Mechanistic-Climatic Characterization of Foamed Asphalt Stabilized Granular Pavements in Saskatchewan

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ABSTRACT

Saskatchewan Department of Highways and Transportation (SDHT) is investigating alternate recycling and strengthening systems for in-service thin granular pavements. This research is being performed in an attempt to improve granular pavement structural integrity through recycling and stabilization, as well as reduce the dependence on new source aggregates. This paper summarizes the findings of a pilot project investigating the mechanistic-climatic laboratory characterization of two typical Saskatchewan thin granular pavements stabilized in the lab with foamed asphalt, cement and asphalt emulsion.

The two granular systems evaluated as part of the study were Control Section 15-11 (C.S. 15-11), comprised of a conventional sealed granular base pavement, and Control Section 6-15 (C.S. 6-15), comprised of select silty sand borrow material with a thin asphaltic concrete wearing surface. The two granular systems evaluated as part of this study were chosen to characterize the typical range of select granular materials used in granular pavements constructed in central and northern Saskatchewan.

The C.S. 15-11 *in situ* granular base was found to require strengthening because it is relatively high in fine sand fraction as well as contains a high fraction of plastic clay fines. These two physical properties are believed to be the primary causes for marginal performance of granular bases in the field. The C.S. 6-15 *in situ* select silty sand base was selected as a typical granular pavement requiring strengthening, as silty sand granular materials are a common road building material used in northern Saskatchewan.

This research showed that conventional indirect tensile testing was relatively insensitive to the effects of foamed asphalt stabilization. In addition, conventional indirect tensile testing does not provide material constitutive relations across the full range of typical Saskatchewan field state conditions, including stress states and load frequencies.

Triaxial frequency sweep characterization determined that foamed asphalt with cement stabilization significantly improved the mechanistic primary constitutive behaviour of the C.S. 15-11 granular base system; however, foamed asphalt only marginally affected the C.S. 6-15 silty sand. It was found that asphalt emulsion with cement significantly improved the mechanistic constitutive behaviour of both granular systems considered.

This research also determined that foamed asphalt stabilization provided only marginal improvements in the unconfined compressive strength of post saturation and freeze-thaw climatic conditioning relative to the asphalt emulsion and cement stabilization system.

KEYWORDS: foamed asphalt, asphalt emulsion, granular base, stabilization, triaxial frequency sweep testing

INTRODUCTION

Saskatchewan Department of Highways and Transportation (SDHT) is currently expanding the provincial primary weight road system across portions of the thin granular pavement system. At the same time, quality aggregate resources used to strengthen roads are becoming increasingly depleted in many regions of Saskatchewan. As a result, in regions of marginal source aggregates and concentrated truck haul, Saskatchewan's granular base materials and design methodologies are falling short of field performance expectations.

In thin granular pavement structures, the granular system provides the primary stress distribution and moisture diffusion layer. Given the age of many thin granular pavements in Saskatchewan, as well as increasing truck traffic within the province, such roadways are in need of structural base rehabilitation (1, 2). In an attempt to reduce the dependence on new source aggregates and to optimize the recycling of *in situ* materials, SDHT is investigating alternate in-place recycling and strengthening systems for *in situ* aggregate materials.

This paper summarizes the findings of a pilot project investigating the mechanistic-climatic laboratory characterization of two Saskatchewan granular pavement materials. The two granular systems evaluated in this study were Control Section Highway 15-11 (C.S. 15-11) which is comprised of a conventional sandy *in situ* granular base, and Control Section Highway 6-15 (C.S. 6-15) which is comprised of select silty sand *in situ* base (3). These two systems represent the range of select granular materials commonly used in granular pavement systems in the central and northern regions of the province.

This study characterized the granular materials using triaxial frequency sweep characterization. The stabilized systems were evaluated under typical field stress states and load frequencies. The results from the triaxial frequency sweep characterization are deemed critical for designing stabilized bases in the future, given that the structural design principles currently employed by SDHT were calibrated across field state conditions of the 1960's and 1970's.

GRANULAR MATERIAL CLASSIFICATION

The grain size distribution for *in situ* granular base materials evaluated in this study was characterized using mechanical washed sieve analysis. The average gradation for C.S. 15-11 and C.S. 6-15, compared to the standard SDHT Type 33 granular base specification, is shown in Figure 1. As seen in Figure 1, the grain size distribution of both the C.S. 15-11 and C.S. 6-15 are finer than the specified base granular requirements, particularly in the fines fraction and fine sand fraction.

According to the USCS soil classification system, the C.S. 15-11 granular base classified as well graded sand-clayey sand (SW-SC). According to the AASHTO soil classification system, the C.S. 15-11 granular base classified as A-2-6 clayey granular. The fines within the C.S. 15-11 granular base were comprised of 9 to 14 percent of the grain size distribution and classified as an USCS low to intermediate plastic clay (CL-CI). The relatively high amount and high plasticity of the fines is believed to be a contributing factor to observed surface deformations on C.S. 15-11.

The fines within the C.S. 6-15 silty sand comprised 13 percent of the grain size distribution and classified as a USCS non-plastic silt. According to the USCS soil classification system, the C.S. 6-15 silty sand base classified as a silty gravel. According to the AASHTO soil classification system, the C.S. 6-15 silty sand base classified as GM A-2-4 silty granular.

