavement Modulus E_P [MPa]	Effective Structural Number SN_{eff}
East	1	245 to 1,632	9.94 to 480	81.79 to 1573	1.87 to 5.01
West	1	310 to 2,045	9.54 to 1377	63.33 to 922	1.98 to 6.35

Table 7: Summary of FWD Testing and Analysis Results Post Construction (May 09)

Direction	Lane	Maximum Normalized Deflection [μm]	Subgrade Resilient Modulus M_R [MPa]	Effective Pavement Modulus E_p [MPa]	Effective Structural Number SN_{eff}
East	1	253 to 1,490	8.36 to 1134	92.22 to 635	1.92 to 5.68
West	1	235 to 1,623	7.61 to 320	94.47 to 1034	2.46 to 6.93

Table 8: Summary of FWD Testing and Analysis Results Post Construction (July 09)

Direction	Lane	Maximum Normalized Deflection [μm]	Subgrade Resilient Modulus M_R [MPa]	Effective Pavement Modulus E_P [MPa]	Effective Structural Number SN_{eff}
East	1	228 to 1,211	12.50 to 646	133.89 to 1063	2.08 to 5.16
West	1	276 to 1,596	8.86 to 729	91.87 to 1569	2.19 to 5.85

Table 9: Average and 75th Percentile of FWD Results Pre Construction (May 08)

Direction	Lane	M_R avg [MPa]	E_P avg [MPa]	SN_{eff} avg	M_R 75%-ile [MPa]	E_P 75%-ile [MPa]	SN_{eff} 75%-ile
East	1	47.71	255.32	3.39	36.47	302.66	3.70
West	1	57.90	236.25	3.37	31.82	274.63	3.62

Table 10: Average and 75th Percentile of FWD Results Post Construction (May 09)

Direction	Lane	M_R avg [MPa]	E_P avg [MPa]	SN_{eff} avg	M_R 75%-ile [MPa]	E_P 75%-ile [MPa]	SN_{eff} 75%-ile
East	1	87.35	300.04	3.63	30.16	367.19	4.04
West	1	40.91	262.96	3.51	31.78	307.77	3.76

Table 11: Average and 75th Percentile of FWD Results Post Construction (July 09)

Direction	Lane	M_R avg [MPa]	E_P avg [MPa]	SN_{eff} avg	M_R 75%-ile [MPa]	E_P 75%-ile [MPa]	SN_{eff} 75%-ile
East	1	58.87	310.24	3.64	41.88	376.74	4.01
West	1	41.87	248.96	3.41	35.12	271.62	3.62

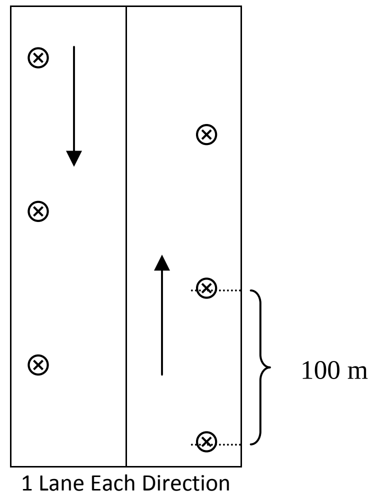

Figure 1: FWD Testing Protocol for Flexible Pavements

Figure 2: Alligator Cracking, Pre and Post Construction (left and right respectively)

Figure 3: Edge Cracking, Pre and Post Construction (left and right respectively)

Figure 4: Transverse Cracking, Pre and Post Construction (left and right respectively)

Figure 5: Alligator Cracking, Pre Construction (left) and Post Construction (right)

Figure 6: Transverse Cracking, Pre and Post Construction (left and right respectively)

Figure 7: Edge Cracking, Pre and Post Construction (left and right respectively)

Figure 8: Alligator Cracking, Pre and Post Construction (left and right respectively)

