Recent Advances Implemented in ACS SASSI Software for Linear and Nonlinear Seismic Soil-Structure Interaction (SSI) Analysis

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Part 2

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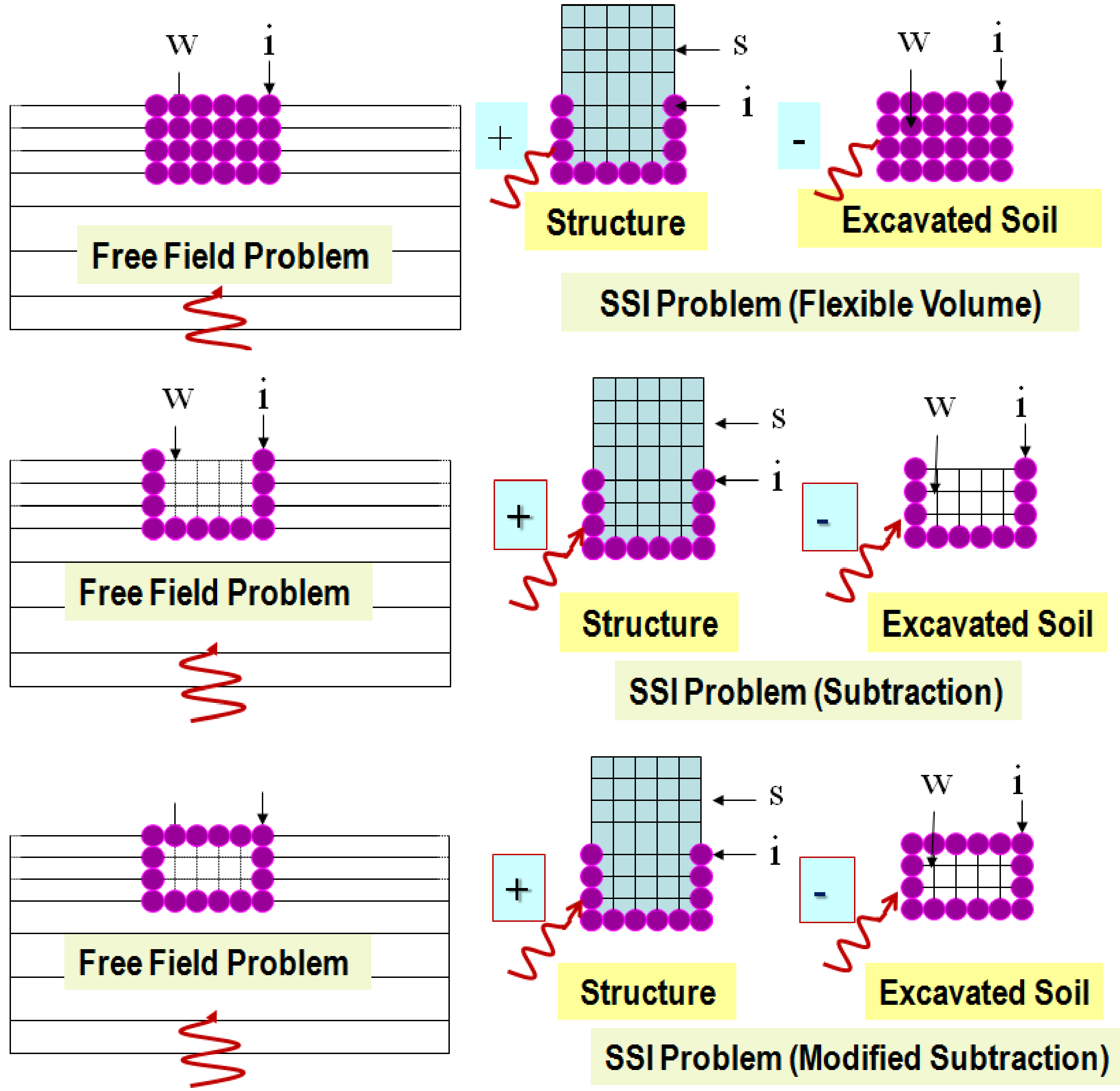
March 24-25, 2014

ACS SASSI V.3.0 Flexible Volume Methods

FV

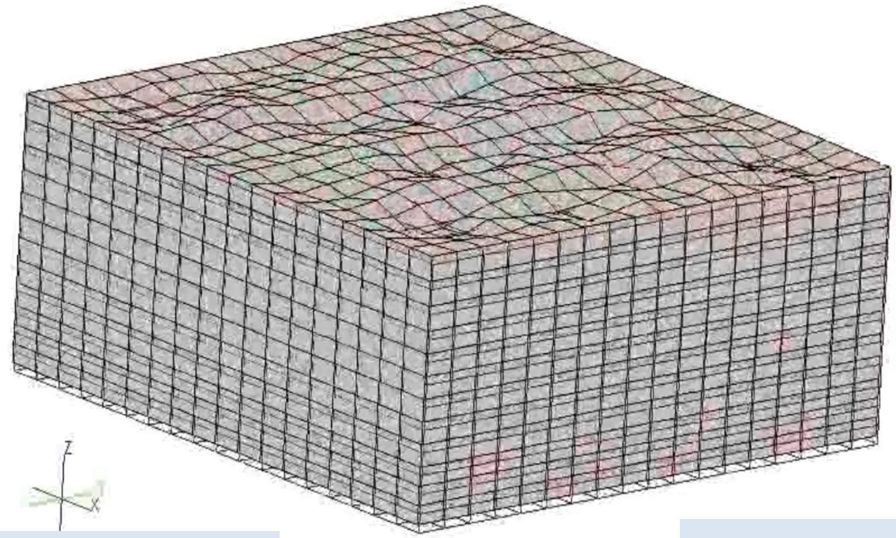
FI-FSIN
SM

FI-EVBN
MSM

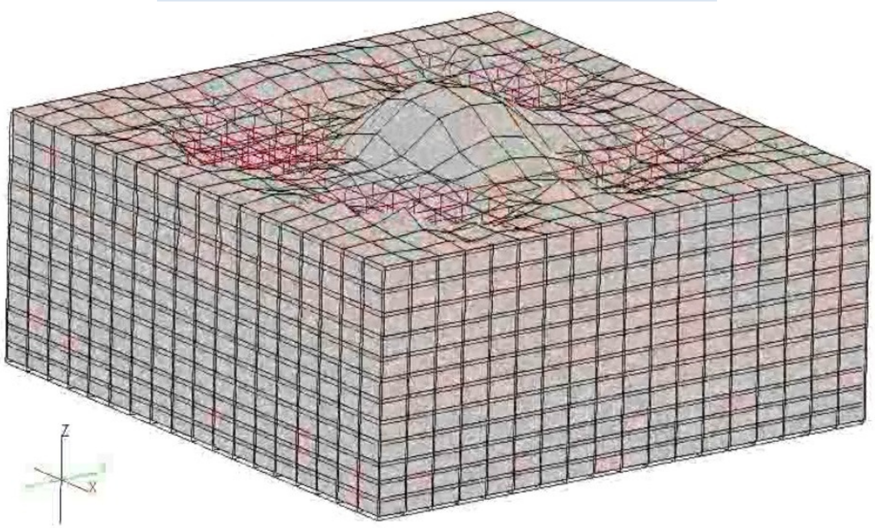


Excavated Soil Motion (Wave Scattering Effects) Using FV Methods

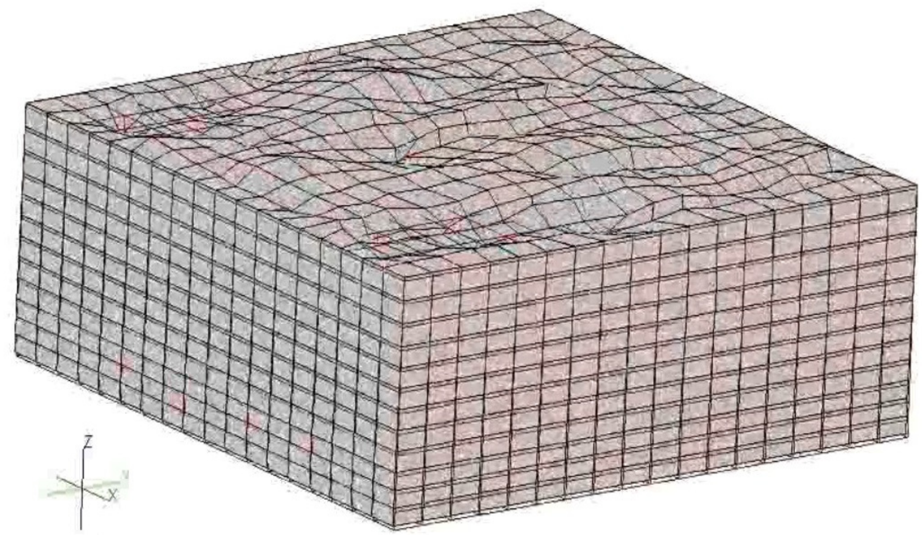
Flexible Volume



Flexible Interface - FSIN

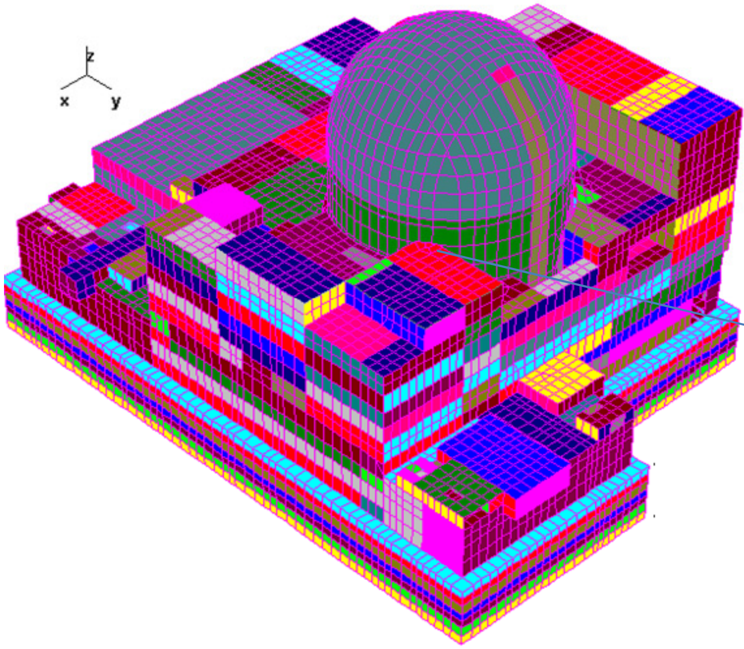


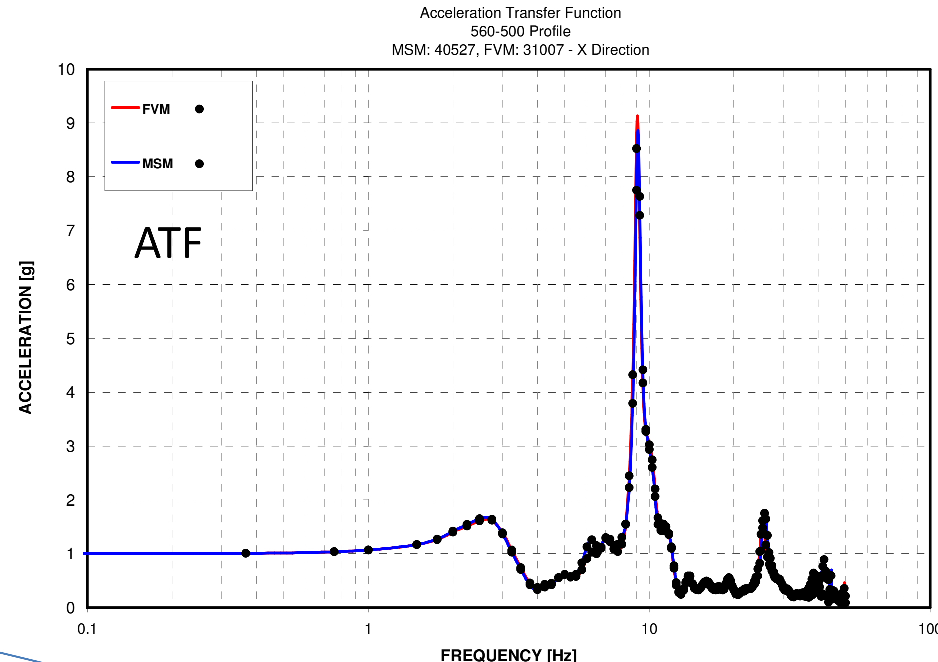
Flexible Interface - EVBN

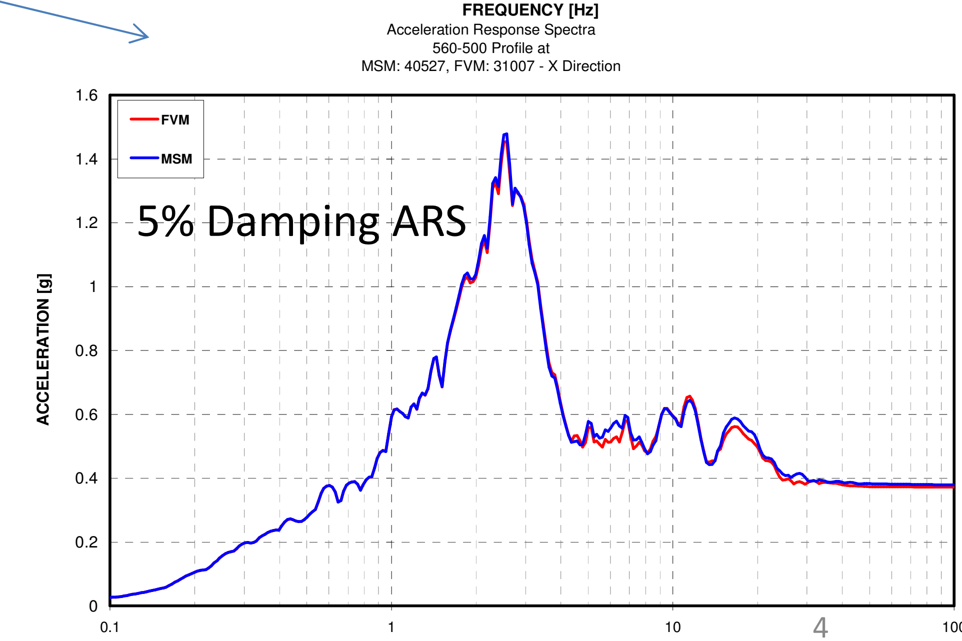


Complete SSI Analysis Using RB Complex SSI Model

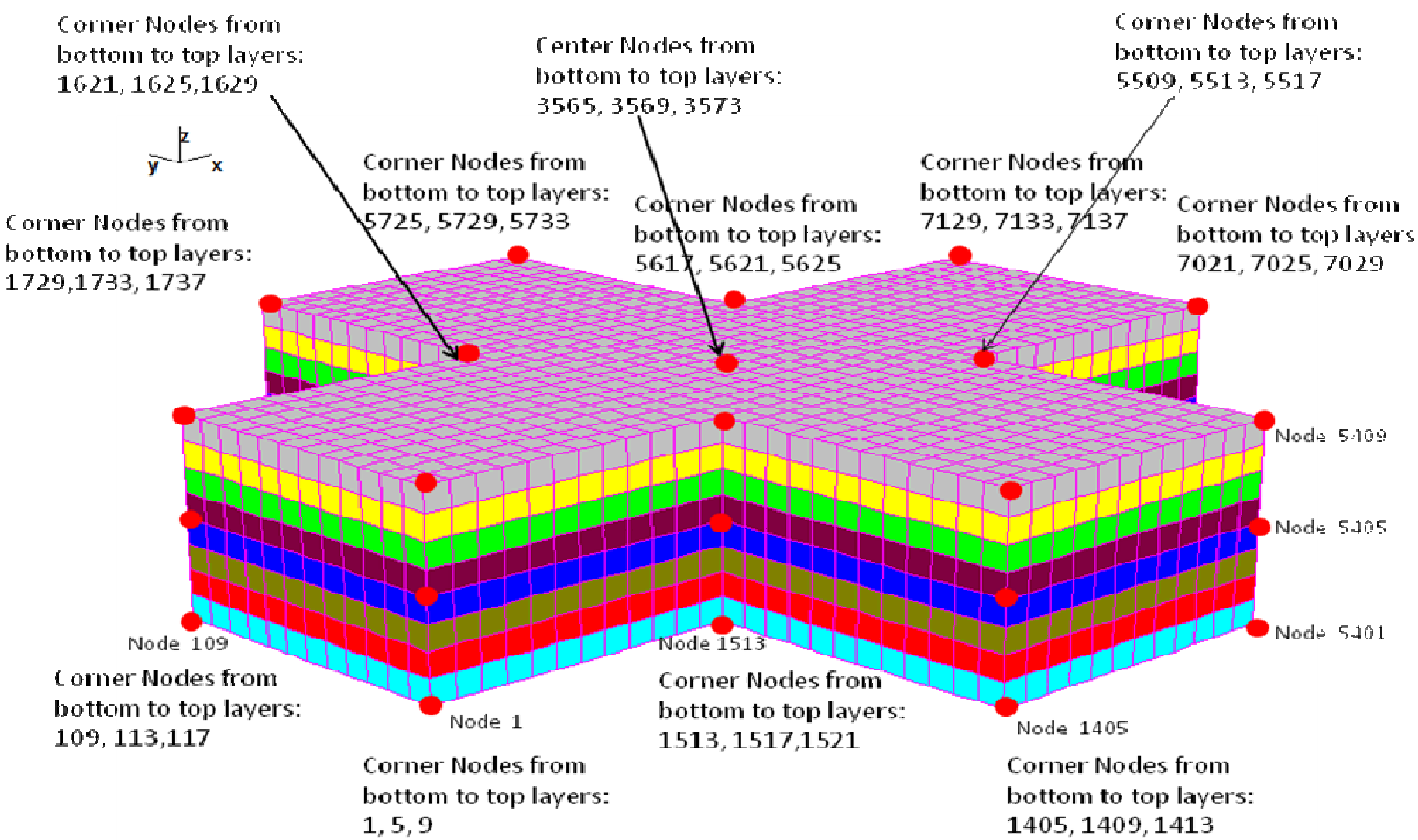
RB Complex SSI Model



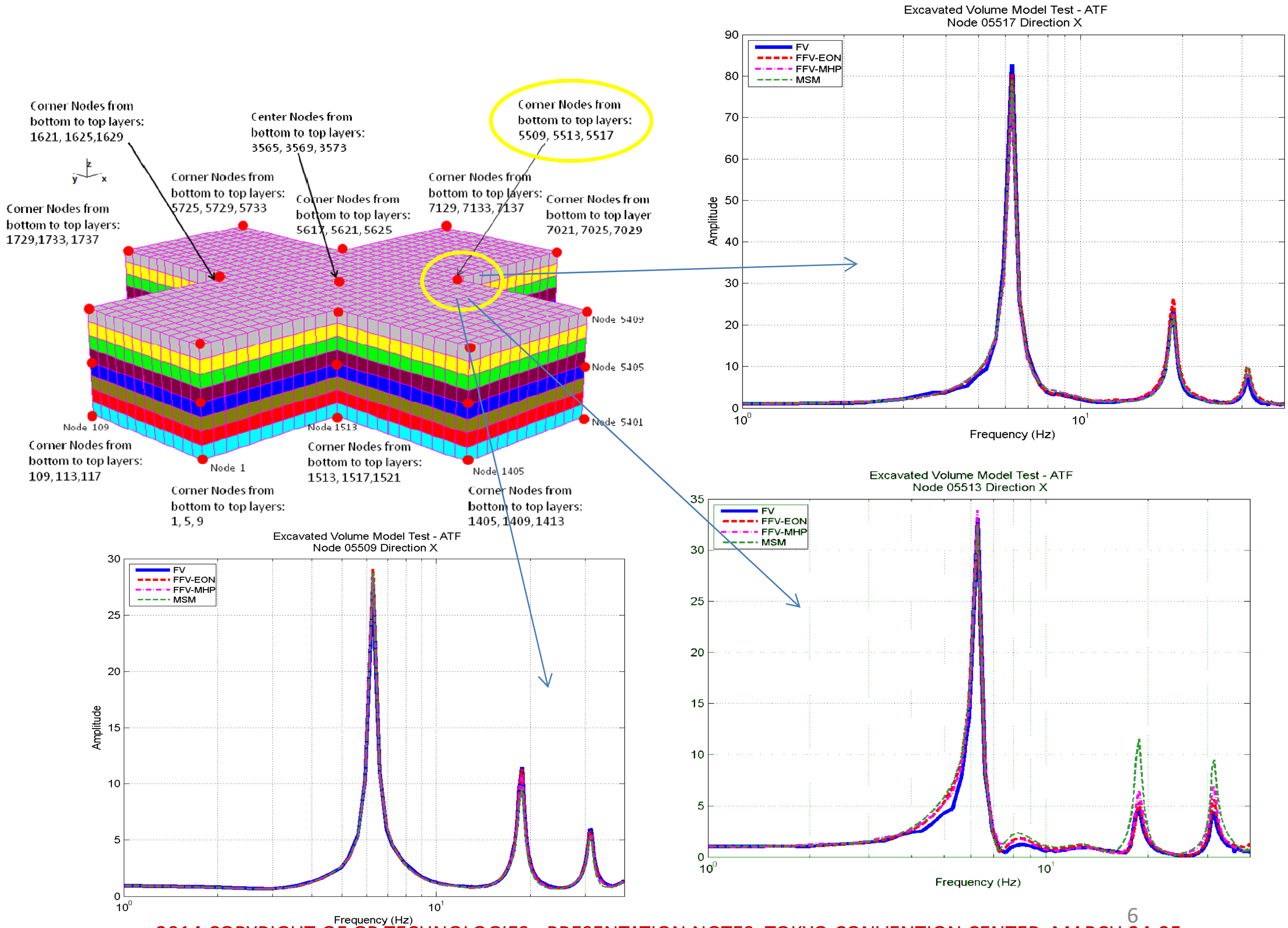




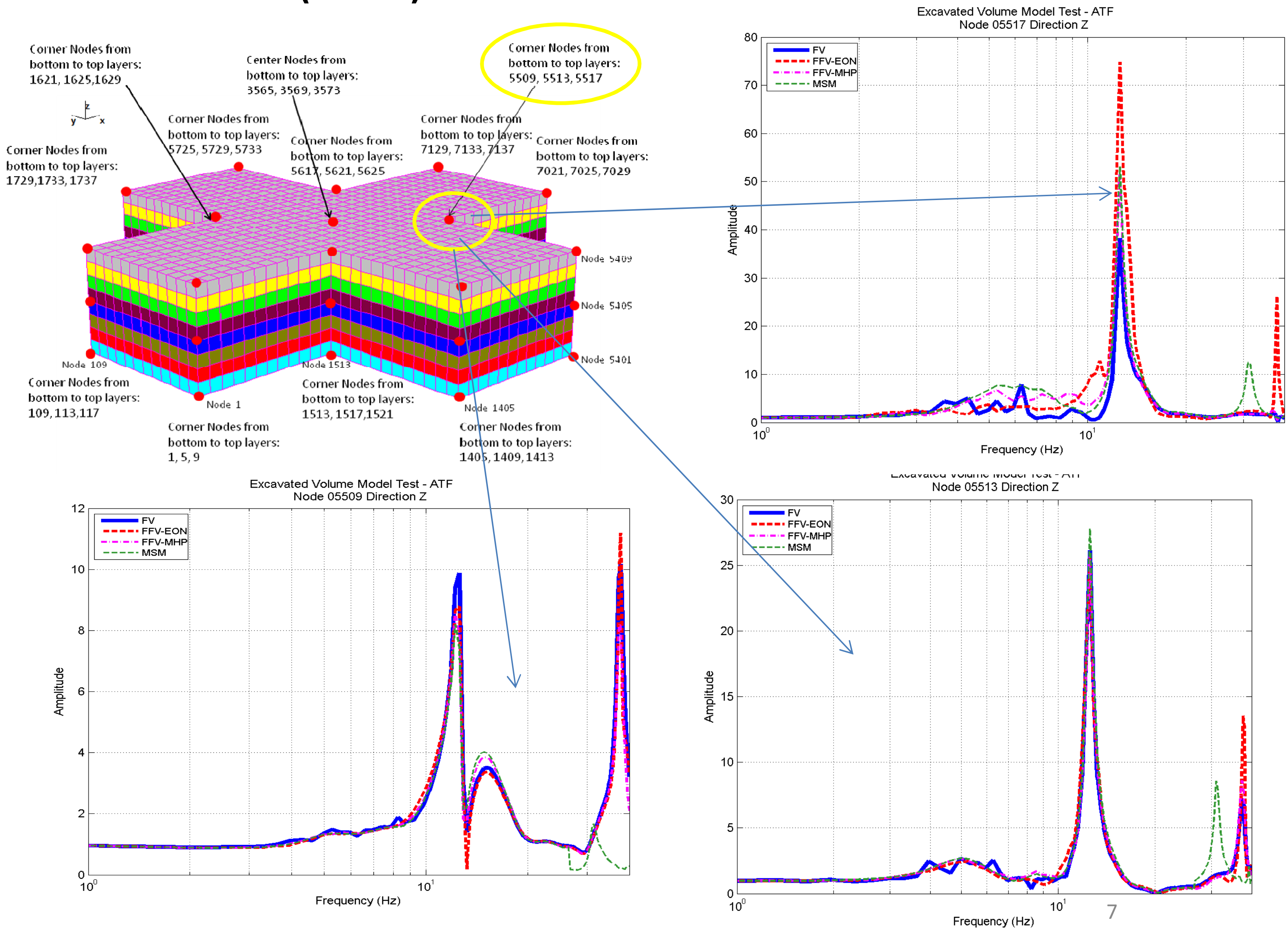
Cross-Shaped Excavation Cavity Study (180 ft x 180 ft x 50ft)



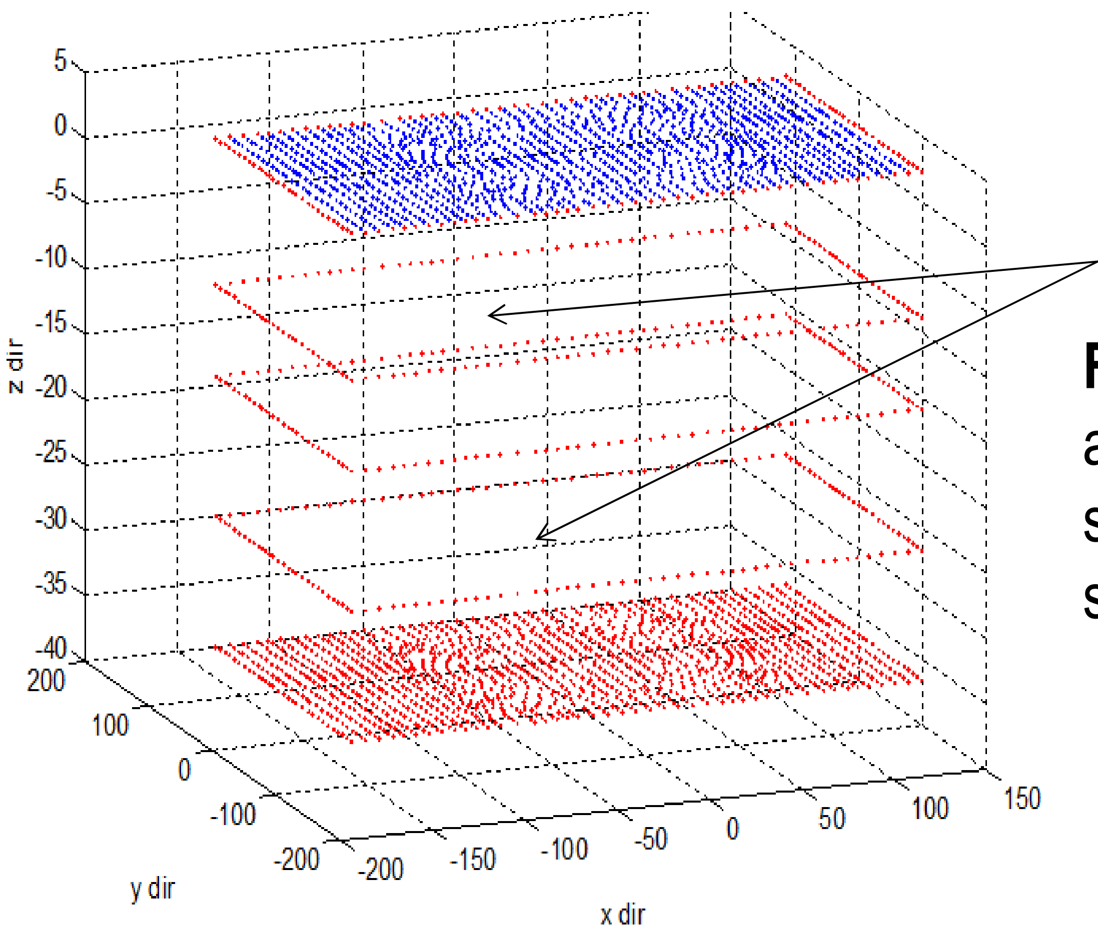
FI-EVBN(MSM) vs. FFV vs. FV Methods: Horizontal ATF



FI-EVN(MSM) vs. FFV vs. FV Methods: Vertocal ATF



Recently Implemented Fast FV (FFV) Method

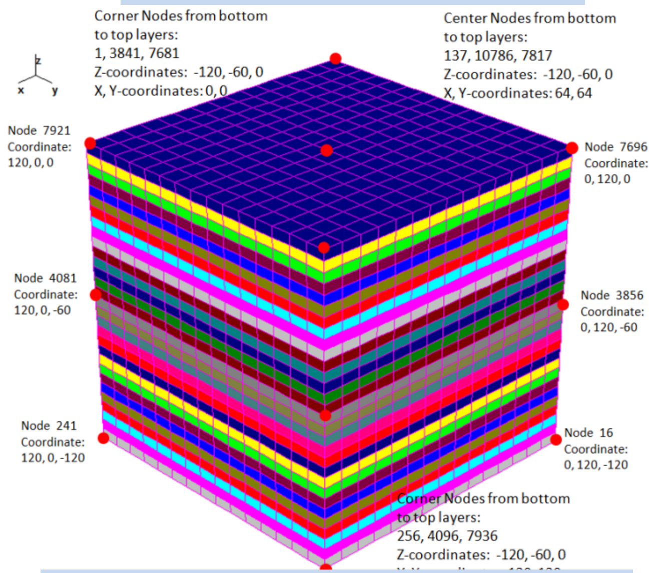


Excavated Soil Interaction Nodes Configuration for MSM

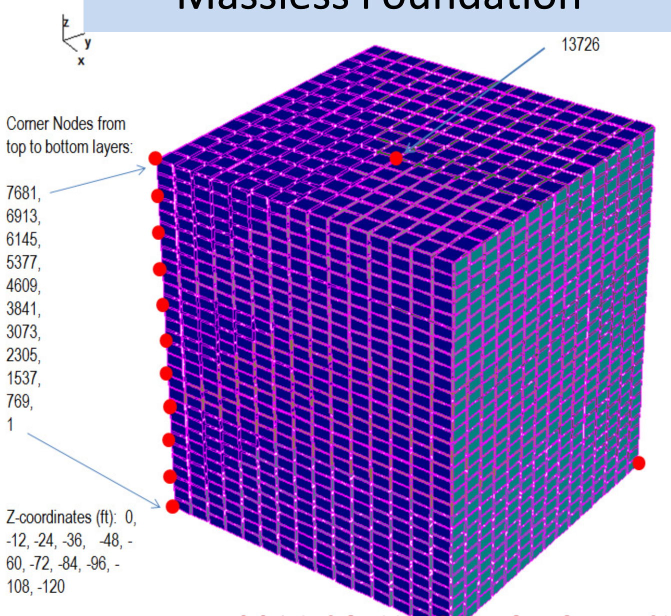
Fast FV methods include additional interaction nodes selected from the excavated soil internal nodes

Deeply Embedded Excavation Models

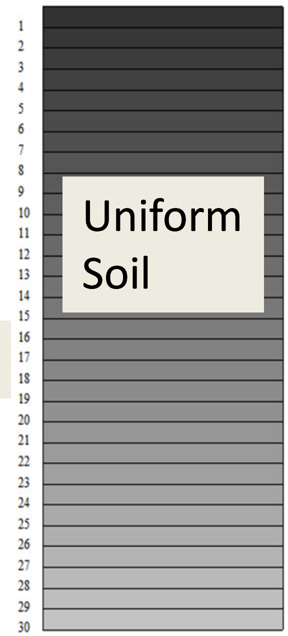
Excavated Soil



Massless Foundation



A



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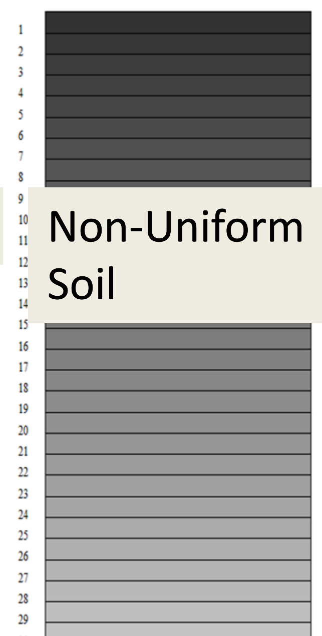
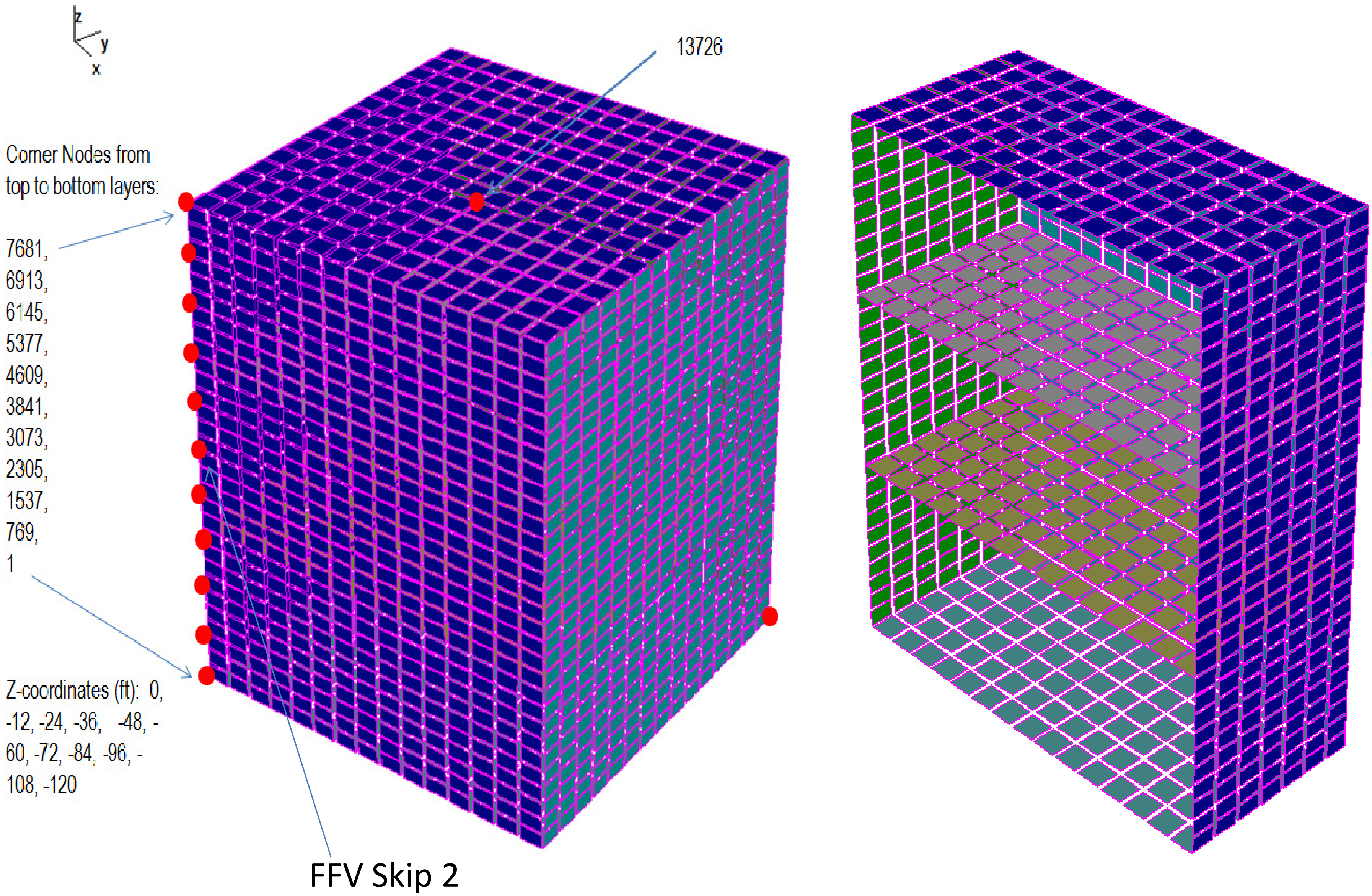
1	4	4	0.1	2000	1000	0.02	0.02
2	4	8	0.1	2000	1000	0.02	0.02
3	4	12	0.1	2000	1000	0.02	0.02
4	4	16	0.1	2000	1000	0.02	0.02
5	4	20	0.1	2000	1000	0.02	0.02
6	4	24	0.1	2000	1000	0.02	0.02
7	4	28	0.1	2000	1000	0.02	0.02
8	4	32	0.1	2000	1000	0.02	0.02
9	4	36	0.1	2000	1000	0.02	0.02
10	4	40	0.1	2000	1000	0.02	0.02
11	4	44	0.1	2000	1000	0.02	0.02
12	4	48	0.1	2000	1000	0.02	0.02
13	4	52	0.1	2000	1000	0.02	0.02
14	4	56	0.1	2000	1000	0.02	0.02
15	4	60	0.1	2000	1000	0.02	0.02
16	4	64	0.1	2000	1000	0.02	0.02
17	4	68	0.1	2000	1000	0.02	0.02
18	4	72	0.1	2000	1000	0.02	0.02
19	4	76	0.1	2000	1000	0.02	0.02
20	4	80	0.1	2000	1000	0.02	0.02
21	4	84	0.1	2000	1000	0.02	0.02
22	4	88	0.1	2000	1000	0.02	0.02
23	4	92	0.1	2000	1000	0.02	0.02
24	4	96	0.1	2000	1000	0.02	0.02
25	4	100	0.1	2000	1000	0.02	0.02
26	4	104	0.1	2000	1000	0.02	0.02
27	4	108	0.1	2000	1000	0.02	0.02
28	4	112	0.1	2000	1000	0.02	0.02
29	4	116	0.1	2000	1000	0.02	0.02
30	4	120	0.1	2000	1000	0.02	0.02
Halfspace							

B



Layer	Thickness	Depth	Unit Weight	P-Wave Velocity	S-Wave Velocity	P-Wave Damping Ratio	S-Wave Damping Ratio
1	4	4	0.1	2000	1000	0.02	0.02
2	4	8	0.1	2000	1000	0.02	0.02
3	4	12	0.1	2000	1000	0.02	0.02
4	4	16	0.1	2000	1000	0.02	0.02
5	4	20	0.1	2000	1000	0.02	0.02
6	4	24	0.1	2000	1000	0.02	0.02
7	4	28	0.1	2000	1000	0.02	0.02
8	4	32	0.1	2000	1000	0.02	0.02
9	4	36	0.1	2000	1000	0.02	0.02
10	4	40	0.1	2000	1000	0.02	0.02
11	4	44	0.1	2000	1000	0.02	0.02
12	4	48	0.1	2000	1000	0.02	0.02
13	4	52	0.1	5000	10000	0.02	0.02
14	4	56	0.1	5000	10000	0.02	0.02
15	4	60	0.1	5000	10000	0.02	0.02
16	4	64	0.1	5000	10000	0.02	0.02
17	4	68	0.1	5000	10000	0.02	0.02
18	4	72	0.1	5000	10000	0.02	0.02
19	4	76	0.1	5000	10000	0.02	0.02
20	4	80	0.1	5000	10000	0.02	0.02
21	4	84	0.1	5000	10000	0.02	0.02
22	4	88	0.1	5000	10000	0.02	0.02
23	4	92	0.1	5000	10000	0.02	0.02
24	4	96	0.1	5000	10000	0.02	0.02
25	4	100	0.1	5000	10000	0.02	0.02
26	4	104	0.1	5000	10000	0.02	0.02
27	4	108	0.1	5000	10000	0.02	0.02
28	4	112	0.1	5000	10000	0.02	0.02
29	4	116	0.1	5000	10000	0.02	0.02
30	4	120	0.1	5000	10000	0.02	0.02
Halfspace							