MECHANICAL CHARACTERIZATION ANALYSIS

The strengthening systems selected for the C.S. 15-11 and C.S. 6-15 materials were 3 percent foamed asphalt without cement, 2 percent foamed asphalt with 1.5 percent cement, and 2 percent asphalt emulsion with 2 percent cement. The design blends were selected according to material availability and economic constraints of constructing the system in the field. The characterization results obtained from each of these selected stabilization systems are presented herein and cross compared to the unstabilized *in situ* granular base properties.

Octahedral Shear Compaction Stiffness Characterization

A critical component to quality continuum mechanics characterization is accurate and repeatable sample preparation. In addition, a critical component to good performance in the field of stabilization systems is proper construction, particularly final density at the time of construction. Continuum laboratory samples were prepared for mechanistic frequency sweep characterization using a computer feedback controlled gyratory compactor. Figure 2 illustrates the average octahedral shear compaction stiffness profiles obtained from the gyratory compaction during sample preparation.

As seen in Figure 2, foamed asphalt stabilization required significantly higher compaction energy, relative to the unstabilized C.S. 15-11 granular base. In contrast, the C.S. 6-15 granular material showed lower compaction energy requirement when stabilized with foam asphalt relative to the unstabilized C.S. 6-15 granular. However, the unstabilized C.S. 6-15 yielded a significantly higher compaction energy requirement relative to the *in situ* C.S. 15-11 granular base.

The foamed asphalt with the addition of cement yielded a significantly higher compaction energy requirement relative to the *in situ* and the other strengthening systems of both the C.S. 15-11 granular base and C.S. 6-15 silty sand base.

The laboratory compaction results concur with construction experience in which contractors typically have difficulties compacting foamed asphalt and cement stabilized base strengthening systems in the field relative to unstabilized systems.

Triaxial Frequency Sweep Characterization

This research employed triaxial frequency sweep testing to characterize the granular base material constitutive relations with respect to stabilization systems across the full range of field state load rates ranging from 0.5 Hz to 10 Hz load frequency, bulk stress states up to 900 kPa, and deviatoric stress states from 50 kPa to 550 kPa (4, 5, 6).

Dynamic Modulus Characterization Results

Material stiffness under dynamic loading is a primary material constitutive property used in road structural design and analysis. Table 1 summarizes and Figure 3 illustrates the dynamic modulus of the C.S. 15-11 *in situ* granular base and C.S. 6-15 silty sand across strengthening system type, stress state, and load frequency. As seen in Table 1 and Figure 3, the unstabilized C.S. 15-11 granular base exhibited a lower stiffness modulus than the C.S. 6-15 silty sand. This indicates that the C.S. 15-11 granular base is a marginal performing base.

In regards to C.S. 15-11 *in situ* granular base, stabilization increased the dynamic modulus across all stabilization systems. It can be seen that the asphalt-emulsion with cement, and the foamed asphalt systems yielded relatively the same, and highest, dynamic modulus behaviour. It can also be seen that foamed asphalt stabilization of the C.S. 15-11 granular base without cement yielded approximately half the increase in stiffness relative to the foamed asphalt stabilization system with cement. The C.S. 6-15 silty sand dynamic modulus exhibited only minor changes across load frequencies and stress state.

Table 1 and Figure 3 also illustrate that a decrease in load frequency resulted in a slight decrease in dynamic modulus across the foamed asphalt strengthening systems without cement for both the granular base and silty sand. As well, increasing deviatoric stress resulted in a decrease in the dynamic modulus across all granular systems evaluated; however, the addition of cement significantly reduced the decreasing effect.

Poisson's Ratio Characterization Results

Poisson's ratio is a primary mechanistic structural modeling material constitutive property. Table 2 summarizes and Figure 4 illustrates the Poisson's ratio of the C.S. 15-11 *in situ* granular base and C.S. 6-15 *in situ* select silty sand base across strengthening system type, stress state, and load frequency.

In regards to C.S. 15-11 *in situ* granular base, Poisson's ratio decreased across all stabilization systems. It is seen that the cement-emulsion and cement-foamed asphalt systems yielded the lowest Poisson's ratios. In regards to C.S. 6-15 *in situ* select silty sand base, Poisson's ratio increased with foamed asphalt stabilization. It is seen that the granular base stabilized with foamed cement exhibits a nearly identical Poisson's ratio to the select silty sand base *in situ*.

Poisson's ratio was also found to be relatively insensitive to load frequency. However, increases in deviatoric stress state caused an increase in the Poisson's ratio particularly that of the *in situ* unstabilized C.S. 15-11 granular base. The significant increase in Poisson's ratio observed in the behaviour of the unstabilized granular base material is a potential indicator of the edge failures being observed in the field on C.S. 15-11.

Radial Strain Characterization Results

Radial microstrain behaviour is believed to be a primary indicator of a material's tendency for edge shear failure under typical truck loading field state conditions. Table 3 summarizes and Figure 5 illustrates the mean radial microstrain the C.S. 15-11 *in situ* granular base and C.S. 6-15 *in situ* select silty sand base across strengthening system type, load frequency and deviatoric stress state.

In regards to C.S. 15-11 *in situ* granular base, the radial microstrain decreased across all stabilization systems. It is seen that the cement-emulsion and cement-foamed asphalt systems yielded similar radial microstrain behaviour. In regards to C.S. 6-15 *in situ* select silty sand base, the radial microstrain increases with foamed asphalt stabilization.

