Effects of Seismic Motion Incoherency on SSI and SSSI Responses of Nuclear Structures for Different Soil Site Conditions

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Purpose of This Presentation:

To disseminate results of some internal research projects done in GP Technologies for a better understanding of the incoherency effects on nuclear structure SSI and SSSI responses.

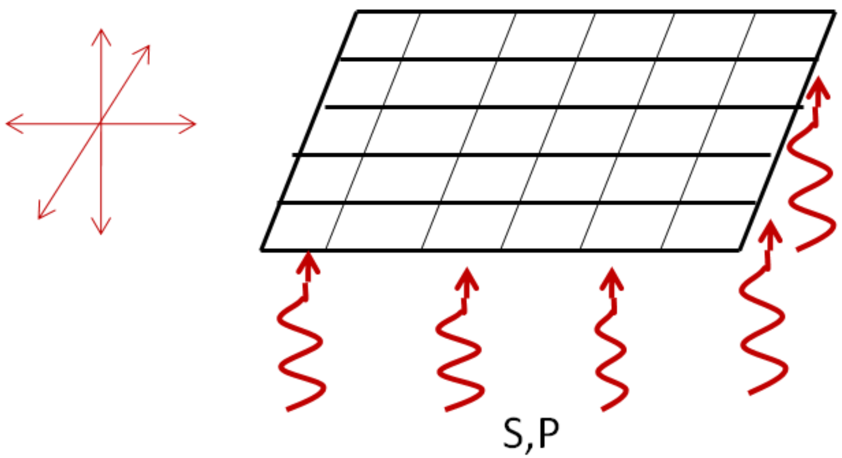
To answer to the following important questions:
- What is the meaning of "incoherent motion"?
- How the foundation flexibility impact on the incoherent SSI methodology and in-structure responses?
- How much can the foundation size influence incoherent responses?
- How much can the seismic input directionality affect incoherent results?
- How much can incoherency influence SSSI effects for rock and soil sites?

Discuss effects on ISRS, soil pressures, structural shear forces, and foundation wall bending moments, SSI relative displacement between neighboring buildings….

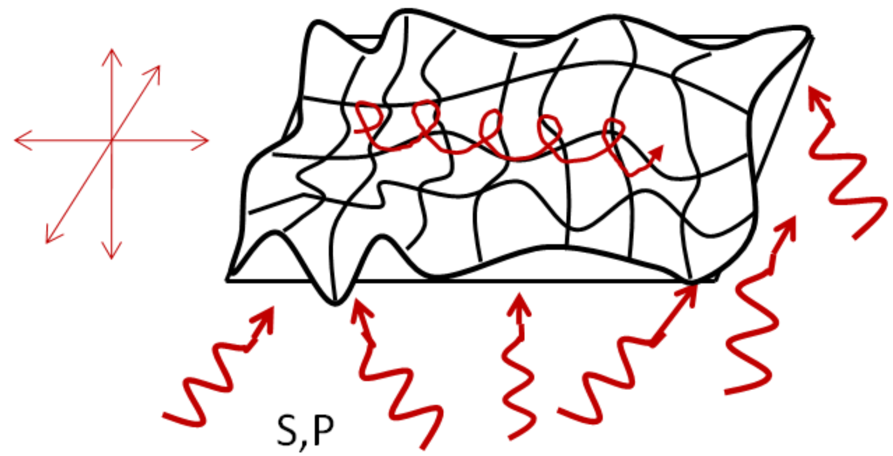
The *ACS SASSI Version 3.0 code* was used for all these studies.

Coherent vs. Incoherent Wave Propagation Models

3D Rigid Body Soil Motion (Idealized)



3D Random Wave Field Soil Motion (Realistic)



1 D Wave Propagation Analytical Model (Coherent)

Vertically Propagating S and P waves (1D)
- No other waves types included
- No heterogeneity random orientation and arrivals included
- Results in a rigid body soil motion, even for large-size foundations

3D Wave Propagation Data-Based Model (Incoherent – Database-Driven Adjusted Coherent)

Includes real field records information, including implicitly motion field heterogeneity, random arrivals of different wave types under random incident angles.

ANIMATIONS

Motion Incoherency Simulation in ACS SASSI

The complex frequency response is computed as follows:

- Coherent SSI response:

Structural transfer function given input at interaction nodes

Coherent ground transfer function at interface nodes given control motion

Complex Fourier transform of control motion

$$U_s(\omega) = H_s(\omega) * H_g^c(\omega) * U_{g,0}(\omega)$$

- Incoherent SSI response:

Incoherent ground transfer function given coherent ground motion and coherency model (random spatial variation in horizontal plane)

$$U_s(\omega) = H_s(\omega) * S_g^i(\omega) * H_g^c(\omega) * U_{g,0}(\omega)$$

$$S_g(\omega) = [\Phi(\omega)][\lambda(\omega)]\{\eta_\theta\}$$

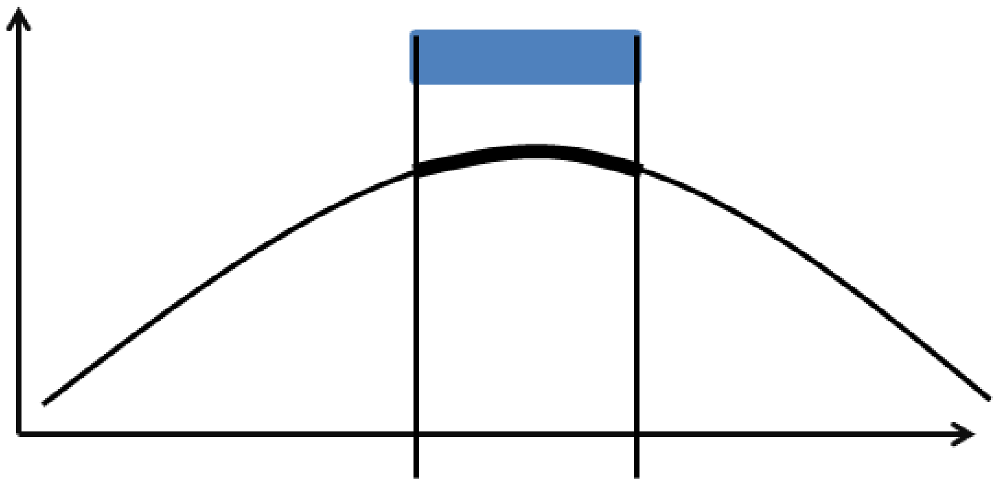
Complex Fourier transform of relative spatial variations of soil motion at interaction nodes = stochastic wave field

