Earth Pressure as a Boundary Condition to Bridge Piers and Abutments

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Abstract

Bridge piers and abutments makeup the bridge substructure and transmit loads from the superstructure to the bridge foundation material. The bridge abutment serves three purposes: to provide vertical support to the bridge superstructure where the bridge ends, to connect the bridge with the approach roadway, and to retain roadway base materials. Generally, the landside of the abutment has a lateral earth pressure applied along the face. Bridge piers are typically found between abutments and help transmit load to the foundation material. Bridge piers are freestanding and typically have earth pressure around the footing for a shallow foundation or around the footing and piles for a deep foundation.

The location of a bridge may lead to a change in the stabilizing design earth pressures over time. This study uses COMSOL to model the change in the bridge pier behavior due to change in earth pressure load in 2D and 3D using the Solid Mechanics Module with Eigenfrequency and Static studies. Dead and live loads representing the bridge superstructure and a single train engine are applied where the superstructure contacts the top of the pier. The earth pressure was applied to the vertical faces of the pier footing geometry as a user defined pressure boundary condition. For this study the piers had T-footings and a vertical pressure, representing the weight of the soil-water media, was applied to the top face of the footing. A spring bottom boundary condition was applied to the bottom of the footing representing the compressibility of the foundation soil.

The loss of stiffness in the substructure was determined through the change in lateral earth pressures, in this case the removal of material through scour. Additionally, the deformations of the substructure eigenmodes indicate that 2D plain strain modeling can adequately model changes in resonant frequencies for vertical and translational failure modes (lowest modal frequencies): most representative of loss of structural stiffness due to decreased earth pressures.

Problem Statement

Soil-structure interaction for both a shallow foundation case (in 2D and 3D) and a deep foundation case are investigated to determine if a significant change in eigenfrequency are present, allowing for detection and assessment of loss of earth pressures (i.e. scour).

Soil Properties

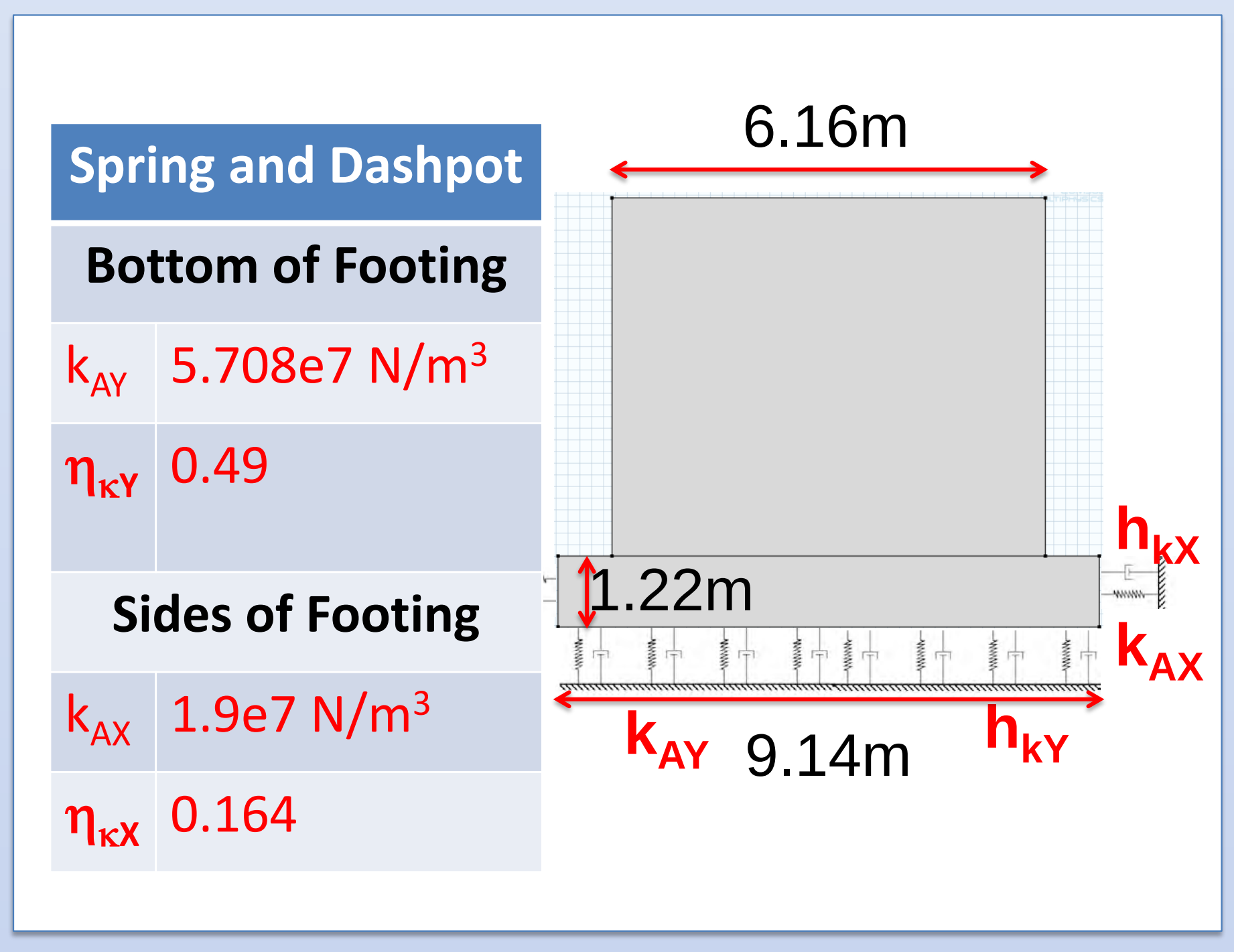
	Sand	Silt
Density (kg/m$^{3)}$	1800	1600
Poisson Ratio	0.4	0.3
Young's Modulus (Pa)	80e6	65e6
P-wave (m/s)	750	450
S-wave (m/s)	450	220
Cohesion (Pa)	0	5e3
Angle of Internal Friction	38°	30°