Figure 9: Transverse Cracking, Pre and Post Construction (left and right respectively)

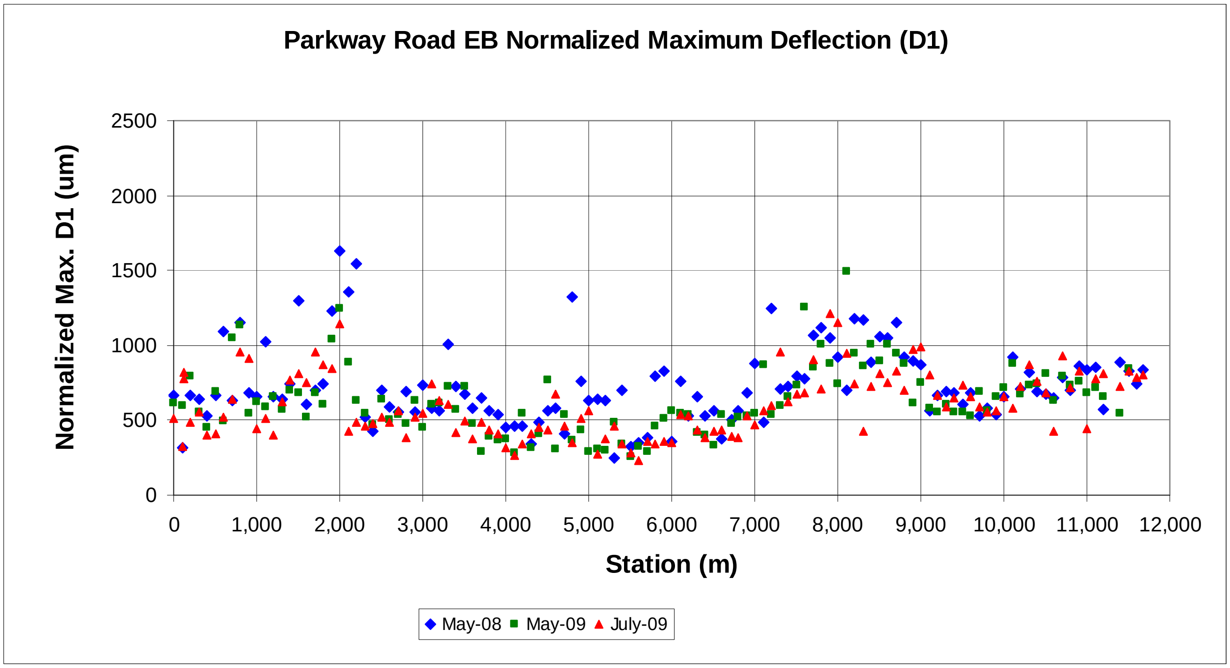

Figure 10: Maximum Normalized