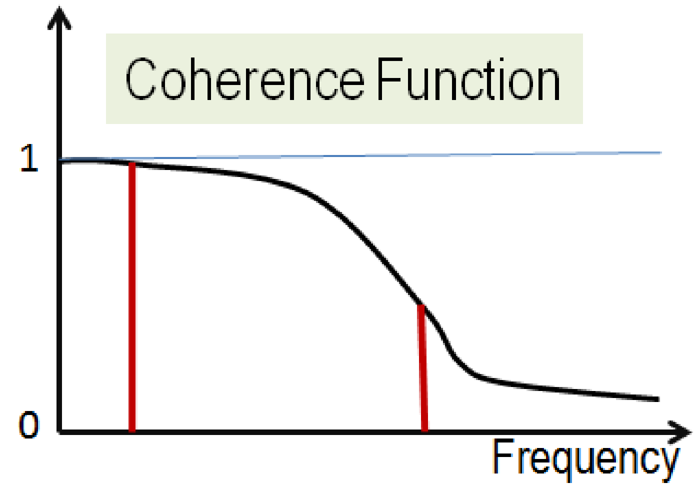
Eigen**modes** of coherency kernel (deterministic part)

Random **phases** (stochastic part)

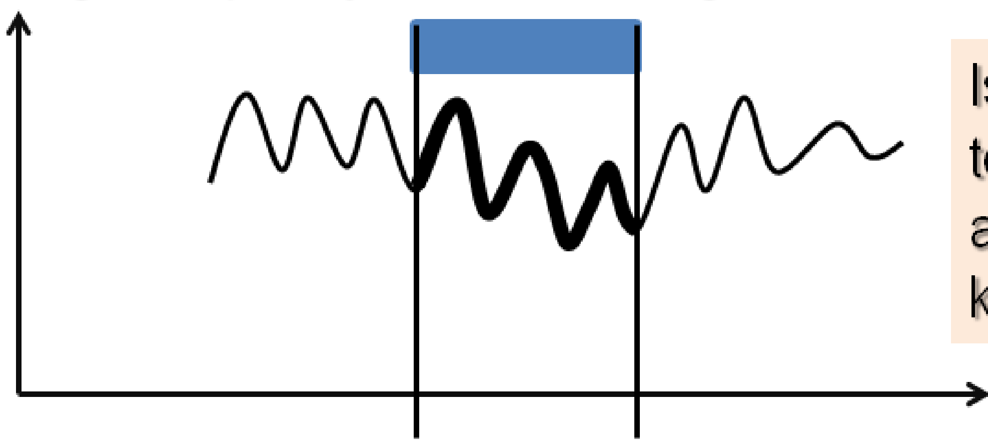
How Many Modes Do we Need to Consider ?

