Rehabilitation of Urban Streets Using Engineered Asphalt Emulsion-Cement Full Depth Strengthening Systems

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ABSTRACT

Many urban centres across Canada are experiencing significant deterioration of their streets, particularly aged streets constructed on weak subgrade materials that were not originally designed for modern traffic load conditions. Benefits of cold in-place recycling on urban service roads include reduced consumption of new source aggregates, reduced rehabilitation costs, and significant reductions in weather exposure during construction. Additional benefits of cold in-place recycling include significant reduction in load induced damages to surrounding streets, and reduced total construction energy required to rehabilitate streets, which reduces vehicle emissions released in urban environments associated with street rehabilitation projects.

This paper demonstrates the use of mechanistic-climatic laboratory characterization applied to the rehabilitation of two cold in-place recycled City of Regina streets. The City of Regina streets employed in this study were chosen as typical urban pavements requiring structural rehabilitation. This study presents the material characterization results of the composite recycled surfacing and granular base materials strengthened with an engineered blend of cement and asphalt emulsion. The mechanistic laboratory characterization was performed across the spectrum of multi-axial stress states and load frequencies typical of urban field state conditions.

The *a priori* ground penetrating radar profiles were used to quantify the spatial quantities of *in situ* recyclable composite surfacing and granular materials. Based on the ground penetrating radar profiles, significant variation in recyclable granular layer thickness was identified across both pavement structures. The thickness information proved critical in the full depth recycling design process to accurately quantify the reclamation thickness, as well as material stabilization design.

This research also presents the use of structural asset management performance measurements taken before and after strengthening of the Regina pilot test sites. The non-destructive falling weight deflection structural asset measurements performed in this study demonstrated a significant increase in structural asset value as a result of the full depth cement-asphalt emulsion strengthening systems employed. The field structural responses concurred with the increase in mechanistic laboratory material properties obtained in the material design phase of this project.

This research also demonstrated cold in-place recycling to be similar in cost to conventional full depth remove and replace street rehabilitation systems. It is believed that the cost to perform cold in-place recycling and full depth strengthening will decrease over time as the technology becomes more reliable and more commonly deployed, whereas the costs of conventional street rehabilitation are believed to continue to increase over time. Additional holistic benefits of cold in-place recycling include reduced construction time, and therefore interruption to homeowners; reduced emissions and energy consumption; as well as recycling of *in situ* materials and conservation of aggregate sources in the Regina area.

KEY WORDS: asphalt emulsion, urban road stabilization, cold in-place recycling

INTRODUCTION

Many City of Regina local streets are experiencing severe structural deterioration, as seen in Figure 1. As well, quality aggregate sources are becoming increasingly scarce in the Regina area. Since conventional full depth remove and replace rehabilitation is labour intensive and quality aggregate sources are becoming more expensive, costs of conventional full depth remove and replace systems are increasing significantly. To compound matters, the City of Regina is constructed on highly expansive lacustrine clay and therefore these costs can further increase if adverse weather conditions occur during conventional road strengthening operations. As a result, the relatively high cost of conventional full depth excavation and replacement treatments renders the structural rehabilitation of many City of Regina streets cost prohibitive.

The City of Regina is investigating advanced non-destructive road structural diagnostic technologies to accurately quantify structural deterioration, as well as *in situ* structural composition, to design cold in-place recycling and strengthening systems. This study is based on the pilot structural rehabilitation of Shannon Road and Assiniboine Avenue undertaken in 2006. The strengthening system employed engineered blends of cement and asphalt emulsion for recycling and strengthening the *in situ* asphaltic surfacing and granular layers.

STUDY OBJECTIVE

The objective of this study was to demonstrate the application of advanced road engineering technologies as applied to full depth strengthening systems for City of Regina streets. As well, the objective was to demonstrate the use of engineered blends of asphalt emulsion and cement for rehabilitating urban streets.

PRE-CONSTRUCTION NON-DESTRUCTIVE STRUCTURAL ASSET MANAGEMENT ASSESSMENT

Prior to strengthening, *in situ* structural properties of the two City of Regina streets considered in this study were characterized using ground penetrating radar and heavy weight deflection equipment shown in Figure 2. The non-destructive test results were used to quantify the *in situ* structural thickness as well as structural primary response profiles prior to strengthening (1, 2, 3). The composite asphaltic surfacing and granular base thickness profiles of Shannon Road were found to average 296 mm, and range from 220 mm to 372 mm. The composite asphaltic concrete surfacing and granular base of Assiniboine Avenue averaged 185 mm and ranged from 132 mm to 226 mm, as summarized in Table 1 and illustrated in Figure 3, respectively. As seen in Table 1 and Figure 3, the approximate volume of recyclable *in situ* granular material based on the ground penetrating radar thickness profiles were 407 m^3 for Assiniboine Avenue and 7160 m^3 for Shannon Road, respectively.

An additional advantage of continuous thickness spatial profiles as employed by ground penetrating radar was that the variable thickness could be used to optimize cut and fill quantities, as well as perform a sensitivity analysis of the stabilization system across various ranges in composite material composition. This can be critical when designing asphalt emulsion stabilization systems on top of highly plastic clay subgrade materials should the clay subgrade material get incorporated into the overall design blend.

Based on the ground penetrating radar surface dielectric permittivity profiles, the PSIPave surface deterioration index was also calculated. The overall PSIPave surface deterioration index for Shannon Road averaged 41.5 and ranged from 15.1 to 67.8. The PSIPave surface deterioration index for Assiniboine Avenue averaged 30.2 and ranged from 13.5 to 47.7, as summarized in Table 1. For reference, an asphaltic pavement surface in good condition typically exhibits a PSIPave surface deterioration index of between 5 and 15 surface deterioration index.

Preconstruction structural asset assessment was performed along Shannon Road and Assiniboine Avenue using a heavy weight deflectometer across a load spectra of typical commercial vehicle weight limits to primary weight limits plus 50 percent. To reference the potential primary deflection response under a heavily loaded garbage or construction truck, the primary plus 50 percent weight limit peak deflection for Shannon Road averaged 1.65 mm, and Assiniboine Avenue averaged 3.36 mm, as summarized in Table 2, and illustrated in Figure 4.

IN SITU MATERIAL SAMPLING AND CONVENTIONAL LABORATORY CHARACTERIZATION

The non-destructive testing results were used to target *in situ* samples from the road structure for laboratory characterization. Using targeted gradehole samples, laboratory characterization of the *in situ* subgrade and base material was performed.

Figure 5 illustrates the grain size distribution from the recyclable material samples retrieved from Shannon Road and Assiniboine Avenue. As seen in the grain size characterization profiles, the *in situ* composite hot mix asphalt concrete (HMAC) and granular base gradation exceeded the fine side of the City of Regina granular base gradation envelope. This is likely due to pumping of fines from the subgrade into the granular system. Therefore, if the *in situ* granular material was to be reclaimed and used in the strengthening system, stabilization of the granular material was determined to be required to accommodate the high fines content within the granular base.

