Evaluation of Recycled Pavement Test Sections with Alternative Surfacing Systems at the University of Saskatchewan

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ABSTRACT
The University of Saskatchewan has a desire to provide environmentally friendly and sustainable infrastructure. PSI Technologies was commissioned to reconstruct North Road at the University of Saskatchewan to provide an environmentally sustainable road structure that was structurally sound for frequent and heavy bus traffic.

In 2009, three test sections were constructed of equal surface areas and pavement structures on North Road. All sections were constructed on the same substructure of drainage sand layer comprised of weeping tile and recycled PCC drainage layer to manage drainage and mitigate frost action. All sections were constructed with an *in situ* recycled and stabilized base layer. Three alternative surfacing systems were constructed: Section 1 was constructed with a surfacing structure of interlocking concrete paving stones with a sand bedding layer; Section 2 was constructed with 50 mm hot mix asphalt concrete (HMAC) over 40 mm engineered cement-emulsion cold mix; and Section 3 was constructed with 80 mm HMAC.

The full depth reconstruction of North Road reclaimed and reused *in situ* material as well as used recycled Portland cement concrete (PCC) rubble from the University of Saskatchewan demolished Health Sciences Building. The post construction structural assessment showed all test sections had relatively equal structural performance, with significant increased load carrying capacity in comparison to pre construction structural measurements. The cost of each test section showed significant savings through the use of recycled road materials in comparison to conventional structures.

(234 words)

INTRODUCTION

The University of Saskatchewan has a strong institutional commitment to sustainability (1). Sustainable initiatives include waste prevention and reduction, energy and water conservation, green buildings, and infrastructure recycling. Green Building standards and practices are being integrated into the planning and design of a number of new buildings and renovations on campus (1). Infrastructure recycling was pertinent to the North Road reconstruction project, which is summarized herein. Overall, these projects incorporate reduced amounts of finishing materials, life cycle analysis, and the reclaim and reuse of infrastructure materials (1).

The University of Saskatchewan is also committed to enhancing access to campus for public transit. Increasing city transit usage on campus will reduce the volume of personal vehicles on campus and in turn reduce greenhouse gas emissions. Primary campus roads must be structurally sound for frequent and heavy bus traffic. In collaboration with the Saskatchewan Centre of Excellence for Transportation and Infrastructure (SCETI) and PSI Technologies Inc, the University of Saskatchewan Facilities Management Division employed a "living laboratory" in evaluating the use of reclaimed and recycled materials including crushed Portland cement concrete (PCC) and reclaimed asphalt pavement (RAP) in the reconstruction of North Road's pavement structure (2). Surfacing systems constructed included conventional hot mix, paving stone, and cold-mixed stabilized RAP. If monitoring and testing confirm these reclaiming and recycling techniques as being successful, it could help transform the road building industry by lowering capital and lifecycle costs, enhancing road performance, and providing practical uses for recycled construction, renovation and deconstruction waste (1, 2, 3, 4).

As part of this research, pre and post construction structural asset management surveys characterized the *in situ* reclaimed and recycled materials as part of the mechanistic design process and were used as end product construction quality control measures. This research effort focused on the use of RAP and PCC as structural layers such as the base course layer, the subbase course layer, and deep substructure drainage and stress dissipation layer.

OBJECTIVE

To provide innovative and reliable recycled road strengthening structures, the purpose of the reconstruction of North Road was to satisfy three primary objectives. Firstly, to better accommodate heavy bus and construction traffic on campus. Secondly, to reduce the environmental footprint associated with reconstructing campus roads. Finally, the third objective was to develop alternative road reconstruction systems that were environmentally sustainable as well as reliable from a materials science and structural design perspective.

SITE LAYOUT AND DESIGN

The construction limits of North Road were from the intersection of Campus Drive at km 0.000, north to km 0.482, as shown in Figure 1. Prior to construction, North Road was comprised of a conventional hot mix asphalt concrete (HMAC) surface on a granular base structure. The construction limits were divided into three test sections for three equal lengths of surfaced areas and pavement structures, seen in Figure 1.

Figure 2 illustrates the full depth post construction cross sections of North Road. Each section was constructed with a different surfacing structure, as summarized in Table 1 and illustrated in Figure 2. Section 1 (km 0.000 to km 0.153) was constructed with a surfacing structure of 80 mm of interlocking concrete paving stones, a 25 mm sand bedding layer, and 125 mm recycled and stabilized reclaimed HMAC base shear dissipation layer. Section 2 was constructed with 50 mm HMAC over 40 mm engineered cement-emulsion cold recycled HMAC mix. Section 3 was constructed with 80 mm HMAC.

