Extending SASSI Methodology to Seismic SSI Analysis for Nuclear Buildings Founded on Soil Deposits With Inclined Layering

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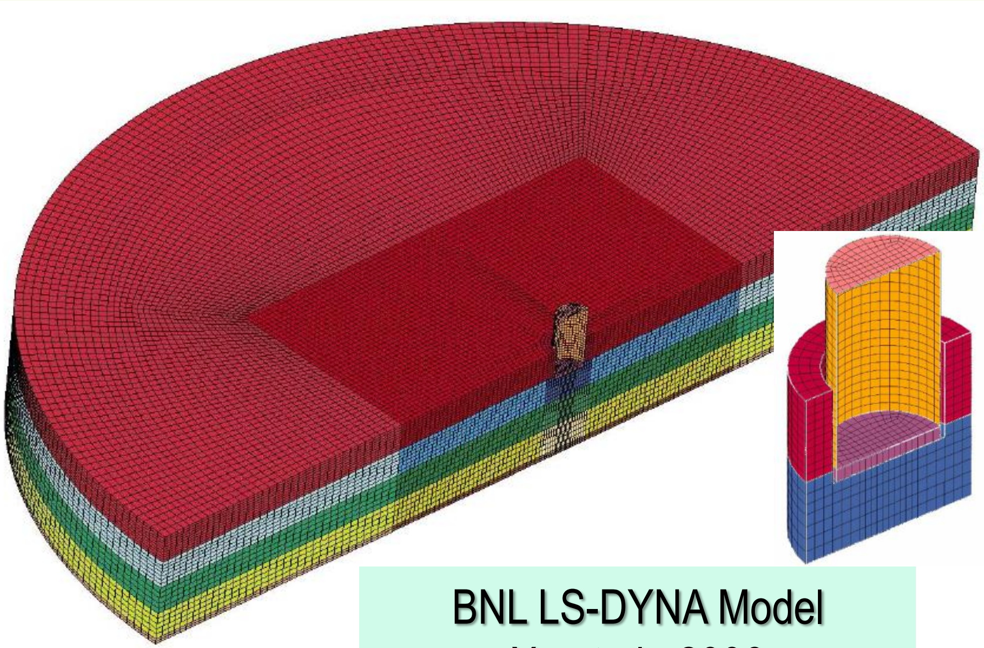
Purpose of Presentation:

To introduce an extended SASSI methodology capable of dealing efficiently with the effects of the 2D soil layering variations on the seismic SSI responses.

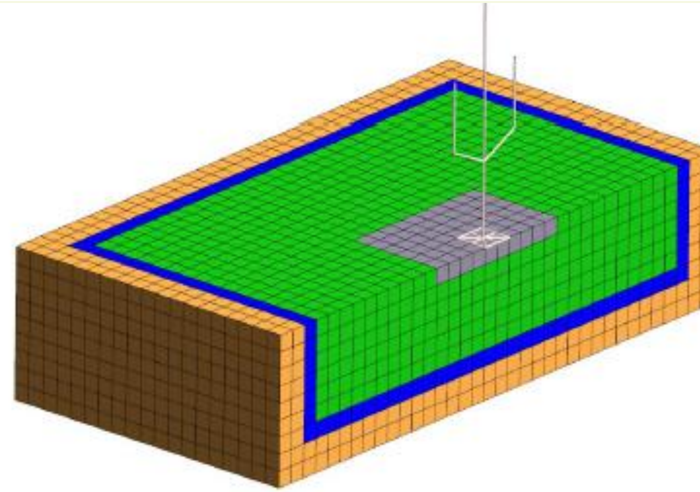
This 2D soil layering modelling is of particularly significance for the deeply embedded structures such as SMR structures that are more sensitive to kinematic SSI effects.

This capability extension of the SASSI methodology for the 2D soil layering has been recently implemented in the ACS SASSI V4 Option 2DSOIL.

Direct SSI Approach and SASSI Approach Models

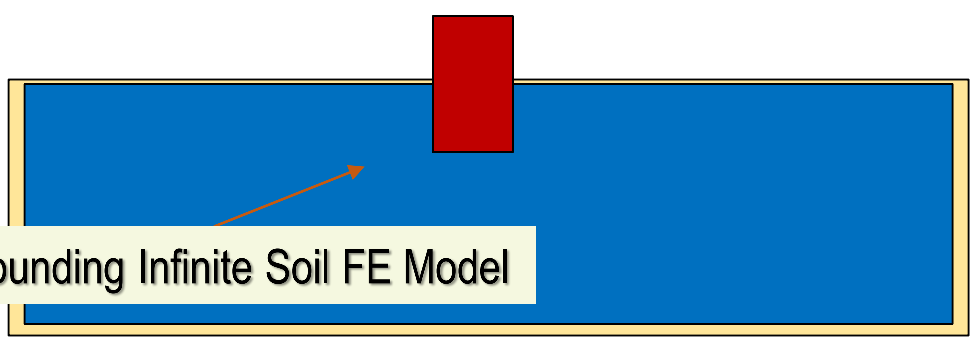


BNL LS-DYNA Model
Xu et al., 2006



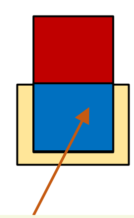
E-SSI Model
Neboja et al., 2015

Direct SSI Approach Model



Surrounding Infinite Soil FE Model

SASSI Approach Model

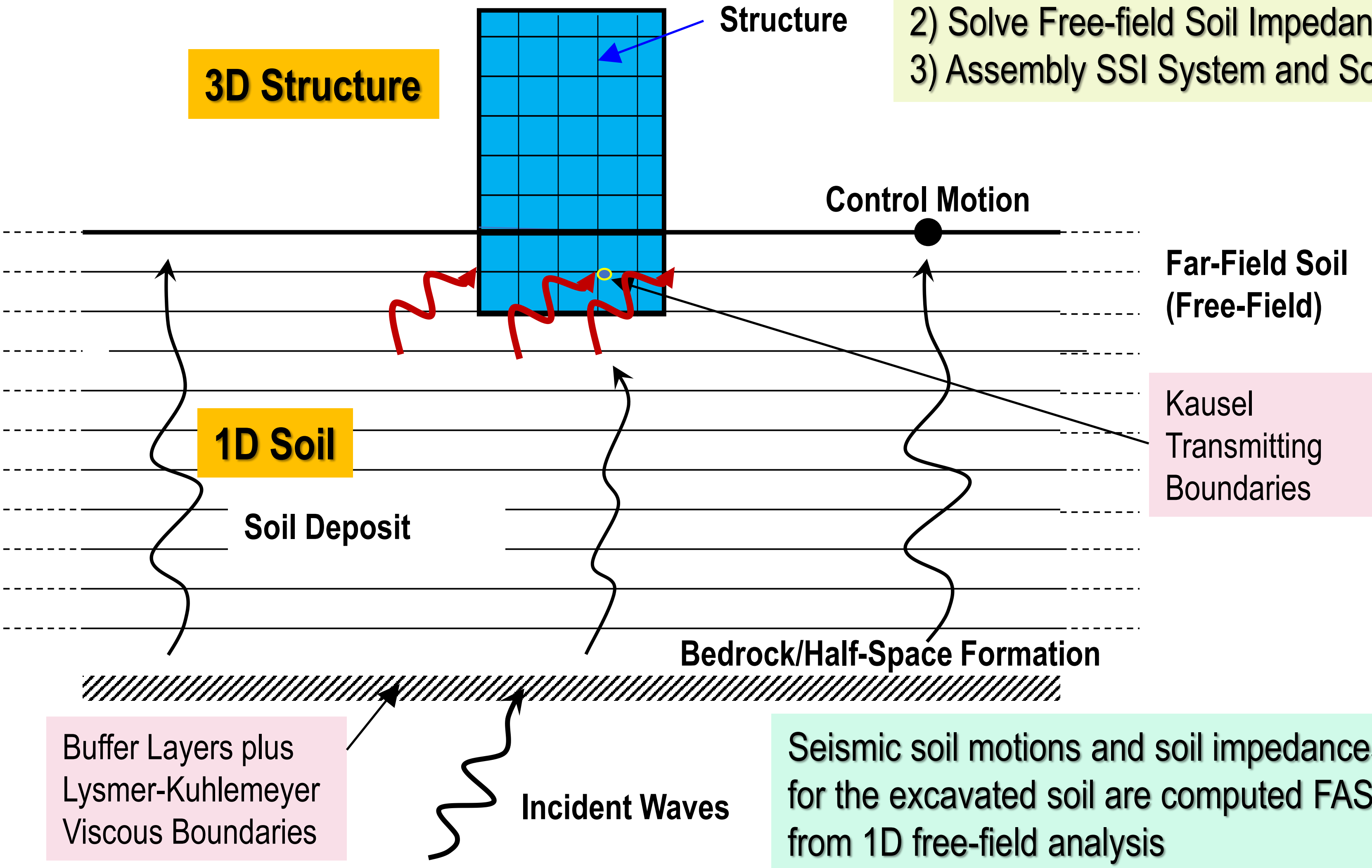


Excavated Soil FE Model
Plus Soil Impedances

SASSI Substructuring Uses 3D1D SSI Models

Computational Aspects:

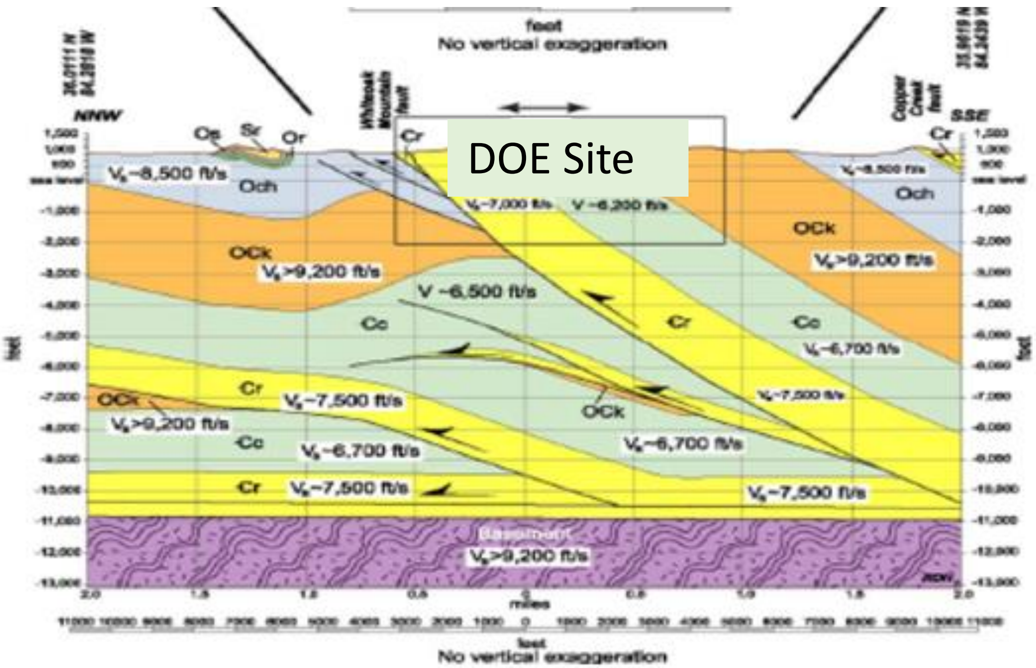
1) Solve Free-filed Motion (1D)
2) Solve Free-field Soil Impedance (1D)
3) Assembly SSI System and Solve (3D)

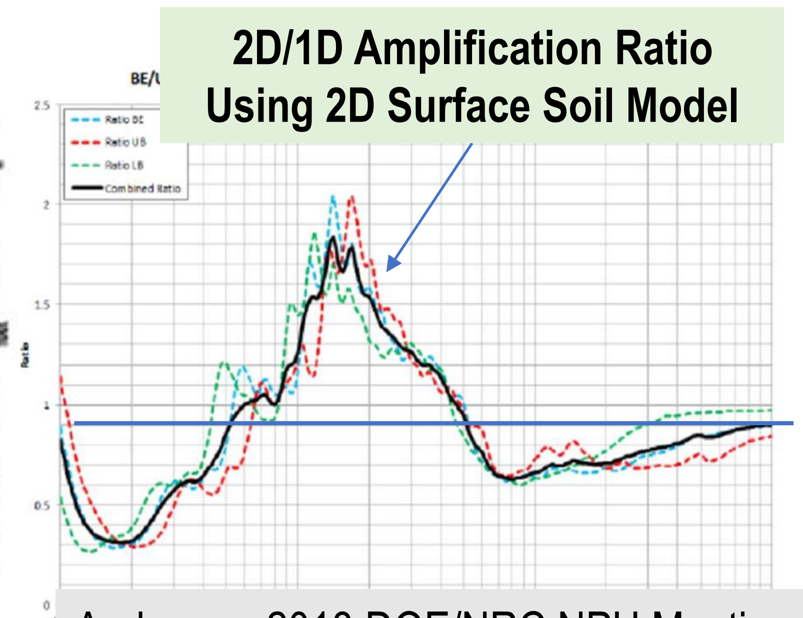


Seismic soil motions and soil impedances for the excavated soil are computed FAST from 1D free-field analysis

