Northern Resource Road Strengthening with Engineered Polyurethane Systems

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Abstract

Northern road corridors serve as critical economic infrastructure for northern resource development, forestry, and access to remote northern communities. There is a growing need for transportation capacity in the north given the expansion of resource development as well as a national vision for national strategic east-west transportation. Due to the inherent geology and repeat glaciation events, northern haul roads are often built out of relatively poor locally available materials and are repeat in areas with significant surface water. Northern roads are also often unsurfaced or thin sealed as conventional paving is typically too cost prohibitive from a capital and life cycle maintenance perspective. Northern roads constructed of local silty-sand soils can however be highly susceptible to differential heave and surface deformations due to exposure to moisture and heavy traffic loadings.

Due to the lack of local quality aggregates throughout the north, this study investigated using engineered polyurethane foam systems to provide improved load carrying capacity and climatic durability of poor graded silty-sand soils common in the north. The expansive polyurethane composite systems considered in this study were specifically designed for silty-sand soils and characterized for improved shear road structural behavior and climatic durability of northern roads.

PSI*Materials*4D triaxial frequency sweep material constitutive testing was used to evaluate silty sand subgrade samples employing a balanced volumetric mix design process. Mechanistic road modelling PSI*Unsurfaced*3D employed the material constitutive relations in three proposed stabilized structures to determine the principal shear strain behaviour experienced under typical heavy industrial loading conditions of a 9-axle b-train.

This paper showed engineered expansive polyurethane foam systems can be tailored for marginal silty-sand materials to improve the structural primary shear response of typical northern road materials. This study also showed remote northern haul road structures can be cost effectively upgraded at a fraction of the time and cost using remote in-place recycling and deep polyurethane injection methods warranting further research in these alternative systems to provide northern haul road load carrying capacity.

Introduction

Many northern roads serve as economic corridors in support of northern resource development such as forestry and mining; as well as access to remote northern communities, support for tourism, etc. However, materials often used to construct northern roads do not meet road structural specifications similar to southern roads due to lack of quality road building materials in the north. As a result, when poorer *in situ* soils such as silty sands are used to construct roads, significant plastic differential strains from heavy industrial truck loadings, as shown in Figure 1 combined with moisture infiltration and frost heave commonly occurs (1,2).

From a road structural performance perspective, significant increases in load induced strain gradients, often beyond the plasticity limit of the *in situ* materials, particularly in high moisture conditions, will accelerate shear failures (3). This failure mode is also accelerated by typical narrow northern road cross sections and abundant surface water creating lateral moisture infiltration into road grade.

As development in the north expands across Canada as part of national resource sector growth, future east-west corridors, in-service northern haul roads will experience increased truck traffic as well as larger heavy haul units as those being seen around the world. Deterioration under growing truck traffic demands and larger trucks configurations challenge engineers to create unconventional structural designs to provide critical transportation infrastructure that supports the northern resource industry.

Expansive polyurethane soil strengthening systems engineered to penetrate soils and improve structural integrity and climatic durability of marginal geo-materials cost effectively could be highly beneficial for providing all season load carrying capacity of northern roads. Polyurethane foam can be used as both a maintenance system through injection and/or as part of structural surface rehabilitation, as seen in Figure 2.

Figure 1. Northern Unsurfaced Haul Road with Heavy Forestry Truck



Figure 2. Polyurethane Foam Shoulder Injection and Full Depth Reclamation





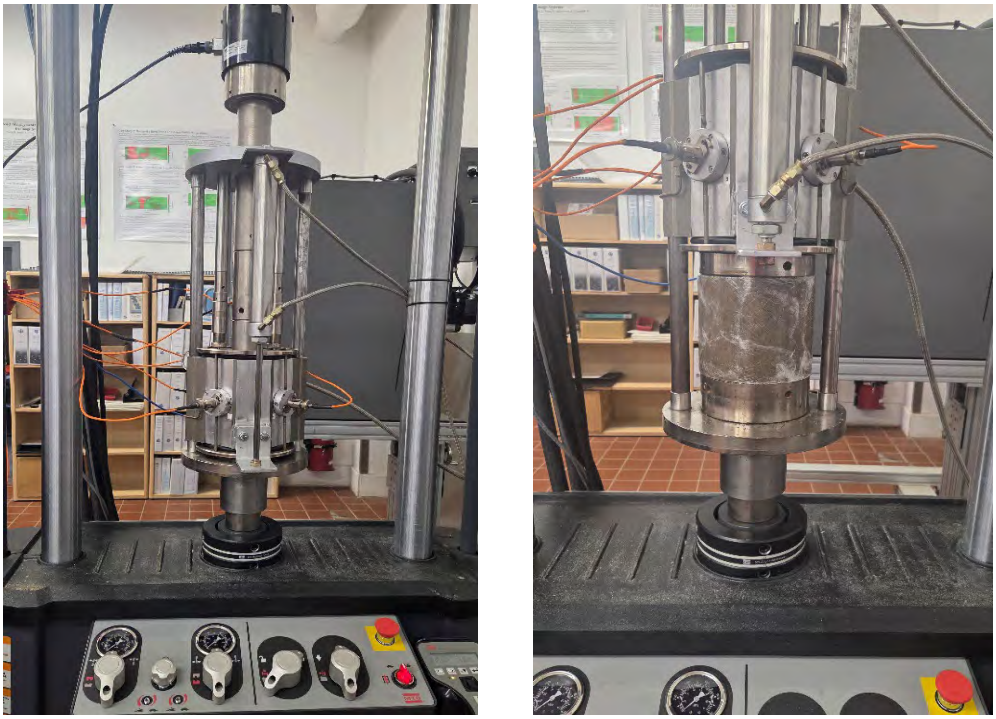
Study Objective and Scope

The objective of this study was to examine the use of cost effective and specialty engineered polyurethane foam systems to improve the shear behaviour of typical *in situ* northern road subgrade materials. Triaxial frequency sweep material characterization was used to provide the material constitutive relations needed to perform full 3D numerical modelling of three typical northern resource road strengthening scenarios.

Triaxial Frequency Sweep Mechanistic Characterization

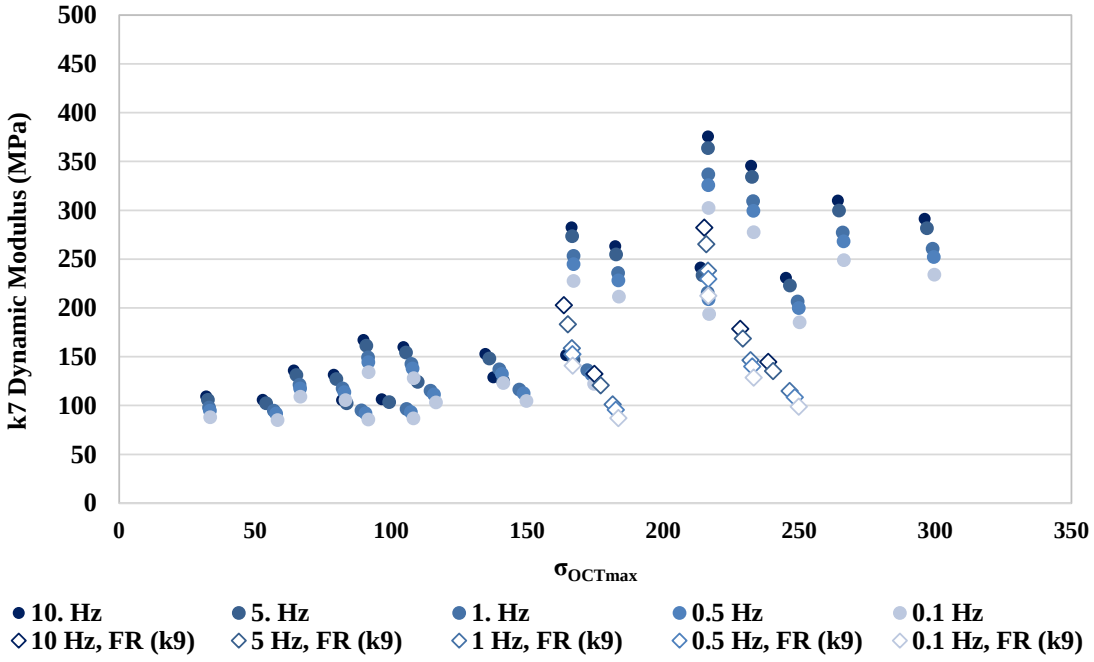
This study employed PSI*Materials*4D triaxial frequency sweep multi-stress step function testing protocols (4) to characterize the effects of expansive polyurethane stabilized silty sand materials, as illustrated in Figure 3. The material constitutive relations obtained from PSI*Materials*4D were characterized across multiple stress states and load frequencies in continual deviatoric compression as well as fully reversed deviatoric stress states to capture the full range of material behaviour within typical northern haul road field state conditions, truck loadings and traffic speeds.