The radial microstrain behaviour across all the strengthening systems was relatively insensitive to changes in load frequency. However, an increase in deviatoric stress state caused a significant increase in the radial microstrain of the *in situ* granular base but stabilization significantly reduced radial microstrain across the strengthened C.S. 15-11 granular base samples. However, the unstabilized granular base exhibited significant increases in radial microstrain as a function of increasing deviatoric stress state relative to the stabilized systems. The radial strain behaviour of the unstabilized granular base material concurs with permanent deformation being observed on C.S. 15-11.

Phase Angle Characterization Results

Phase angle is a measure of the delay in observed strain response resulting from an applied traction state. Table 4 summarizes and Figure 6 illustrates the phase angle of the C.S. 15-11 *in situ* granular base and C.S. 6-15 *in situ* select silty sand base across strengthening system type, load frequency and deviatoric stress state.

In regards to C.S. 15-11 *in situ* granular base, the foamed asphalt strengthening system without cement yielded a significant increase in phase angle. Cement stabilization did not significantly change the phase angle relative to the unstabilized base but significantly reduced the phase angle relative to the sample stabilized with 3 percent foamed bitumen. It is seen that the *in situ* granular base, cement asphalt emulsion and cement-foamed asphalt stabilization systems yielded similar phase angles. In regards to C.S. 6-15 *in situ* select silty sand base, the phase angle increased significantly with 3 percent foamed asphalt stabilization.

The phase angle results are not yet fully understood in how they relate to field performance, however, phase angle analysis has correctly identified the effect that added bitumen has on stabilized granular bases. Given the historic problems with brittleness of granular base stabilized with cement (7, 8), it is hypothesized that increasing phase angle may be an indication of increasing fracture toughness of stabilization systems. However, this hypothesis will have to be validated through observed field performance of the C.S. 15-11 or C.S. 6-15 test sections.

CLIMATIC DURABILITY TESTING

Climatic durability is an important performance parameter of stabilized granular base materials, particularly in northern climates such as Saskatchewan, where the granular base is the primary load carrying member (9, 10, 11). To characterize the climatic durability of granular base materials as it relates to moisture and freeze-thaw conditions in the field, the unconfined strength of neat *in situ* and strengthened samples were recorded after 14 days of moisture capillary conditioning and 28 days of freeze-thaw conditioning. The moisture capillary conditioning was modelled after the tube suction test developed by Scullion et al. at Texas A&M University (12) with the exception that the moisture conditioned samples in this test were not confined, to allow the samples to expand freely as they do in the field. In addition, freeze-thaw cycles were conducted on a 48 hour cycle basis with temperatures ranging from -20ºC to +20ºC.

As seen in Figure 7, the stabilization systems yielded increases in strength after climatic durability conditioning relative to the unstabilized granular material. Also seen in Figure 7, the foamed asphalt stabilization systems yielded marginal post climatic conditioned strength relative to the foamed asphalt and asphalt emulsion strengthening systems with cement. It is interesting to note that although the foamed asphalt stabilization with cement of the C.S. 15-11 granular base yielded the same, and best, mechanical properties equivalent to cement-emulsion stabilization of C.S. 15-11 prior to climatic conditioning, the foamed asphalt without cement yielded a significant reduction in strength after moisture and freeze-thaw conditioning relative to the samples prepared with cement. In addition, it can be seen in Figure 7 that the foamed asphalt with cement yielded approximately half the strength of the asphalt emulsion and cement sample. Based on these results, it appears that foamed asphalt and asphalt emulsion stabilization should be augmented with cement in applications where the system may be exposed to moisture and/or freeze-thaw field state conditions under relatively high deviatoric stress states. However, it appears that the modified emulsified asphalt with cement stabilization system yielded the highest climatic durability relative to all other strengthening systems evaluated.

SUMMARY AND CONCLUSIONS

Saskatchewan Department of Highways and Transportation maintains and operates several thousand kilometres of thin granular pavements. Increasing commercial truck load spectra, decreasing supply of quality aggregates, and increasing road construction costs contribute to the need to investigate alternate granular base strengthening and rehabilitation systems. This study investigated the laboratory characterization of two Saskatchewan granular pavement materials commonly used for pavement construction in Saskatchewan, a fine granular base and silty sand material.

Based on the findings of this study, it was observed that cement and bituminous stabilization systems improved the mechanistic and climatic behaviour of the granular materials. Foamed asphalt stabilization of the silty sand material only marginally improved the mechanical and climatic durability. Cement was found to significantly improve the mechanistic-climatic behaviour of the granular base with both emulsified and foamed bitumen materials. It was also found that the emulsion with cement stabilization system yielded the most favourable material properties in terms of combined mechanistic behaviour and climatic durability.

Based on the results of this study, triaxial frequency sweep characterization is a pragmatic system to measure fundamental mechanistic material properties of granular base materials, across various stabilization systems. The triaxial frequency sweep test generated realistic material constitutive properties and was sensitive across all stabilization systems considered in typical field state conditions. The phase angle measurement from the triaxial frequency sweep test may also provide an indication of fracture toughness but this will have to be confirmed through test section performance validation.

