SASSI Methodology-Based Sensitivity Studies for Deeply Embedded Structures, Such As Small Modular Reactors (SMRs)

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2014 U.S. Department of Energy Natural Phenomena Hazards Meeting

Germantown, MD, October 21-22, 2014

Purpose of This Presentation:

To disseminate results of some internal multiyear research projects done in GP Technologies for a better understanding of the behavior of deeply embedded nuclear structures such as SMRs in nonuniform soil layering.

To answer to the following key questions:
- How the SSI uncertainties affect the ISRS in SMRs?
- Is deterministic SSI analysis more or less conservative for SMR?
- How important is inertial SSI vs. kinematic SSI for SMRs?
- How accurate are the SASSI MSM or ESM methods for SMRs?
- How sensitive are SSI responses to the excavated soil mesh size variation and mesh nonuniformity?
- Are HO Rayleigh wave mode effects significant for nonuniform soils?
- How important are SSSI effects due to Annex Bldgs.?
- How important is the influence of ground water level on SMR response?

The *ACS SASSI Version 3.0 including new Option PRO was* used.

SMR Probabilistic-Deterministic SSI Case Studies

SEISMIC INPUT:

We considered a typical UHSRS shape input corresponding to the baserock (Vs=9200 fps) at the 500ft depth. Assume deterministic and probabilistic UHSRS shape at the 500 ft depth.

SOIL LAYERING:

Probabilistic SSI: We considered the 60 randomized soil profiles. The Vs and Damping for each soil profile were considered as dependent random variables with lognormal distribution. Damping variable is considered statistically dependent (varying inversely than Vs) as recommended by ASCE 04-2013. Vs c.o.v. was 0.20 and Damping c.o.v. was 0.35. The Vs profiles were assumed to have a spatial correlation corresponding to a 20 ft correlation length

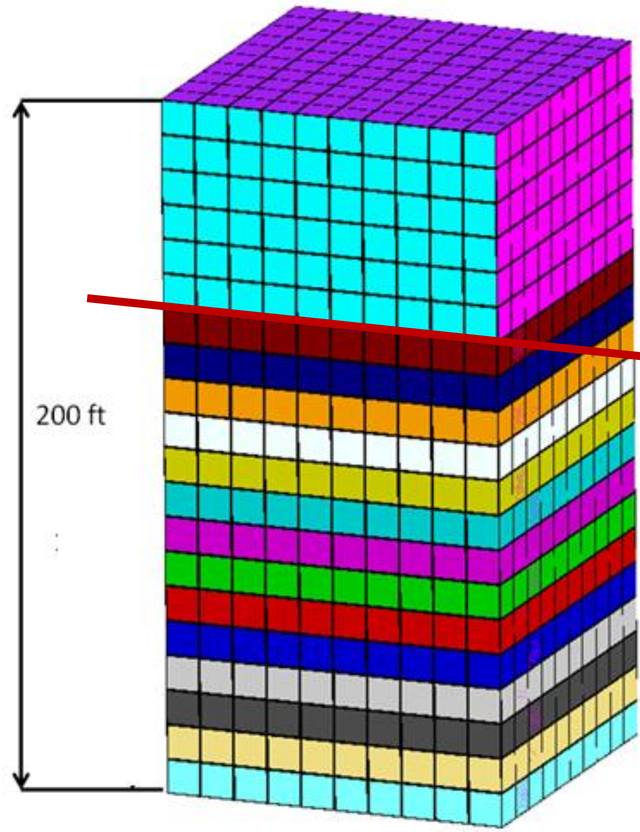
Deterministic SSI: The deterministic LB, BE and UB soil profiles were computed as the 16%, 50% and 84% NEP for the Vs and Damping profiles.

SSI ANALYSIS:

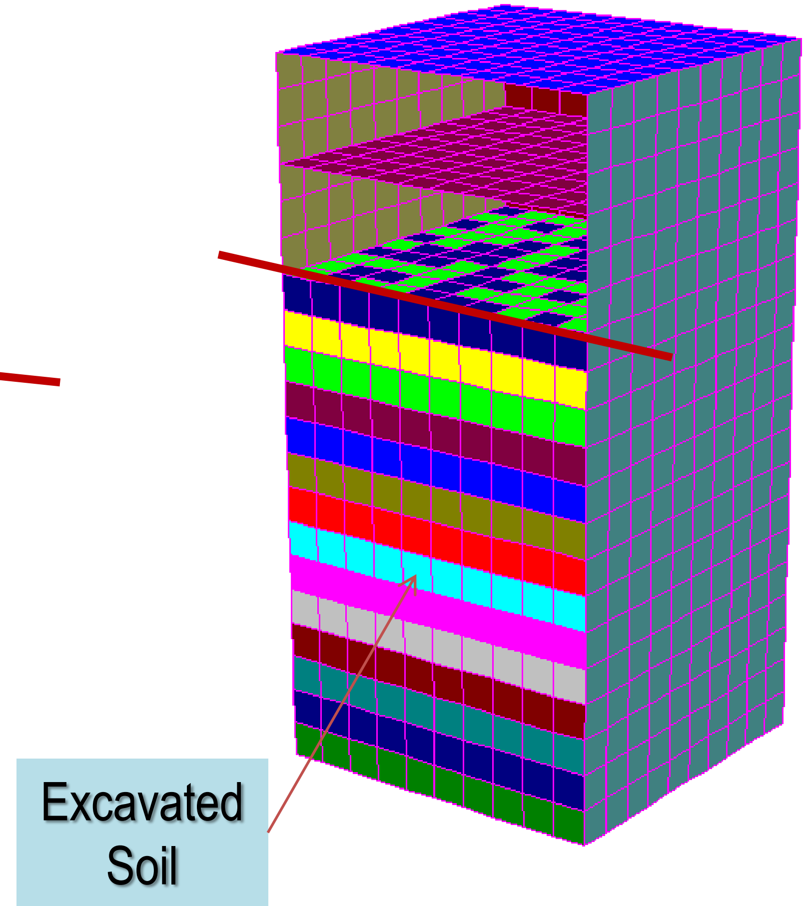
Probabilistic SSI: We considered the 60 simulated in-column soil motions at the foundation level for the embedded models, and simulated surface motions for the surface model.

Deterministic SSI: We considered the outcrop probabilistic mean response spectra of the 60 simulations as the outcrop FIRS. Then, we performed 3 SHAKE type deterministic analyses for LB, BE and UB soil profiles to compute the in-column FIRS motions to be used for the deterministic SSI analysis.

SMR Seismic Deeply Embedded SSI Model



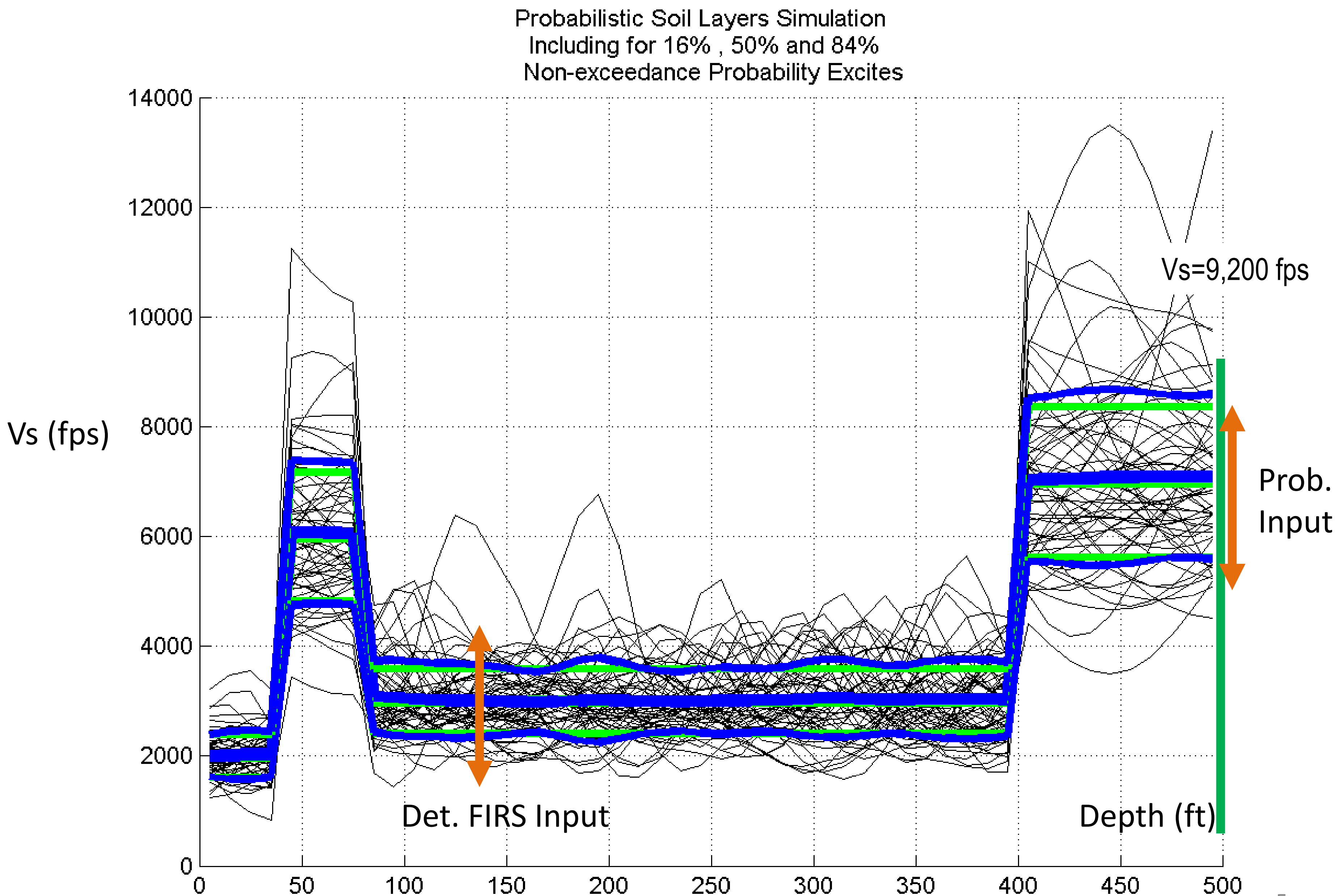
Generic SMR Structure



SMR size: 100 ft x 100 ft X 200 ft
Embedment: 140 ft
Mesh size: 10 ft X 10 ft X 10 ft
Number of Nodes: 2,580
Interaction Nodes: 1,815

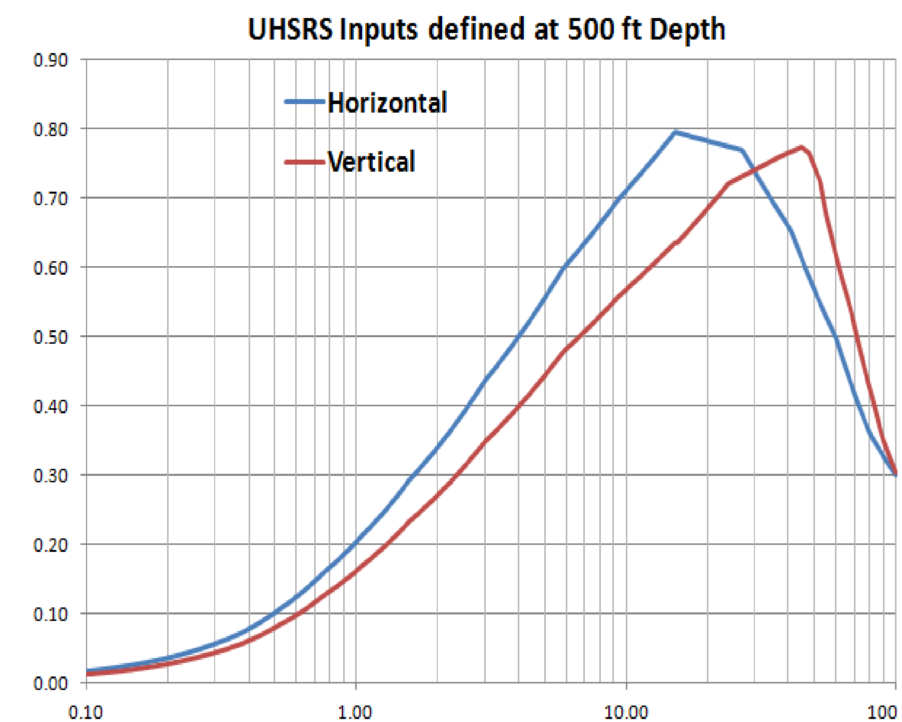
140 ft Embedment SMR SSI Model (use FV method)

Probabilistic and Deterministic Soil Profiles

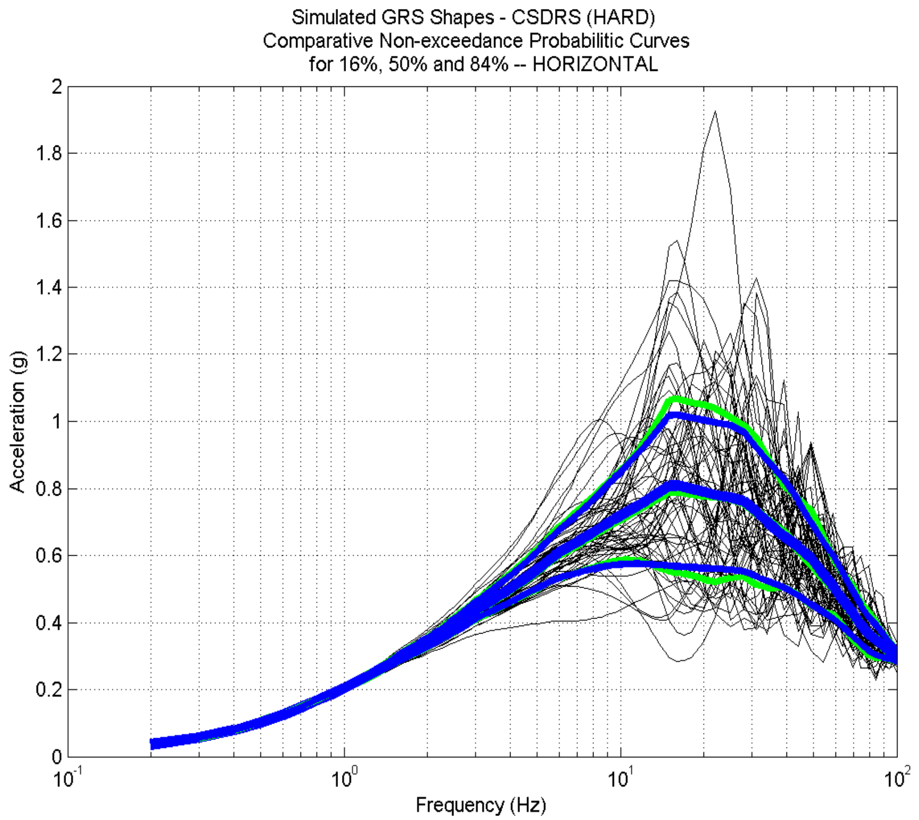


UHSRS Seismic Input Defined at the Baserock (with Vs= 9,200 fps) Situated at 500 ft Depth