Figure 3. PSI*Materials*4D Triaxial Frequency Sweep Test Apparatus of Engineered Expansive Polyurethane Stabilized Northern Silty Sand Road Material



The expansive polyurethane material properties were engineered to improve shear strain profiles with depth into a typical northern road structure under critical state truck loading. As seen in Figure 4 through Figure 9, the engineered polyurethane systems specifically designed to strengthen silty sands significantly improved the mechanistic shear stiffness behaviour of the *in situ* sand material, particularly at higher deviatoric stress states.

Figure 4. Dynamic Modulus across Bulk Stress States



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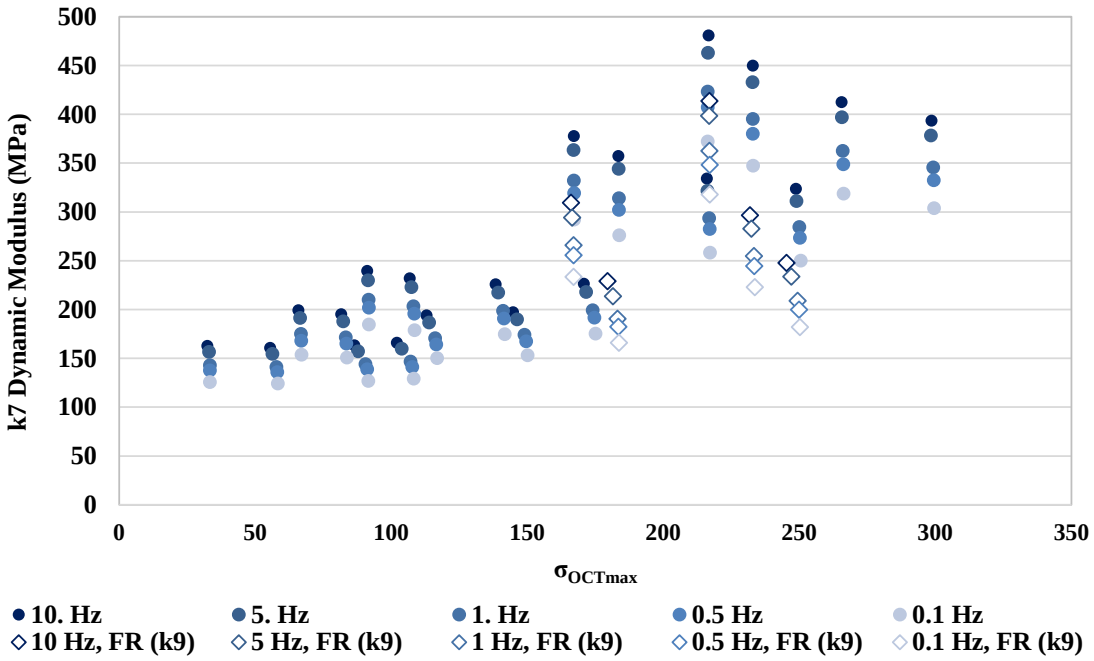

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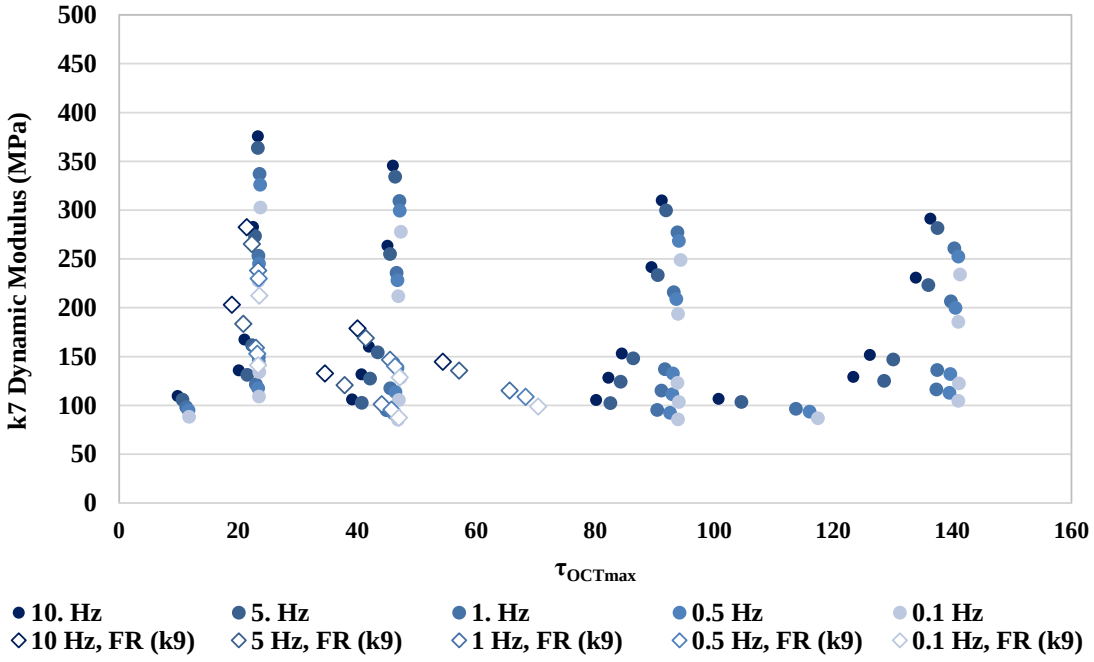
Figure 5. Dynamic Modulus across Deviatoric Stress States



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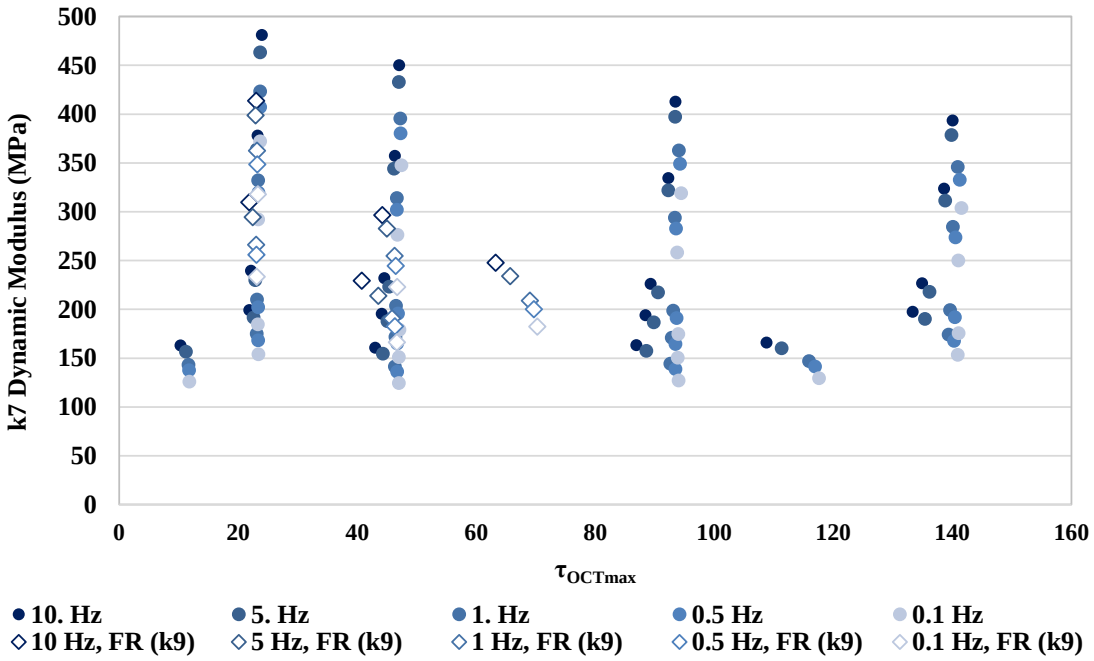