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Table 1 Dynamic Modulus Averaged Across Deviatoric Stress State and Frequency

Frequency/ Stress State	C.S. 15-11				C.S. 6-15	
	in situ (MPa)	**3%Foamed Asphalt** (MPa)	**2%Foamed Asphalt-1.5%Cement** (MPa)	**2%Asphalt Emulsion-2%Cement** (MPa)	***in situ*** (MPa)	**3%Foamed Asphalt** (MPa)
10 Hz	665	1618	1954	1873	930	1036
5 Hz	668	1483	1743	1806	895	930
1 Hz	667	1230	1746	1755	797	746
0.5 Hz	671	1142	1694	1748	768	720
250:200	835	1620	2133	2229	1044	948
250:400	786	1539	1949	2100	955	933
50:400	508	1143	1459	1378	698	753
50:600	542	1171	1596	1476	688	826
Average	**668**	**1368**	**1784**	**1796**	**847**	**862**

Table 2 Poisson's Ratio Averaged Across Deviatoric Stress State and Frequency

Frequency/ Stress State	**C.S. 15-11**				**C.S. 6-15**	
	in situ	**3%Foamed Asphalt**	**2%Foamed Asphalt-1.5%Cement**	**2%Asphalt Emulsion-2%Cement**	***in situ***	**3%Foamed Asphalt**
10 Hz	0.40	0.34	0.15	0.19	0.34	0.49
5 Hz	0.42	0.36	0.16	0.19	0.37	0.51
1 Hz	0.42	0.40	0.18	0.19	0.41	0.54
0.5 Hz	0.43	0.42	0.19	0.21	0.43	0.62
250:200	0.23	0.30	0.14	0.16	0.30	0.44
250:400	0.33	0.35	0.17	0.19	0.36	0.49
50:400	0.47	0.39	0.17	0.17	0.39	0.56
50:600	0.64	0.47	0.21	0.25	0.50	0.68
Average	**0.42**	**0.38**	**0.17**	**0.19**	**0.39**	**0.54**

Table 3 Radial Microstrain Averaged Across Deviatoric Stress State and Frequency

Frequency/ Stress State	**C.S. 15-11**				**C.S. 6-15**	
	in situ	**3%Foamed Asphalt**	**2%Foamed Asphalt-1.5%Cement**	**2%Asphalt Emulsion-2%Cement**	***in situ***	**3%Foamed Asphalt**
10 Hz	307	90	34	45	162	90
5 Hz	324	108	38	47	189	108
1 Hz	329	152	47	53	243	152
0.5 Hz	327	178	52	57	276	178
250:200	55	37	13	14	58	37
250:400	167	93	33	36	149	93
50:400	366	143	46	50	224	143
50:600	699	254	79	100	439	254
Average	**322**	**132**	**43**	**50**	**218**	**132**

Table 4 Phase Angle Averaged Across Deviatoric Stress State and Frequency

Frequency/ Stress State	**C.S. 15-11**				**C.S. 6-15**	
	in situ (Degrees)	**3%Foamed Asphalt** (Degrees)	**2%Foamed Asphalt-1.5%Cement** (Degrees)	**2%Asphalt Emulsion-2%Cement** (Degrees)	***in situ*** (Degrees)	**3%Foamed Asphalt** (Degrees)
10 Hz	12.1	18.2	12.2	12.8	17.3	22.3
5 Hz	9.8	17.2	10.4	12.2	15.6	20.6
1 Hz	8.9	15.6	10.1	10.8	14.6	18.7
0.5 Hz	7.7	16.2	9.7	10.9	14.5	8.2
250:200	8.3	14.6	8.6	9.8	13.0	17.4
250:400	9.4	16.1	9.9	10.8	15.0	19.0
50:400	11.2	17.5	11.2	12.0	16.0	21.7
50:600	11.4	18.4	12.3	13.2	17.9	22.6
Average	**9.9**	**16.7**	**10.6**	**11.6**	**15.0**	**18.8**

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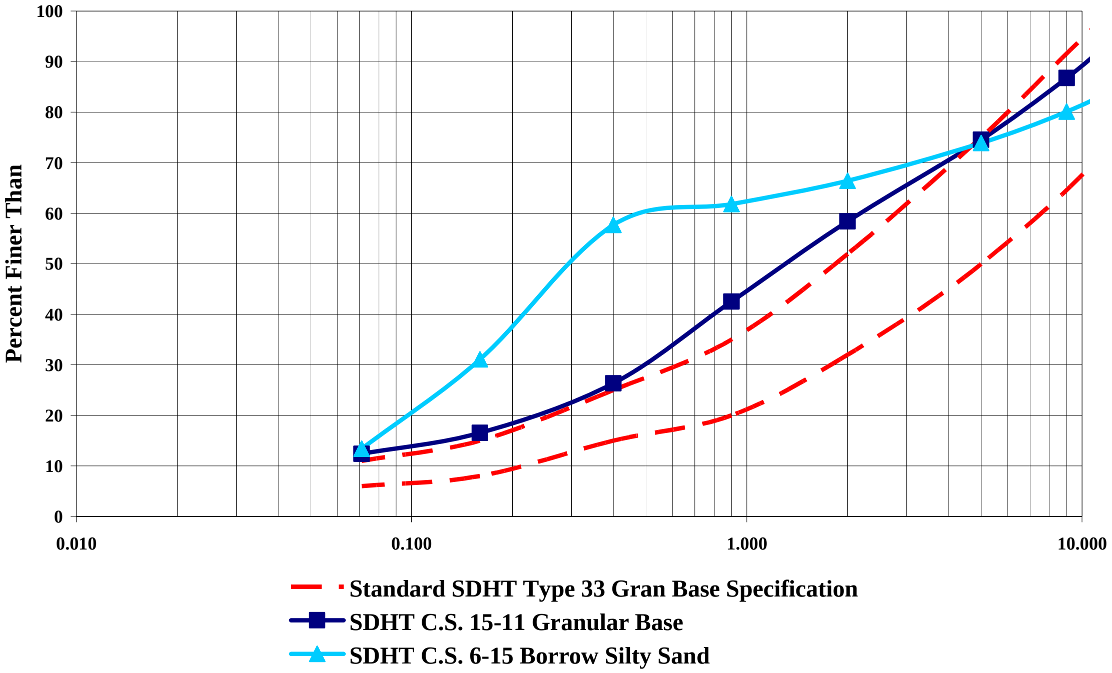