Deflection; Eastbound Lane

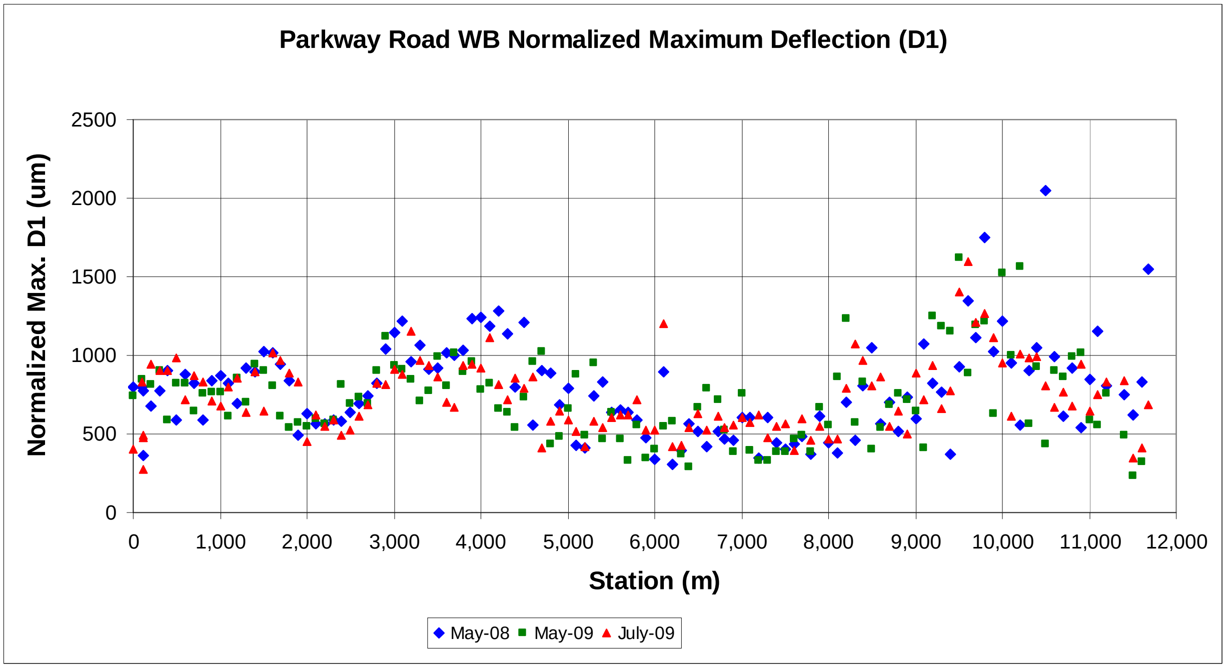

Figure 11: Maximum Normalized Deflection; Westbound Lane

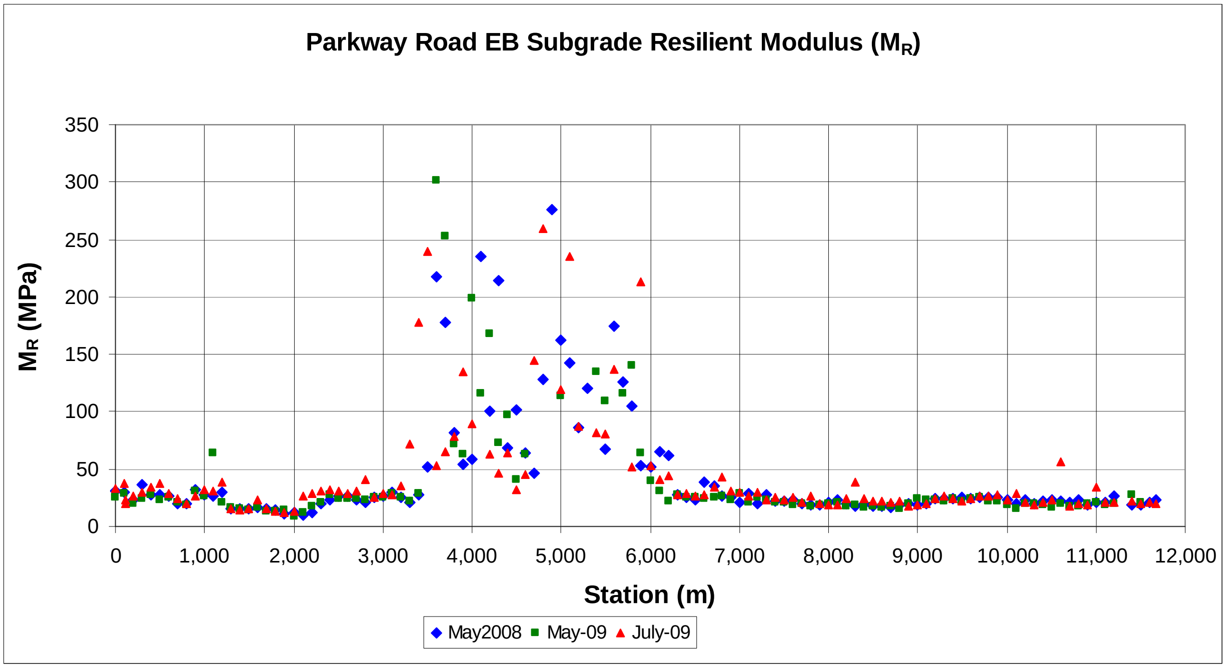