Soil properties for dense sand and silt

Soil-Structure Interaction

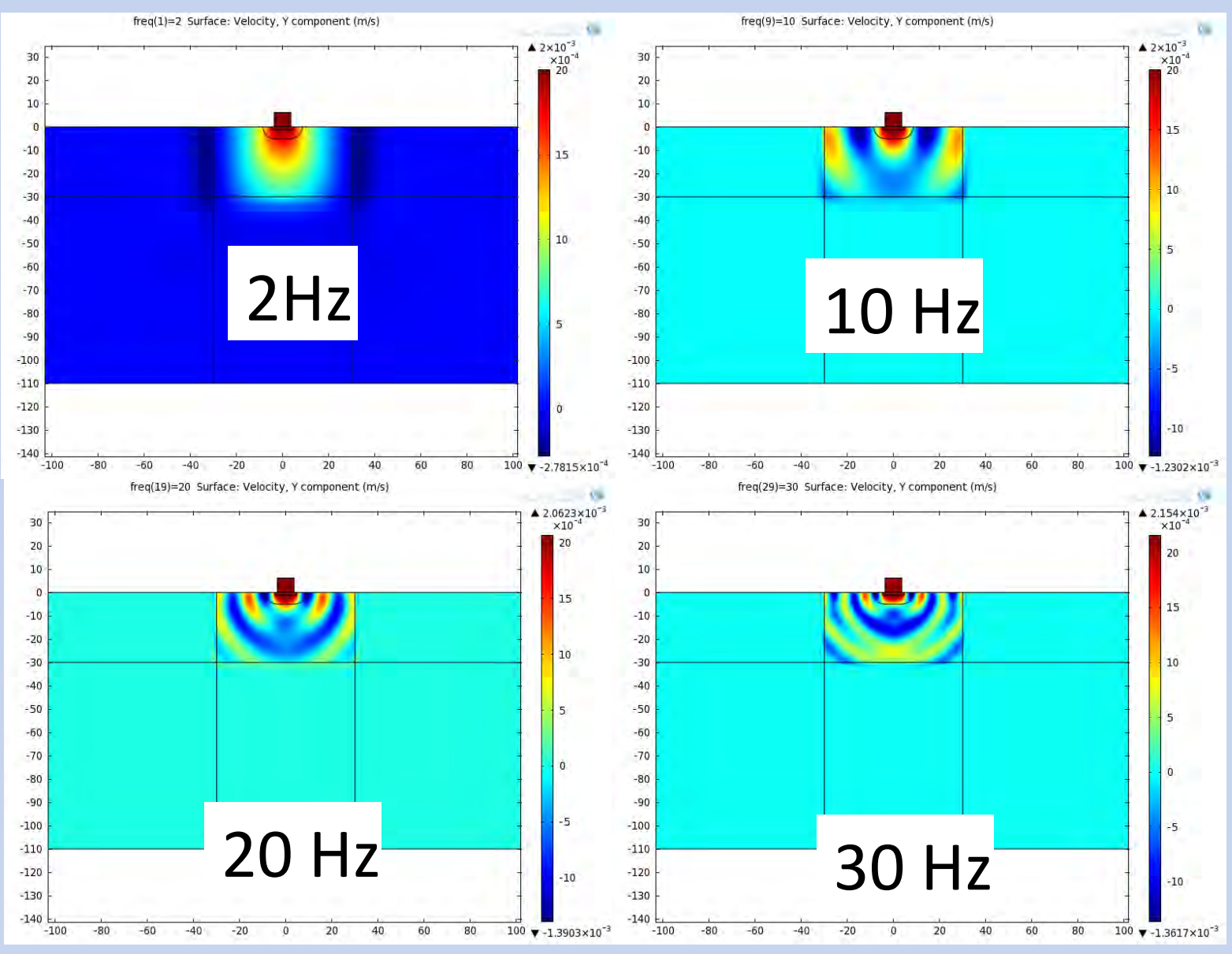
For the 2D Model:

- the interaction between the footing and surrounding soil was modeled as a series of springs and dashpots
- The outer boundaries of the soil block were modeled as rollers along the sides of the soil block.
- The bottom of the soil block was modeled as a fixed boundary.