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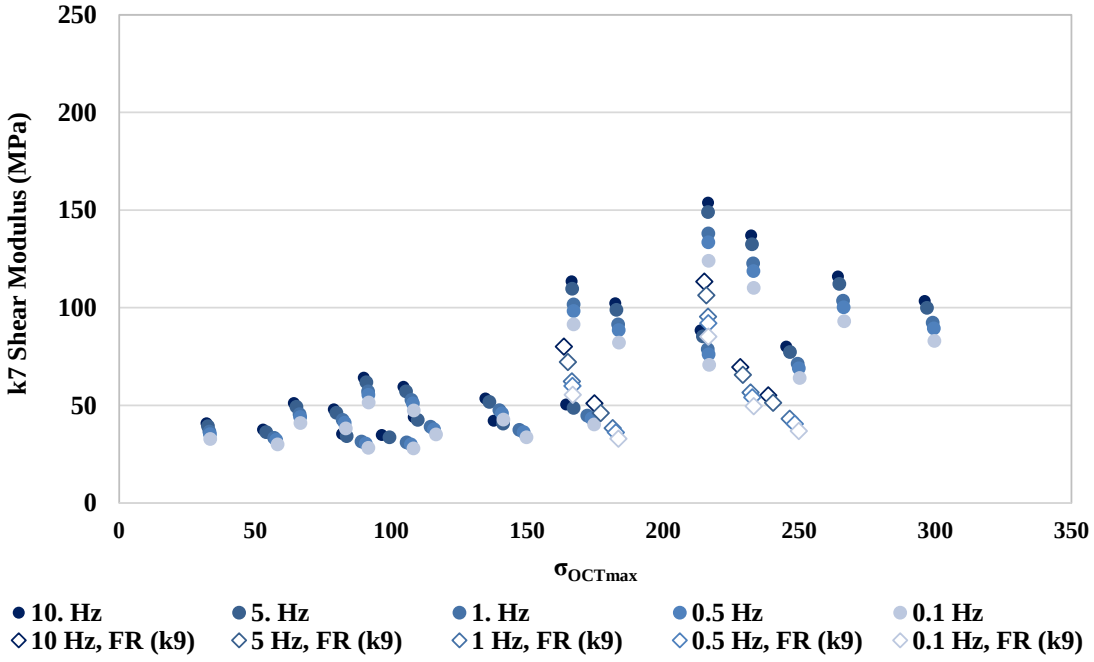
Figure 6. Shear Modulus across Bulk Stress States



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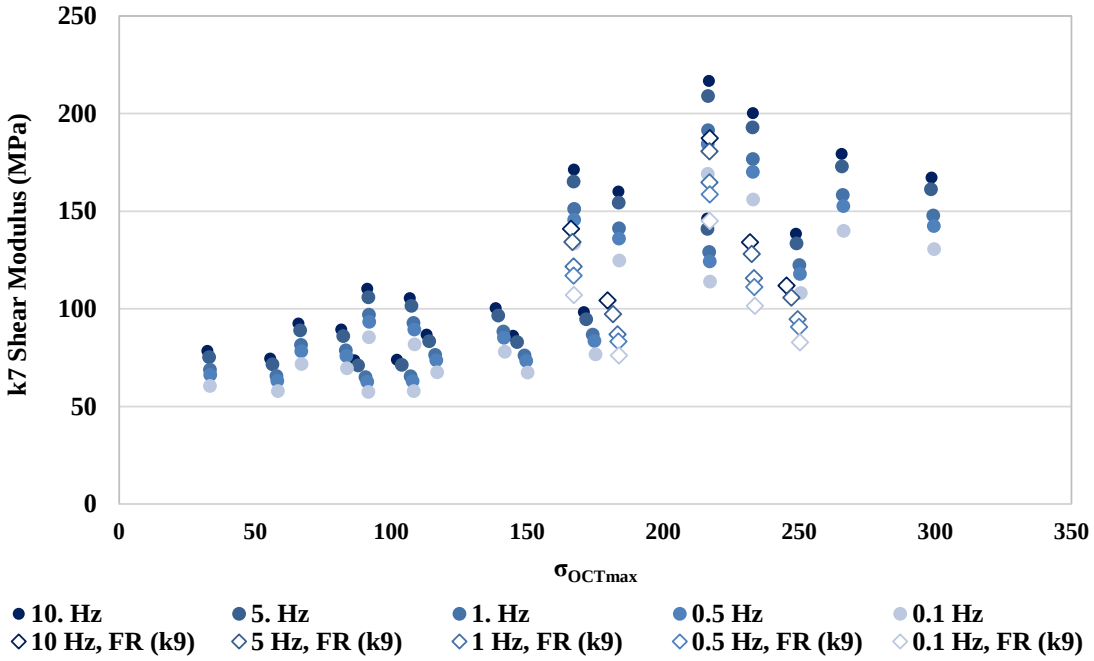

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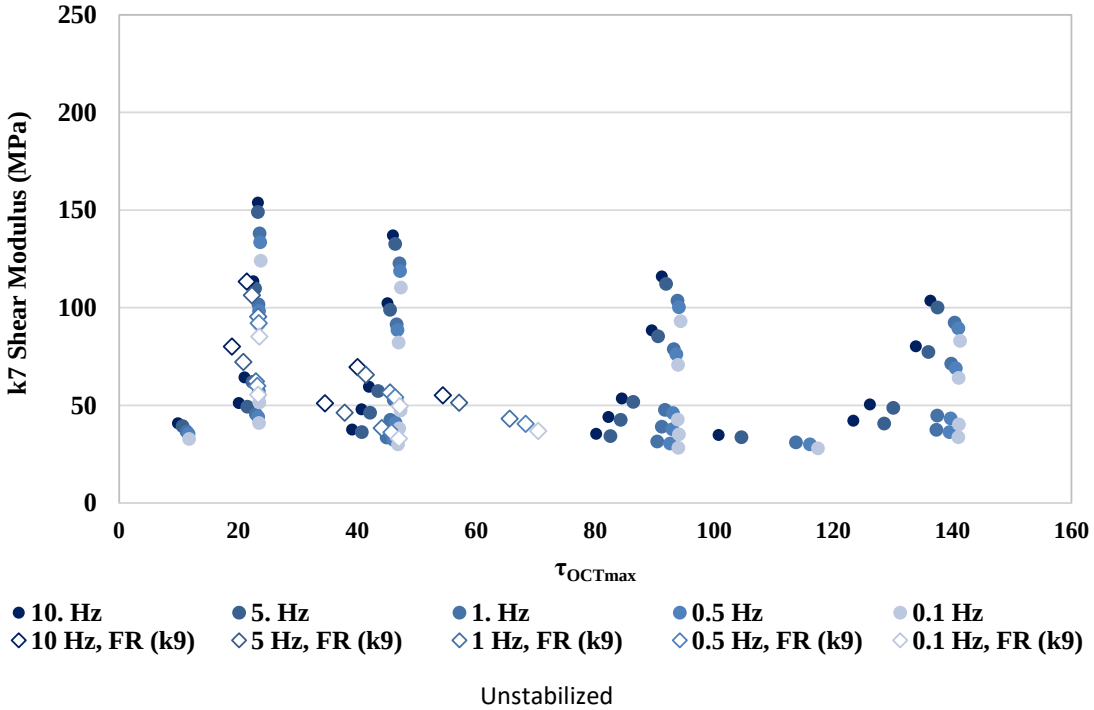
Figure 7. Shear Modulus across Deviatoric Stress States