Massless Foundation Deeply Embedded Model

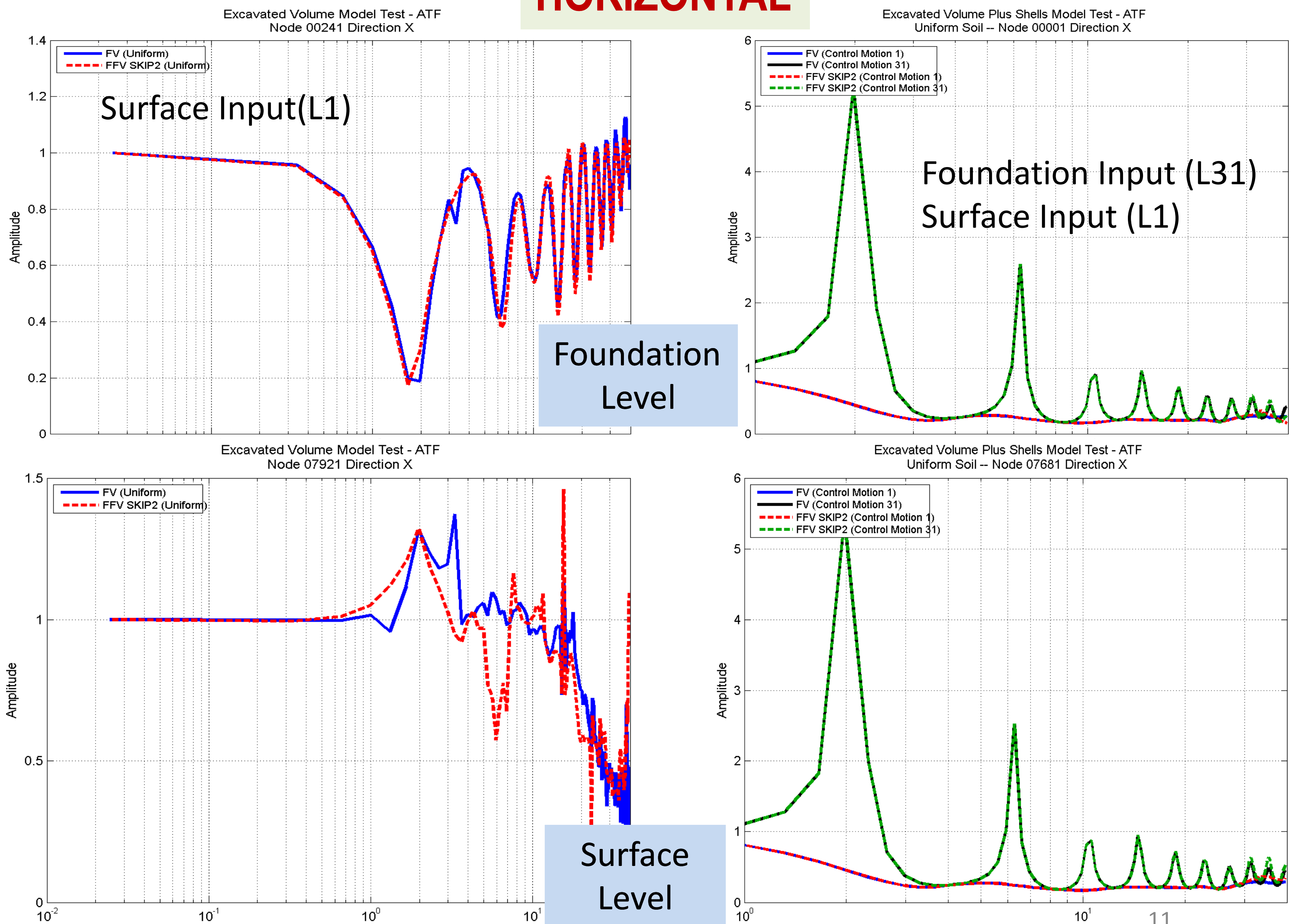


Excavation vs. Massless Foundation Models for Uniform Soil

Excavation Cavity Model

HORIZONTAL

Massless Foundation

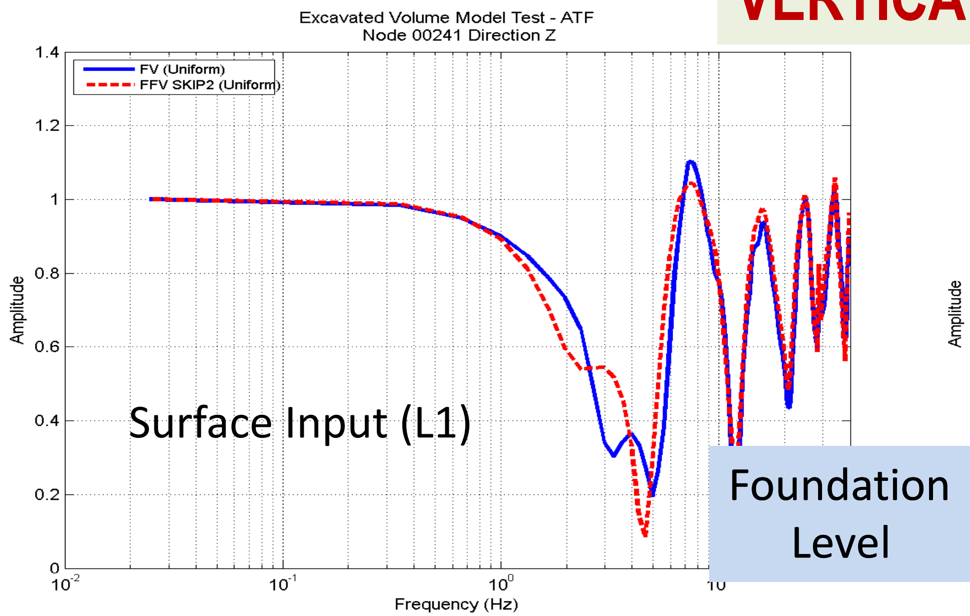


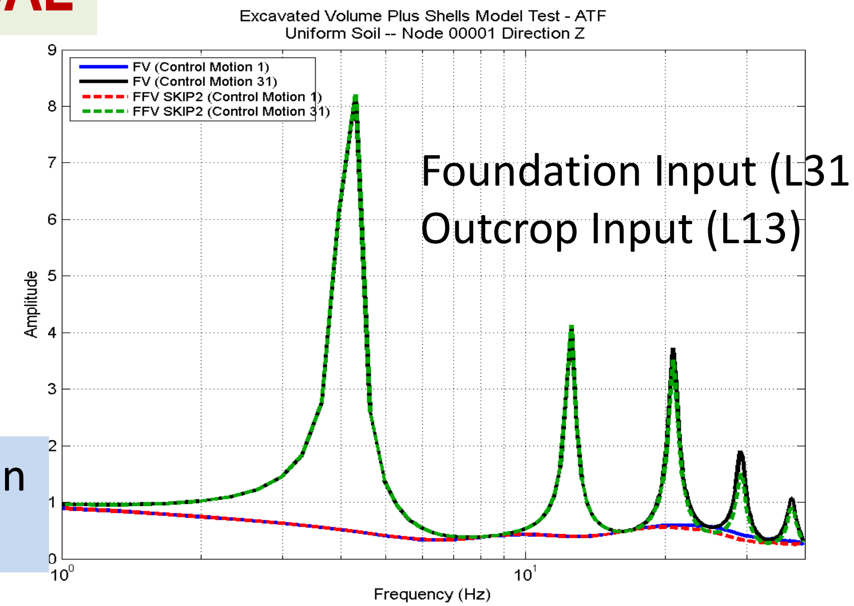
Excavation vs. Massless Foundation Models for Uniform Soil

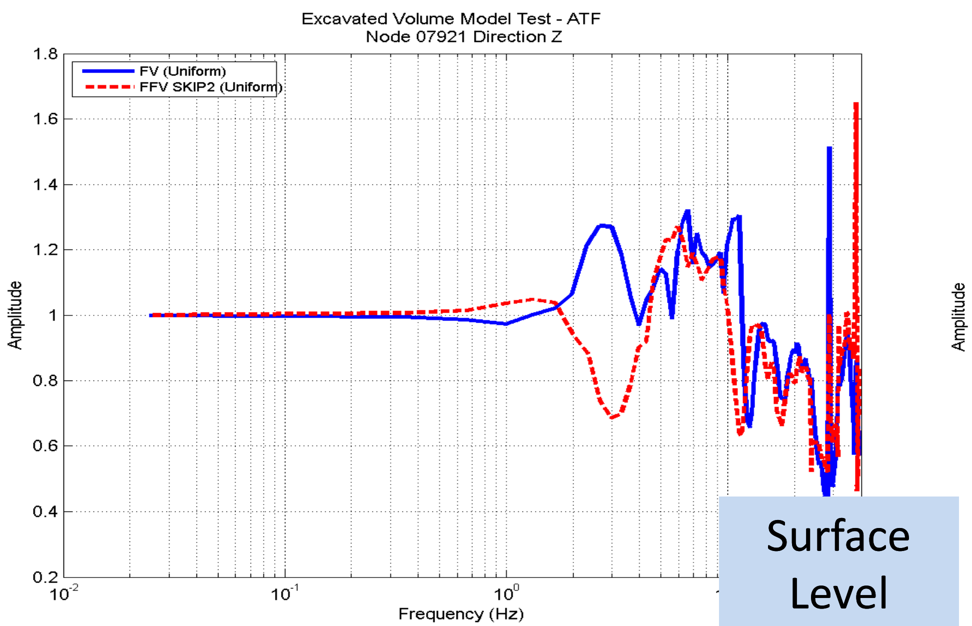
Excavation Cavity Model

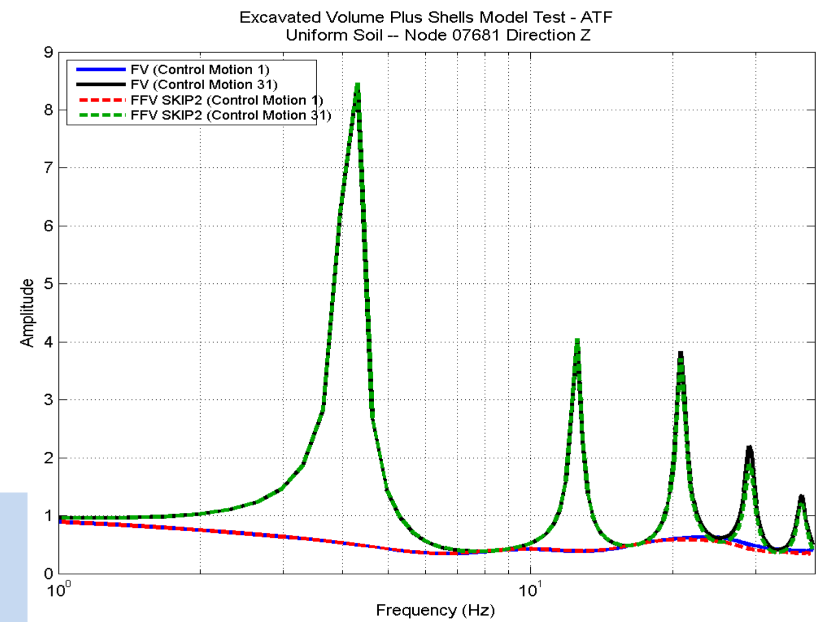
VERTICAL

Massless Foundation



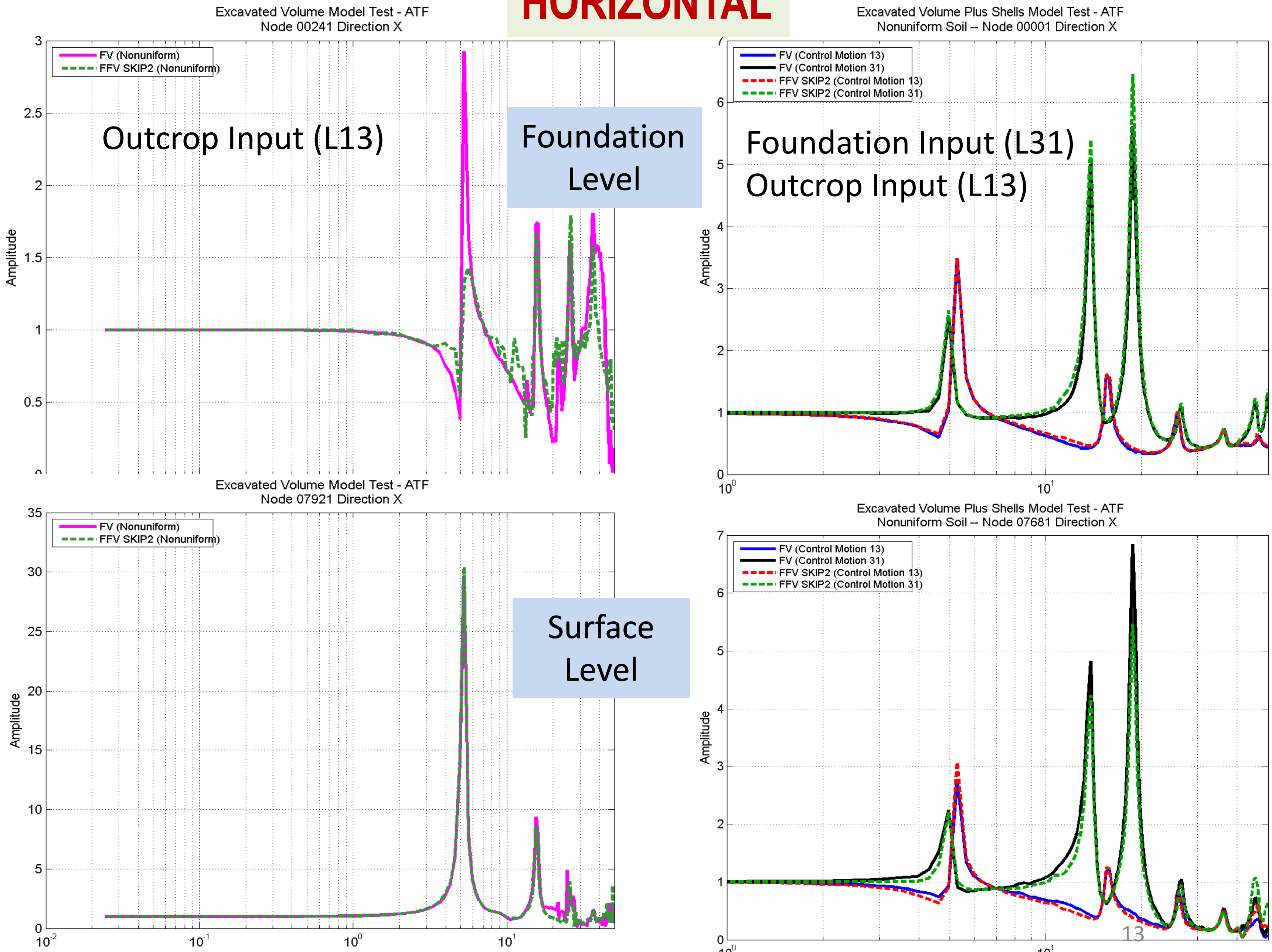






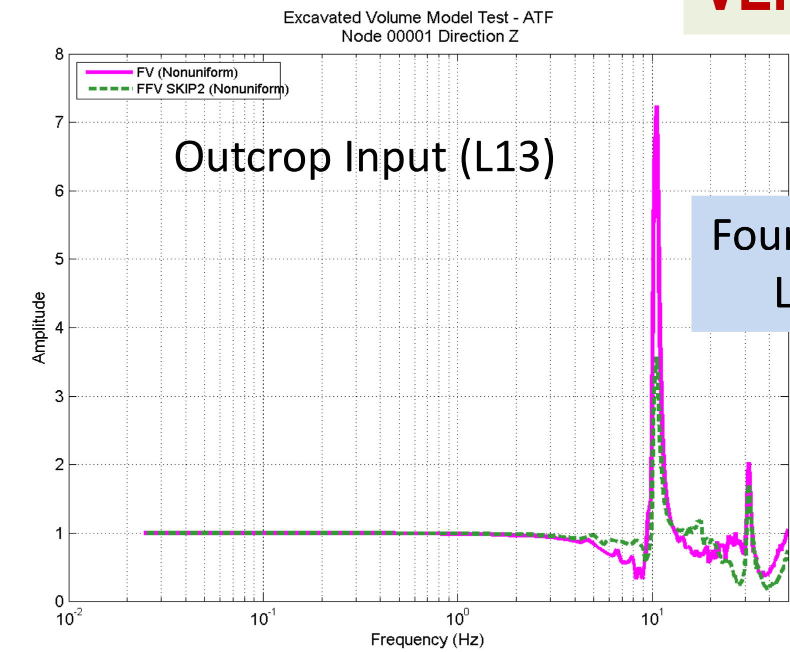
Excavation vs. Massless Foundation for Non-Uniform Soil

Excavation Cavity Model **HORIZONTAL** Massless Foundation Model

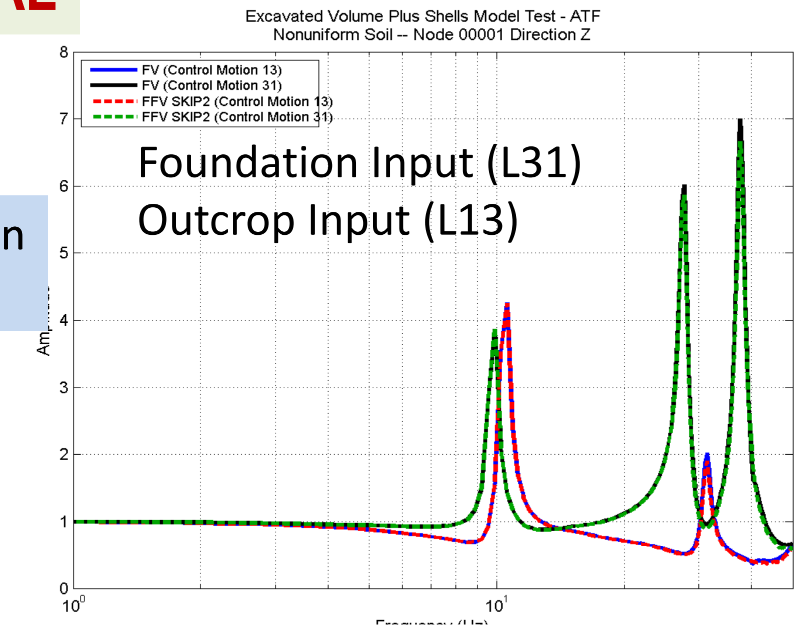


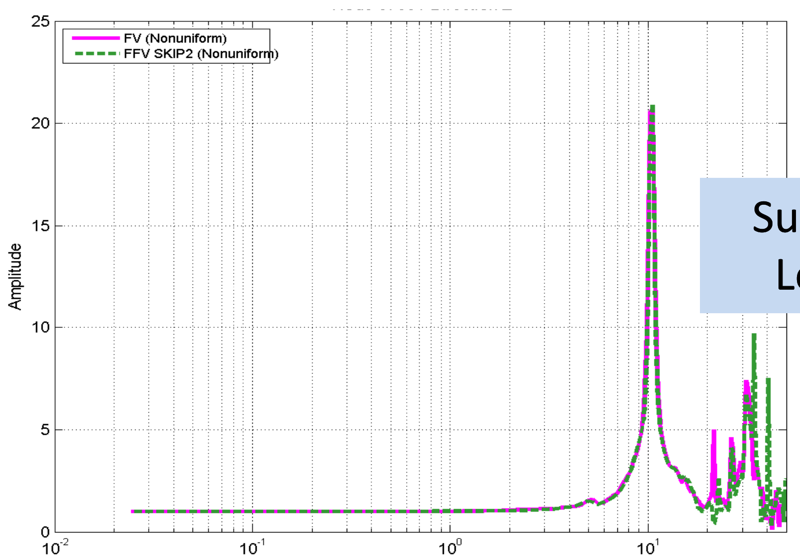
Excavation vs. Massless Foundation for Non-Uniform Soil

Excavation Cavity Model | **VERTICAL** | Massless Foundation

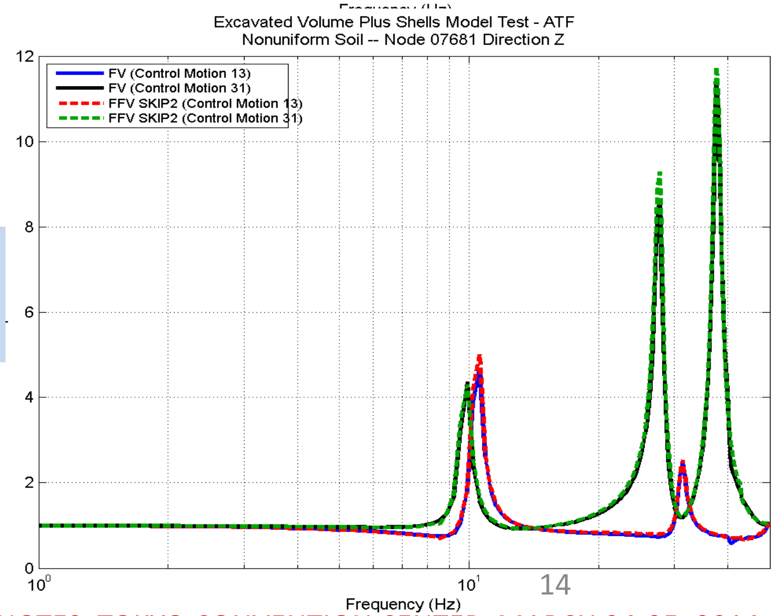


Foundation Level





Surface Level



ACS SASSI Version 3.0 Fast Nonlinear Analysis Capability in Complex Frequency (Option Non)

This capability is a novel nonlinear SSI approach for modeling of nonlinear hysteretic behaviors of reinforced concrete structures in the complex frequency domain.

The new approach can be used to perform fast and accurate nonlinear SSI analyses, including sophisticated nonlinear hysteretic models, at a small fraction of the runtime of a time domain nonlinear SSI analysis.

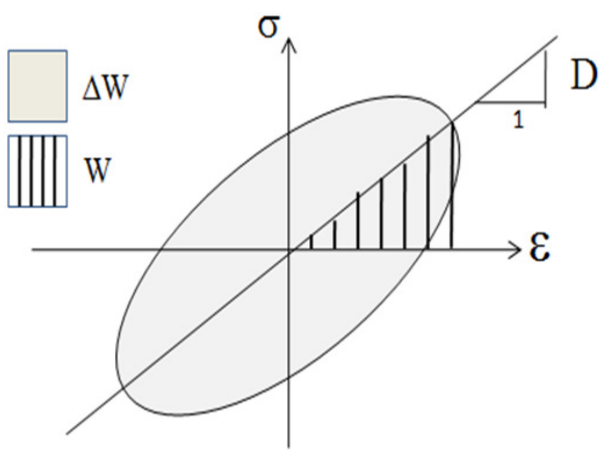
Initially the new approach will be limited to low-rise shearwall structures with planar walls (no curved walls)

Equivalent-Linear System in Complex Frequency

Based on the up-to-date literature, the nonlinear behavior of dynamic structural systems can be captured only by nonlinear time history analyses.

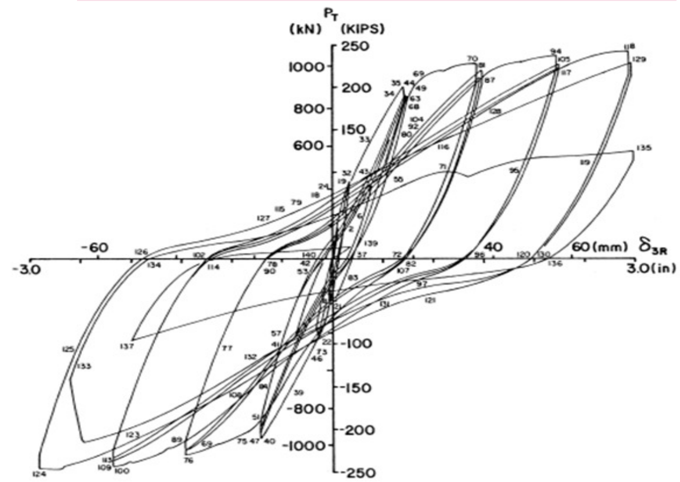
Only simple equivalent linear (EQL) approaches were applied in frequency domain. As a result of the EQL model *time invariant behavior*, the SSI response could be either over or under estimated at different time moments.

Linear Hysteretic Model



Frequency Domain
(Time-Invariant System)
(Frequency-Invariant)

Non-Linear Hysteretic Model



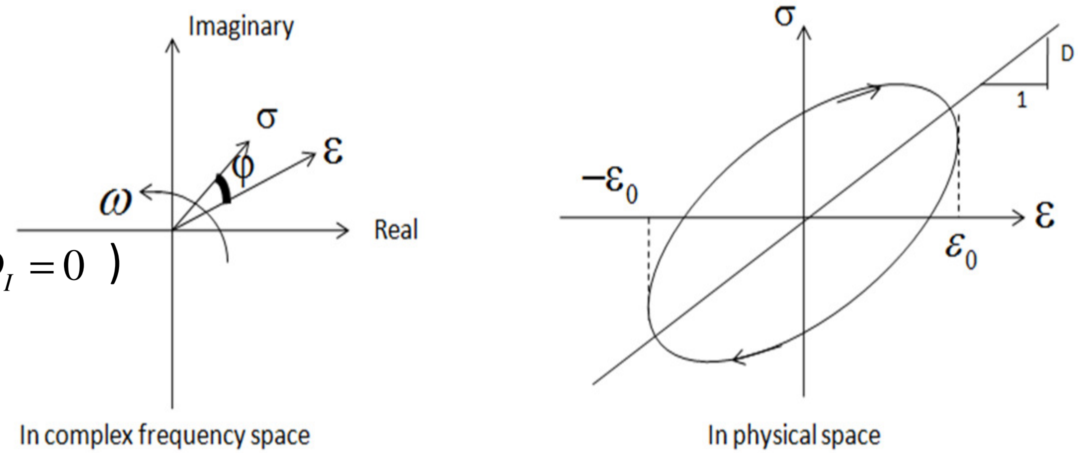
Time Domain
(Time-Dependent System)
(Frequency-Dependent)

Linear Hysteretic (Voigt) Model in Complex Frequency

In complex frequency, Hooke Law is:

$$\sigma^*(\omega) = D^*(\omega)\varepsilon^*(\omega)$$

$D^*(\omega) = D_R + iD_I$ (for elastic solid $D_I = 0$)

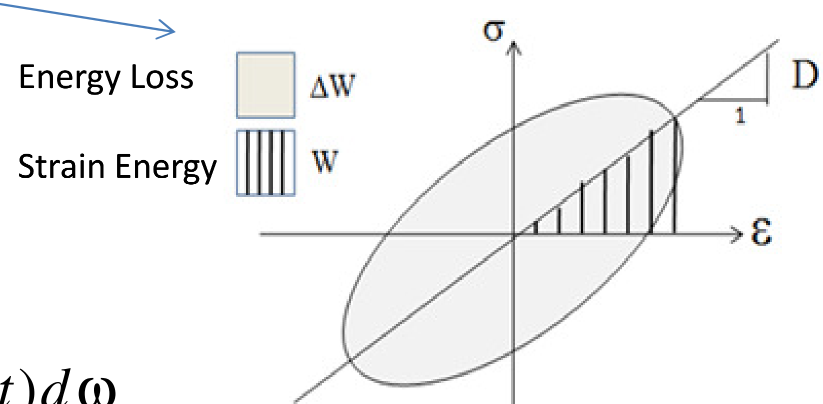


Visco-Elastic Material Model

Linear Hysteretic Model Parameters:

$$\beta = \frac{1}{4\pi}\frac{\Delta W}{W}$$

$$D^* = D_R\left(\underbrace{1-2\beta^2}_{\text{real part}} + \underbrace{2i\beta\sqrt{1-\beta^2}}_{\text{imag part}}\right)$$



In time domain, using Fourier duality:

$$\sigma(t) = \sigma_{elast}(t) + \sigma_{diss}(t)$$

$$\sigma_{elast}(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} D_R(\omega)\varepsilon^*(\omega)\exp(-i\omega t)\,d\omega$$

$$\sigma_{diss}(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} D_I(\omega)\varepsilon^*(\omega)\exp(-i\omega t)\,d\omega$$

Using Fourier duality linear (nonlinear) time response can be mapped in a complex frequency response and vice-versa.

Nonlinear Hysteretic Models in Time and Frequency

To map a linear system response time history we need a linear (frequency-independent) hysteretic model.

To map a nonlinear system response time history we need a nonlinear (frequency-dependent) hysteretic model.

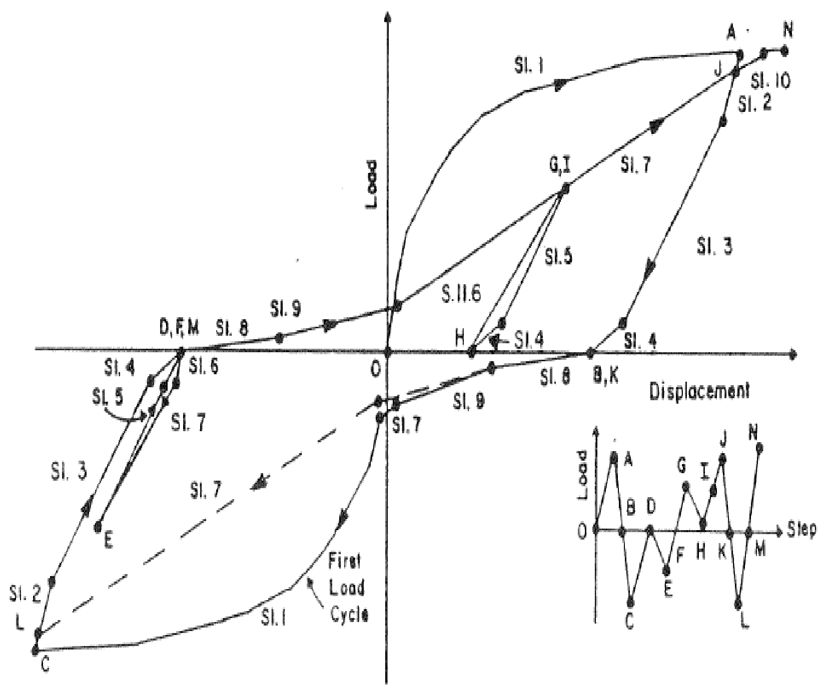
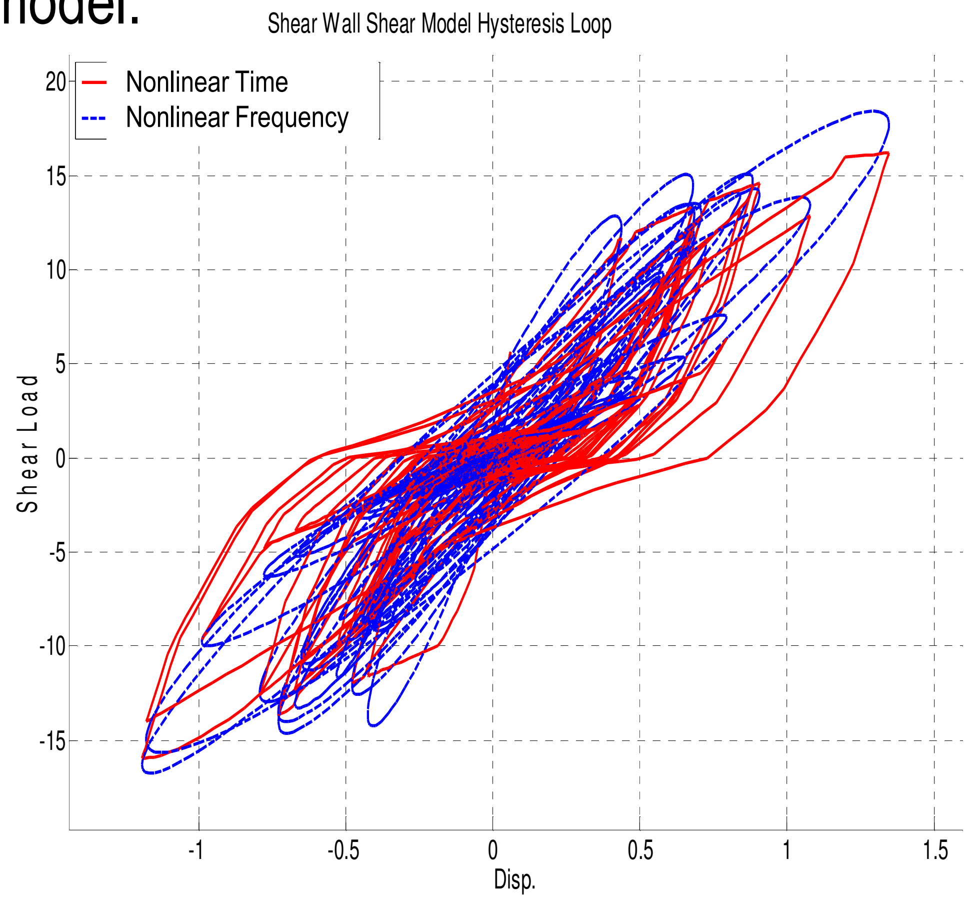
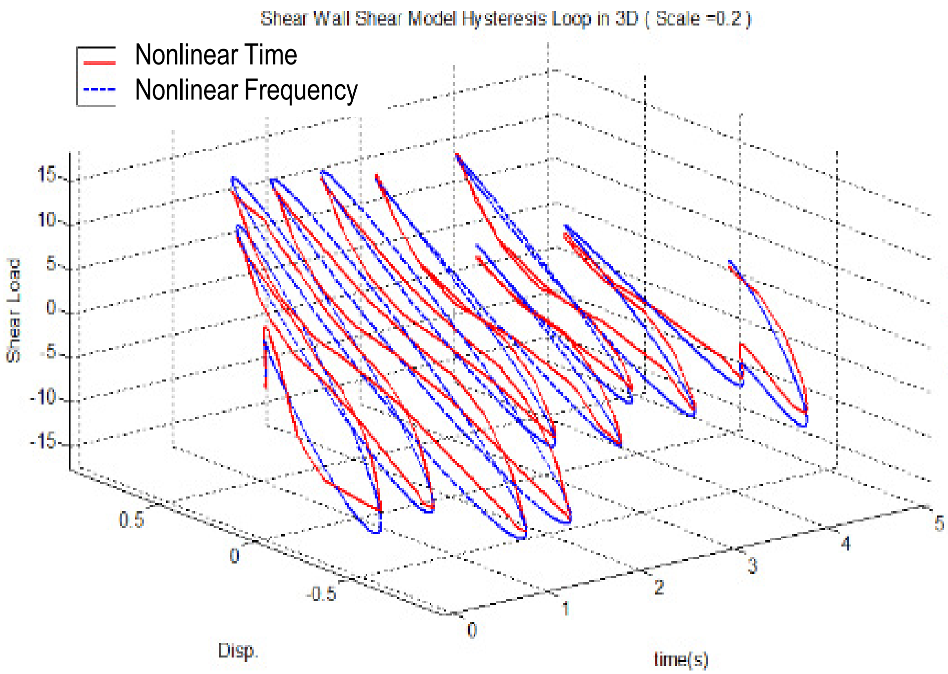


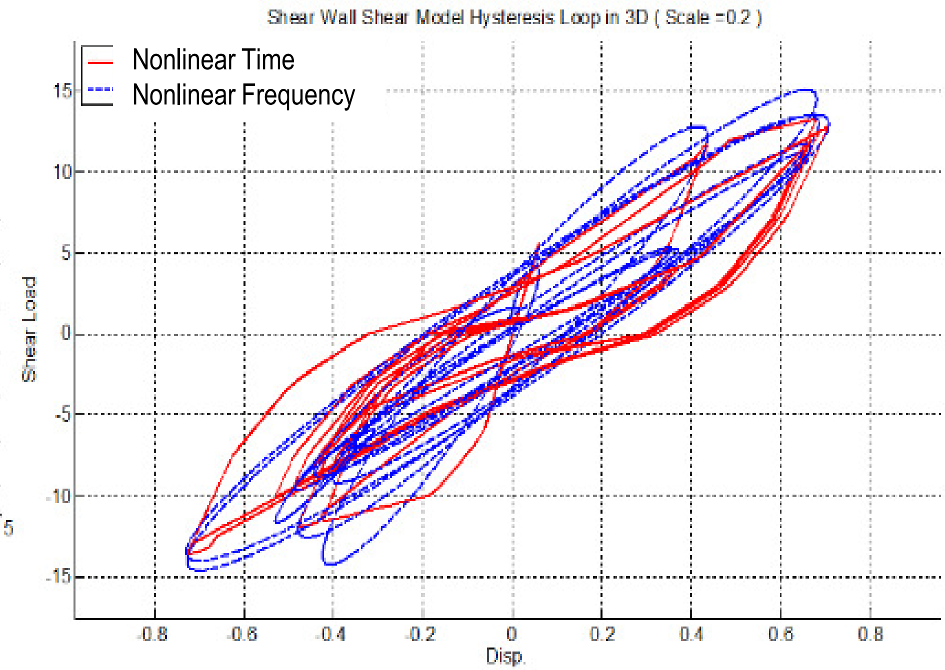
Figure 5b. Shear hysteresis model



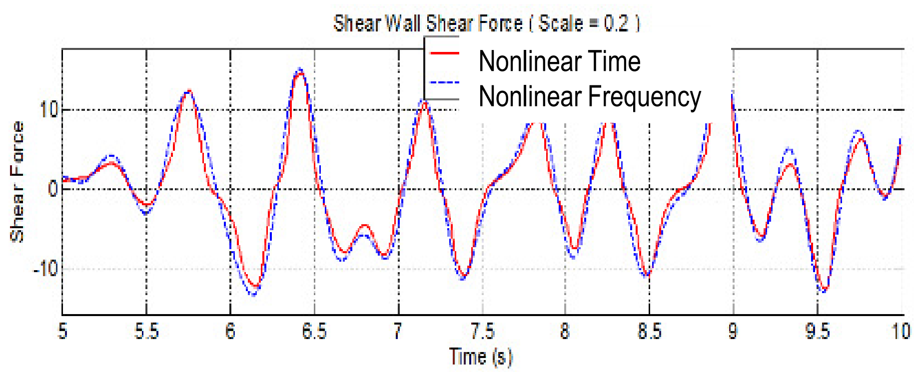
Nonlinear Hysteretic Model in Complex Frequency



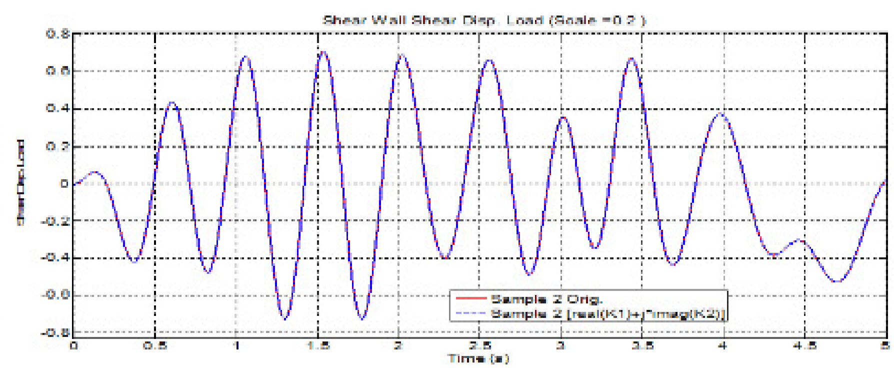
Comparison Hysteretic Loops in Time-Domain