Deterministic (Mean) Spectra



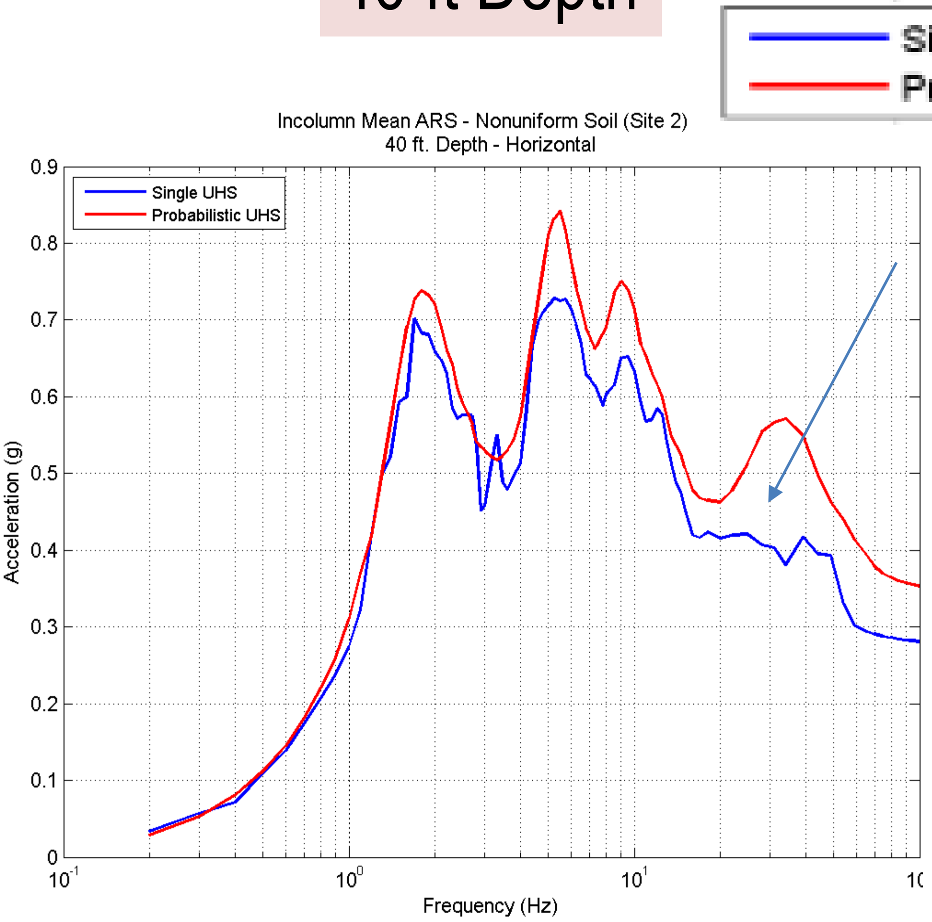
Probabilistic (Simulated) Spectra

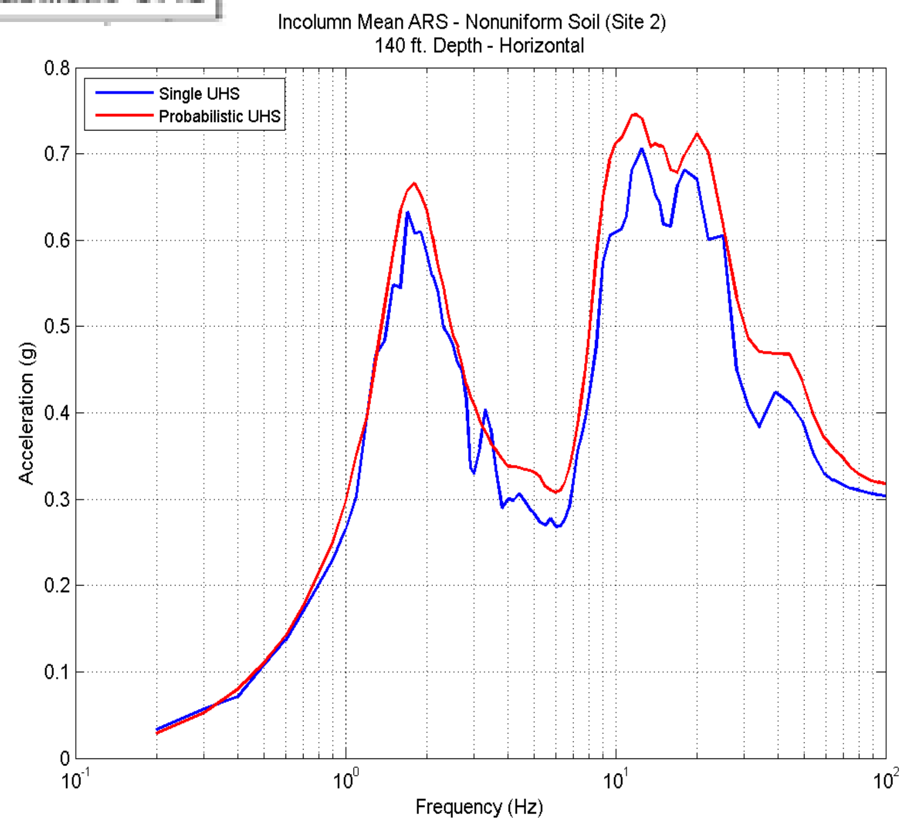


In-Column Probabilistic Mean RS Computed for Deterministic and Probabilistic UHSRS Inputs

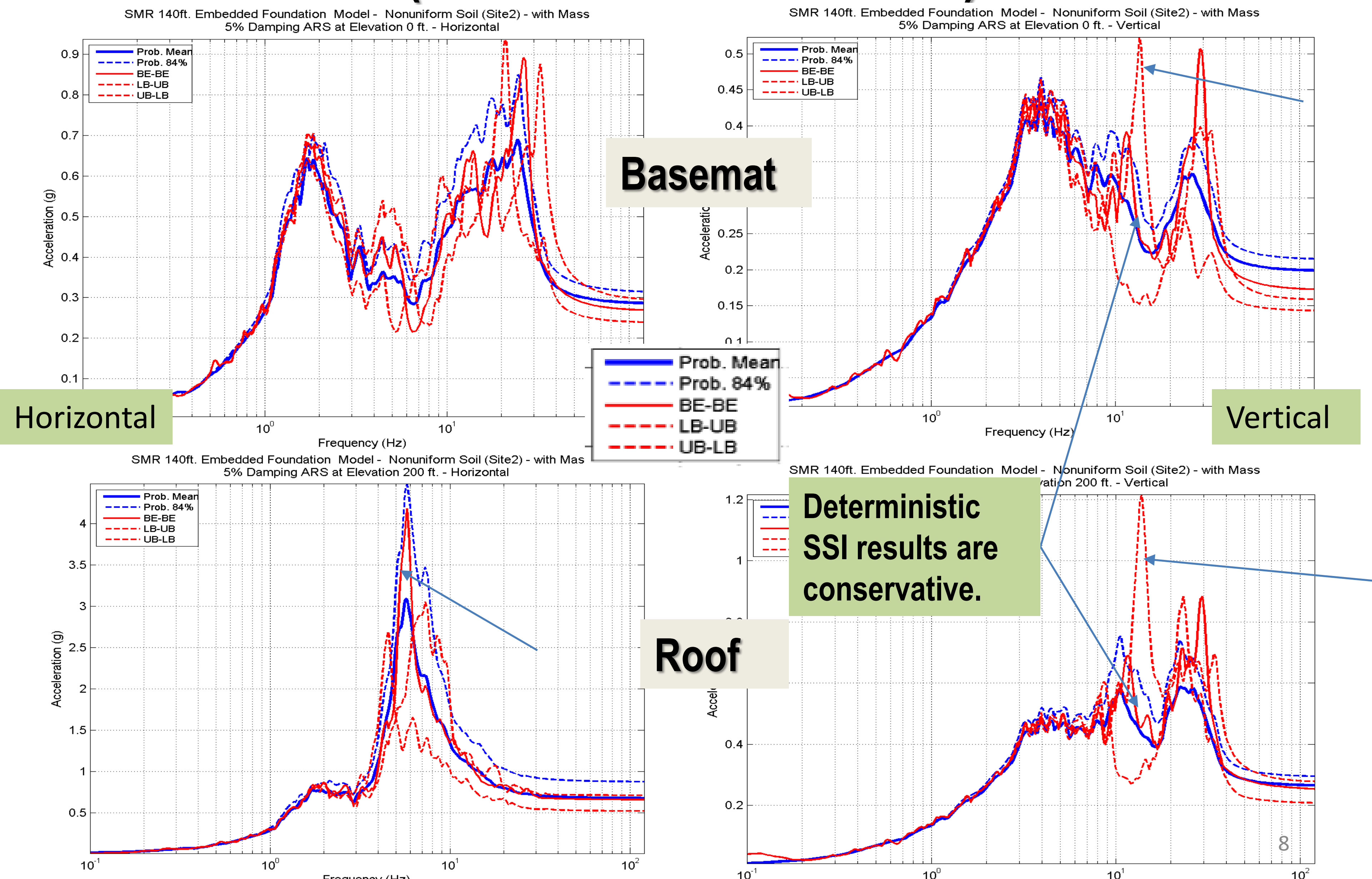
40 ft Depth

140 ft Depth

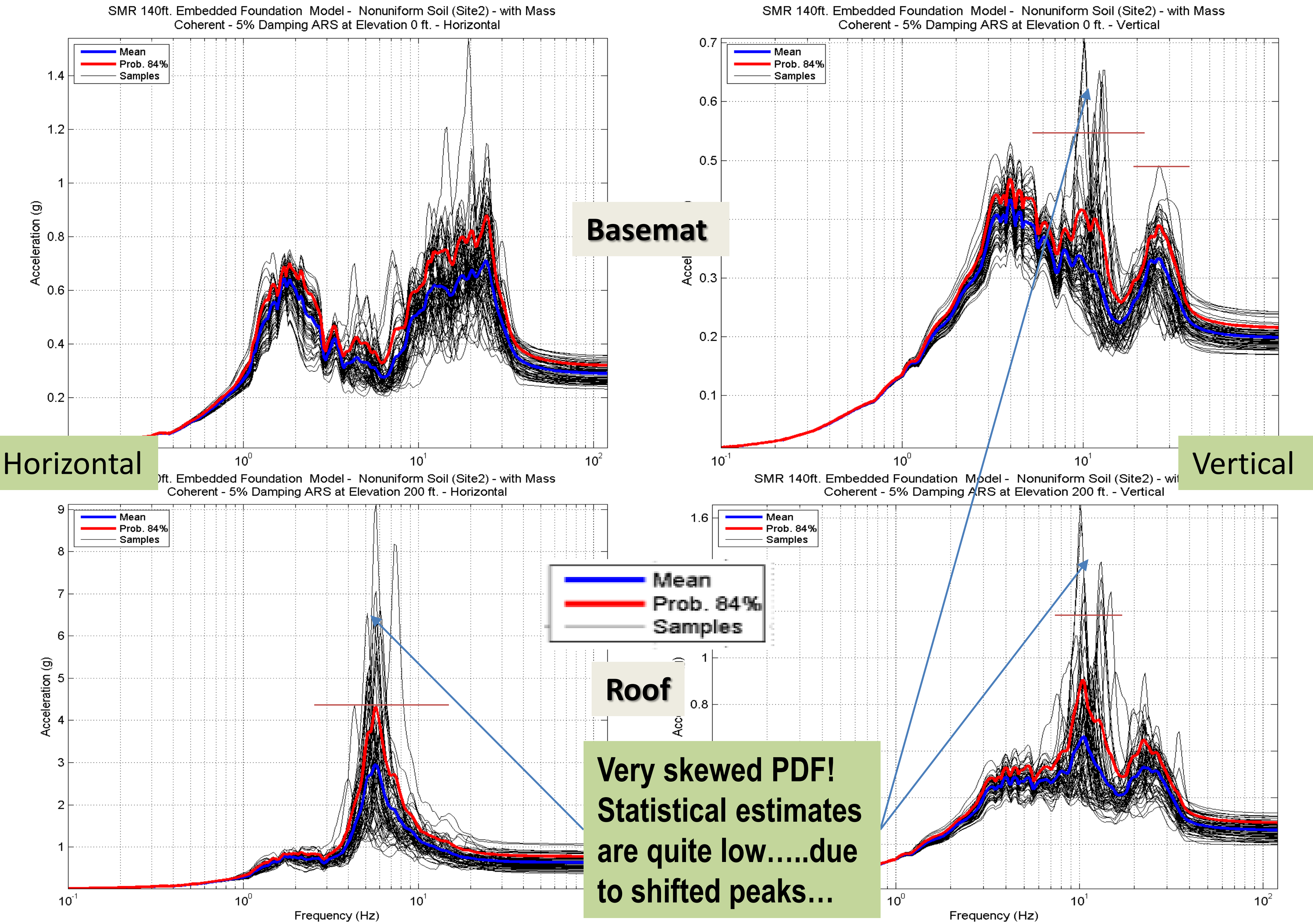




Deterministic ISRS (for LB, BE, UB) vs. Probabilistic ISRS (for Mean and 84% NEP)



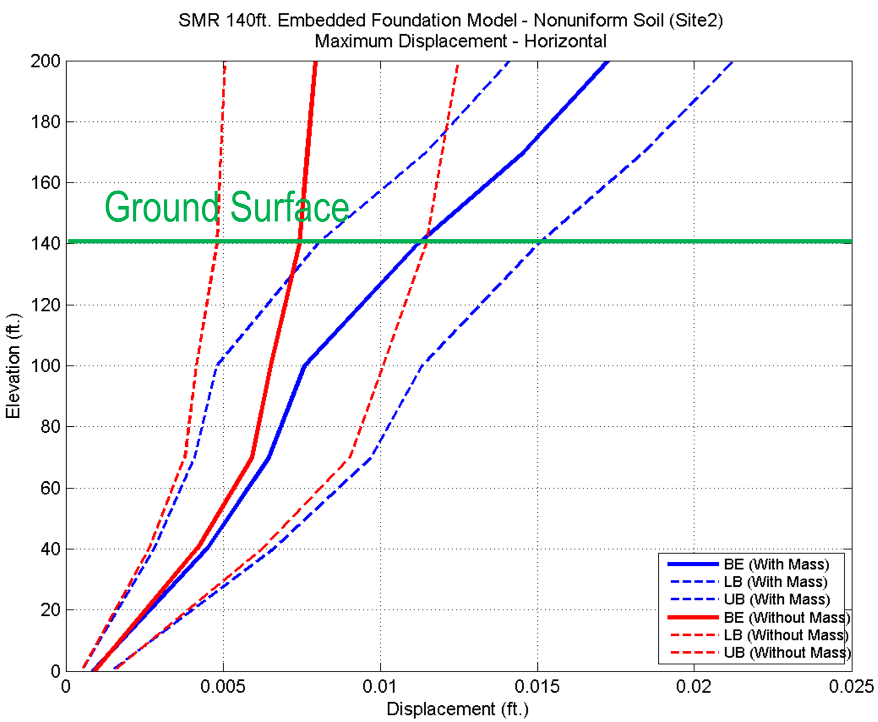
Probabilistic ISRS – Simulated vs. Mean and 84% NEP



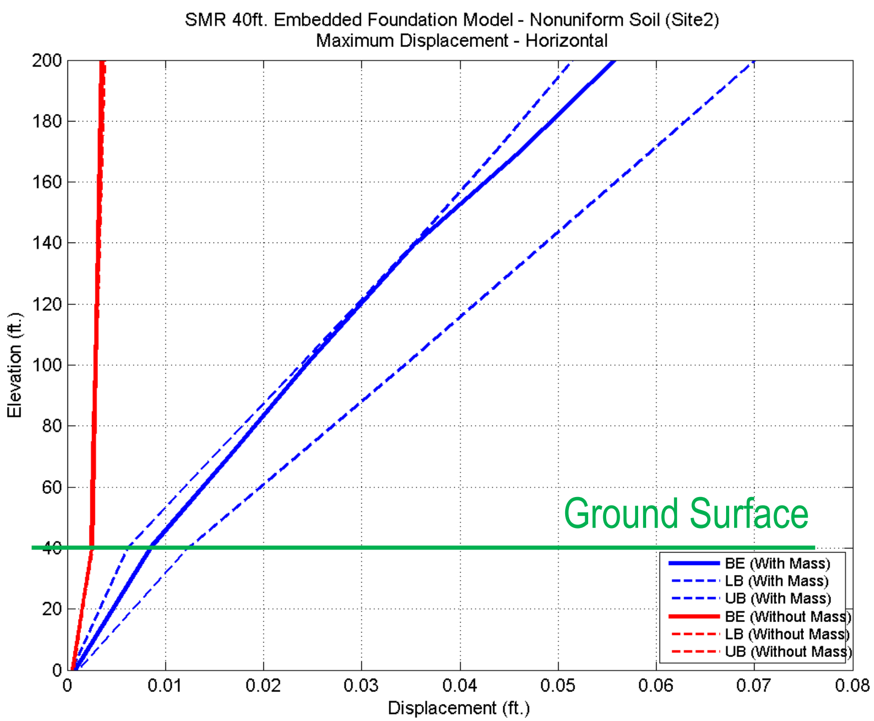
Effects of Kinematic SSI for Embedded SMRs