Spring and Dashpot	
Bottom of Footing	
k_{AY}	5.708e7 N/m^3
$\eta_{\kappa Y}$	0.49
Sides of Footing	
k_{AX}	1.9e7 N/m^3
$\eta_{\kappa X}$	0.164

Soil Properties on the COMSOL model for Dense Sand

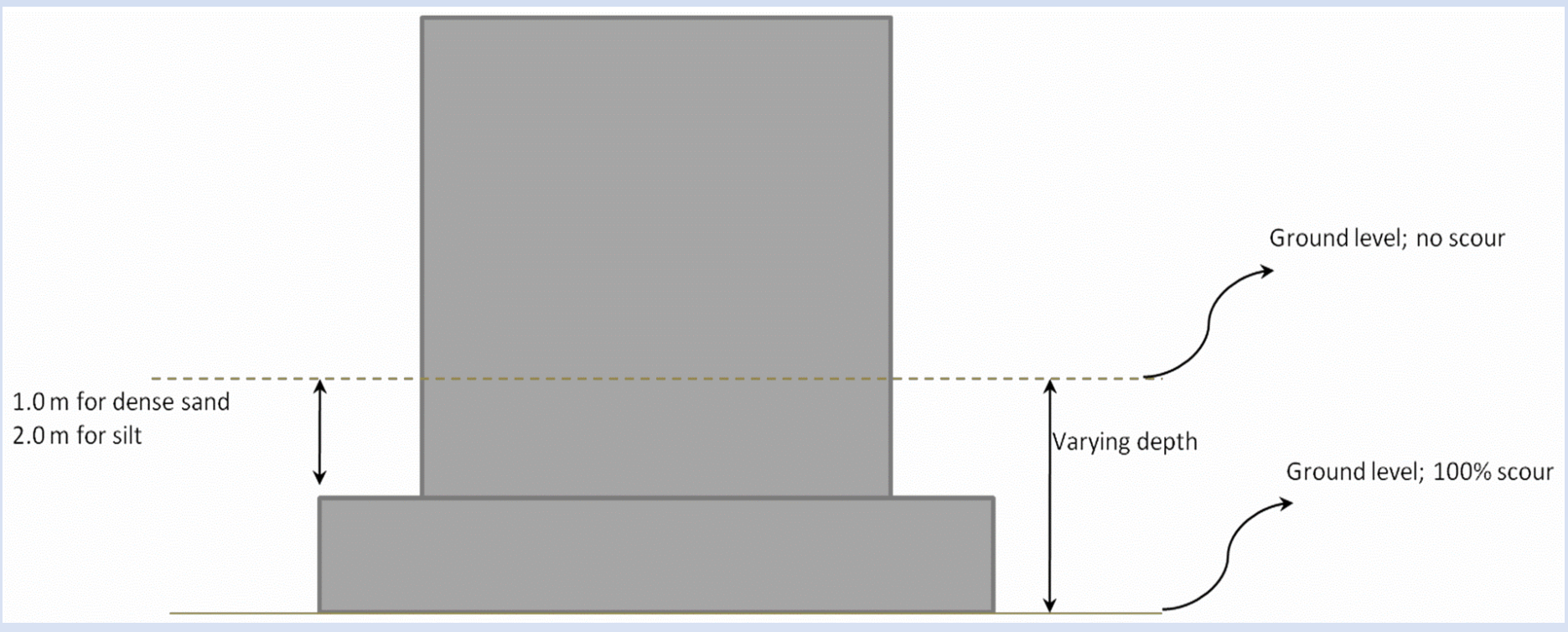


Surface Velocity amplitude Y component

Ft. Leonard Wood Railroad Truss

The Ft. Leonard Wood bridge pier was modeled using:

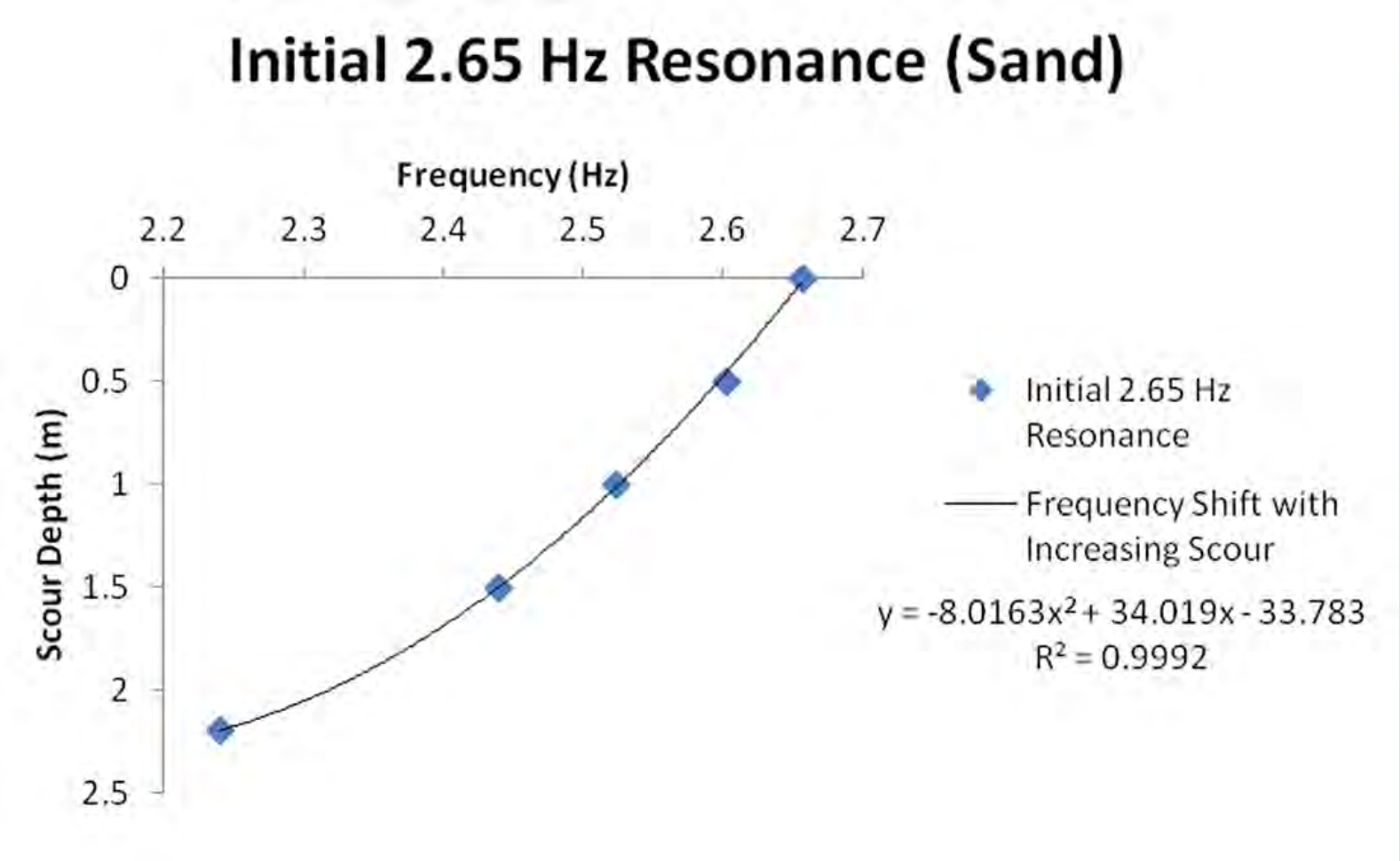
- 2D plane strain and loaded with a prescribed velocity corresponding to previously monitored and modeled train traffic moving across the bridge;
- A fine, triangular mesh was used and the model tested with two soil types: dense sand and silt;
- For each soil type, the loss of lateral earth pressure was modeled in 0.5 m increments of material loss;
- A frequency analysis performed at each interval to determine the new natural frequency.