All sections were constructed on the same structure, designed to manage drainage and mitigate frost action: 300 mm prepared subgrade, drainage sand (frost action layer), weeping tile, recycled PCC aggregate (drainage layer), and woven geotextile fabric. The purpose of the woven geotextile layer was to separate the recycled PCC drainage layer aggregate from the recycled and stabilized asphalt concrete base shear dissipation layer. Sections 1, 2, and 3 were constructed with recycled and stabilized base layers of 125 mm, 140 mm, and 150 mm depth, respectively. These depths were determined based on the type and depth of the surfacing layer.

Prior to construction, North Road was comprised of a conventional HMAC surface on a granular base structure. As part of the pre construction survey, a digital photo log was collected to evaluate the visual condition of North Road. Figure 3 illustrates the typical surface condition of North Road. As seen in the visual condition survey, North Road surface was experiencing severe rutting, potholes, fatigue cracking, and longitudinal and transverse cracking. In addition, several locations were exhibiting full depth structural failures. It is expected that the distresses observed along North Road were due to a combination of substructure as well as surface moisture problems combined with heavy traffic loadings, specifically bus traffic.

CONSTRUCTION PROCESS

A photo log documenting the North Road construction process for Section 1, Section 2, and Section 3 is presented in Figure 4. Figure 4 a) shows the excavation of the subgrade and b) shows the placement of the drainage sand subbase layer. Figure 4 c) and d) show the step-by-step installation of the geotextile fabric, weeping tile, and the PCC drainage layer. As seen in Figure 4 e) and f), the reclaimed base layer was stabilized, graded, compacted, and prepared for surfacing. Figure 4 g) and h) show the base layer prepared for surfacing and the curbing for North Road. Each surfacing system is pictured in Figure 5.

As seen in Figure 5 a), Section 1 (km 0.000 to km 0.153) was constructed with a surfacing structure of 80 mm of interlocking concrete paving stones, a 25 mm sand bedding layer, and 125 mm recycled and stabilized reclaimed asphalt concrete base shear dissipation layer. Section 2 was constructed with 50 mm HMAC over 40 mm engineered cement-emulsion cold mix (Figure 5 b). Section 3 was constructed with 80 mm HMAC over the remixed and stabilized base layer (Figure 5 c).

LABORATORY CHARACTERIZATION OF MATERIALS

Laboratory characterization was conducted during the reconstruction of North Road. Materials characterized during construction included the HMAC surfacing, the engineered cold mix, the *in situ* RAP used in the black base layer, the reclaimed and crushed PCC, the sand subbase, and the subgrade. All samples were retrieved during construction. The crushed PCC material was generated from on-campus buildings such as the Health Science Building and was impact crushed by PSI Technologies and used in the PCC drainage layer, as seen in Figure 6. The *in situ* RAP is a typical representative sample of the in-place HMAC and base material rotomixed and reused in the black base layer as in the engineered cold mix, as seen in Figure 7.

Mechanistic laboratory testing using the rapid triaxial test apparatus was conducted to evaluate the mechanistic properties of the construction materials including the HMAC surfacing, the engineered cold mix, the *in situ* RAP used in the black base layer, the reclaimed and crushed PCC, the sand subbase, and the subgrade. Rapid triaxial frequency sweep testing mechanistically characterizes the structural behaviour of conventional and unconventional road materials under realistic field state conditions. Details on the rapid triaxial test apparatus are summarized elsewhere (5). Table 2 lists and Figure 8 illustrates the dynamic modulus results (as per rapid triaxial testing) across three stress states (ranging from low, to medium, to high) for the materials placed on North Road.

As expected, the subgrade failed in the medium and high stress states; it had a high proportion of fines. Also expected, the HMAC exhibited the highest stiffness across all stress states. The engineered cold mix and the *in situ* RAP showed dynamic modulus values well above typical dynamic modulus values of a conventional granular base (5). The engineered cold mix dynamic modulus values were near those of HMAC. Therefore, a thinner HMAC surface of 50 mm was used in Section 2. The *in situ* RAP was used for the black base layer in all test sections. The PCC drainage layer also showed high dynamic modulus results.

NON DESTRUCTIVE SURVEY

Non-destructive heavy weight deflection (HWD) surveys were conducted pre construction and post construction. The purpose of the pre construction non-destructive survey was to determine if any unusual or unexpected conditions in the road structure were identifiable prior to construction. In addition, the pre construction survey was used to measure the performance of the rehabilitated structure when compared to post construction survey results. A post construction project level structural asset management survey employing HWD was performed to validate the road structure design and construction quality. Post construction quality assurance of the process is critical to ensure end product performance of the mechanistic structural design and construction materials.