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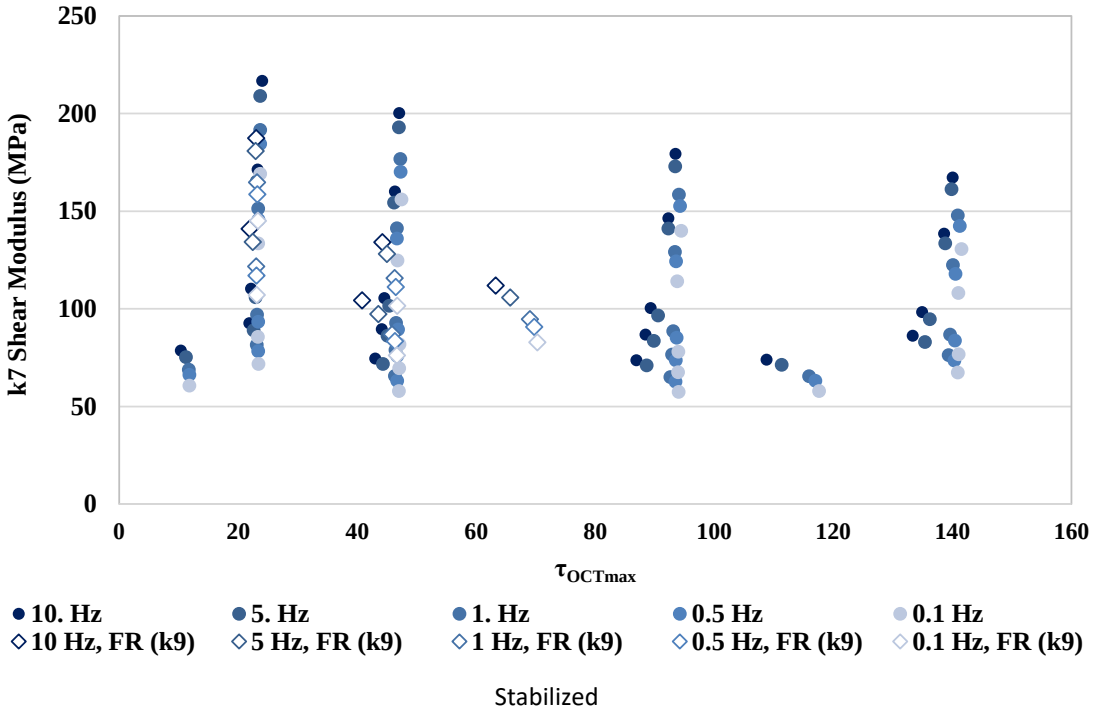

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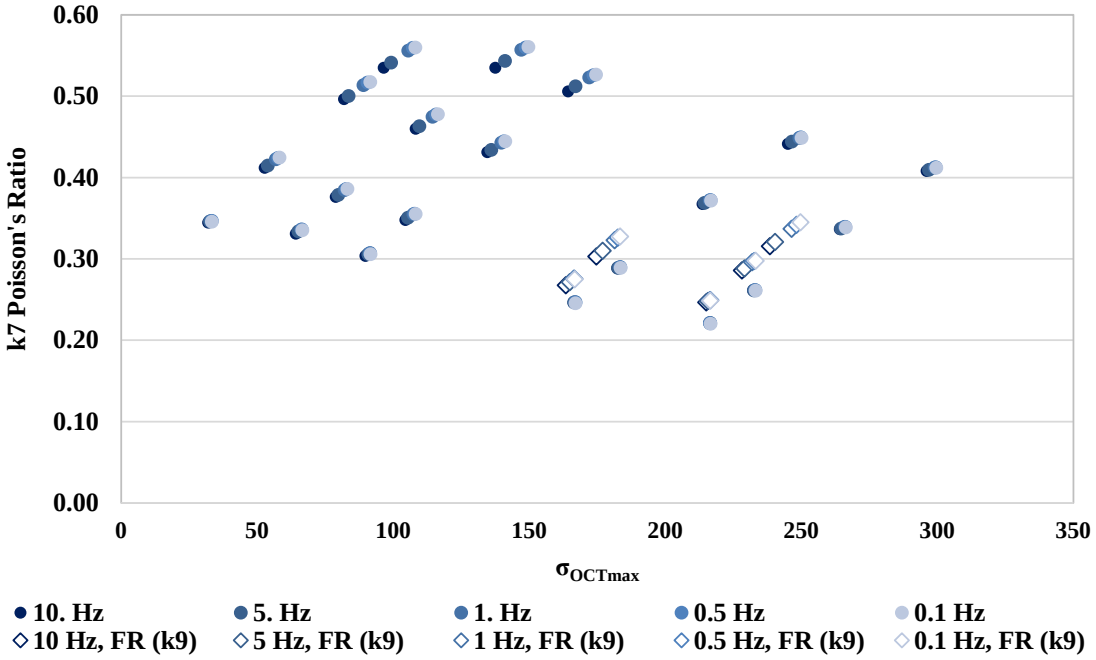
Figure 8. Poisson's Ratio across Bulk Stress States



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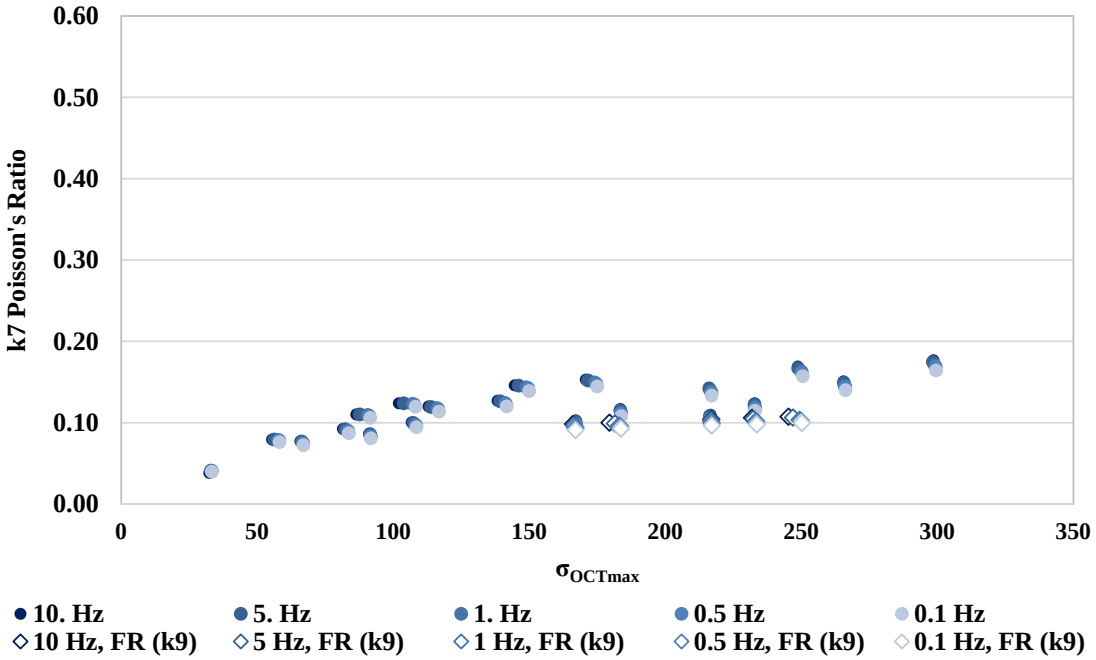