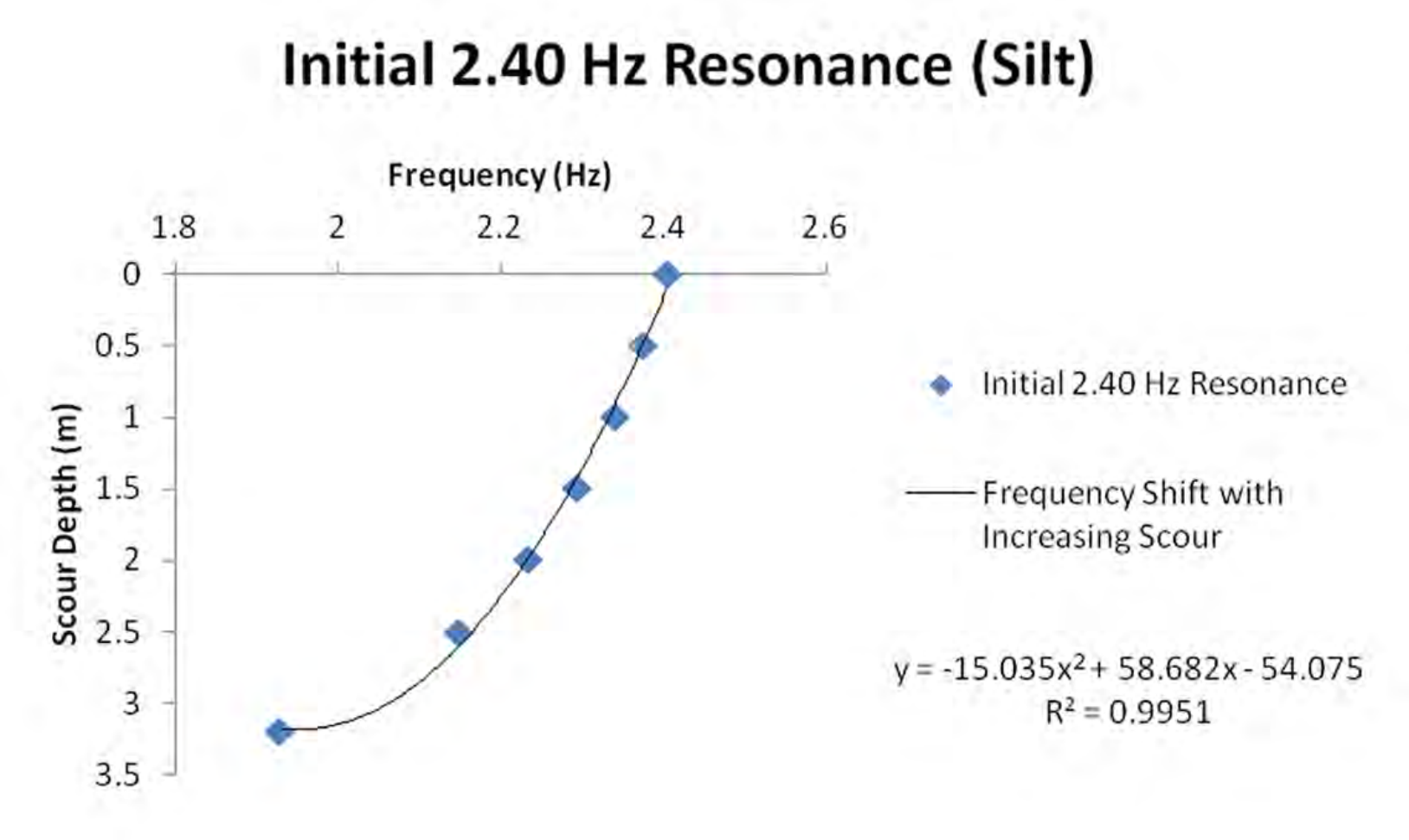
Varying scour depth

For each mode the variation in eigenfrequency with loss of lateral earth pressure (i.e. scour) was plotted to determine magnitude of variation and correlation to scour depth. For both soil types, the eigenfrequencies with the highest degrees of variability corresponded to field data obtained for this bridge.