Comparison of the Two Nonlinear Hysteretic Models



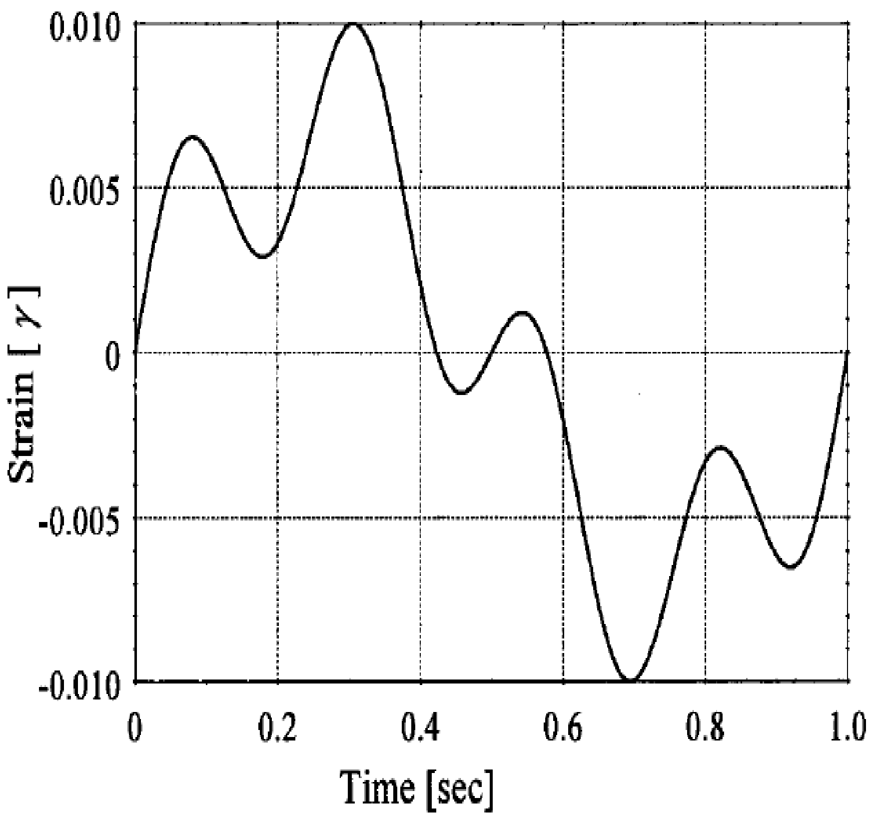
Shear force in time



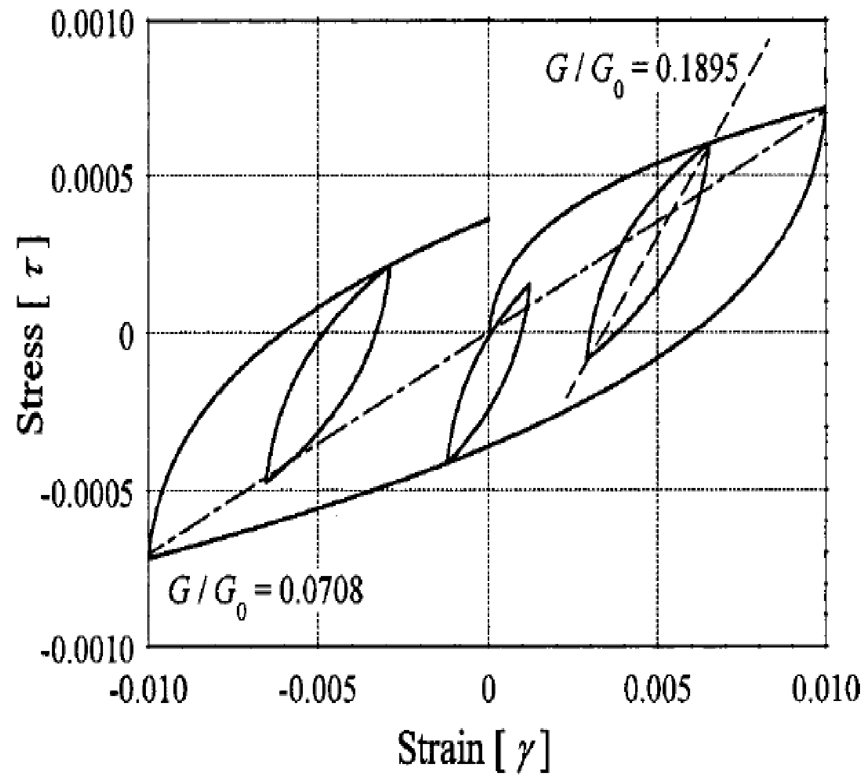
Displacement

Frequency-Dependent Linearized Hysteretic Models in Complex Frequency: Kausel-Assimaki Model

Time Response

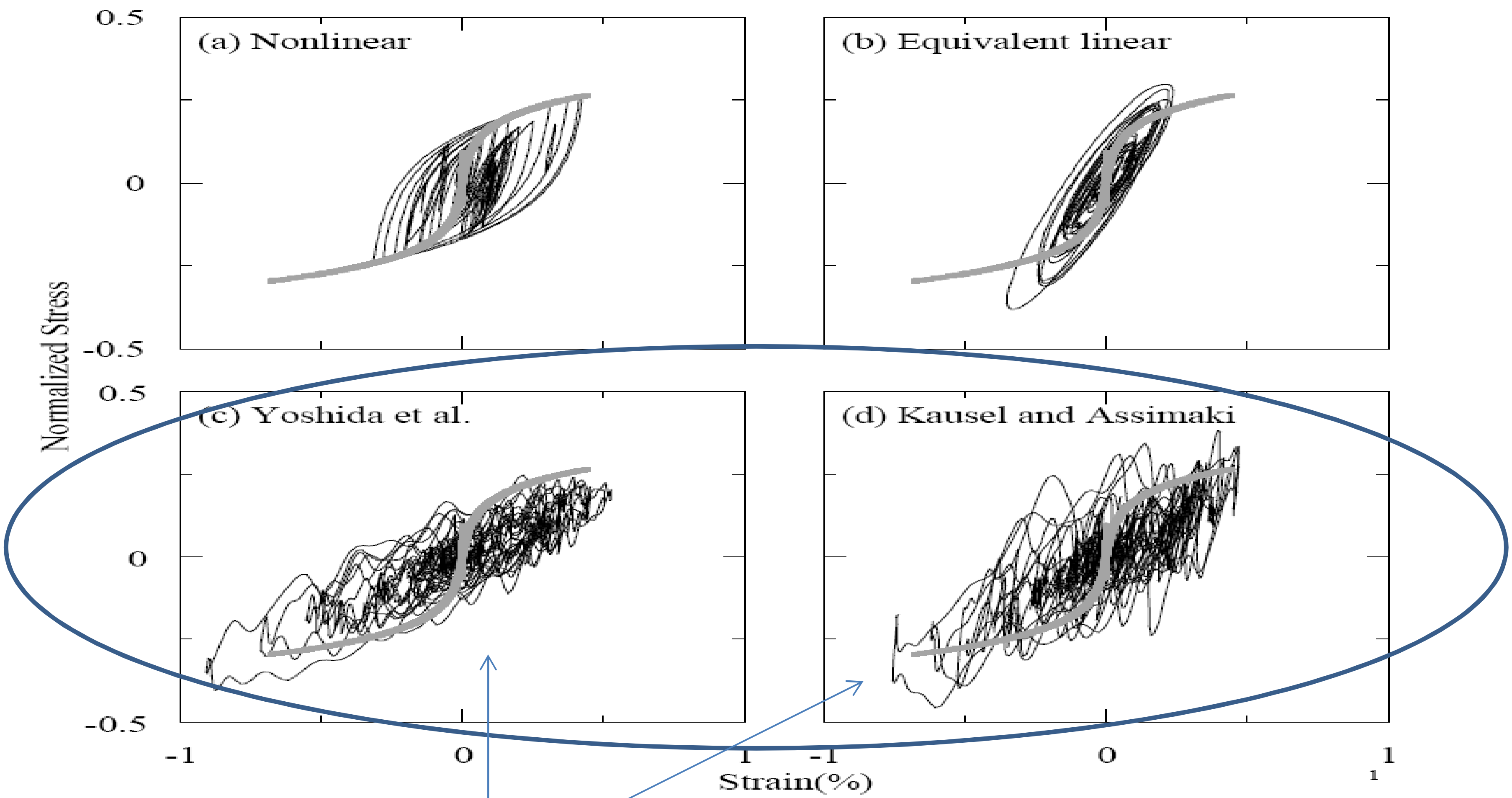


Hysteretic Loops



Kausel, E. and Assimaki, D. ,2002

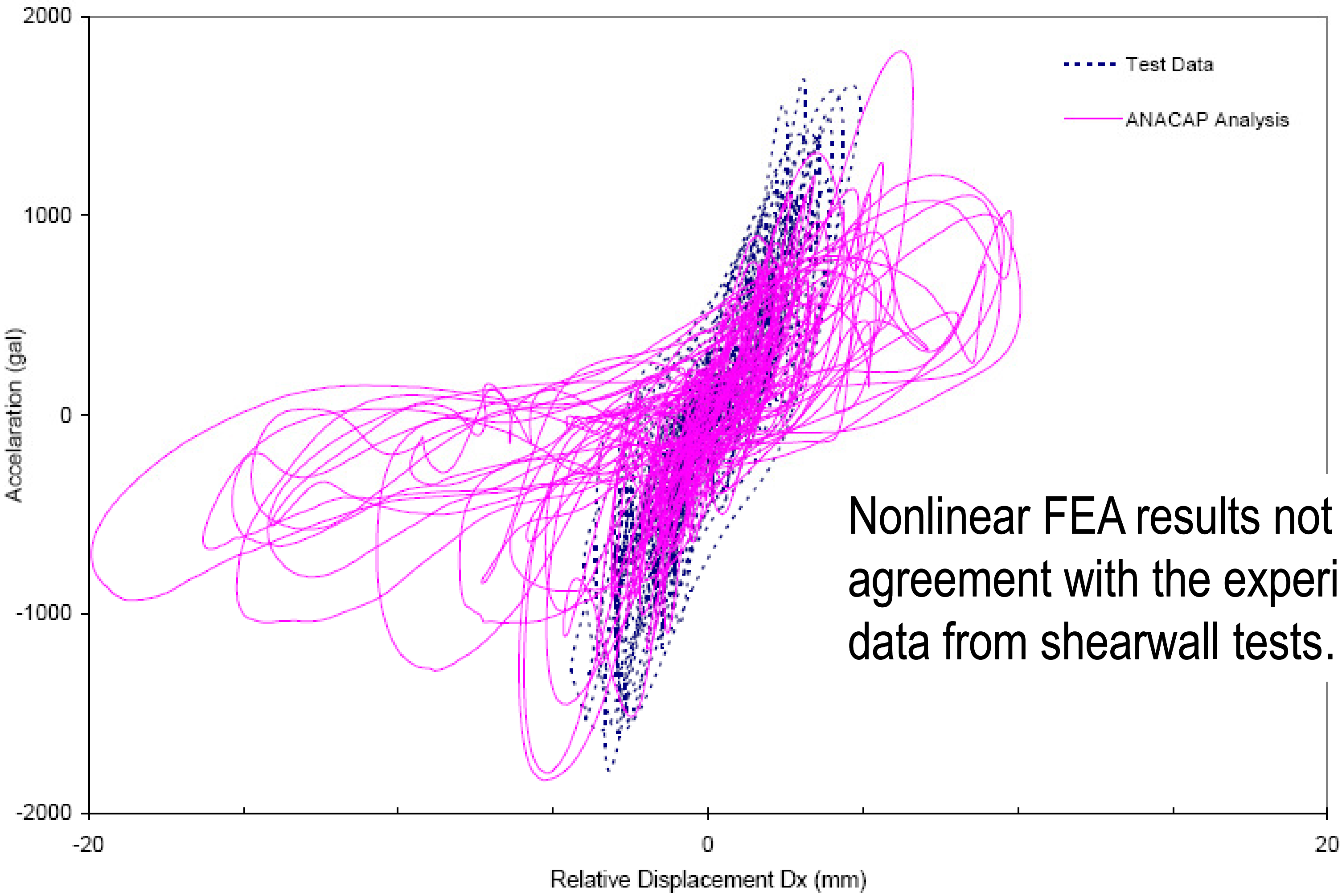
Frequency-Dependent Hysteretic Model Results



Kwak, D.Y.K., Jeong, C.G., Park, D. and Park, S. ,2008

REMARK: *Kausel and Assimaki (2002) and Yoshida et al. (2002) implementations lacked in the compatibility between the frequency and the time domain representations.*

Nonlinear Plasticity FEA Models: ANACAP Model



Nonlinear FEA results not fully in agreement with the experimental data from shearwall tests…..

Figure 5-86 Comparison of X-Direction Hysteresis from ANACAP Analysis Considering Prior Damages but with X-Input Motion only and Test Result for Run-6

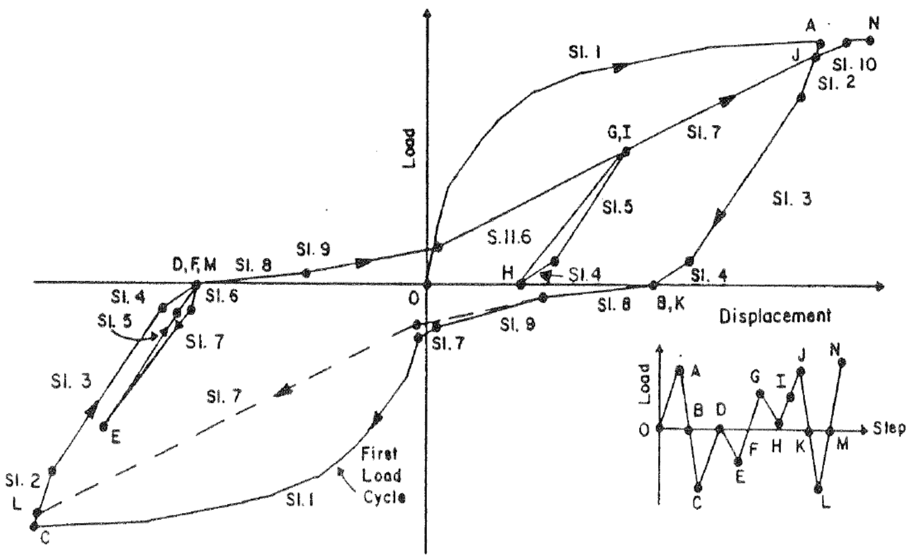
NUREG/CR-6925, BNL-NUREG-77370, 2006

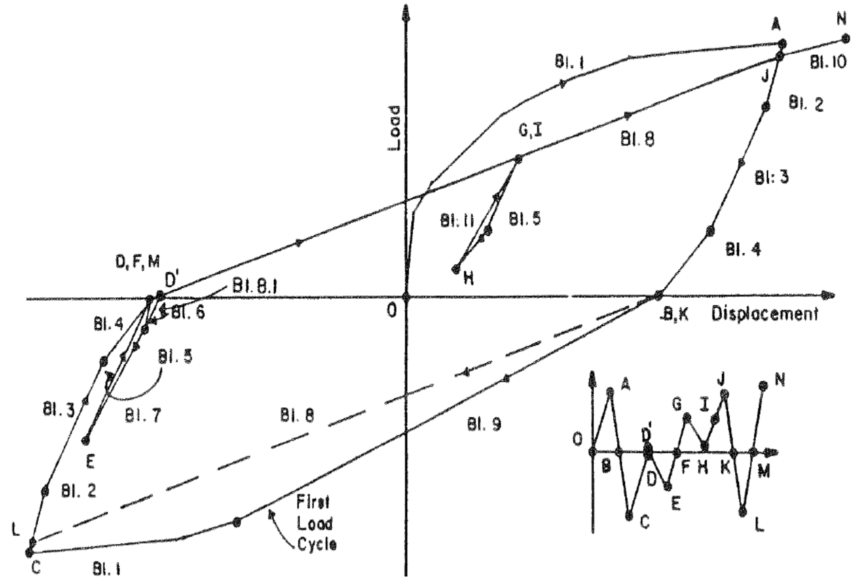
Nonlinear SSI Analysis in Complex Frequency:

Computational Steps:

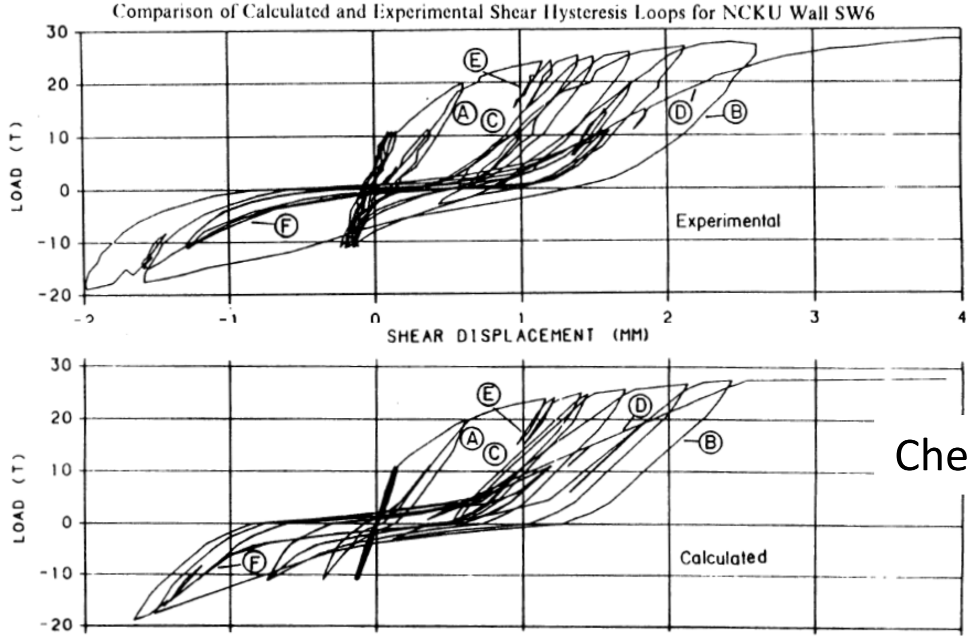
- For the initial iteration, perform a linear SSI analysis using the elastic properties for the selected shearwall panels
- Compute the reinforced concrete shearwall panel behavior in time domain and frequency domain using the hysteretic model associated to each selected panel
- Perform a new SSI analysis iteration using a fast SSI reanalysis (restart analysis) in the complex frequency domain using the hysteretic models computed in Step 2 for all selected panels
- Check convergence of the nonlinear SSI response after new SSI iteration, and go back to Step 2 if the convergence was not achieved.

Chen-Mertz Hysteretic Model for Low-Rise Shearwalls





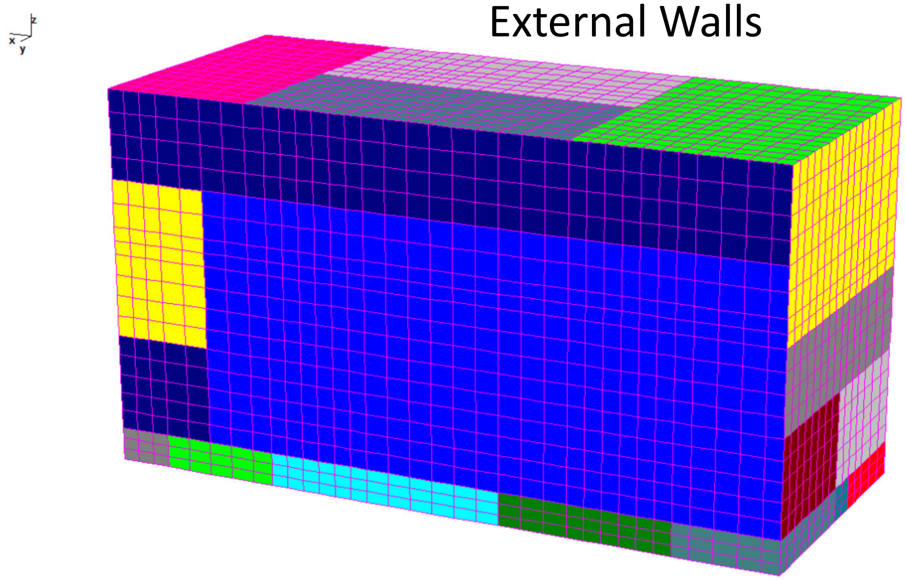
Comparison of Calculated and Experimental Shear Hysteresis Loops for NCKU Wall SW6



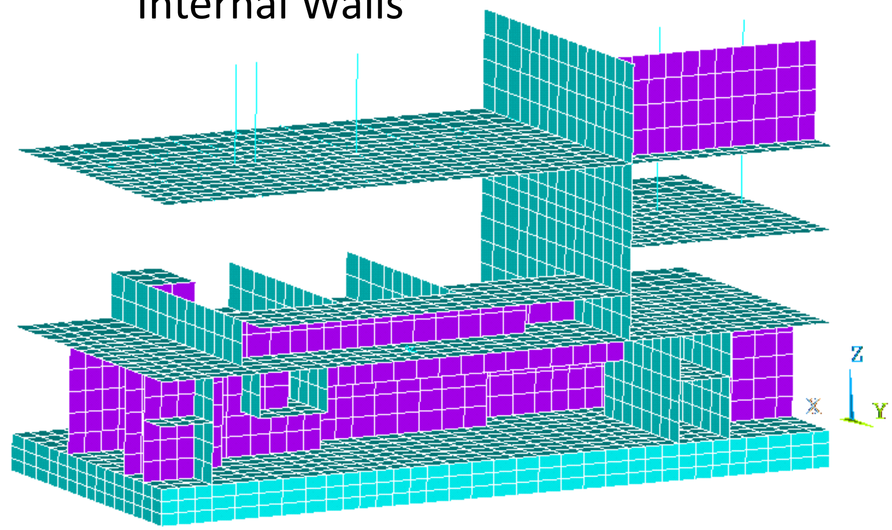
Cheng and Mertz, 1989

Nuclear Shearwall Building on A Rock Site

External Walls

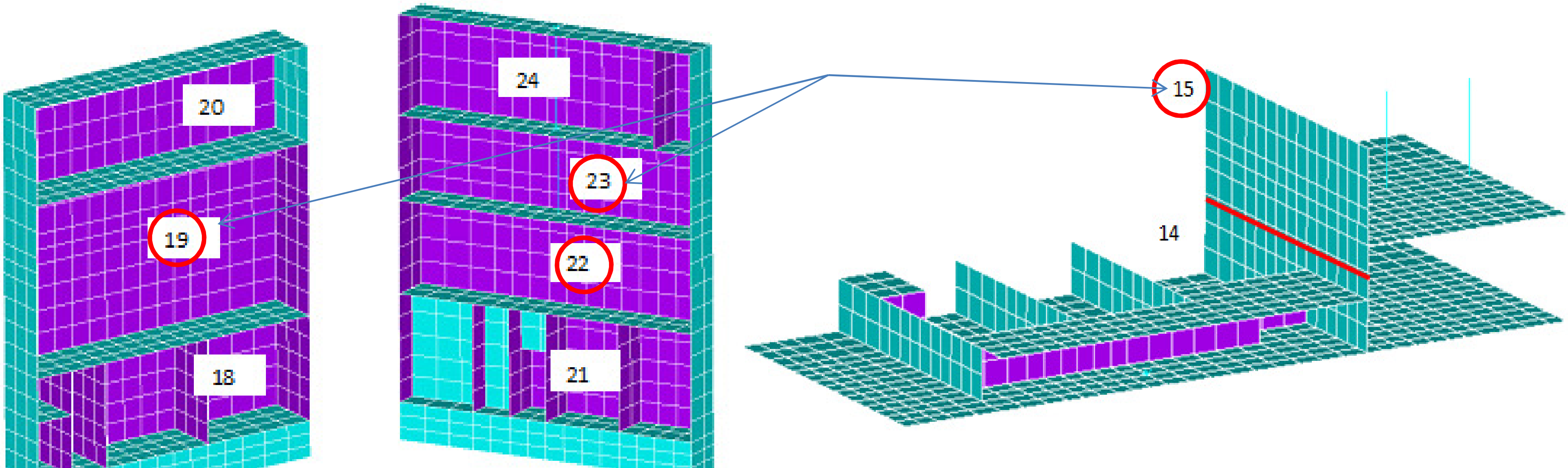


Internal Walls



Transverse External Walls

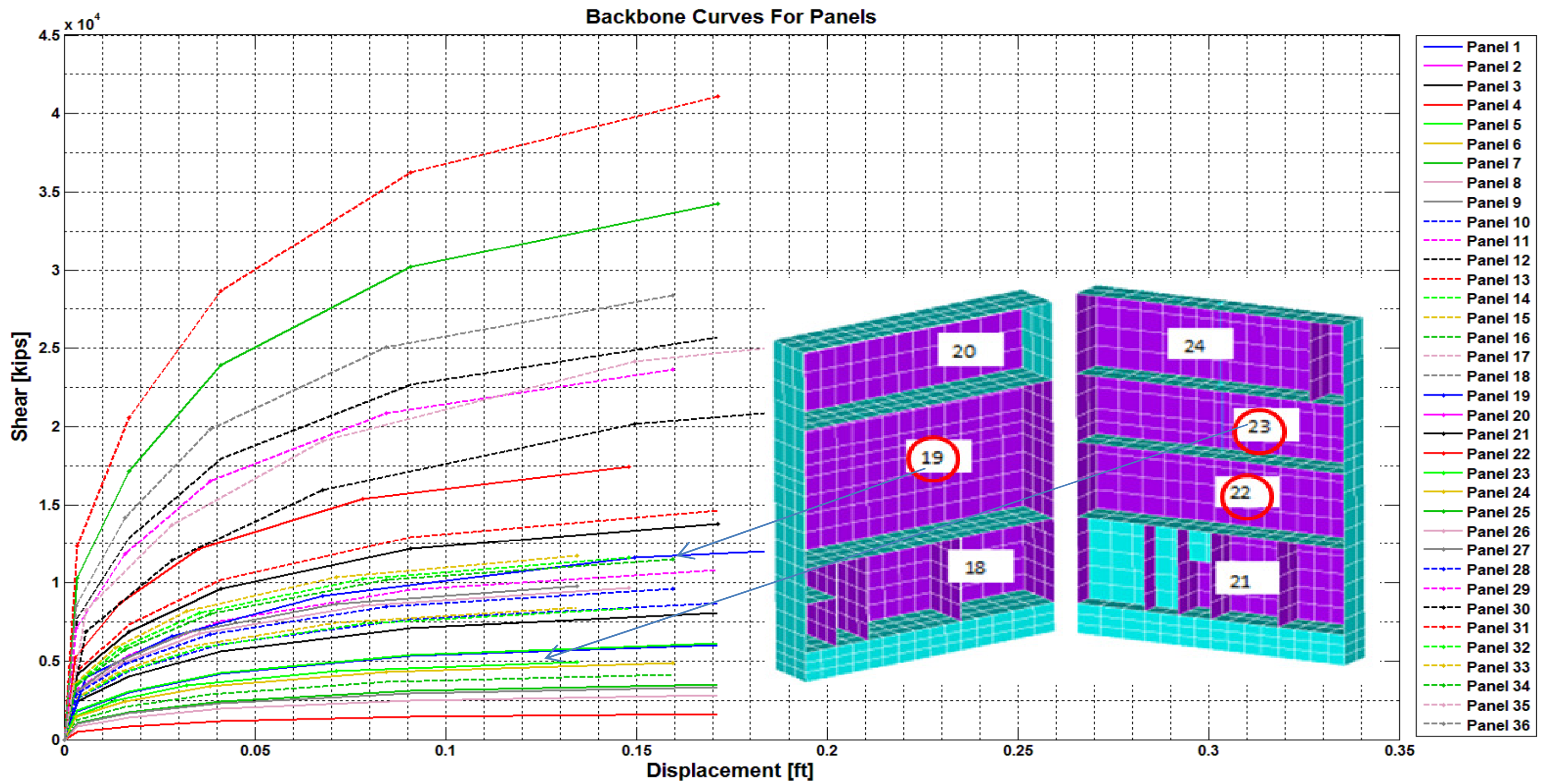
Transverse Internal Walls



Shearwall Back Bone Curves (BBC) for All Shearwalls

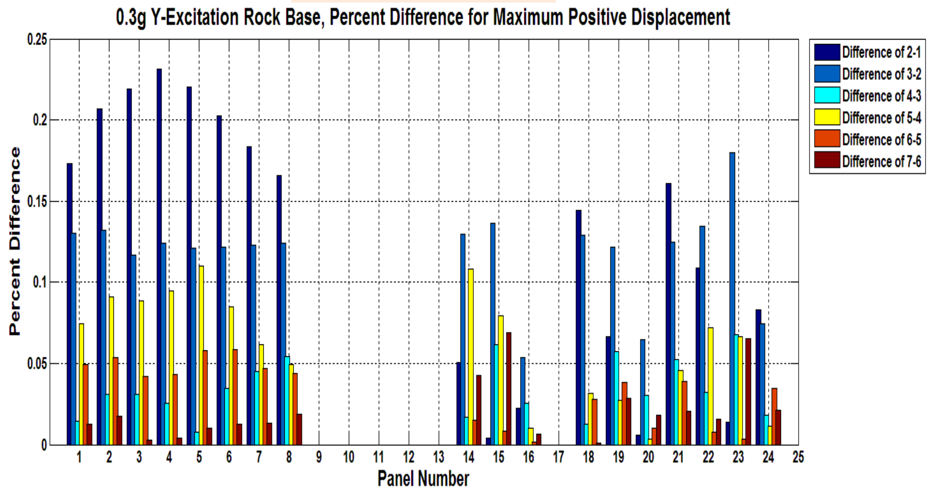
A number of 36 wall panels were modeled for nonlinear SSI analysis.
For each BBC were determined based on ASCE 41-2006 and ASCE 43-05.

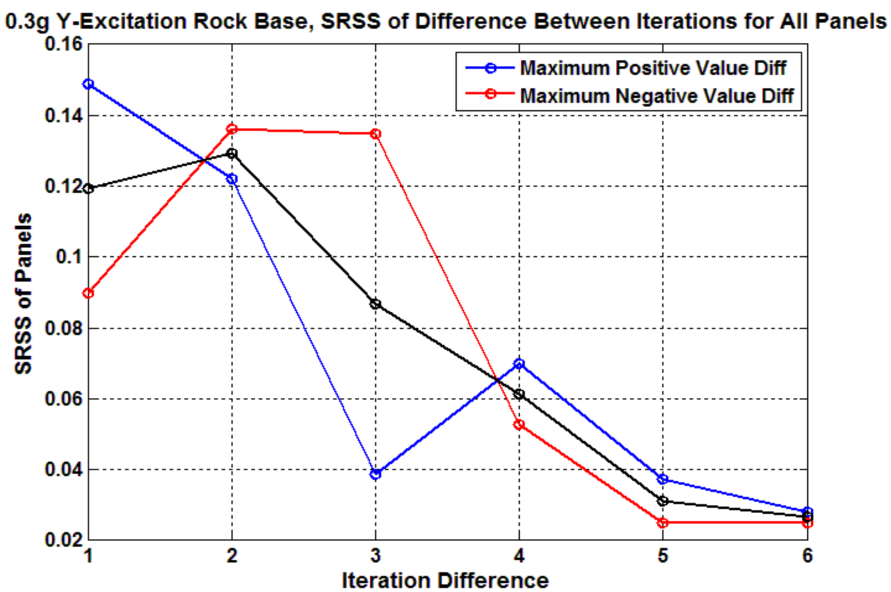
Focus of the weak story (results shown for the panels #19 and 23)



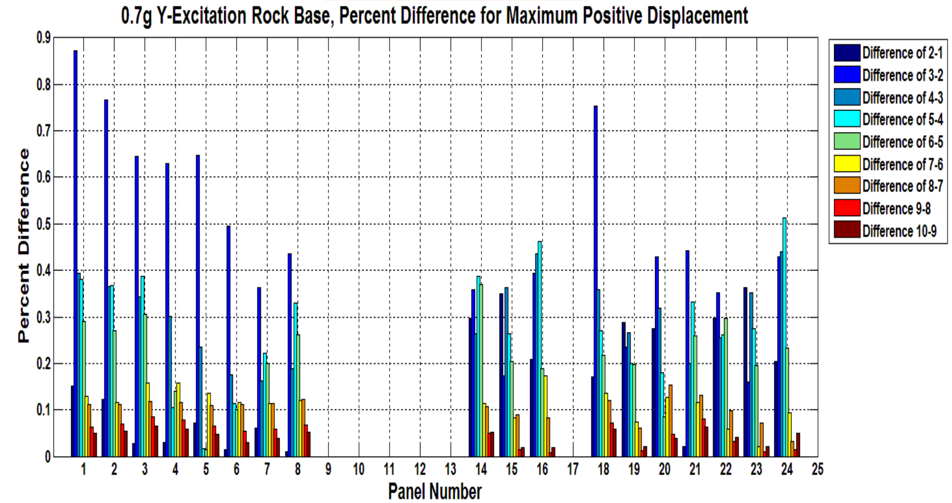
Nonlinear SSI Analysis Convergence (Per Panel and Global)