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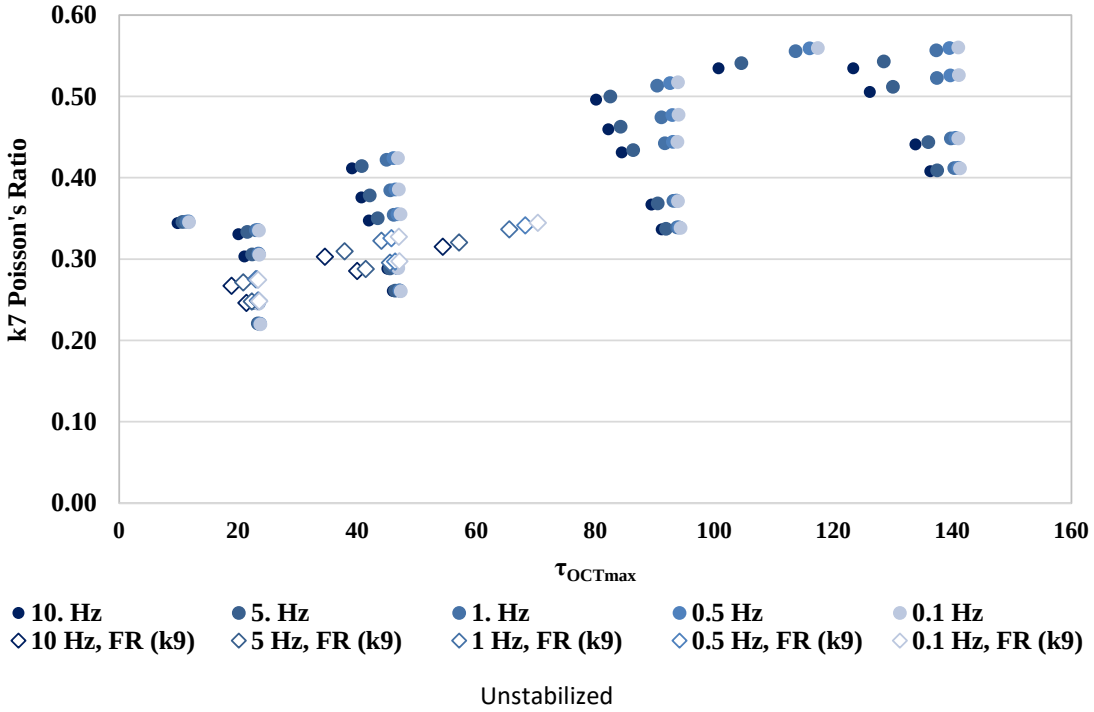
Figure 9. Poisson's Ratio across Deviatoric Stress States



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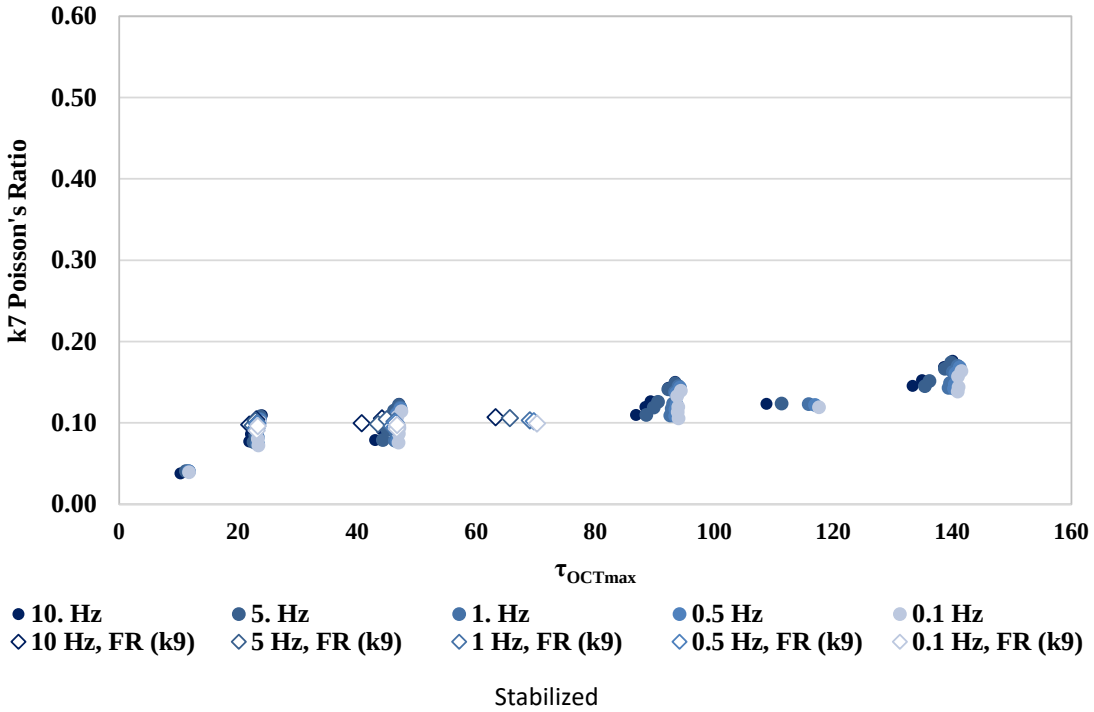

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PSI*Unsurfaced*3D Modelling Results

The numerical road modelling employed in this study was specifically targeted to simulate the challenging field state shear behaviour of a narrow road with steep side slopes and adjacent water against the side slope of the road, as illustrated in Figure 10.

Figure 10. Typical Edge Shear Failure with Adjacent Water and Steep Side Slopes



The material constitutive relations of the unstabilized and polyurethane stabilized silty sand were encoded into PSI*Unsurfaced*3D numerical road structures (5), as shown in Figure 11. As seen in Figure 11, the northern haul road modelling scenarios included: 10m top grade with 2:1 side slopes, 3m road top to ditch bottom made of silty sand typical of the north.

As seen in Figure 11 and Figure 12, a 9-axle truck configuration at 72,500 kg permitted load limit used in northern resource trucking was used as the applied surface loading. Given the road structure considered was an unsurfaced northern haul road, shear strain profiles within the road structure and the shoulders were used to compare primary structural response results across the cases considered in this study.

This base case model was then modified with 5.0m polyurethane stabilized shoulders and a 0.5m stabilized wearing surface, as shown in Figure 13. The PSI*Unsurfaced*3D numerical finite element model used to evaluate the specific case studies to compare an engineered expansive polyurethane stabilized unbound granulars with those unstabilized. Principal shear strain magnitude and lateral strain movement of each case were compared as the primary performance indicator variable

Figure 11. PSI*Unsurfaced*3D Numerical Haul Road Cross Section and Loadings Base Case Evaluated