Ft. Leonard Wood Railroad Truss—Model Results



Frequency vs. scour depth for 2D shallow foundation sand case



Frequency vs. scour depth for 2D shallow foundation silt case

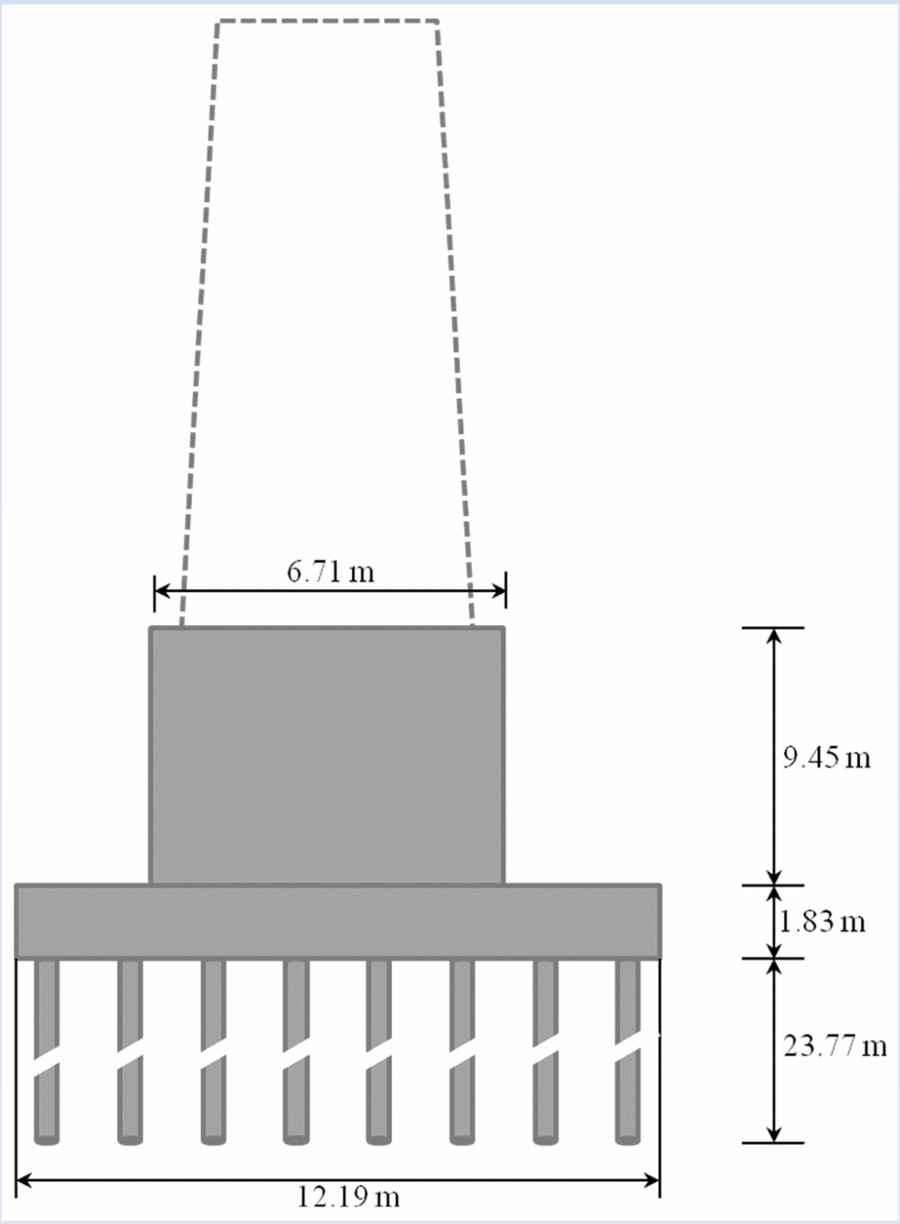
A 3D model of this bridge was completed next. In this case:

- The pier superstructure coupling was modeled as a series ok know reactionary forces;
- The soil was modeled as a lateral pressure boundary layer;
- The same procedure of varying the overburden depth used in the 2D model was repeated for the 3D model.

Results indicate no change between the total scour case and the no scour case, which is not representative of field data for this bridge. Further the foundations cannot be modeled independently of the soil. In other words, the soil cannot simply be modeled as a lateral pressure. Work to resolve the 3D soil-structure interaction boundary issues is ongoing.