Relative Displacement wrt Basemat Center

140 ft Embedment



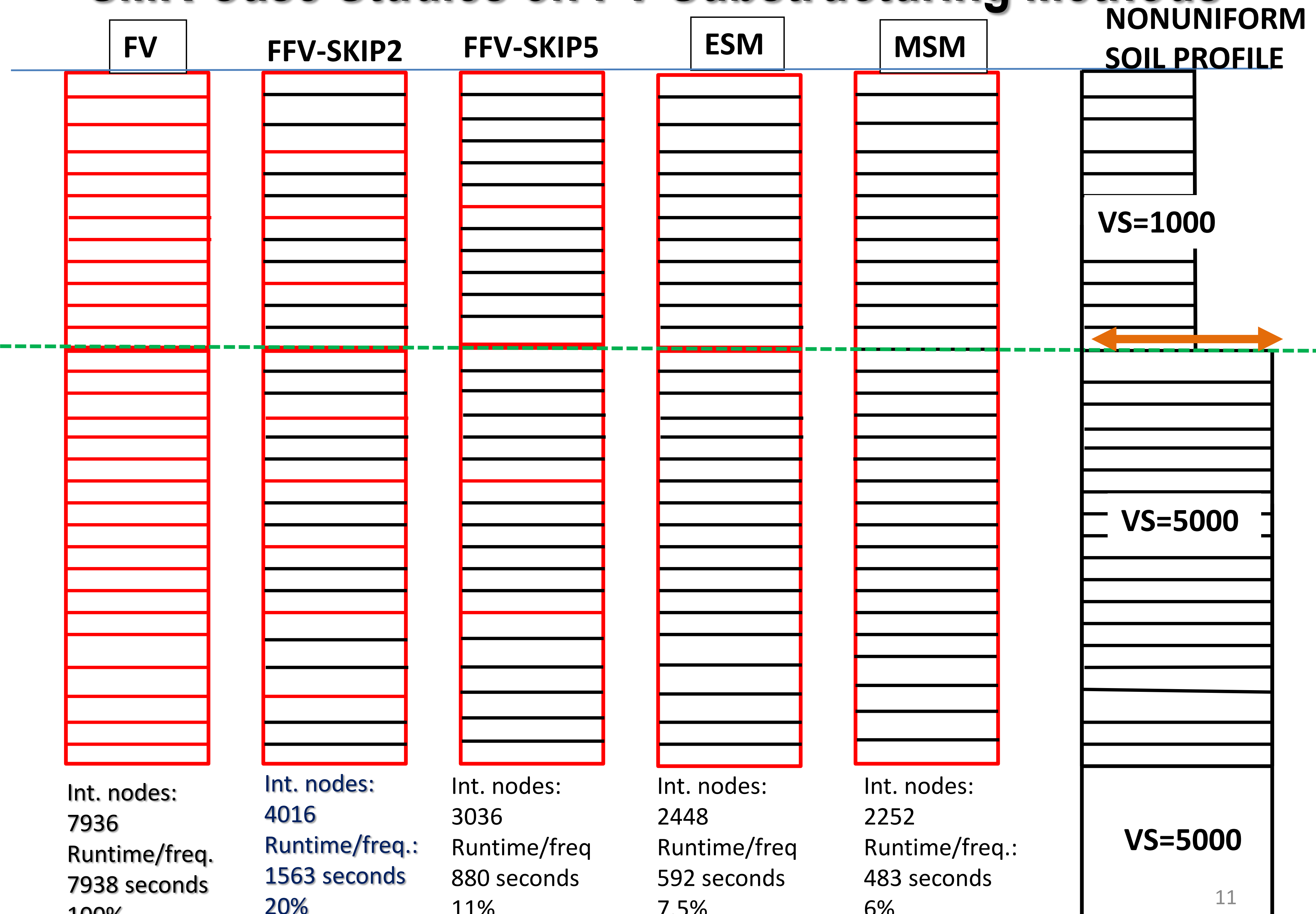
40 ft Embedment



For 140 ft embedment the kinematic SSI effects are dominant, 80-90%, up to the ground surface elevation at 140 ft.

For 40 ft embedment the kinematic SSI much less significant, 20-30%, below the the ground surface elevation at 40 ft.

SMR Case Studies on FV Substructuring Methods

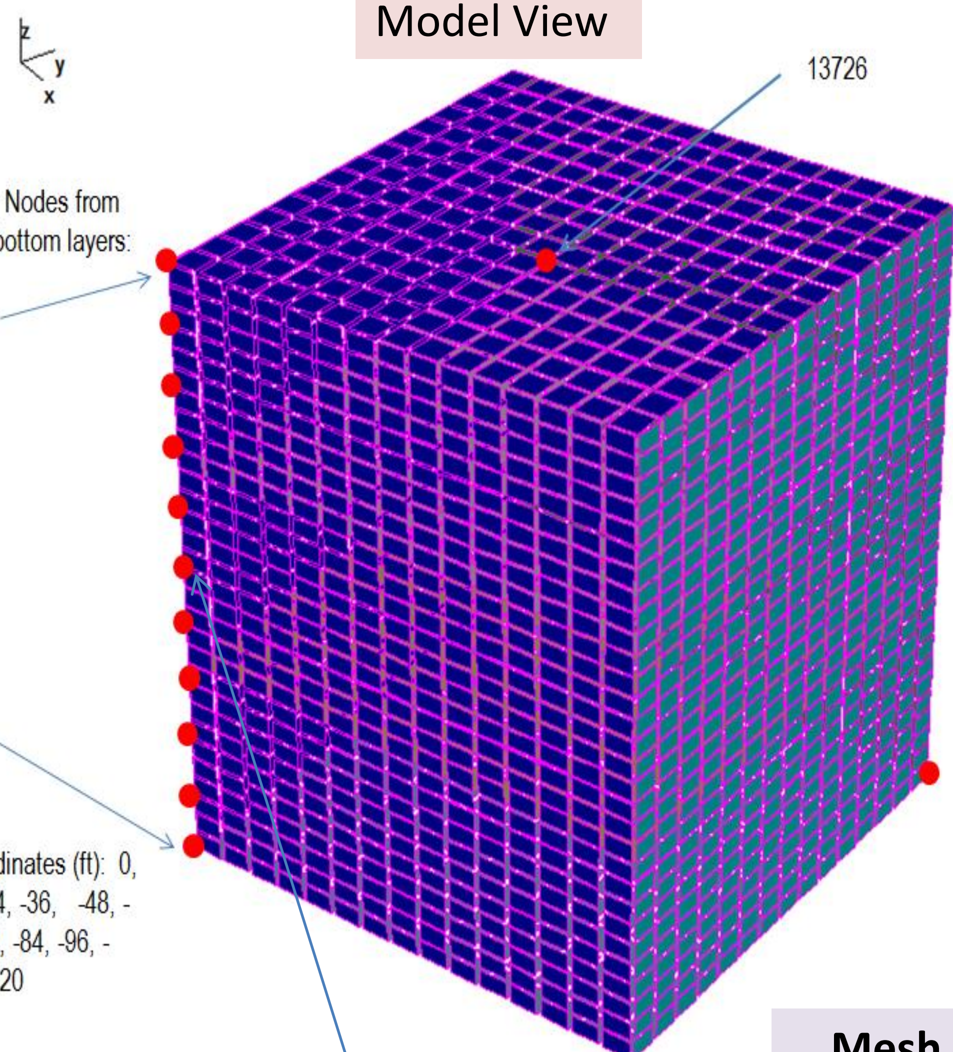


FV	FFV-SKIP2	FFV-SKIP5	ESM	MSM
Int. nodes: 7936	Int. nodes: 4016	Int. nodes: 3036	Int. nodes: 2448	Int. nodes: 2252
Runtime/freq. 7938 seconds	Runtime/freq.: 1563 seconds	Runtime/freq 880 seconds	Runtime/freq 592 seconds	Runtime/freq.: 483 seconds
100%	20%	11%	7.5%	6%

SMR Massless Foundation (Fully Embedded) Model

Volume Size: 120 ft x 80 ft x 80 ft

Model View



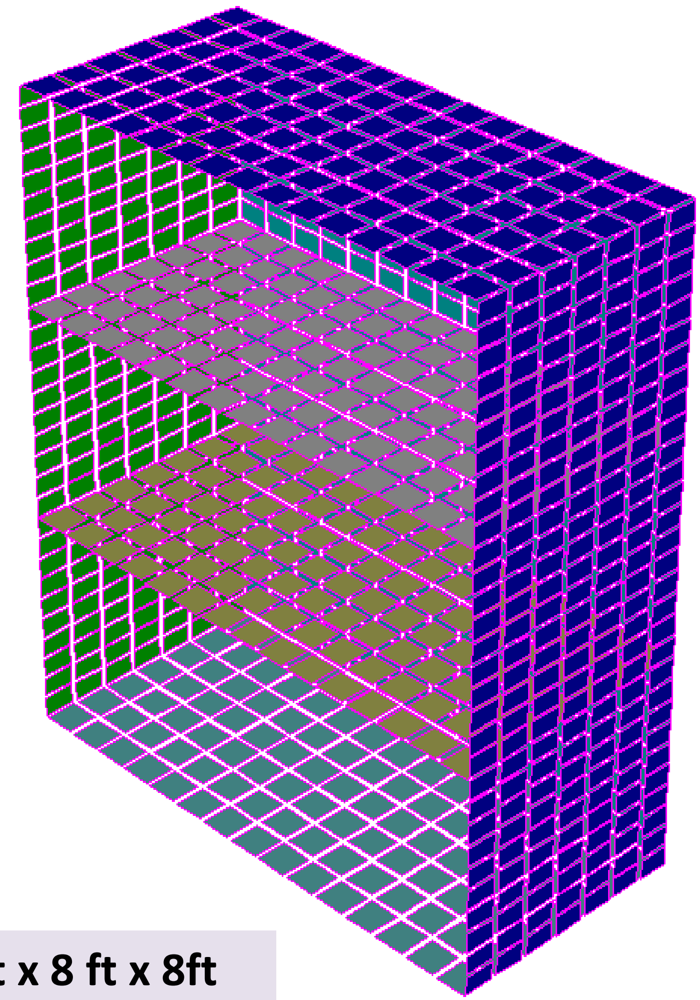
Corner Nodes from top to bottom layers:

7681,
6913,
6145,
5377,
4609,
3841,
3073,
2305,
1537,
769,
1

Z-coordinates (ft): 0, -12, -24, -36, -48, -60, -72, -84, -96, -108, -120

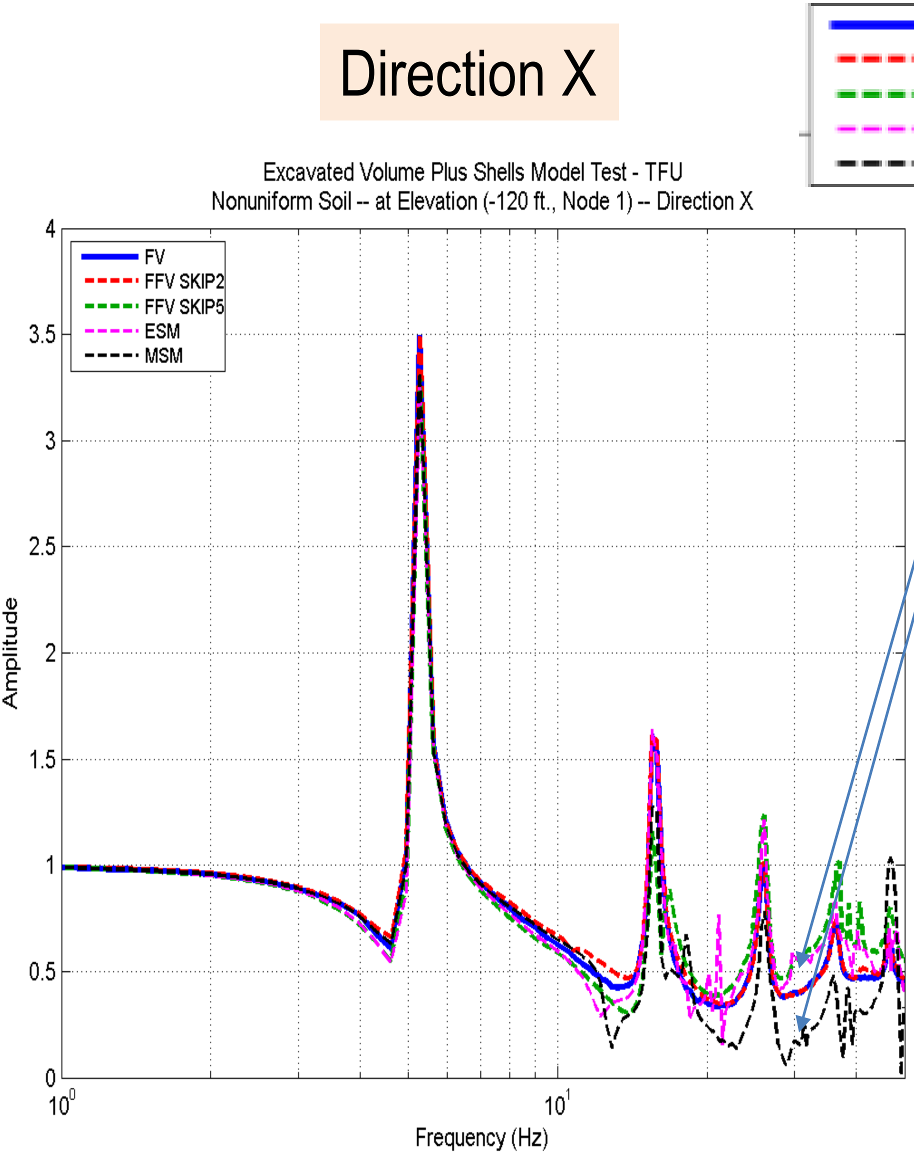
FFV-Skip 2 Levels

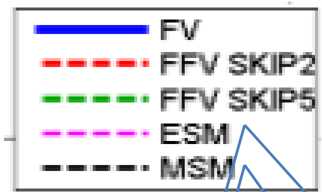
Vertical Section

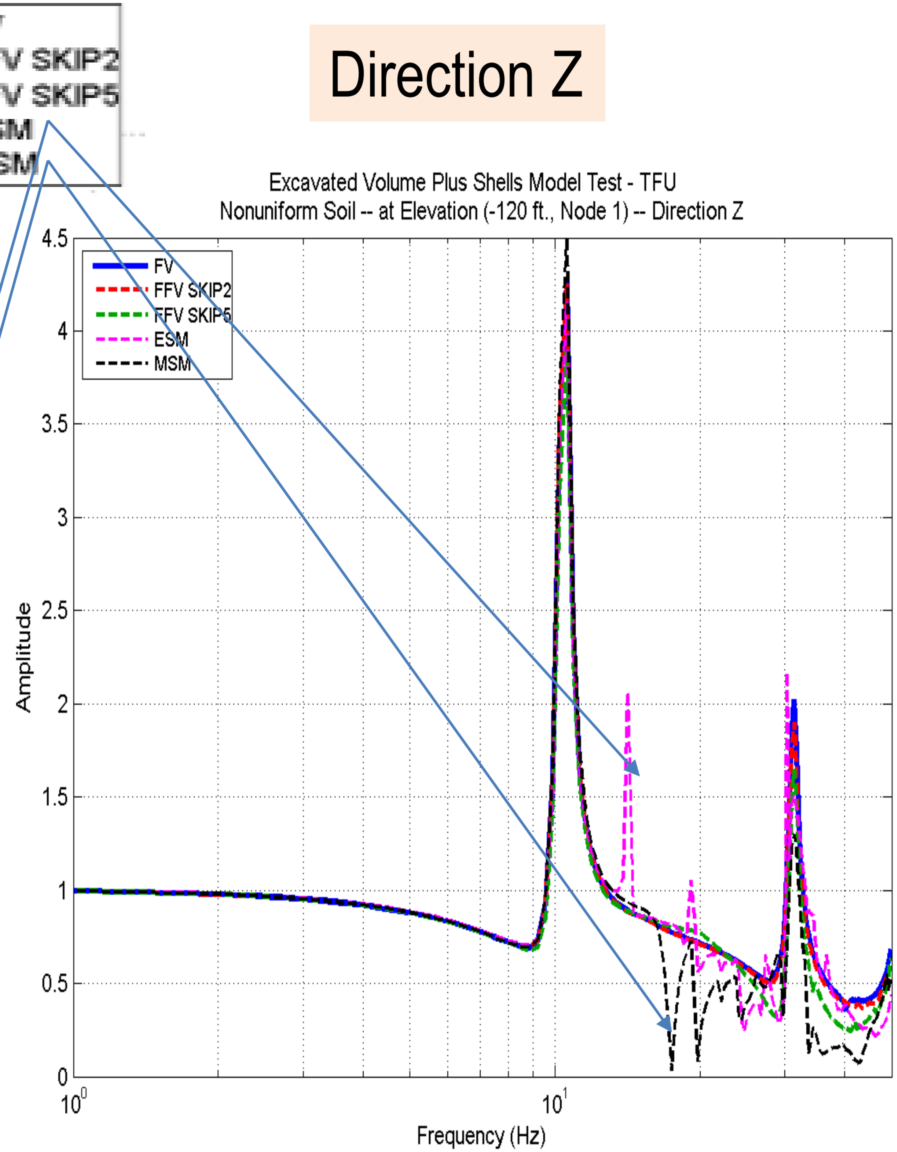


Mesh 4 ft x 8 ft x 8ft
7,938 Interaction Nodes

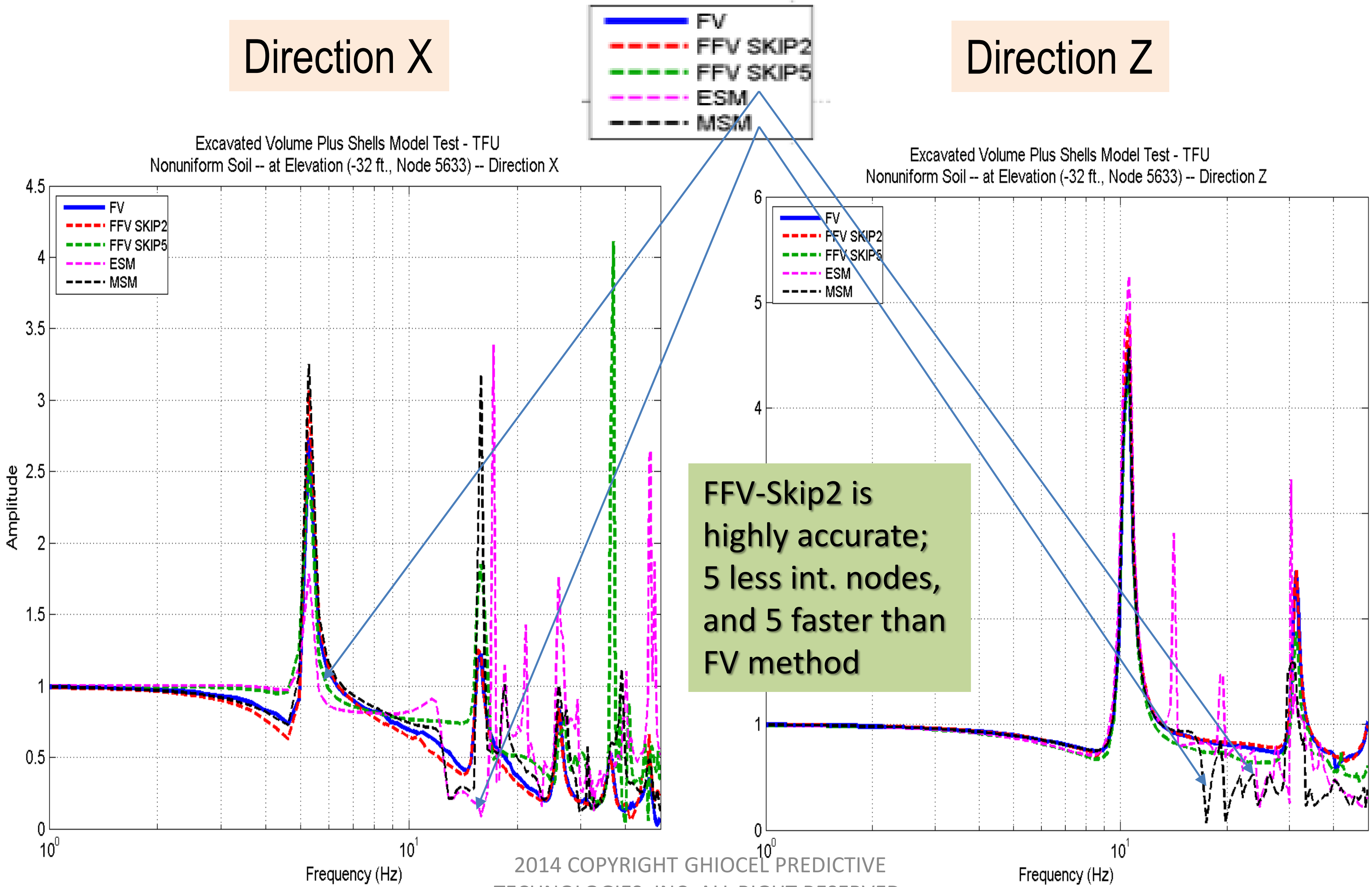
Comparative ATF at -120 ft Depth (Foundation Level)







Comparative ATF at -32 ft Depth (1/4 of Embedment)



SMR Massless Foundation Excavation Mesh Size Study

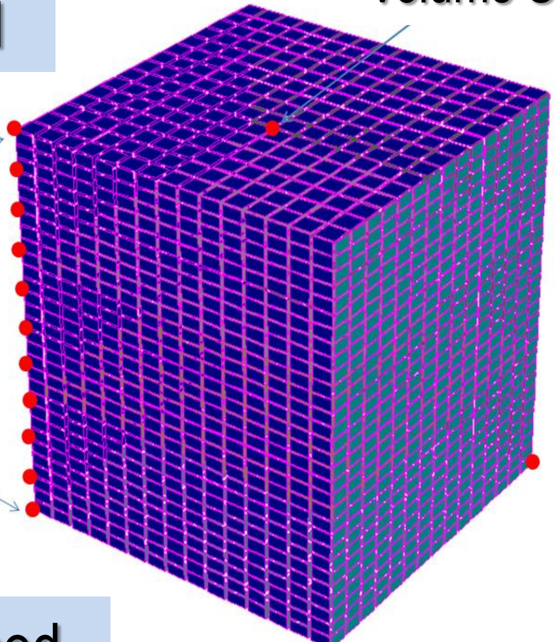
Volume Size: 120 ft x 80 ft x 80 ft

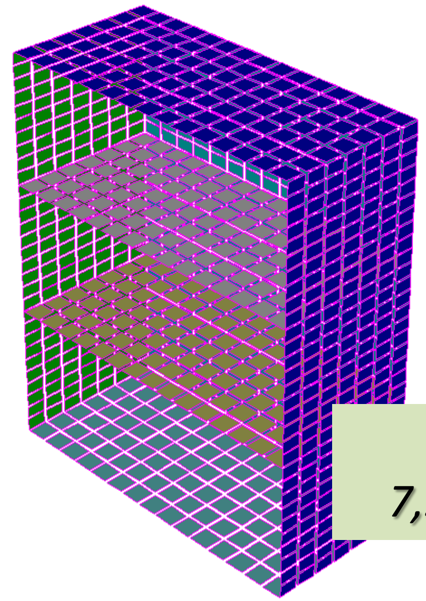
Original

Corner Nodes from top to bottom layers:

7681,
6913,
6145,
5377,
4609,
3841,
3073,
2305,
1537,
769,
1

Z-coordinates (ft): 0, -12, -24, -36, -48, -60, -72, -84, -96, -108, -120



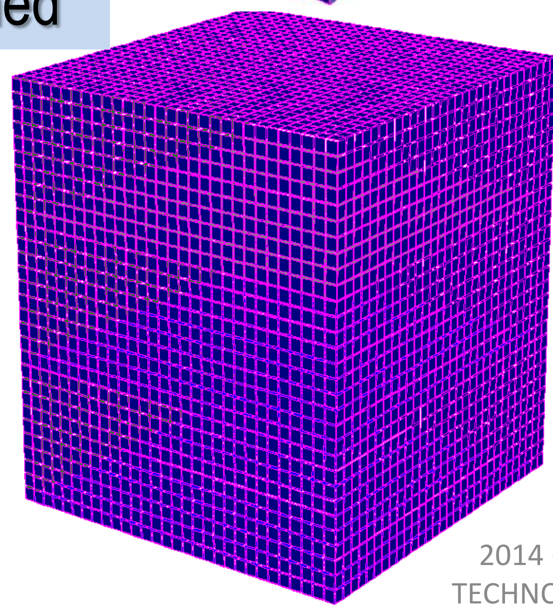


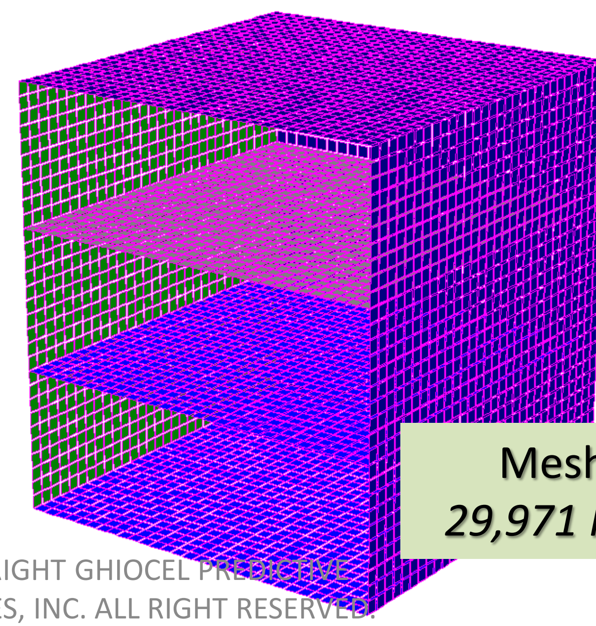
Uniform soil
Vs=1000 fps;