Figure 12: Subgrade Resilient Modulus; Eastbound Lane

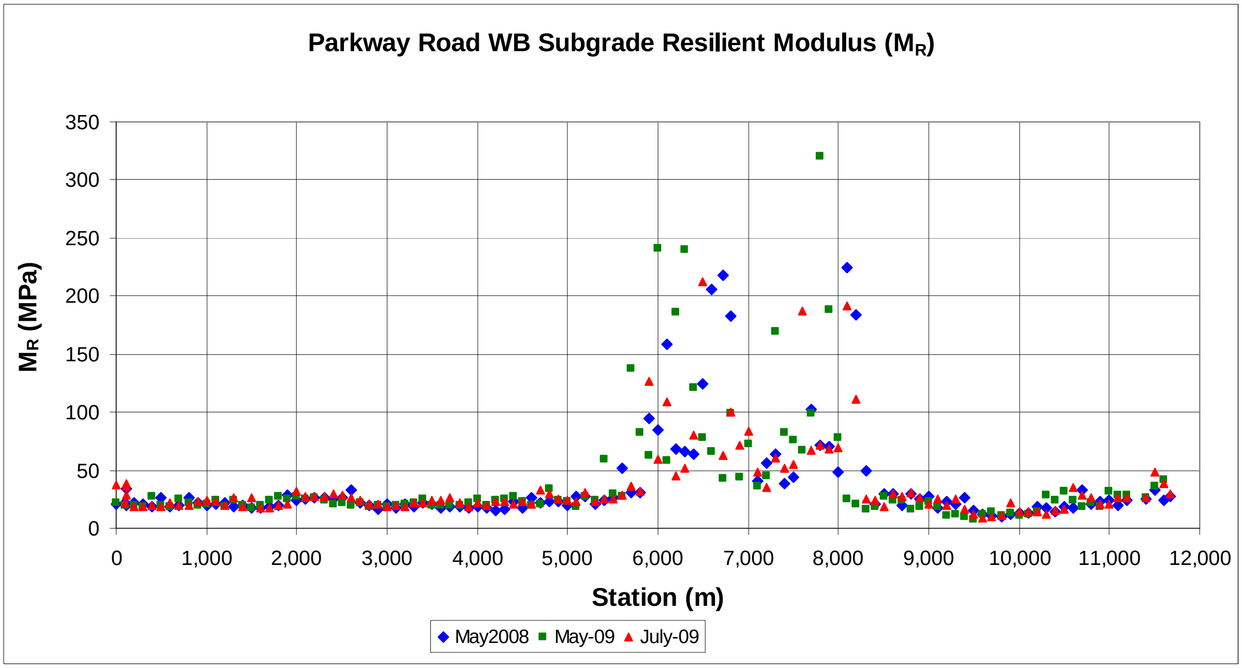

Figure 13: Subgrade Resilient Modulus; Westbound Lane