According to the Unified Soil Classification System (USCS), the *in situ* reclaimed granular base of both roads classified as well graded gravel (GW). The *in situ* subgrade soil of both roads classified as a high plastic clay (CH). Table 3 summarizes and Figure 6 illustrates the USCS distribution and classification for the recycled material retrieved from each road, respectively.

According to the American Association of State Highway and Transportation Officials (AASHTO) soil classification system, the granular base for both roads classified as A-2 granular material. The subgrade soil for all three roads classified as A-7-5 highly plastic clay soil. Table 4 summarizes the AASHTO grain size distribution and classification for the recycled material retrieved from each road.

RECLAIMED STRENGTHENING ANALYSIS

Material octahedral shear compaction stiffness, unconfined compressive strength, climatic durability, and triaxial frequency sweep characterization were performed on blended samples comprising the *in situ* reclaimed asphaltic surfacing and granular base with the cement-emulsion strengthening system employed in the project (4, 5).

OCTAHEDRAL SHEAR COMPACTION STIFFNESS CHARACTERIZATION

Continuum laboratory samples were prepared for mechanical and climatic characterization. Figure 7 illustrates the average octahedral shear compaction stiffness profiles obtained during sample preparation. Cement and asphalt emulsion strengthening increased the octahedral shear compaction stiffness of the granular base from 429 kPa for the *in situ* granular base samples to 447 kPa for cement and asphalt emulsion strengthened samples for Shannon Road. Cement and asphalt emulsion strengthening increased the octahedral shear compaction stiffness of the granular base from 348 kPa for the *in situ* granular base samples to 360 kPa for cement and asphalt emulsion strengthened samples for Assiniboine Avenue.

UNCONFINED COMPRESSIVE STRENGTH

California bearing ratio characterization has traditionally been employed for characterizing stabilized granular materials. Figure 8 illustrates the unconfined compressive strength of the reclaimed granular base from Shannon Road and Assiniboine Avenue. The unconfined compressive strength of Shannon Road and Assiniboine Avenue *in situ* granular base was determined to be 113 kPa and 91 kPa, respectively. When strengthened with cement and asphalt emulsion, the unconfined compressive strength of the Shannon Road and Assiniboine Avenue reclaimed surfacing materials increased to 2588 kPa and 3390 kPa, respectively.

TRIAXIAL FREQUENCY SWEEP CHARACTERIZATION

Linear viscoelastic triaxial frequency sweep characterization was performed on stabilized and unstabilized granular base samples across load frequencies and relatively high deviatoric stress states considered typical of those experienced in the field under modern field state conditions.

Dynamic Modulus

Figure 9 illustrates the mean dynamic modulus averaged across deviatoric stress state and frequency for the reclaimed Shannon Road and Assiniboine Avenue reclaimed surfacing materials. The dynamic modulus of Shannon Road and Assiniboine Avenue *in situ* recycled material was assumed zero because the samples failed during testing. When strengthened with the cement and asphalt emulsion system employed in this project, the dynamic modulus of Shannon Road and Assiniboine Avenue increased to 1897 MPa and 2019 MPa, respectively.

Poisson's Ratio

Figure 10 illustrates the mean Poisson's ratio averaged across deviatoric stress state and frequency for the reclaimed Shannon Road and Assiniboine Avenue materials. Poisson's ratio of Shannon Road and Assiniboine Avenue *in situ* granular base were assumed >0.5 because the unstabilized samples failed during testing. When strengthened with cement and asphalt emulsion, Poisson's ratio of Shannon Road and Assiniboine Avenue was recorded to be 0.14 and 0.13, respectively.

Radial Microstrain

Figure 11 illustrates the mean radial microstrain across deviatoric stress state and frequency for Shannon Road and Assiniboine Avenue recycled surfacing materials. The radial microstrain of Shannon Road and Assiniboine Avenue *in situ* granular base also could not be determined because the samples failed during testing. When strengthened with cement and asphalt emulsion, the radial microstrain of Shannon Road and Assiniboine Avenue was recorded as 27×10^{-6} and 24×10^{-6}, respectively.

MOISTURE CLIMATIC DURABILITY TESTING

The maximum conductivity of *in situ* and cement and asphalt emulsion strengthened samples was also recorded during moisture climatic testing. Figure 12 illustrates the climatic durability conductivity results. The climatic durability conductivity of Shannon Road and Assiniboine Avenue *in situ* granular base was determined to be 29 µS/cm and 66 µS/cm, respectively. When strengthened with cement and asphalt emulsion, the peak conductivity of Shannon Road and Assiniboine Avenue decreased to 10 µS/cm and 7µS/cm, respectively. These results illustrate the cement-emulsion stabilization significantly decreased the moisture sensitivity of the *in situ* recycled material retrieved from Shannon Road and Assiniboine Avenue.

POST CONSTRUCTION STRUCTURAL ASSET MANAGEMENT VALUE ENGINEERING ANALYSIS

The peak surface deflection profiles resulting across the spectrum of applied loads are summarized spatially and are directly compared to the *a priori* structural primary response measurements taken before the project. As summarized in Table 2 and illustrated in Figure 13, the full depth strengthening system resulted in a significant improvement in the structural response profiles across the spatial limits of the reclaimed and strengthened Shannon Road and Assiniboine Avenue.

Based on the peak surface deflections and primary response profiles across load spectra, the PSIPave structural index was calculated. Prior to strengthening, the PSIPave structural index for Shannon Road averaged 65 and Assiniboine Avenue averaged 15, as illustrated in Figure 14. Also seen in Figure 14, strengthening with cement and asphalt emulsion resulted in a PSIPave structural index of 162, an increase of 97, for Shannon Road and a PSIPave structural index of 96, an increase of 81, for Assiniboine Avenue, respectively.

STRUCTURAL OPTIONS ANALYSIS

Based on the proposed strengthening design, Figure 15 illustrates the conventional full depth remove and replace granular option, as well as the cold in-place recycling and strengthening option. Based on the laboratory material properties, the full depth strengthening system was recommended to be comprised of 300 mm full depth cement-emulsion strengthening with 60 mm hot mix asphalt concrete surfacing for Assiniboine Avenue, and 85 mm asphalt concrete surfacing placed on Shannon Road.

The recycled full depth strengthening systems proposed significantly improved the climatic and mechanistic performance of the material systems, which should improve the long term performance of the structural system. In addition, full depth strengthening provides the ability to optimize the use of select aggregate materials already in place. The benefits of strengthening Shannon Road and Assiniboine Avenue with full depth strengthening are significant relative to conventional full depth remove and replace.

As seen in Table 5, the cost for the conventional strengthening was estimated at \$49.37/m^2. The cost for the full depth strengthening was \$61.14/m^2.