Dynamic surface deflection measurements were obtained by heavy weight deflection testing, as seen in Figure 9. To characterize the structural asset condition of North Road, HWD testing was conducted under the spectra of typical commercial truck loadings ranging from secondary legal load limits to primary legal load limits plus 50 percent. Peak surface deflection and PSIPave structural index profiles were calculated based on the collected primary deflection profiles and are presented herein. Contour profiles are presented for primary weights plus 25 percent as this represents the weight of a typical, fully loaded, City of Saskatoon transit bus, of which North Road is routinely subjected.

Figure 10 illustrates the peak surface deflection contour profiles at primary plus 25 percent weight limits of North Road both pre and post construction for Section 1, Section 2, and Section 3. Figure 11 summarizes the peak deflection results across all weight limits. Pre construction, all test sections rated fair to poor across all weight limits with significant variability across the road structure. Section 3 was especially weak pre construction towards the last end of the test section. Post construction, the peak surface deflection improved significantly and rated good across all weight limits. In addition, there was a reduction in variability across all test sections. At the beginning of Section 2, a minimal amount of variability in deflection measurements were observed at primary plus 25 percent weight limits, as seen in Figure 10. This is due to the connecting parking lot entrance at this location.

Figure 12 illustrates and Figure 13 summarizes the PSIPave structural index results of North Road both pre and post construction of all test sections. The PSIPave is a measurement of the structural integrity of the road. Pre construction, the entire length of North Road, across all test sections, exhibited poor structural condition. Post construction, the PSIPave structural indices improved significantly and rated good, as seen in Figure 12 and Figure 13. The contour profiles, as seen in Figure 12, show the same variability in Section 2 as previously noted. The PSIPave structural index exhibited some variability post construction in the northern most past of Section 3. This is most likely due to the significantly poor structural condition pre construction and the seam to the existing North Road.

SUMMARY AND CONCLUSIONS

North Road was reconstructed to provide a recycled road structural system that can accommodate heavy bus and construction traffic in addition to reducing the University of Saskatchewan's environmental footprint. Infrastructure recycling was pertinent to the University of Saskatchewan reconstruction of North Road. North Road's reconstructed pavement structure included a drainage layer comprised of reclaimed and crushed PCC material generated from the demolished Health Sciences Building on campus. The black base layer of North Road's pavement structure was built using *in situ* reclaimed asphalt pavement.

Three alternative surfacing systems were constructed at North Road: Section 1 was constructed with a surfacing structure of interlocking concrete paving stones with a sand bedding layer; Section 2 was constructed with 50 mm HMAC over 40 mm engineered cement-emulsion cold mix; and Section 3 was constructed with 80 mm HMAC. Post construction non-destructive HWD testing showed all test section met their structural performance targets.

Further structural monitoring of North Road's recycled pavement test sections will be conducted to assess the long term performance of the alternative structures. Since the University of Saskatchewan is committed to overall environmental sustainability in addition to enhancing campus roads for city transit, using reclaimed and recycled roads and buildings generated on campus in road reconstruction and rehabilitation may be the link to sustainable, long term transportation infrastructure.

ACKNOWLEDGMENTS
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REFERENCES
(1) Facilities Management Division, University of Saskatchewan Sustainability website. URL: http://facilities.usask.ca/sustainability/. Saskatoon, SK., Accessed: April 23, 2010.

(2) PSI Technologies. University of Saskatchewan North Road Turnover Package. Internal document. Saskatoon, SK, 2010.

(3) Berthelot, C., Haichert, R., Podborochynski, D., Wandzura, C., Taylor, B., Guenther, D. Mechanistic Laboratory Evaluation and Field Construction of Recycled Concrete Materials for Use in Road Substructures. Presented at the 89th Annual Meeting of the Transportation Research Board, Washington, D.C., 2010.

(4) Sustainable "Green Street" Road Rehabilitation using Recycled Asphaltic Concrete, Portland Cement Concrete, and Other Waste Rubble Materials, One Year Final Report, 2010. City of Saskatoon Green Street Program, Saskatoon, Canada, 2010.

(5) Crockford, W. Berthelot, C, Tritt, B., and Sinados, C. Rapid Triaxial Test. *Journal of the Association of Asphalt Paving Technologists*, Vol. 71, 2002, pp. 712-724.