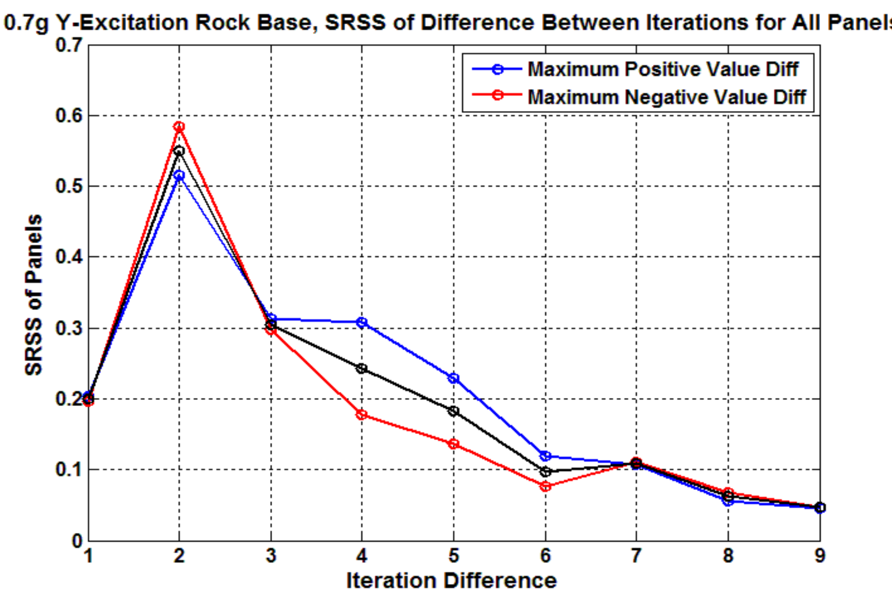
0.30g ZPGA



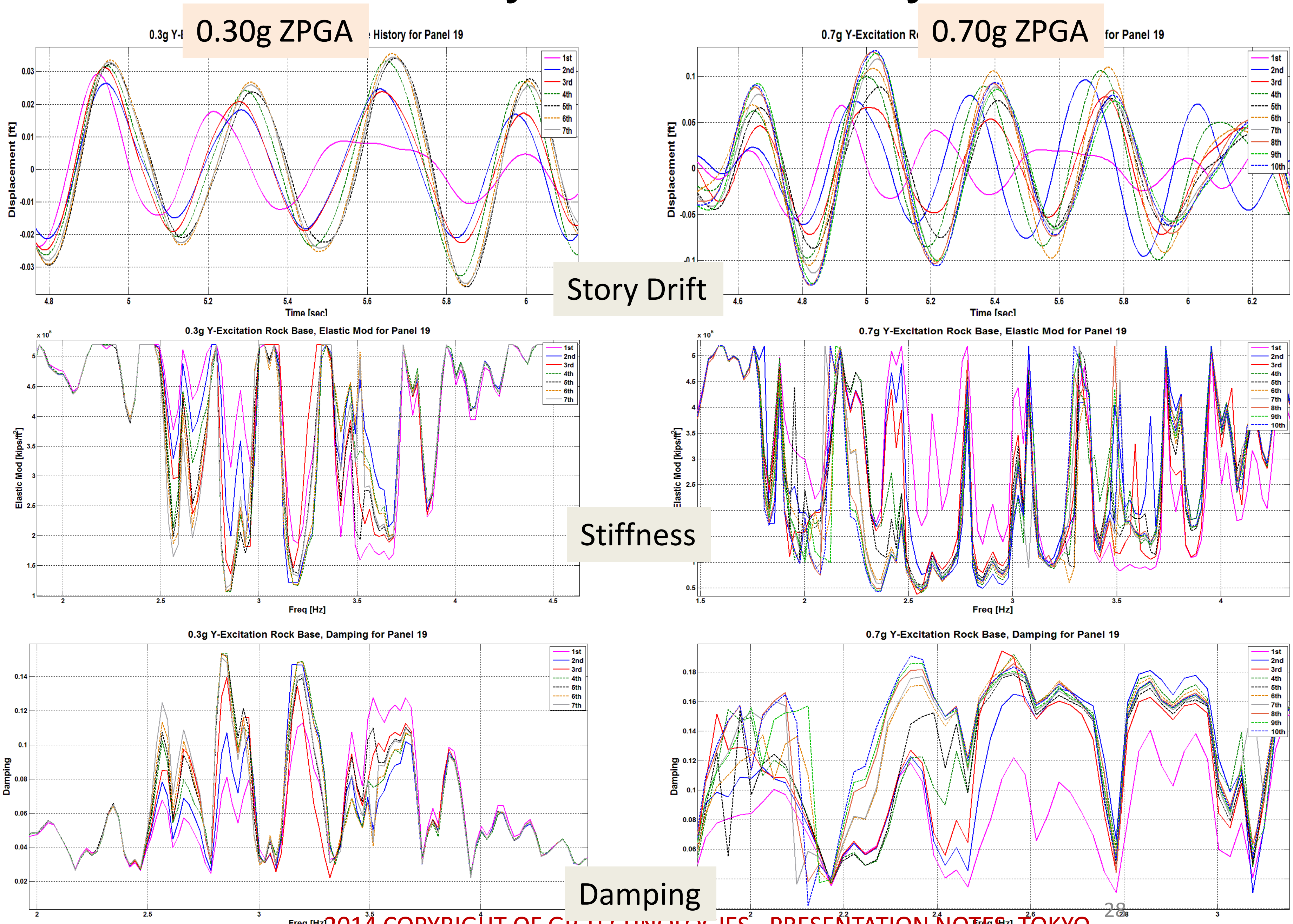


0.70g ZPGA



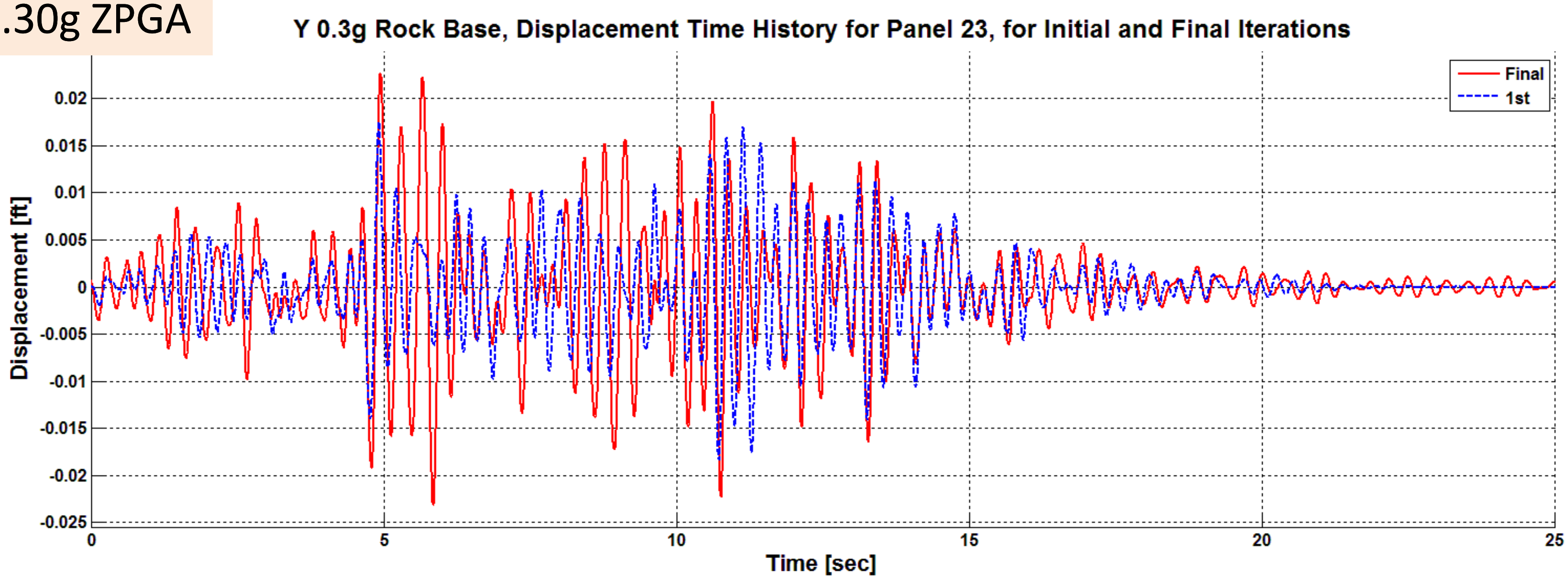


Nonlinear SSI Analysis Iteration History for Panel # 19

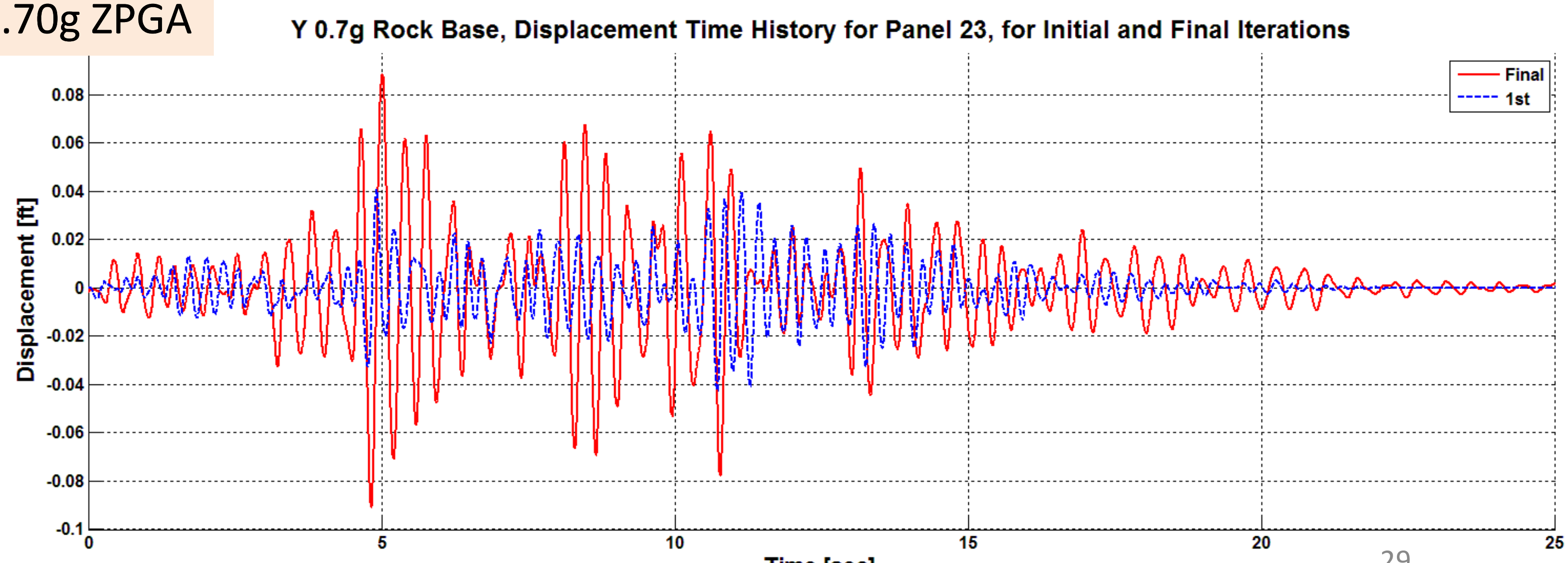


Panel #23 Comparative Linear and Nonlinear Story Drifts

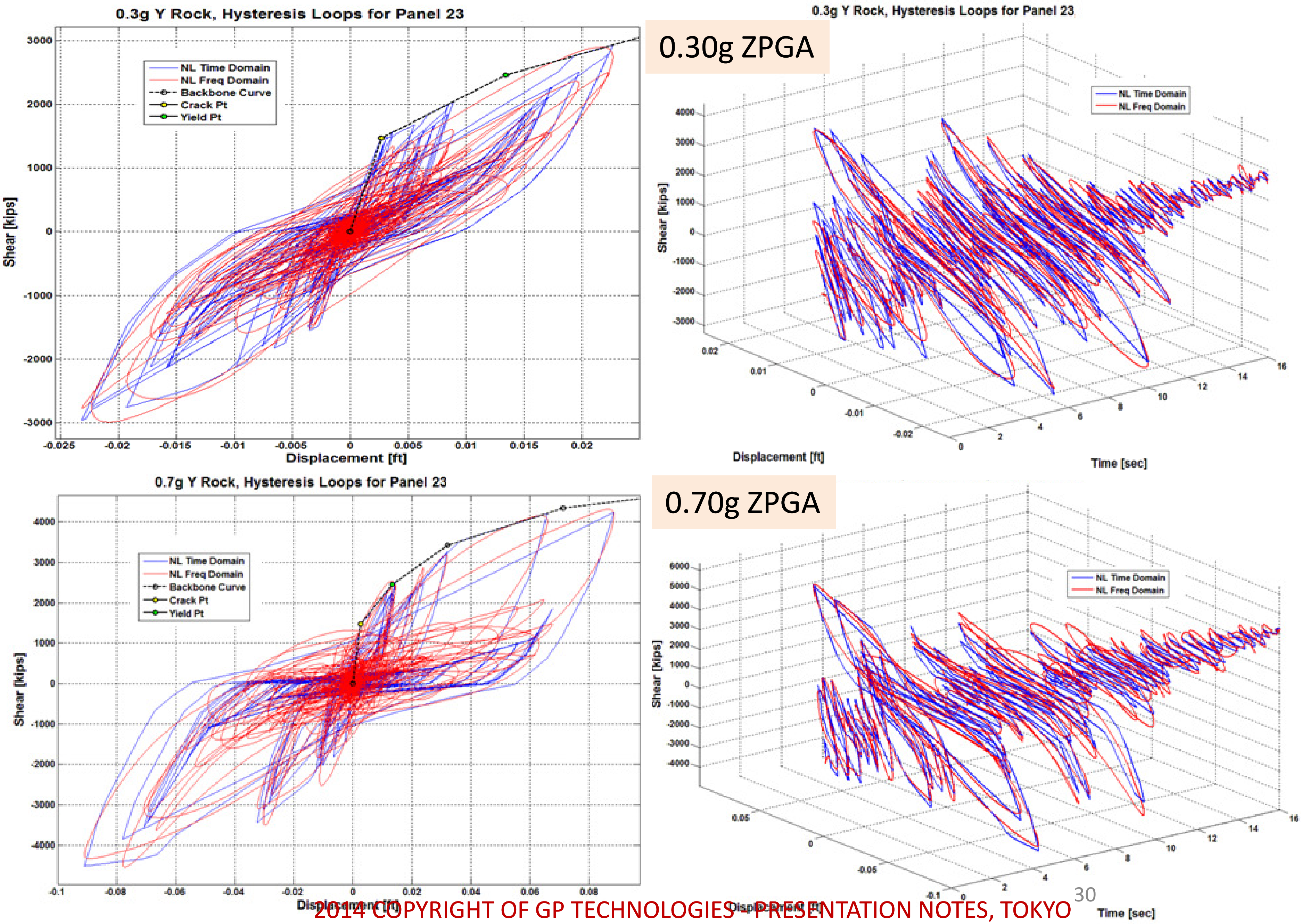
0.30g ZPGA



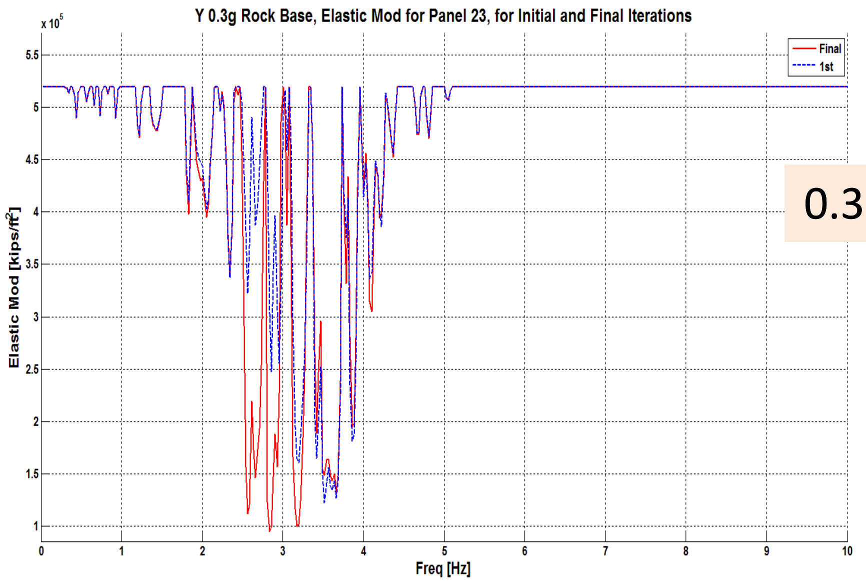
0.70g ZPGA

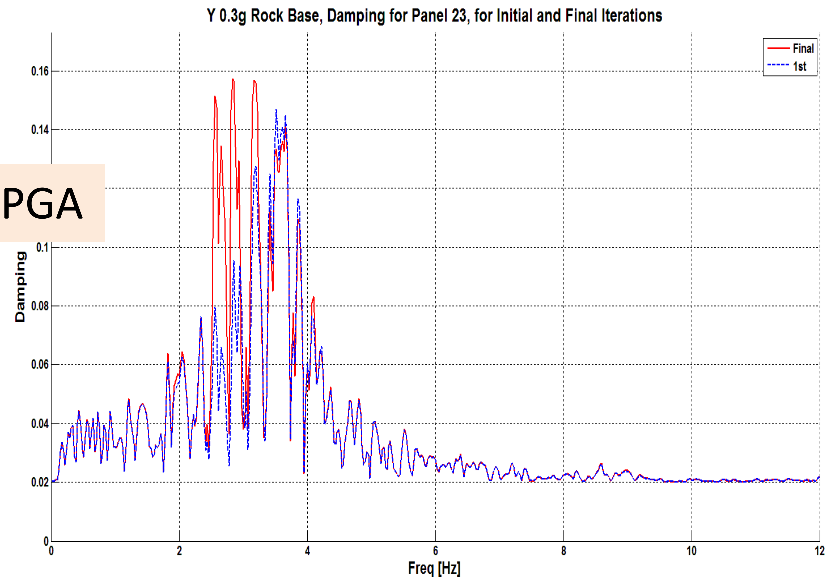


Panel #23 Hysteretic Loops for 1st and Final Iterations



Panel #23: Frequency-Dependent Stiffness and Damping

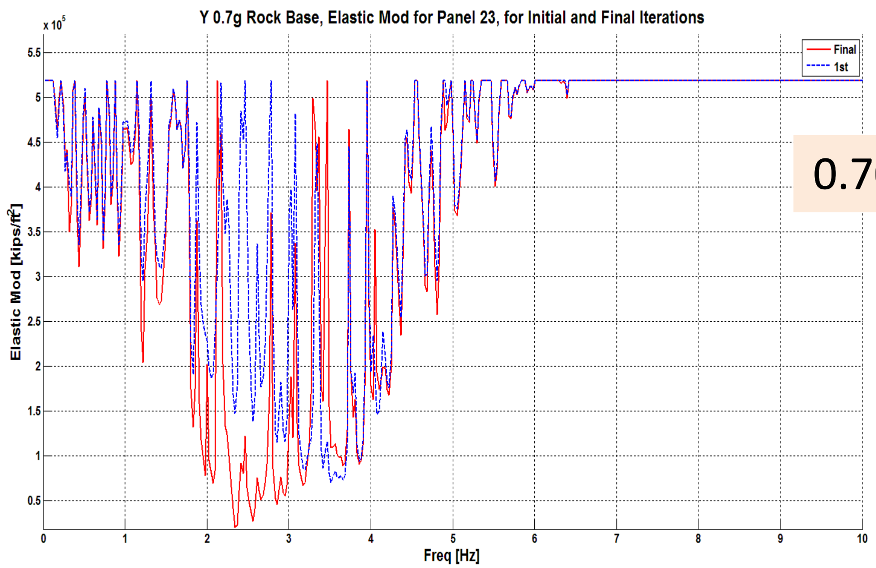


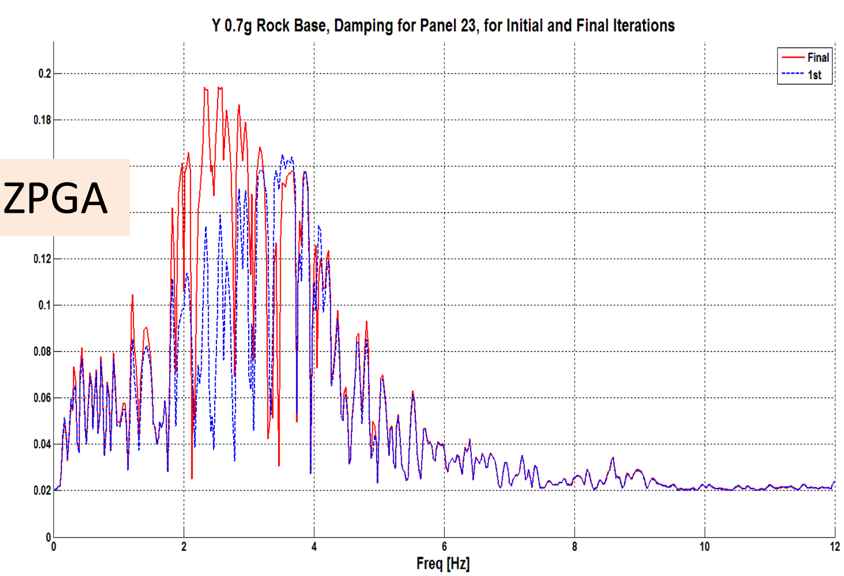


0.30g ZPGA

Stiffness

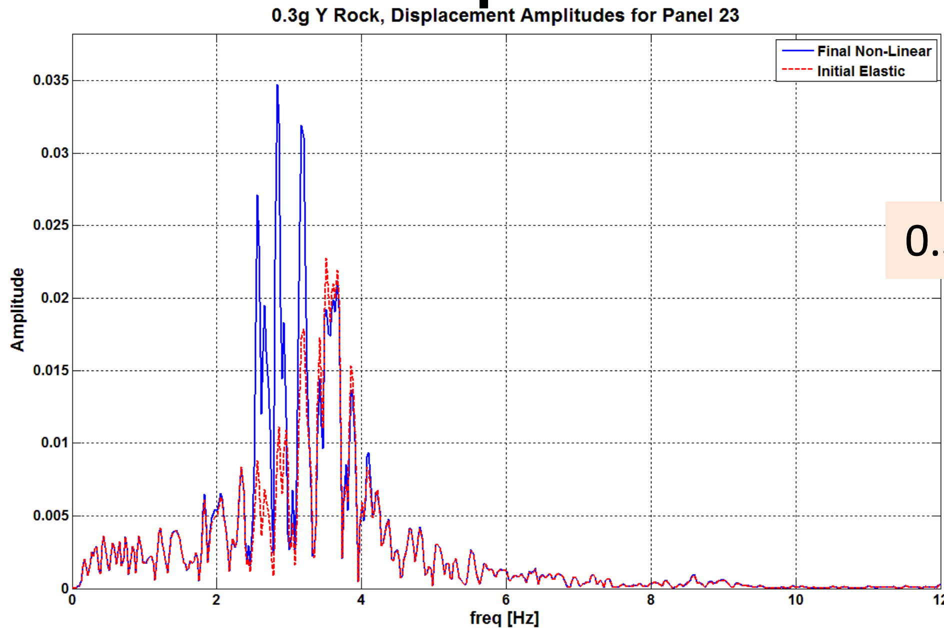
Damping

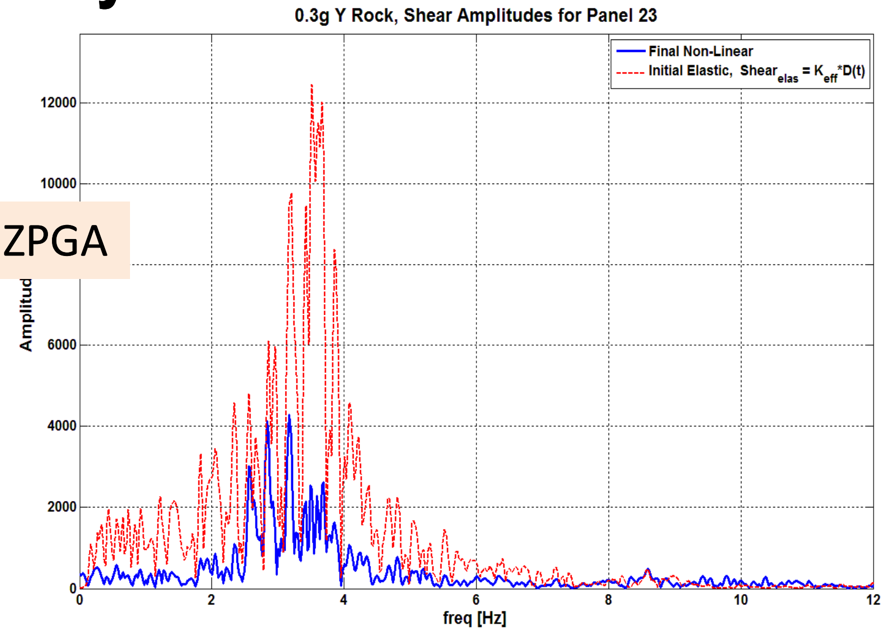




0.70g ZPGA

Panel #23: Amplitude Fourier of Story Drifts and Shear Forces

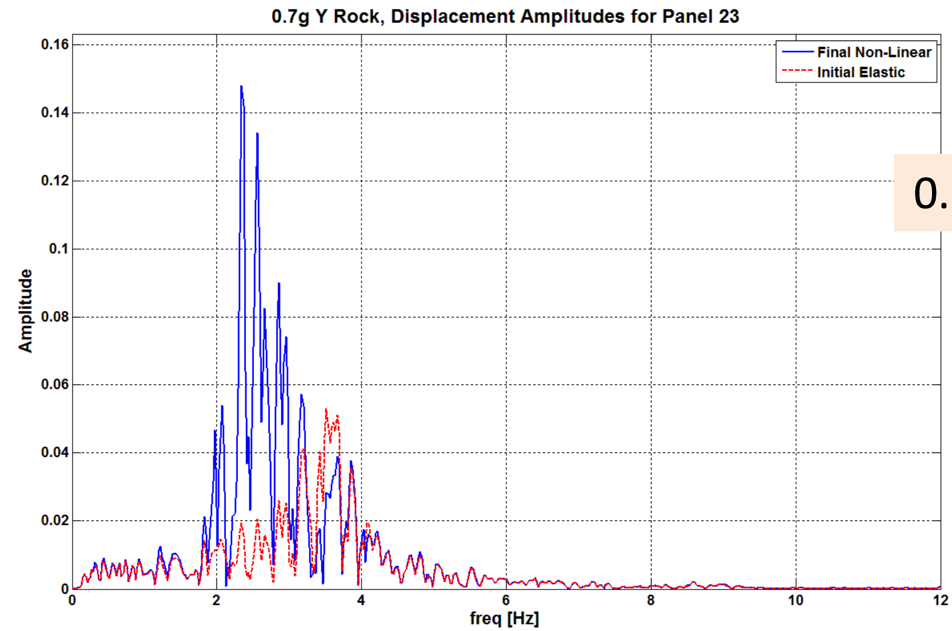


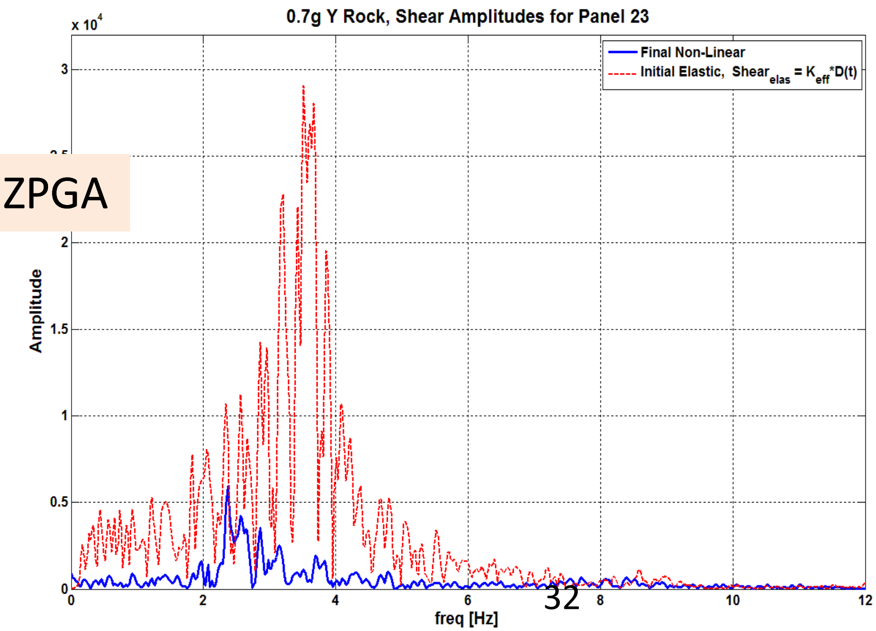


0.30g ZPGA

Story Drift Fourier Amplitude

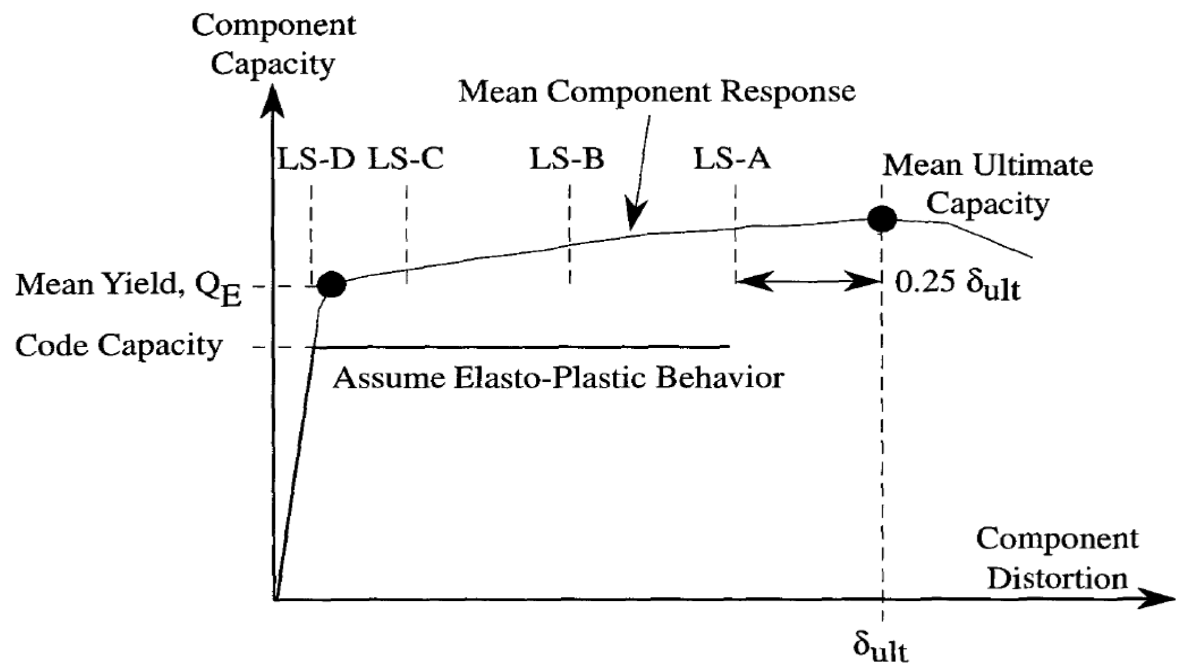
Shear Force Fourier Amplitude





0.70g ZPGA

ASCE 43-05 Inelastic Reduction Factors for Different Damage States



C5-4 Typical Load-Deformation Curve and Limit States

Limit State	LS-A	LS-B	LS-C
SMRF reinforced concrete moment frames			
Beams $(15 \le \ell/h)$	5.25	4.0	2.5
Beams $(\ell/h \le 10)$	3.25	3.0	2.5
Columns**	2.0	1.75	1.5
Reinforced concrete shear wall, in plane:			
Bending controlled walls, $\frac{h_w}{\ell_w} \ge 2.0$			
$6\sqrt{f'_c} < f_v$	2.25	2.0	1.75
$f_v < 3\sqrt{f'_c}$	2.5	2.25	1.75
Shear controlled walls, $\frac{h_w}{\ell_w} < 2.0$	2.0	1.75	1.5

Nonlinear SSI and ASCE 43-05 Inelastic Reduction Factors

0.30g ZPGA Design Level (LS-D)

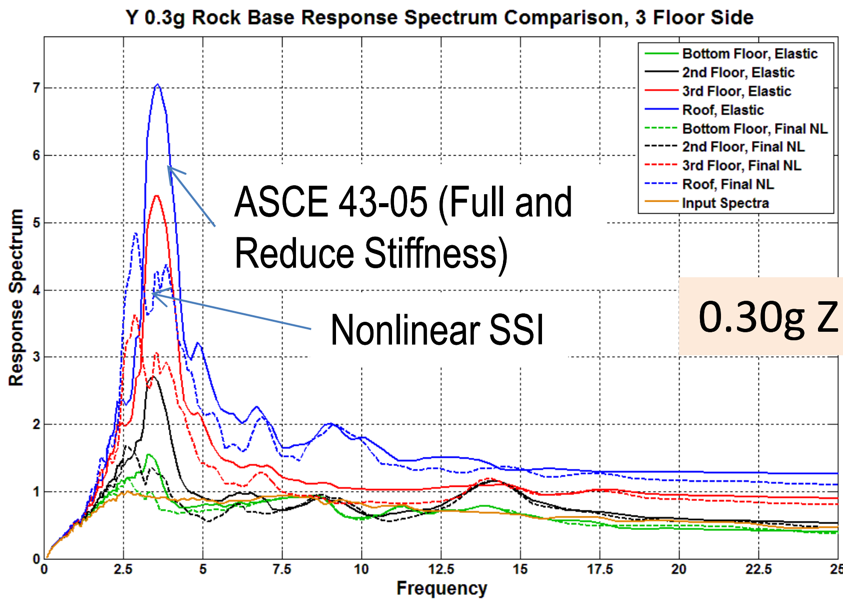
Panel Number	μ, Final Analysis	ASCE 43 Fμ, Final Analysis	Calcs Fμ, Shear
1	0.716	0.657	1.042
2	0.662	0.568	1.004
3	0.664	0.573	1.029
4	0.734	0.684	1.097
5	0.776	0.743	1.153
6	0.756	0.715	1.153
7	0.708	0.645	1.093
8	0.735	0.686	1.122
14	1.373	1.321	1.315
15	1.662	1.524	1.348
16	1.230	1.208	1.358
18	0.800	0.775	1.104
19	1.238	1.215	1.222
20	1.198	1.182	1.328
21	0.732	0.681	1.112
22	1.100	1.095	1.144
23	1.721	1.562	1.339
24	1.070	1.068	1.241
Average	**0.993**	**0.939**	**1.178**
Building	**1.177**	**1.163**	**-----**

0.70g ZPGA Review Level (LS-A)

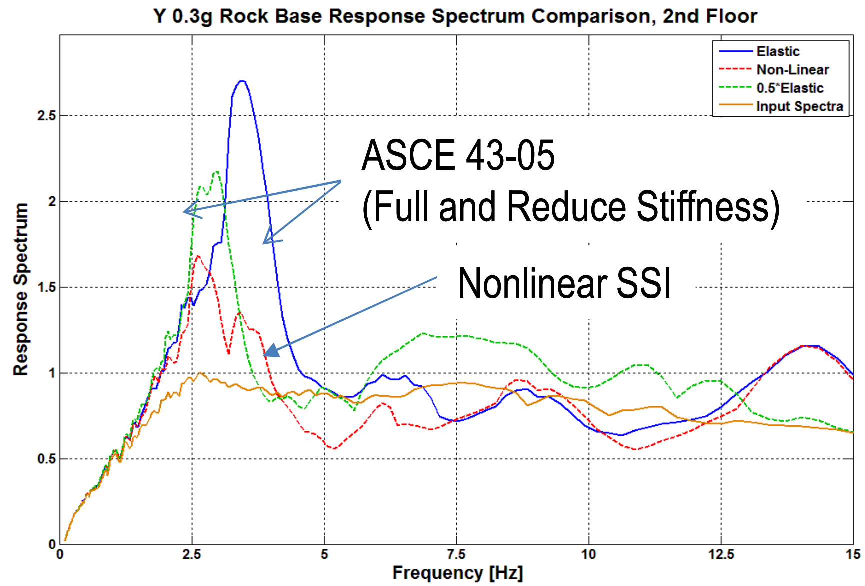
Panel Number	μ, Final Analysis	ASCE 43 Fμ, Final Analysis	Calcs Fμ, Shear
1	1.811	1.619	1.697
2	1.673	1.532	1.636
3	1.615	1.493	1.703
4	1.716	1.559	1.846
5	1.720	1.562	1.985
6	1.596	1.480	2.022
7	1.515	1.425	1.901
8	1.621	1.497	1.887
14	4.500	2.828	2.040
15	6.390	3.432	2.052
16	3.810	2.573	2.143
18	2.020	1.743	1.801
19	4.523	2.836	1.819
20	4.058	2.668	2.031
21	1.648	1.515	1.855
22	3.745	2.548	1.752
23	6.764	3.539	2.046
24	3.143	2.299	1.982
Average	**2.993**	**2.119**	**1.900**
Building	**3.801**	**2.569**	**----**

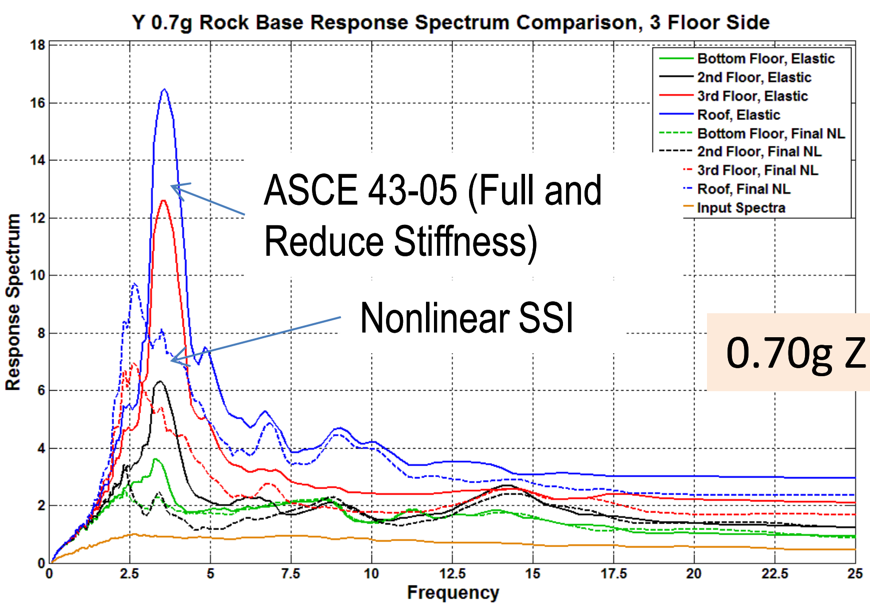
Large ductility demands

Nonlinear SSI and ASCE 43-05 Inelastic Reduction Factors

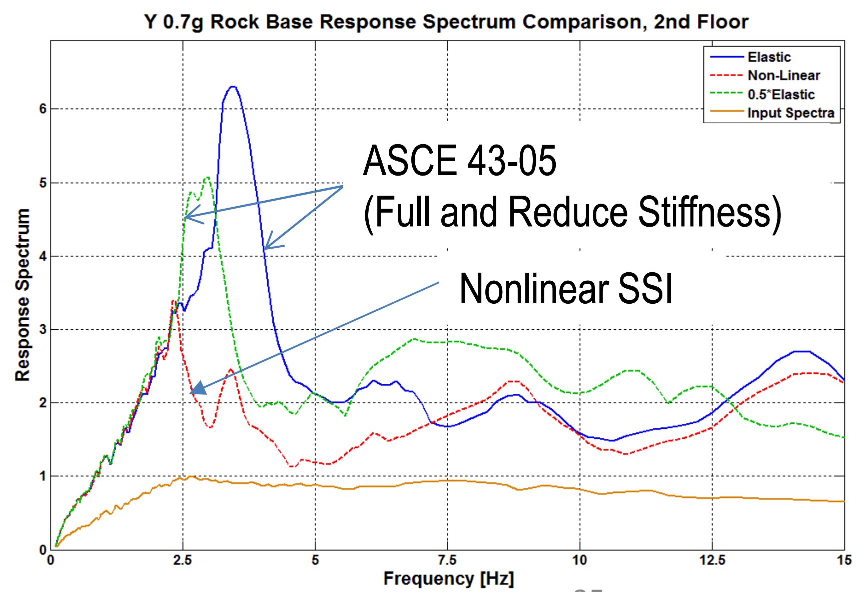


0.30g ZPGA





0.70g ZPGA



Concluding Remarks

- Nonlinear SSI analysis in complex frequency domain is a very promising engineering approach. It is at least 500 -1000 times faster than nonlinear SSI analysis in time domain.
- It provides results consistent with the ASCE 43-05 recommendations.
- Nonlinear SSI analysis in complex frequency is much more robust that nonlinear SSI analysis in time domain that is much more sensitive, especially for higher frequencies.

ACS SASSI V.3.0 SUBMODELER for FE Model Checking and Improving Its Numerical Condition

The SUBMODELER provides a new GUI module for generating and checking SSI models and also improving their numerical conditioning.

New commands:

FIXROT, FIXSHELL, FIXSOLID, FIXSPRING

INTGEN, SOILMERGE, EXCAV, EXTRACTEXCAV

FIXROT to automatically add the needed soft rotational springs to improve numerical conditioning for detailed flat shell models (for the Kirchhoff plate element the drilling degree of freedom has no stiffness associated with it, and therefore could produce poorly conditioned or unstable numerical models), FIXROT,<Stiff>.

Example code:

```
* Code to Fix rotations on a model.
Actm,1
Inp, Example_Model.pre
* Add soft springs with overall stiffness 10 to oblique shell nodes;
FixRot,10
```

INTGEN to generate automatically interaction nodes for different substructuring approaches FV, FI-FSIN (SM), FI-EVBN (MSM) and Fast FV.

INTGEN,<type> to generate the interaction nodes based on the selected SSI substructuringapproach. The excavation volume must be explicitly defined by the ETYPE command for options 1-3.
If the ETYPE is left to default values, this command will not work.

<type> :Type of iteration node generation
= 1 for Embedded Foundation - Flexible Volume (FV)
= 2 for Embedded Foundation - Flexible Interface with Excavation Volume Boundary Nodes, denoted FI-EVBN or Modified Subtraction Method (MSM)
= 3 for Embedded Foundation - Flexible Interface with Foundation-Soil Interface Nodes, denoted FI-FSIN or Subtraction Method (SM)
= 4 for Surface Foundation (interaction nodes are only at the ground surface level)

HINGED checks model to find all hinged connections between solids and shell and beams and beams and shells. These hinged connections could be potentially indicate incorrect FE modeling,since the node rotations from beams and shells are not transmitted to solids at the common nodes, and the node rotations from beams are not transmitted the in-plane shell rotations at the common nodes (the drilling dof equations have no stiffness terms by default)

The SOILMERGE command takes 2 models in memory and merges the models together. This command will be used to combine models from ANSYS(r) most of the time but the 2 models can come from any location.

Example code to merge an excavation model to a structural model.

```
Actm,1
Convert,ansys,struct.cdb,32.2
* Adjust Model before the merge
Actm,2
Convert, ansys,Soil.cdb,32.2
* Adjust Model before merge so that the excavation to have elements
of type o2
etypegen,2
Actm,3
MergeSoil,1,2,1,,,,mappingfile.txt
```

EXCAV command creates an excavation model for a model that doesn't have an excavation

Example code

```
* Code create an excavation from a model.
Actm,1
INP, Example_model.pre
EXCAV,2
ACTM,2
* Writing for example purposes
Write, Example_Excavation.pre
```

EXTRACTEXCAV command copies excavation elements from the current model to the model specified by the user. The original model is not changed.

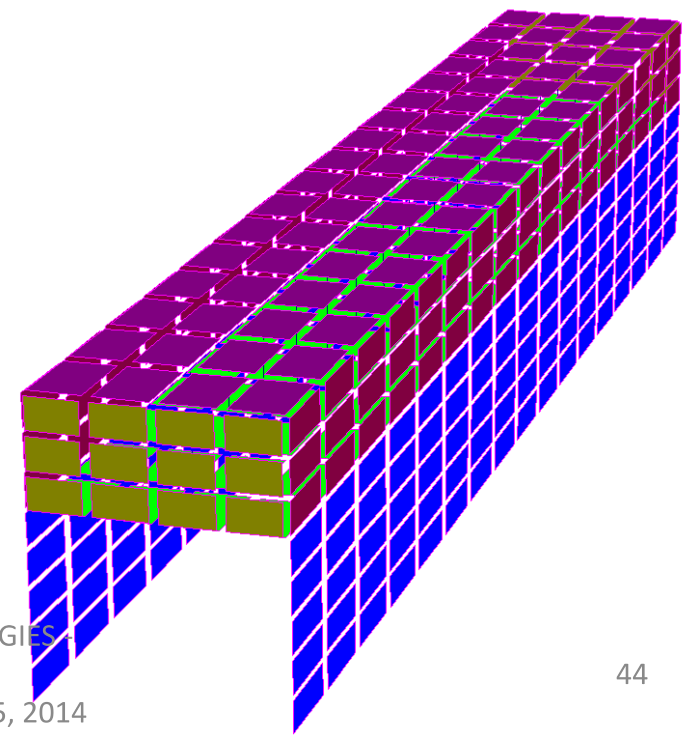
Example of code to extract excavation elements from a SSI model.

```
Actm,1
INP, Example_model.pre
*Create excavation model in Model 2
Extractexcav,2
Actm,2
*Showing the Excavation is in model 2 by writing the model to .pre
Write, Example_Excavation.pre
```

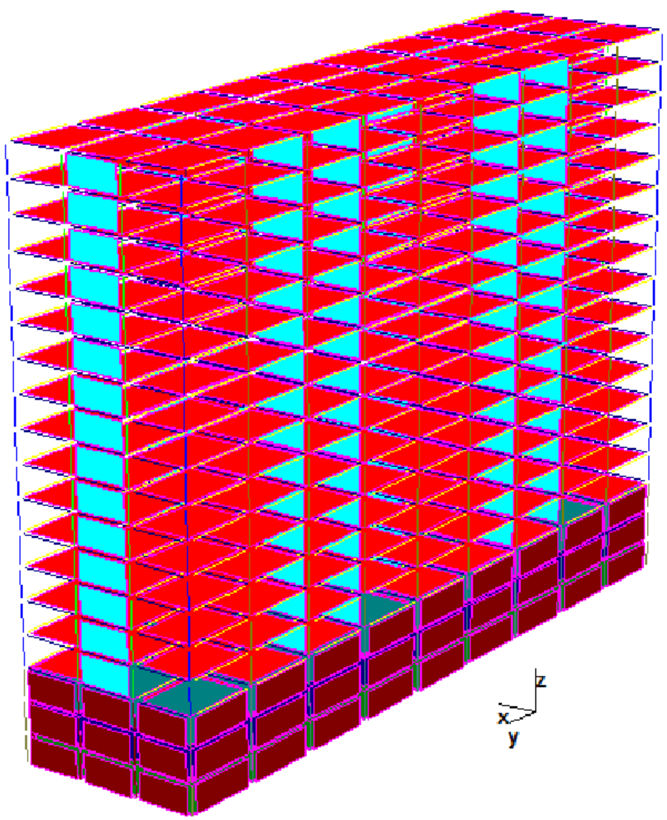
SSSI Effects for Buildings in Dense Urban Areas

Study for evaluating the SSI and SSSI effects for neighboring structures in dense urban areas including the effects of incoherency.