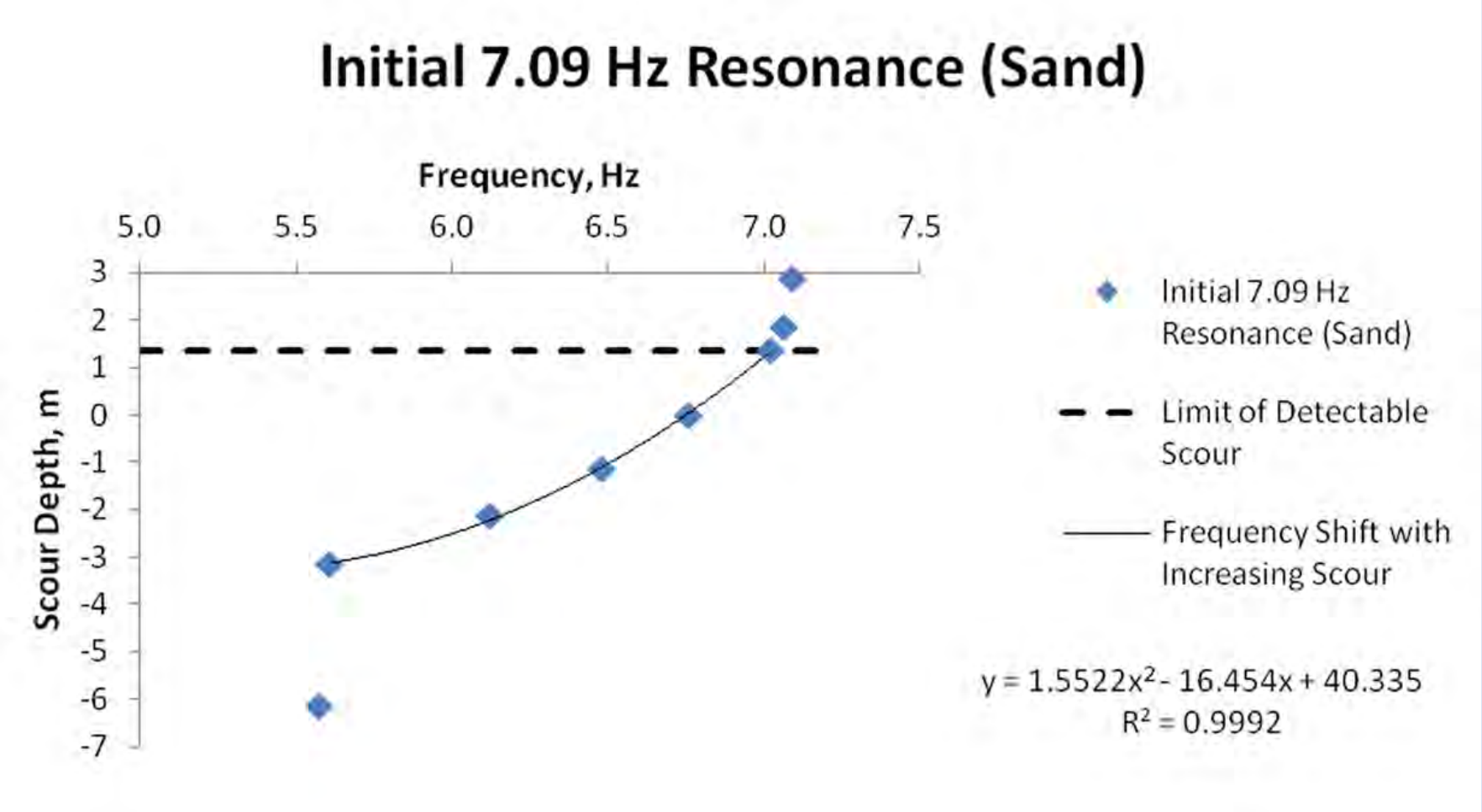
Interstate-20 River Bridge

A 2D model of one of the bridge piers from the I-20 Bridge over the Mississippi River in Vicksburg, MS was modeled to investigate the use of infrasound to detect and assess scour on a deep foundation. The model was tested with both dense sand and silt at varying levels of overburden corresponding to the top of the footing, mid-depth of the footing, bottom of the footing, and at 1m, 2m, 3m, and 6m of exposed pile with a frequency analysis performed at each interval (same procedure as shallow foundation).