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Table 1 Post construction surfacing systems of North Road

North Road Section	Construction Limits	Surfacing Wearing Course
Section 1	km 0.000 to km 0.153	80 mm Interlocking Concrete Paving Stones
Section 2	km 0.153 to km 0.322	50mm Hot Mix Asphalt Concrete over 40 mm Engineered Cold Mix
Section 3	km 0.322 to km 0.482	80mm Hot Mix Asphalt Concrete

Table 2 Dynamic Modulus Averaged By Stress State

	Dynamic Modulus (MPa)			
	Low Stress State	**Medium Stress State**	**High Stress State**	**Average**
HMAC	1896	1814	1514	1741
Engineered Cold Mix	1699	1705	1244	1549
Typical *in situ* RAP	1303	1345	993	1214
Recycled Concrete	1550	1287	735	1191
Sand	897	850	625	791
Subgrade	191	Sample Failed	Sample Failed	Sample Failed

LIST OF FIGURES

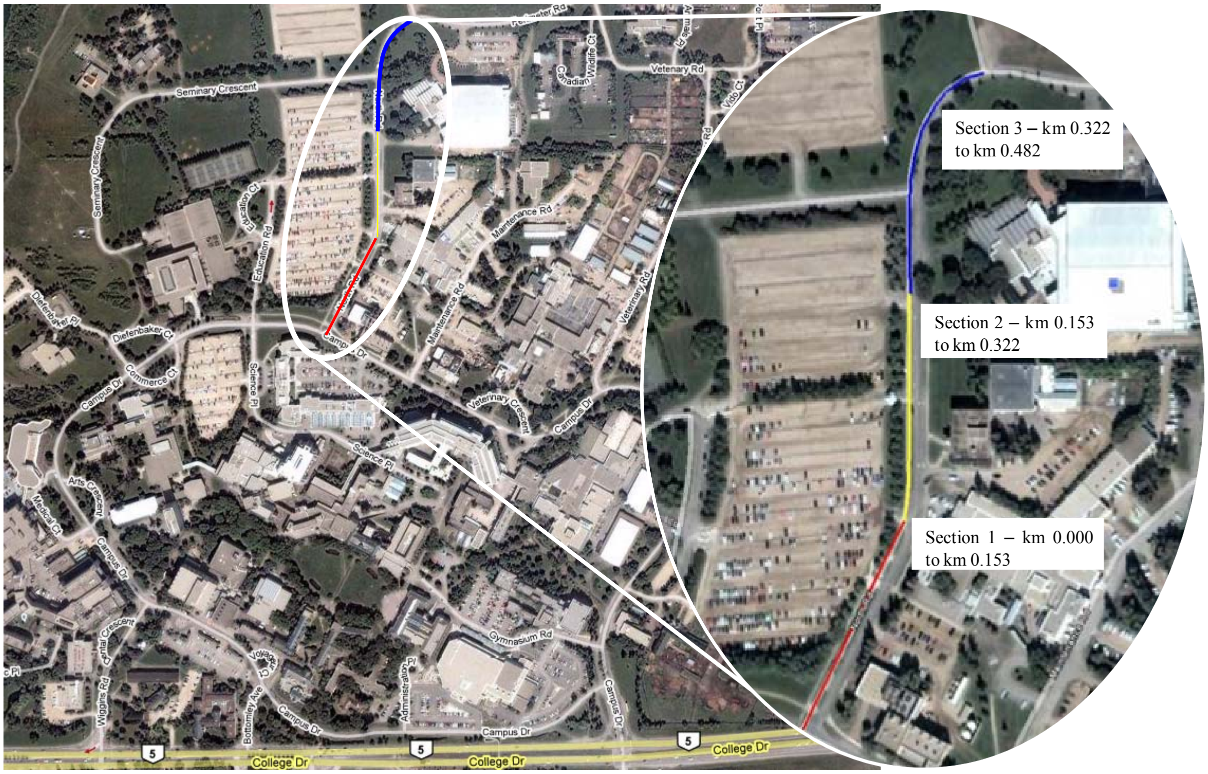
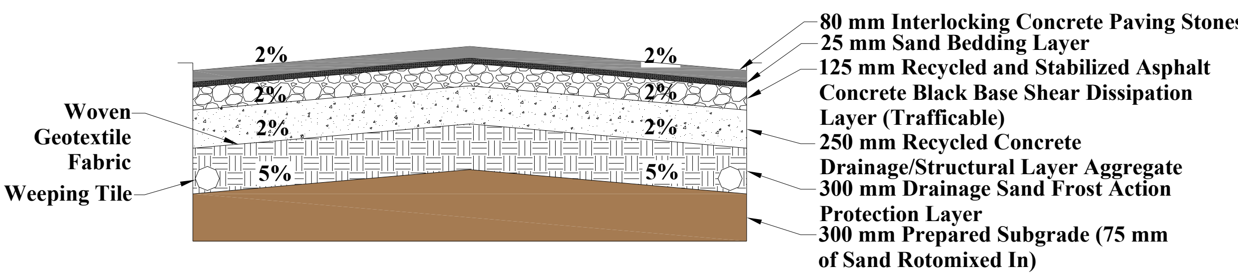
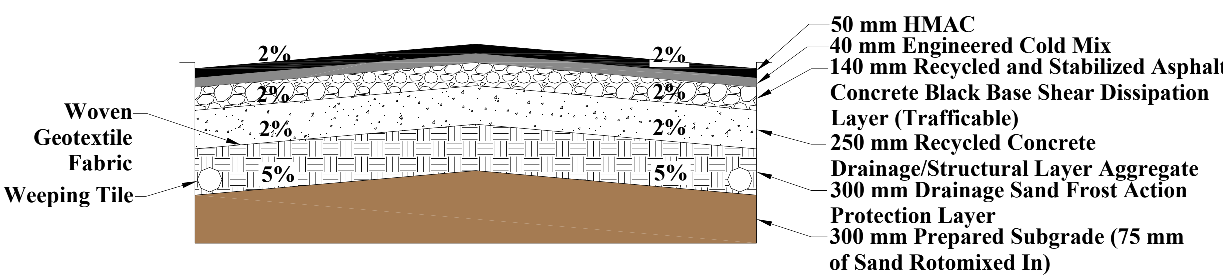