Low Frequency/Large Wavelengths/Only Few Low Order Incoherency Modes



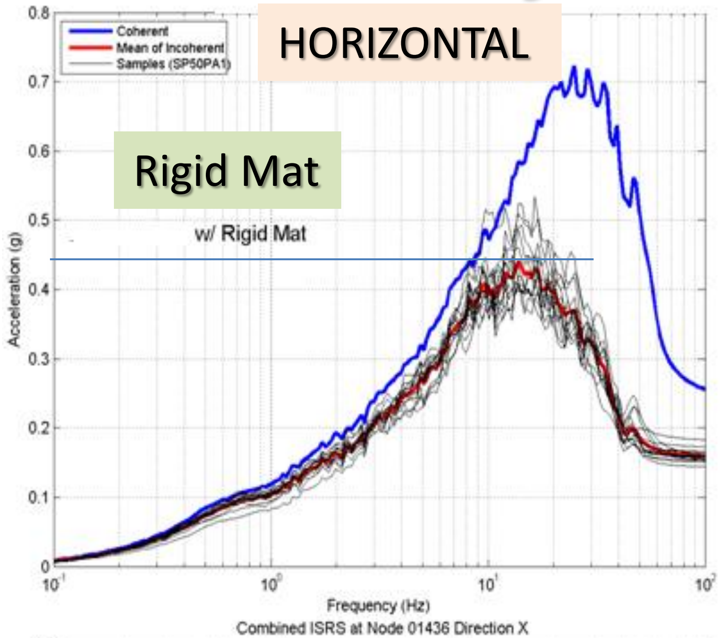


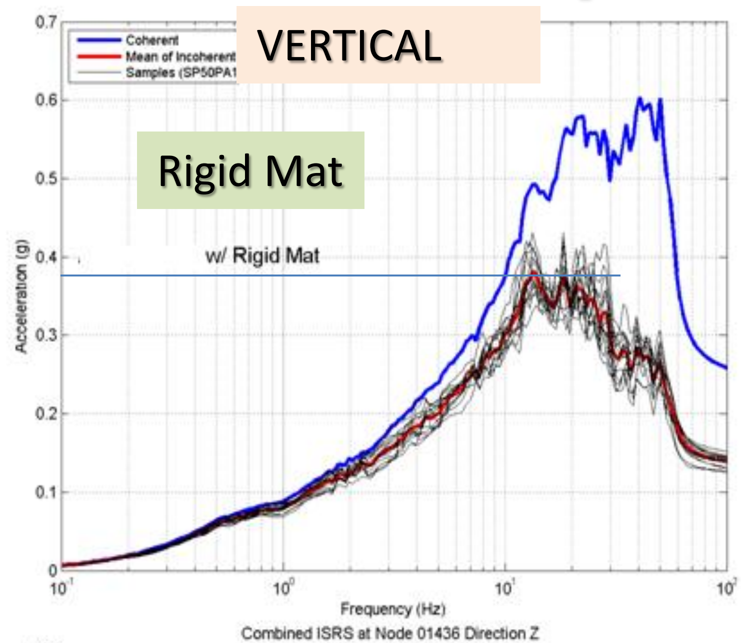
High Frequency/Short Wavelengths/Low and High Order Incoherency Modes



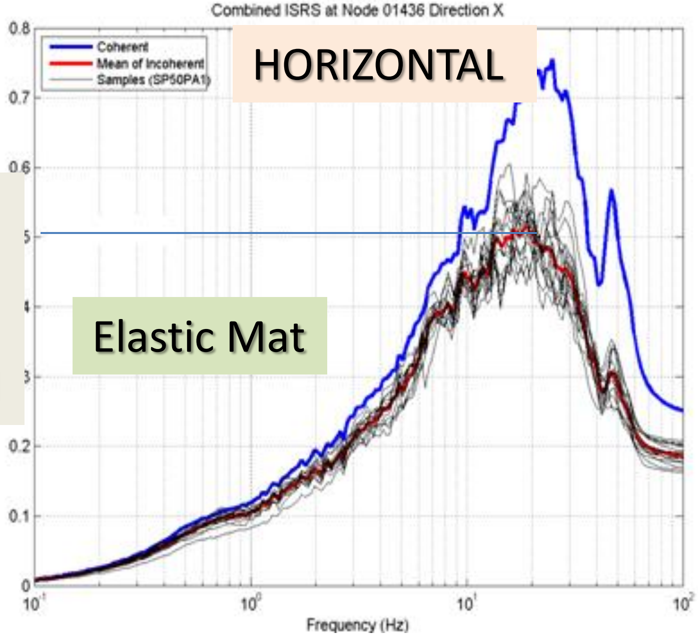
Is the foundation sufficiently rigid to neglect high order modes at high frequency due to kinematic interaction effects?

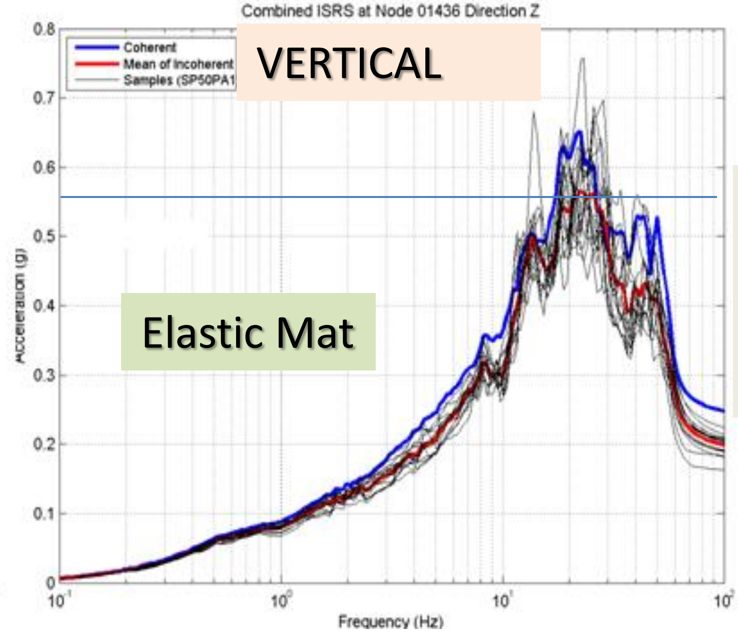
Basemat Flexibility Effects on RB Complex ISRS