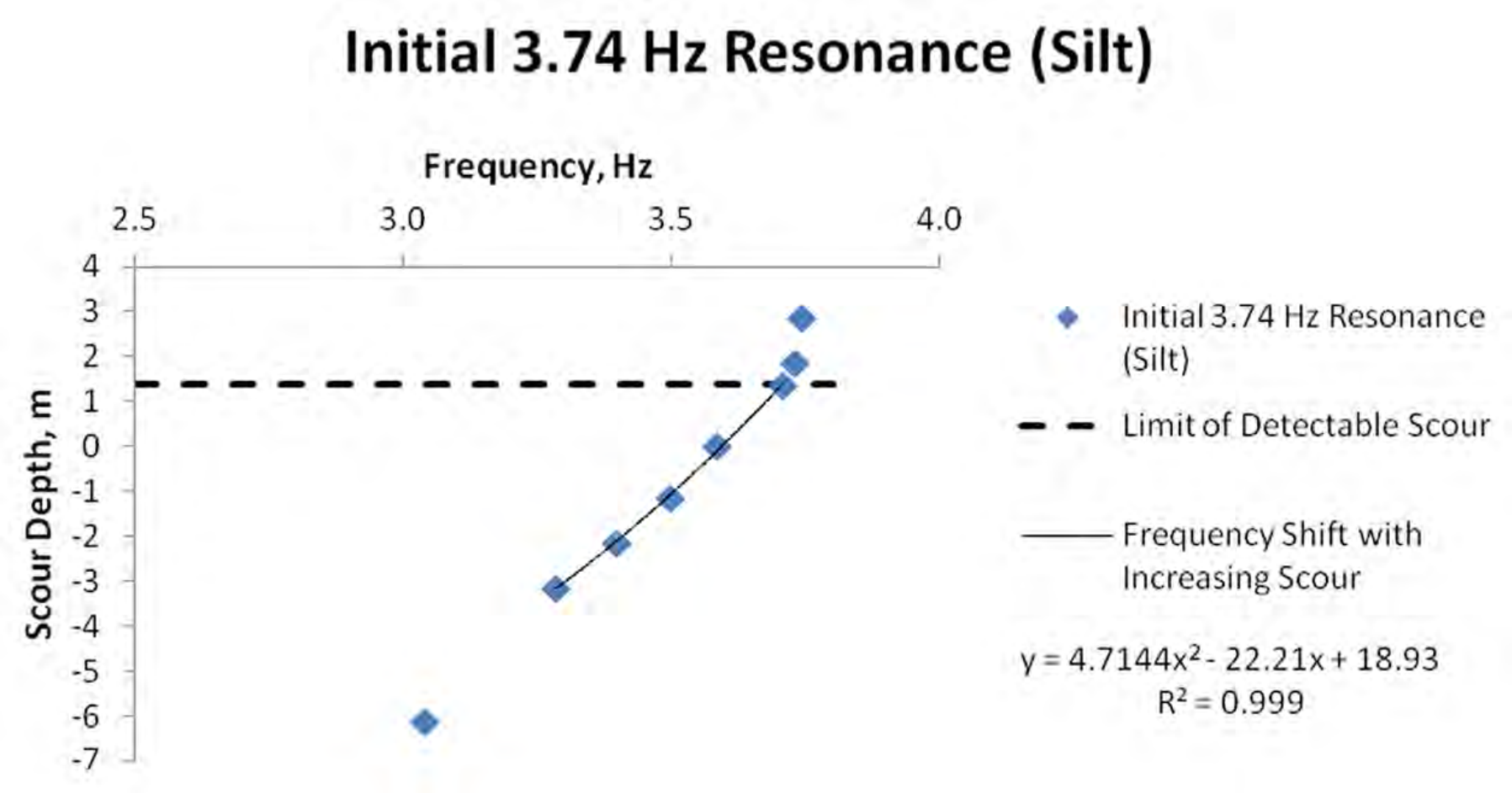


I-20 bridge pier schematics

Interstate-20 River Bridge—Model Results



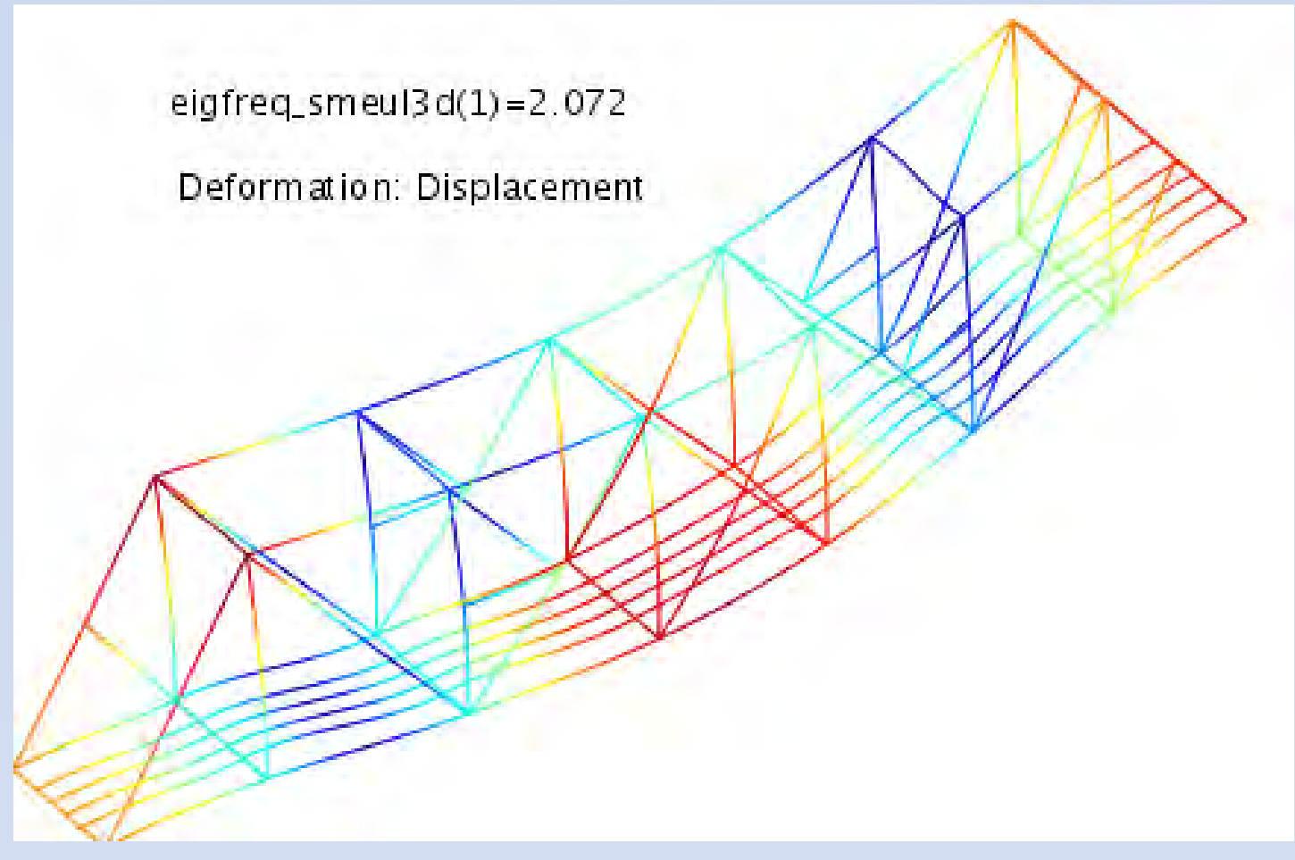
Frequency vs. scour depth for 2D deep foundation sand case