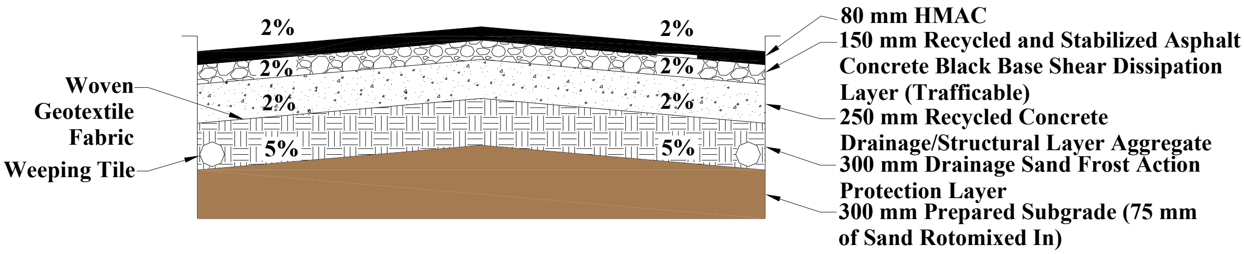
Figure 1 North Road construction limits



a) North Road Section 1 (km 0.000 to km 0.153)



b) North Road Section 2 (km 0.153 to km 0.322)



c) North Road Section 3 (km 0.322 to km 0.482)

Figure 2 Post construction cross sections of North Road

Figure 3 Typical surface distresses and structural failures of North Road – km 0.225

a) Excavation

b) Sand subbase layer

c) Installation of geotextile fabric

d) Recycled PCC drainage layer

e) Preparation of reclaimed base layer

f) Engineered cold mix added

g) Base layer prepared for surfacing

h) Curbing

Figure 4 North Road Construction Process

a) Section 1 sand bedding layer (left) and final paving stone surfacing (right)

b) Section 2 engineered cold mix layer (left) and final HMAC surfacing (right)

c) Section 3 stabilized reclaimed base layer (left) and HMAC surfacing (right)