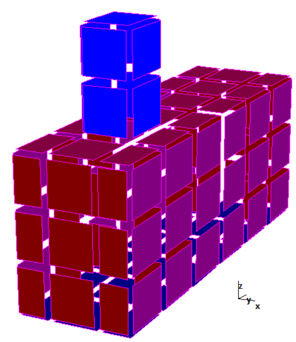
Subway Station (SS)



Multistory Building (MB)

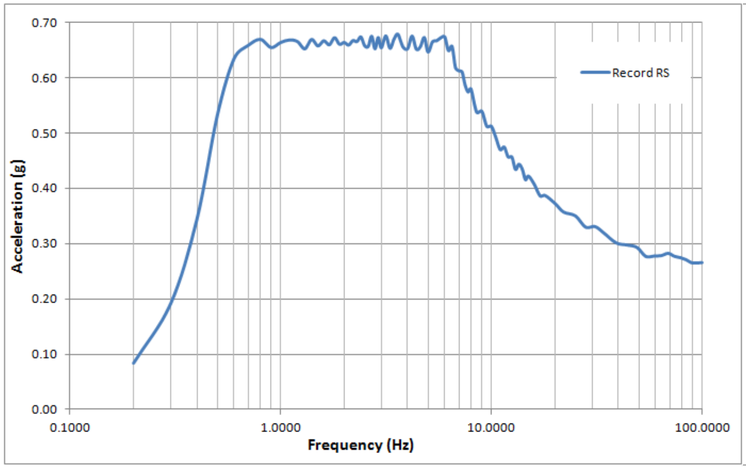


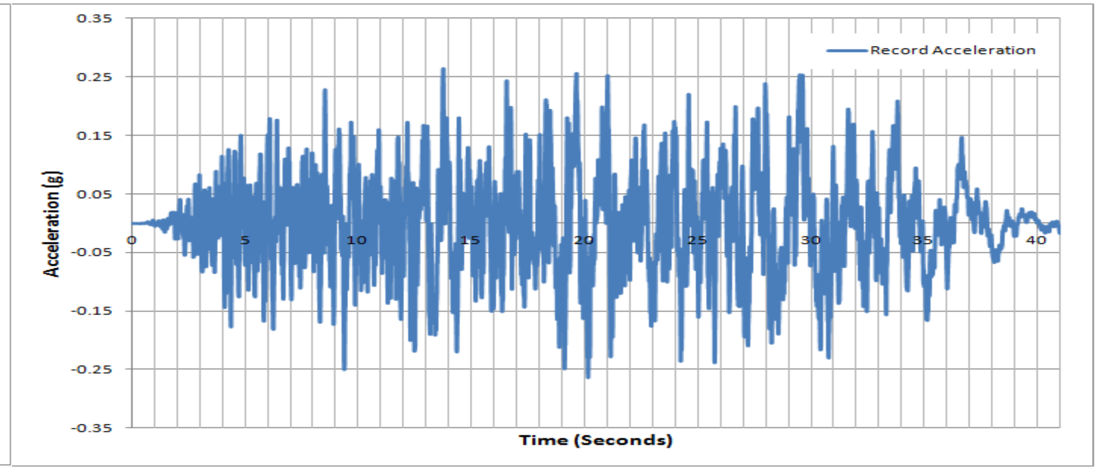
Church



Seismic SSI Analysis Inputs

Seismic Input Motion at Ground Surface:





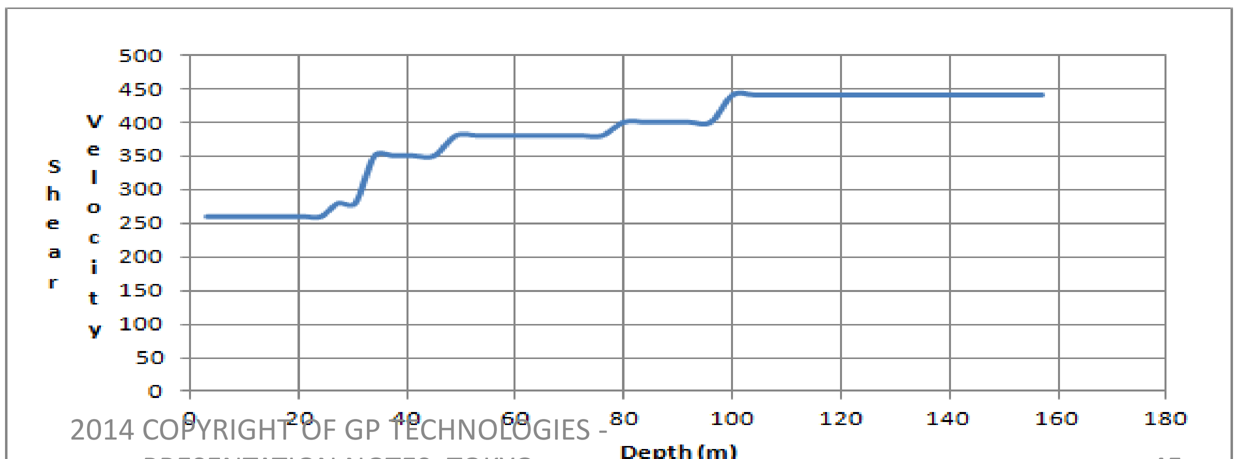
Design Spectrum (0.25g)

Simulated Acceleration Input (0.25g)

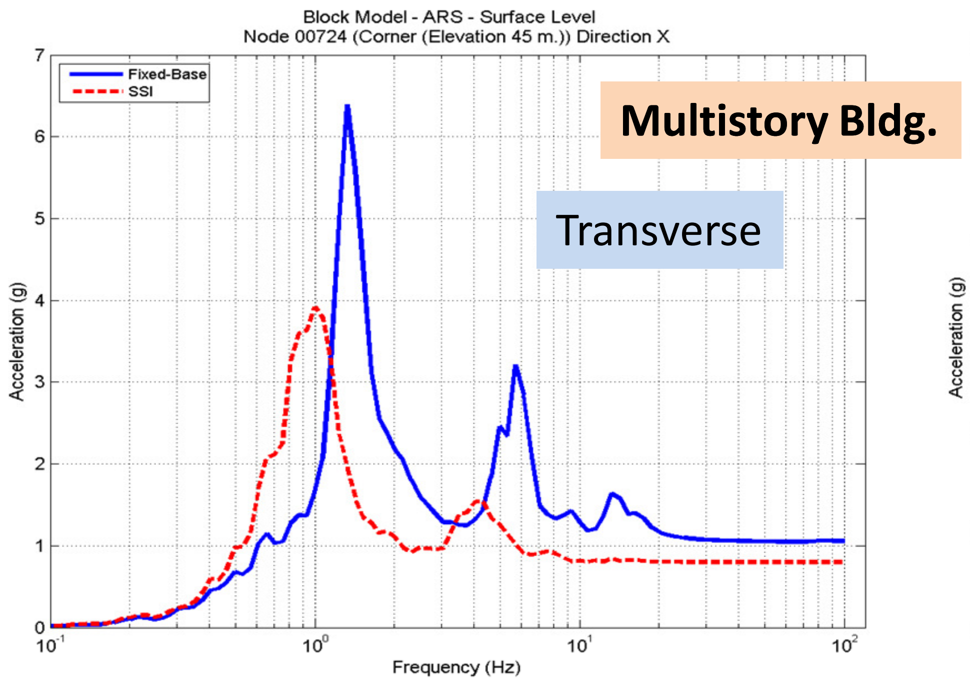
Incoherent Motion: 2005 Abrahamson coherency model, with wave passage Va=1,300m/s

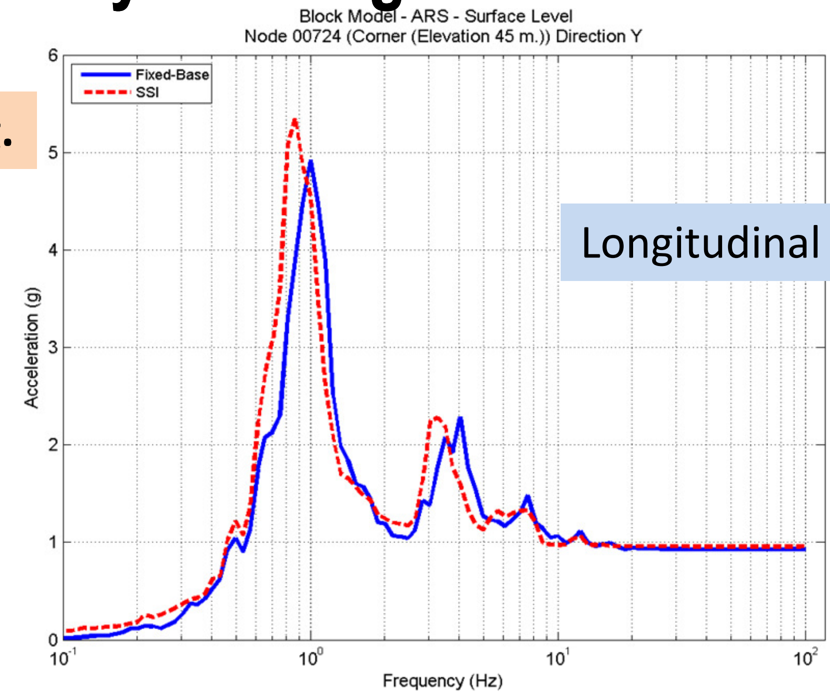
Soil Layering:

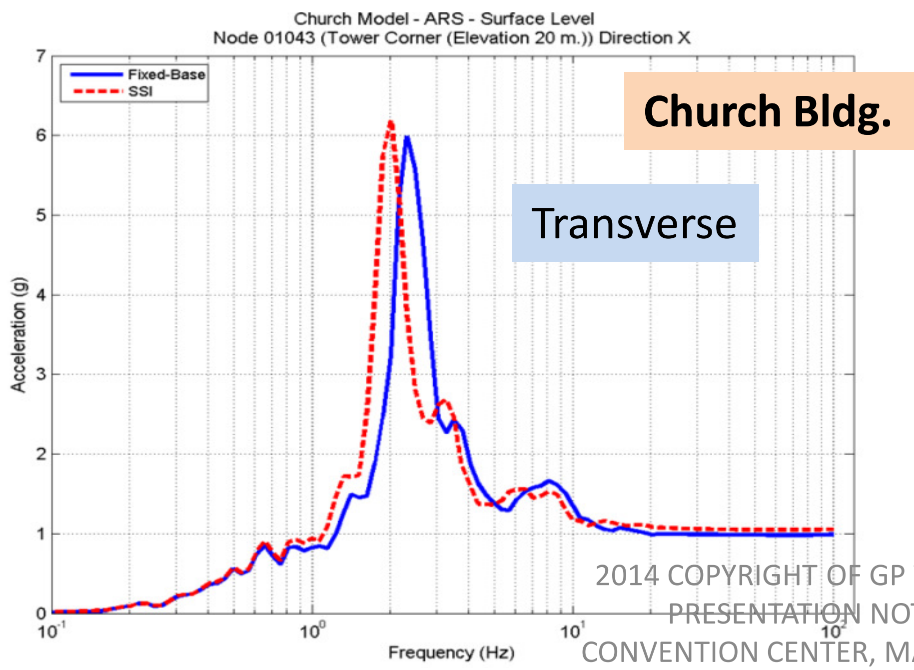
Deep soft soil deposit,
Vs = 260…..450m/s

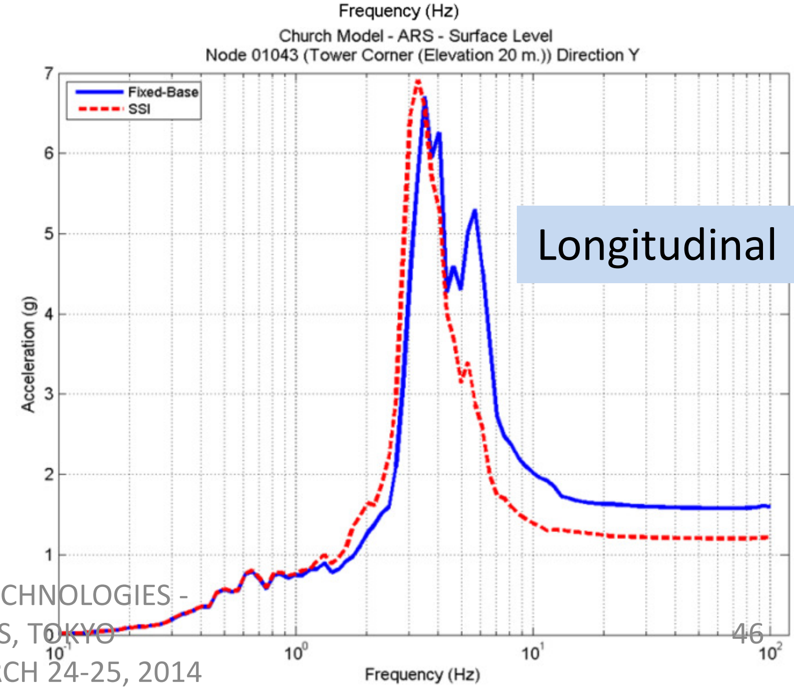


SSI Effects on ISRS for Multistory Building and Church

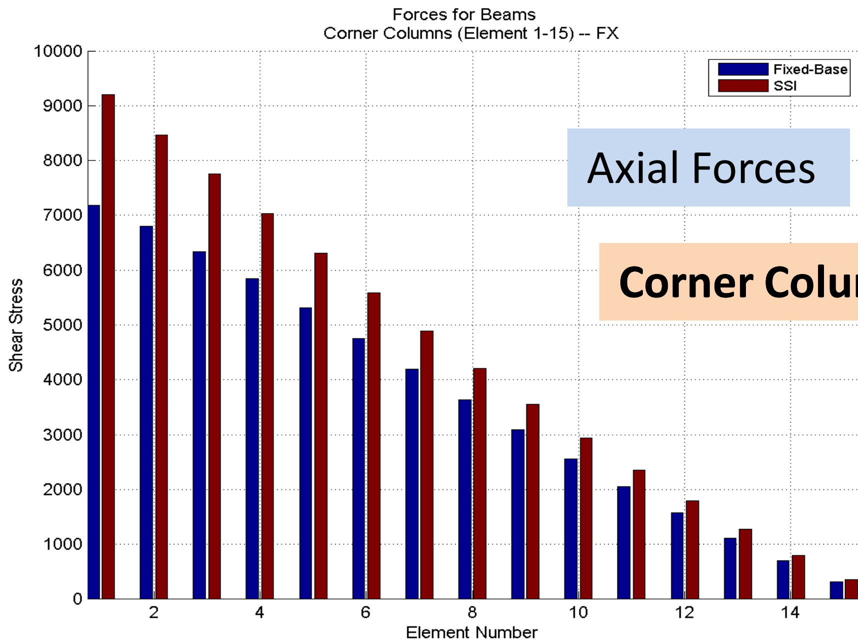


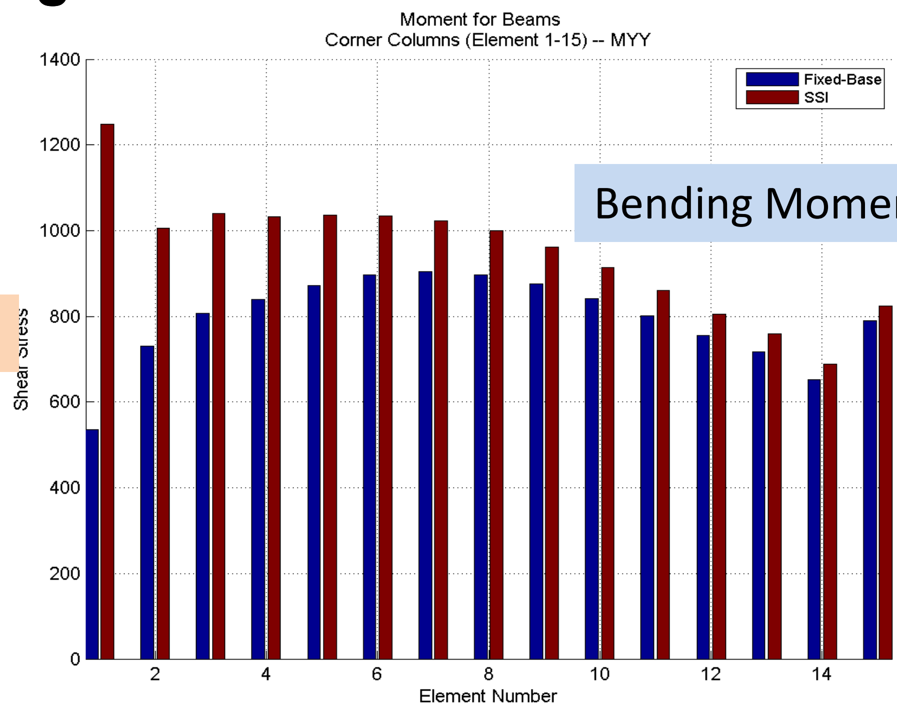


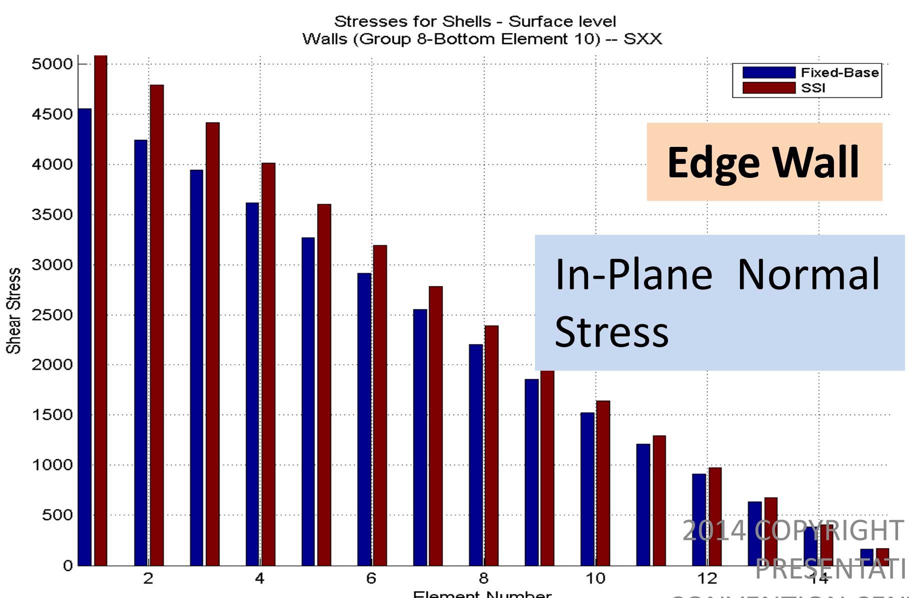


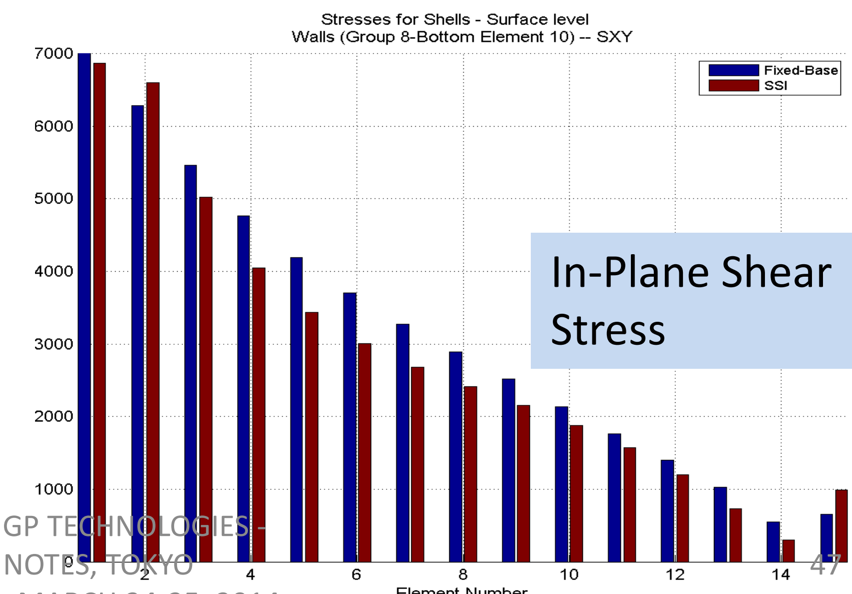


SSI Effects on Multistory Building Forces in Columns and Walls

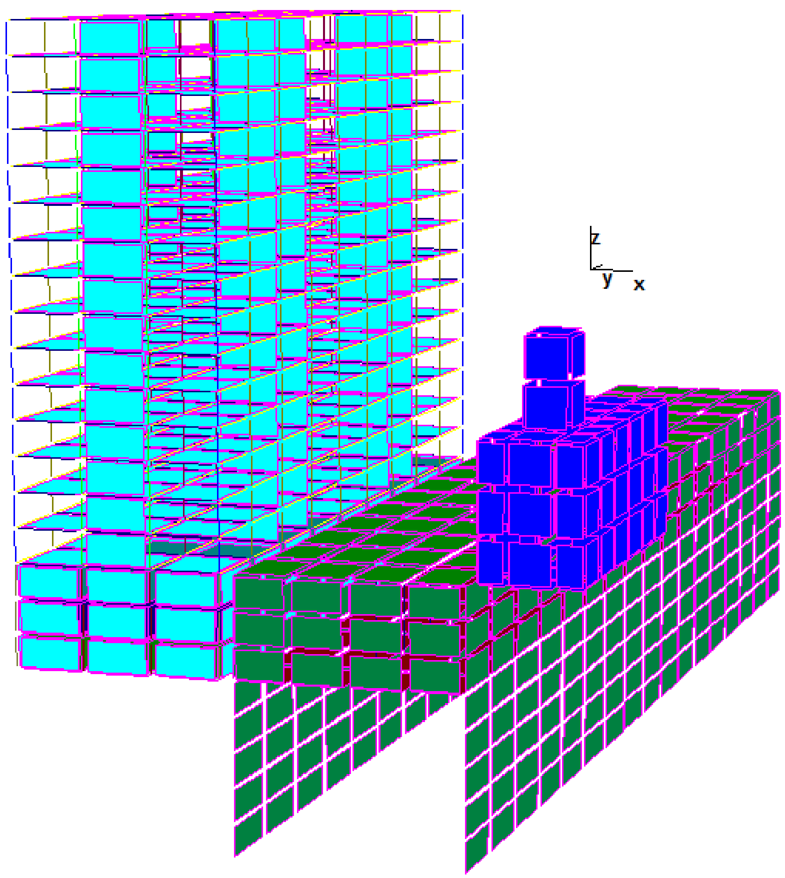




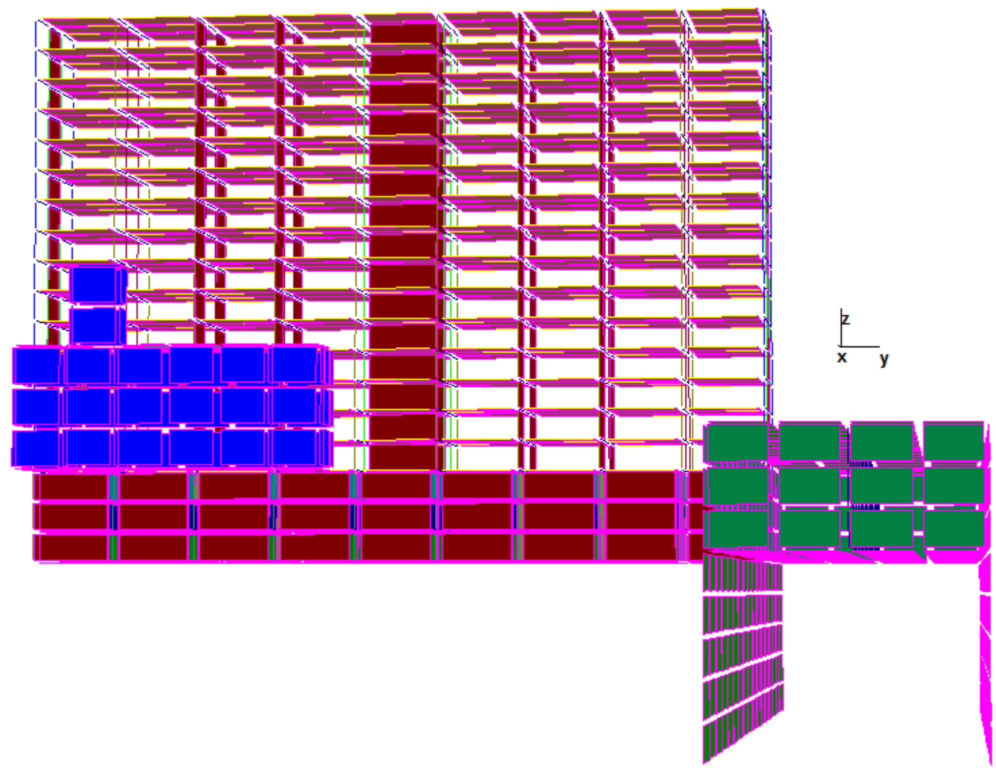




Two Different Layout Scenarios for SSSI Models

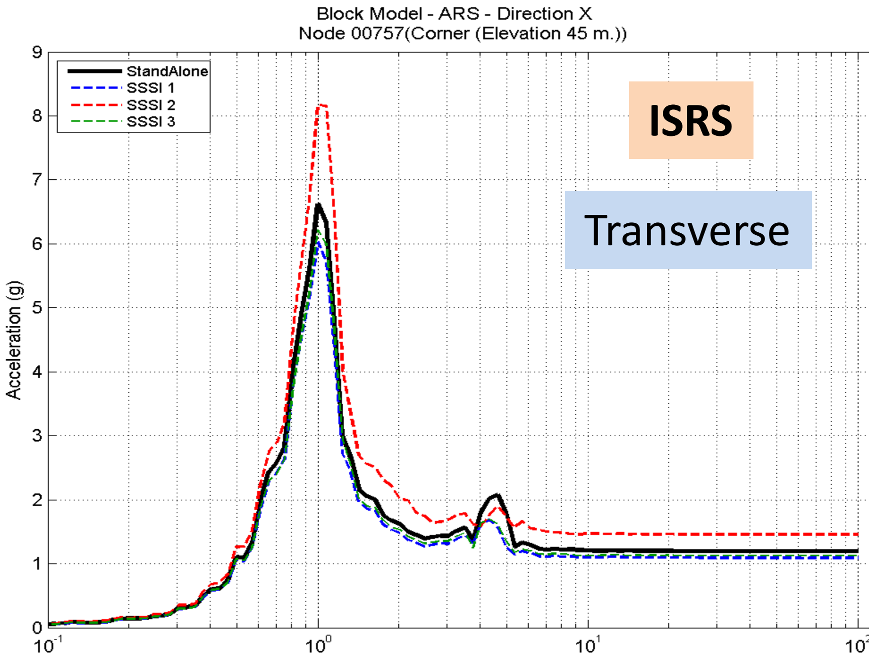


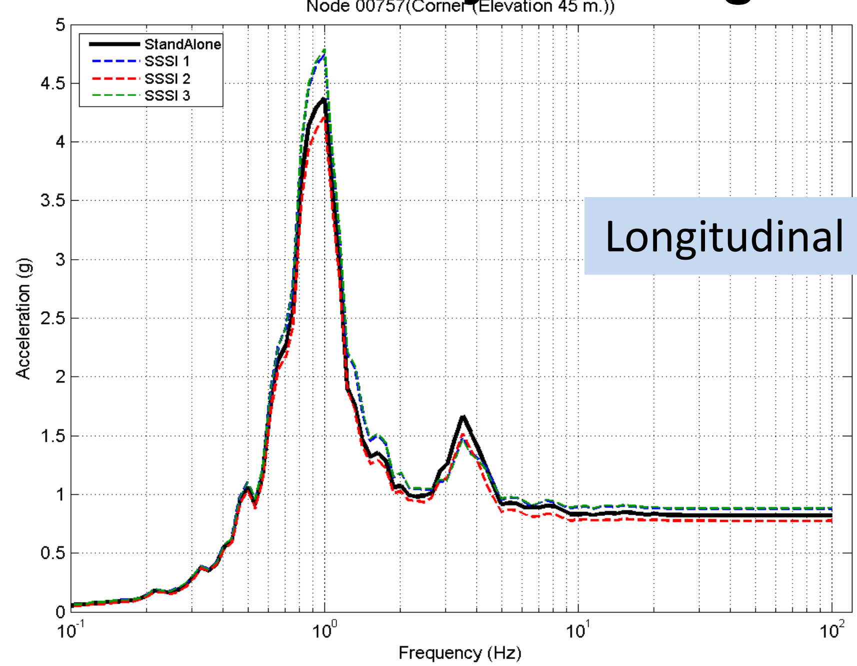
SSSI Model 2
(Parallel MB and SS)

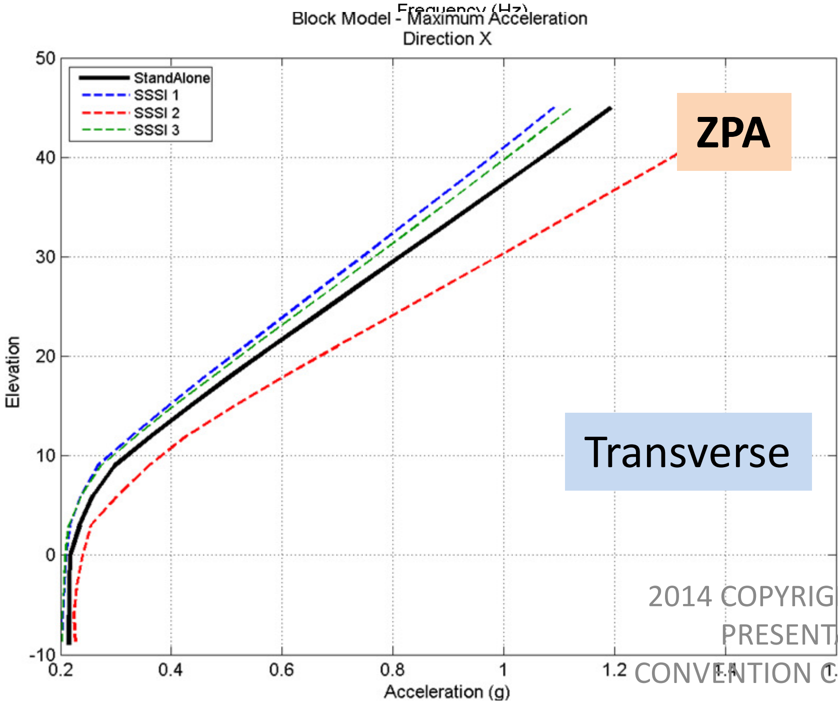


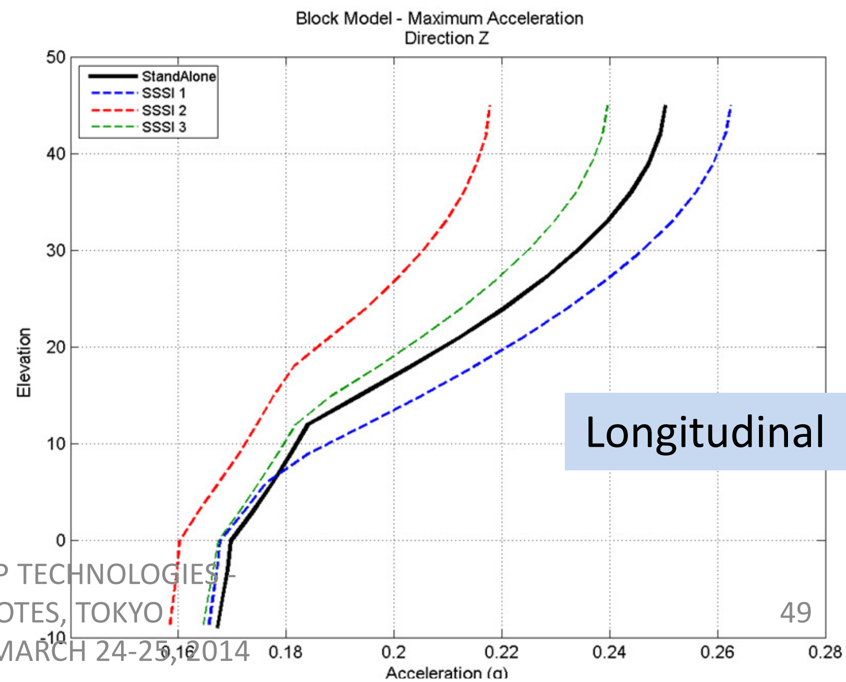
SSSI Model 3
(Perpendicular MB and SS)