NPP Sites with Inclined Soil Layering

1-D site response (SHAKE methodology) may not capture all significant aspects of the wave propagation at a site. *The 2-Dimensional soil models are useful for these situations. See example below for a DOE site:*



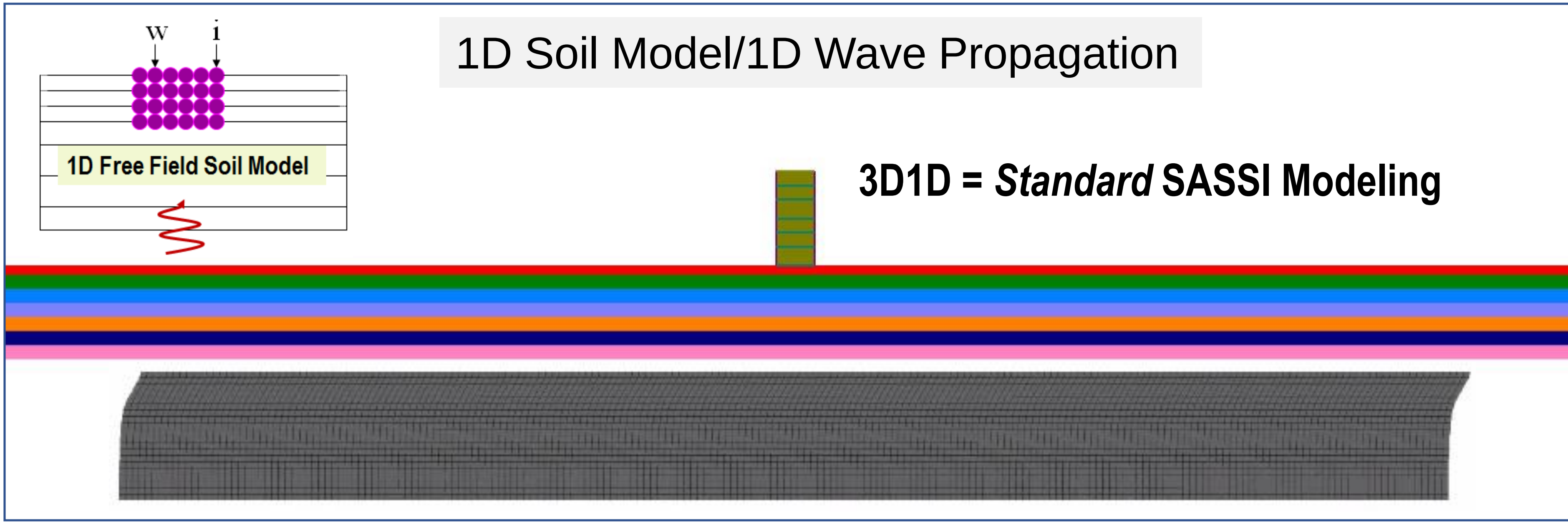


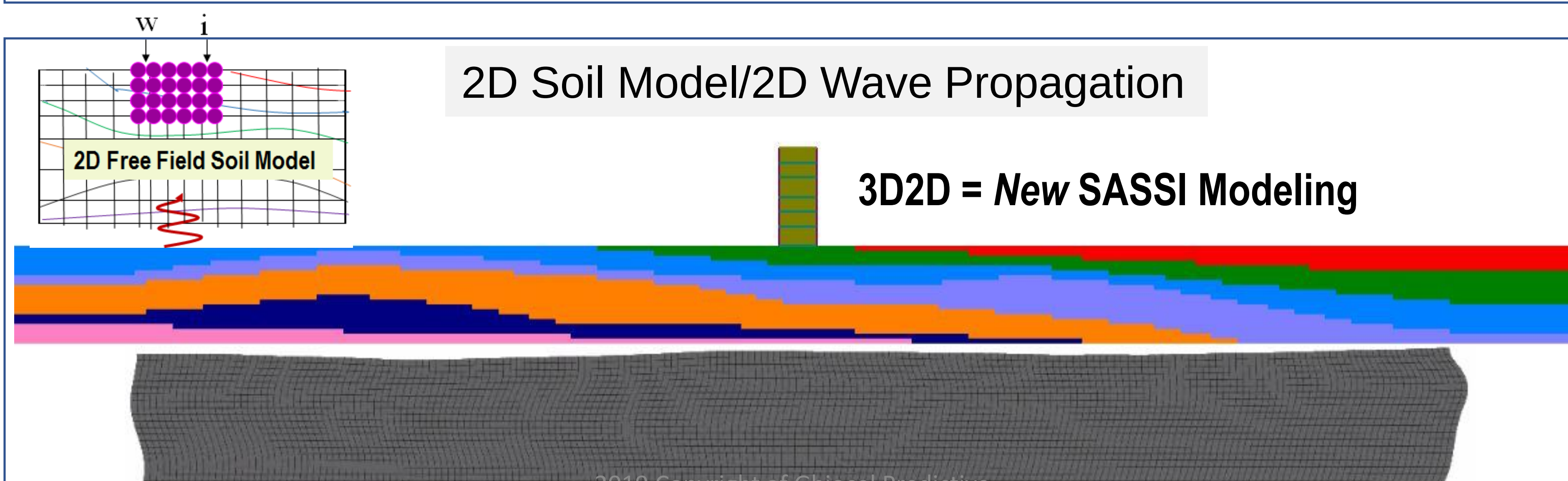
Anderson, 2018 DOE/NRC NPH Meeting

5

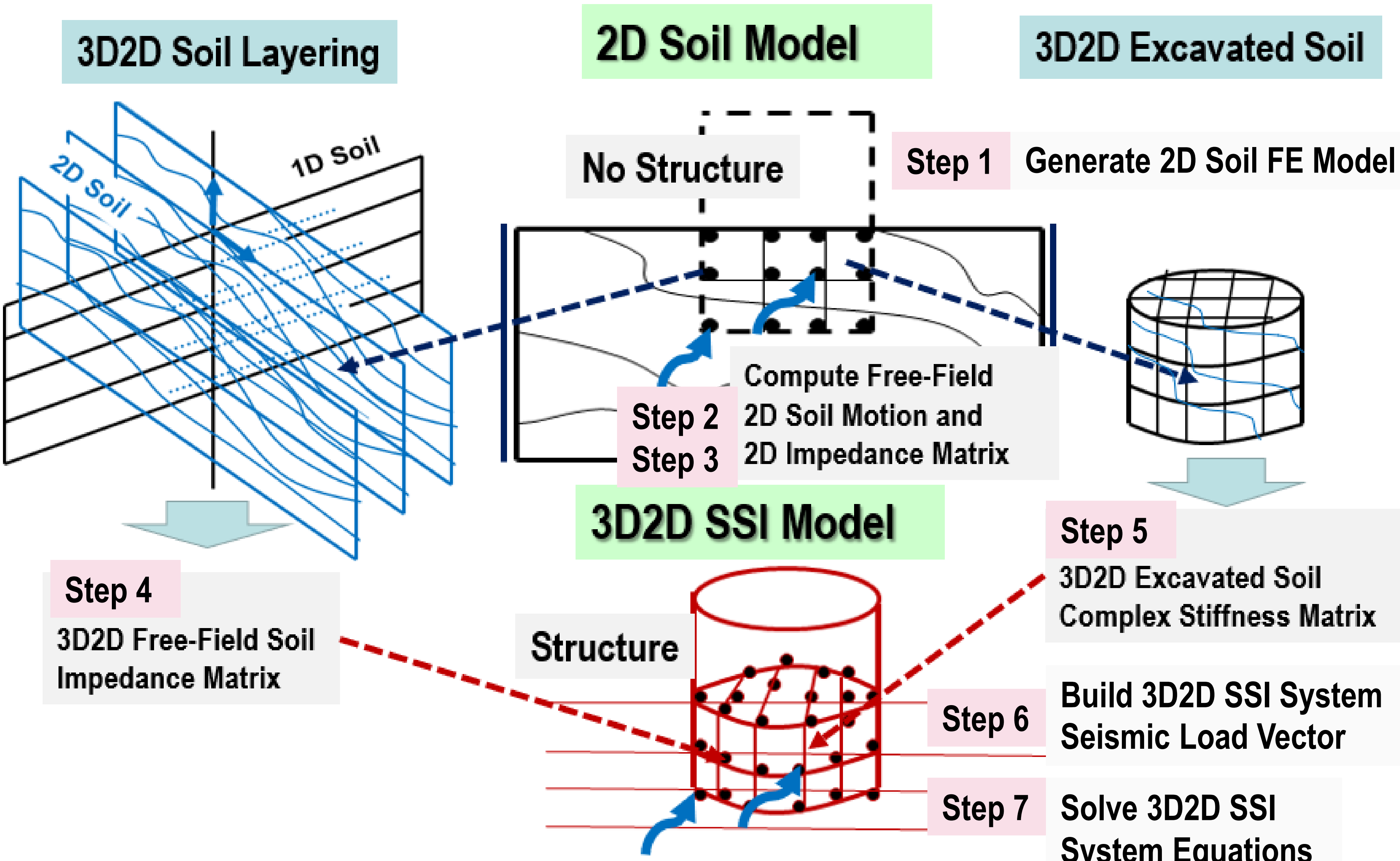
What happens with the soil impedance calculation?
Use the 1D soil model to get soil impedances for the 2D soil layering?
Then, combine 2D model soil motion with 1D model soil impedances?

Option 2DSOIL Uses New 3D2D SASSI Modeling





3D2D SASSI Modeling Concept Description



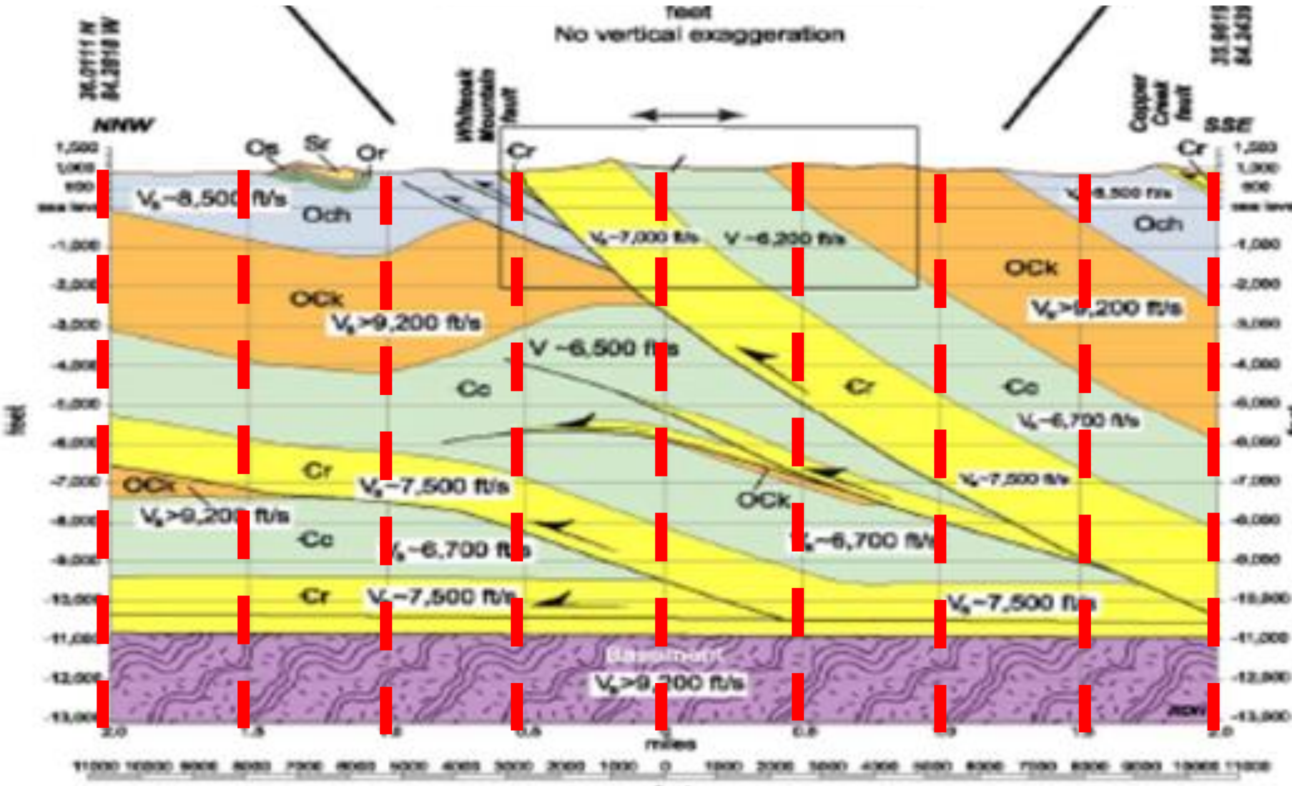
3D2D SASSI Modeling Implementation

3D2D SASSI (2D in X-Z plane and 1D in Y-Z plane) implementation includes seven main steps:

1) Build the 2D layered soil FE model based on site-specific soil data (2D plane-strain model in X-Z plane)
2) Compute free-field soil motion based on 2D layered soil model (2D plane-wave assumption in X-Z plane)
3) Compute free-field soil impedance based on 2D layered soil model (2D plane-strain model in X-Z plane)
4) Compute free-field soil impedance based on 3DCSM (3D cylindrical soil model is 2D in X-Z plane and 1D variation in Y-Z)
5) Build excavated soil model for the 3DCSM (3D cylindrical soil model is 2D in X-Z plane and 1D variation in Y-Z)
6) Assemble the 3D SSI system, including the 3D structure FE model and the 3DCSM soil impedances, excavated soil FE model, and the seismic load vectors

1) Solve efficiently the 3D SSI motion equations in the complex frequency

Generate 2D Complex Soil FE Models



GEN2DSOILFLD,<hmin>,<hmax>,<zmin>,<zmax>,<hdist>,<zdist>,<xy>

PRNTSOILPRO,<sr>

REFINESOIL,<L>

RMVSOILPRO,<sr>

SOILCORE,<sr>,<Hor>,<Ver1>,<Lay1>,…,<VerN>,<LayN>

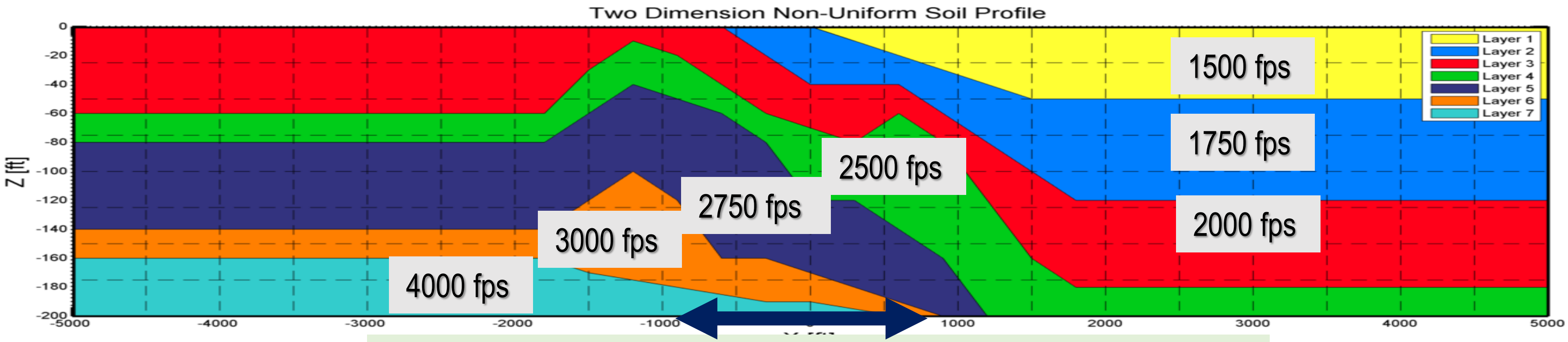
SOILPRJ2D,<Mdl>,<sr>,<XY>

SOILPROUT,<sr>,<mdl>,<xy>

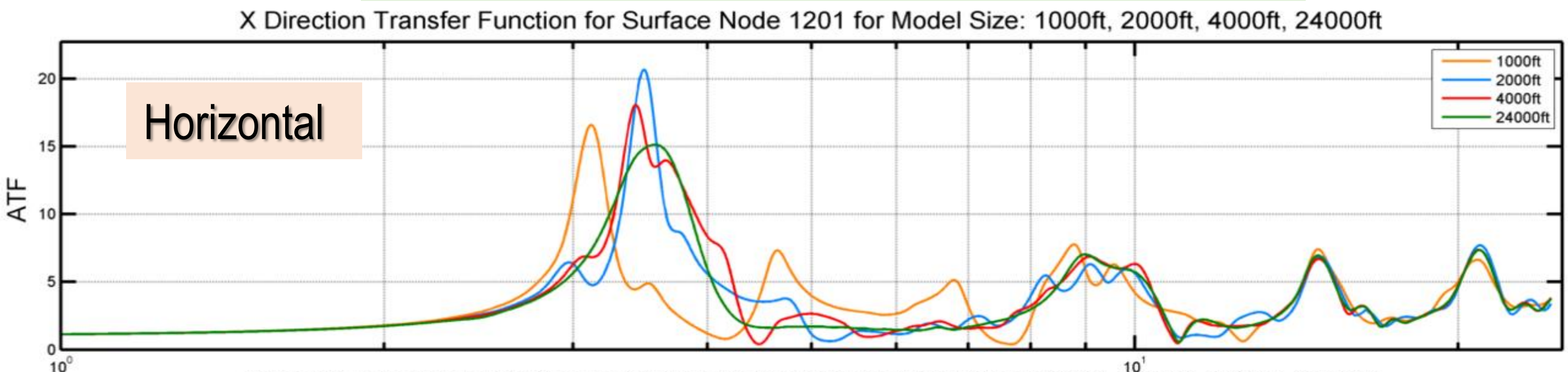
VOLNODES

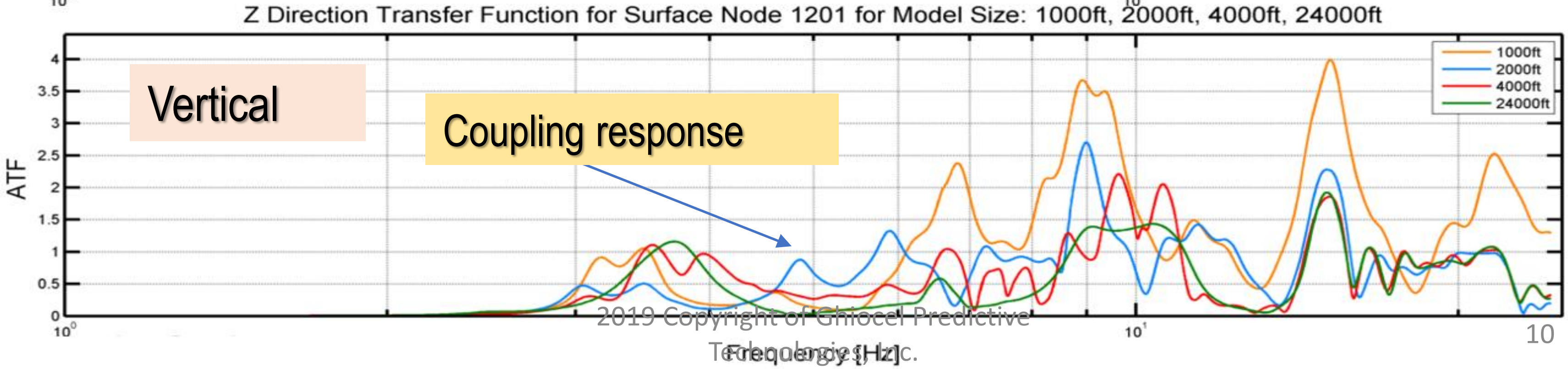
ACS SASSI User Interface commands to generate complex 2D soil FE models from separate soil columns

2D *Surface* Soil Models Not Applicable



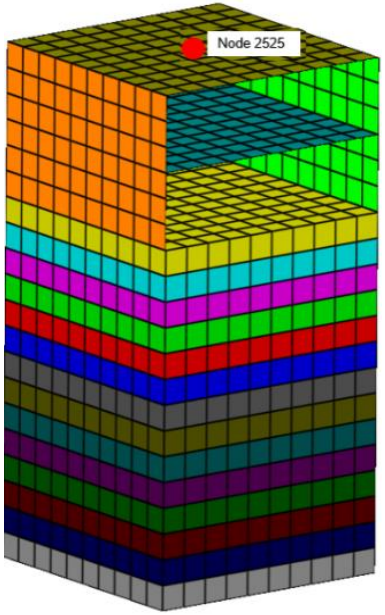
2D Soil Model Lateral Size Convergence Study





3D2D SASSI Implementation Validation Against Standard 3D1D SASSI Modeling

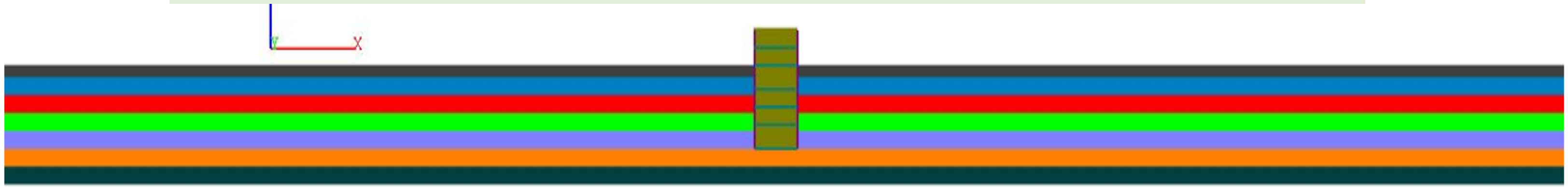
Embedded SMR



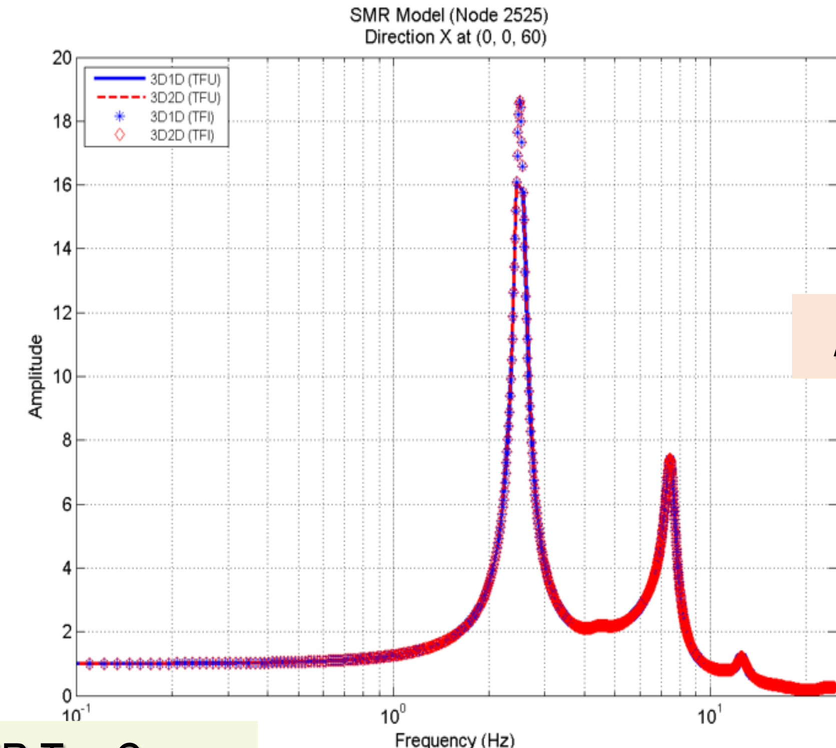
Soil Layering

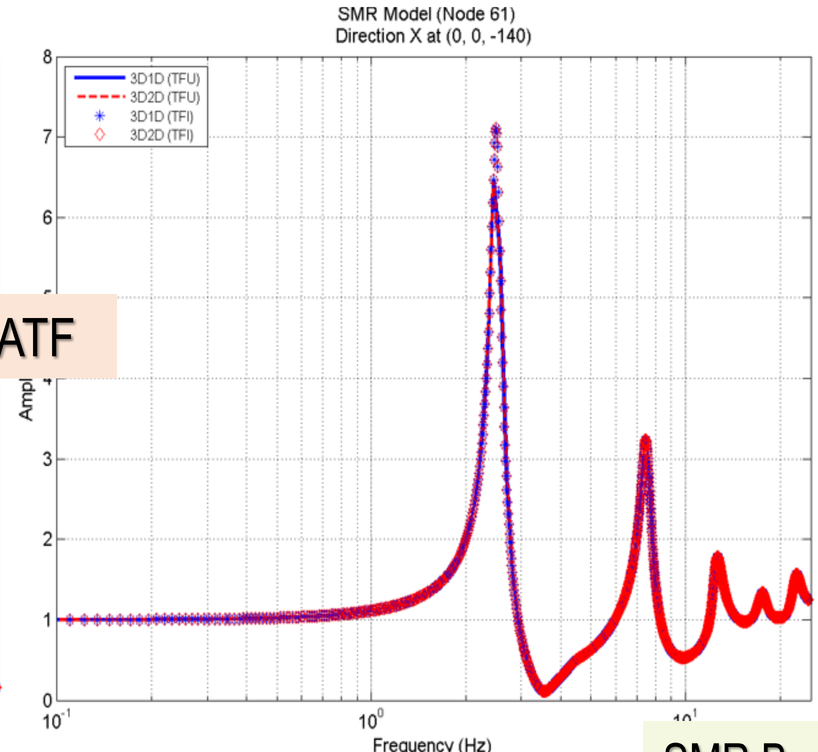
Layer	Thickness	Specific Weight	SV Wave Velocity	P Wave Velocity	Damping Ratio
1	20	0.15	1500	3000	0.04
2	30	0.15	1750	3500	0.04
3	30	0.15	2000	4000	0.035
4	30	0.15	2500	5000	0.03
5	30	0.15	2750	5500	0.025
6	30	0.15	3000	6000	0.02
7	30	0.15	4000	8000	0.02
Base	200 ft Halfspace	0.15	4000	8000	0.02