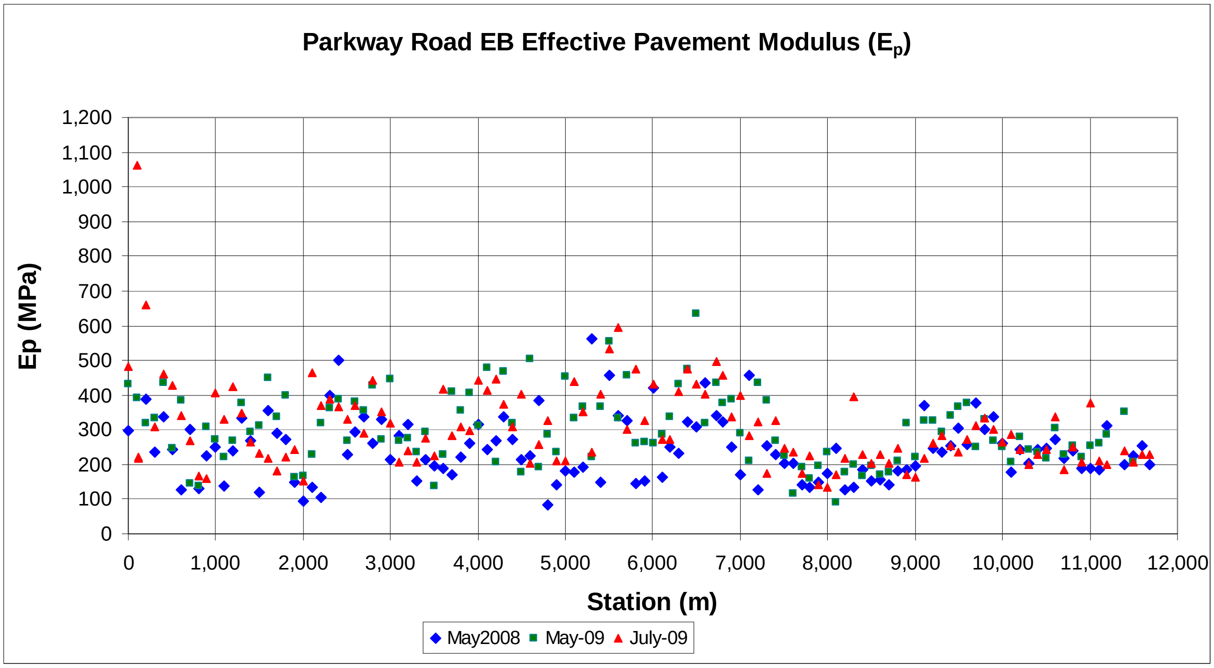

Figure 14: Effective Pavement Modulus; Eastbound Lane

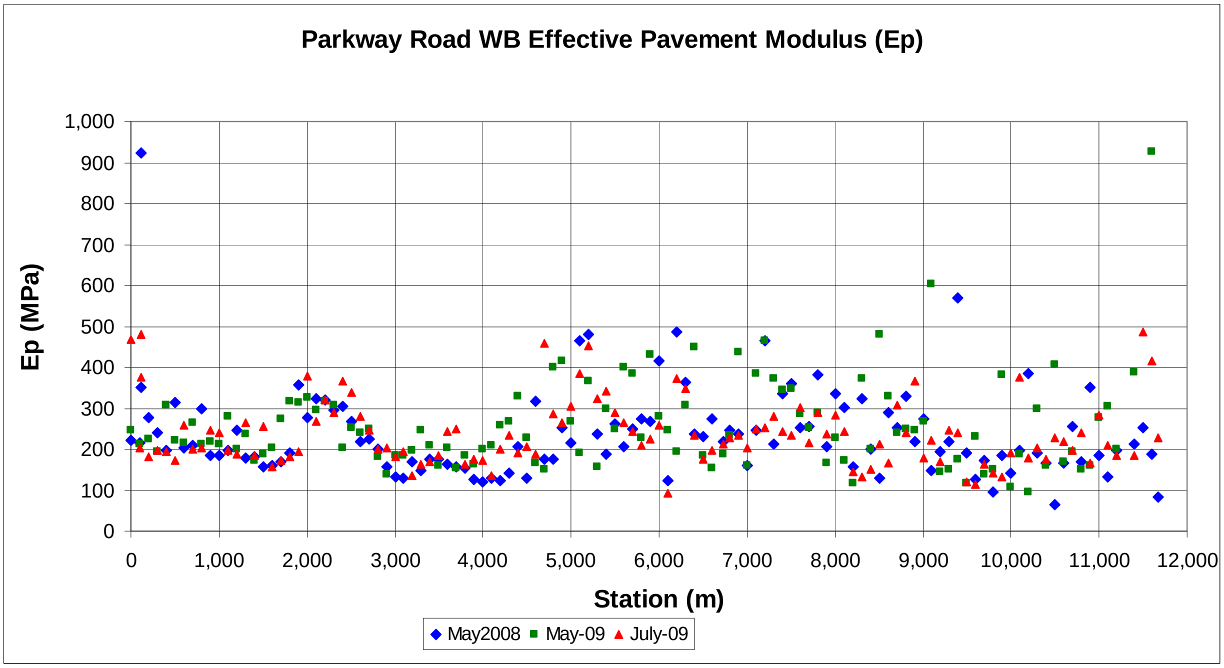