Figure 1 Grain Size Distribution of C.S. 15-11 and C.S. 6-15 Granular Materials relative to SDHT Type 33 Granular Base Specification

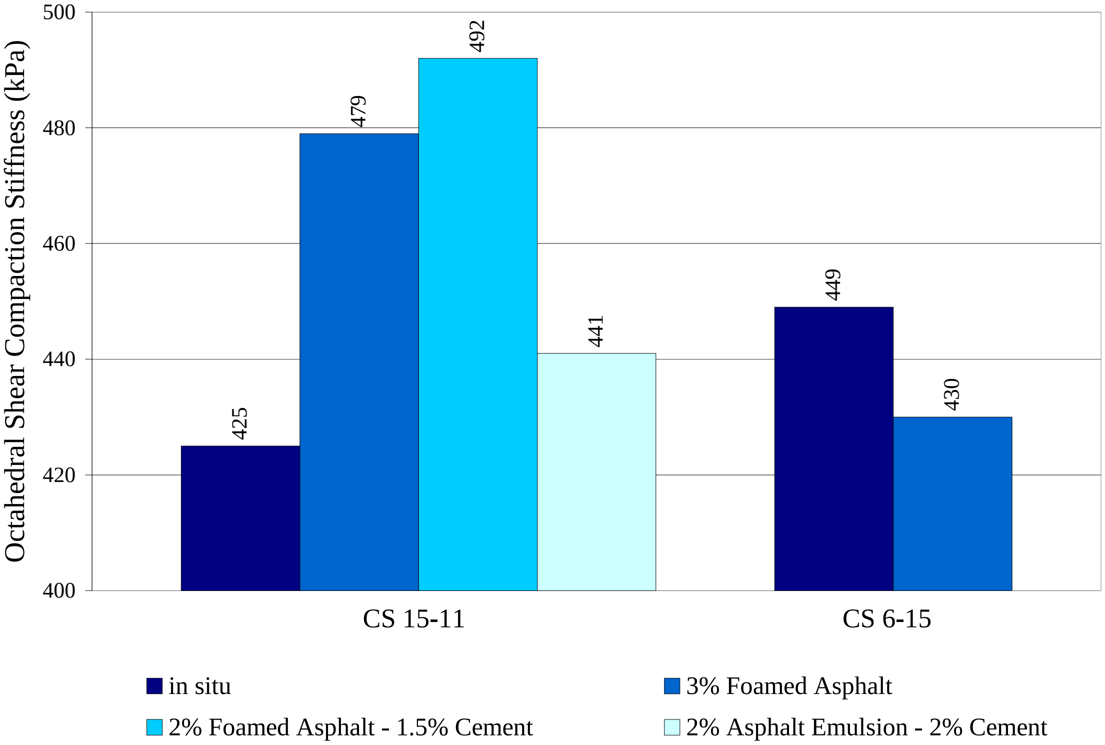


Figure 2 Octahedral Shear Compaction Stiffness