2D Soil Model (Structure is not included)



3D2D vs. 3D1D Model: Horizontal ATF and ISRS

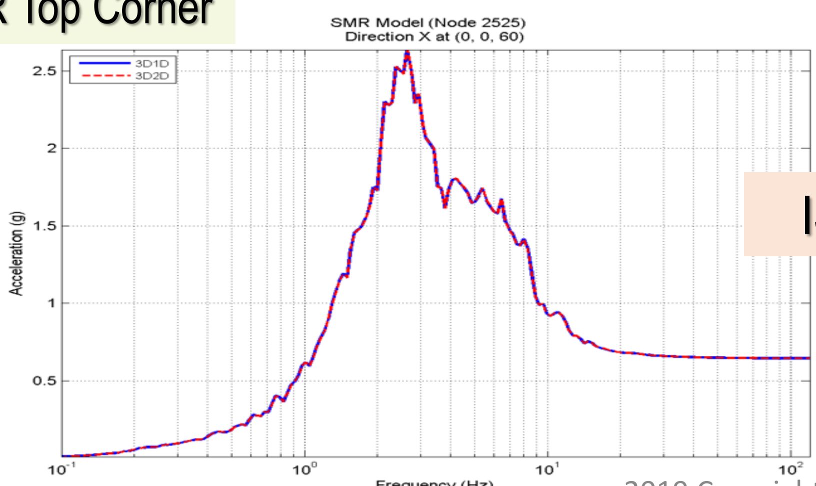


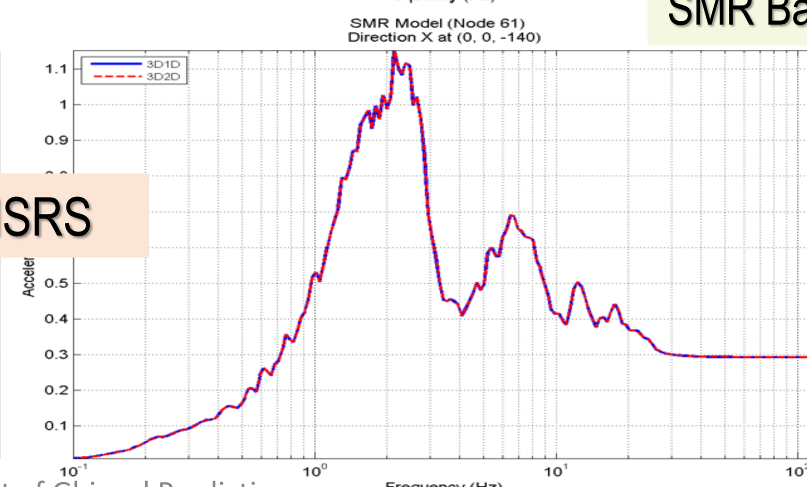


ATF

SMR Top Corner

SMR Base Corner



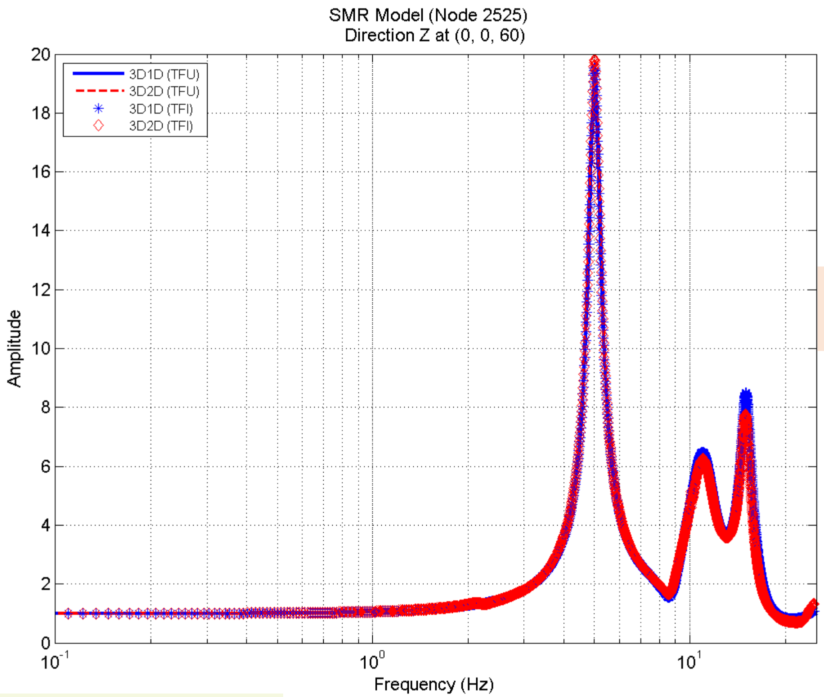


ISRS

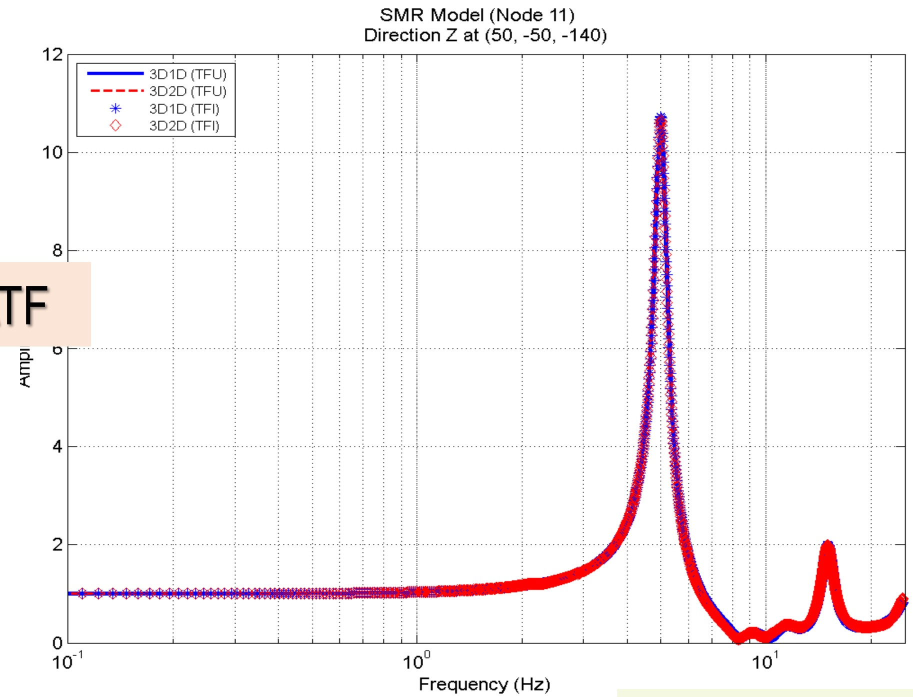
3D2D vs. 3D1D Model: Horizontal ATF and ISRS