Elastic is 20% up for horizontal





Elastic is 65% (!) up for vertical

Cumulative Modal Contribution for 10 Modes

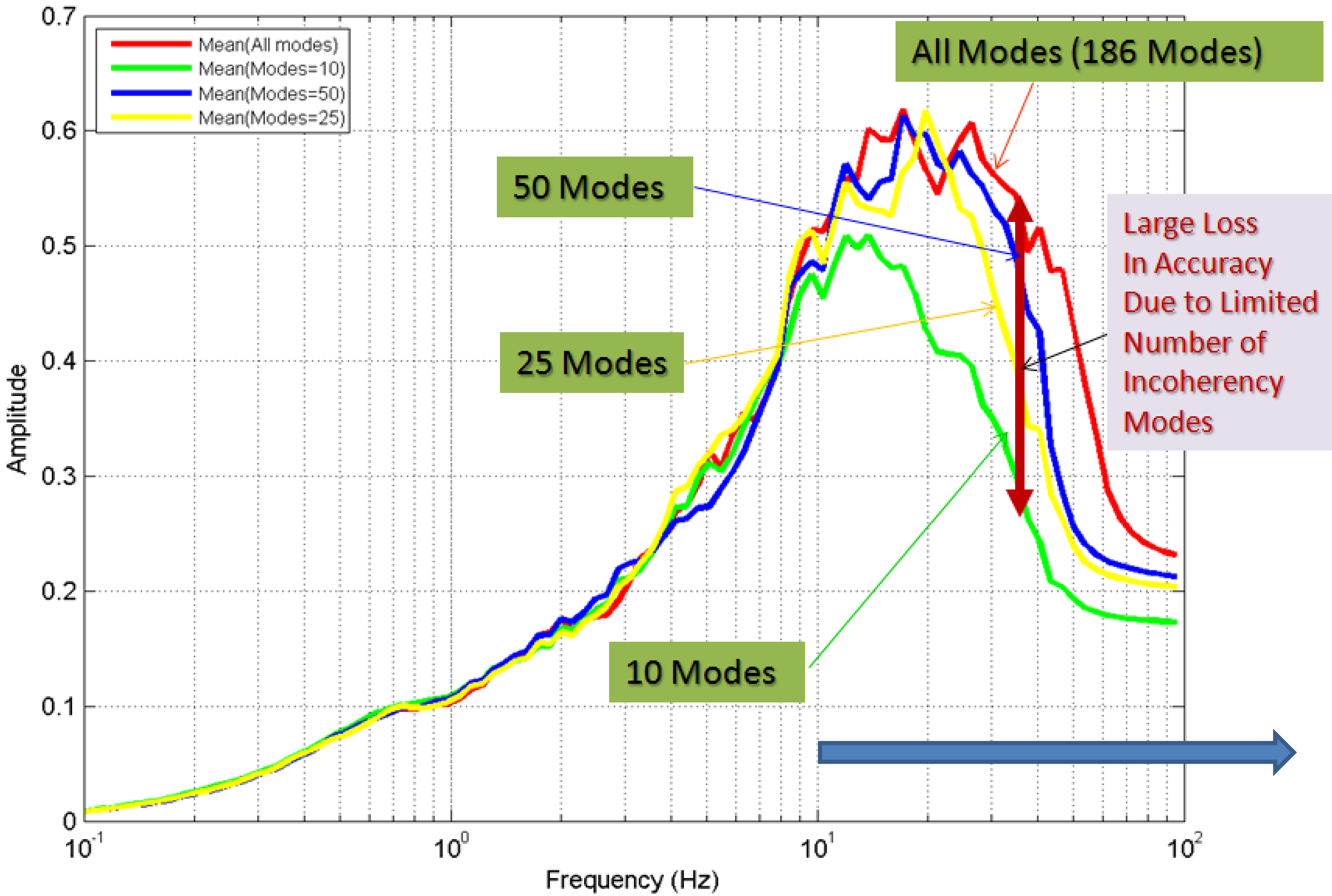
2007 Abrahamson Rock Site Model

*** CUMULATIVE MODAL MASS/VARIANCE (%) ***

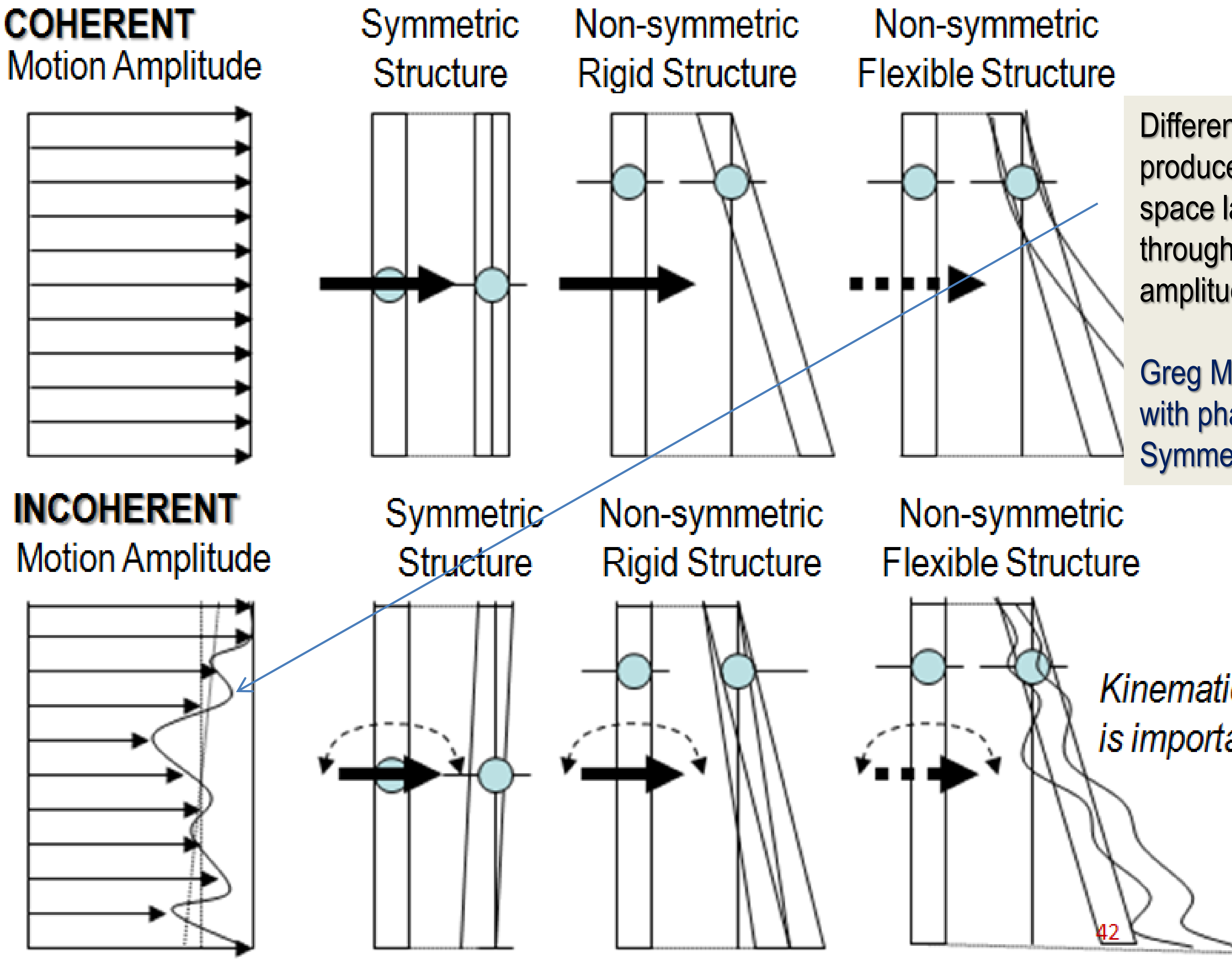
Frequency	=	0.098	Horizontal =	100.00%	Vertical	=	100.00%
Frequency	=	1.562	Horizontal =	100.00%	Vertical	=	99.97%
Frequency	=	3.125	Horizontal =	99.94%	Vertical	=	99.75%
Frequency	=	4.688	Horizontal =	99.69%	Vertical	=	99.20%
Frequency	=	6.250	Horizontal =	98.90%	Vertical	=	98.09%
Frequency	=	7.812	Horizontal =	97.01%	Vertical	=	96.00%
Frequency	=	9.375	Horizontal =	93.55%	Vertical	=	92.59%
Frequency	=	10.938	Horizontal =	88.54%	Vertical	=	87.93%
Frequency	=	12.500	Horizontal =	82.47%	Vertical	=	82.46%
Frequency	=	14.062	Horizontal =	75.90%	Vertical	=	76.67%
Frequency	=	15.625	Horizontal =	69.31%	Vertical	=	70.92%
Frequency	=	17.188	Horizontal =	63.02%	Vertical	=	65.45%
Frequency	=	18.750	Horizontal =	57.20%	Vertical	=	60.37%
Frequency	=	20.312	Horizontal =	51.92%	Vertical	=	55.74%
Frequency	=	21.875	Horizontal =	47.19%	Vertical	=	51.55%
Frequency	=	23.438	Horizontal =	42.99%	Vertical	=	47.79%
Frequency	=	25.000	Horizontal =	39.26%	Vertical	=	44.40%
Frequency	=	26.562	Horizontal =	35.96%	Vertical	=	41.37%
Frequency	=	28.125	Horizontal =	33.04%	Vertical	=	38.65%
Frequency	=	29.688	Horizontal =	30.42%	Vertical	=	36.20%
Frequency	=	31.250	Horizontal =	28.04%	Vertical	=	34.00%
Frequency	=	32.812	Horizontal =	25.81%	Vertical	=	32.01%
Frequency	=	34.375	Horizontal =	23.63%	Vertical	=	30.21%
Frequency	=	35.938	Horizontal =	21.37%	Vertical	=	28.57%
Frequency	=	37.500	Horizontal =	18.93%	Vertical	=	27.09%
Frequency	=	39.062	Horizontal =	16.31%	Vertical	=	25.74%