Input at Surface

Mesh 4 ft x 8ft x 8ft
7,938 Interaction Nodes

Remeshed

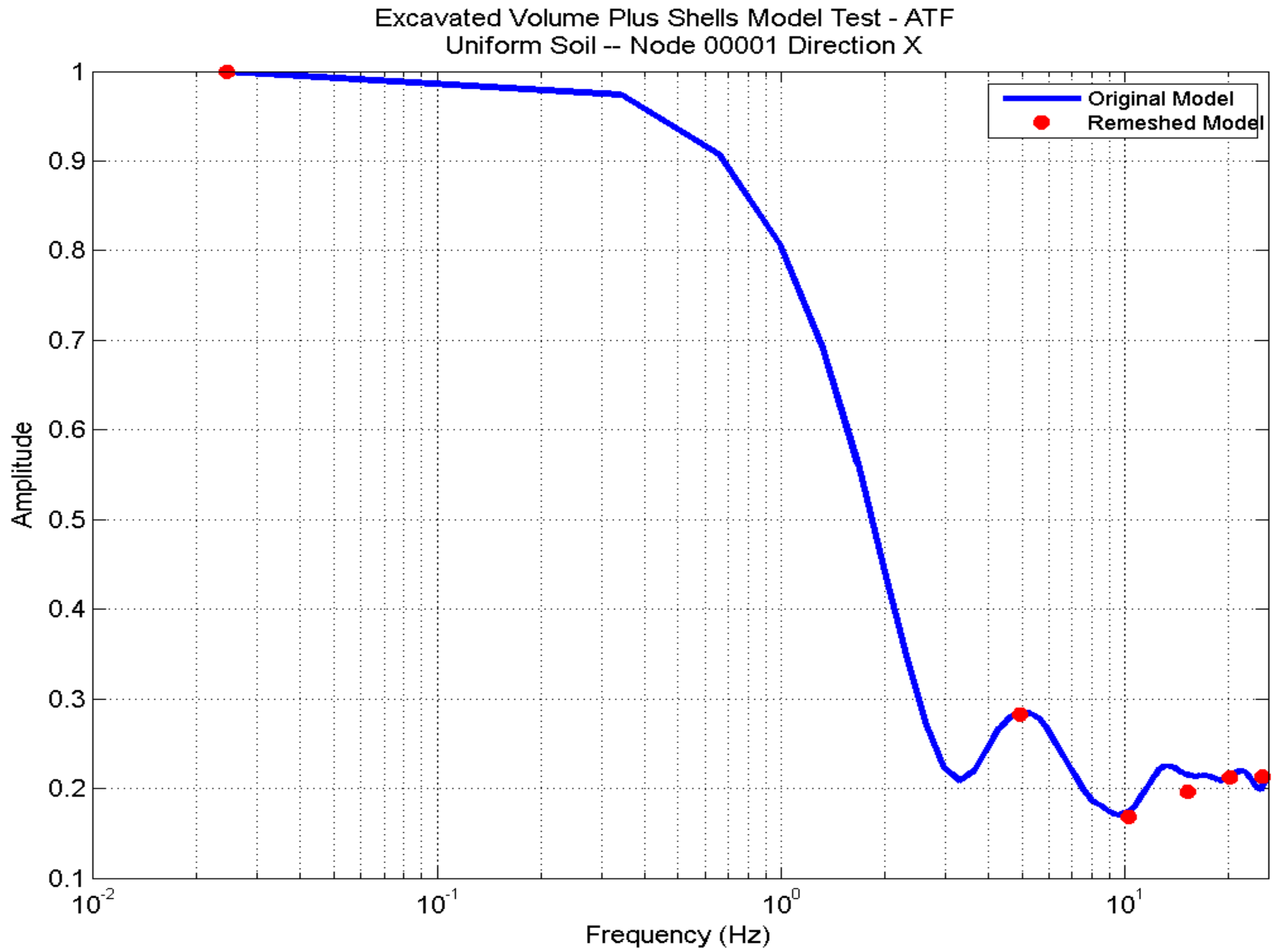




Mesh 4 ft x 4ft x 4ft
29,971 Interaction Nodes

Comparative ATF at Foundation and Surface Levels

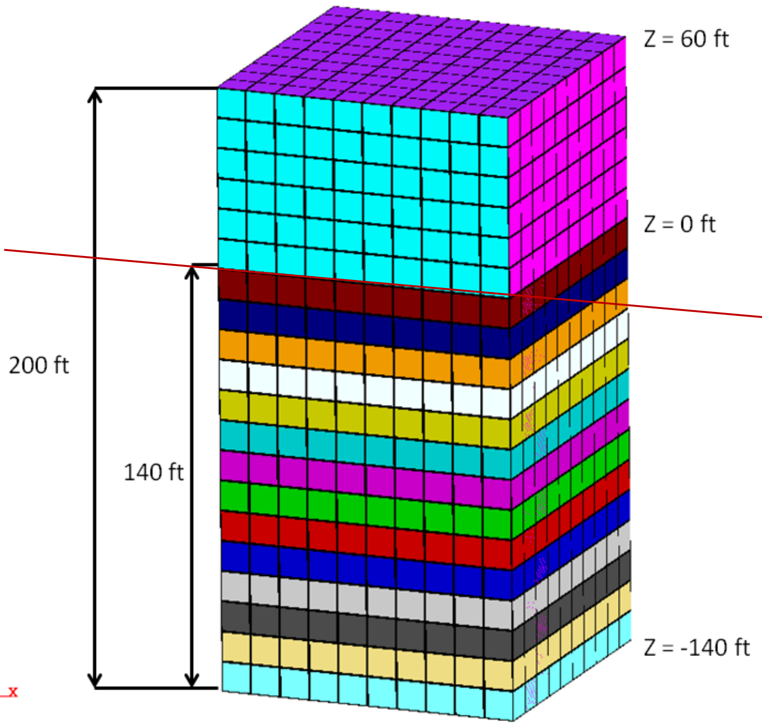
120 ft Depth

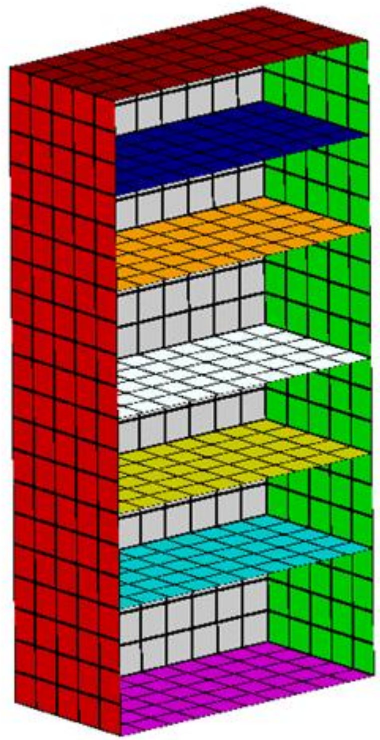


SMR Excavation Volume Mesh Nonuniformity Study

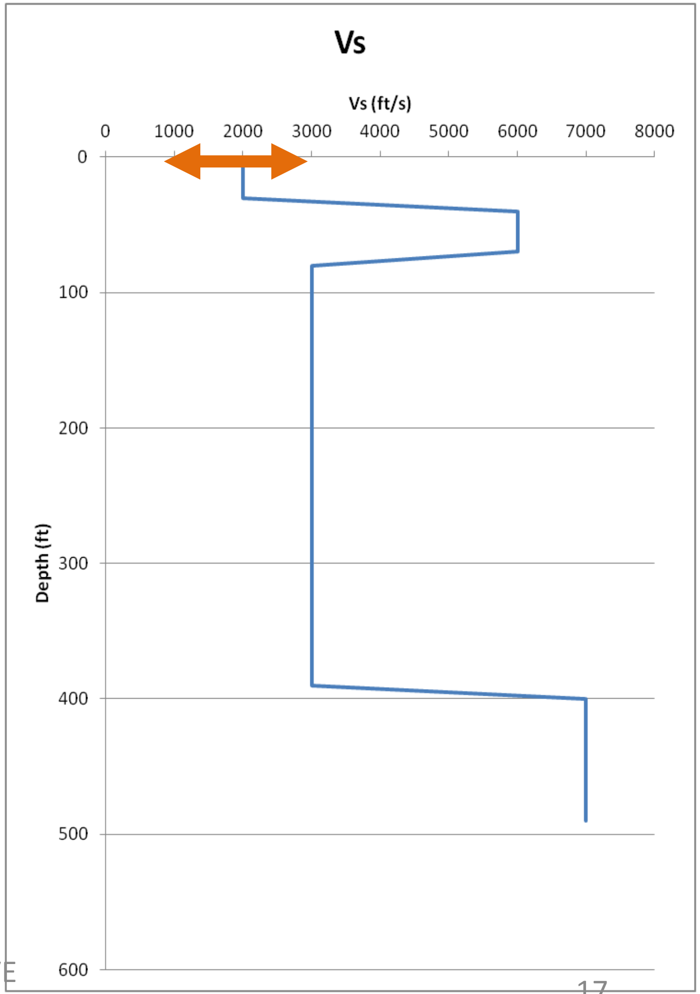
Volume Size: 200 ft x 100 ft x 100 ft

140 ft Embedded SMR Model





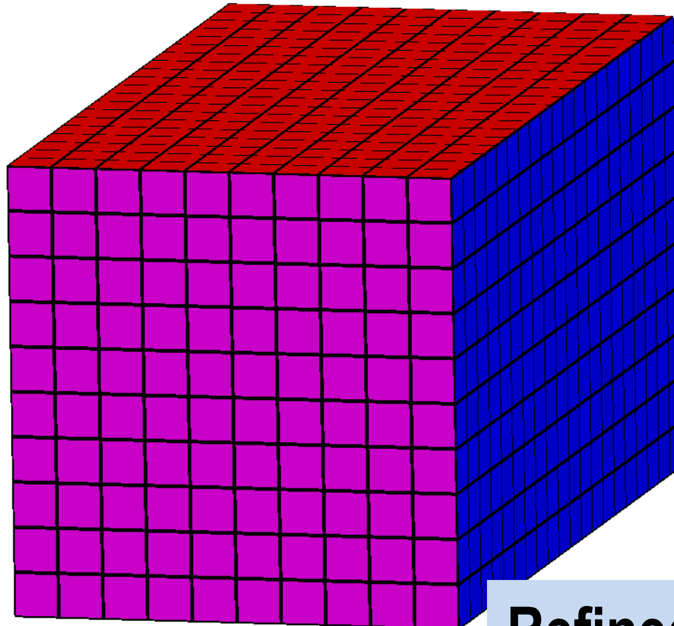
Vs Soil Profile (fps)



SMR size: 100 ft x 100 ft X 200 ft
Embedment: 140 ft
Mesh size: 10 ft X 10 ft X 10 ft
Number of Nodes: 2,580
Interaction Nodes: 1,815

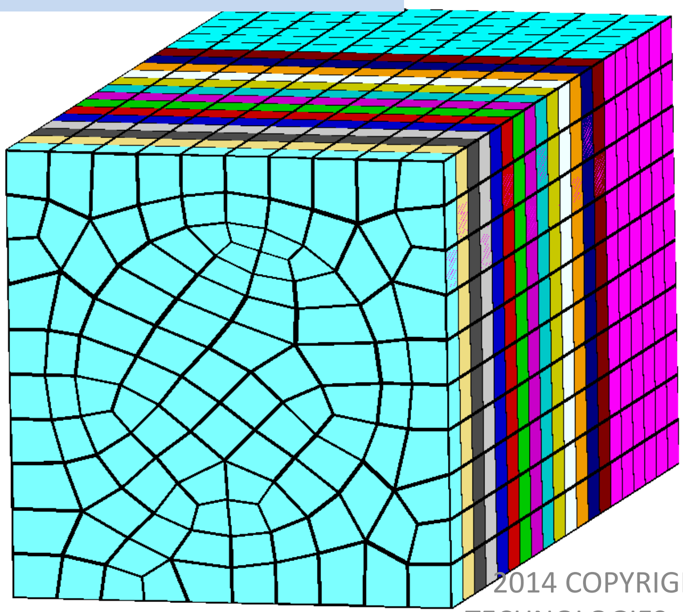
140 ft Embedment SMR Excavation Volume Meshes

Uniform Model

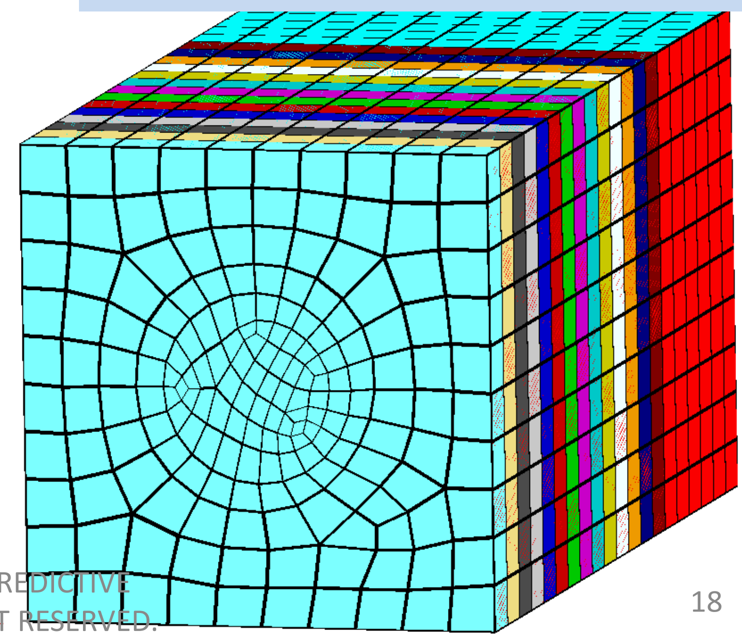


For nonuniform meshes the average radius values are used.

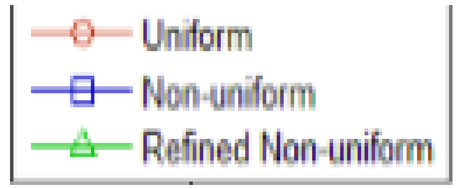
Non-uniform Model



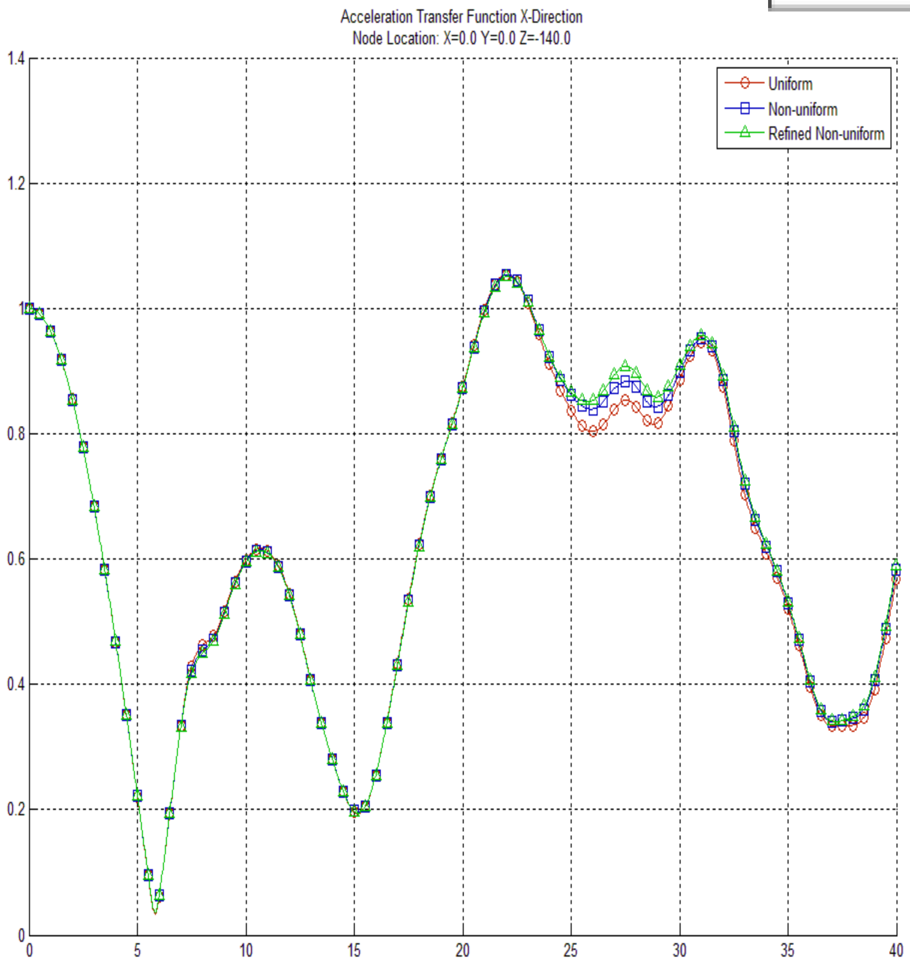
Refined Non-uniform Model



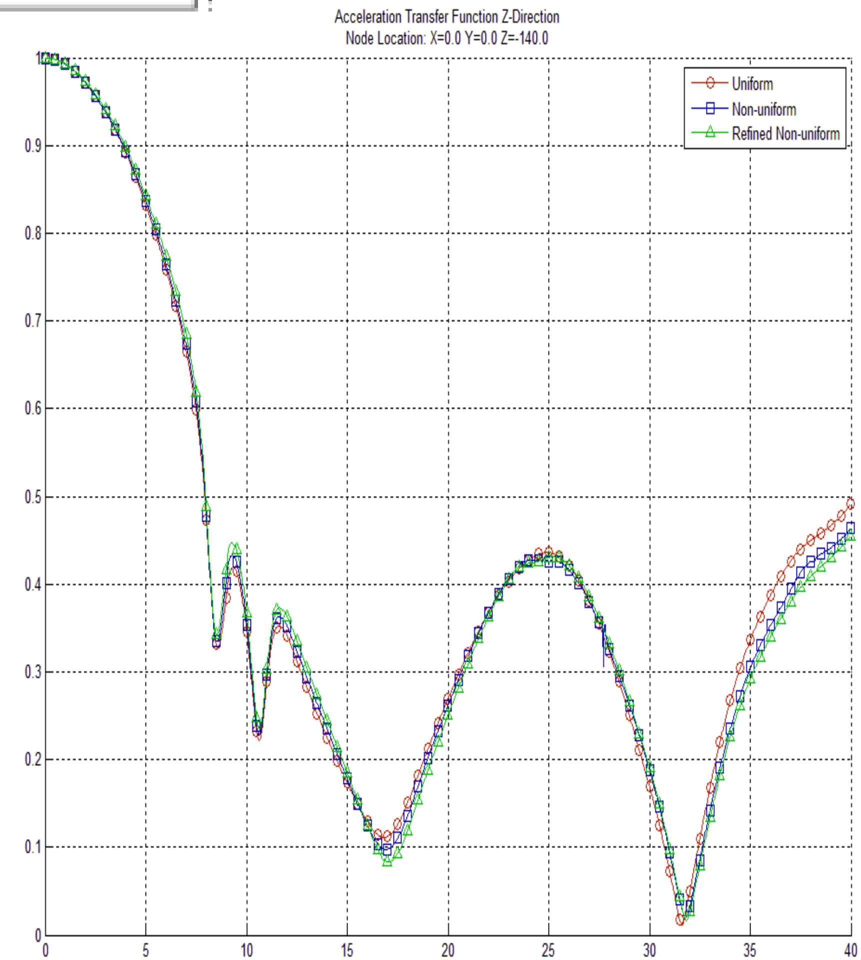
Comparative ATF at -140 Depth (Foundation Level)