SUMMARY AND CONCLUSIONS

Many urban centres across Canada are experiencing deterioration of their streets. This is the case for the City of Regina, with aged streets constructed on weak subgrade materials and that were not originally designed for modern field state traffic load conditions. Benefits of cold in-place recycling of service roads has been well documented and include reduced consumption of new source aggregates, reduced road rehabilitation costs, and significant reductions in weather exposure during construction. Additional benefits of cold in-place recycling include significant reduction in load induced damages to surrounding streets, and reduced total construction energy required to rehabilitate streets, which reduces vehicle emissions released in urban environments associated with street rehabilitation projects.

This paper demonstrated the pragmatic use of mechanistic-climatic laboratory characterization of two cold in-place recycled systems. This study was based on material characterization results of the composite recycled surfacing and granular base materials strengthened with cement and asphalt emulsion. Mechanistic laboratory characterization was performed across the spectrum of multi-axial stress states and load frequencies typical of urban street field state conditions and showed a significant improvement in terms of material constitutive relations known to be related to field performance.

This research showed how the *a priori* structural composition could be quantified using ground penetrating radar profiles to quantify the spatial quantities of *in situ* recyclable surfacing and granular materials. Based on the ground penetrating radar profiles, significant variation in layer thickness was identified across each pavement structure, and the thickness information proved critical in the full depth recycling design process to accurately quantify the reclamation thickness as well as material stabilization design.

This research also presented non-destructive structural asset management performance measurements taken before and after strengthening of the two Regina pilot test sites. The non-destructive falling weight deflection structural asset measurements performed in this study demonstrated a significant increase in structural asset value realized from the full depth cement-asphalt emulsion strengthening systems employed. The field structural primary responses obtained from the falling weight deflection measurements also concurred with the mechanistic laboratory material properties obtained in the material design phase of this project.

In summary, this study demonstrated the ability to employ advanced engineering technologies in the lab as well as in the field when integrated with cold in-place recycling and full depth strengthening of urban local streets. This research shows the potential of realizing sustainable future benefits of deploying advanced mechanistic engineering with innovative cold in-place recycling, which could be significant for urban road agencies across Canada.

REFERENCES

1. Berthelot, C., and Gerbrandt, R. 2002. Cold In Place Recycling and Full Depth Strengthening of Expansive Subgrade Soils using Cementitious Waste Products in Northern Climates. Transportation Research Record Vol. 1787. Washington D.C., USA. p.p.: 3-12.
2. Berthelot, C., Gerbrandt, R., and Majerison B. 2004. Mechanistic-Climatic Characterization of Cold In-Place Recycling and Full Depth Strengthened Road Systems. Canadian Society of Civil Engineers Annual Conference Proceedings. Saskatoon, Canada. CDROM Proceedings.
3. Wourms, O., Baker, D., Berthelot, C., and Gerbrandt, R. 2000. Cold In-Place Recycling Using Asphalt Emulsion for Strengthening Saskatchewan Low Volume Roads. Canadian Technical Asphalt Association Proceedings, 45th Annual Conference, Vol. XLVII. p.p.: 145-166.
4. Berthelot, C., Marjerison, B., Houston, G., McCaig, J., Warrener, S., and Gorlick, R. 2007. Mechanistic Comparison of Cementitious and Bituminous Stabilized Granular Base Systems. Transportation Research Board, 85th Annual Conference. Washington D.C., USA. CDROM Proceedings (Accepted).
5. Gerbrandt, R., and Berthelot, C., 2003. Full Depth Recycling and Full Depth Strengthening of Low Volume Roads, Highway 19-06 Case Study. Transportation Research Board 8th Low Volume Road Conference. Reno, USA. p.p.: 32-43.

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Table 1 Pre-Construction Composite HMAC and Granular Base Thickness

	Shannon Road	Assiniboine Avenue
Composite HMAC and Granular Base Thickness		
Minimum (mm)	220	132
Maximum (mm)	372	226
Average (mm)	296	185
PSIPave Surface Deterioration Index		
Minimum	15.1	13.5
Maximum	67.8	47.7
Average	41.5	30.2

Table 2 Peak Surface Deflection Summary Across Commercial Vehicle Load Spectra

Load Spectra	*A Priori* Unstrengthened			Post Construction Strengthened			Average Improvement in Structural Deflection (mm)	Percent Improvement (%)
	Mean (mm)	SD (mm)	CV (%)	Mean (mm)	SD (mm)	CV (%)		
Shannon Road								
Secondary	0.96	0.47	48.4	0.27	0.10	39.2	0.70	72.9
Primary	1.08	0.52	48.4	0.30	0.12	39.5	0.78	72.2
Primary +25%	1.36	0.66	48.3	0.37	0.15	40.2	0.99	72.8
Primary +50%	1.65	0.80	48.3	0.45	0.18	40.9	1.20	72.3
Assiniboine Avenue								
Secondary	2.38	1.13	47.55	0.39	0.13	33.25	1.99	83.6
Primary	2.56	1.09	42.61	0.44	0.15	34.07	2.12	82.8
Primary +25%	3.03	1.06	34.88	0.57	0.20	35.85	2.46	81.2
Primary +50%	3.36	1.00	29.80	0.69	0.26	37.33	2.67	79.5

Table 3 USCS Distribution and Classification

Segment		Grain Size Gravel (%)	Grain Size Sand (%)	Grain Size Fines (%)	USCS Classification
Shannon Road	**Subgrade**	2.9	28.3	68.9	CH
	Granular Base	25.5	62.1	12.4	GW
Assiniboine Avenue	**Subgrade**	2.9	28.3	68.9	CH
	Granular Base	29.2	56.4	14.4	GW

Table 4 AASHTO Grain Size Distribution and Classification

Segment		Grain Size Gravel (%)	Grain Size Coarse Sand (%)	Grain Size Fine Sand (%)	Grain Size Silt Clay (%)	AASHTO Classification (Group Index)
Shannon Road	**Subgrade**	6.8	19.1	5.1	68.9	A-7-5 (33)
	Granular Base	41.6	32.1	13.9	12.4	A-2
Assiniboine Avenue	**Subgrade**	6.8	19.1	5.1	68.9	A-7-5 (33)
	Granular Base	45.5	27.5	12.6	14.4	A-2

Table 5 Construction and Engineering Cost Comparison across Alternative Strengthening Systems

	Estimated Conventional Option A ($\$/m^2$)	Estimated FDS w/o Drainage Sand Option B ($\$/m^2$)	Actual Construction Costs Option B ($\$/m^2$)
Construction Items			
Utilities	\$7.31	\$7.31	\$9.65
Drainage System	\$5.37	\$1.64	\$4.51
Strengthening	\$30.96	\$19.19	\$24.25
Construction Extras	\$0.00	\$0.00	\$1.17
Total	**\$43.64**	**\$28.14**	**\$39.58**
Engineering Items			
PSI Materials	\$0.60	\$22.27	\$19.22
PSI Engineering Services	\$5.13	\$2.82	\$2.34
Total	**\$5.73**	**\$25.09**	**\$21.56**
TOTAL	**\$49.37**	**\$53.23**	**\$61.14**