ATF

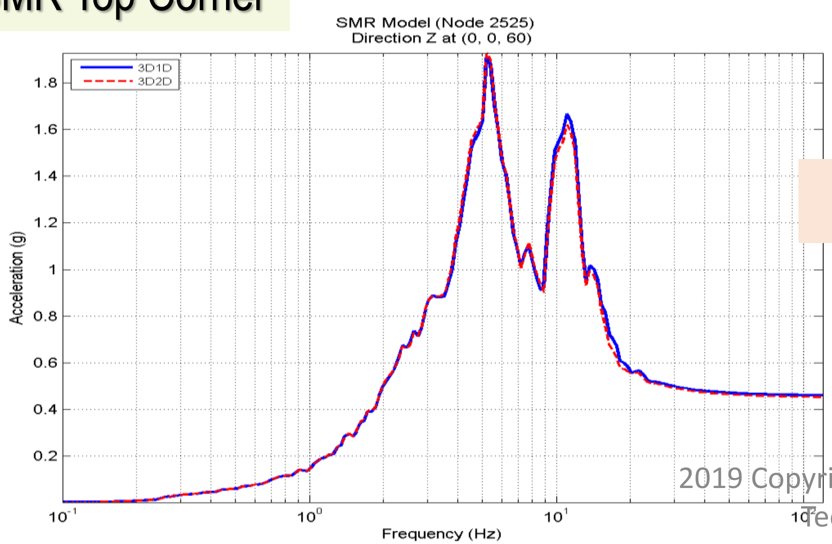
SMR Top Corner

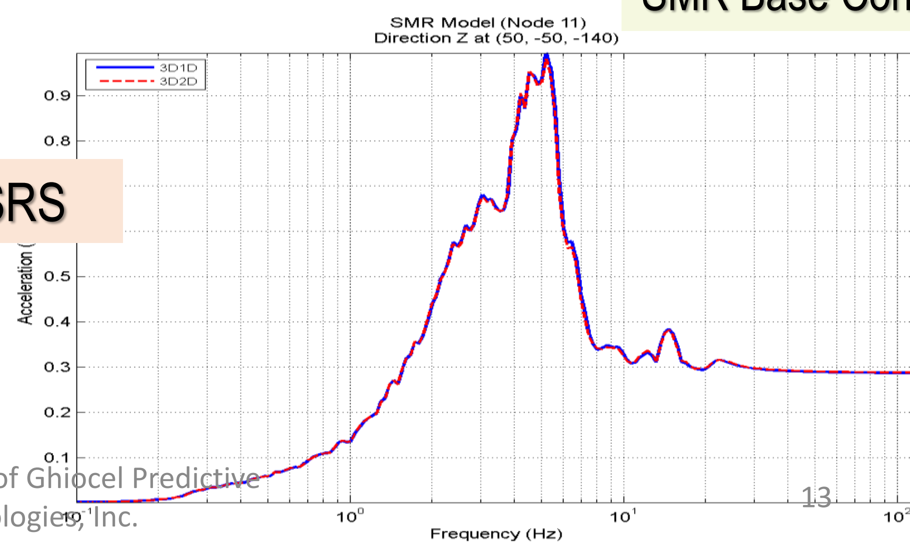


SMR Base Corner

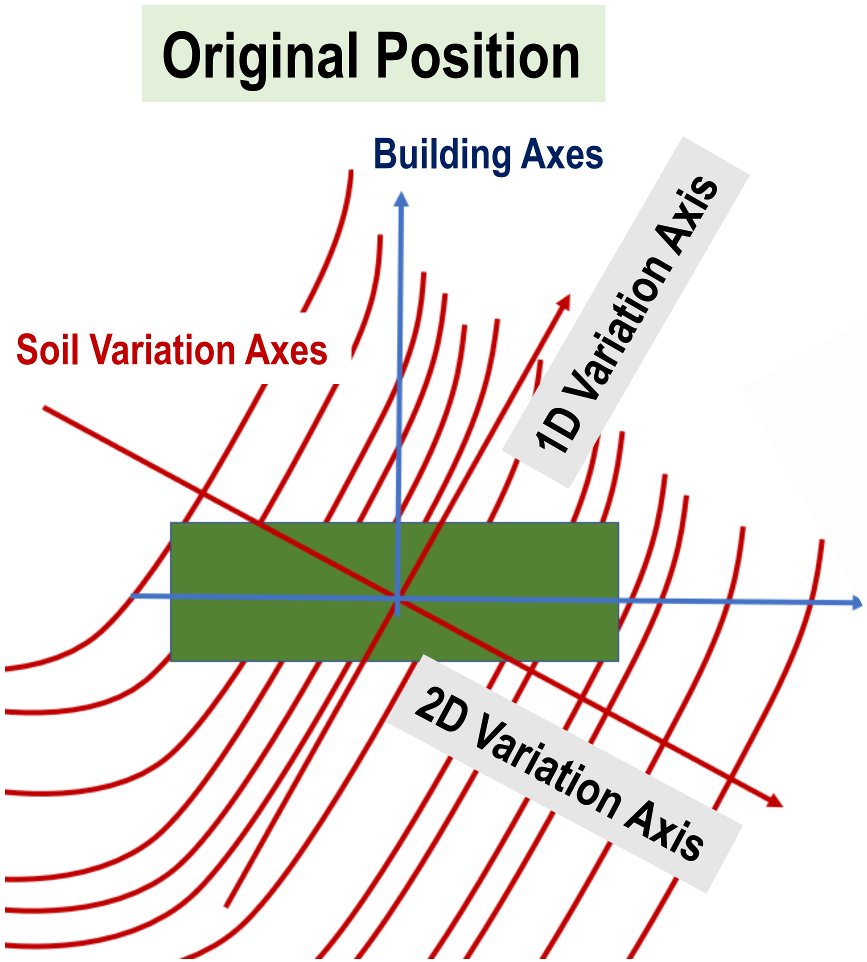


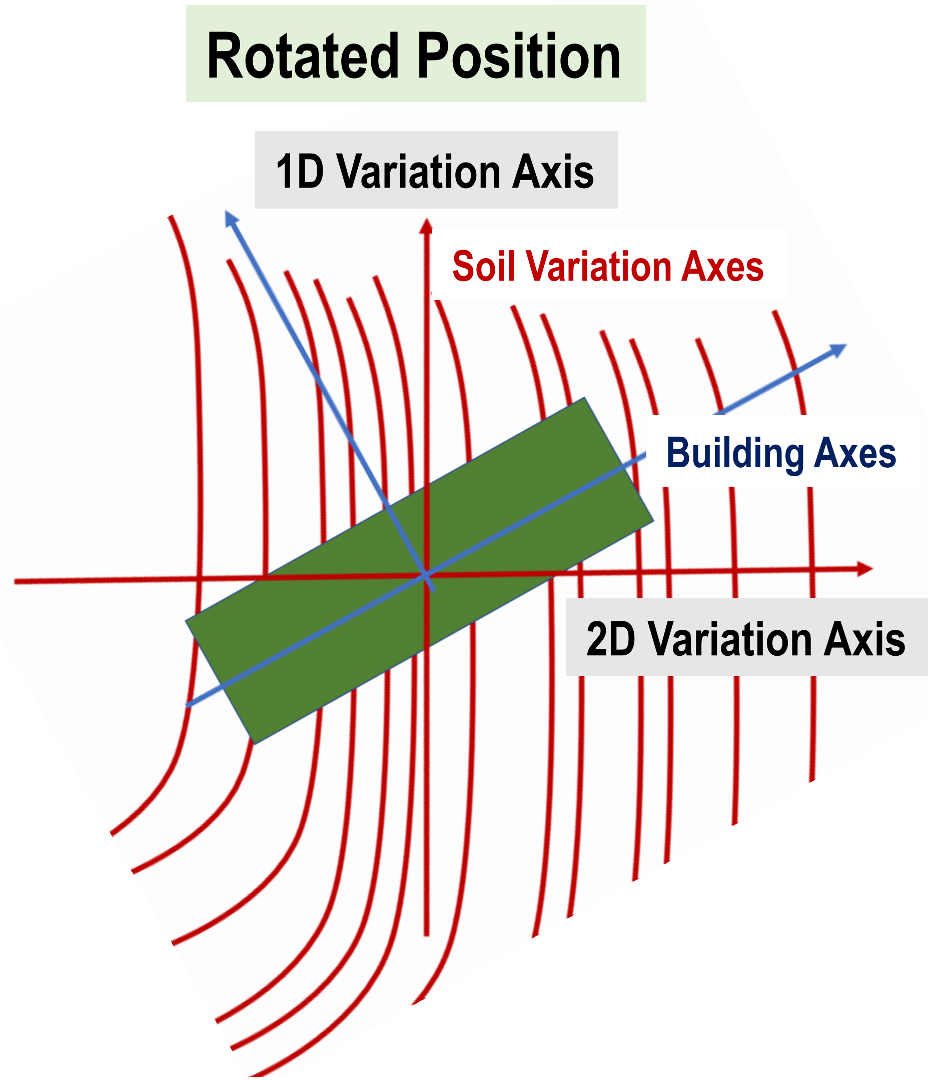
ISRS





2D Soil and 3D Excavation Meshes Are Different

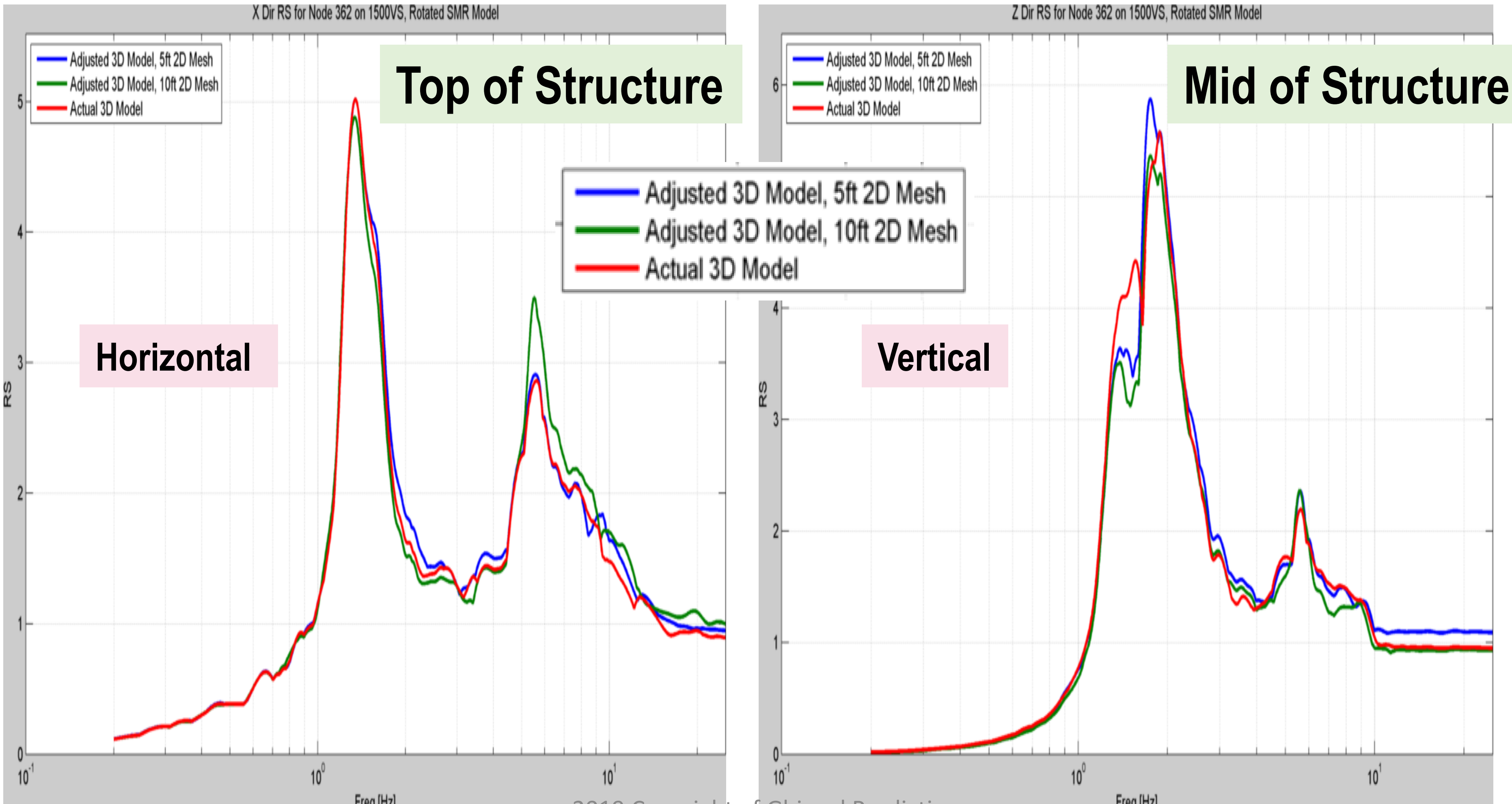




ACS SASSI software UI have specialized SSI model translation and rotation commands.

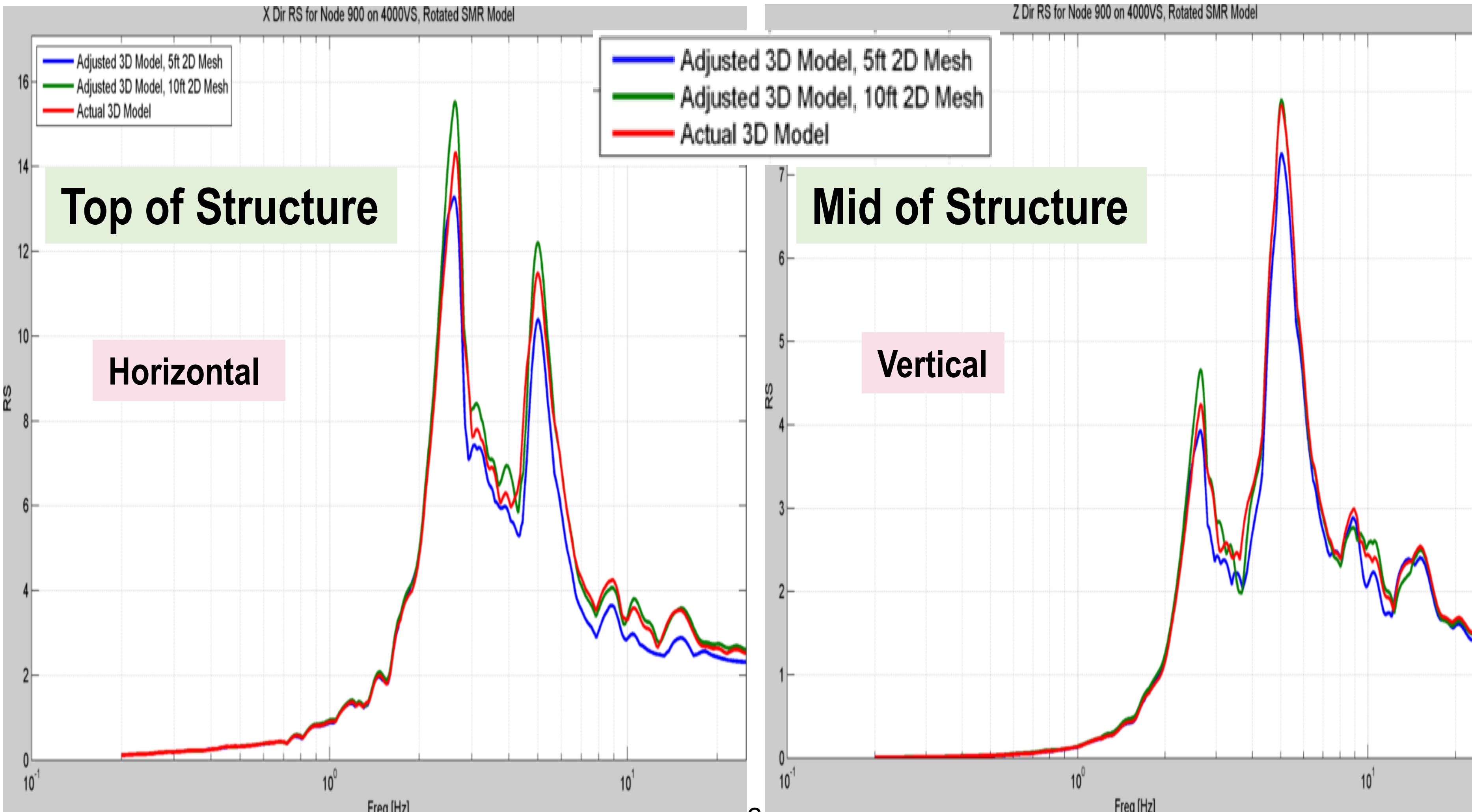
2D Soil Mesh Sensitivity Studies with 5ft and 10ft for 3D Structure With Average Mesh Size of 7.5ft

Vs =1500 fps



2D Soil Mesh Sensitivity Studies with 5ft and 10ft for 3D Structure With Average Mesh Size of 7.5ft