Horizontal

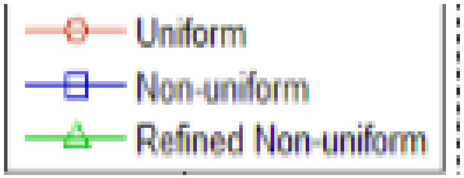


Vertical

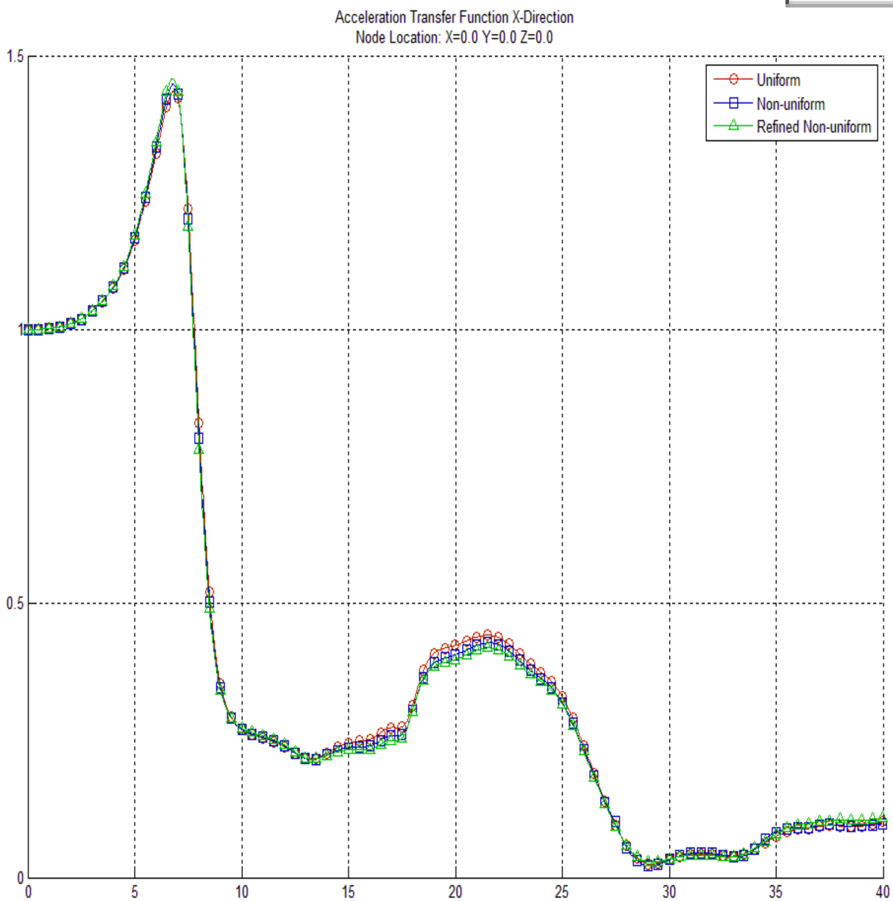


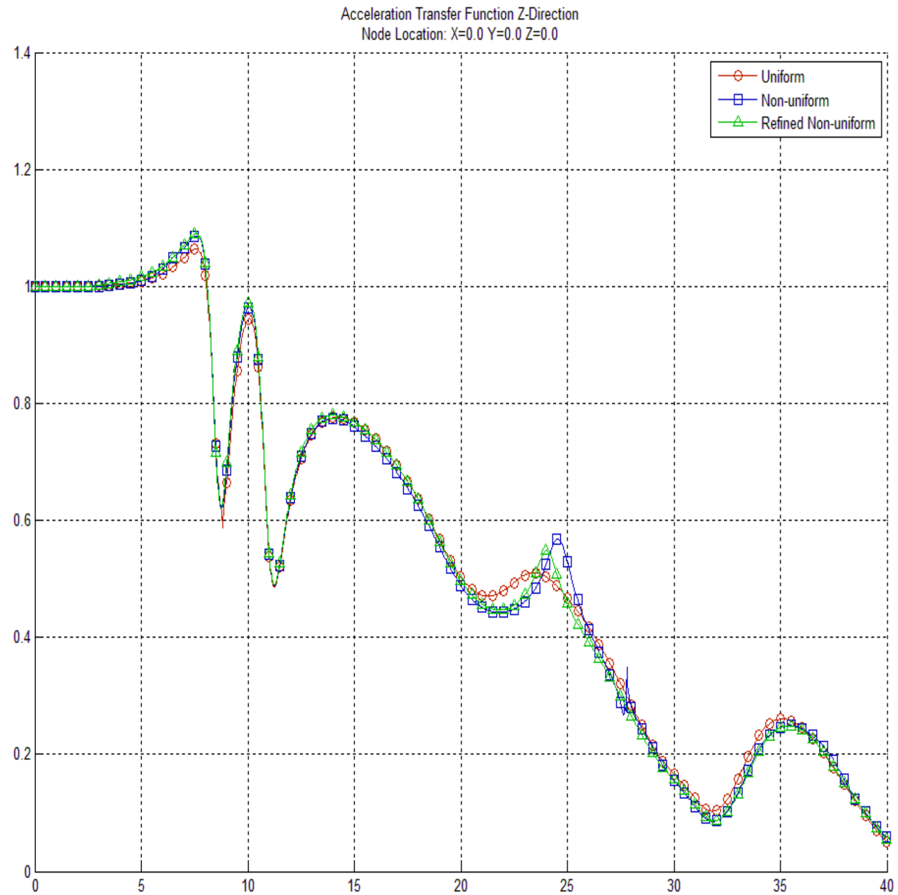
Comparative ATF at Ground Surface Level

Horizontal



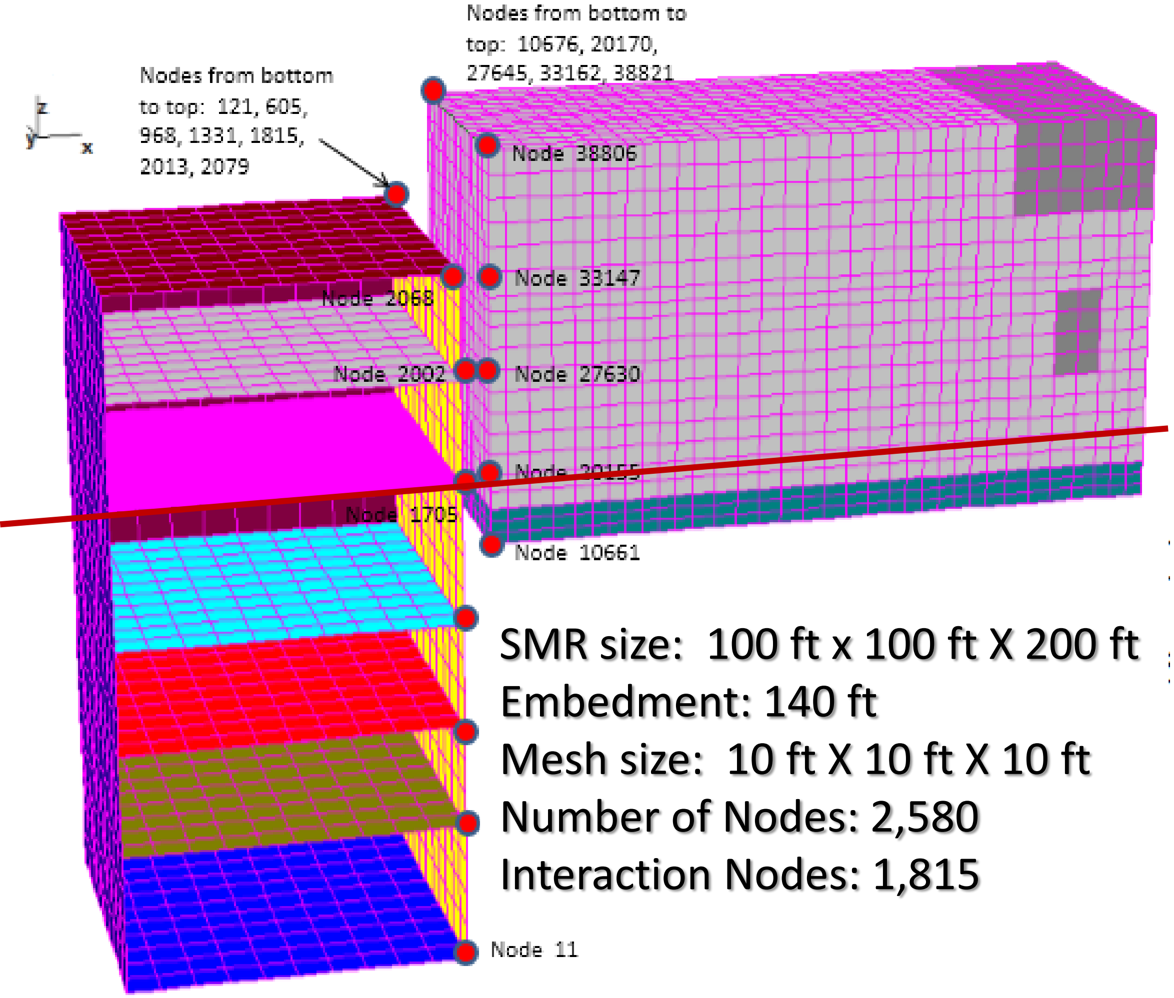
Vertical





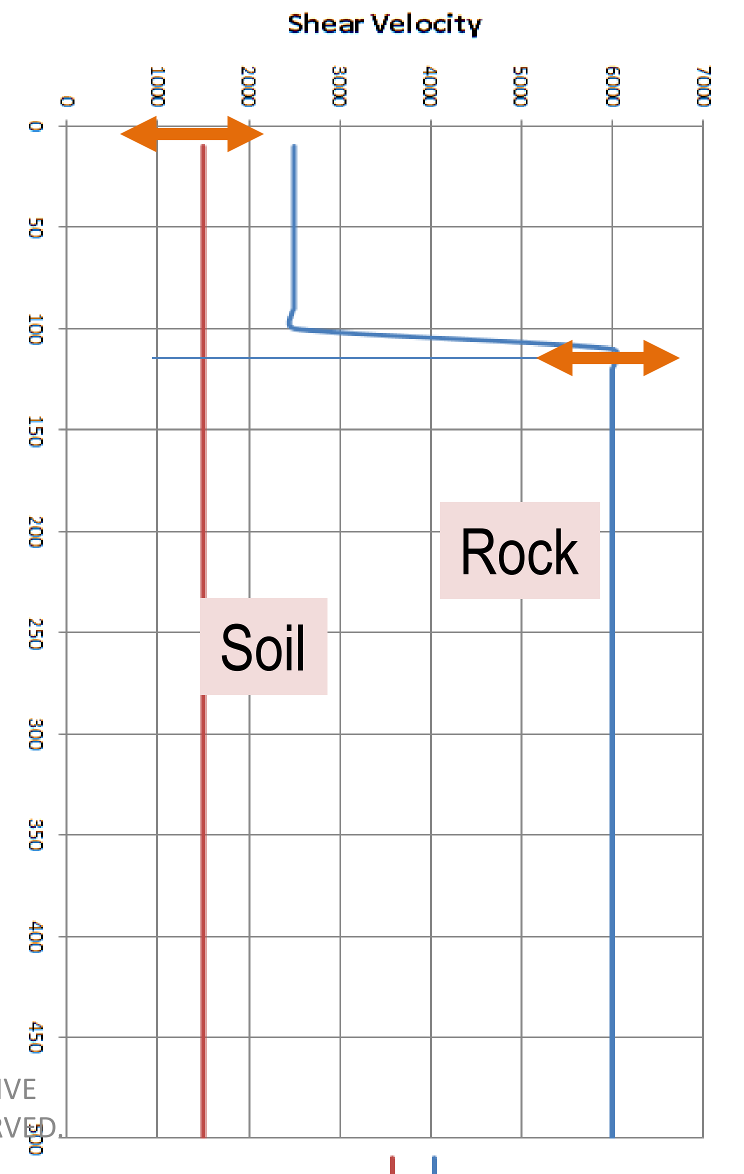
SMR-AB Seismic SSSI Effects Study

140 ft Embedded SMR-AB SSSI Model



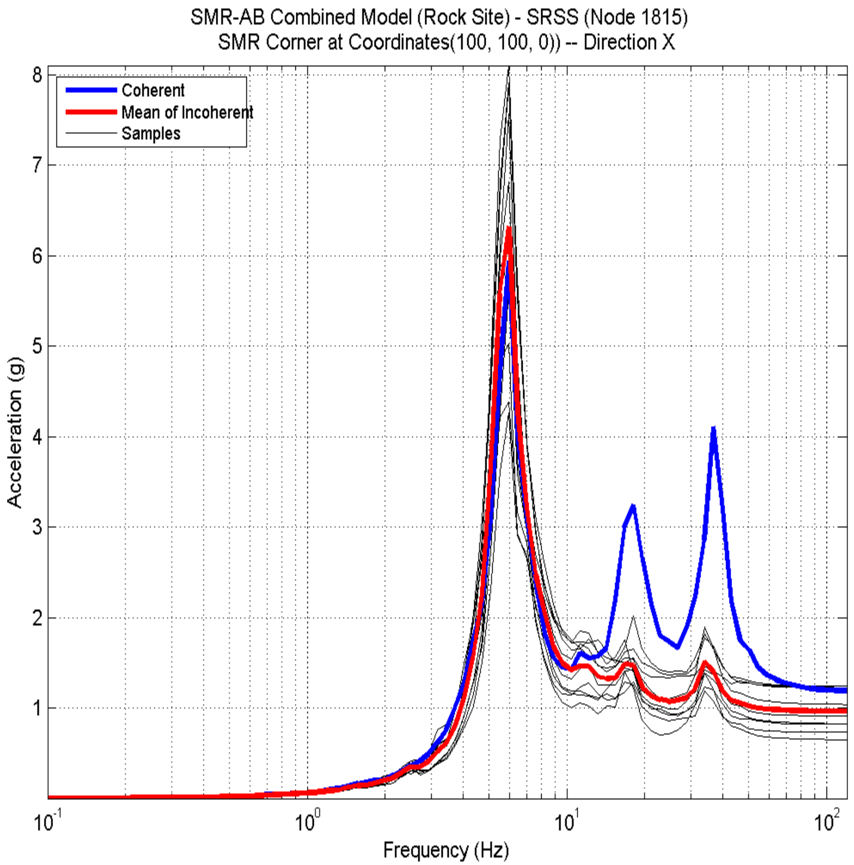
SMR size: 100 ft x 100 ft X 200 ft
Embedment: 140 ft
Mesh size: 10 ft X 10 ft X 10 ft
Number of Nodes: 2,580
Interaction Nodes: 1,815

Vs Soil Profile (fps)