Effects of Number of Incoherent Modes on ISRS

Elastic Basemat Corner – X Direction



Motion Incoherency Differential Phasing Effects



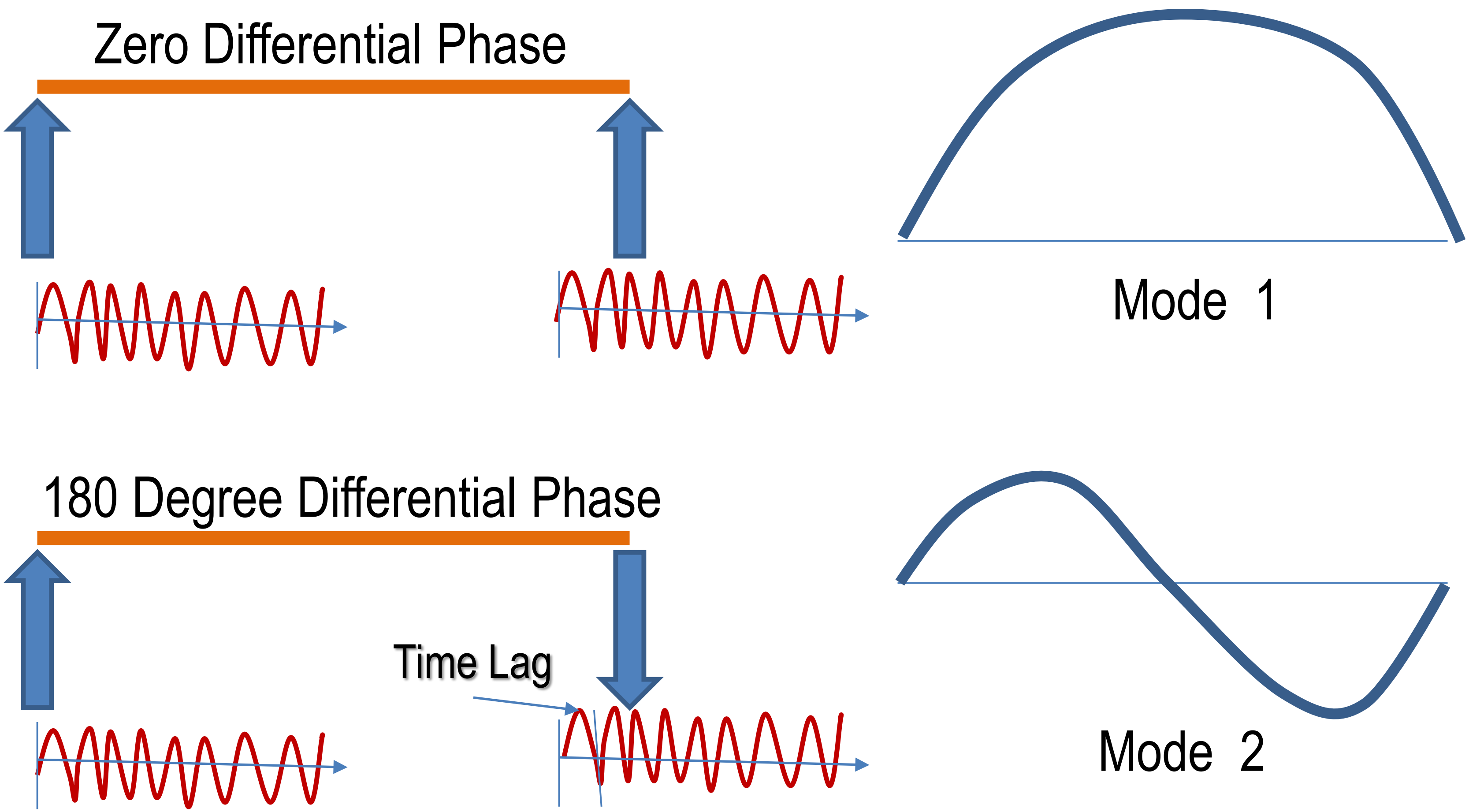
Differential phasing produces time and space lags and through these, amplitude variations