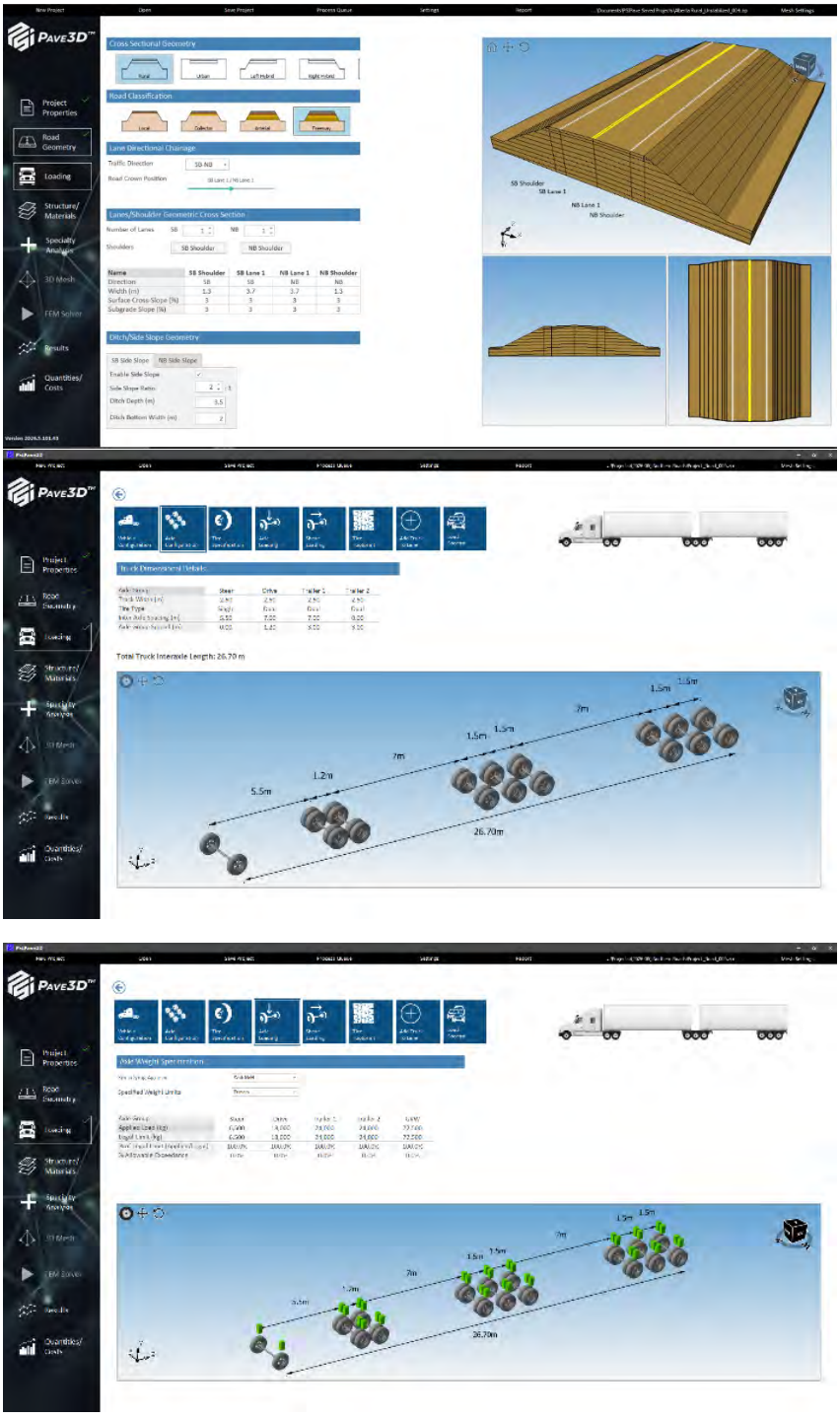


Figure 12. PSI*Unsurfaced*3D Numerical Northern Haul Road Cross Section and Numerical Mesh

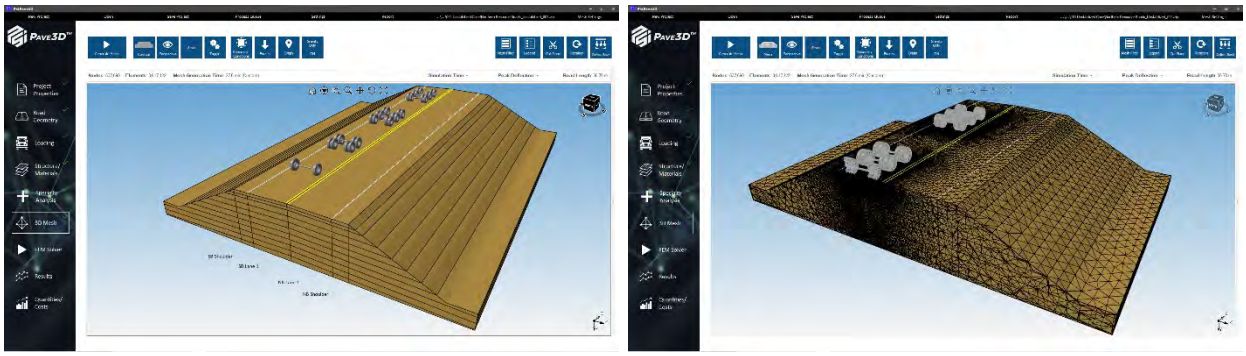
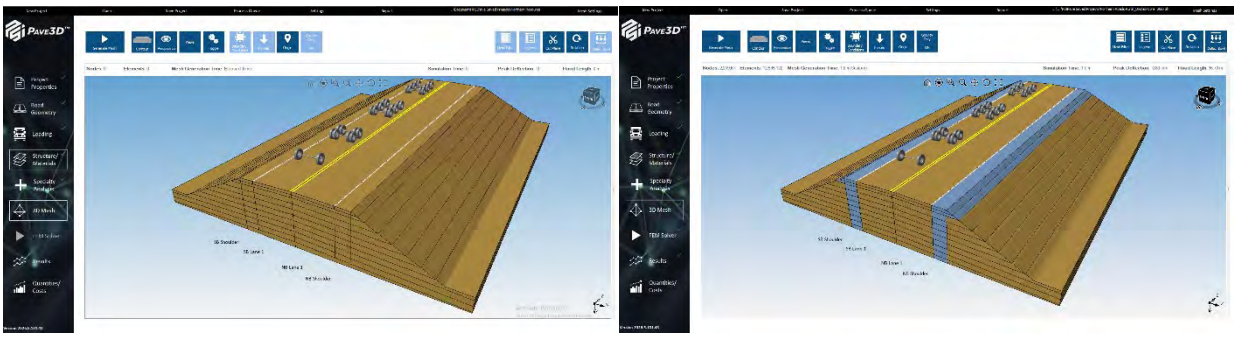


Figure 13 illustrates the four road structure scenarios evaluated in this study.

a) Unstabilized
b) Stabilized Shoulder (5.0m)
c) Stabilized Surface (0.5m)
d) Stabilized Surface (0.5m) and Stabilized Shoulder (5.0m)

Figure 13. PSI*Unsurfaced*3D Numerical Model of Polyurethane Stabilized Road Structures Evaluated



a) Unstabilized

b) Stabilized Shoulder (5.0m)



c) Stabilized Surface (0.5m)



d) Stabilized Surface (0.5m) and Shoulder (5.0m)

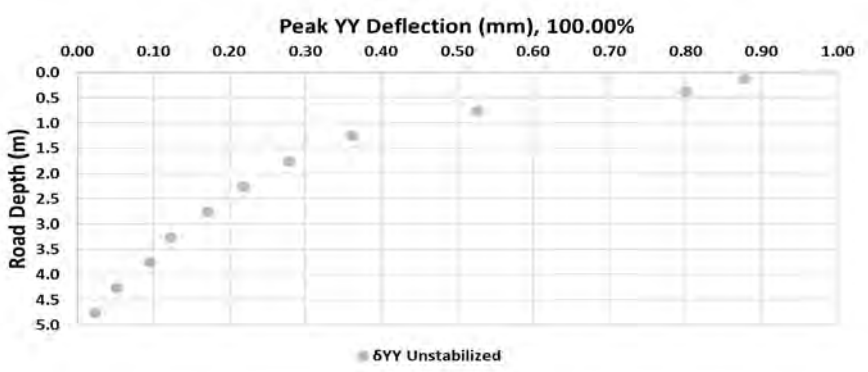
To evaluate the effects of the three alternate polyurethane foam stabilized road structures, the results of each structure were compared directly to the unstabilized road structure. Two primary response profiles with depth were examined: 1) peak vertical deflection profile, and 2) principal shear strain profile with depth into the road structure.

Each scenario compared vertical deflection and principal shear strain within the core of the road as well as the shoulder of the road separately. Figure 14 through Figure 17 illustrates the results obtained from each scenario, respectively.

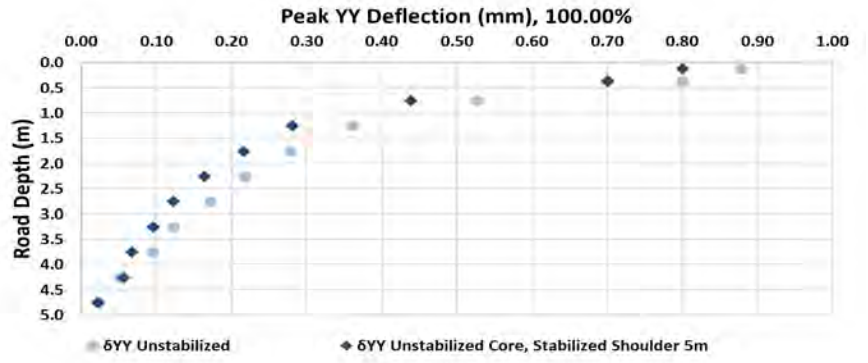
As seen in Figure 14, polyurethane foam injection within the shoulders to a depth of 5.0m only marginally decreased vertical deflection profiles in the core of the road, as expected. However, both surface stabilization (0.5m) scenarios evaluated significantly decreased the vertical deflection profile within the core of the road. If the surface was stabilized with 0.5m of polyurethane foam, there was minimal to no added vertical deflection profile reduction observed by stabilizing the shoulders. Similar trends in principal shear strain were observed in the core of the road across the three stabilization profiles, as seen in Figure 15.