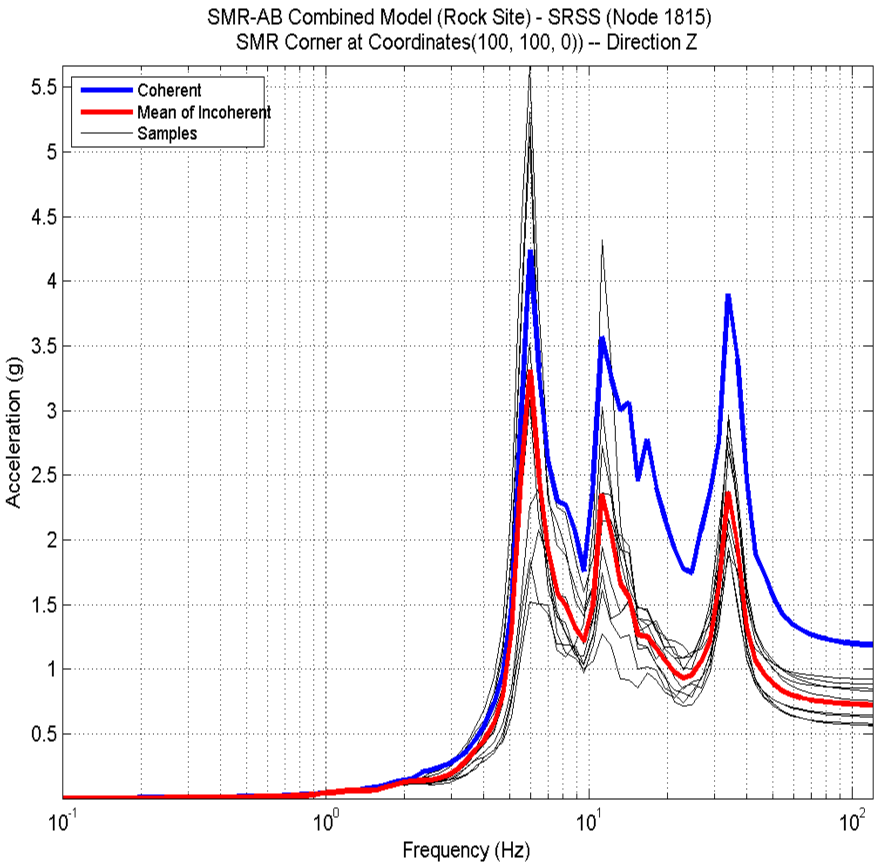


Seismic SSSI Effects on ISRS at Computed at Surface Level for Rock Site

Horizontal



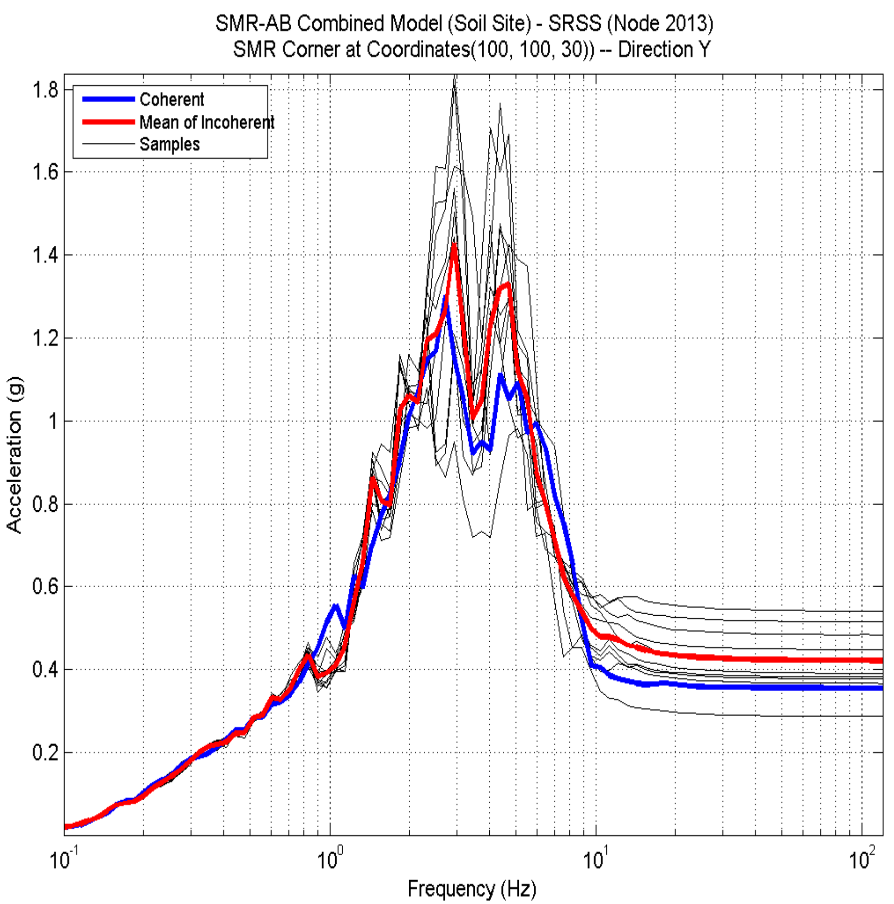
Vertical

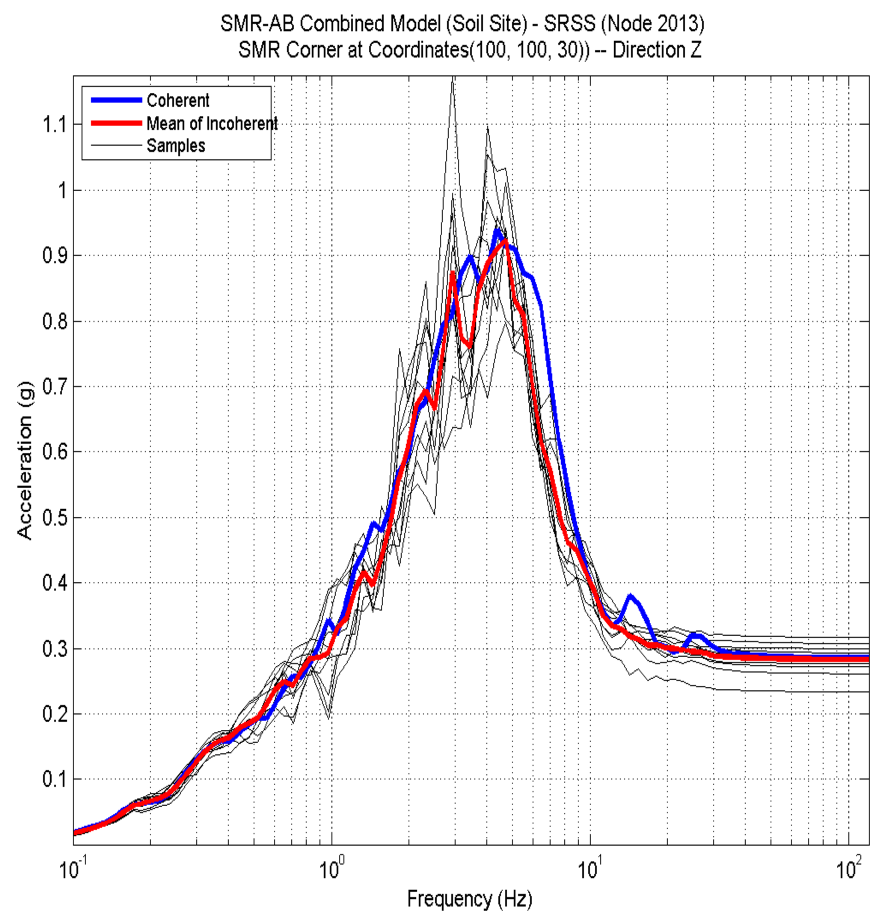


Seismic SSSI Effects on ISRS at Computed at 30 ft Above Surface for Soil Site

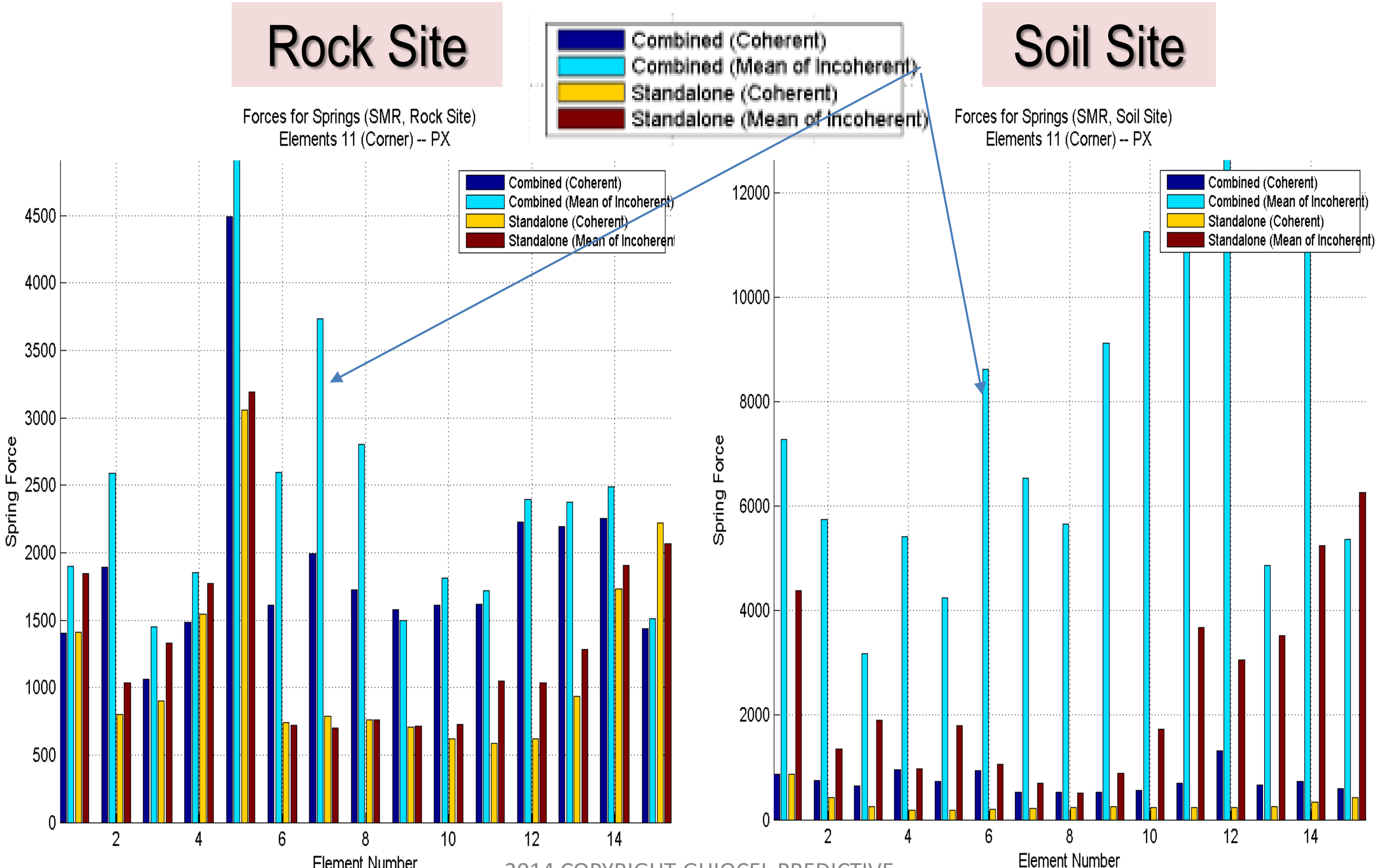
Horizontal

Vertical

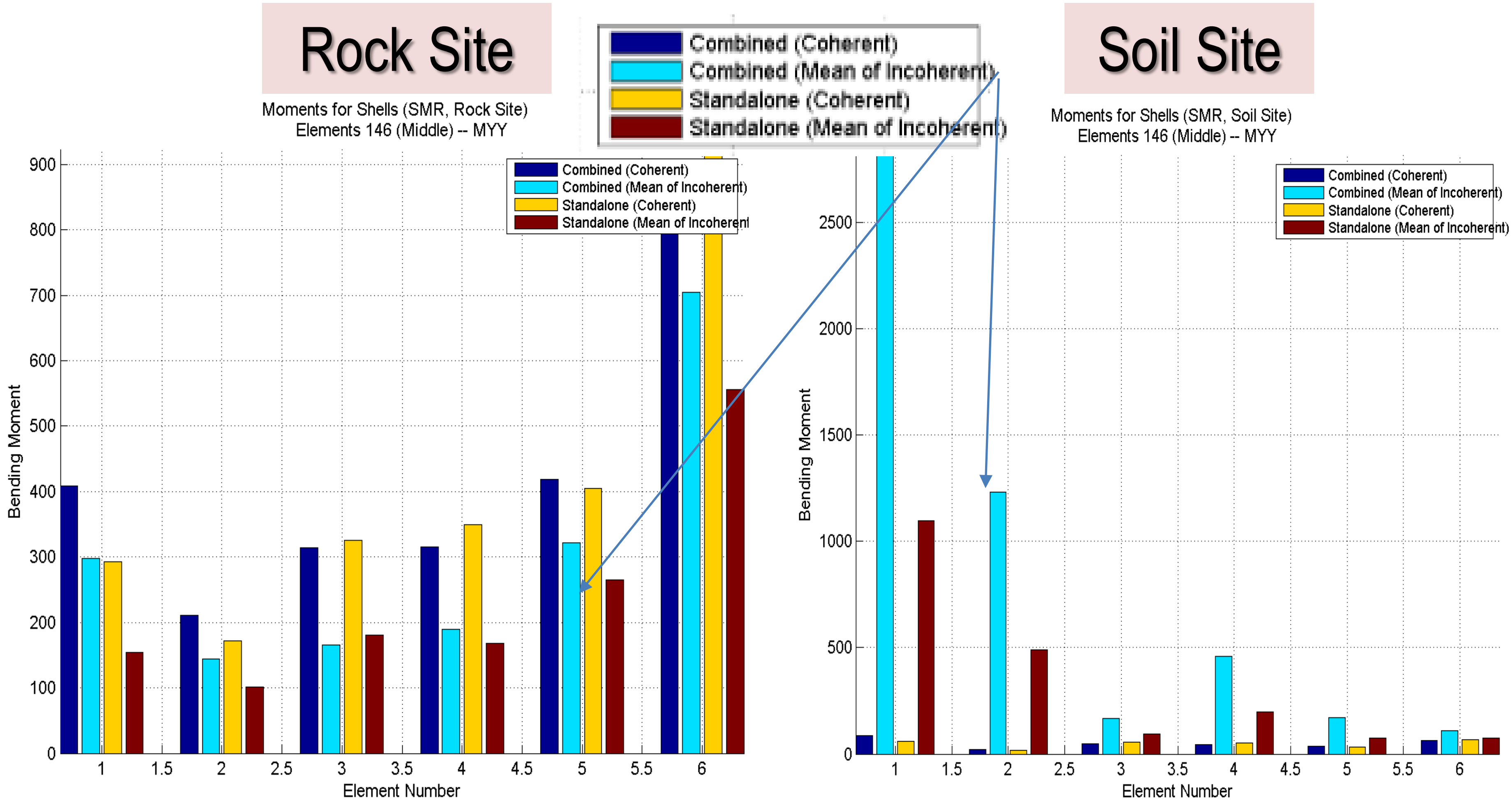




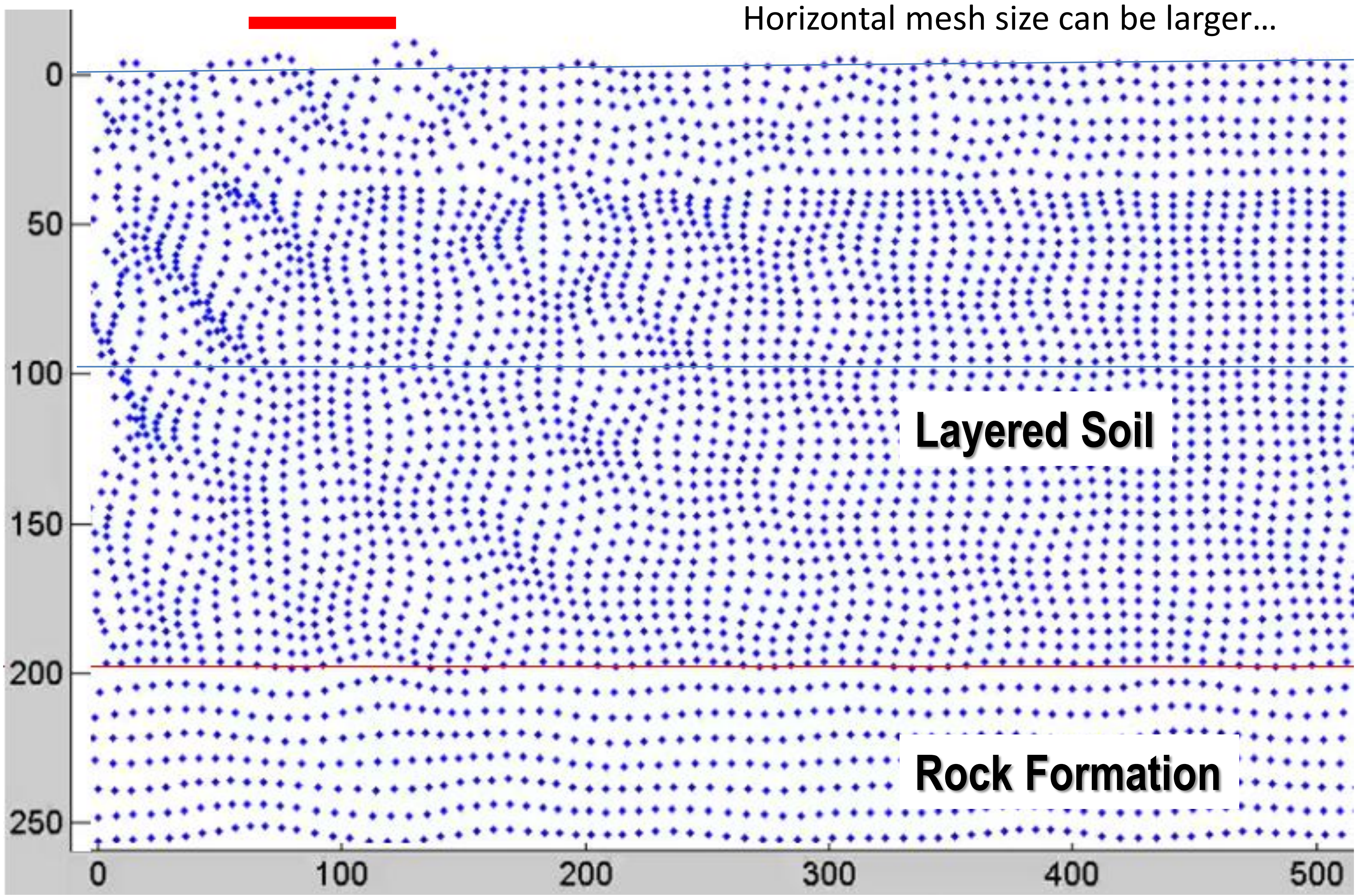
SSSI Effects on Seismic Soil Pressure (Spring Forces) Along the SMR Vertical Corner Edge Near AB (140 ft)