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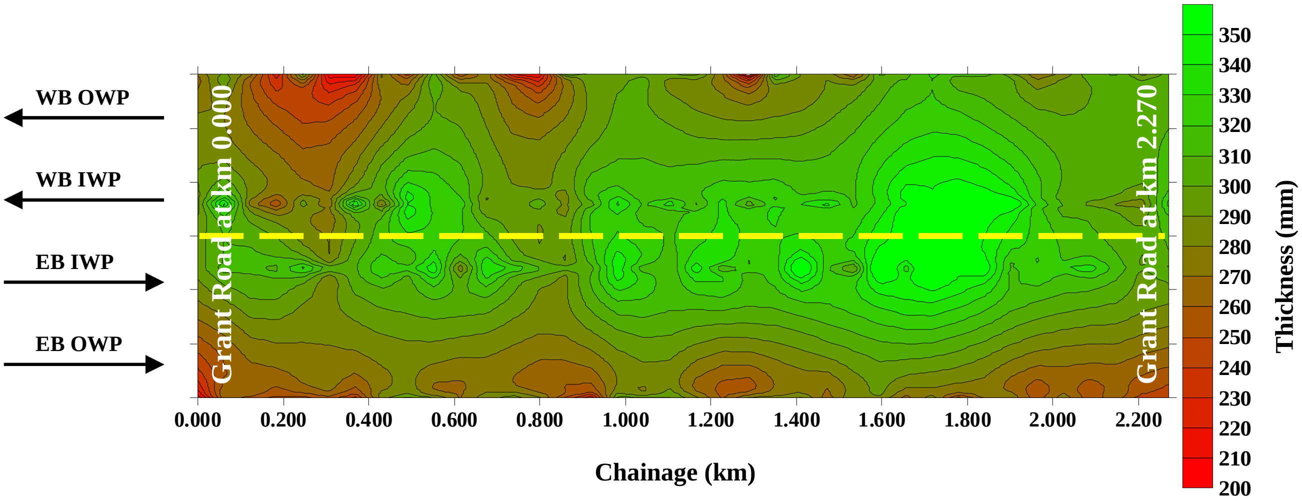
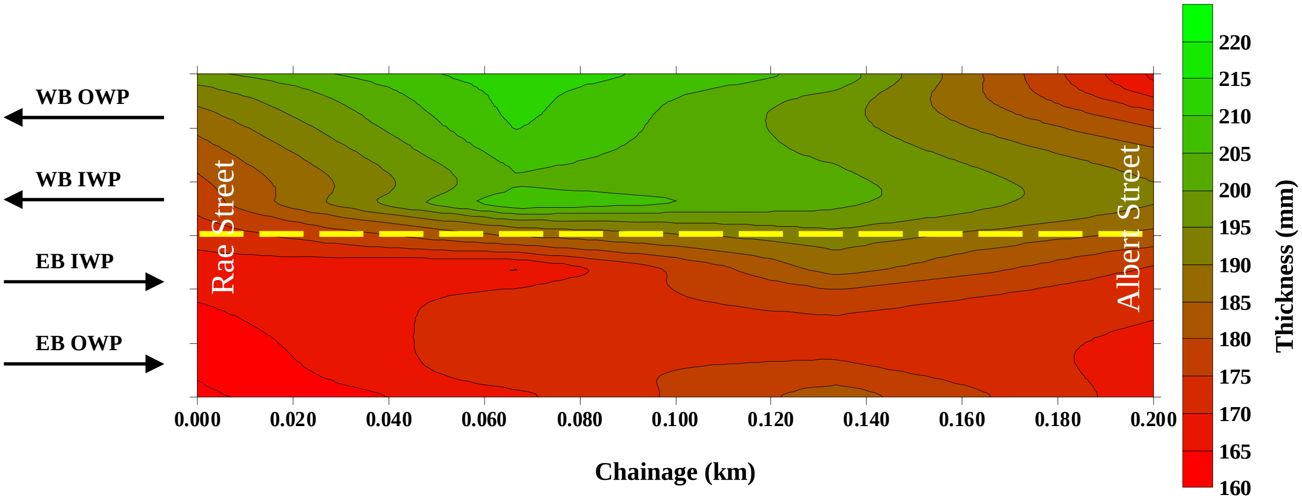
Figure 1 Typical *A Priori* Surface Distresses of Shannon Road