Figure 15: Effective Pavement Modulus; Westbound Lane

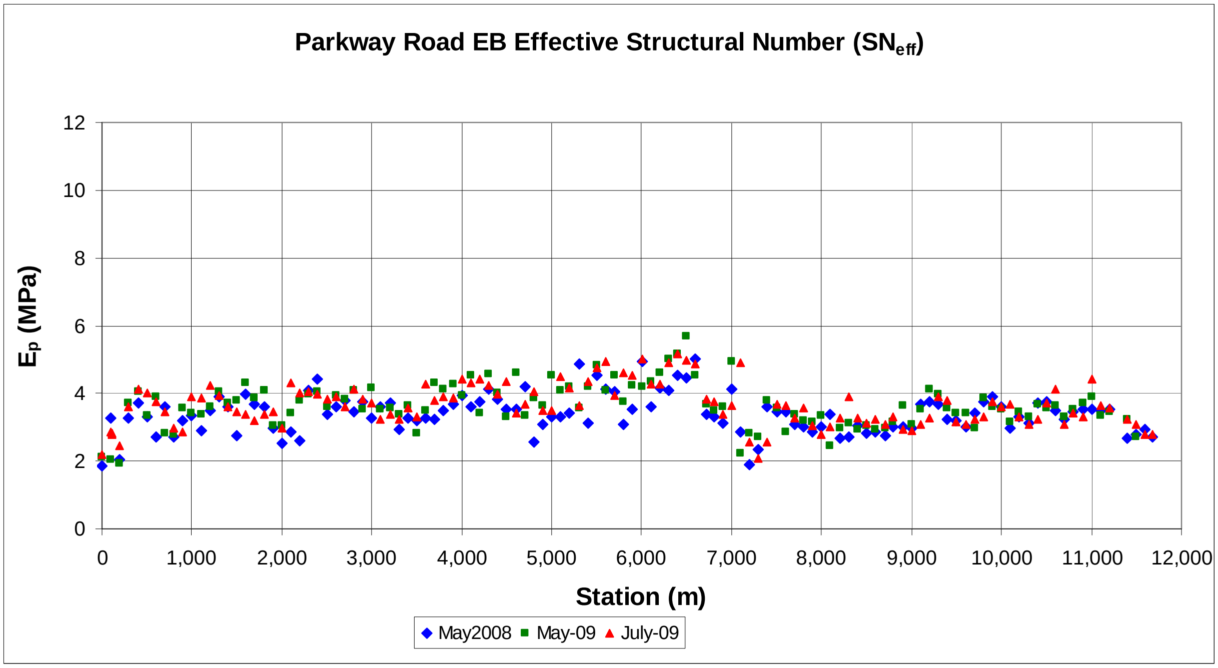

Figure 16: Effective Structural Number; Eastbound Lane