SSSI Effects on ISRS and ZPA for Multistory Building

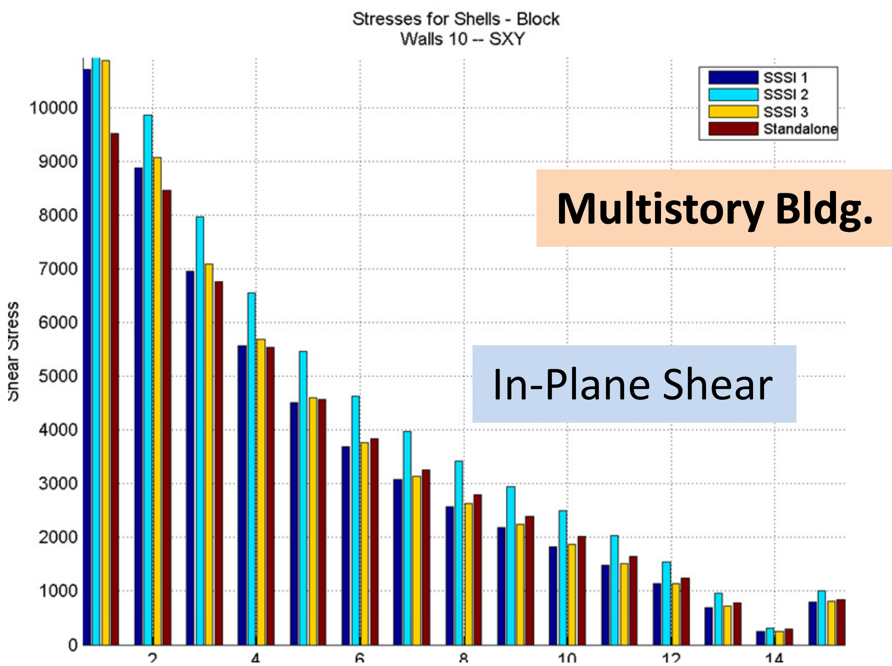


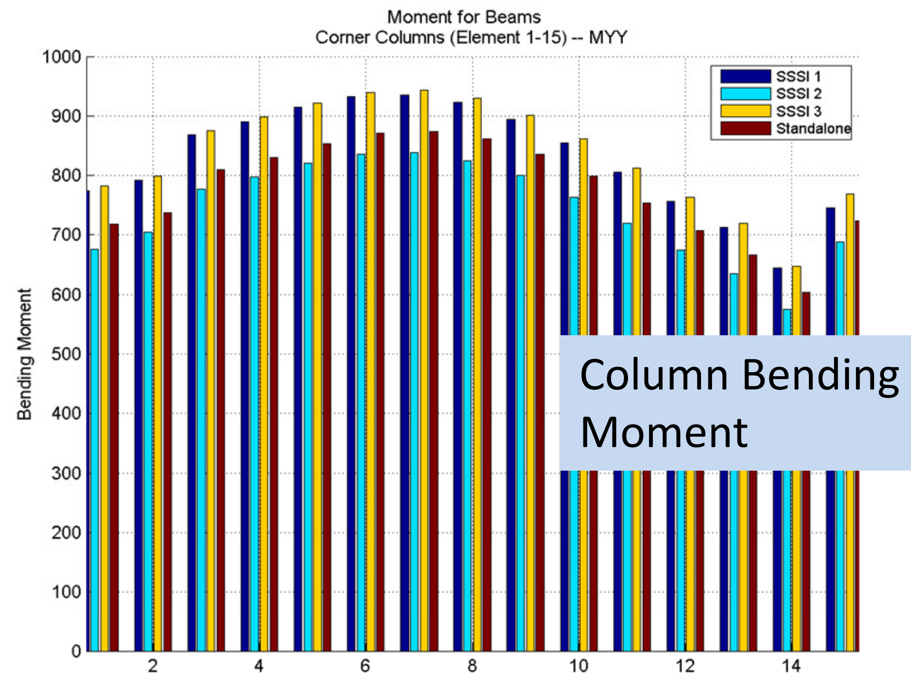


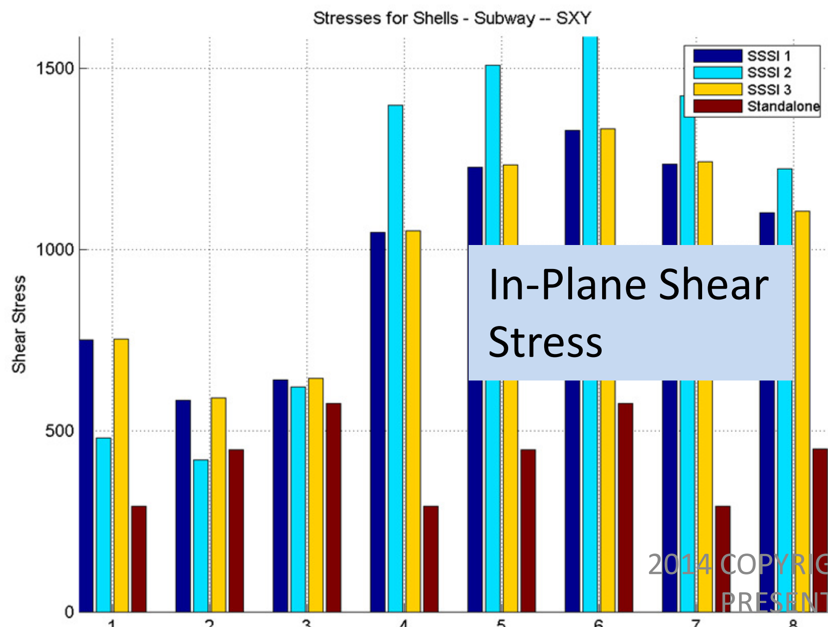


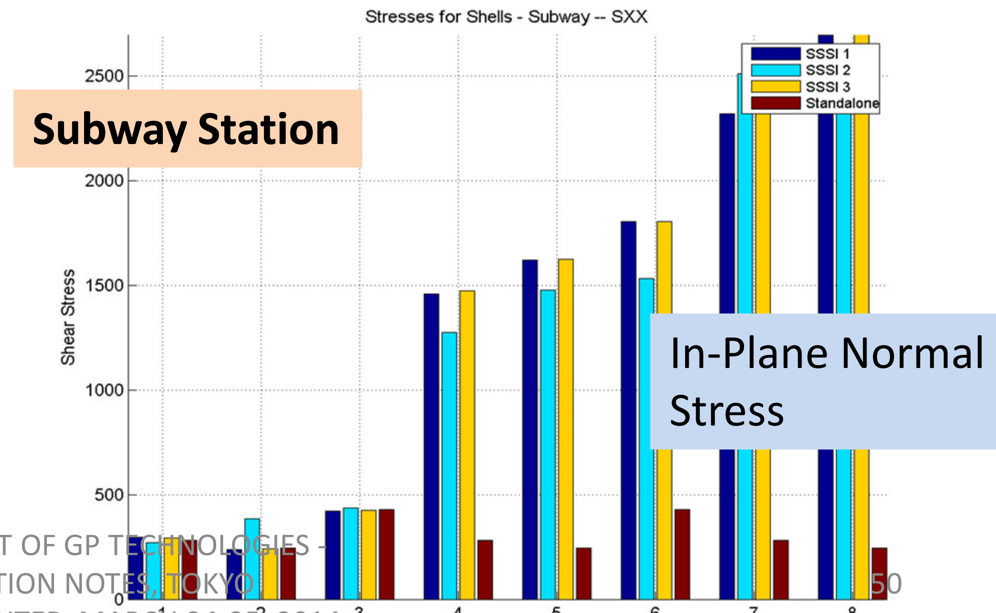


SSSI Effects on Structural Forces/Stresses in MB and SS

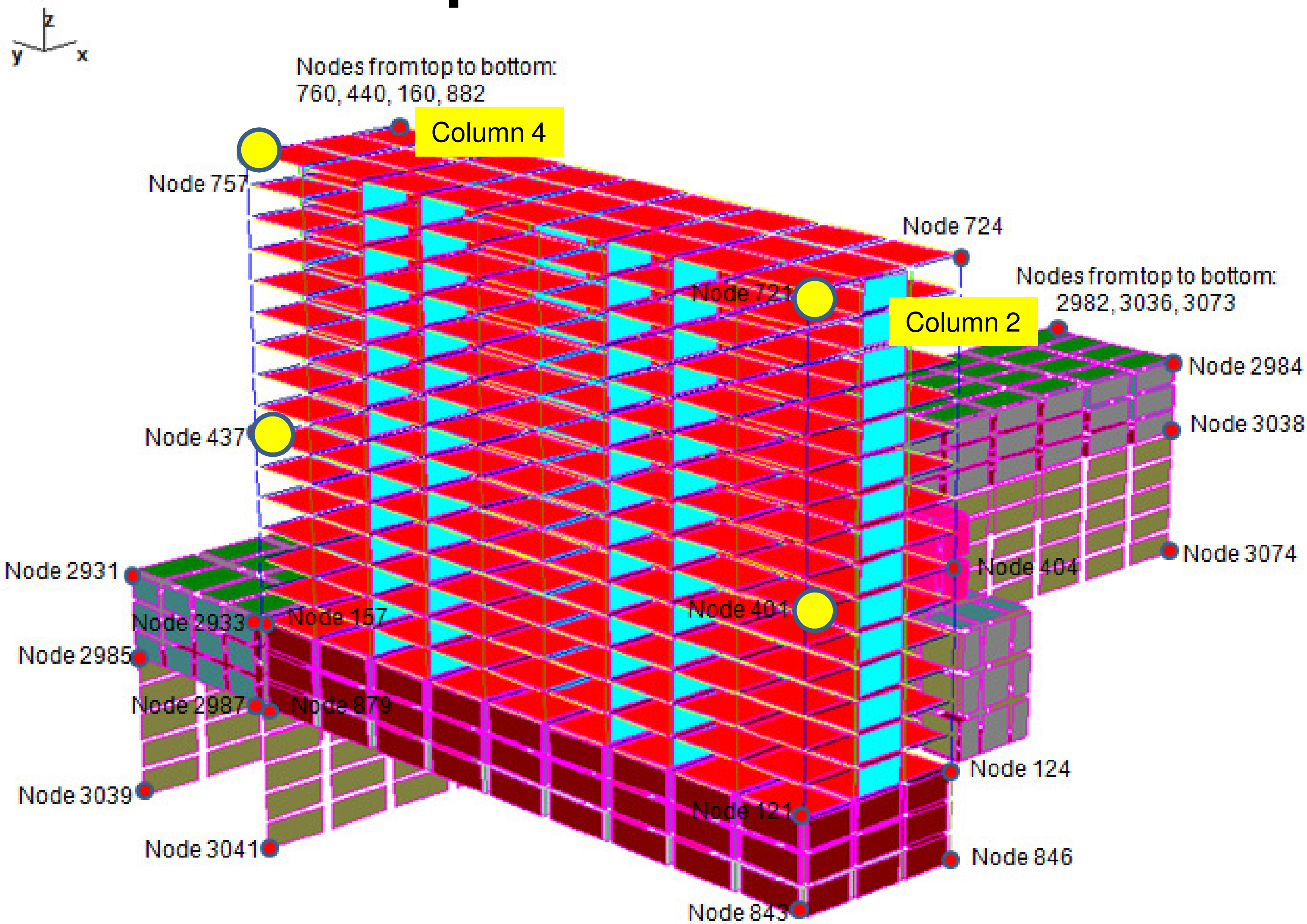




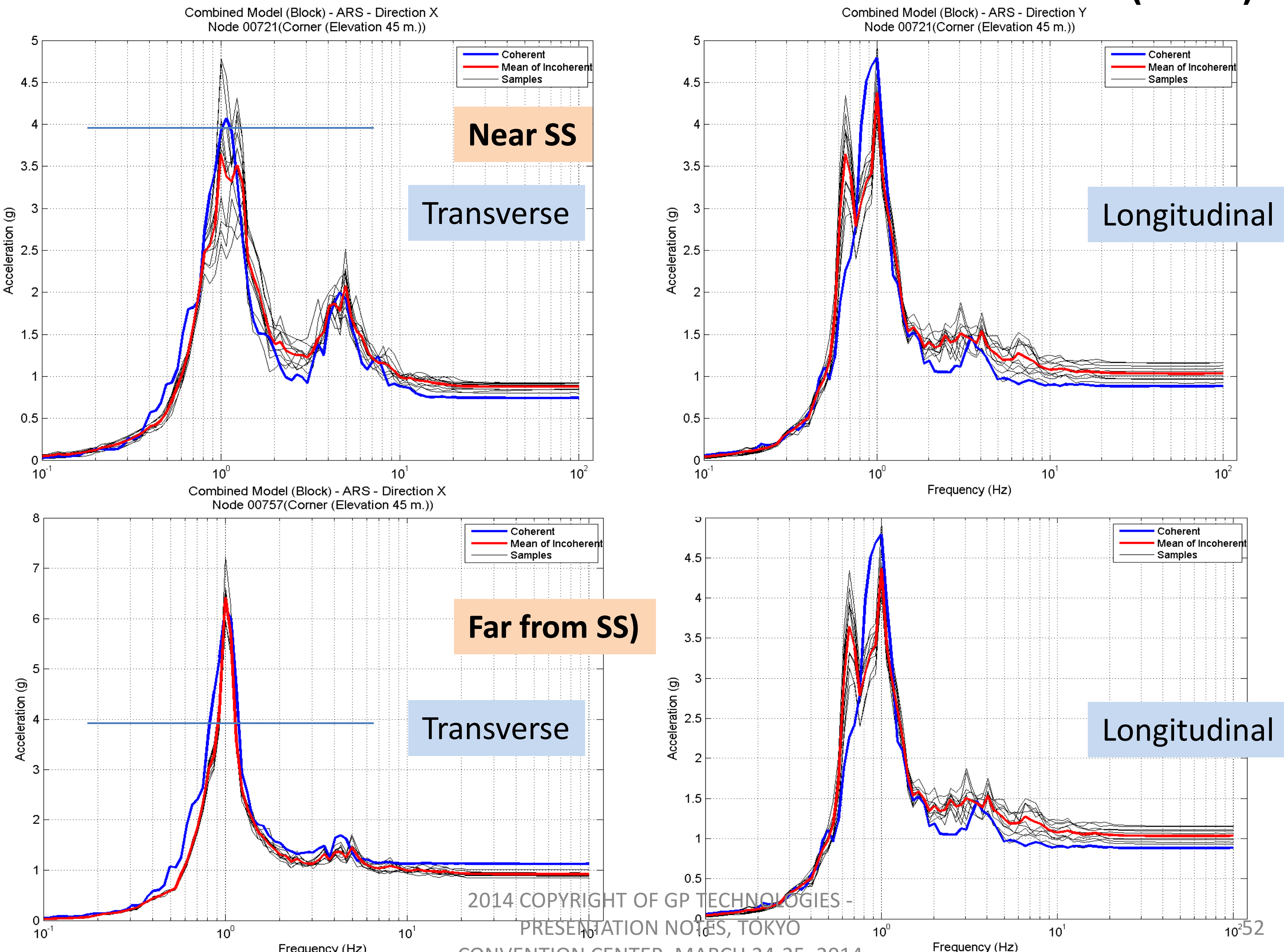




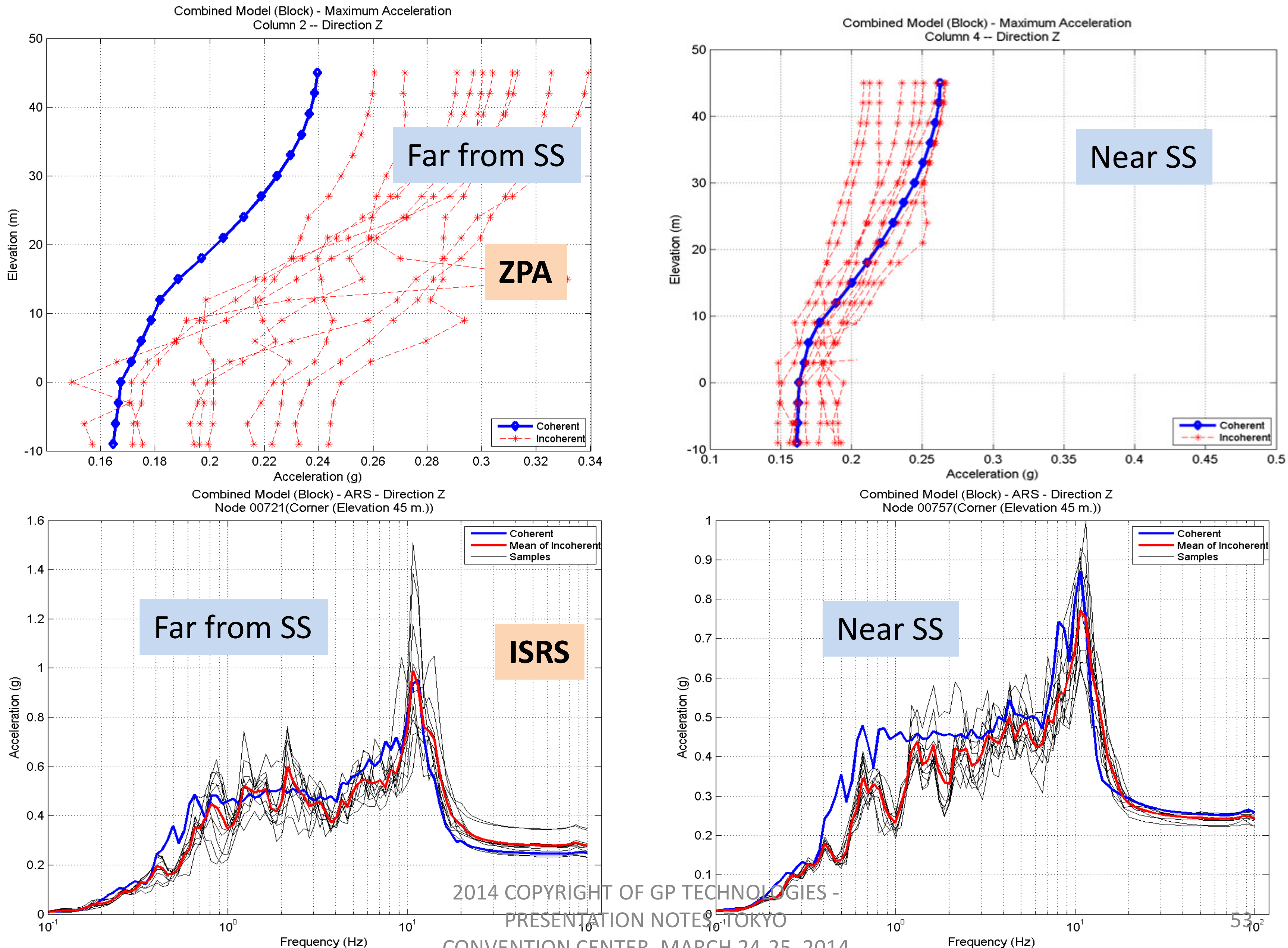
SSSI Response Location for MB



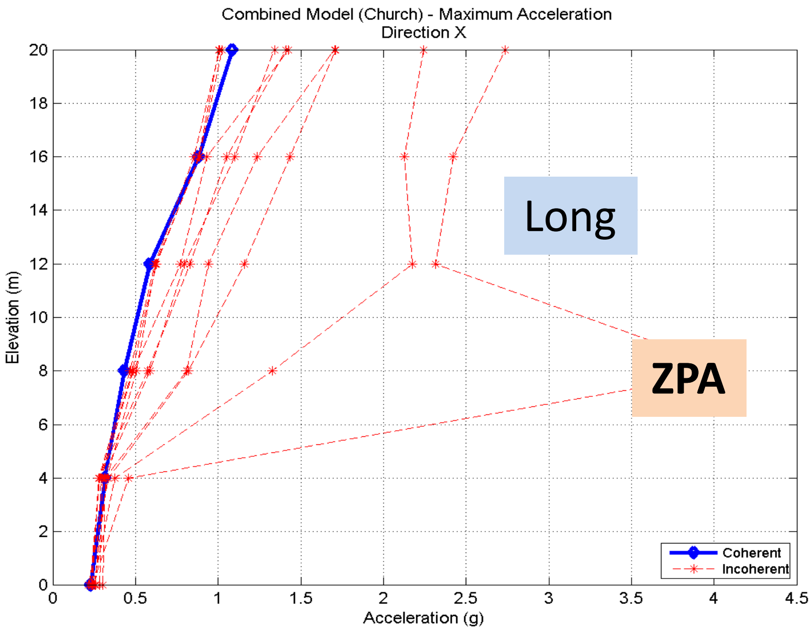
Incoherent SSSI Effects on Horizontal ISRS for MB (Roof)

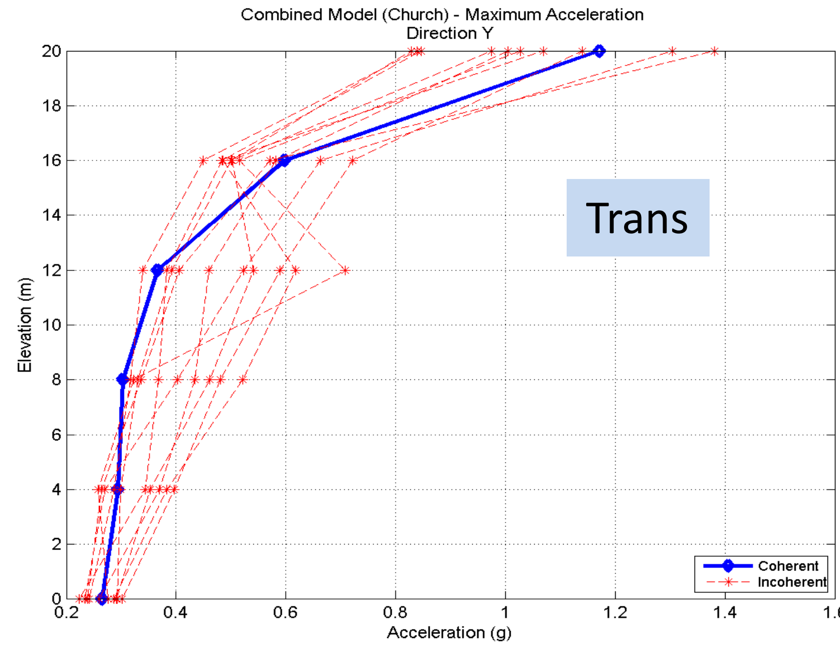


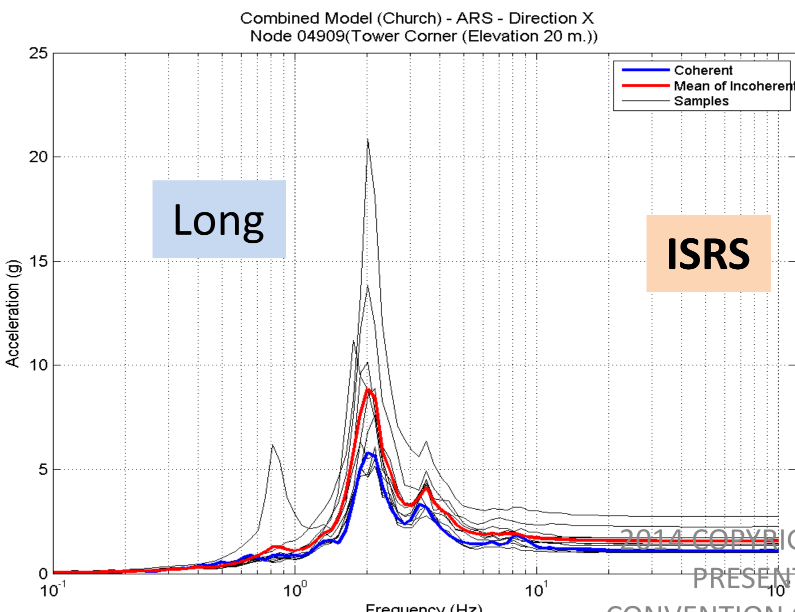
Incoherent SSSI Effects on Vertical ISRS and ZPA for MB (Roof)

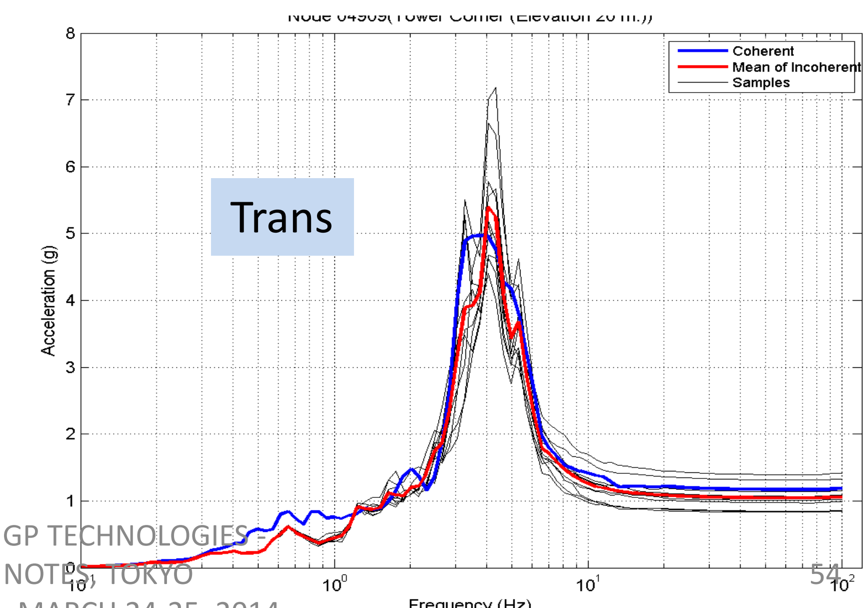


Incoherent SSSI Effects on Horizontal ISRS and ZPA for C (Roof)

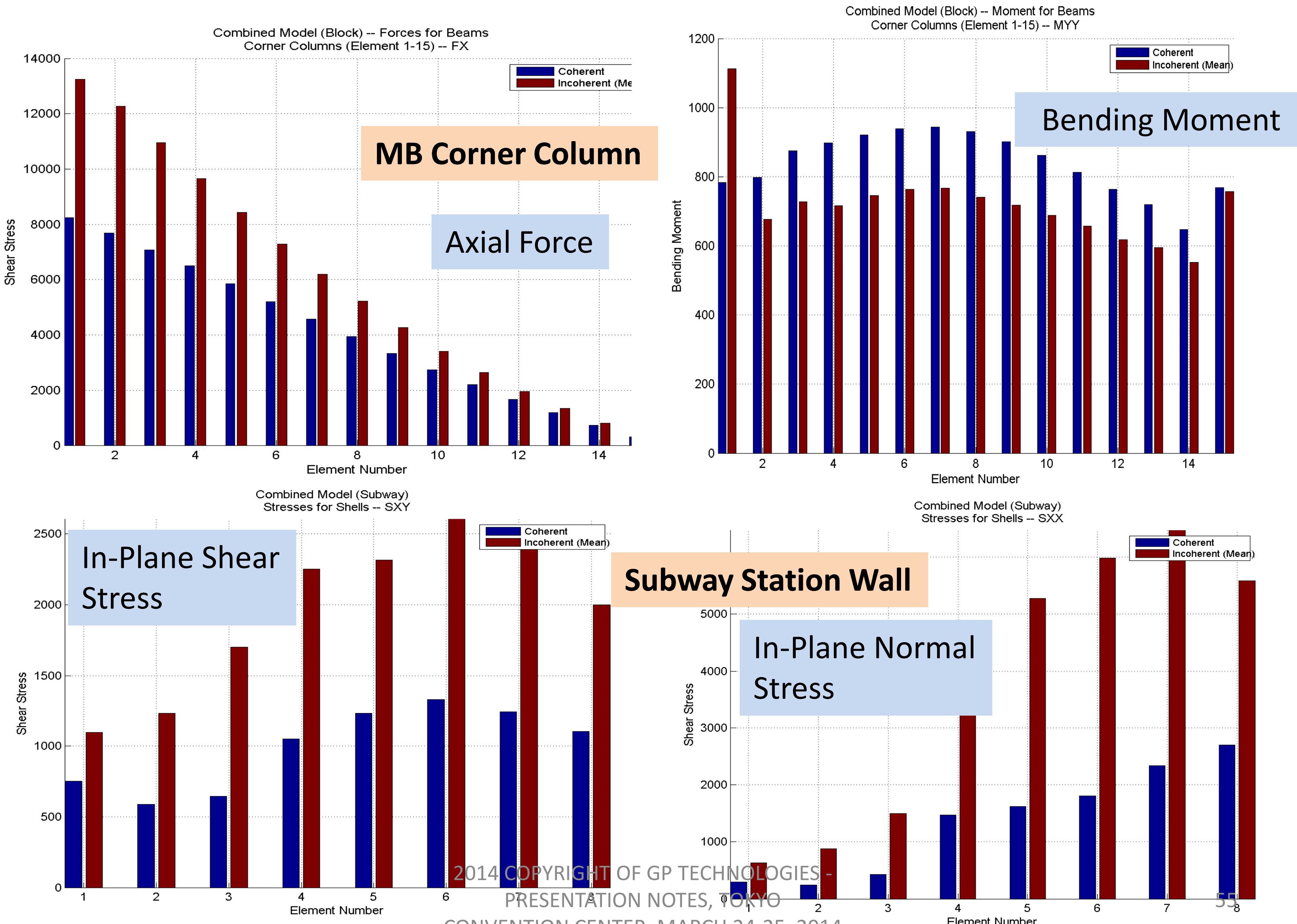








SSSI Effects on Structural Forces/Stresses in MB and SS



SSSI Effects for Buildings in Dense Urban Areas

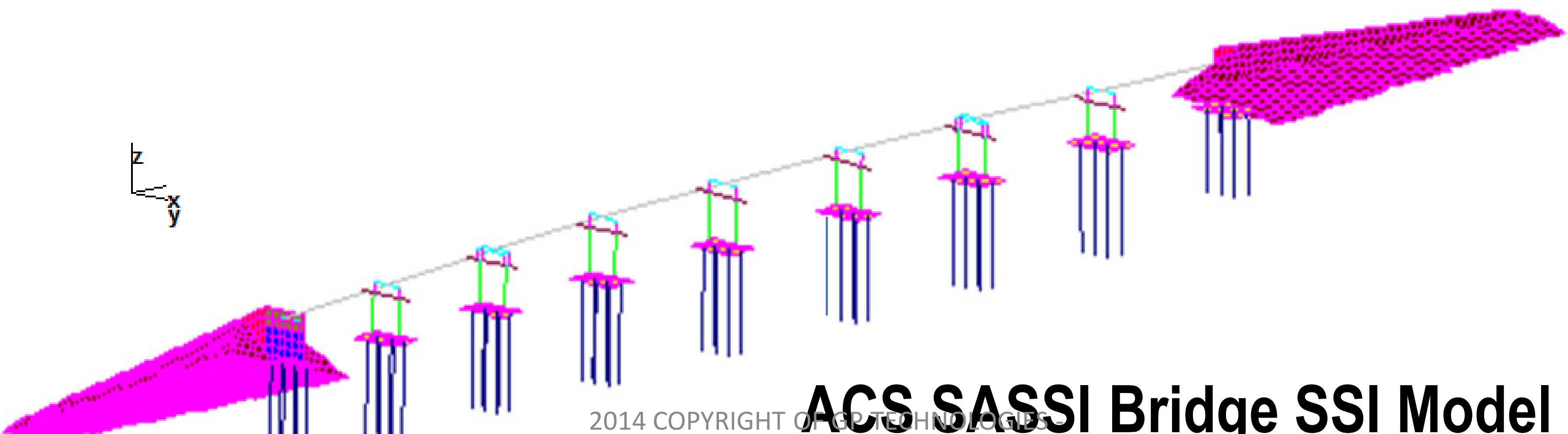
This study shows that for dense urban areas where buildings are close to each other, the SSSI effects could be quite large, between 10% to 500% depending on the type of building.

It should be noted that the SSSI effects are highly amplified due to motion spatial variation in horizontal direction, i.e. motion incoherency, that creates random differential phasing between neighbor building motions.

REMARK:

It shows a serious deficiency of the current state-of-practice of seismic SSI analysis. Need to revise the requirements for seismic analysis in design codes. Need to use ACS SASSI V3.0 to capture these important SSI-related aspects that are typically ignored.

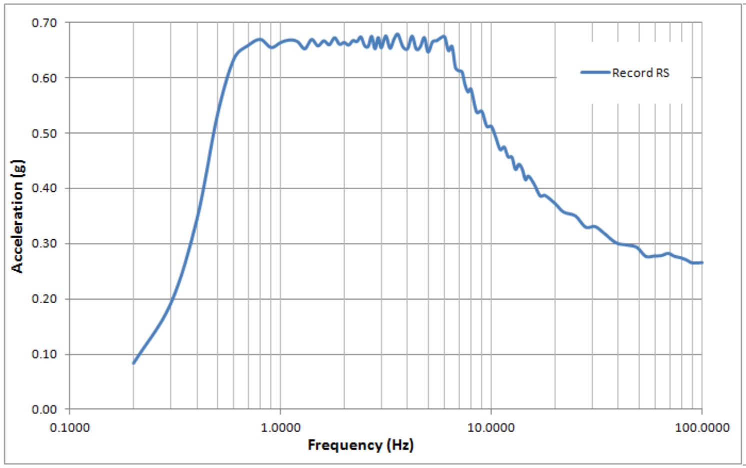
Seismic Analysis for 242m Highway Bridge



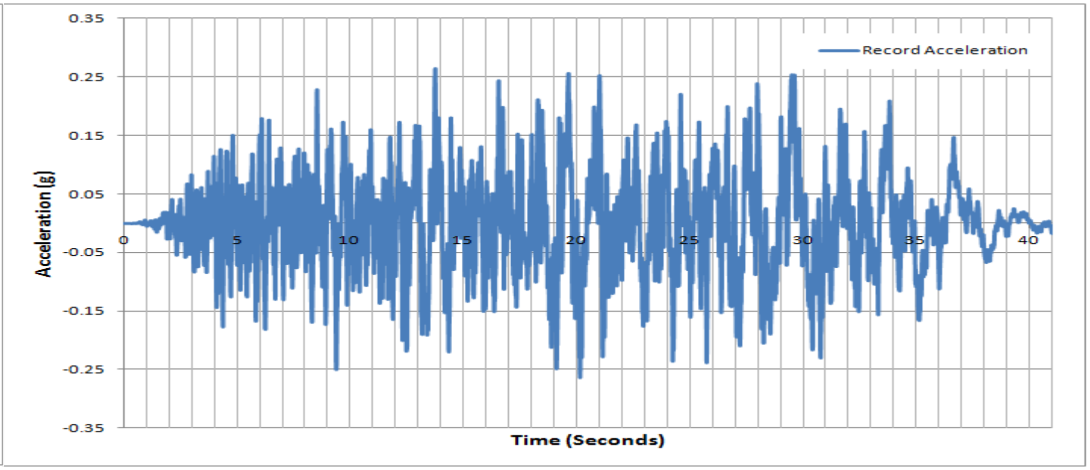
ACS SASSI Bridge SSI Model

Seismic SSI Analysis Inputs

Seismic Input Motion at Ground Surface:



Design Spectrum (0.25g)



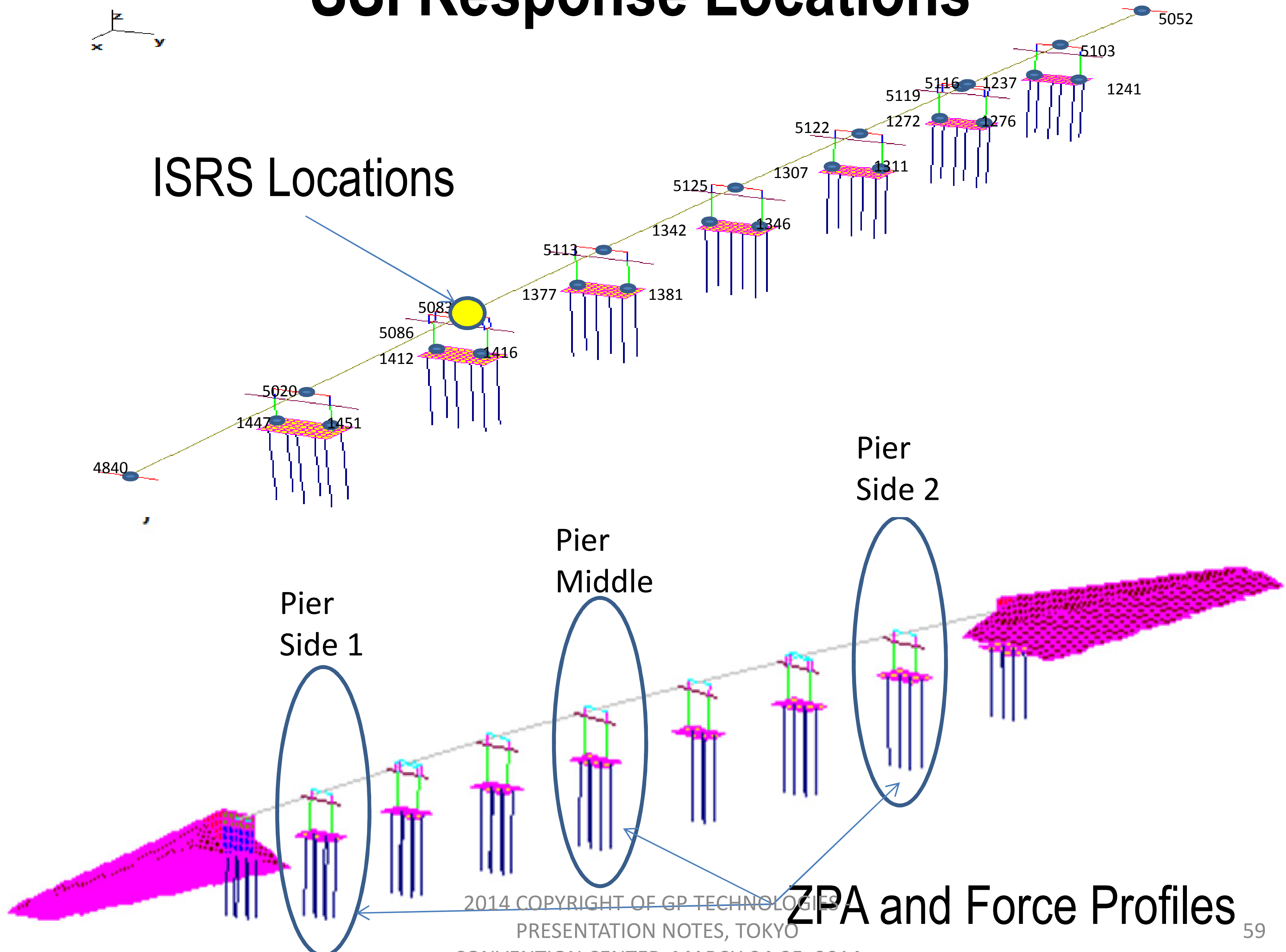
Simulated Acceleration Input (0.25g)

Incoherent Motion: 2005 Abrahamson coherency model, with wave passage Va=1,300m/s

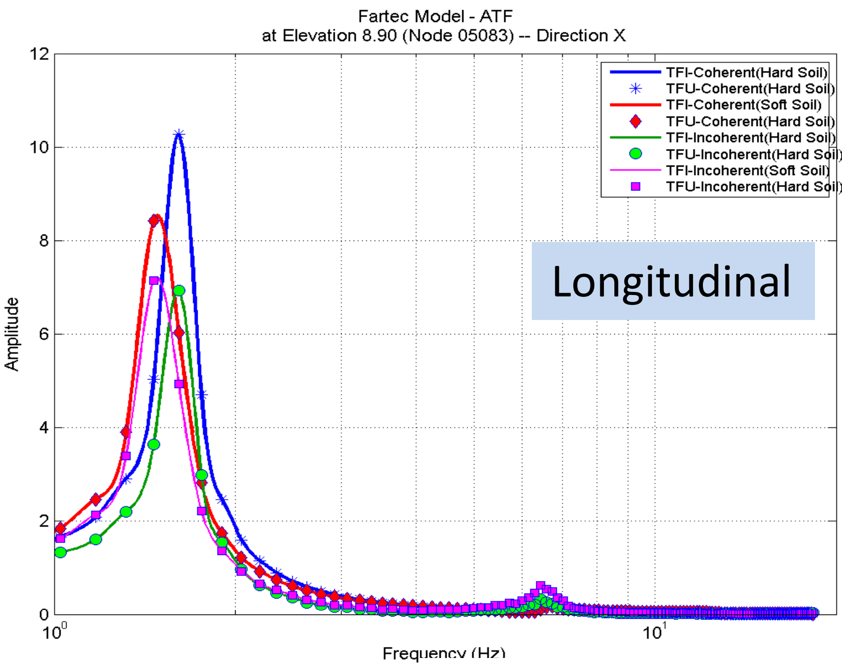
Soil Layering:

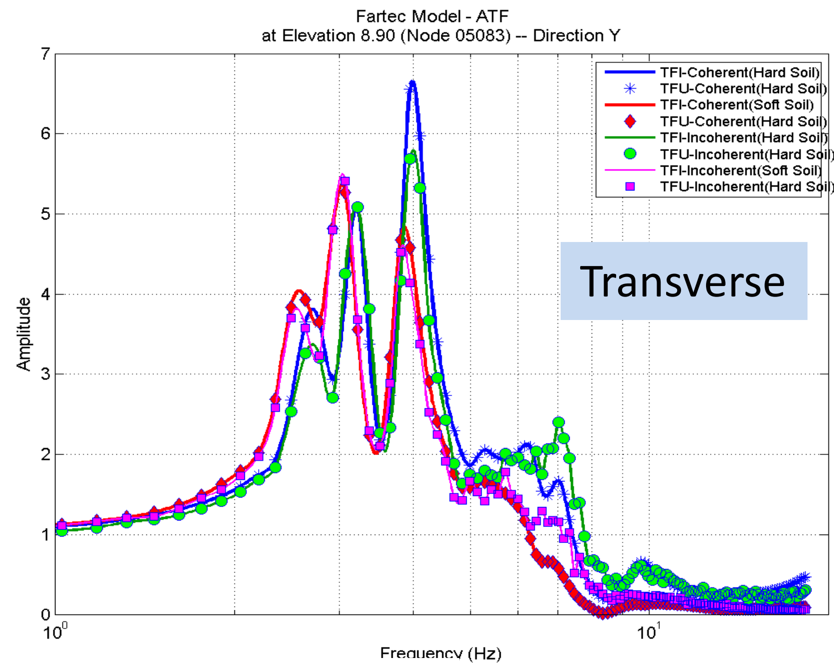
Hard Soil: Vs=1,300m/s, Uniform Profile
Soft Soil: Vs=200m/s, Uniform Profile

SSI Response Locations

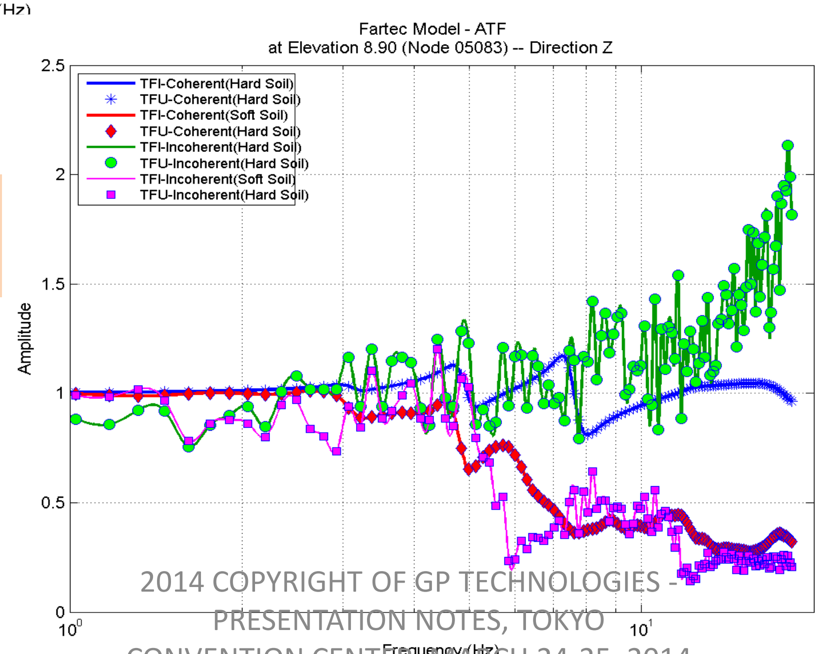


SSI Response Acceleration Transfer Functions



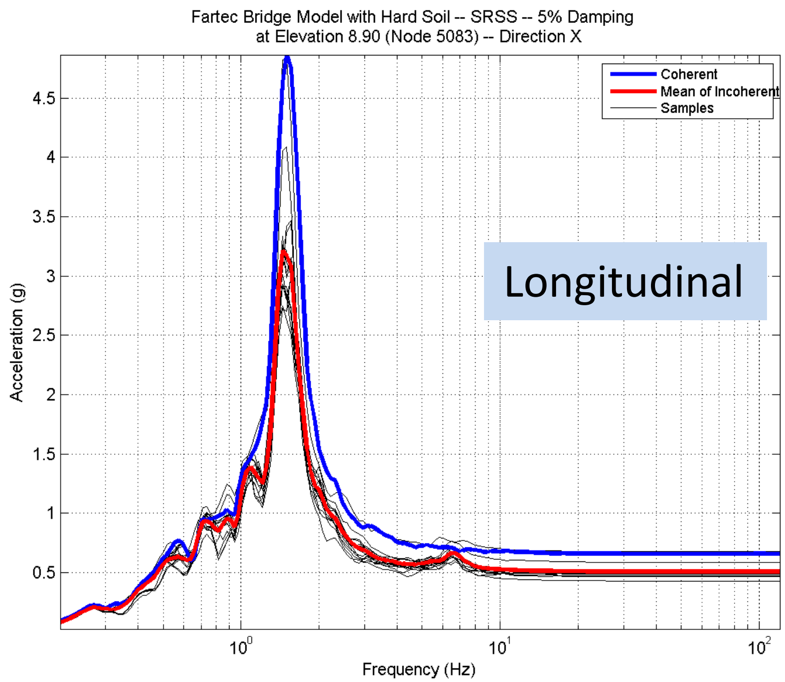


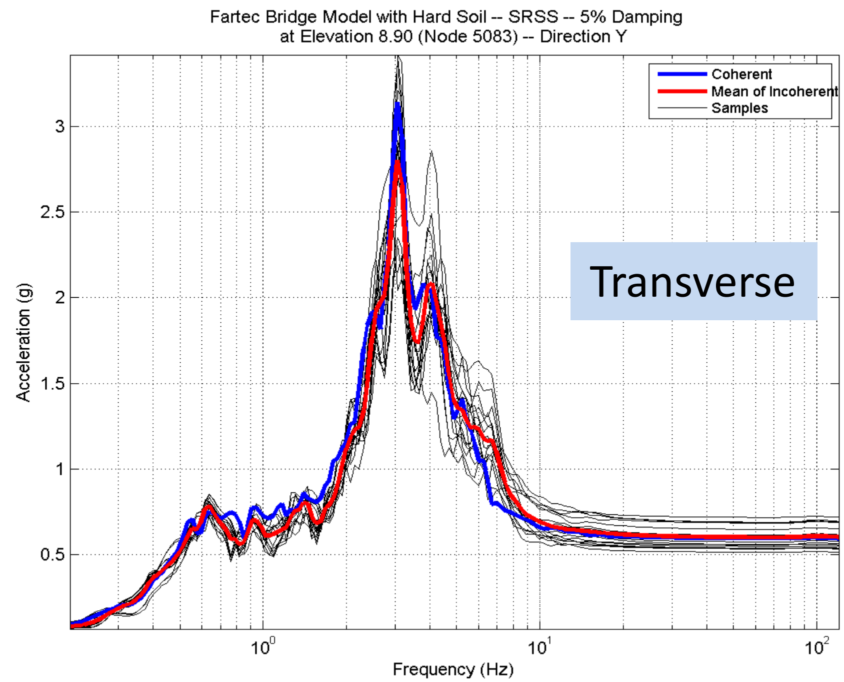
Node 5083



Vertical

SSI Response Acceleration Response Spectra





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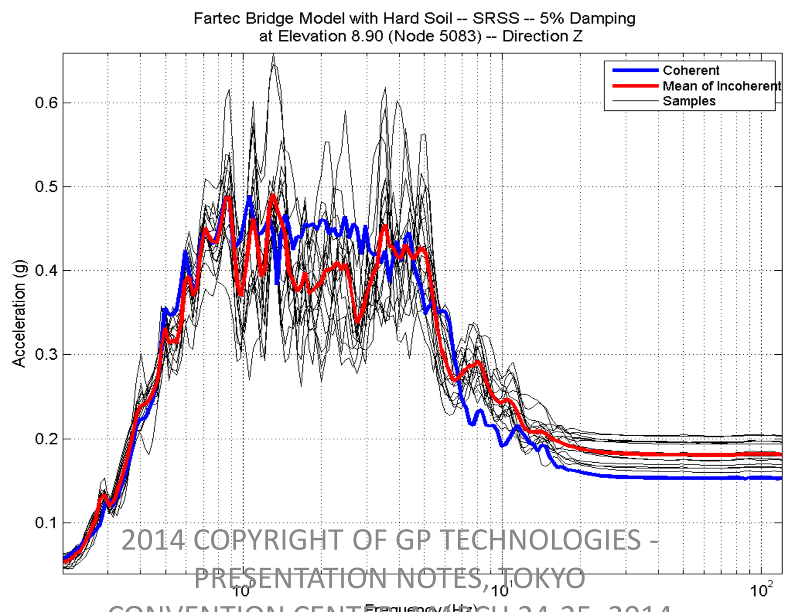
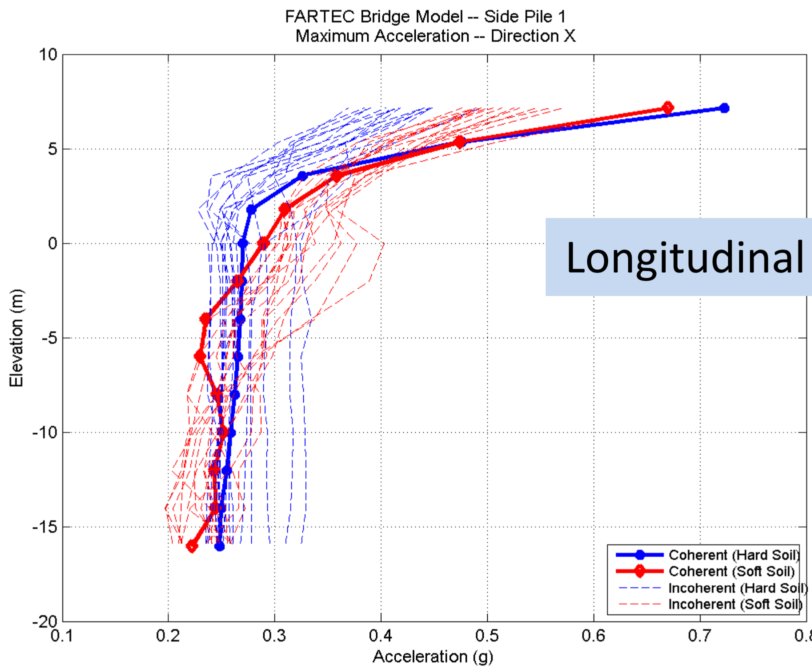
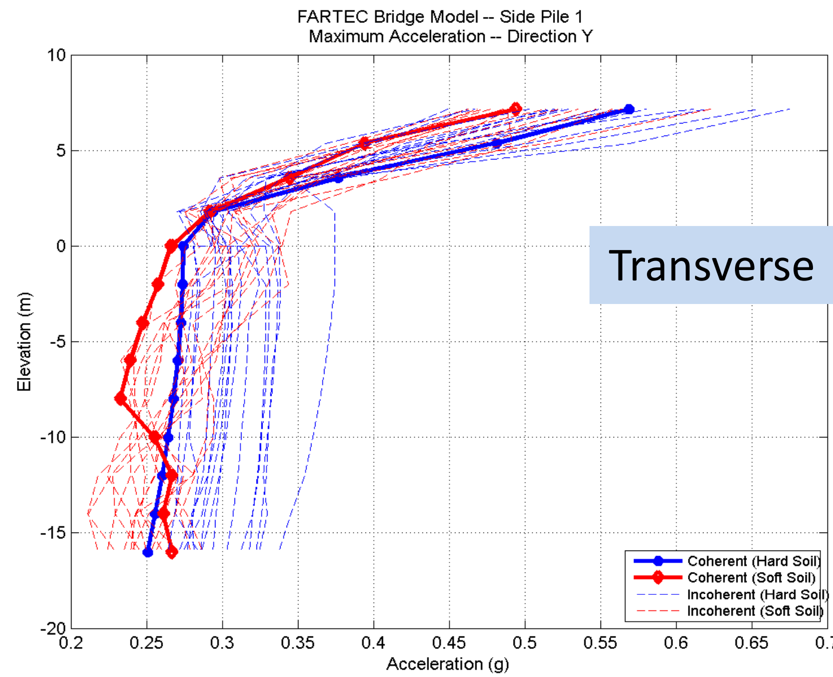