Figure 2 Ground Penetrating Radar and Dynatest Heavy Weight Deflectometer

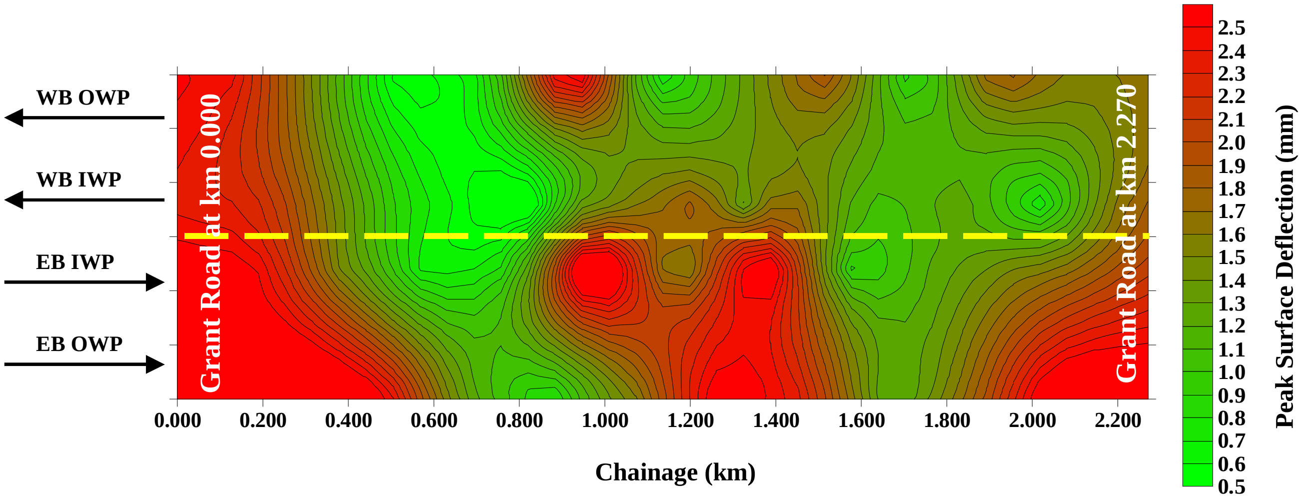


(a) Shannon Road

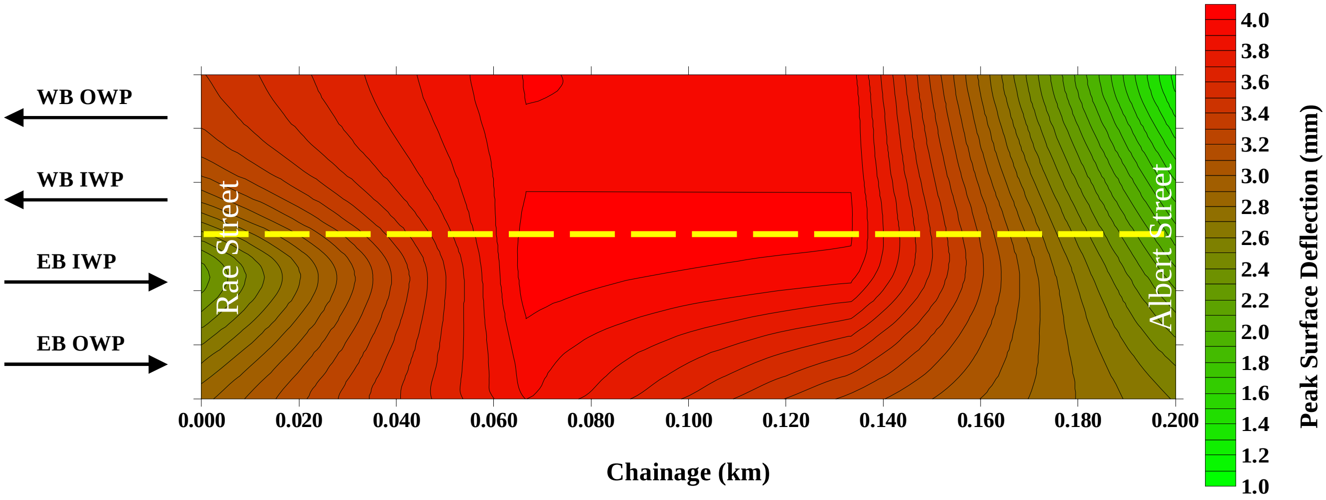


(a) Assiniboine Avenue

Figure 3 Pre-Construction Composite Asphaltic Concrete and Granular Base Thickness Profile for (a) Shannon Road and (b) Assiniboine Avenue



(a) Shannon Road



(a) Assiniboine Avenue

Figure 4 Pre-Construction Peak Surface Deflection Profile at Primary Weight Limits+ 50% for (a) Shannon Road and (b) Assiniboine Avenue