As seen in Figure 16, vertical deflection with depth in the shoulders was significantly reduced with shoulder stabilization, and was only minimally improved further with surface stabilization. As seen in Figure 17, principal shear strains were significantly reduced in the shoulder with all three stabilization scenarios, but the most significant reduction in principal shear strain in the shoulder was observed in the shoulder only stabilization scenario.

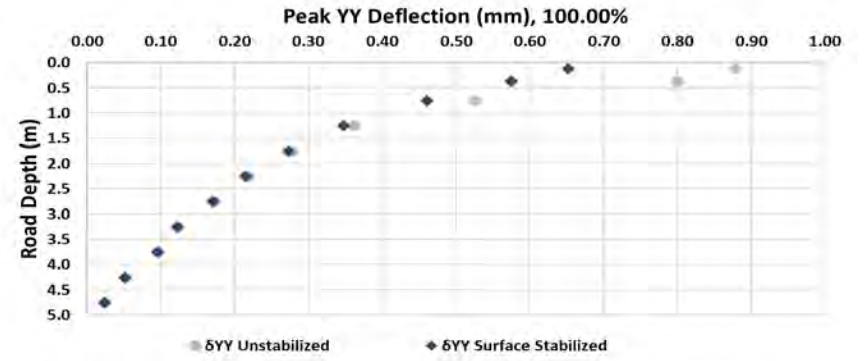
Figure 14. Core of Road Vertical Deflection Profile with Depth



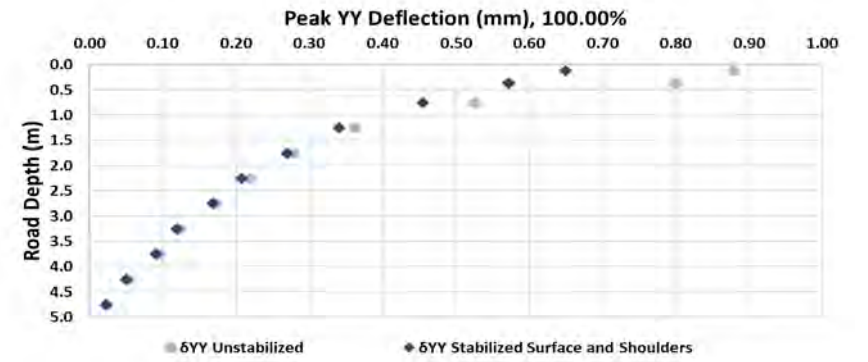
a) Unstabilized



a) Stabilized Shoulder (5.0m)



c) Stabilized Surface (0.5m)

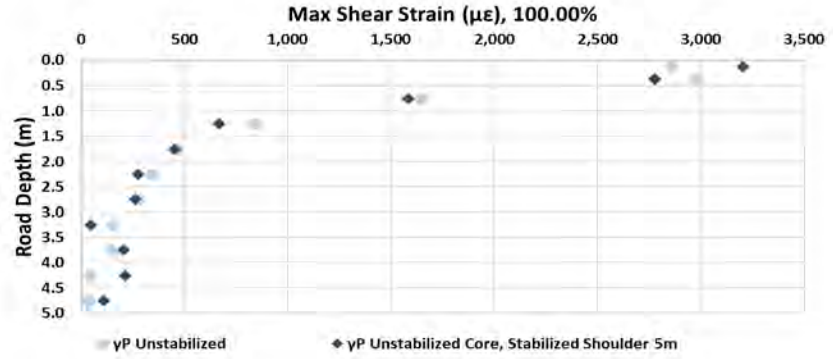


d) Stabilized Surface (0.5m) and Shoulder (5.0m)

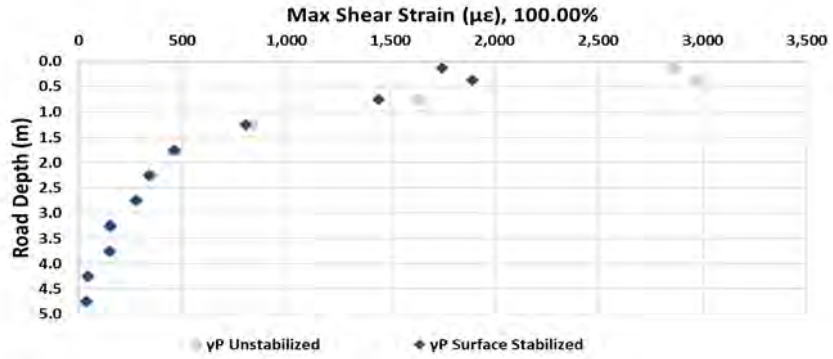
Figure 15. Core of Road Peak Shear Strain Profile with Depth



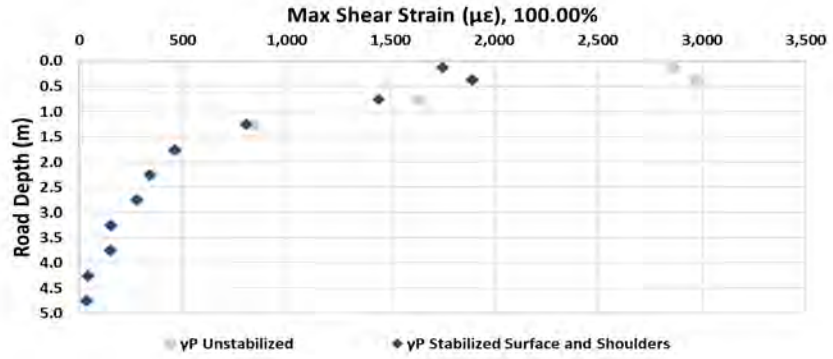
a) Unstabilized



b) Stabilized Shoulder (5.0m)

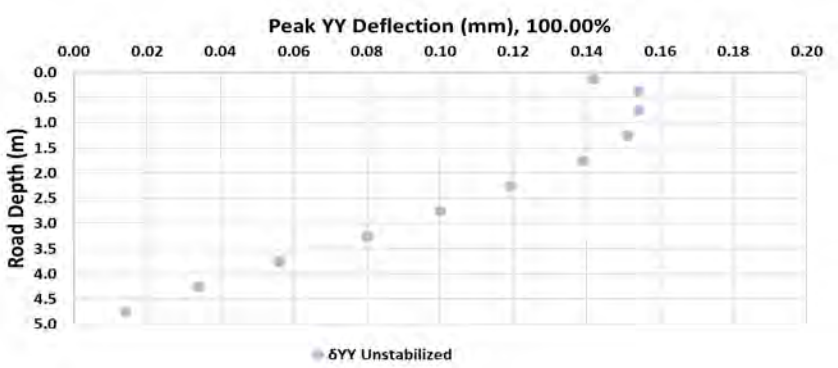


c) Stabilized Surface (0.5m)

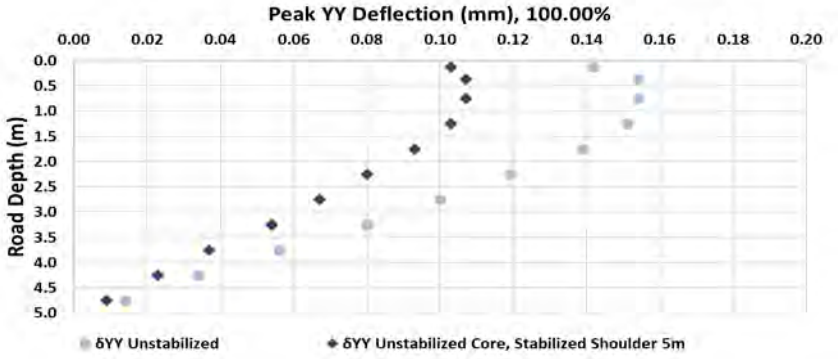


d) Stabilized Surface (0.5m) and Shoulder (5.0m)