Greg Mertz's example with phasing effect on Symmetric beam

Kinematic SSI is important

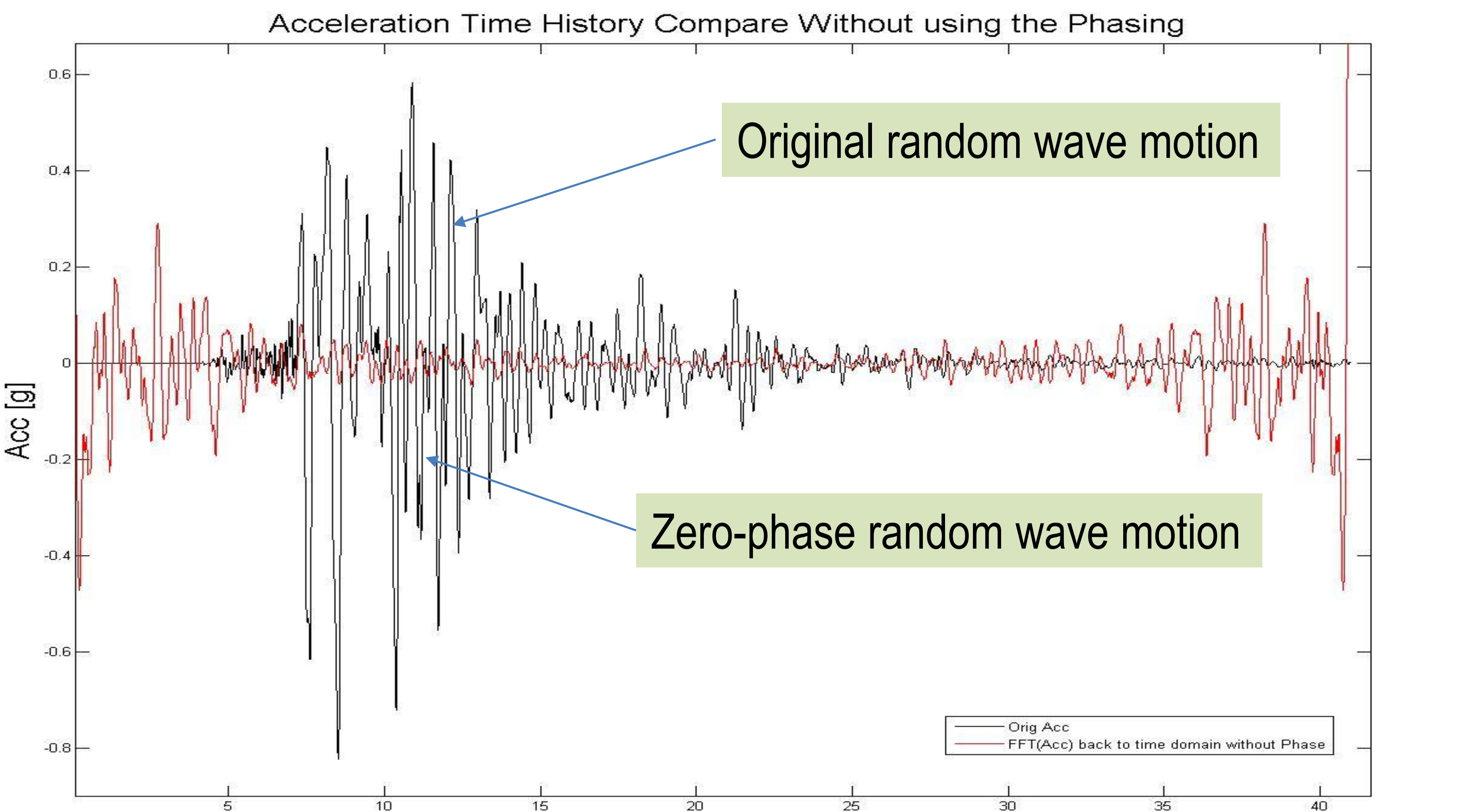
Greg's Example on Differential Phasing Effects Same Amplitude Harmonic Input