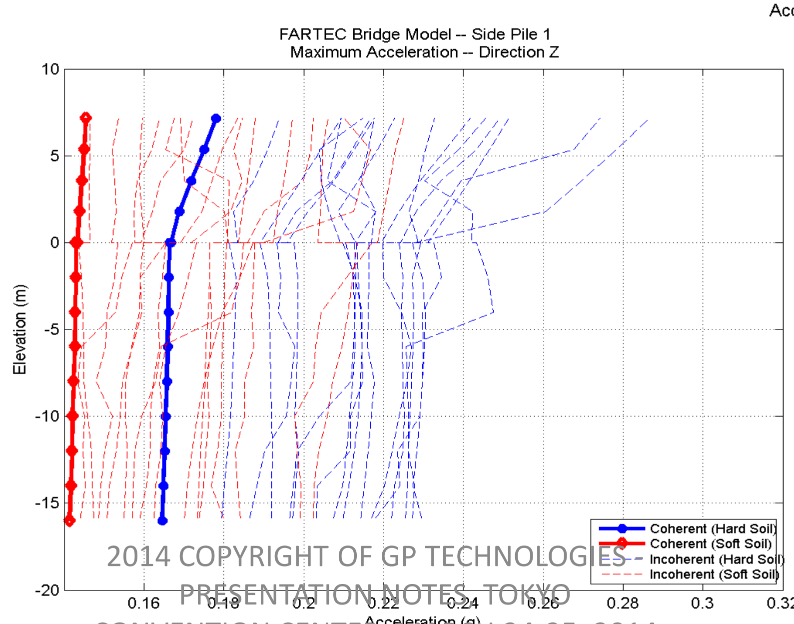
Vertical

SSI ZPA Profile at Pier Side 1



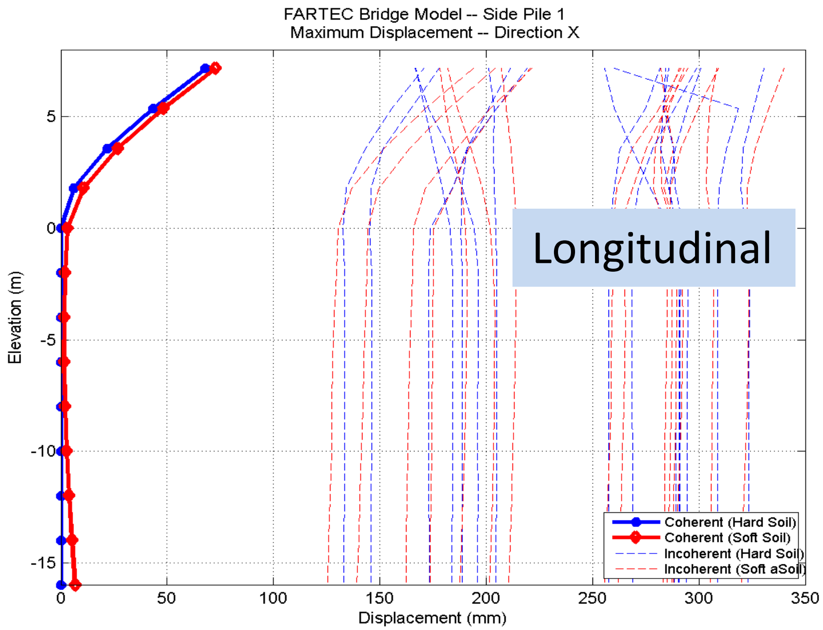


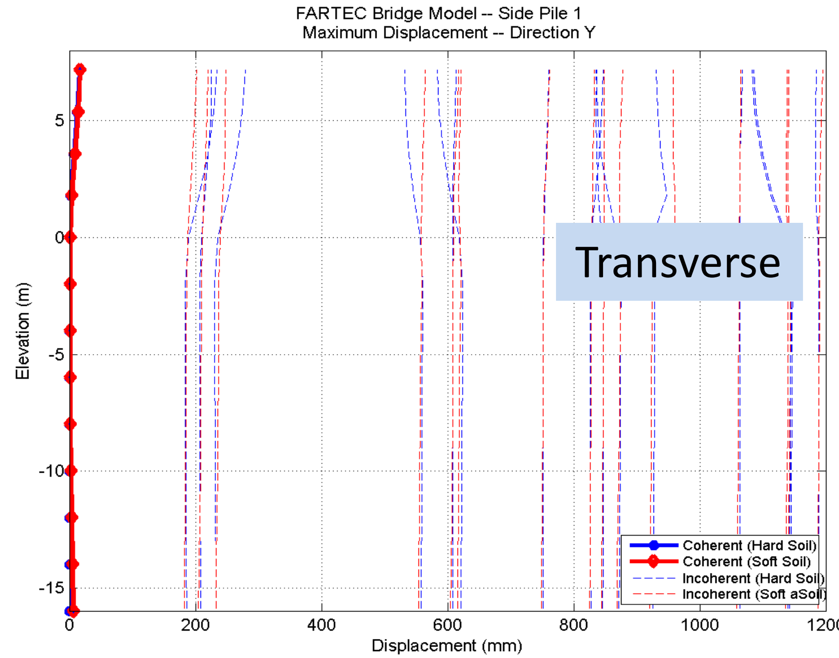
Pier Side 1



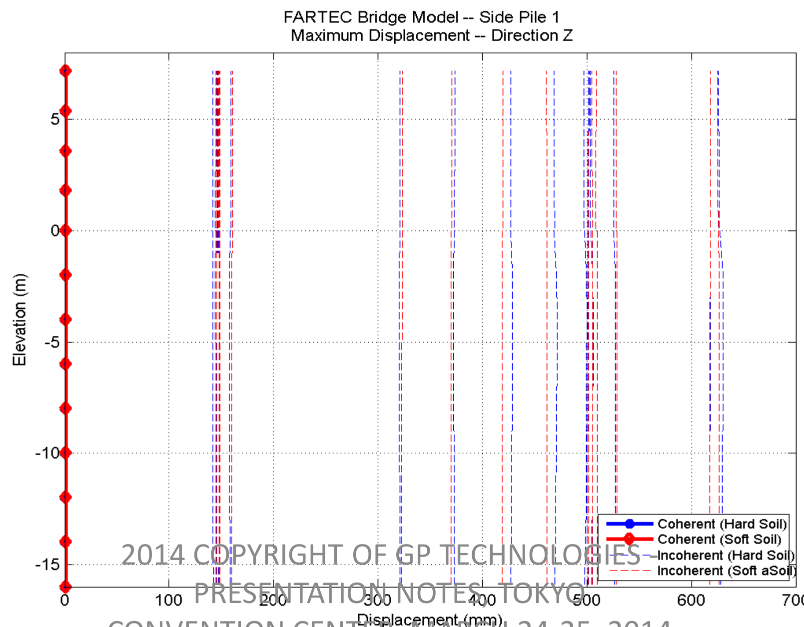
Vertical

SSI Maximum Displacement Profile at Pier Side 1



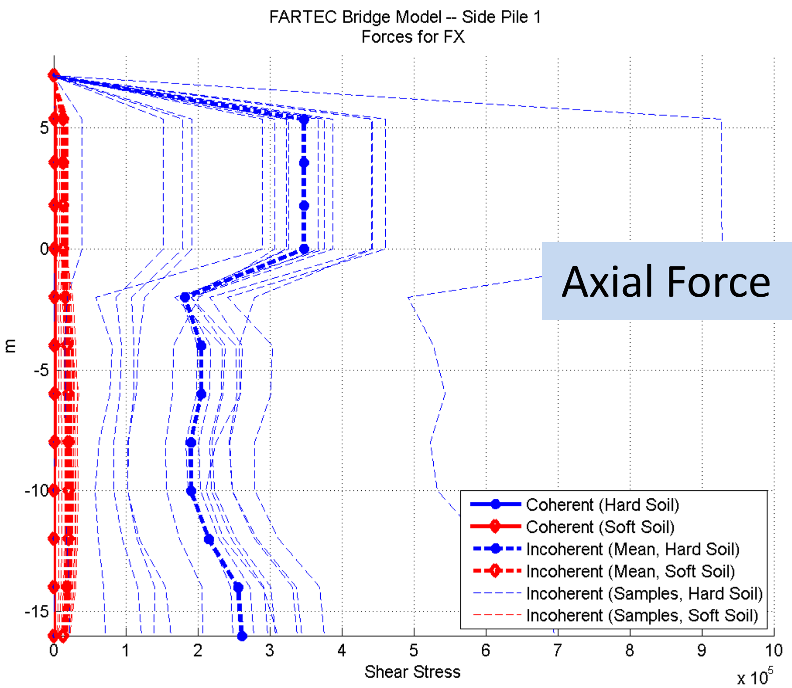


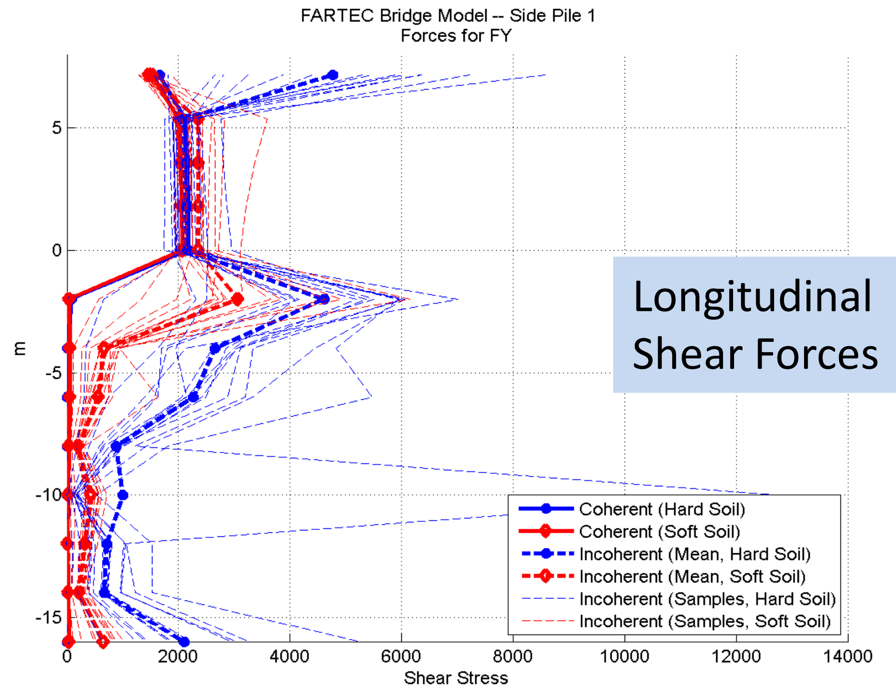
Pier Side 1



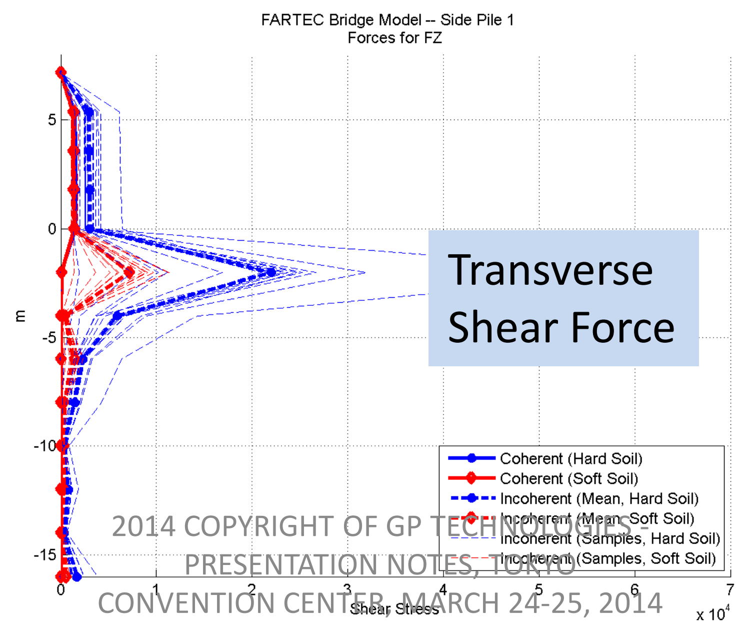
Vertical

SSI Response ZPA Profile at Pier Side 1

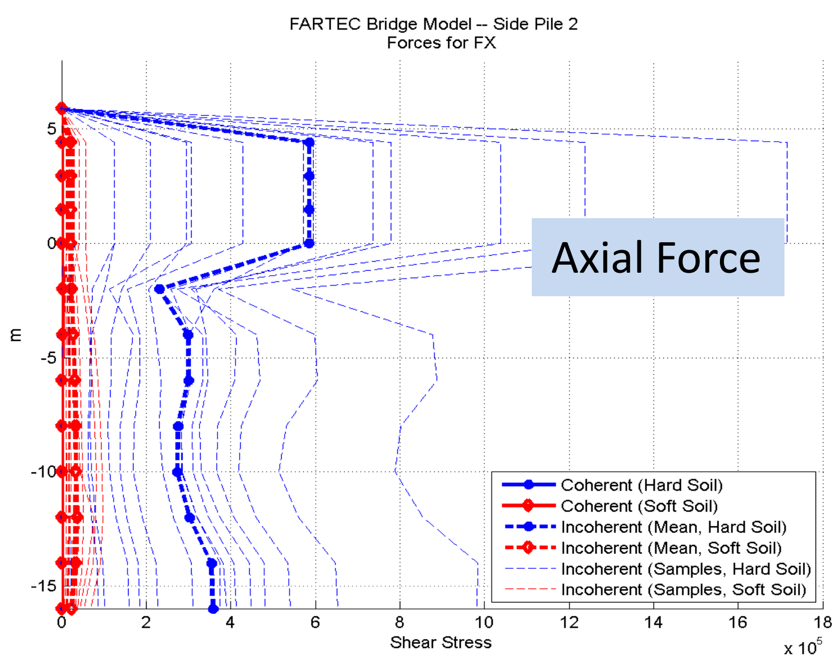


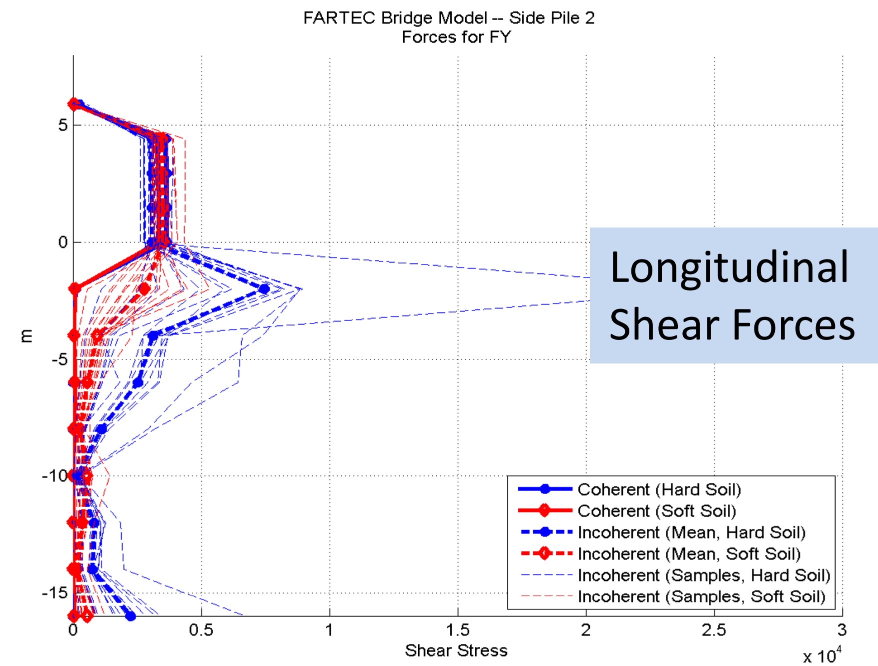


Pier Side 1

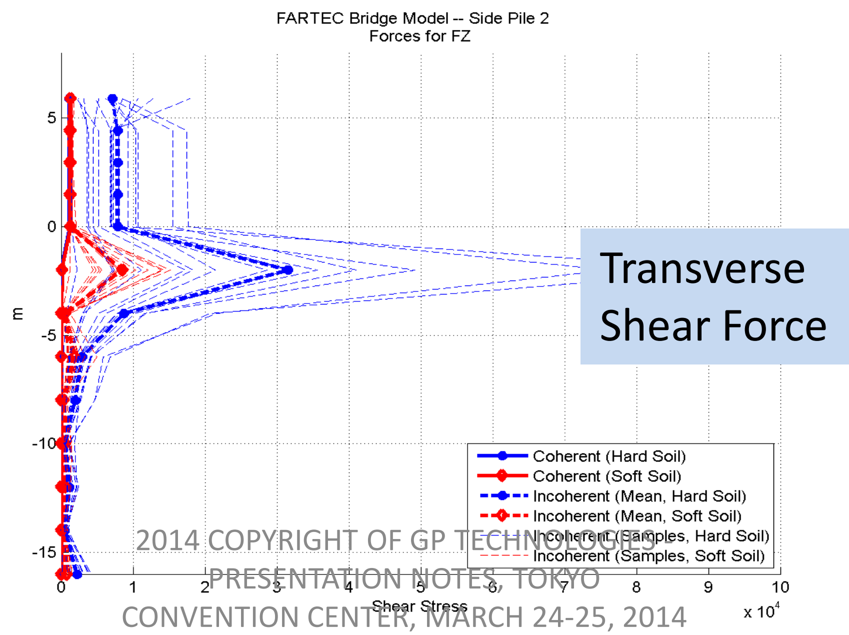


SSI Response ZPA Profile at Pier Side 2

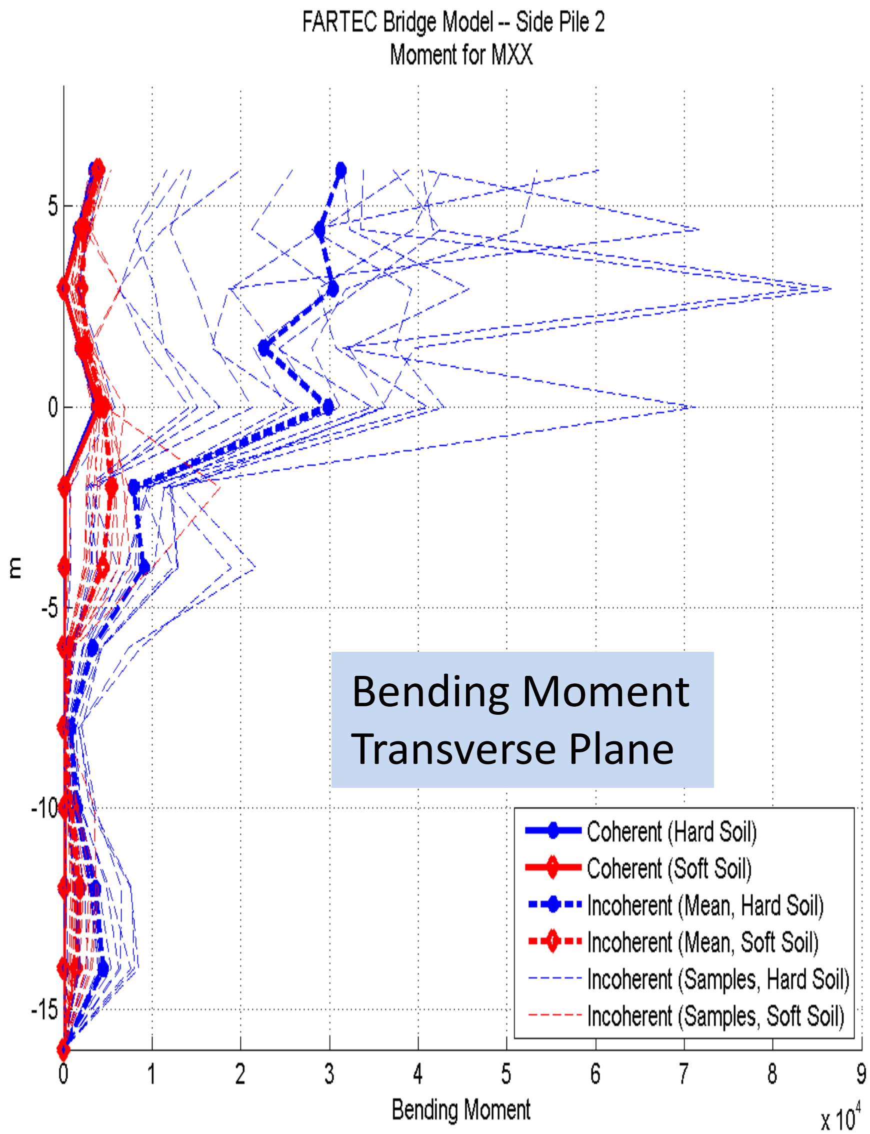


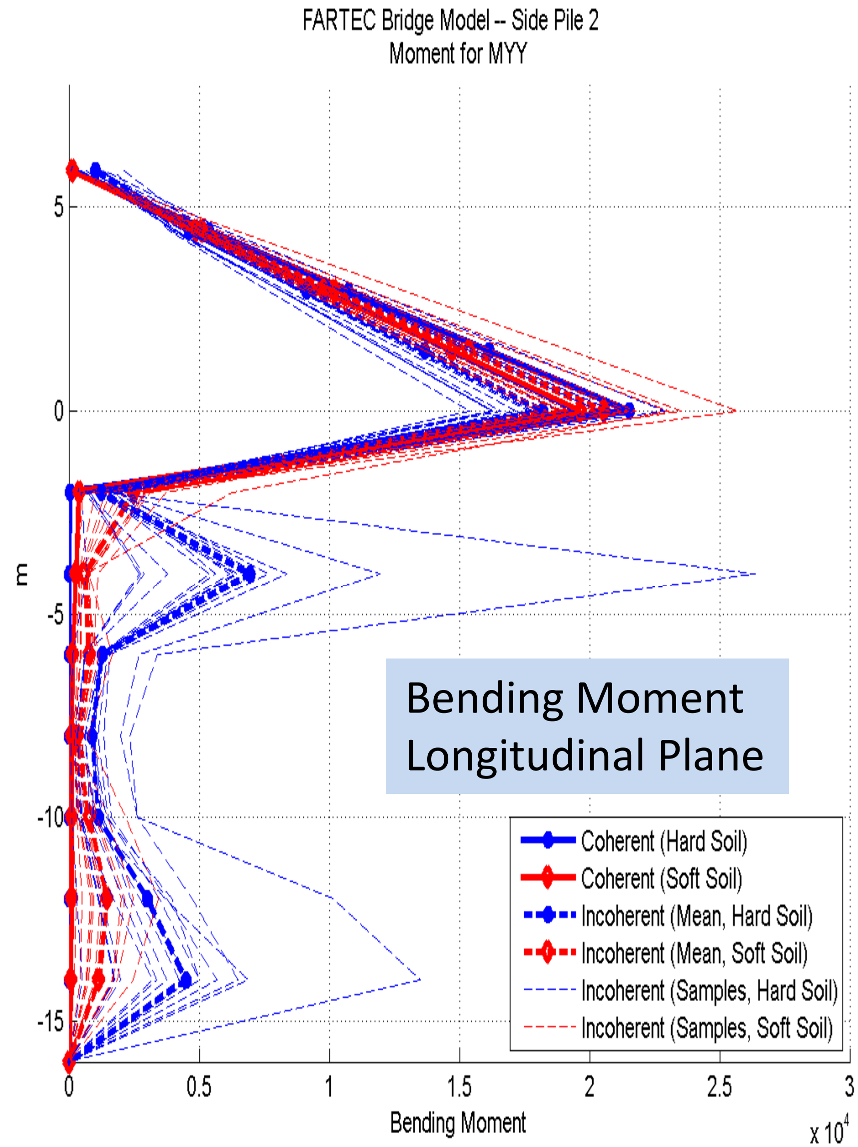


Pier Side 1



SSI Response ZPA Profile at Pier Side 2





Motion Incoherency Effects on Concrete Bridges

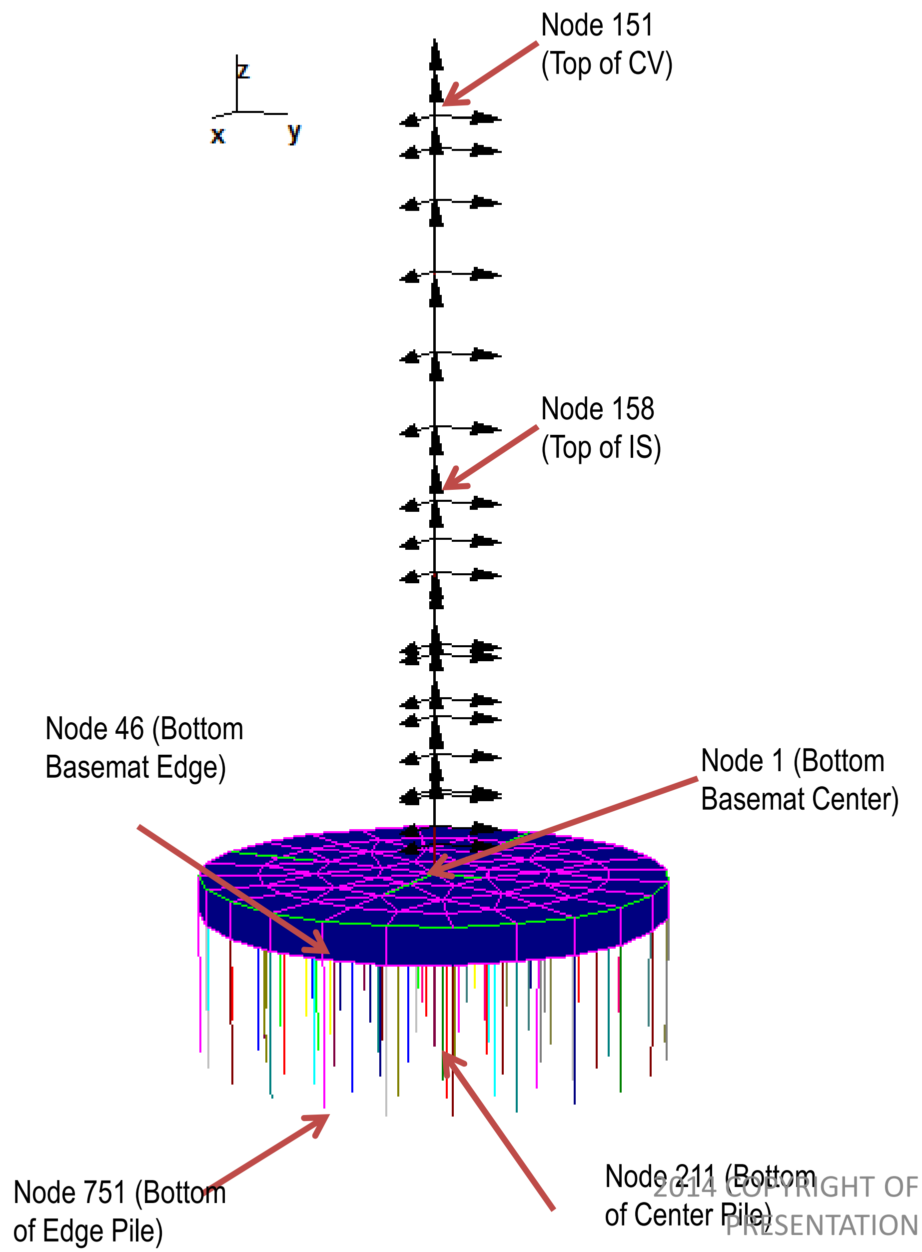
This study shows that the effects of motion incoherency and wave passage can increase the maximum forces in the bridge pier columns and piles by up to 500% in the transverse direction.

It should be noted that the SSSI effects are highly amplified due to motion spatial variation in horizontal direction, i.e. motion incoherency, that creates random differential phasing between neighbor building motions.

REMARK:

It shows a serious deficiency of the current state-of-practice of seismic SSI analysis. Need to revise the requirements for seismic analysis in design codes. Need to use ACS SASSI V3.0 to capture these important SSI-related aspects that are typically ignored

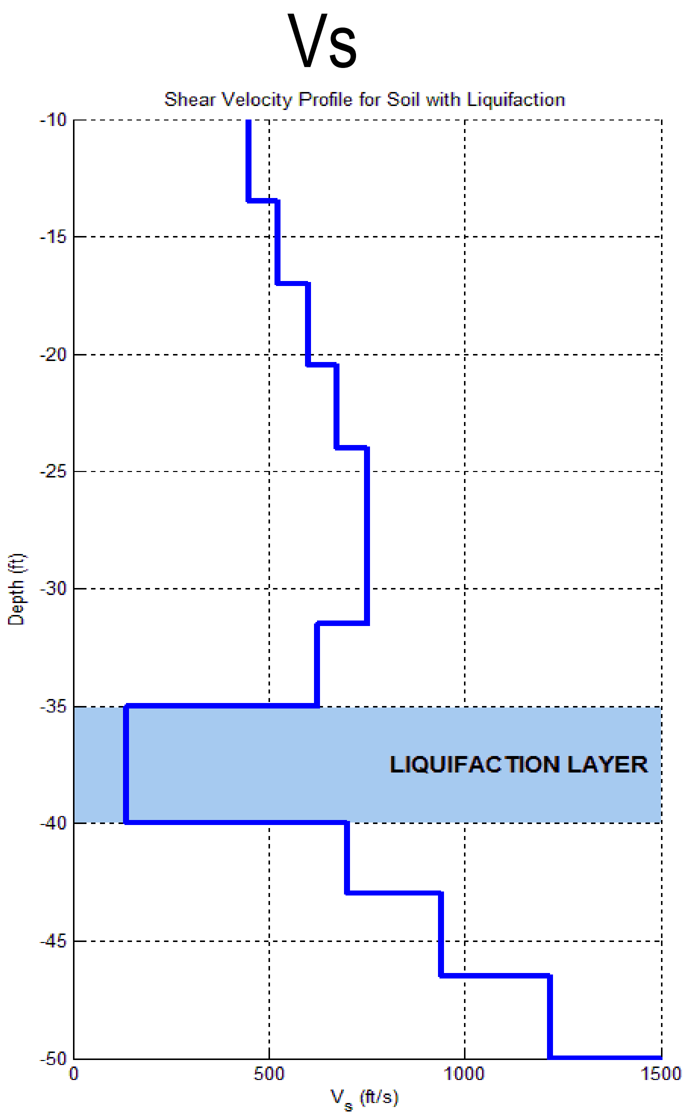
Effects of Liquefaction of Reactor Building on Piles

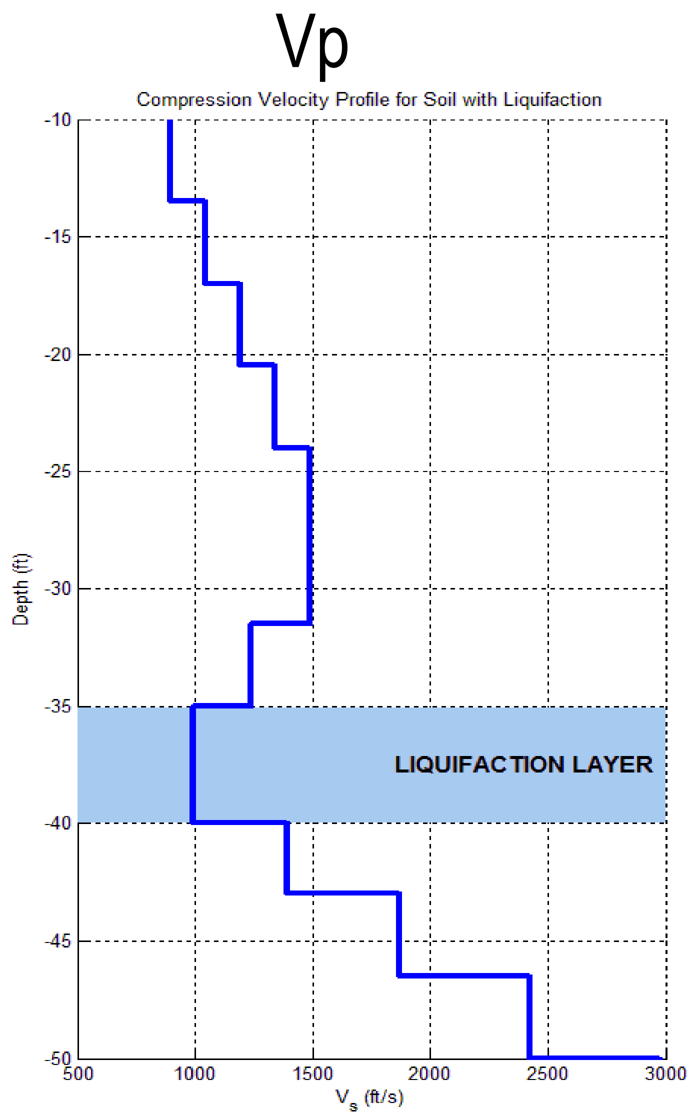


PWR RB Stick Model

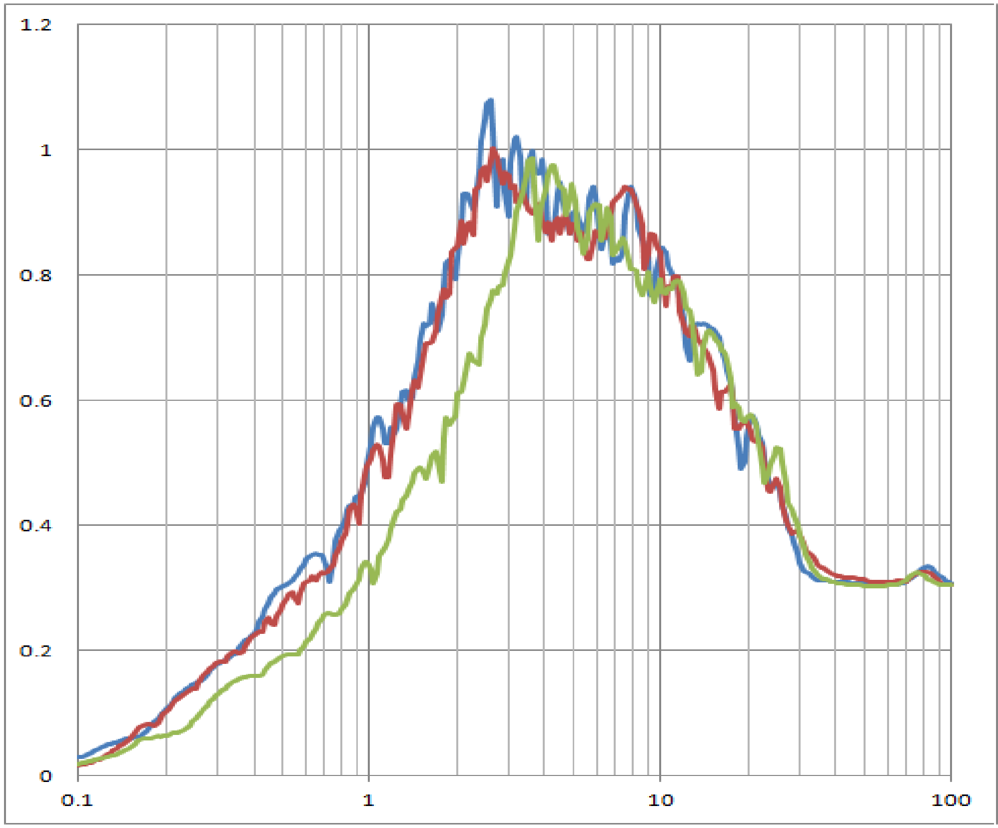
- 69 Piles, one at each basemat node
- Pile length = 40 ft
- Pile radius = 2.5 ft
- Beams with masses used to model Containment Vessel (CV) and Internal Structure (IS)
- Foundation radius = 65 ft
- Selected output piles are attached to nodes 1 and 46 (Center basemat and edge of basemat).