Figure 5 North Road surfacing systems

Figure 6 Rubble PCC Generated from U of S Demolished Buildings

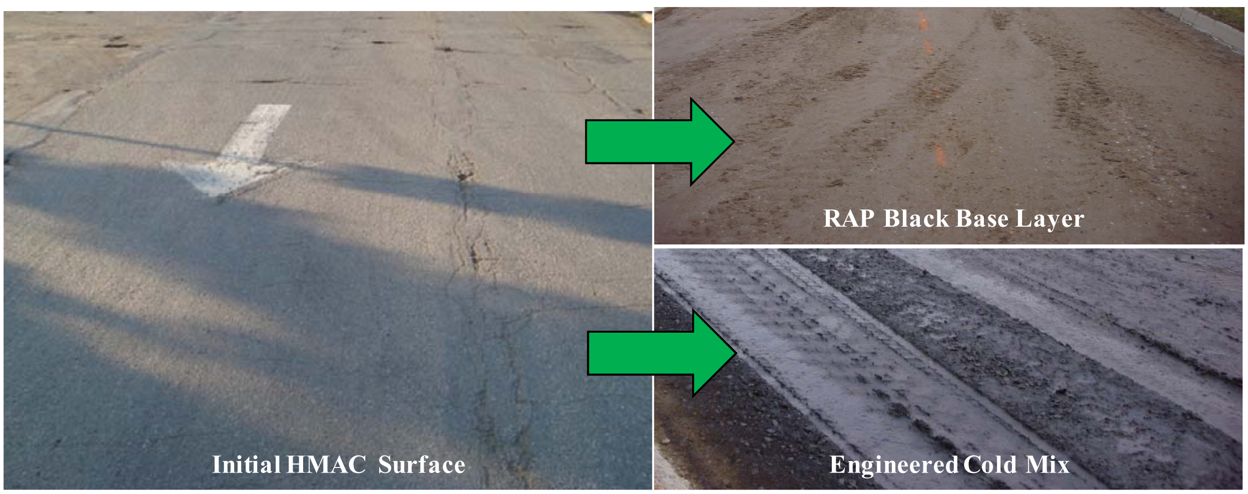


Figure 7 Engineered Cold Mix Using RAP Generated North Road

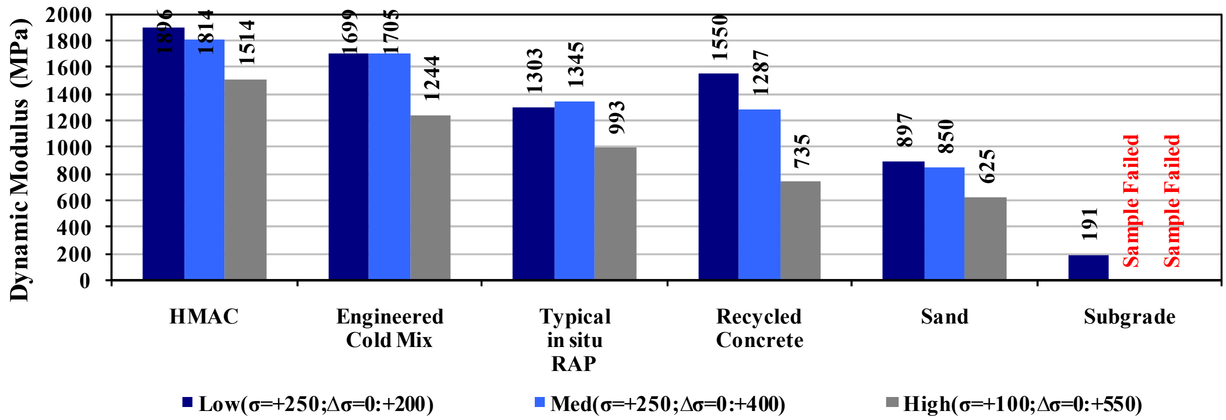
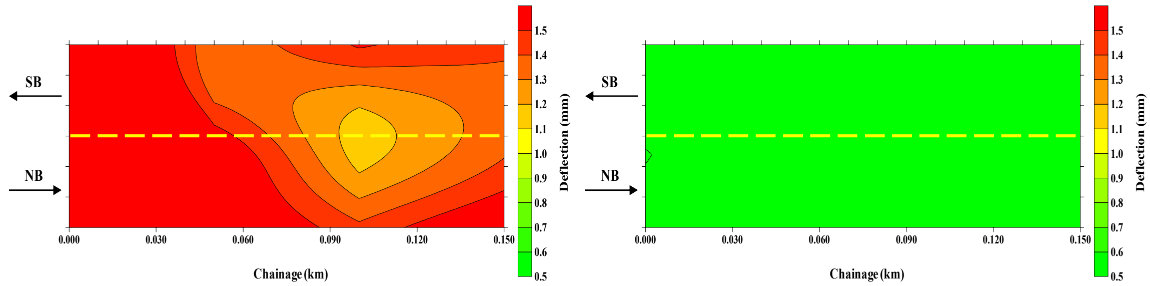
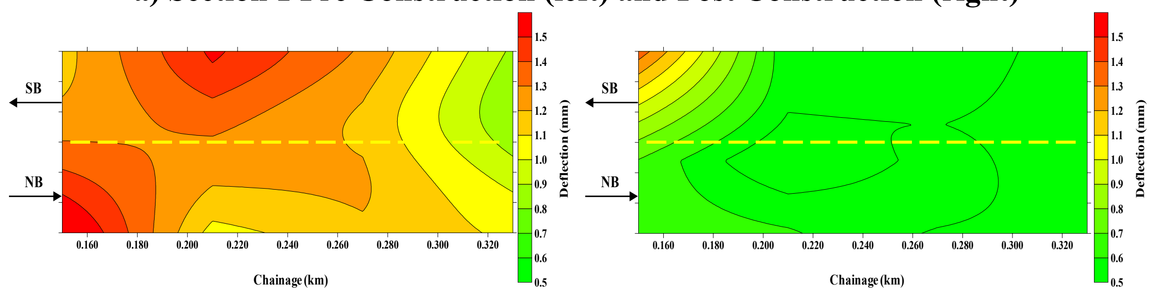


Figure 8 Dynamic Modulus Results

Figure 9 PSI Technologies Heavy Weight Deflectometer on North Road



a) Section 1 Pre Construction (left) and Post Construction (right)