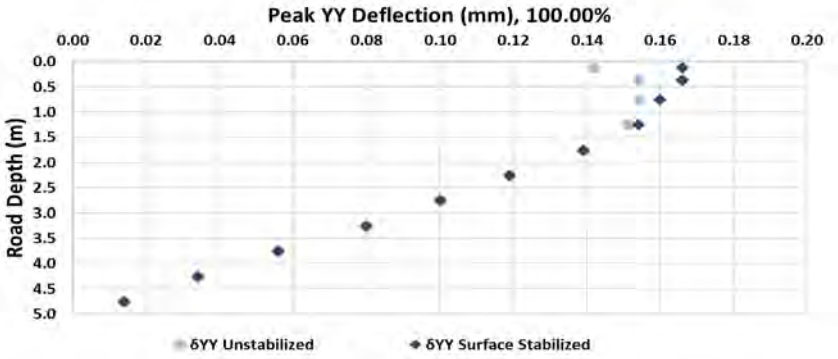
Figure 16. Shoulder of Road Vertical Deflection Profile with Depth



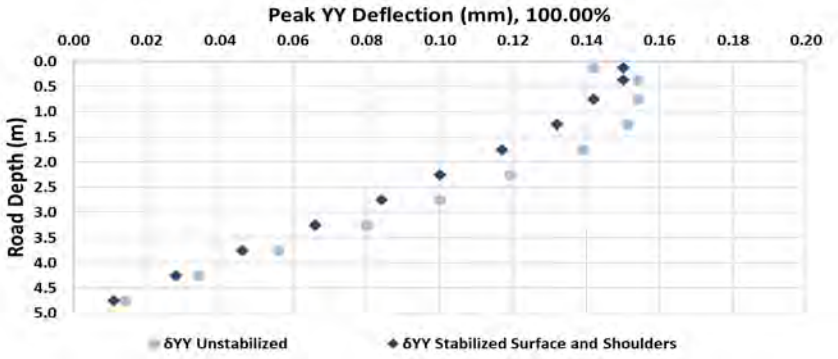
a) Unstabilized



b) Stabilized Shoulder (5.0m)

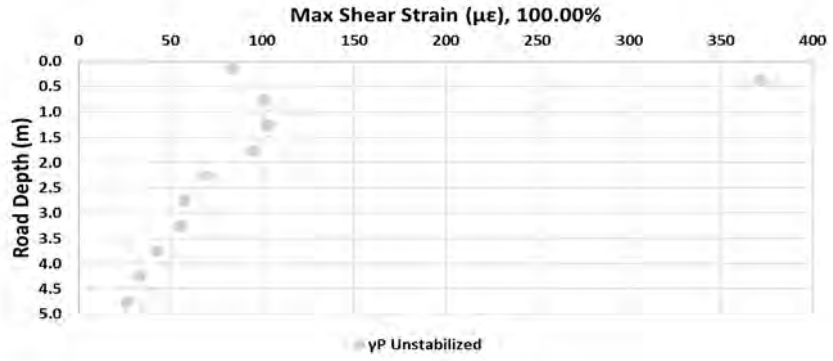


c) Stabilized Surface (0.5m)

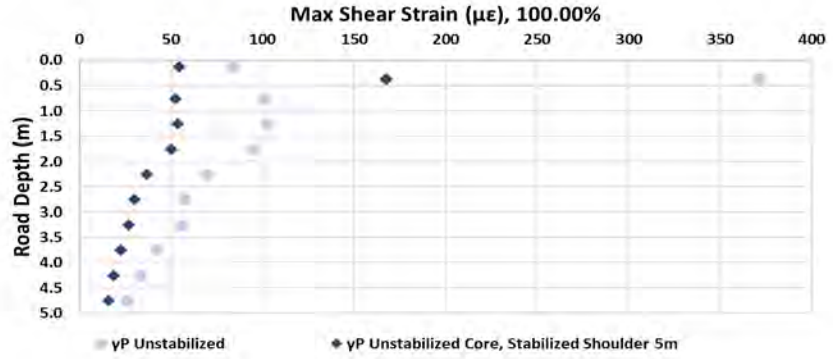


d) Stabilized Surface (0.5m) and Shoulder (5.0m)

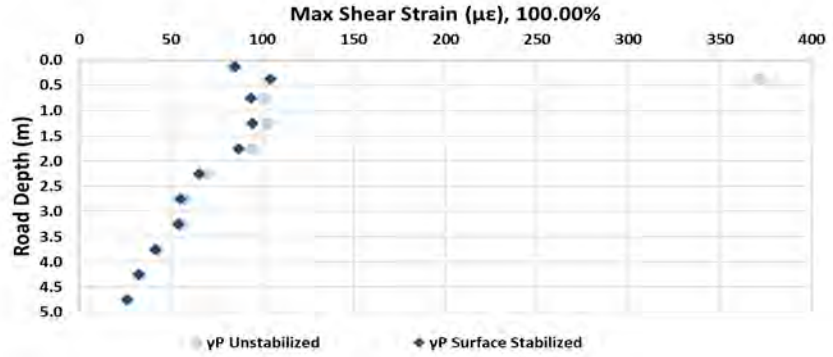
Figure 17. Shoulder of Road Peak Shear Strain Profile with Depth



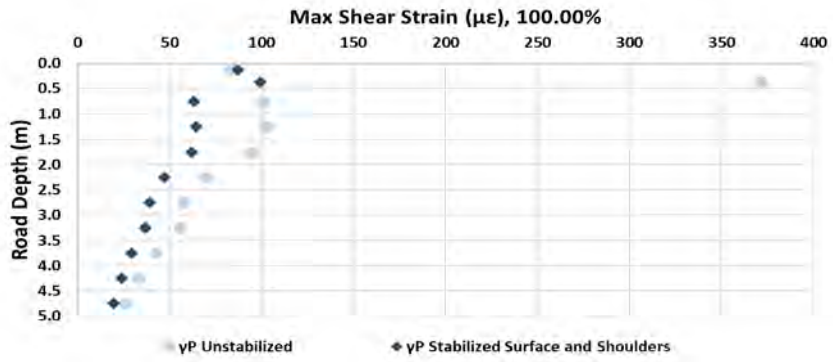
a) Unstabilized



b) Stabilized Shoulder (5.0m)



c) Stabilized Surface (0.5m)



d) Stabilized Surface (0.5m) and Shoulder (5.0m)

Conclusions

Haul road corridors serve as a critical economic infrastructure for northern resource development. Due to the geologic history of the north, northern haul roads are often built out of relatively poor locally available materials and are often unsurfaced. Many northern roads contain poor *in situ* silty-fine sandy soils that are highly susceptible to differential heave, settlements and rutting due to the combined effects of heavy traffic loadings and top down, as well as lateral moisture infiltration. Northern roads therefore often perform poorly structurally. Many northern roads could therefore benefit from cost effective strengthening systems that provide improved load carrying capacity and climatic durability.

This study employed mechanistic materials characterization and 3D numerical road modelling to evaluate engineered composite expansive polyurethane modified road material systems. The specialty engineered polyurethane expansive systems considered herein were found to provide several primary response performance advantages to improve remote northern haul roads constructed of marginal silty sand from a load carrying capacity and climatic durability perspective.

Based on the analysis performed, northern haul road structural primary response can be significantly improved with engineered polyurethane foam systems over conventional untreated silty-sand materials. It was also shown that expansive polyurethane modified northern subgrade materials can be engineered to reduce the 3D strain profiles in both the core of the road as well as the shoulders. An additional advantage of engineered polyurethane foam for road strengthening is it can be chemically modified to suit specific road material types and structural needs to improve road structural primary performance, particularly lateral road edge shear failures.

Additional operational benefits of polyurethane material systems for road strengthening is the ability to inject from surface without reworking the road structure. This can be highly advantageous in areas in need of repair quickly to improve structural capacity and climatic durability, particularly in areas requiring lateral shear edge failures are occurring which is common in northern road structures. As well, the expansive behaviour of the engineered polyurethane modified unbound granulars system helps to penetrate into the interstitial voids, thus reducing differential shear strains due to particle binding effects. Therefore, improved structural densification and structural confinement support under heavy resource haul load conditions typical of northern road edge field state conditions is possible. High elastic strain limit behaviour of the expansive polyurethane modified unbound granulars can also absorb significant 3D strains resulting from repeat heavy loads common in northern resource haul roads therefore making it a well suited for repeat loading structural road applications.

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