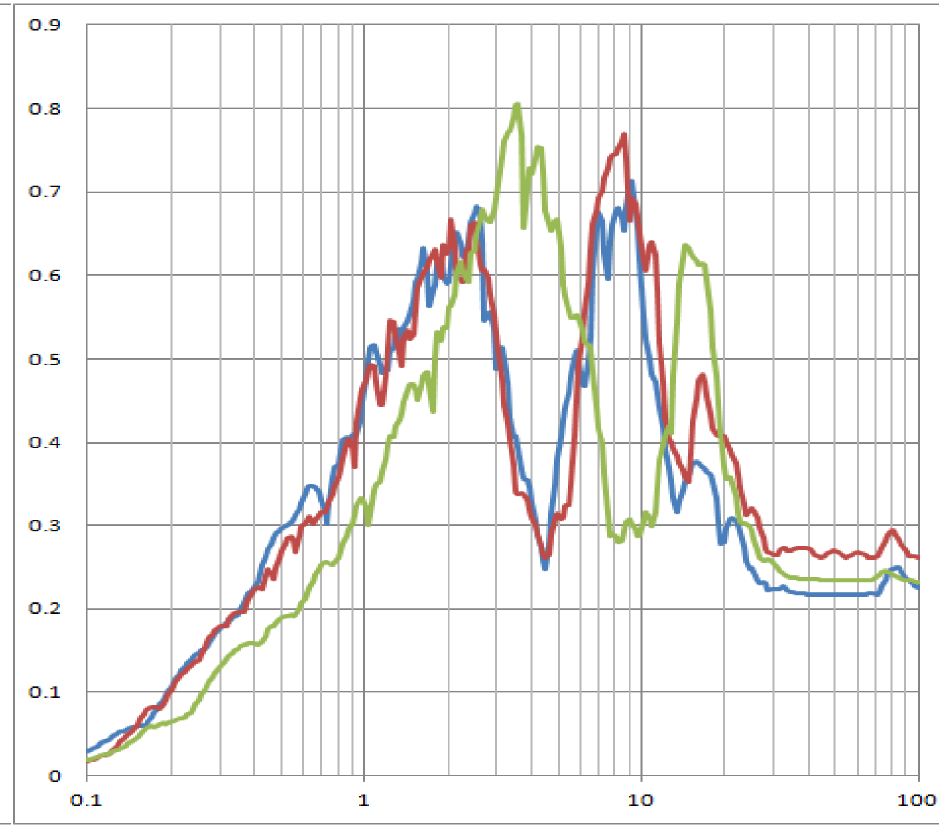
Soil Layering Vs and Vp Profiles





Seismic Input Ground Response Spectra (GRS)

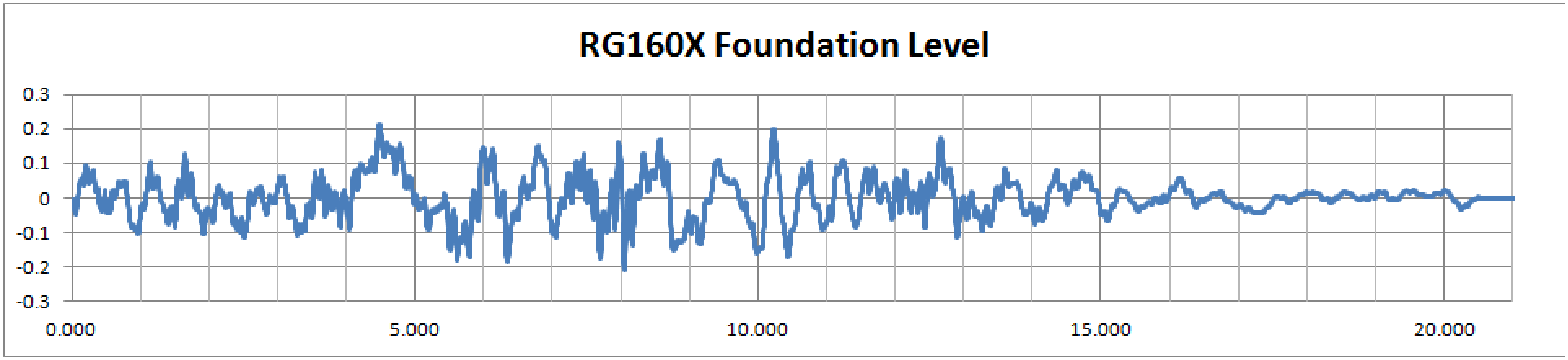


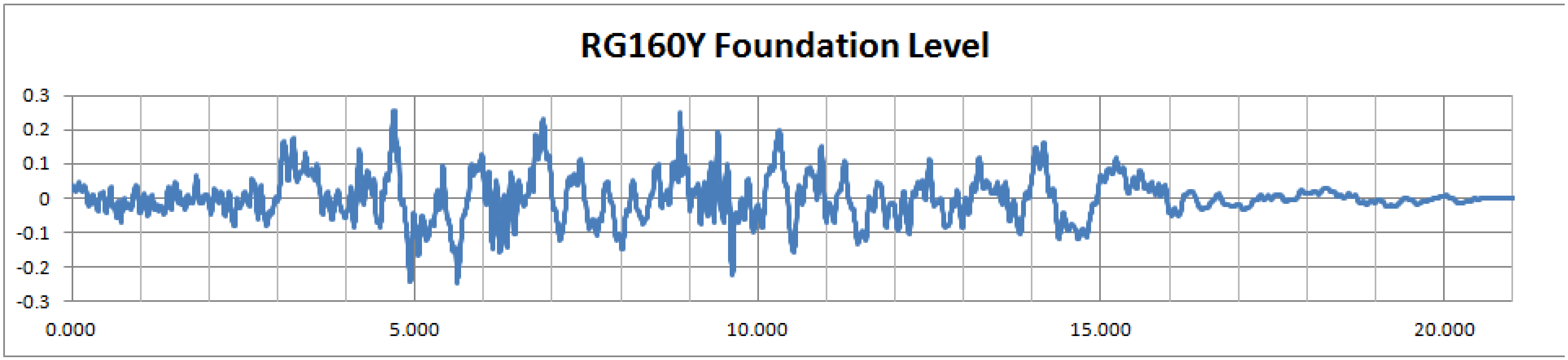


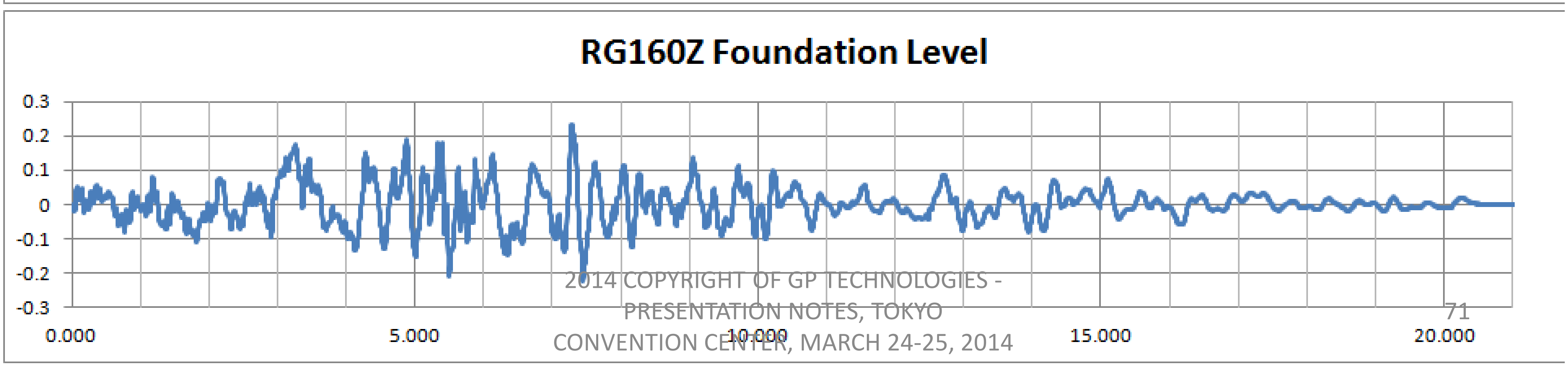
Ground Surface Spectra
RG 1.60 Shape

Foundation Level Spectra
(In-Column Motions)

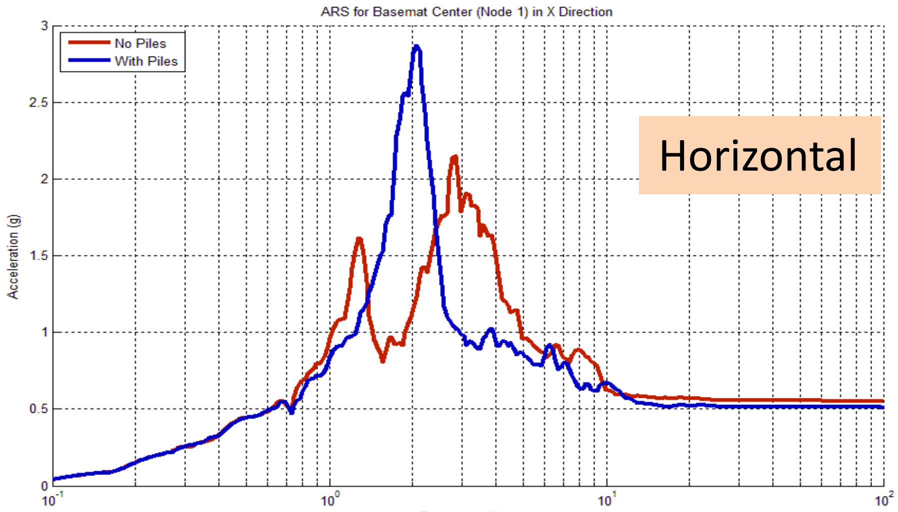
Input Acceleration Time Histories

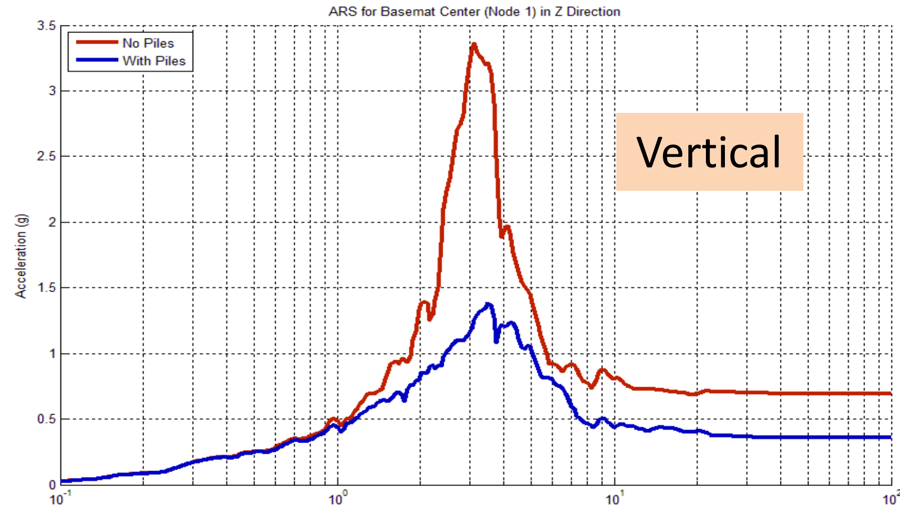




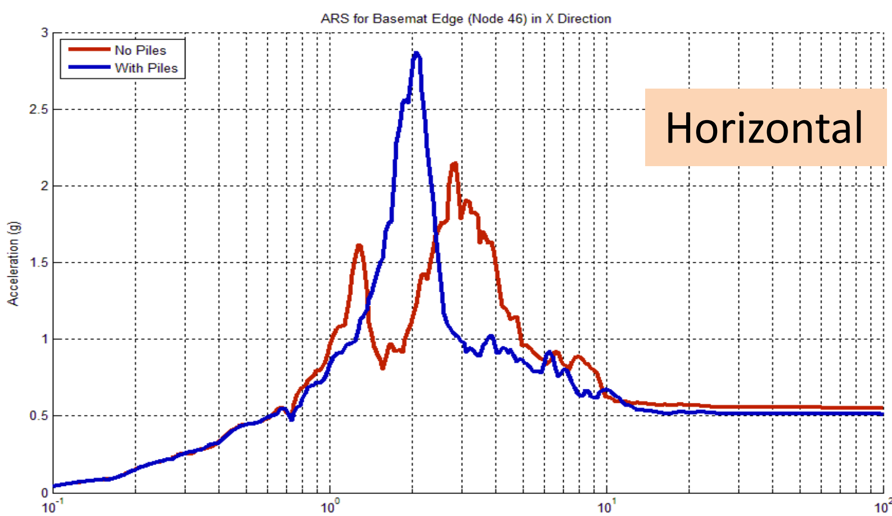


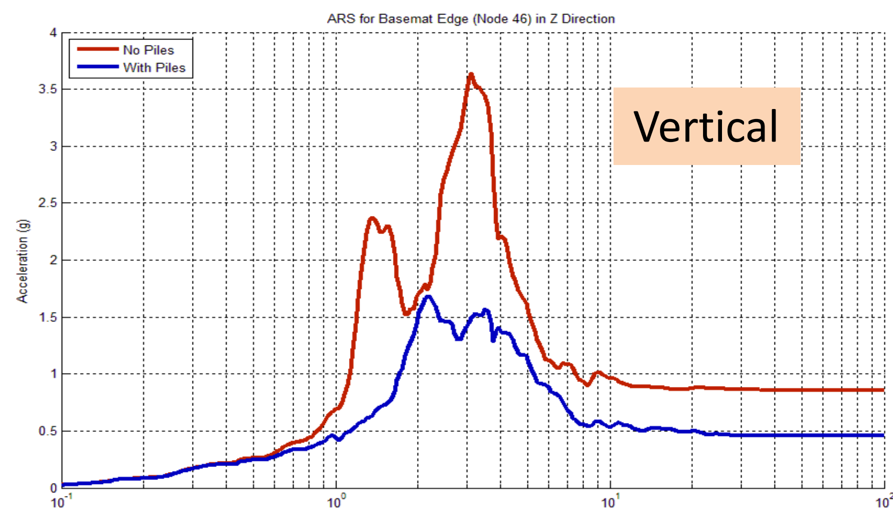
Effects of Piles on RB SSI Response





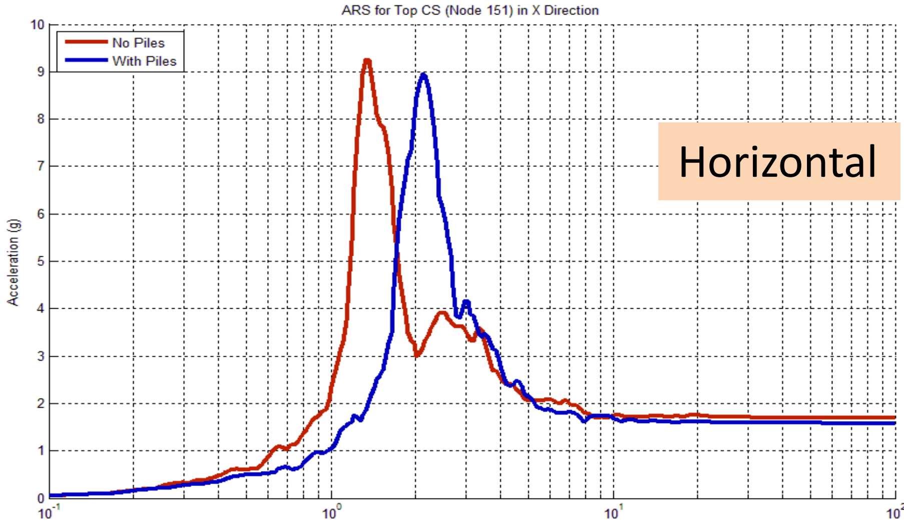
ARS at Basemat Center

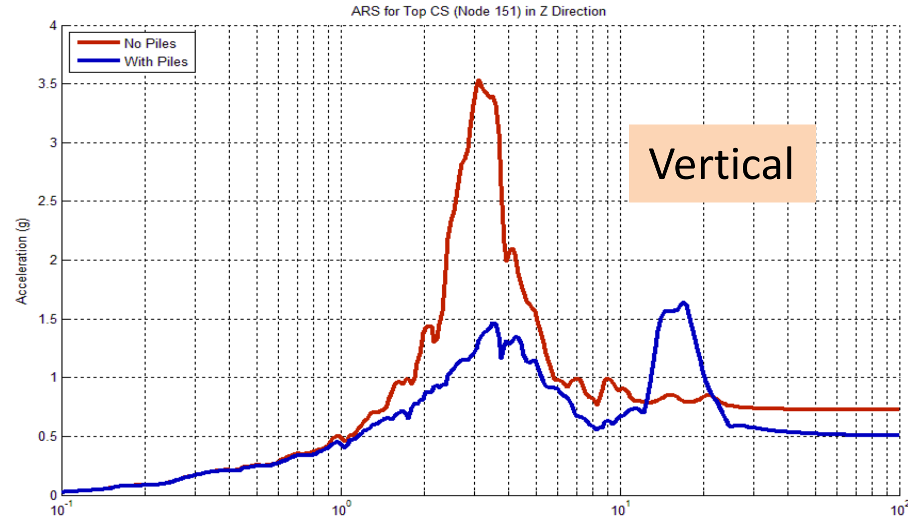




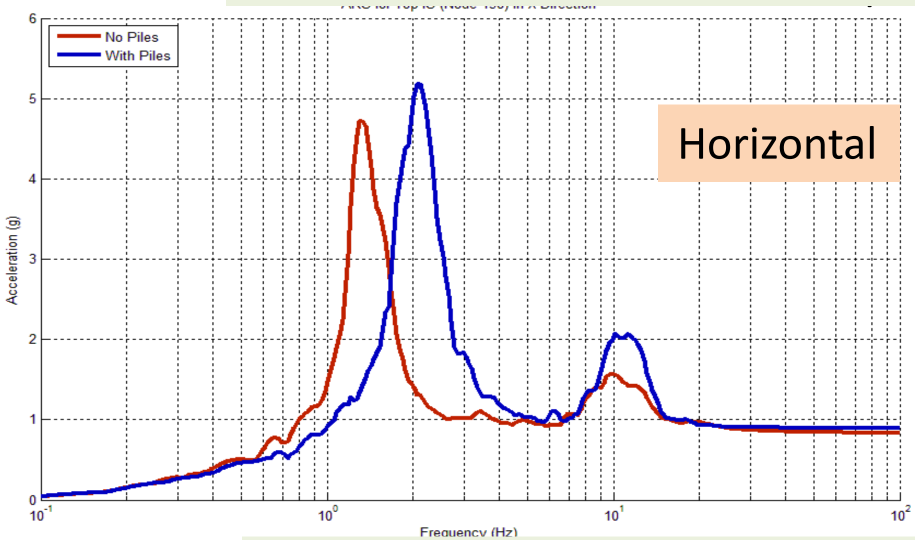
ARS at Basemat Edge

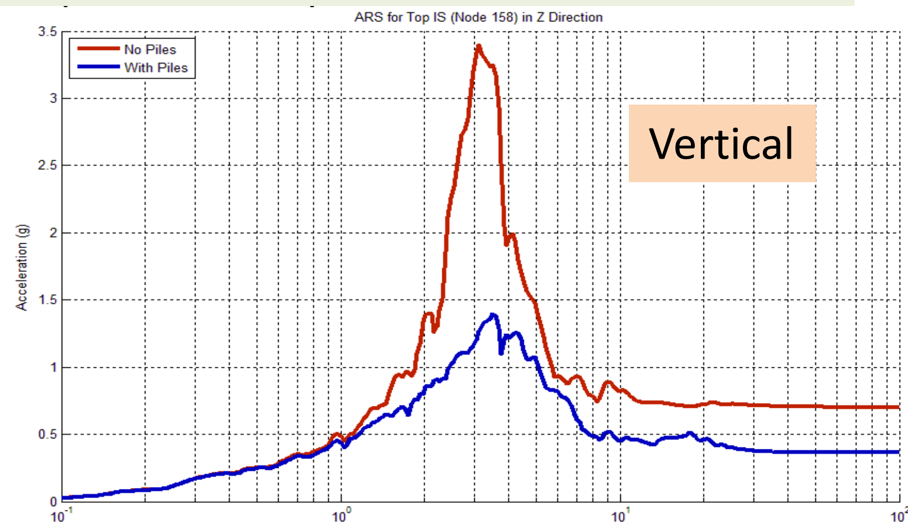
Effects of Piles on RB SSI Response





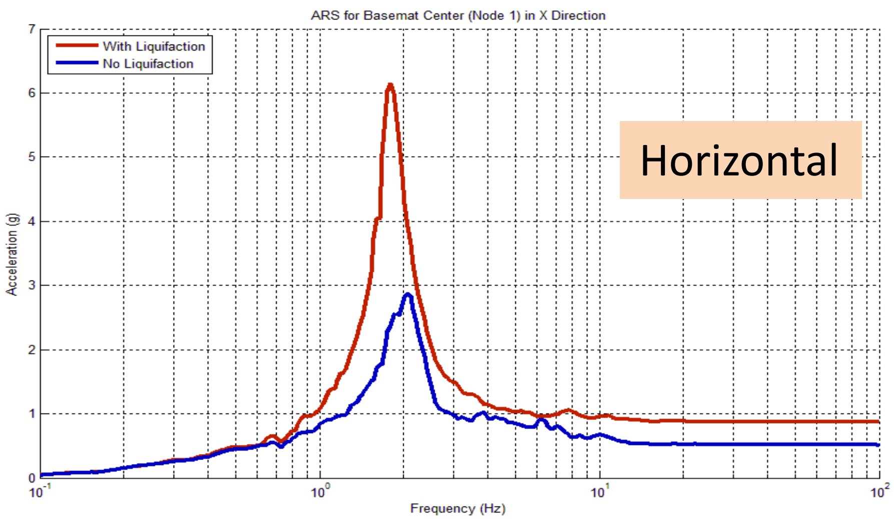
ARS at Top of CS

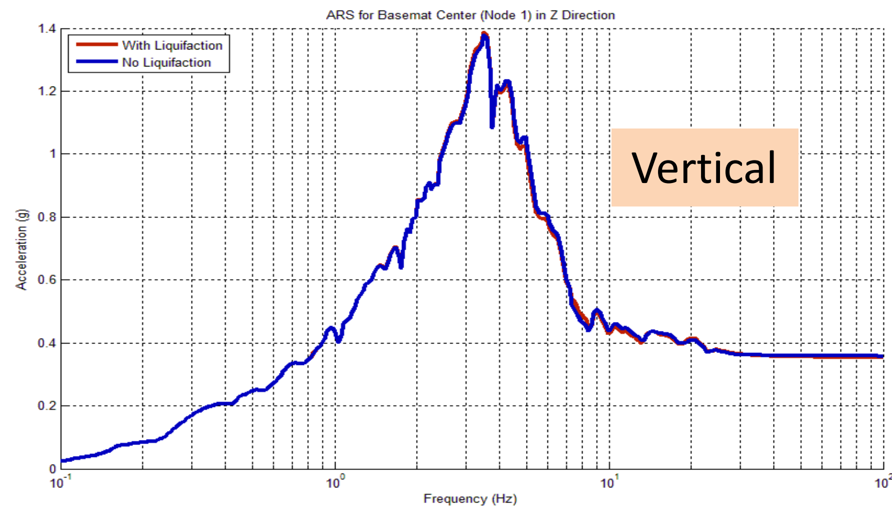




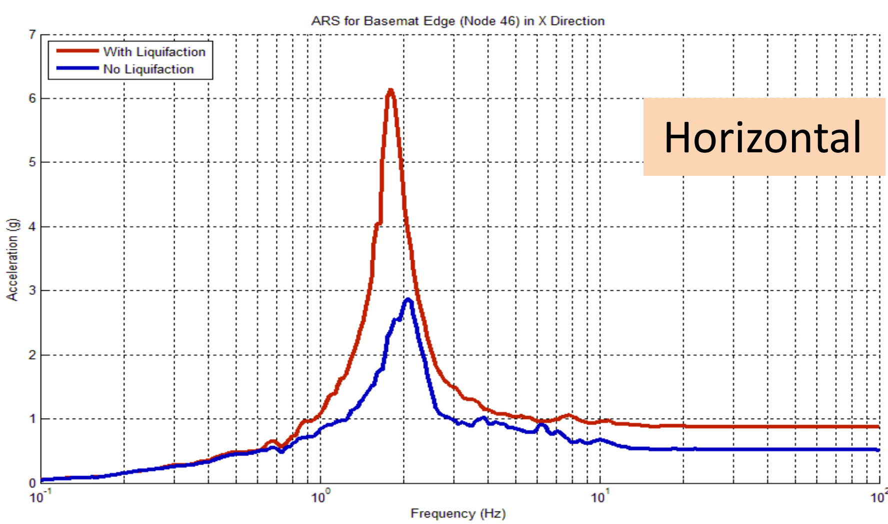
ARS at Top of IS

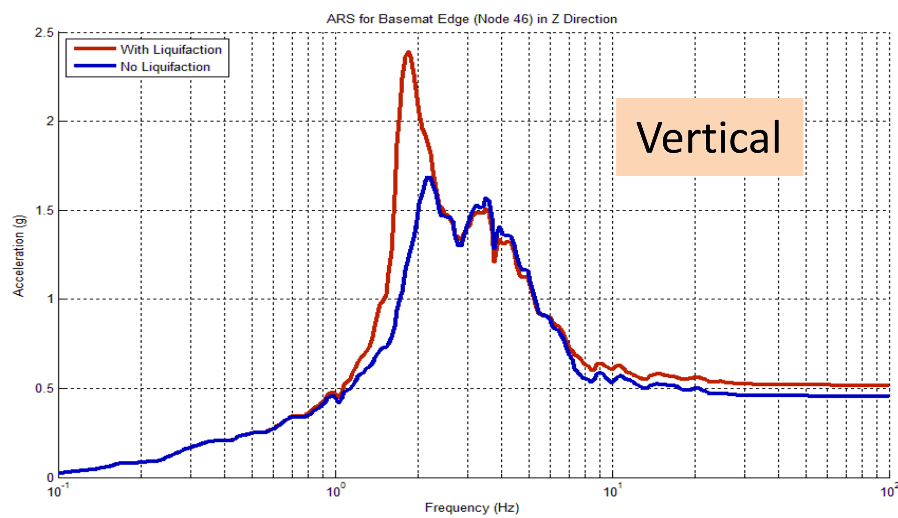
Effects of Liquefaction for RB on Piles





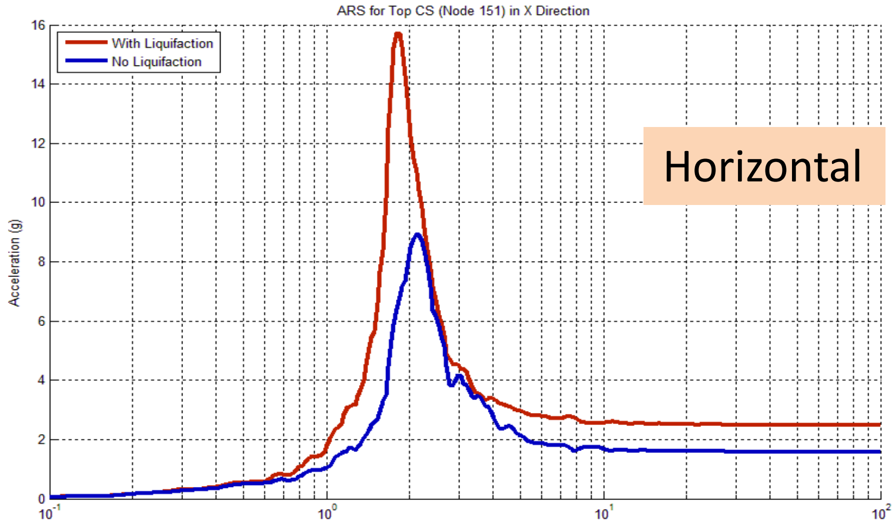
ARS at Basemat Center

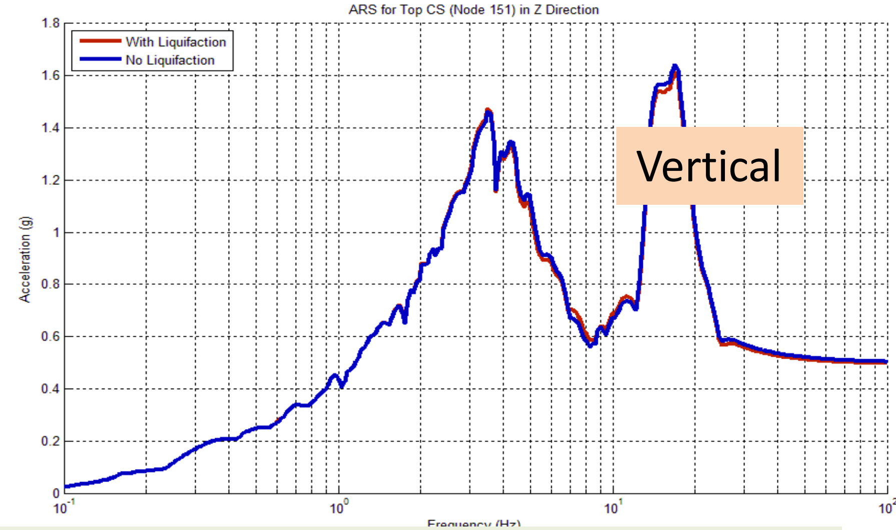




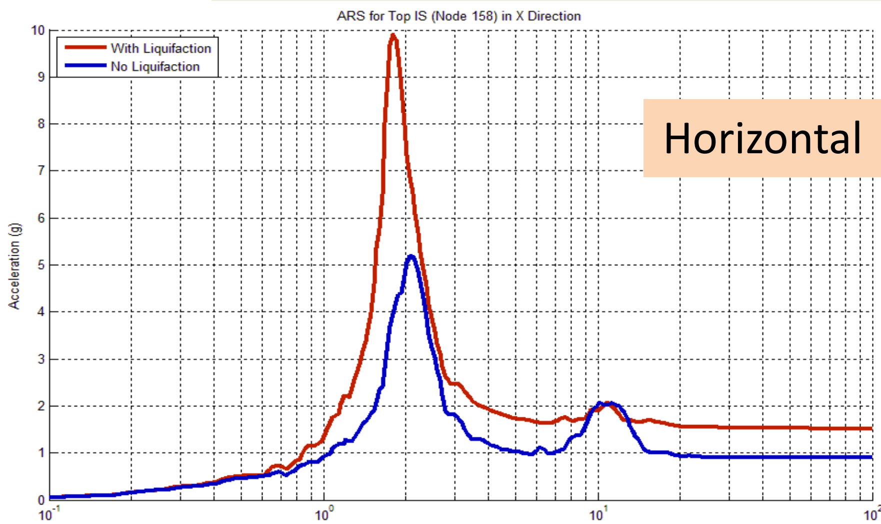
ARS at Basemat Edge

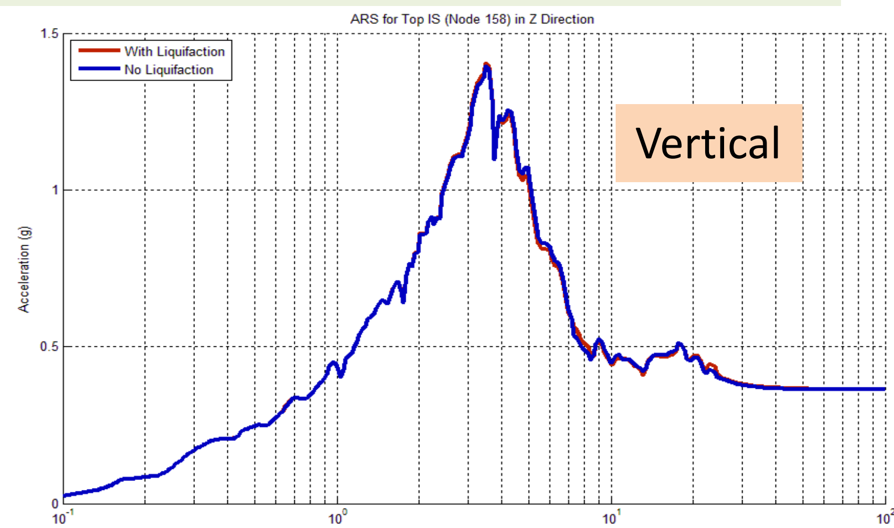
Effects of Liquefaction for RB on Piles





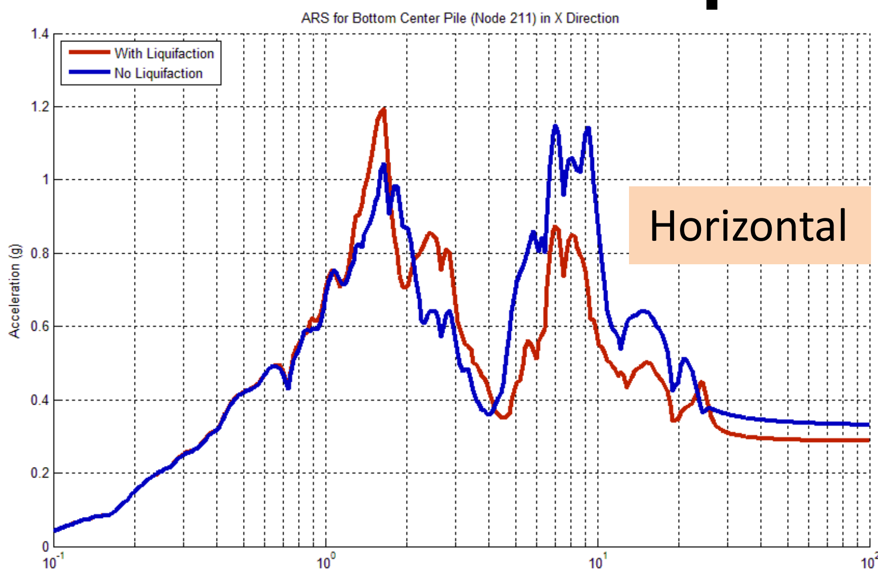
ARS at Basemat Center

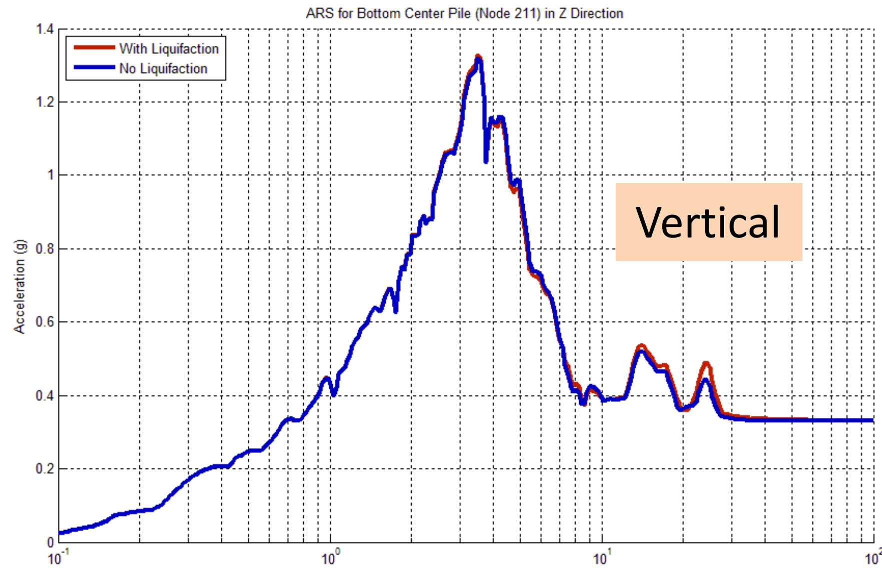




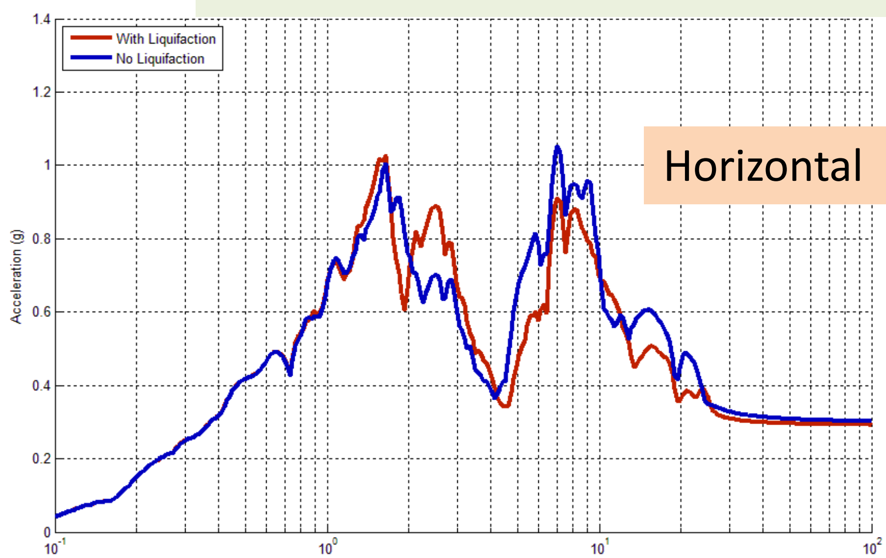
ARS at Basemat Edge

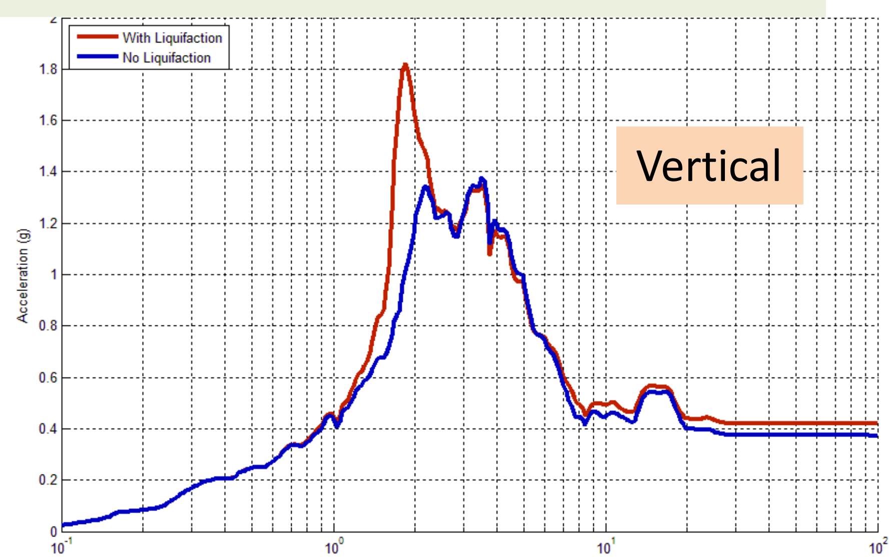
Effects of Liquefaction for RB on Piles





ARS at Foundation Level for Center Pile

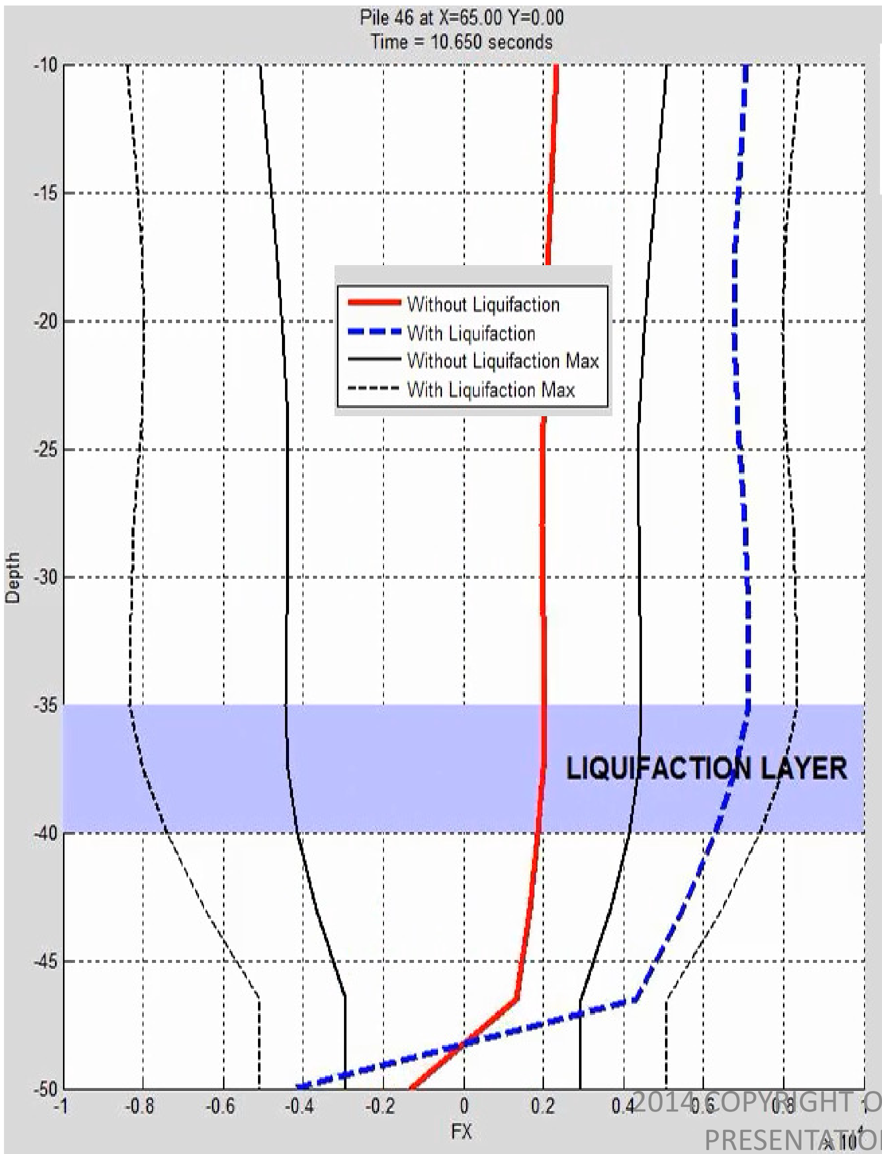




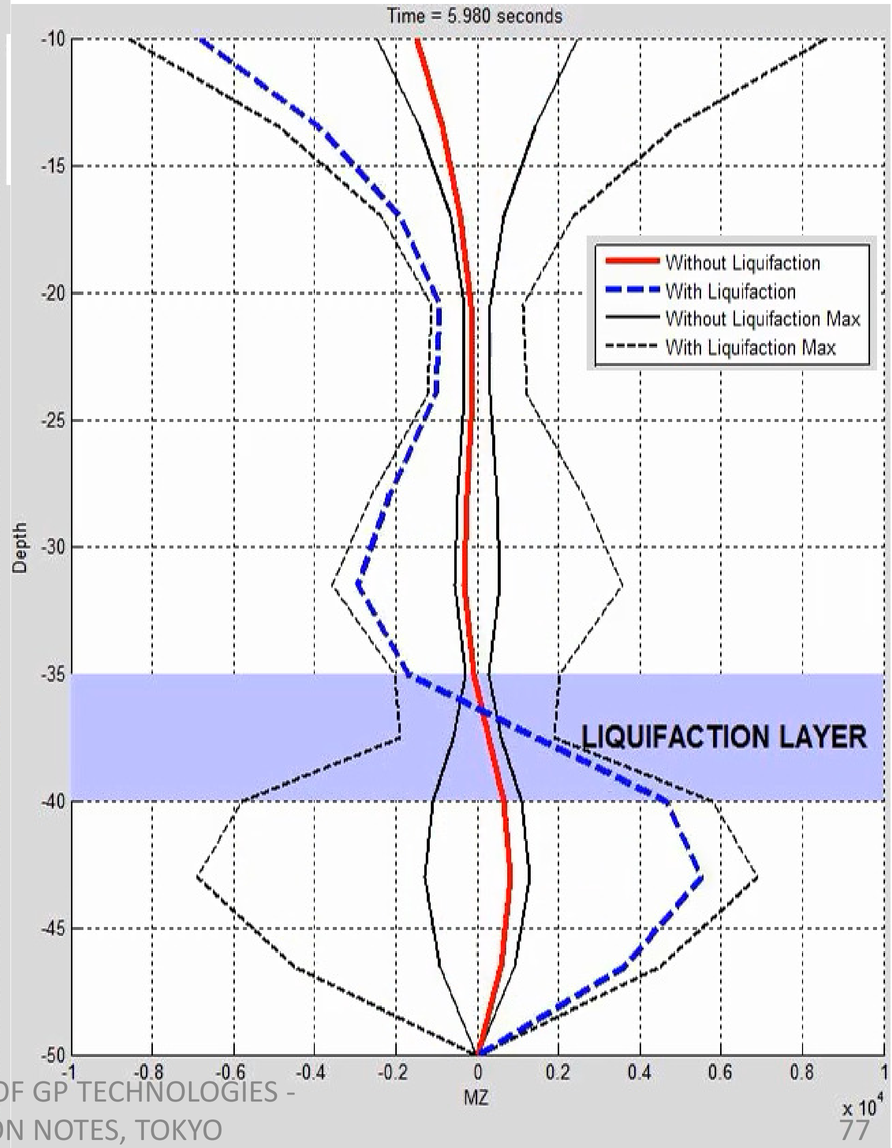
ARS at Foundation Level for Edge Pile

Liquefaction Effects on Pile Forces and Moments

Axial Force in Edge Pile



Bending Moment in Edge Pile



Soil Liquefaction Effects on Pile Foundations

This study shows that the local soil liquefaction effects could increase the shear forces and bending moments in piles by a factor of 200-300% due to large soil deformations.

The soil liquefaction could also increase largely the structure inertial SSI effects.

REMARK:

It shows a serious deficiency of the current state-of-practice of seismic SSI analysis for pile foundation. Need to use ACS SASSI V3.0 to capture these important SSI-related aspects that are typically ignored.

Thank you for your interest in ACS SASSI software!