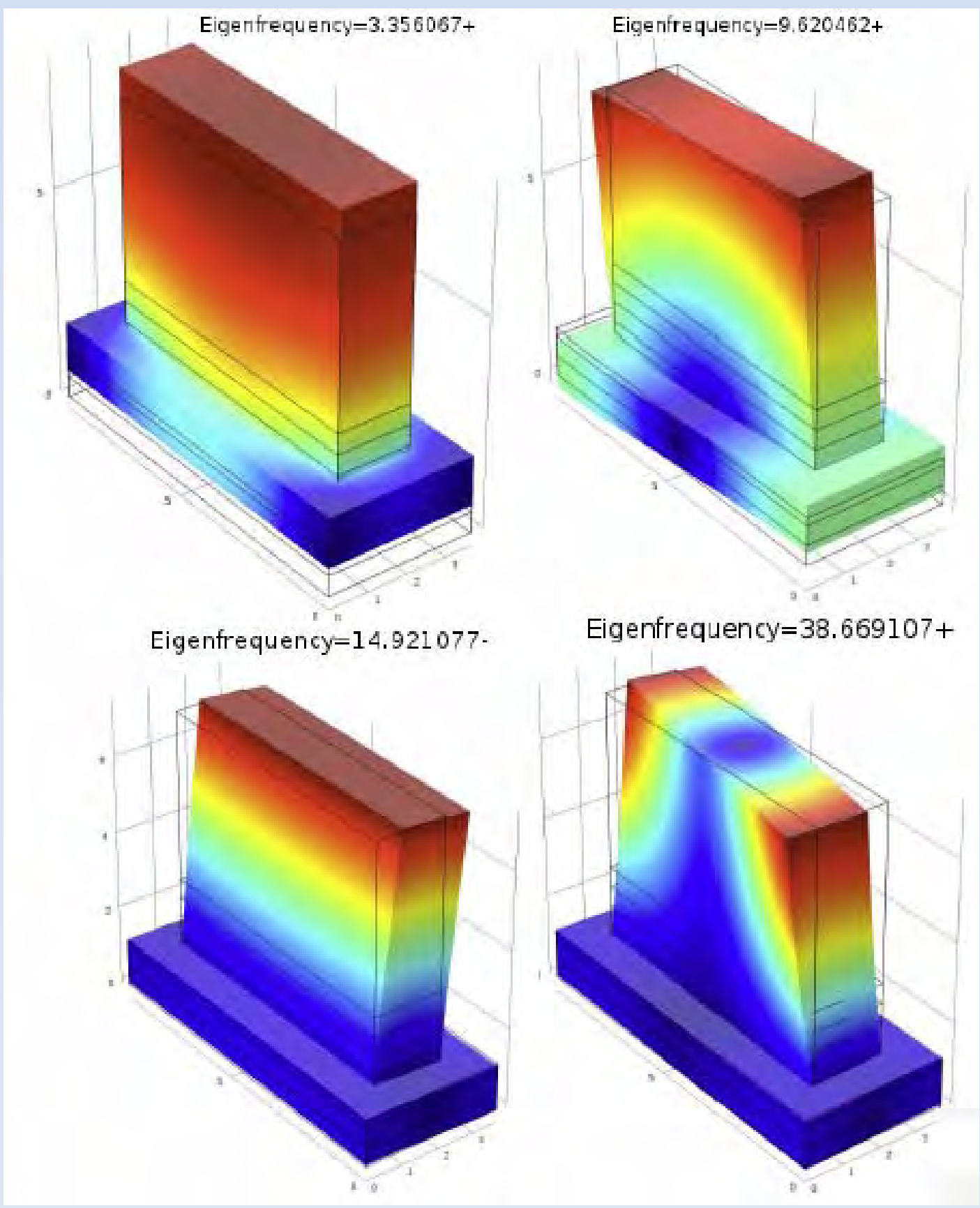
Frequency vs. scour depth for 2D deep foundation silt case

Conclusions

- **2D plane strain is more than adequate for modeling provided that it is modeled with a soil layer and at low frequencies.**
- **In higher frequencies, plane strain conditions are no longer present and therefore require more complex soil-structure interaction.**
- **Foundations cannot be modeled independently of the soil, meaning they cannot simply be modeled as a lateral pressure.**
- **The bridge superstructure resonates in a manner consistent with 2D plane strain at low frequencies. This is not true of the higher frequencies.**



Eigenmode at 2Hz for Ft. Leonard Wood bridge



Eigenfrequencies observed with an earth pressure equivalent to 3m of silt

Excerpt from the Proceedings of the 2012 COMSOL Conference in Boston