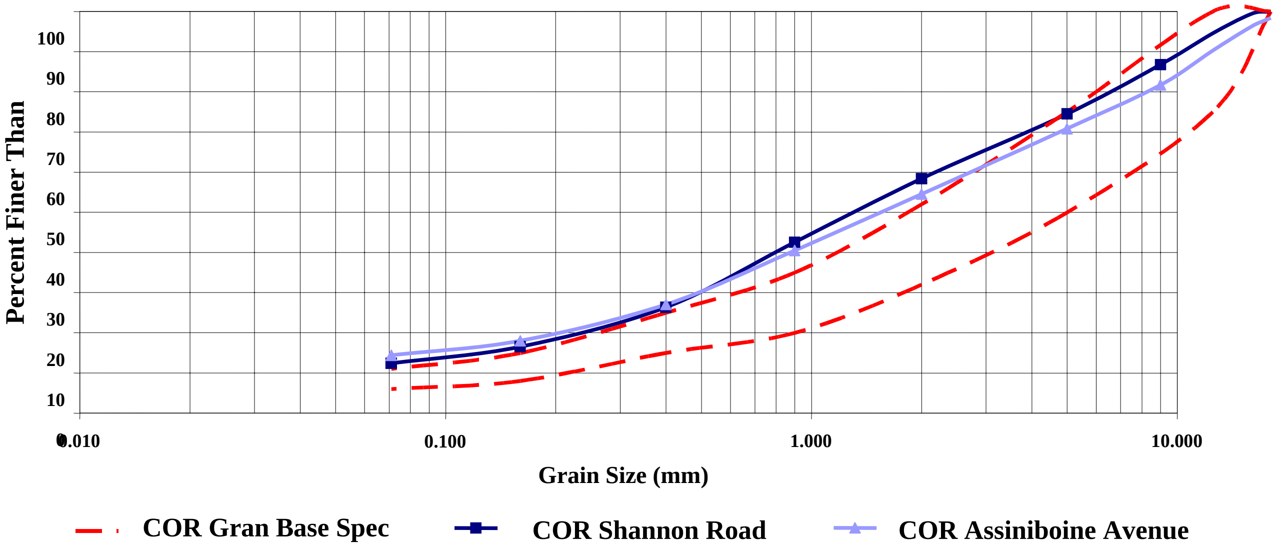


Figure 5 Recycled Composite HMAC Surfacing Granular Base Grain Size Distribution

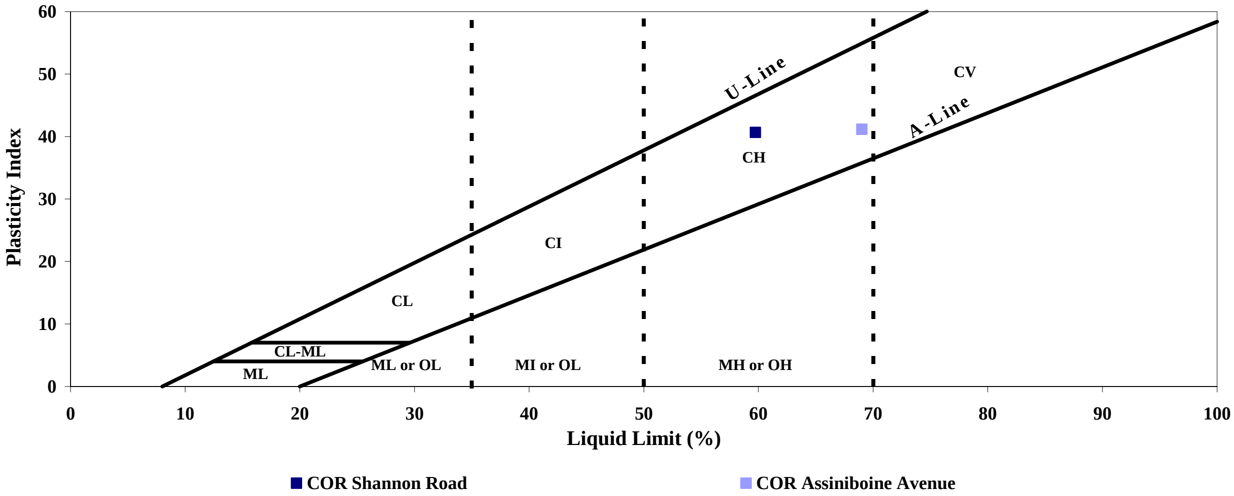


Figure 6 USCS Classification of Fines Portion of *in situ* Subgrade

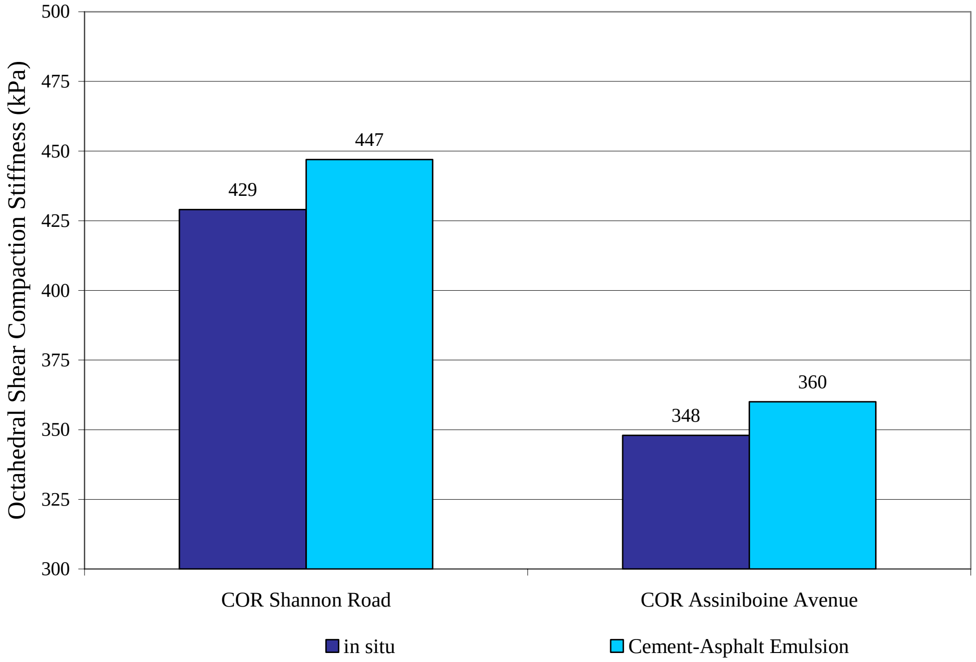


Figure 7 Peak Octahedral Shear Compaction Stiffness of Recycled Composite HMAC and Granular Base

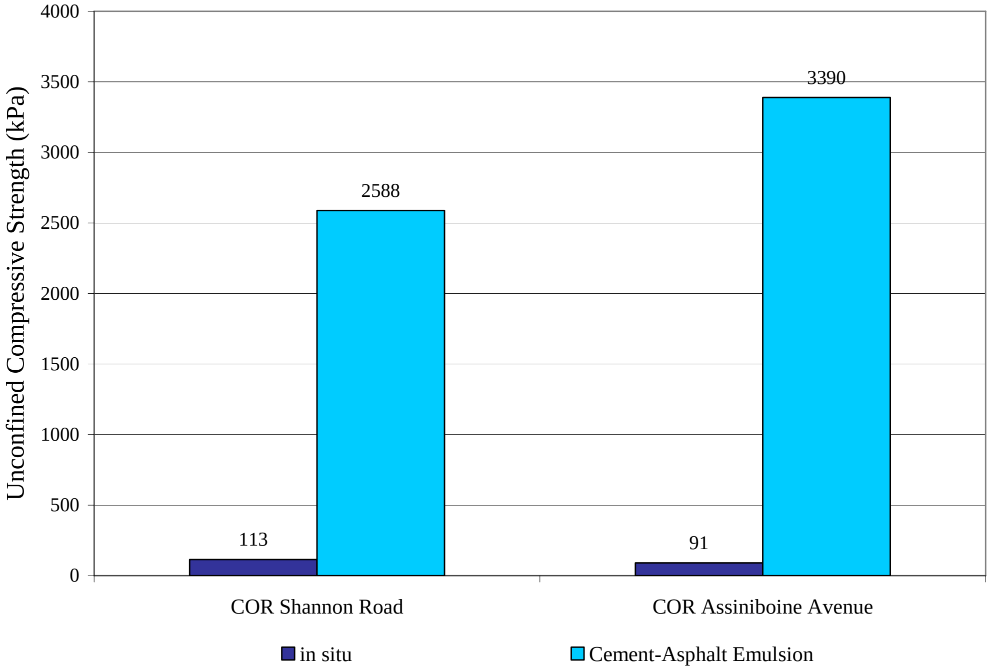


Figure 8 Unconfined Compressive Strength of Recycled Composite HMAC and Granular Base