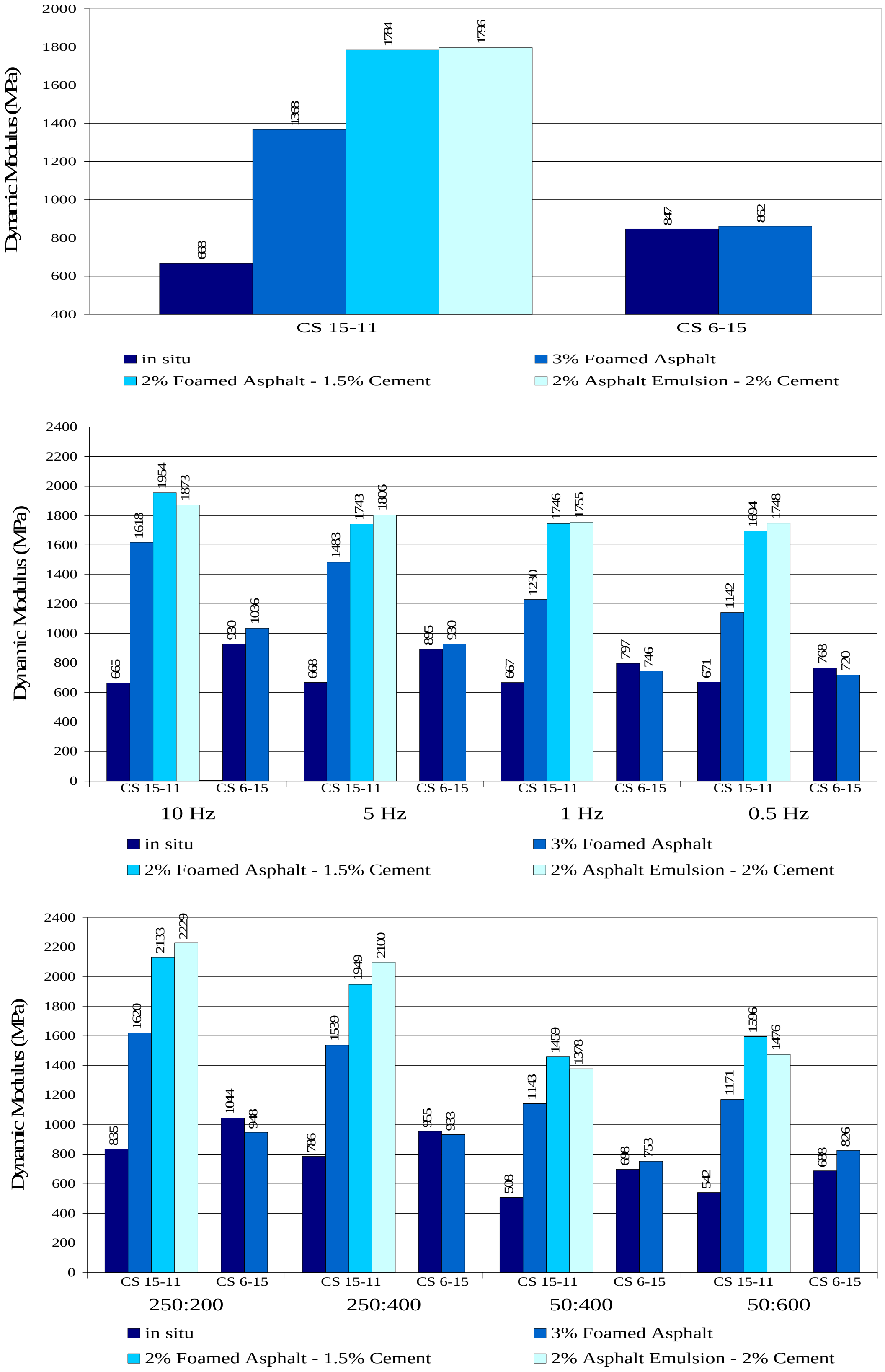


Figure 3 Dynamic Modulus across Stabilization System, Load Frequency and Stress State

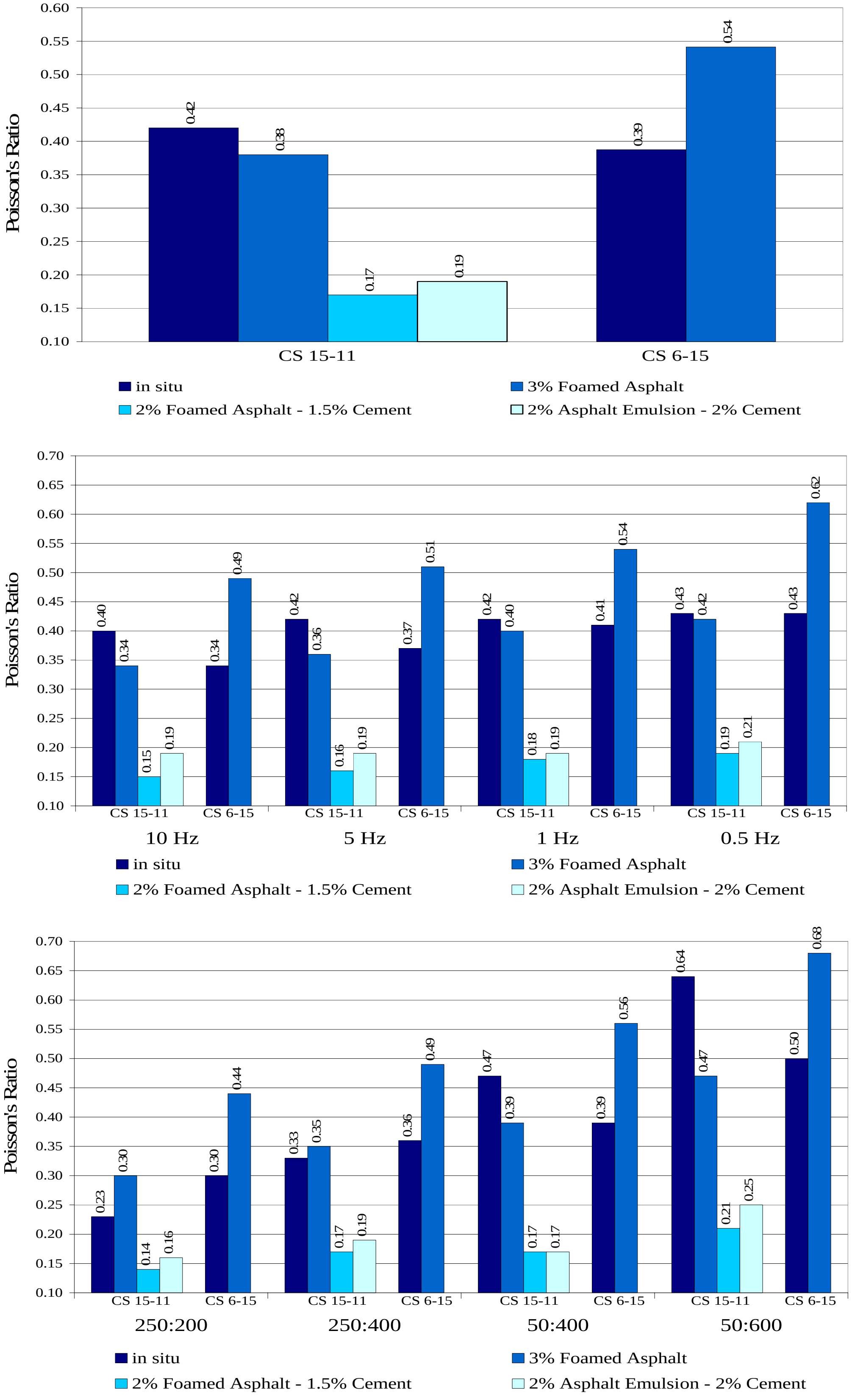


Figure 4 **Poisson's Ratio across Stabilization System, Load Frequency and Stress State**