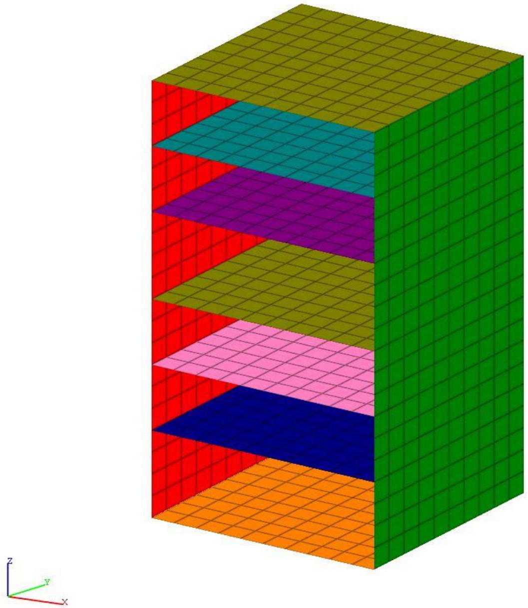
Vs = 4000 fps



3D2D SASSI Model Case Studies for X-Input

A) SMR Surface Model and B) 140 ft Embedded Model

SMR Structure



Soil Layering

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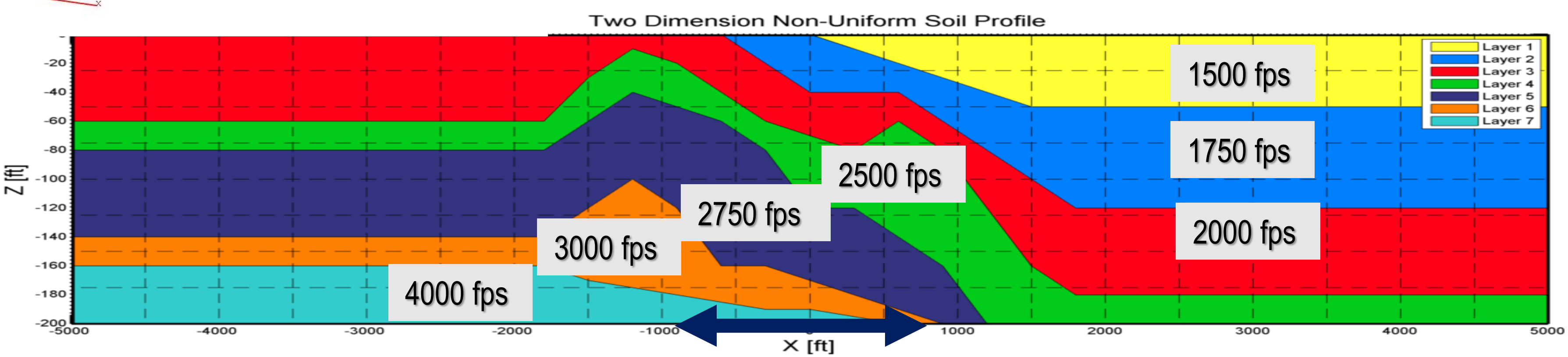
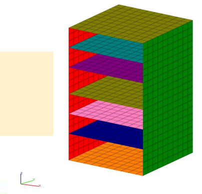
5	30	0.15	2750	5500	0.025
6	30	0.15	3000	6000	0.02
7	30	0.15	4000	8000	0.02
Base	200 ft Depth Bedrock	0.15	10000	20000	0.001

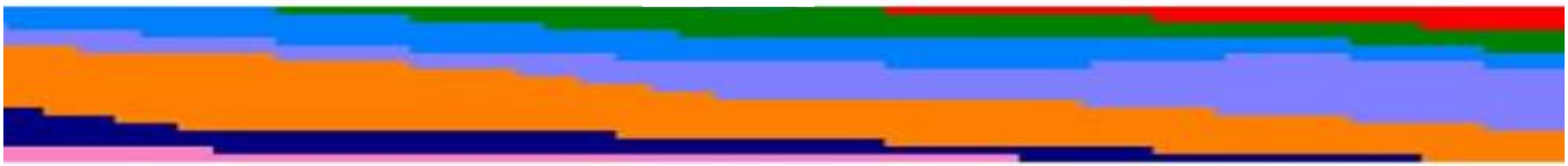


3D2D SASSI Model Case Studies for X-Input

SMR Structure



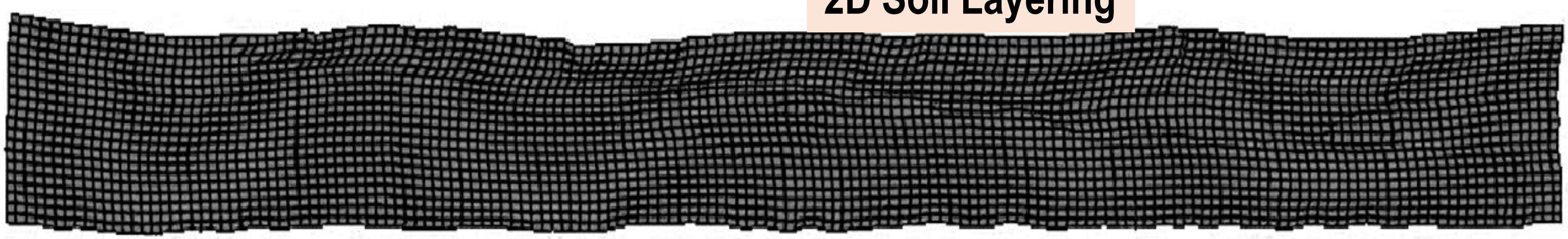
Soil Layering
(1000 ft Window)



Rot: X = 62.000000 Y = 0.000000 Z = 0.000000
Zoom: 14.413000 Pan: X = 0.000000 Y = 0.000000
Screen Size: X = 941 Y =
Frame: 947

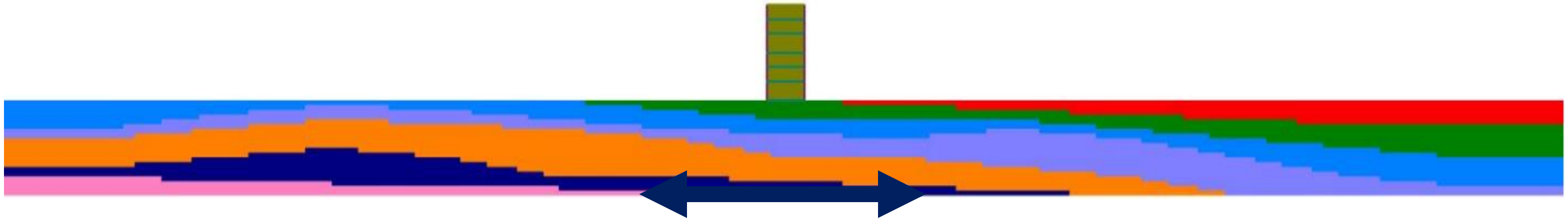
Free-Field Soil Accelerations (time step # 947)

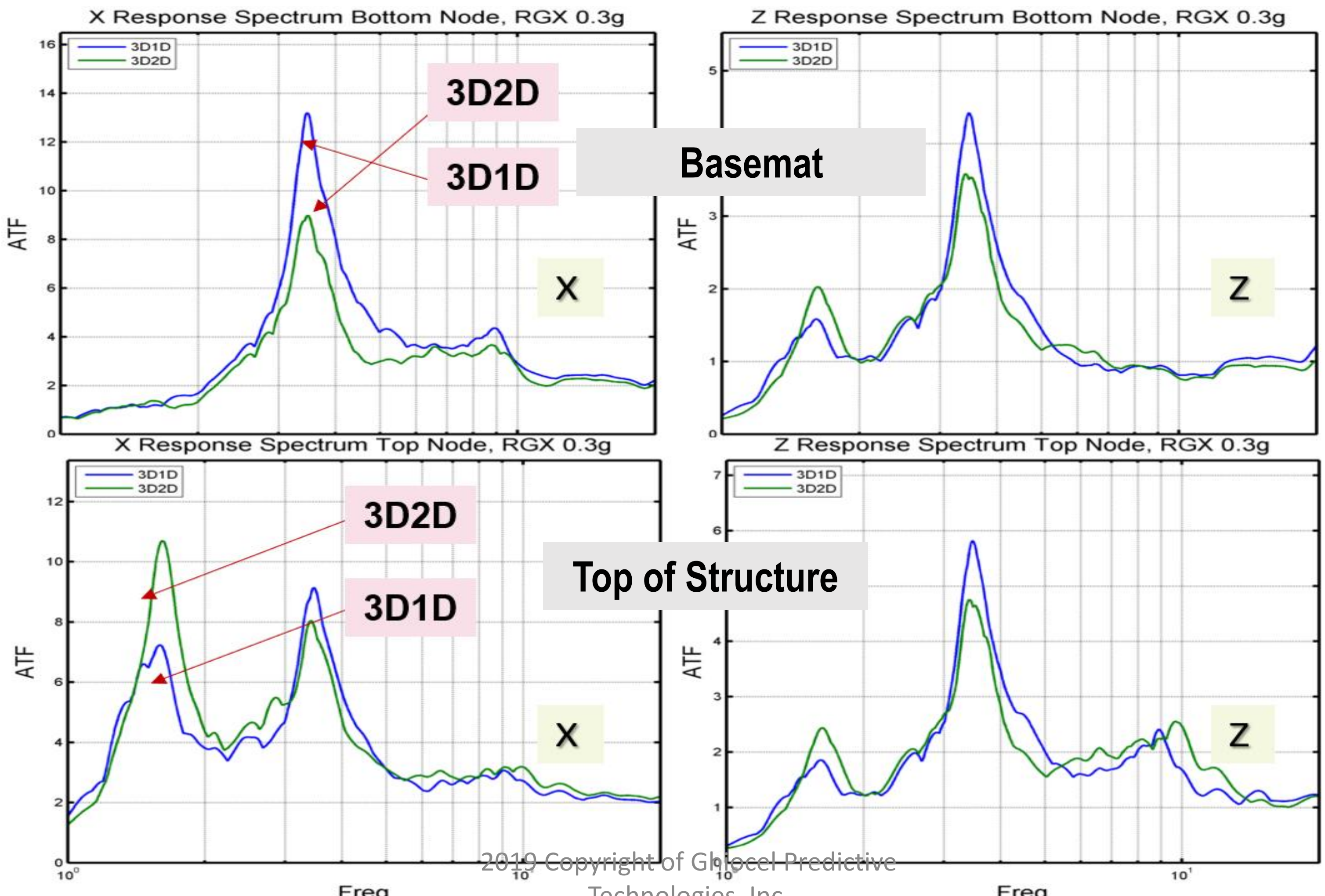
2D Soil Layering



1D Soil Layering (Average 500 ft Windows)