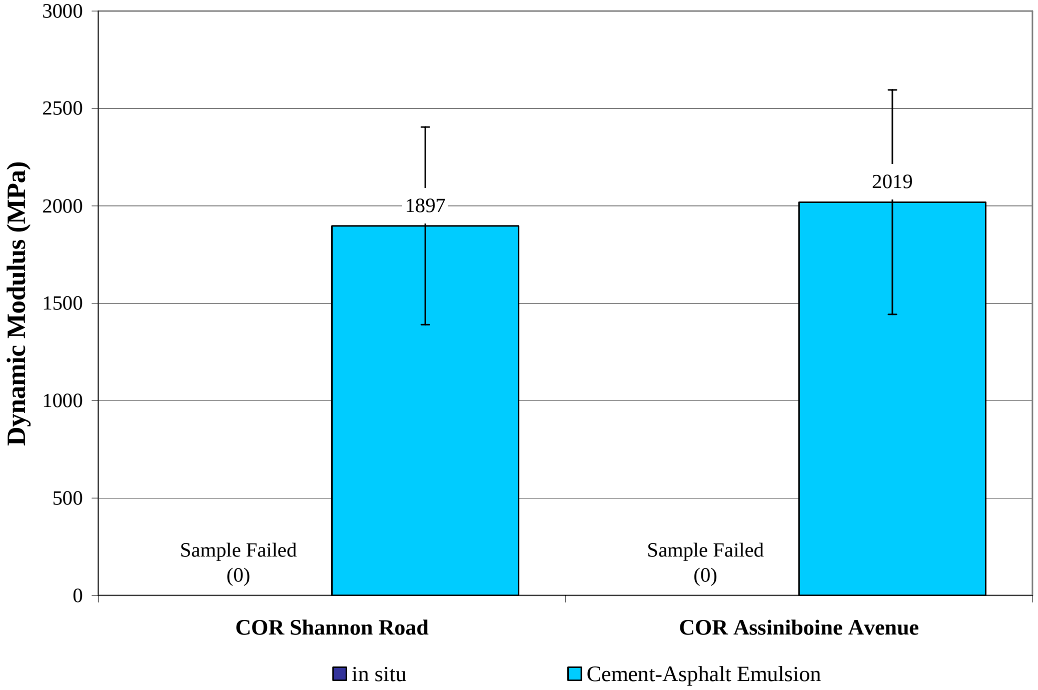


Figure 9 Dynamic Modulus Averaged Across Deviatoric Stress State and Frequency

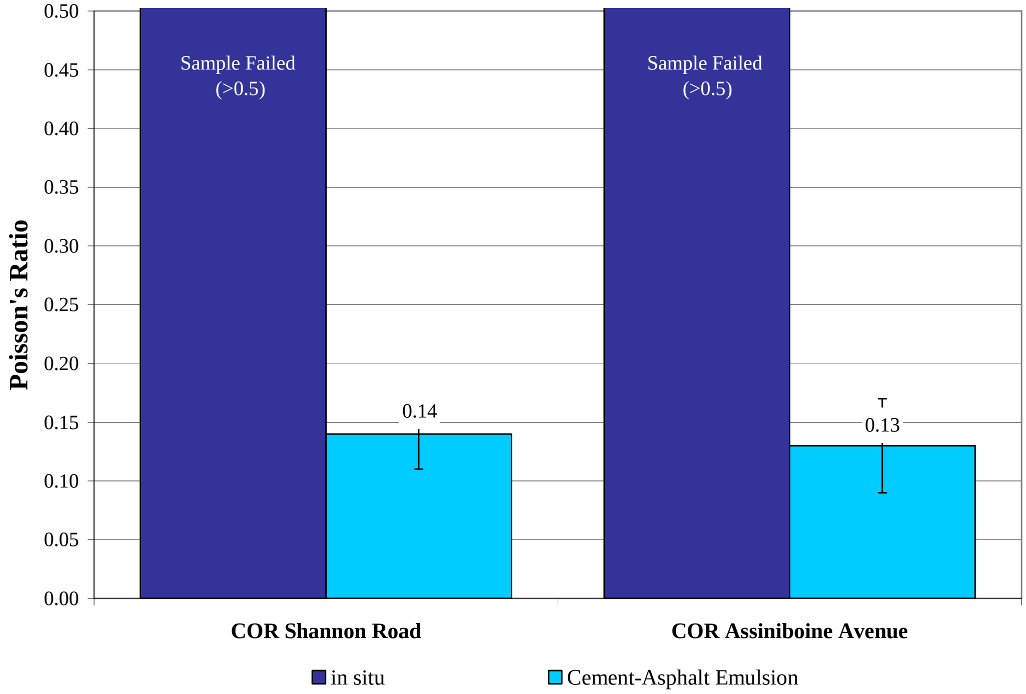


Figure 10 Poisson’s Ratio Averaged Across Deviatoric Stress State and Frequency

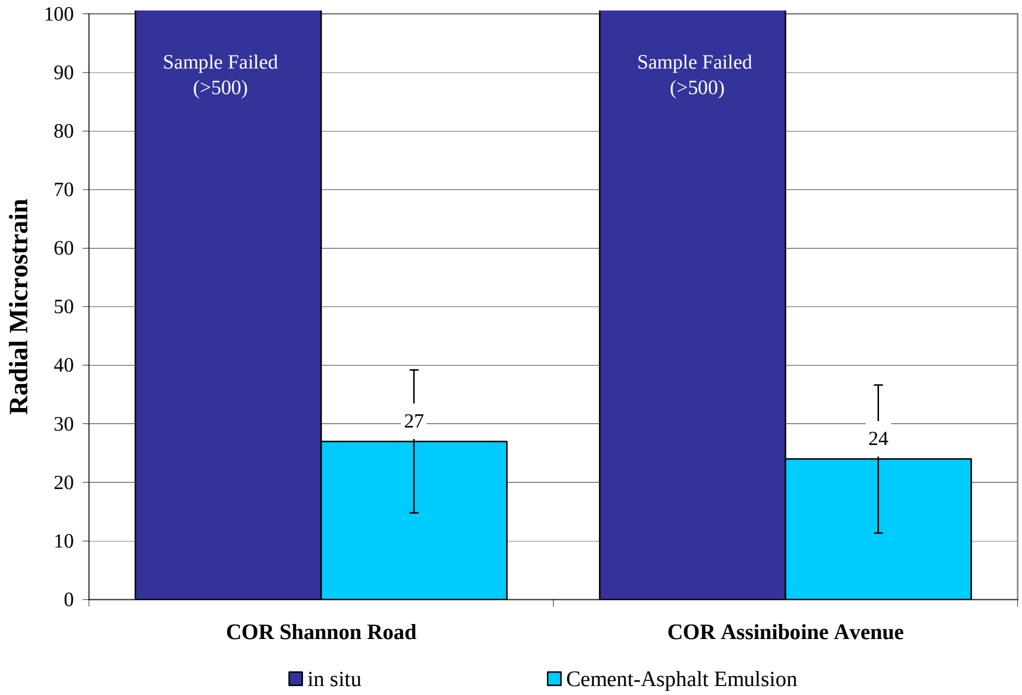


Figure 11 Radial Microstrain Averaged Across Deviatoric Stress State and Frequency