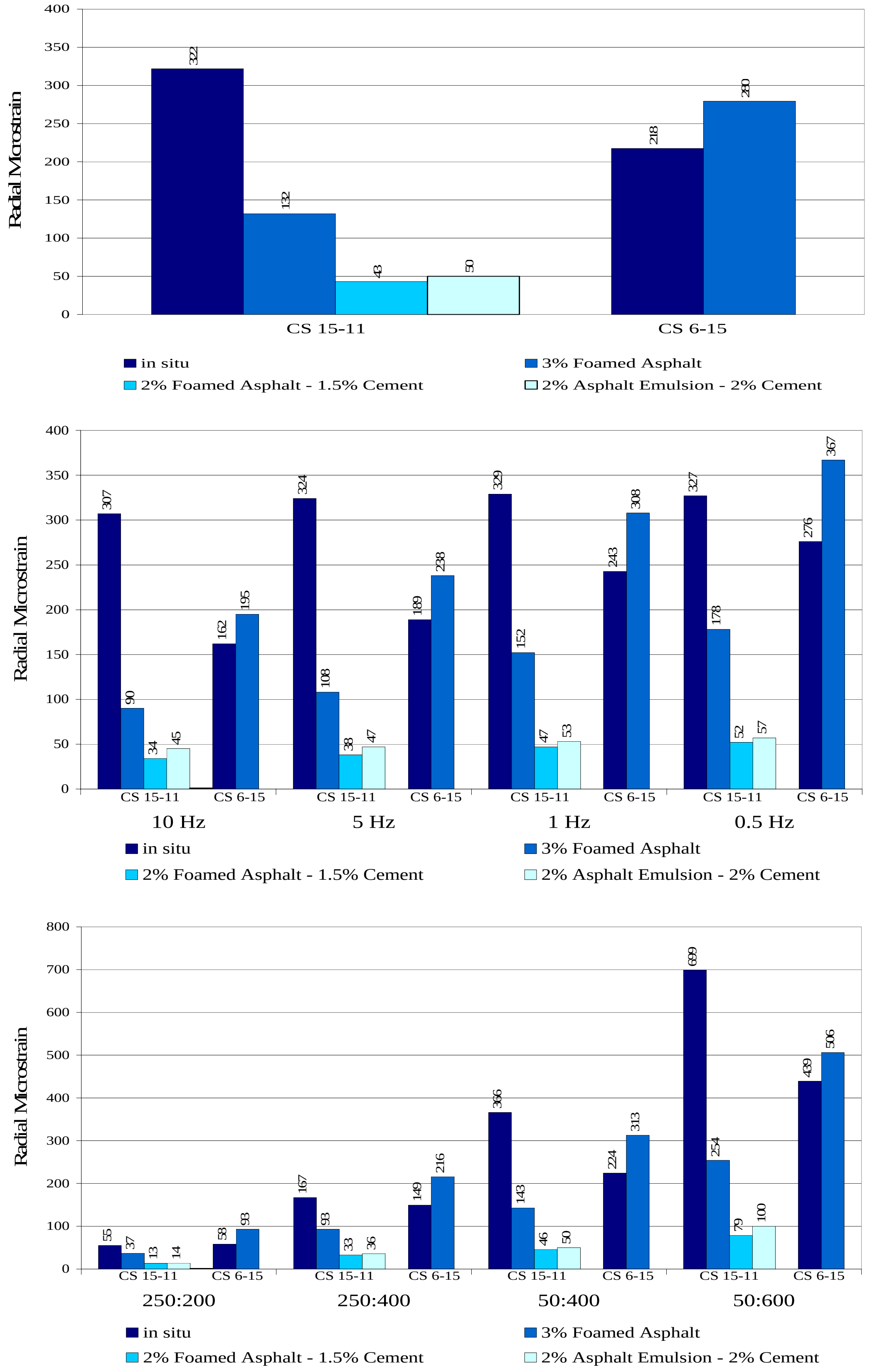
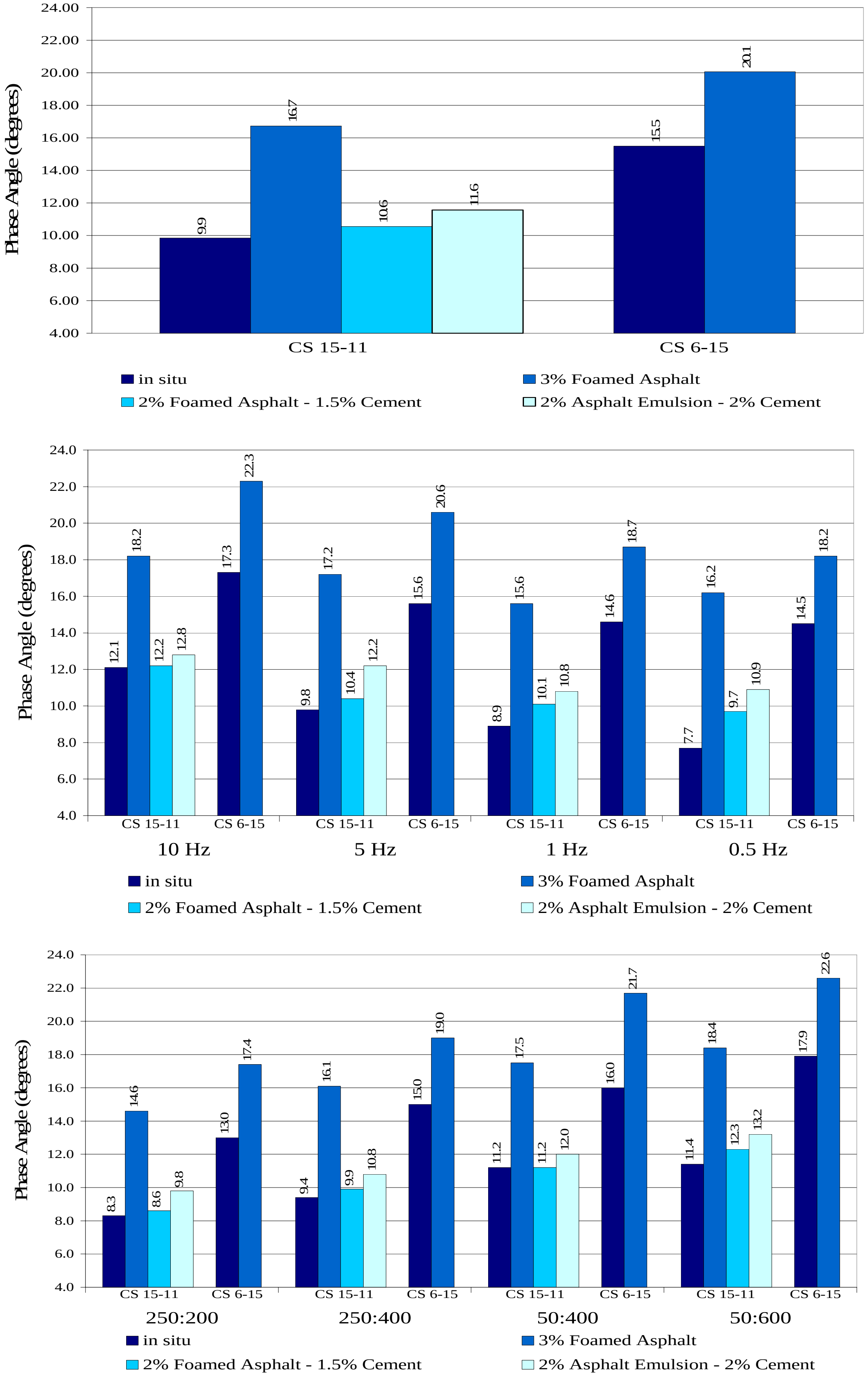