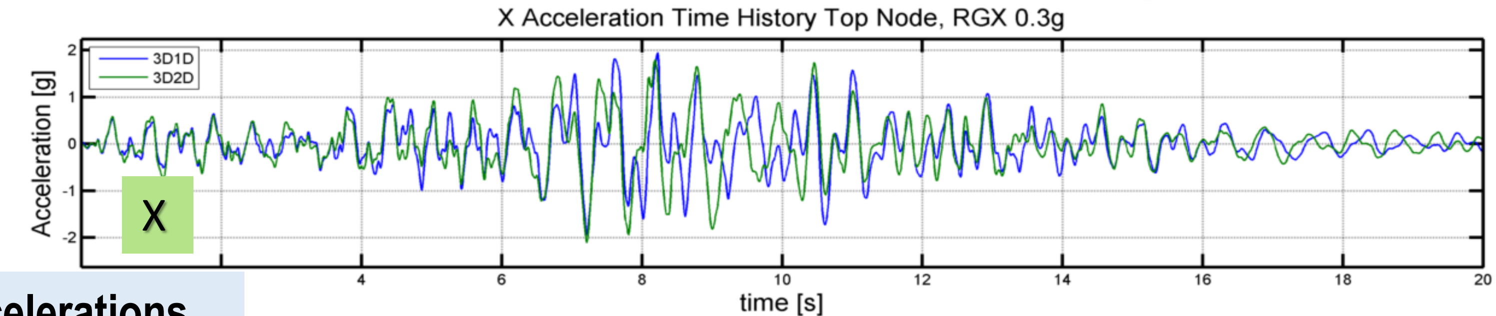
Case A: Surface RB Structure - ISRS



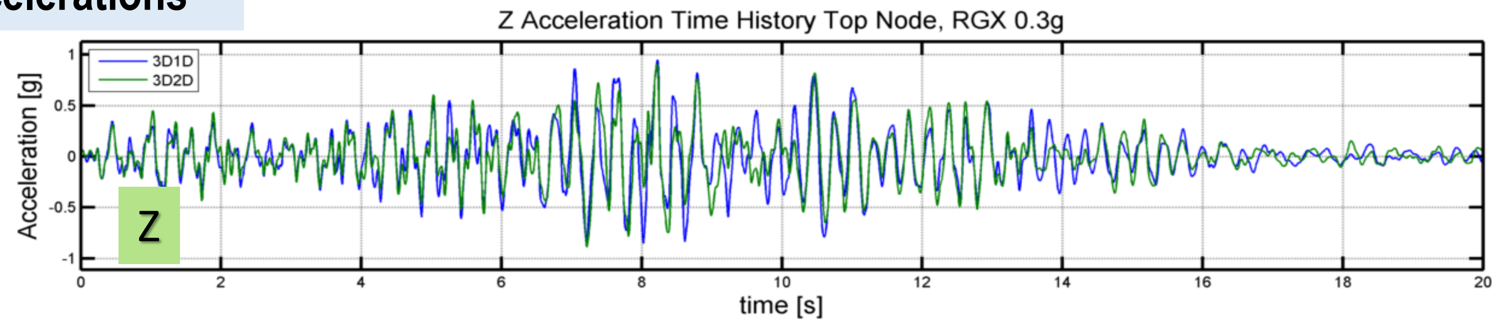


Structure Accelerations and Displacements

Accelerations

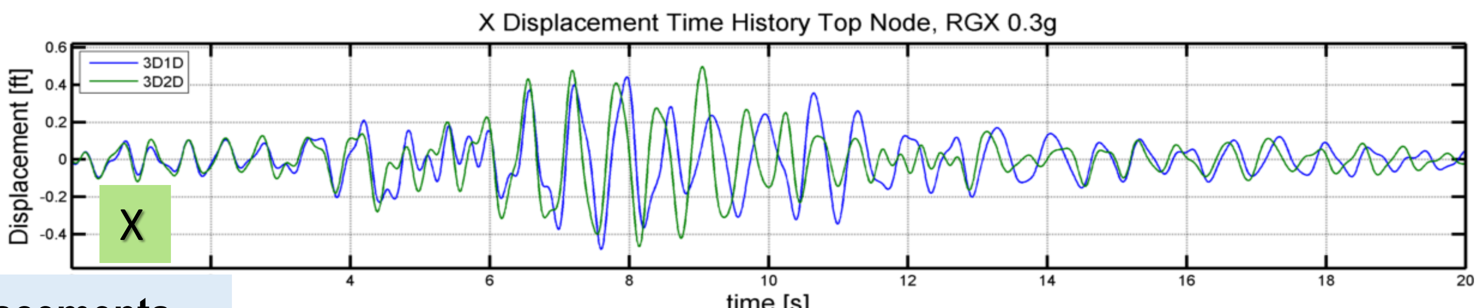


X

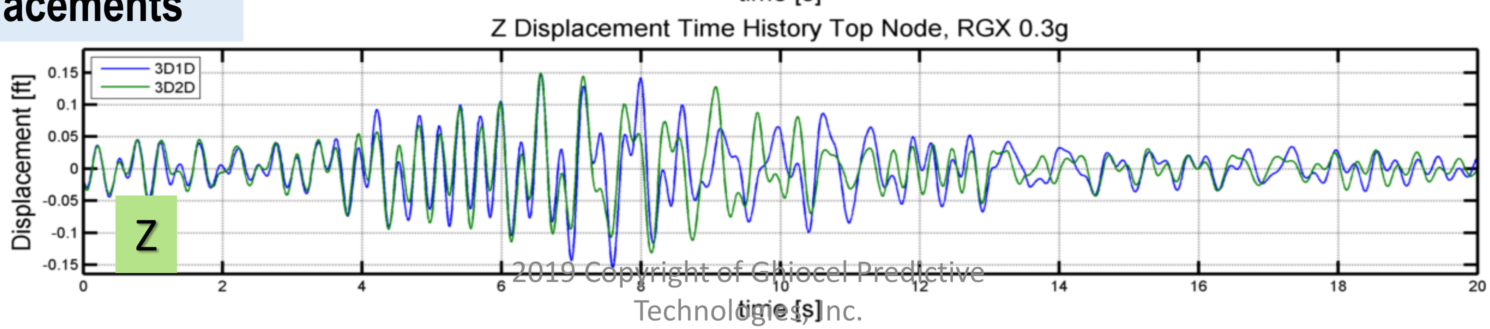


Z

Displacements

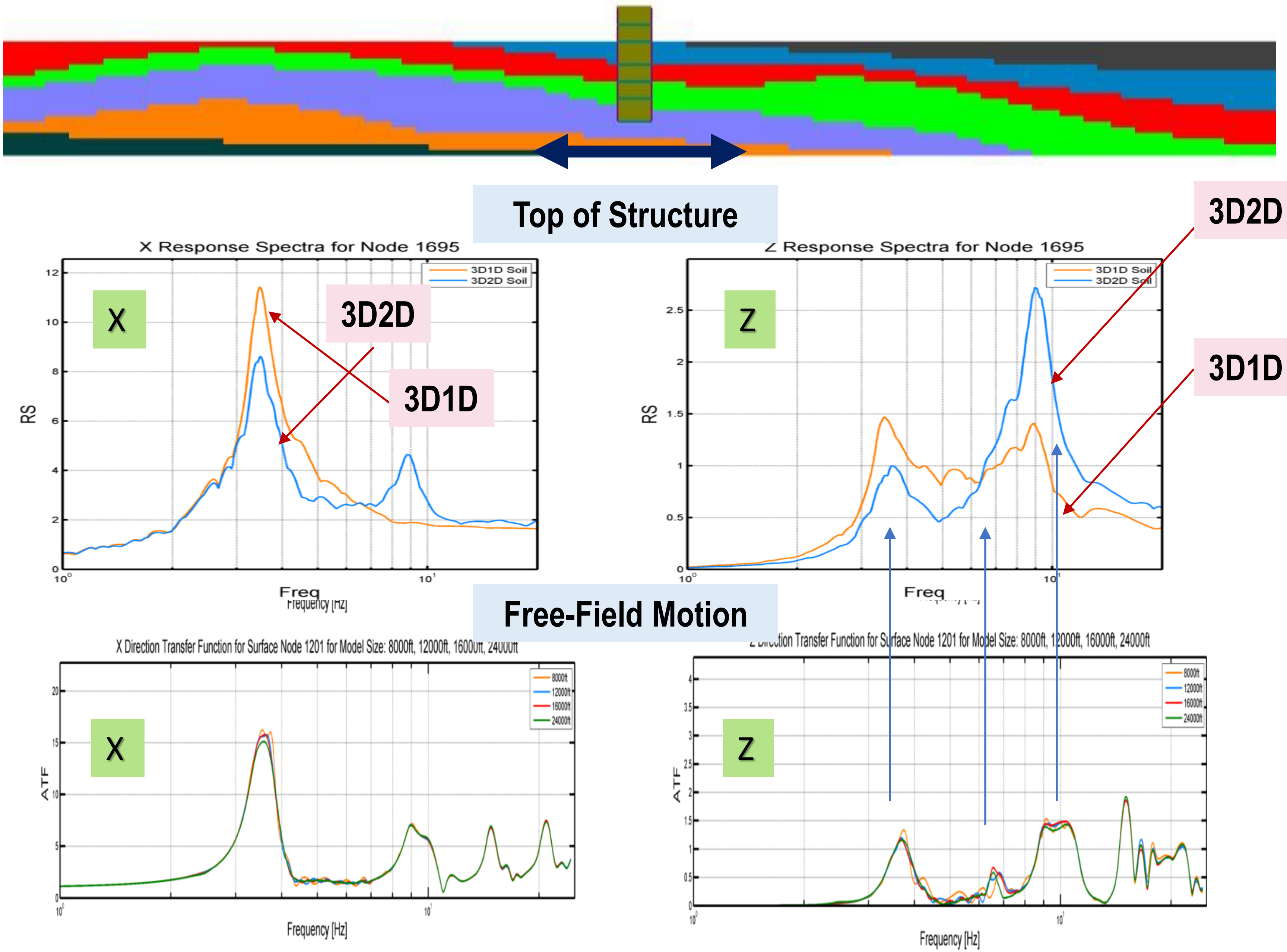


X

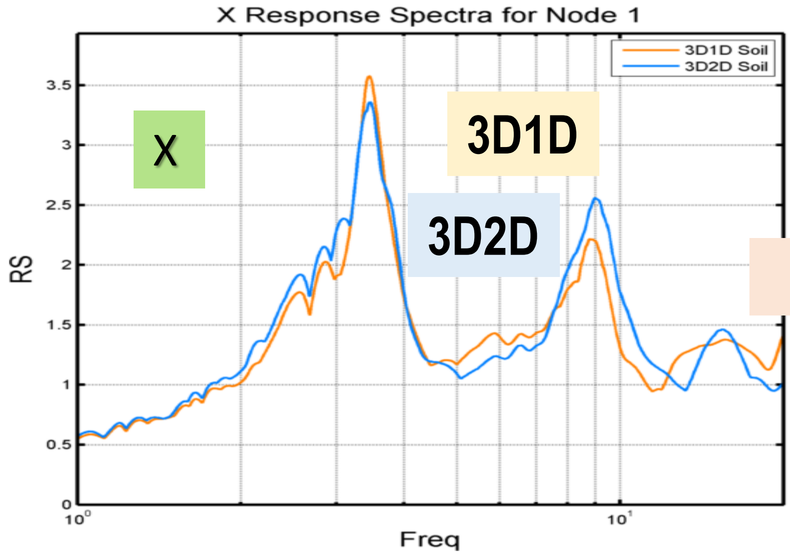


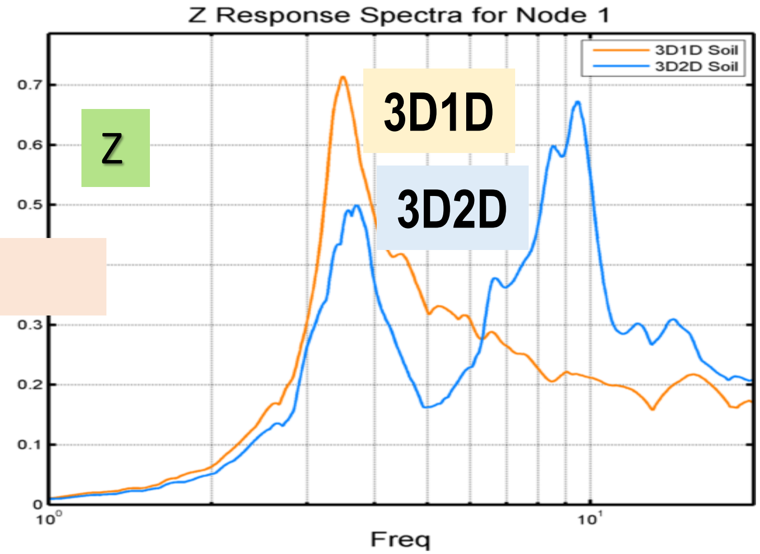
Z

Case B. Embedded RB Structure - ISRS



Basemat Corner ISRS and ATF

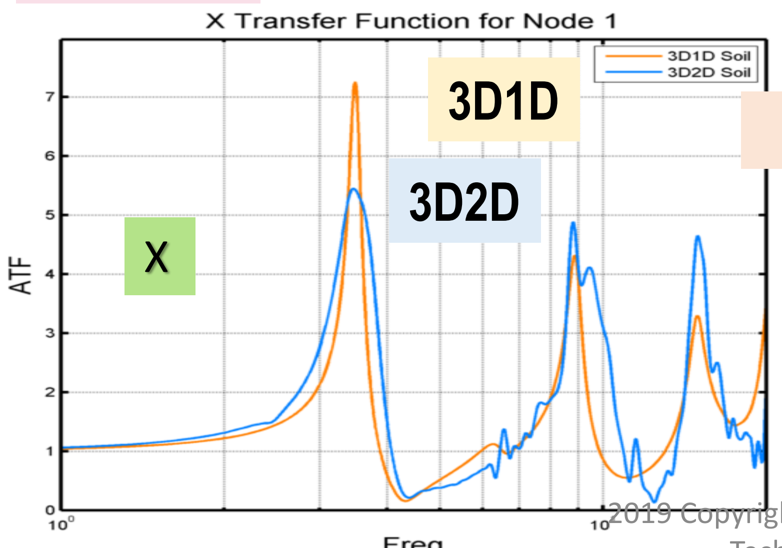




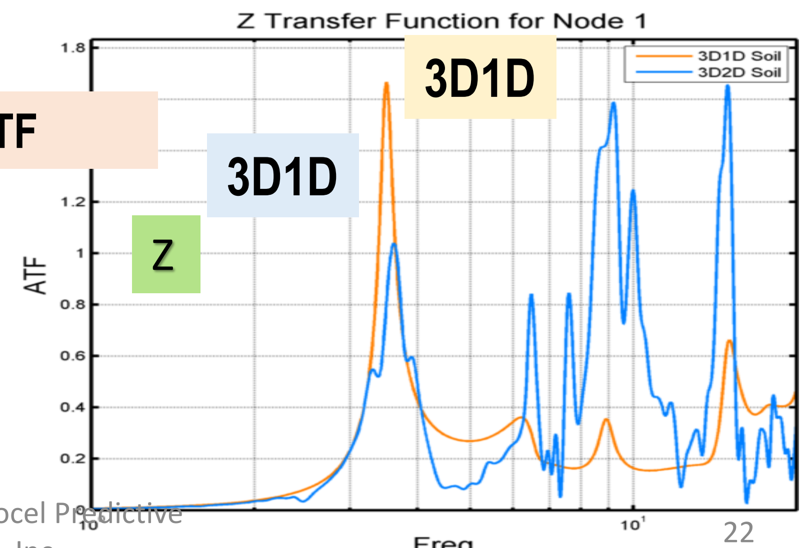
ISRS

Horizontal

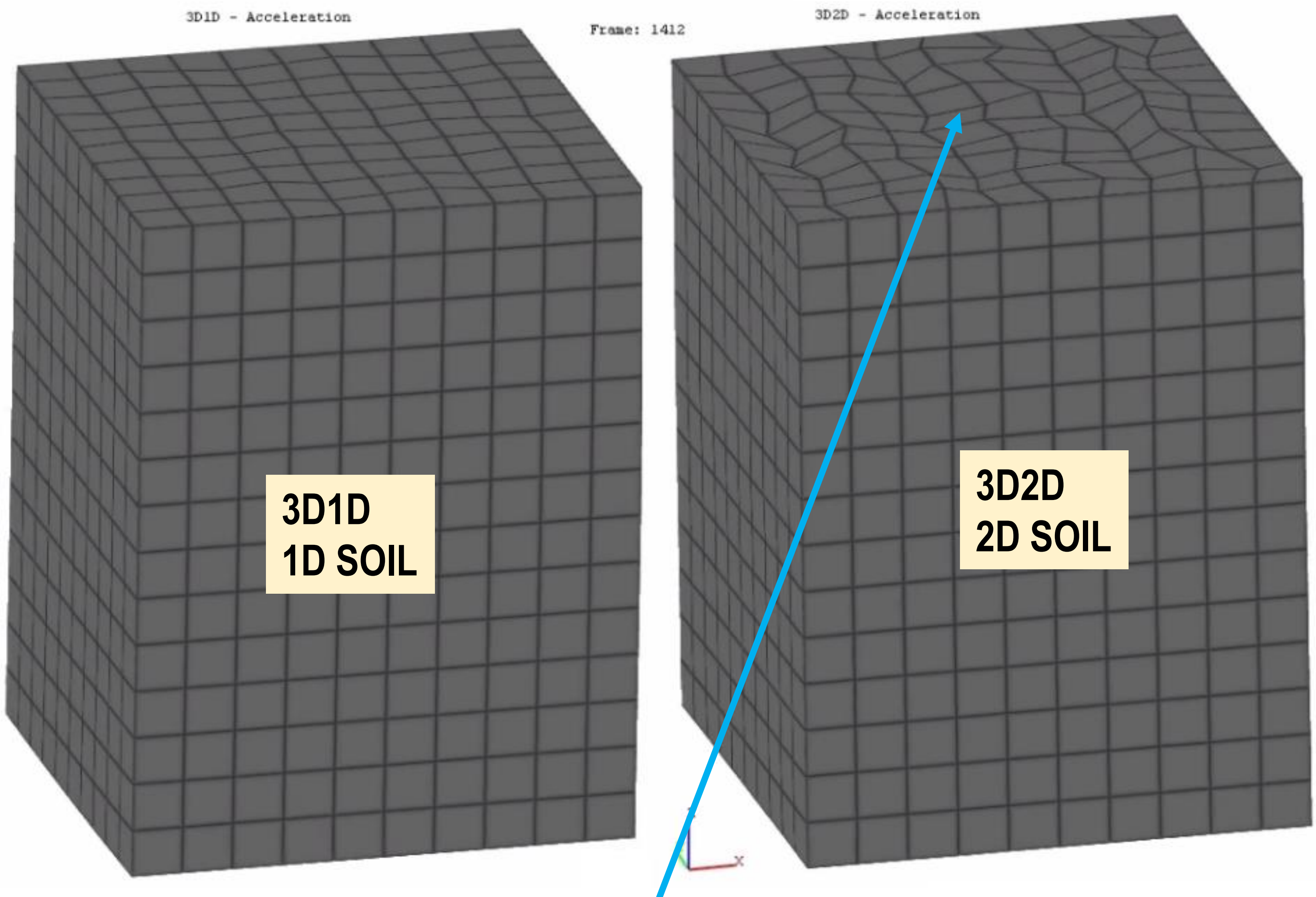
Vertical



ATF

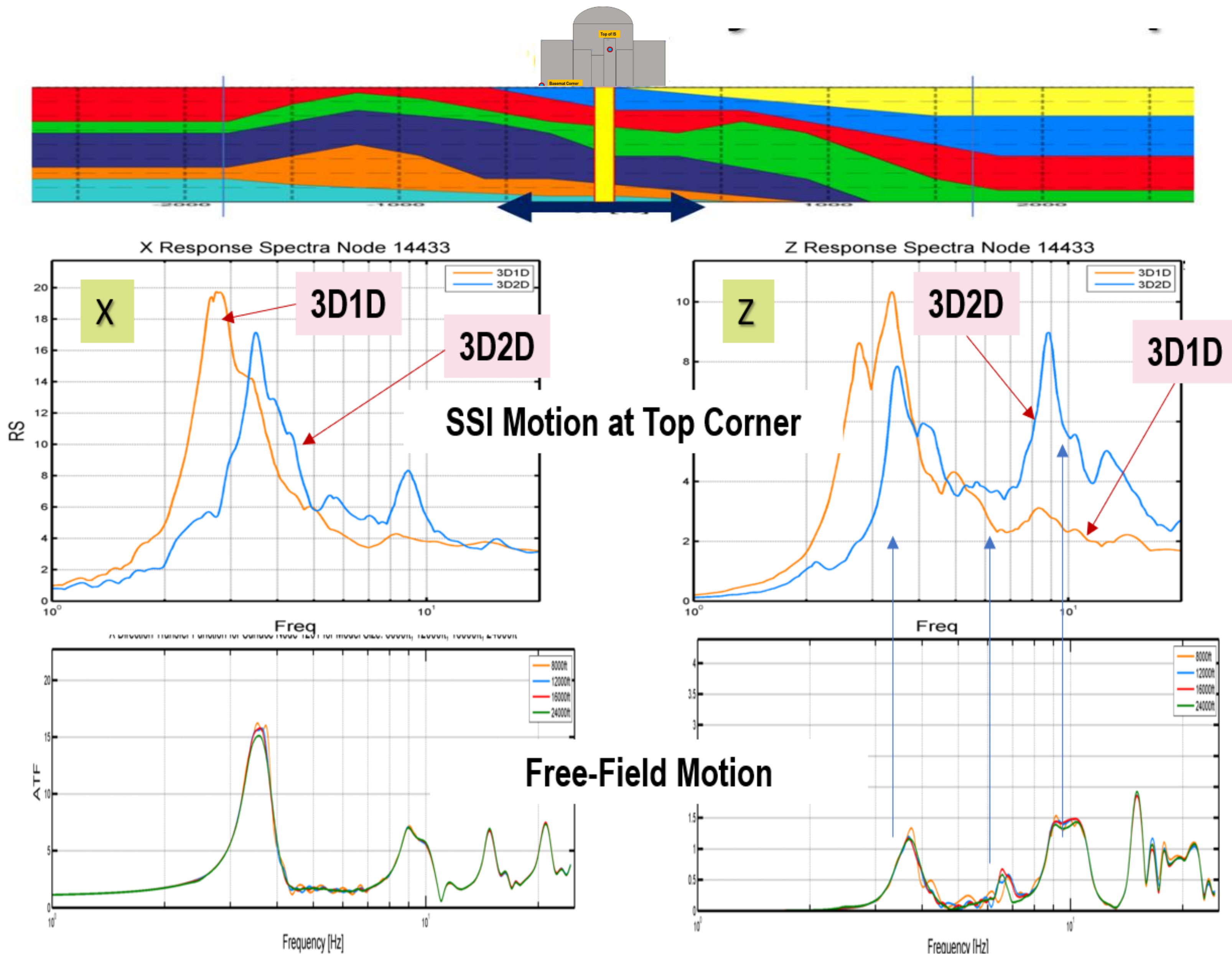


Excavated Soil Scattered Wave Accelerations

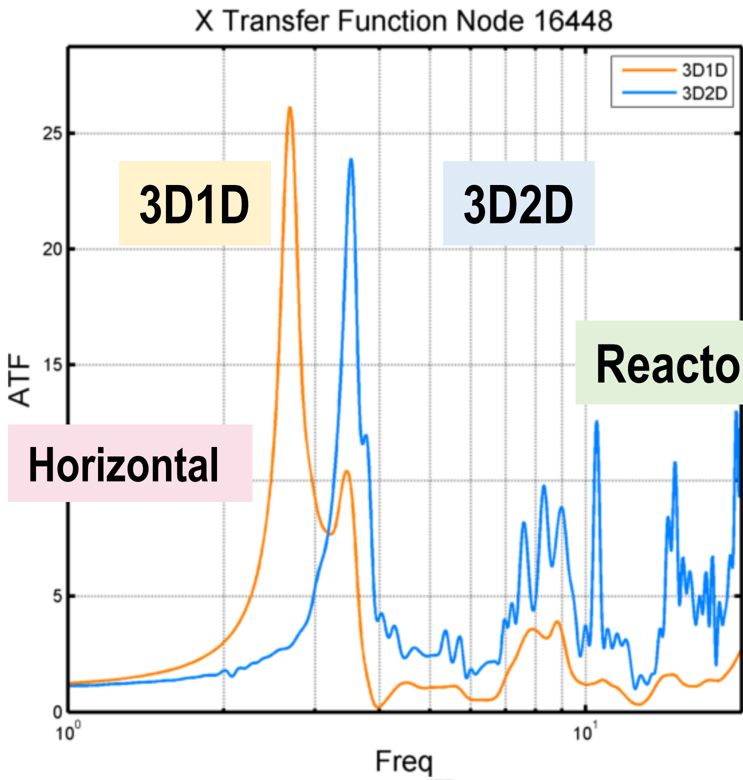