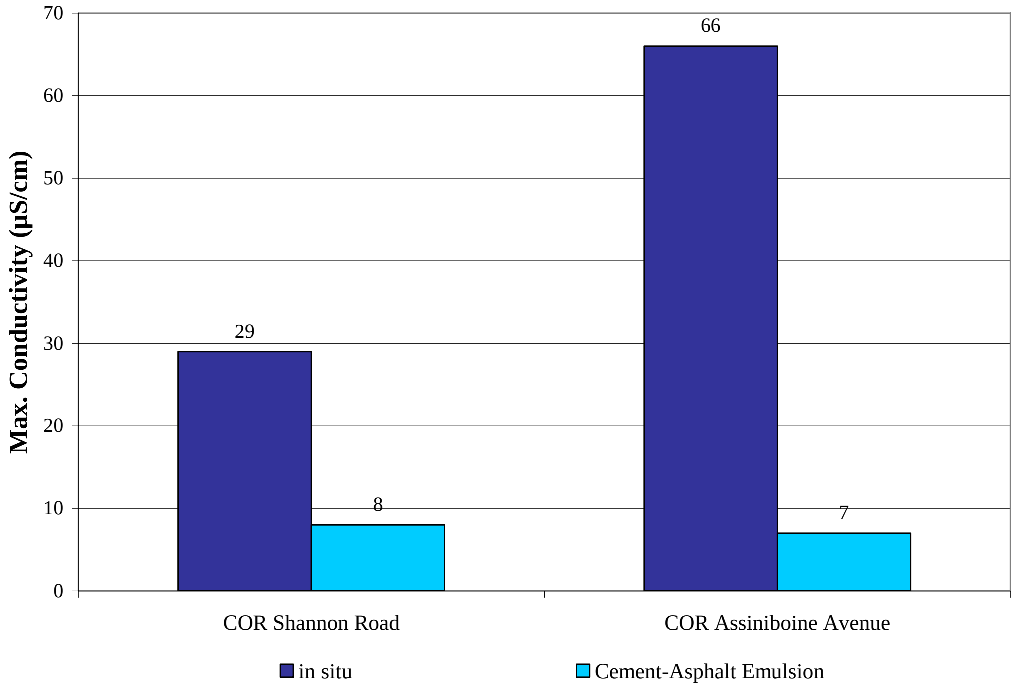


Figure 12 Climatic Durability Conductivity Characterization of Granular Base

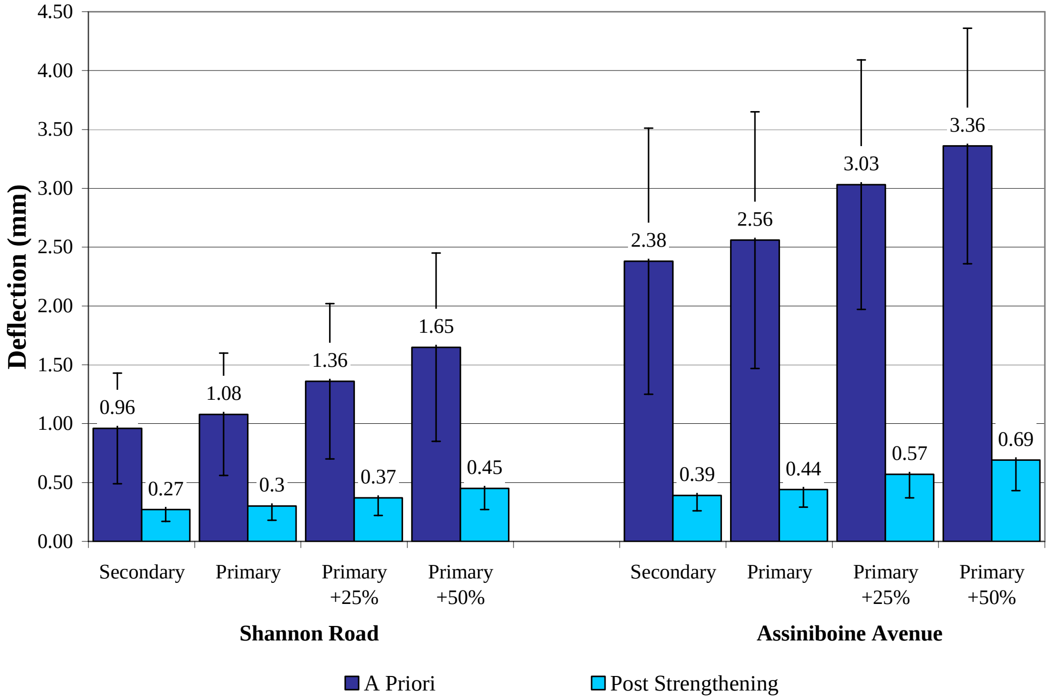


Figure 13 Peak Surface Deflection Response across Commercial Vehicle Load Spectra

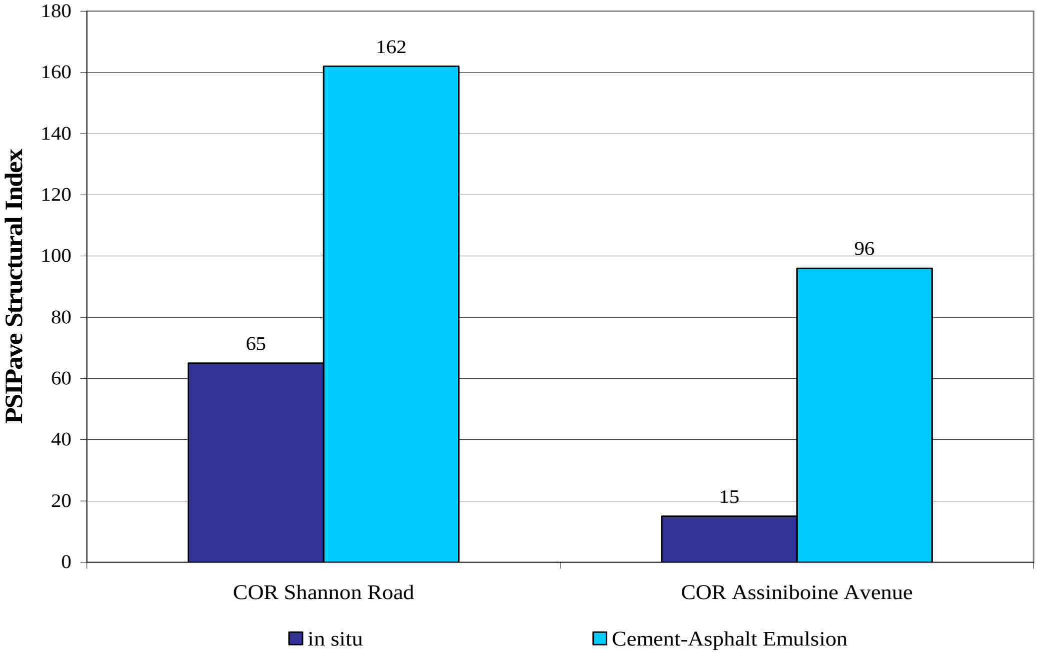
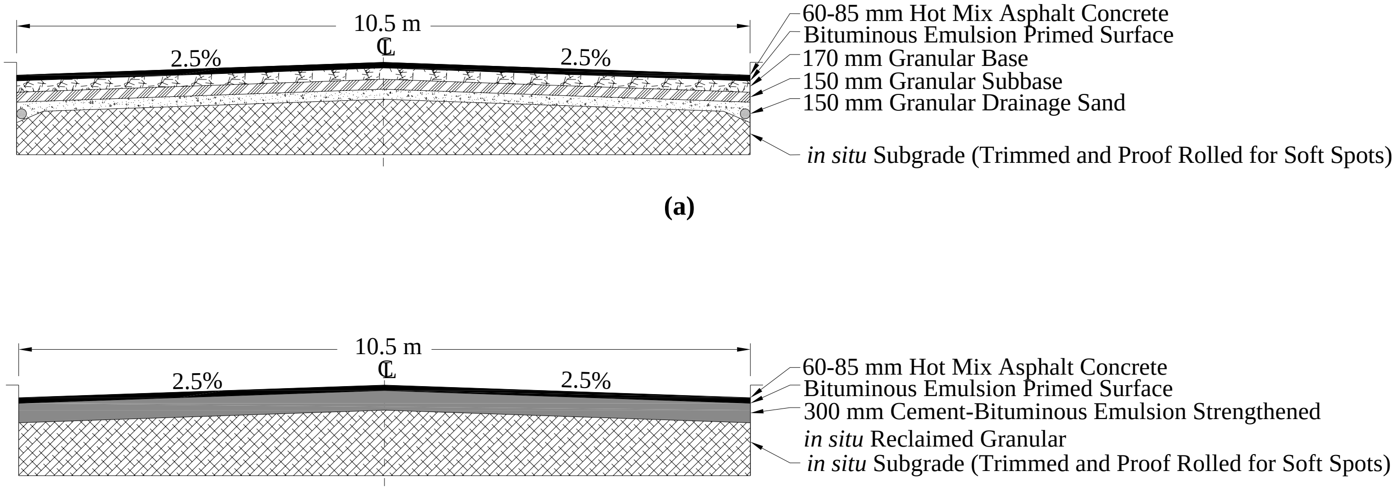


Figure 14 Average Structural PSIPave Index



(a)

(b)

Figure 15 Conventional Granular (a) and Full Depth Strengthening (b) Structural Cross Sections