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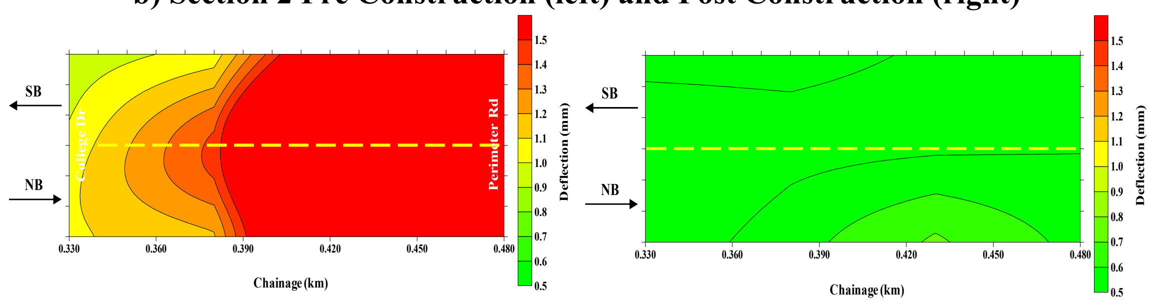

c) Section 3 Pre Construction (left) and Post Construction (right)

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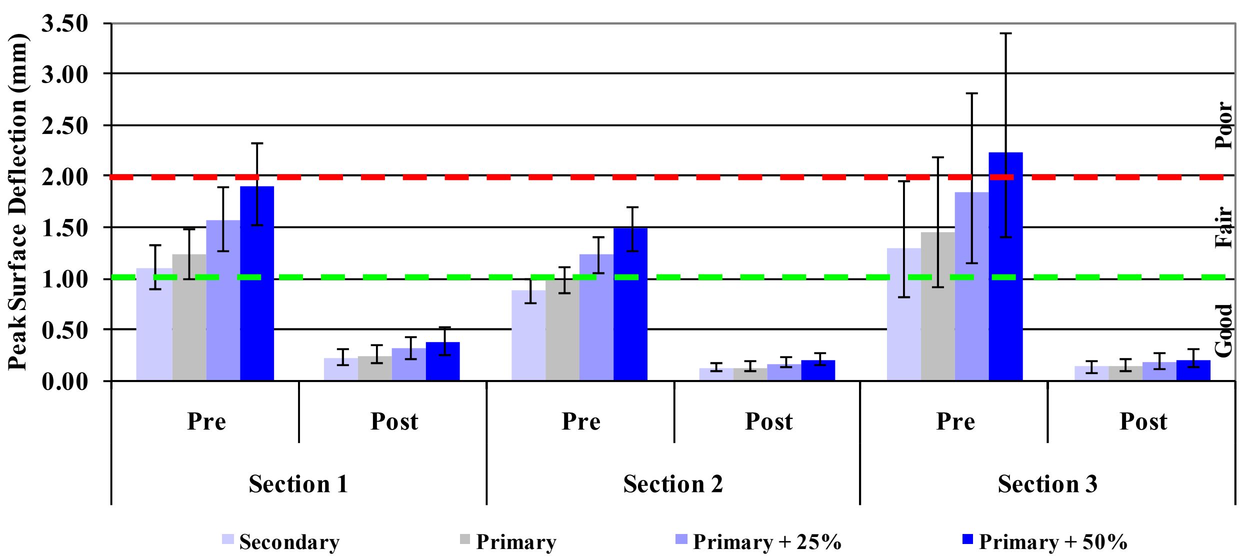
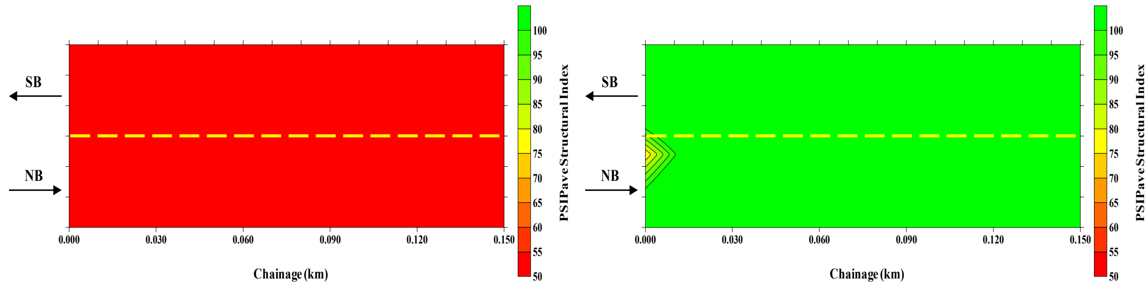
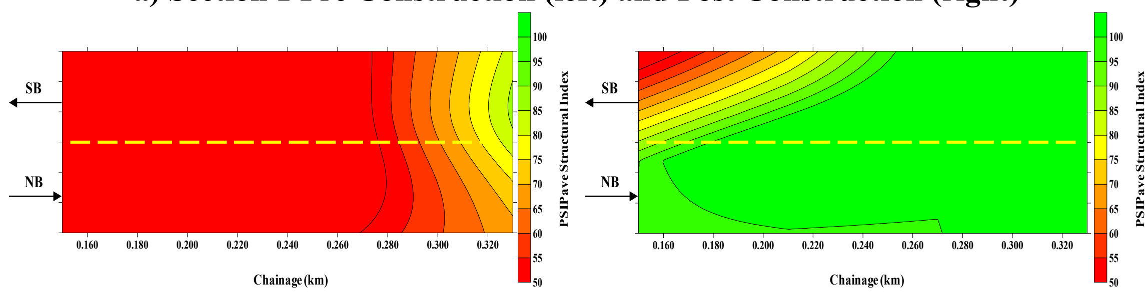