Symmetric Beam Subjected to Harmonic Motion at Supports



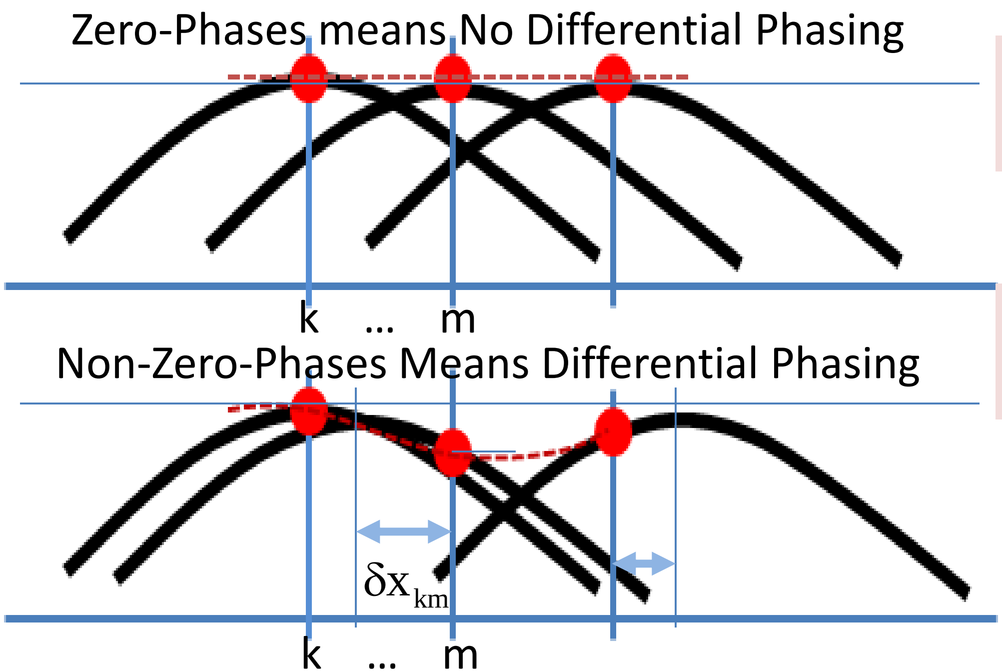
Effects of Zeroing Phases of Complex Responses in Frequency on Time Domain Responses

Fourier Transform Example



Effect of Zeroing Differential Phases at Lower-Mid Frequencies

For dominant single mode situations (in lower frequency range), the *neglect of the (differential) phases* that produce random amplitude variations in space, *basically changes the problem and departs from reality.*



Single Mode "Zero-Phase" Motion produces a "deterministic rigid body" motion

Single Mode "Non-Zero-Phase" Motion produces a "random field" motion

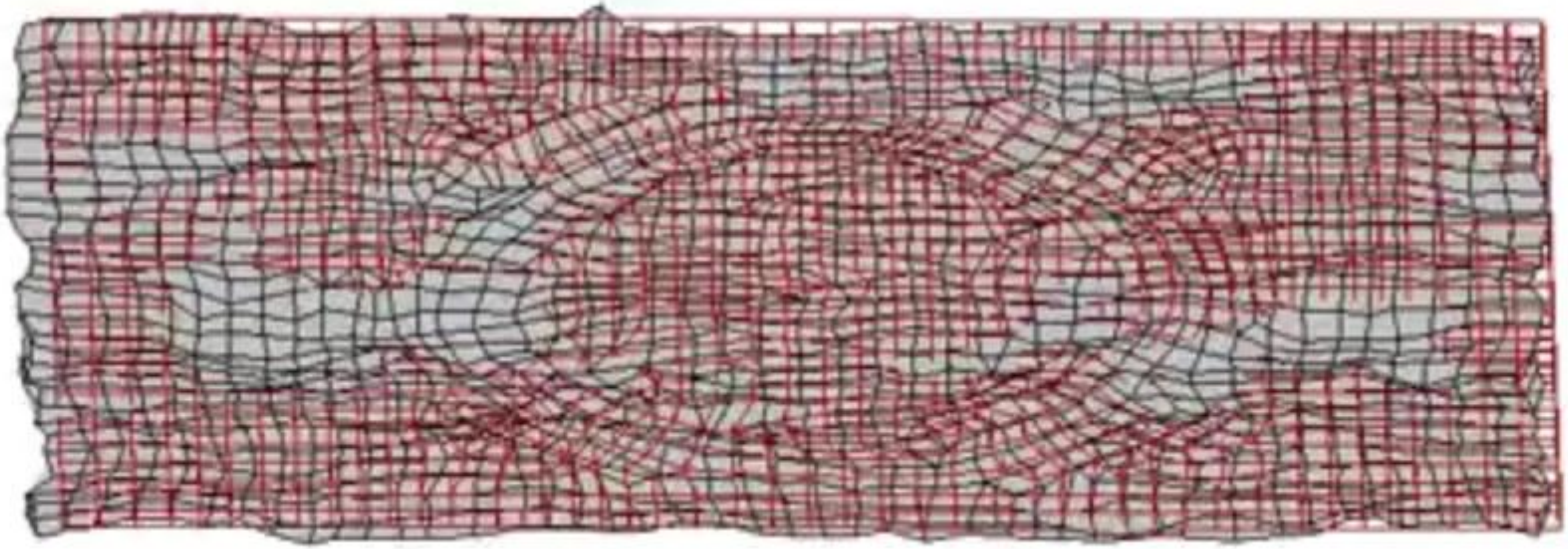
Differential Amplitude Variations due to Differential Random Phasing