SSSI Effects on Wall O-P Bending Moments Along SMR Shell Element Vertical Line Near AB (60 ft)



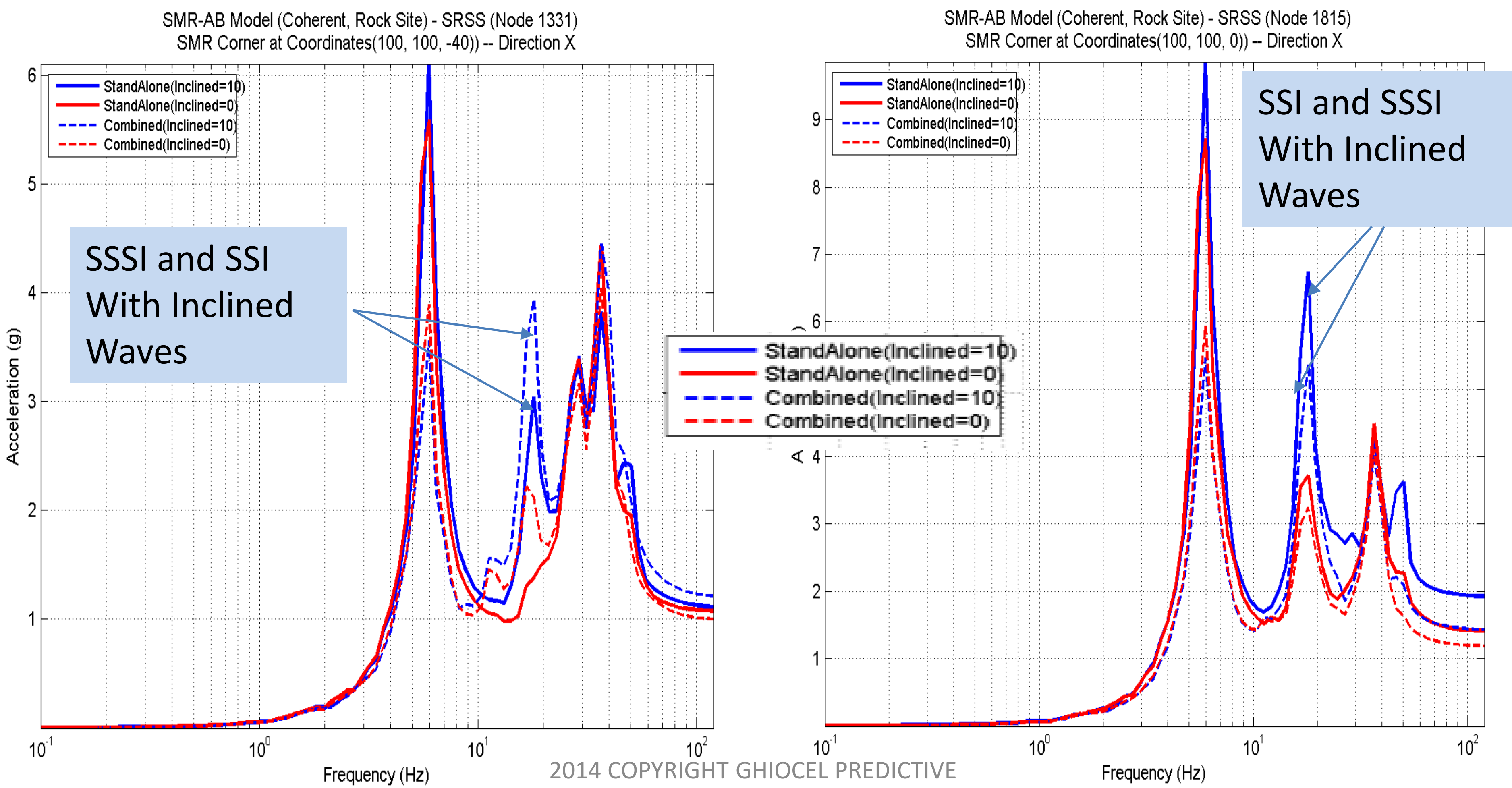
HO Rayleigh Wave Modes Manifest at High Frequencies in Nonuniform Layered Soils (shown at 30 Hz)



SSI and SSSI HO Rayleigh Wave Mode Effects on SMR ATF for Nonuniform Soil Layering – in X-Dir

-140 ft Depth

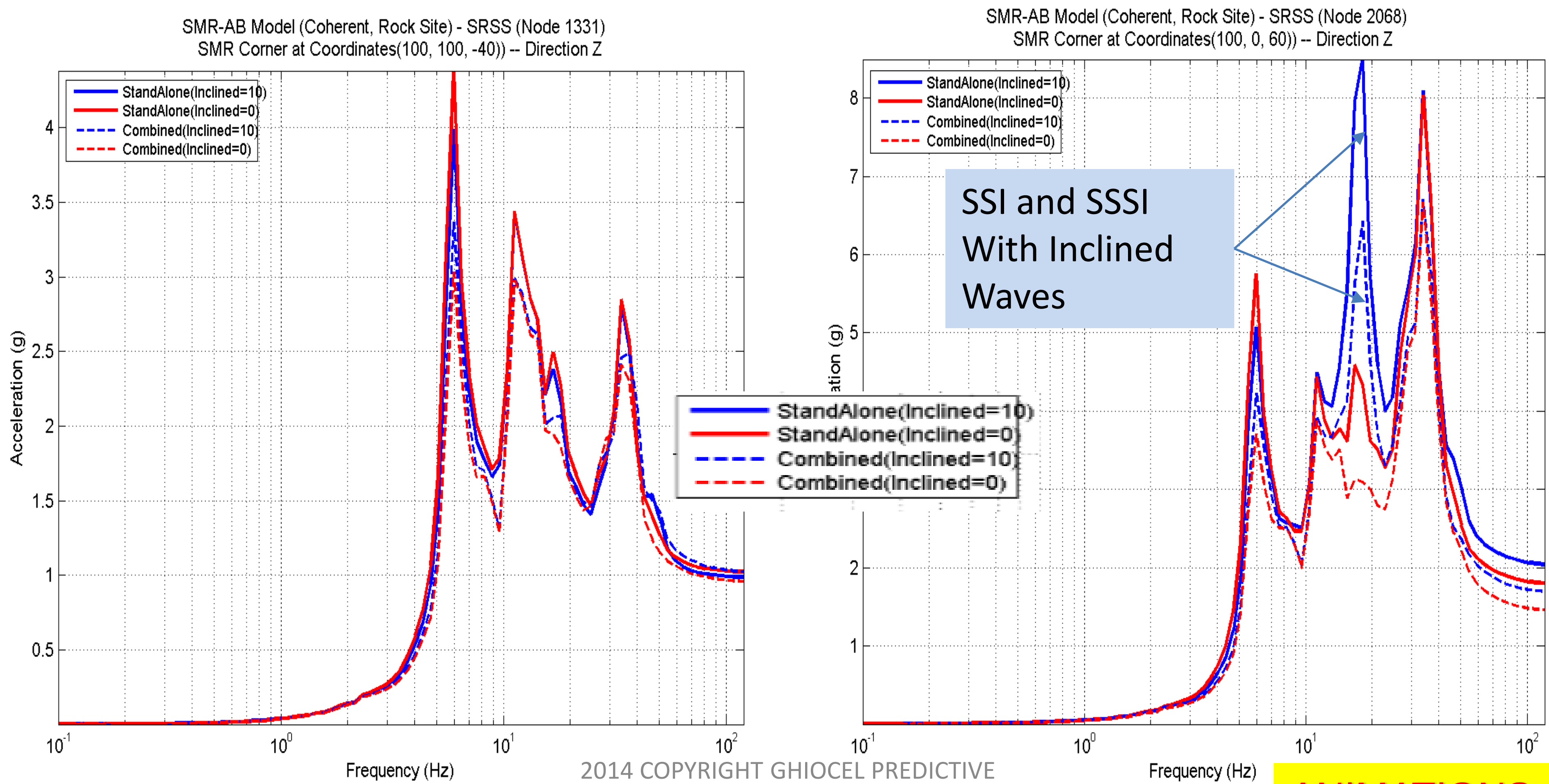
Surface Level



SSI and SSSI HO Rayleigh Wave Mode Effects on SMR ATF for Nonuniform Soil Layering – in Z-Dir

-140 ft Depth

Surface Level

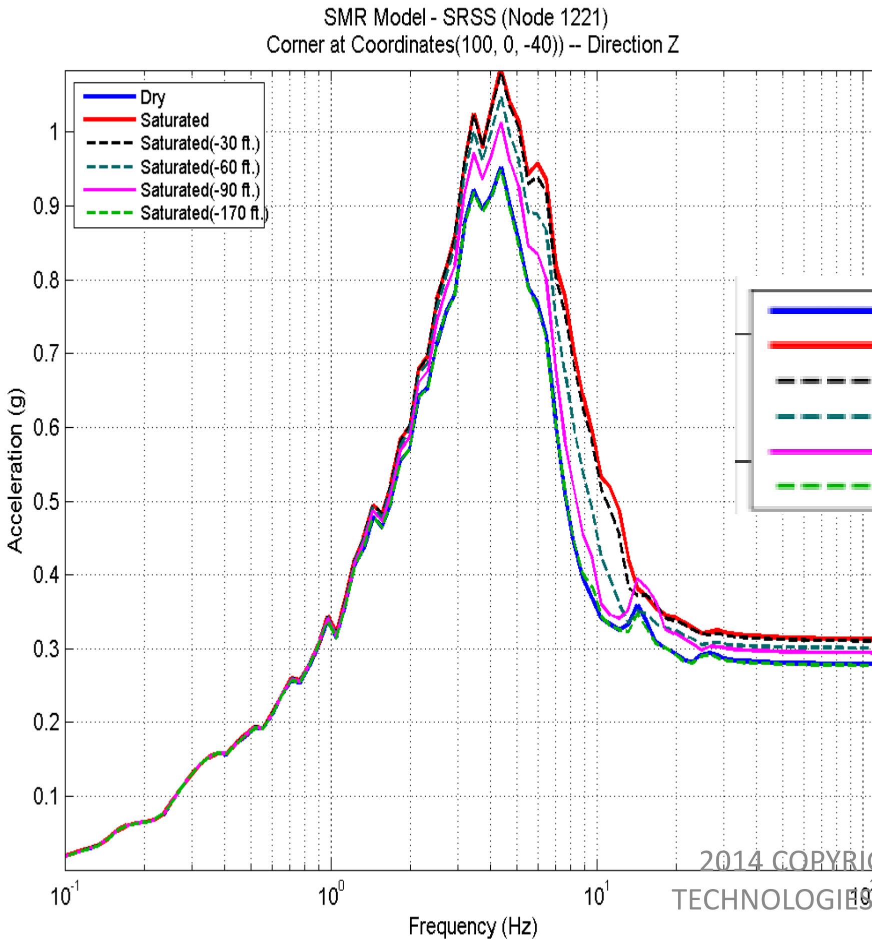


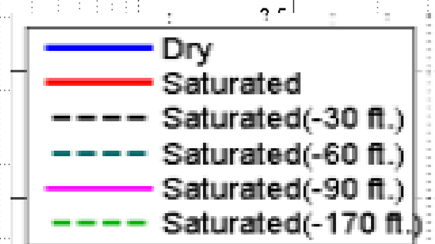
ANIMATIONS

Ground Water Level Effects on the Vertical SMR Vibration at 40 ft Depth Floor Level

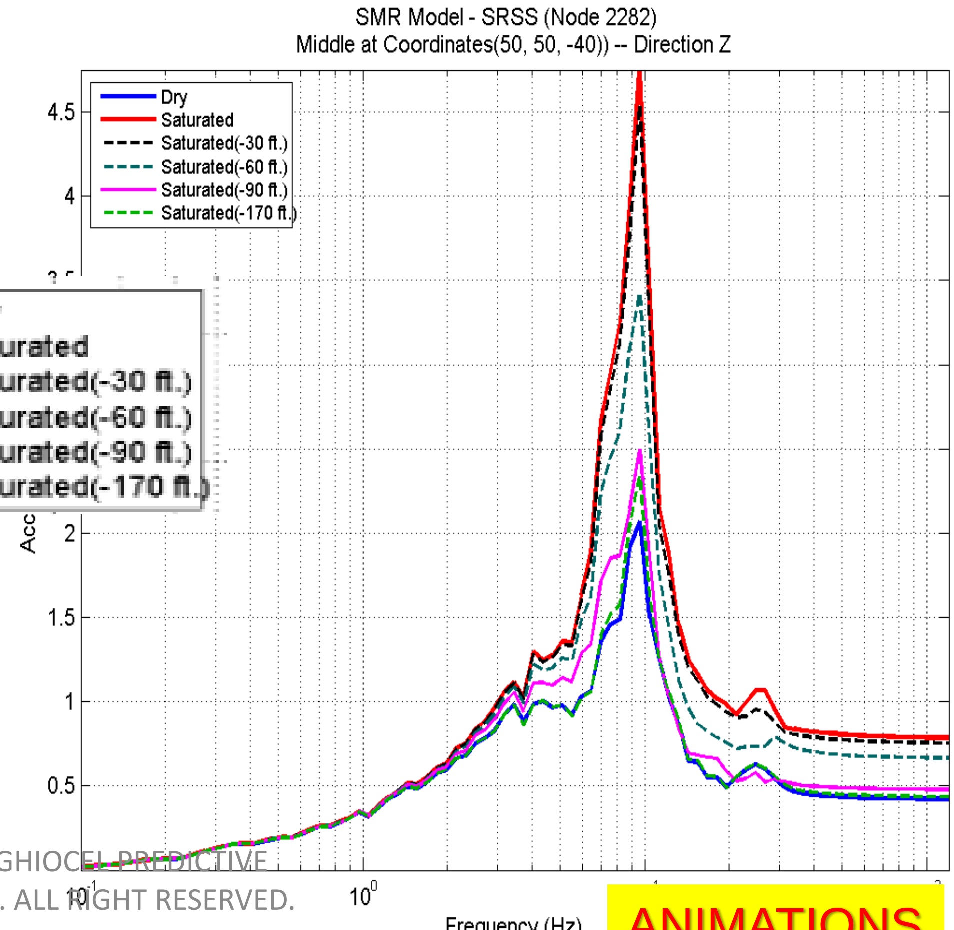
140 ft Embedded SMR SSI Model

Floor Corner





Floor Center



ANIMATIONS

Conclusions for Investigated Case Studies

- Deterministic ISRS could be significantly higher Probabilistic ISRS. However it appears that the 84% NEP provided too low estimates, due to the smoothing effect produced by statistical averaging on the sharp ISRS peaks - frequency shifts due to soil stiffness variations are important.
- The use of the SASSI MSM and ESM with only one or two interaction node layers that are internal to the excavation volume provide crude results when compared with the FV method for the investigated SMR cases.
- Excavation horizontal mesh sensitivity studies indicate a good solution robustness for variations in the mesh size and its nonuniformity. This contradicts some published results. We will continue our investigations…
- The SMR-AB SSSI effects are important for deep soft soil deposit case, especially on the seismic soil pressures and embedded walls o-p bending
- The effects of HO Rayleigh wave modes in high-frequency appears to be significant for nonuniform layered soil deposits. We will continue…
- Ground water level can affect largely the SMR floor vertical vibration. This is not fully recognized by all.