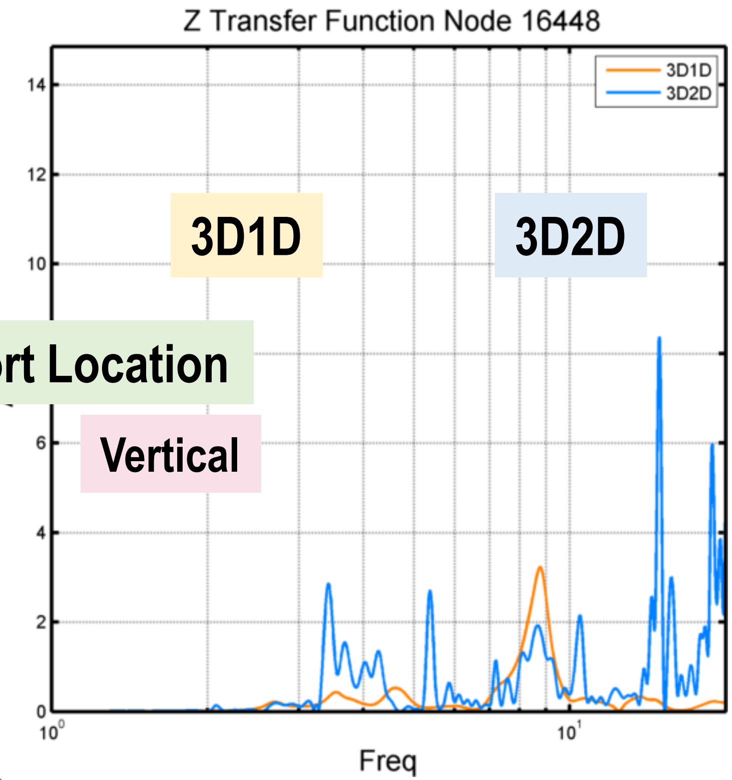
2D soil layering produce much larger scattered waves within the excavated soil

Case C. Heavy Surface RB Complex - ISRS

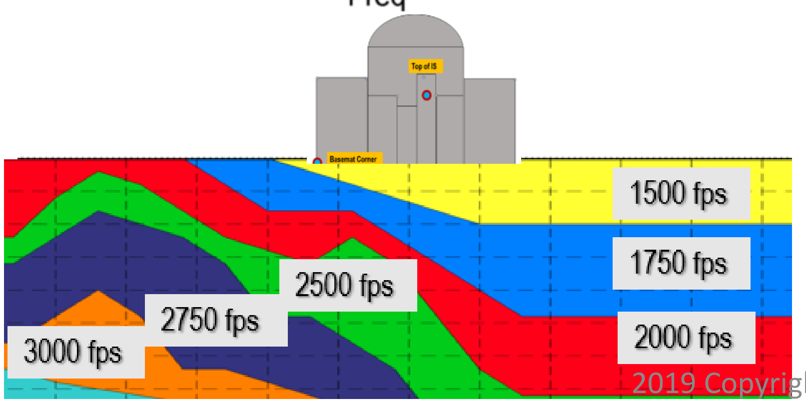


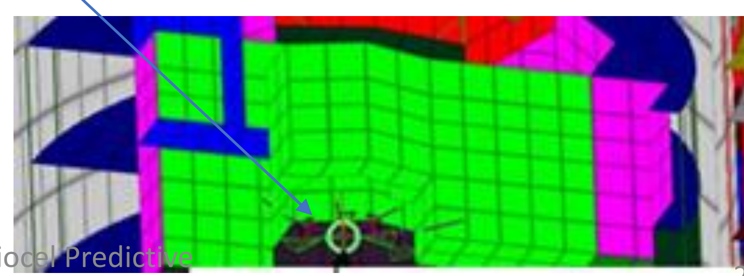
Reactor Vessel Supports ATF





Reactor Support Location





Concluding Remarks

The paper introduces new 3D2D SASSI methodology applicable to the inclined soil layering SSI problems.

The 3D2D SASSI methodology has the capability of accurately capturing the 2D soil variation and the wave scattering effects due to the non-vertically propagating waves produced by the soil layer inclination, and eventual topography features.

This aspect is of particularly significance for the deeply embedded structures such as SMR structures.

Thank you!