Figure 11 Peak Surface Deflection Summary Statistics (±90th Percentile)



a) Section 1 Pre Construction (left) and Post Construction (right)



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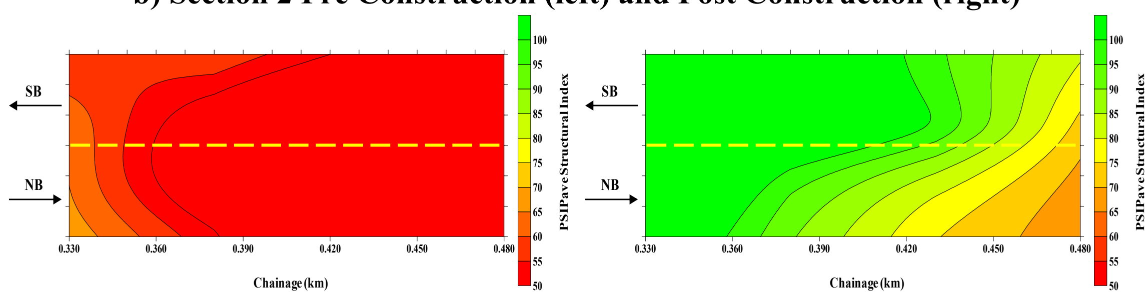

c) Section 3 Pre Construction (left) and Post Construction (right)

Figure 12 PSIPave Structural Index Contour Profiles

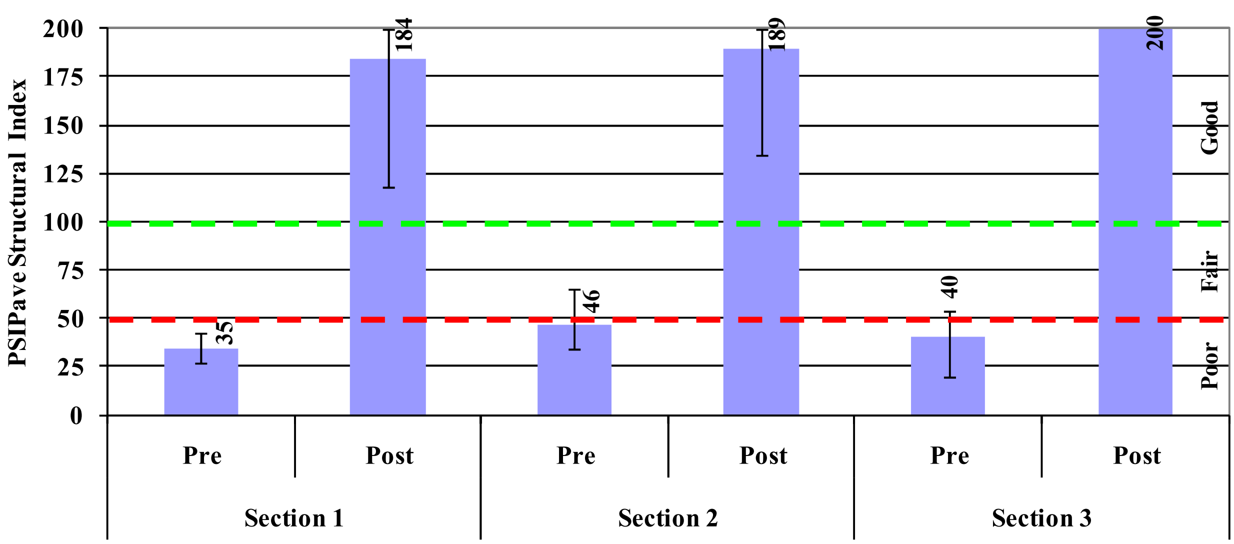

Figure 13 PSIPave Structural Index Summary Statistics (±90th Percentile)