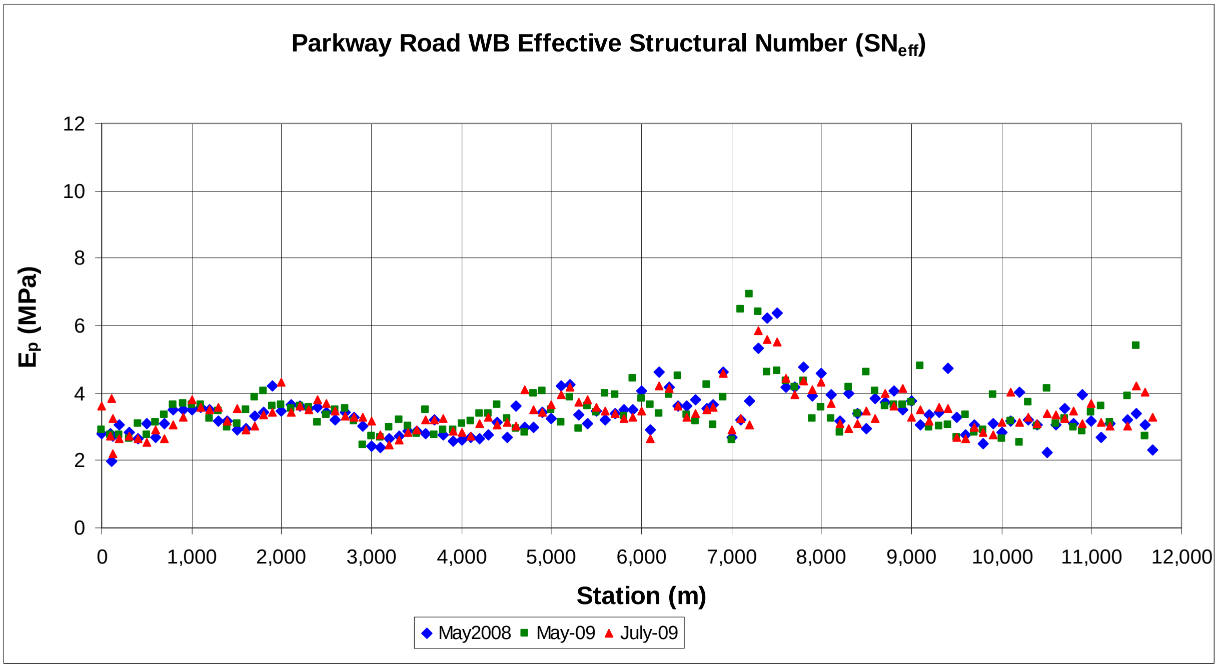

Figure 17: Effective Structural Number; Westbound Lane

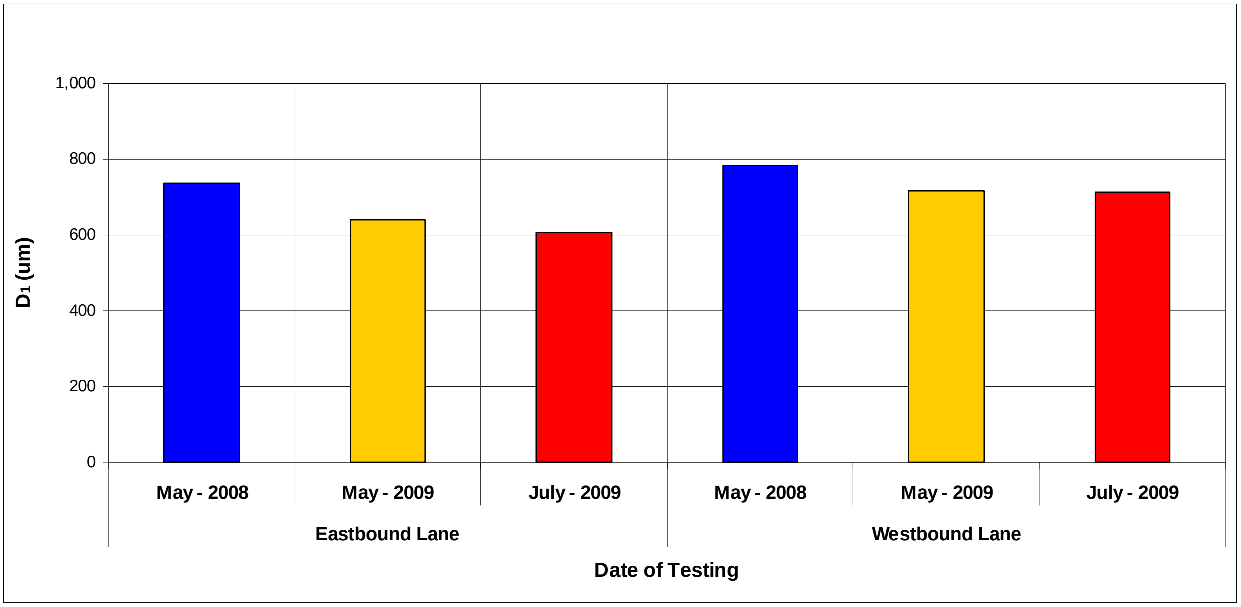

Figure 18: Average Normalized