Figure 5 Radial Microstrain across Stabilization System, Load Frequency and Stress State



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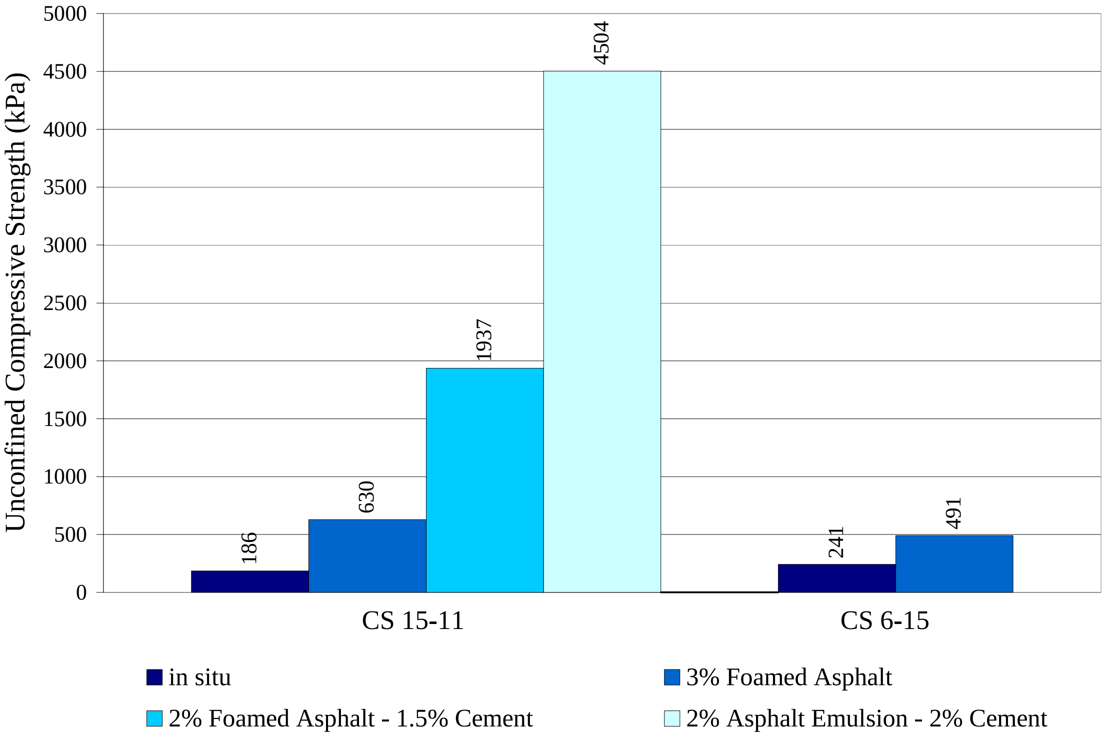

Figure 7 Post Moisture and Freeze-Thaw Climatic Conditioning Unconfined Compressive Strength across Stabilization System