Deflection Pre and Post Construction

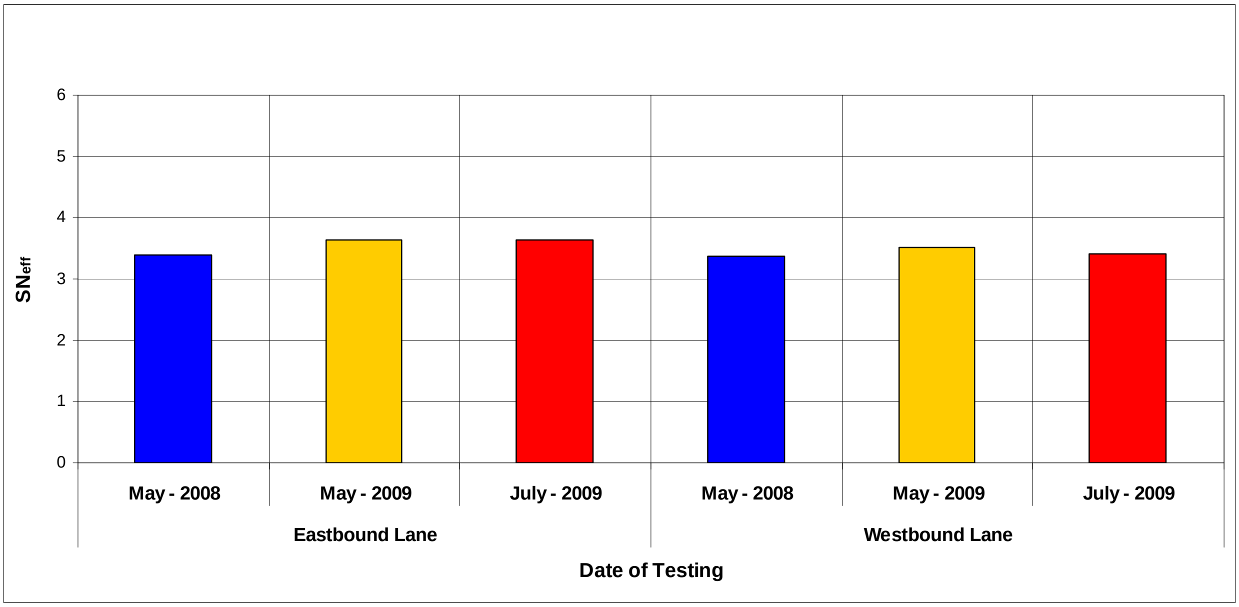

Figure 19: Average Effective Structural Number Pre and Post Construction