Mode 1 Contribution

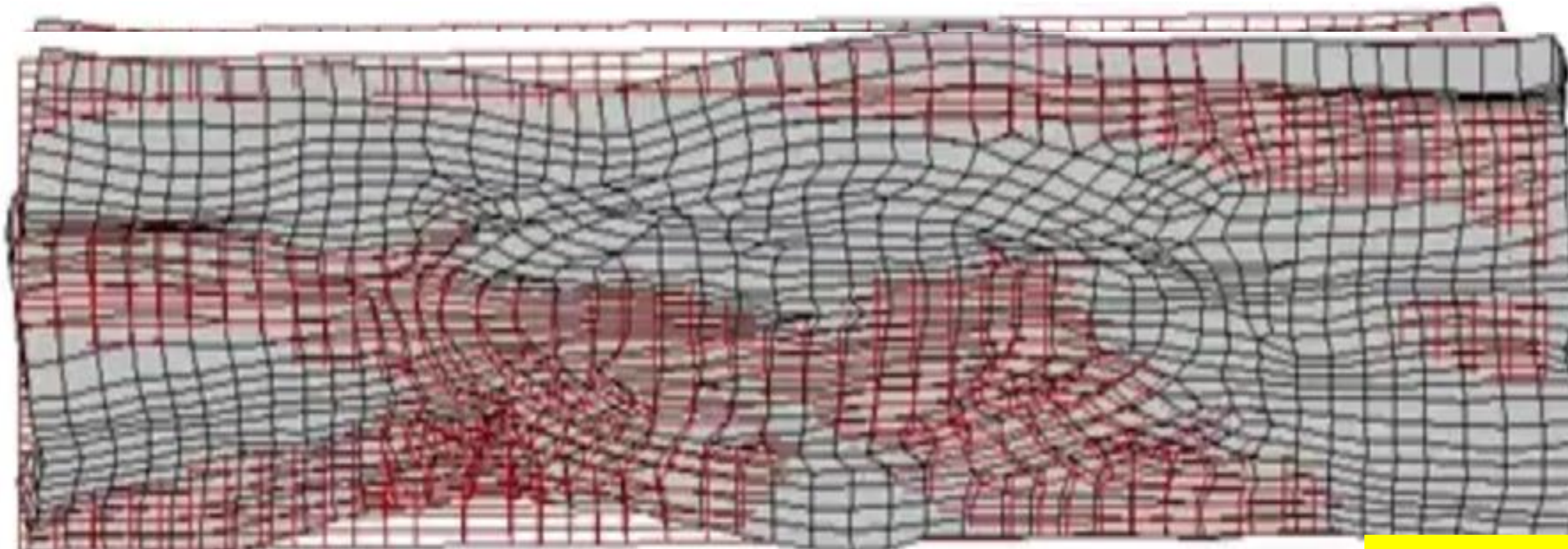
Freq	Part H	Part V
1 Hz	100%	98.2
8 Hz	84%	67%
25 Hz	7%	21%

At the lower frequencies, below 10 Hz, where a single mode (Mode 1) is governing, the zero-phase assumption practically neglects the differential phase variations between motion components due to incoherency.

Incoherency Simulation With Zero-Phasing (Loss of Physics)



Incoherency Simulation With Random Phasing (No Loss of Physics)



ANIMATIONS

Effects of Foundation Size on SSI Responses

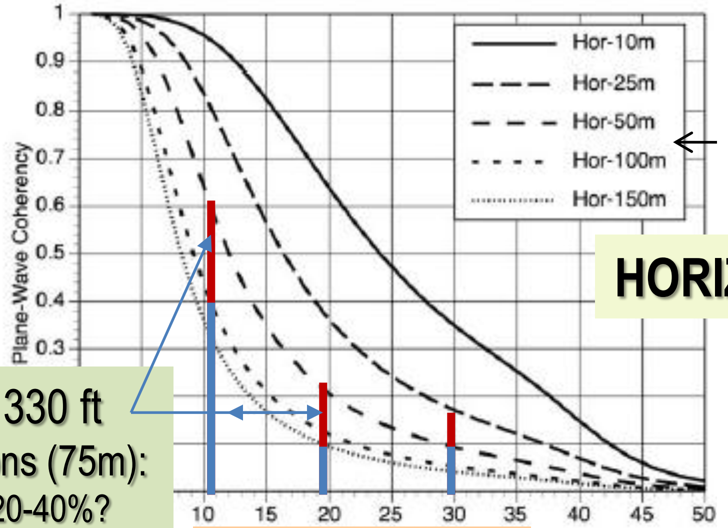
ASCE 04-1998 and SRP 3.7.2 Requirements

TABLE 3.3-2. Reductions to Ground Response Spectra

Frequency (Hz)	Reduction Factor for Plan Dimension of 150 ft	Reduction Factor for Plan Dimension of 300 ft
5	1.0	1.0
10	0.9	0.8
≥25	0.8	0.6

SRP 3.7.2
0.0/10Hz
0.7/30Hz
for all foundation sizes

2007 Abrahamson Coherence for Hard-Rock and Soil Sites

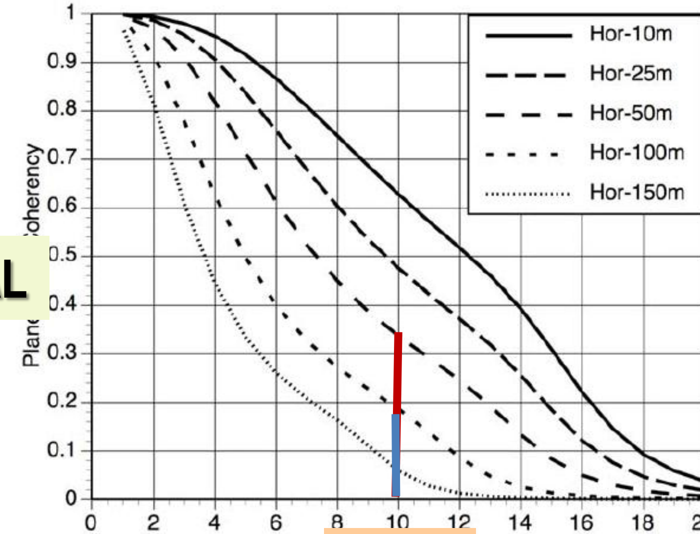


HORIZONTAL

420 ft x 330 ft
Reductions (75m):
At 10 Hz 20-40%?
At 20 Hz 50-70%?

HARD-ROCK

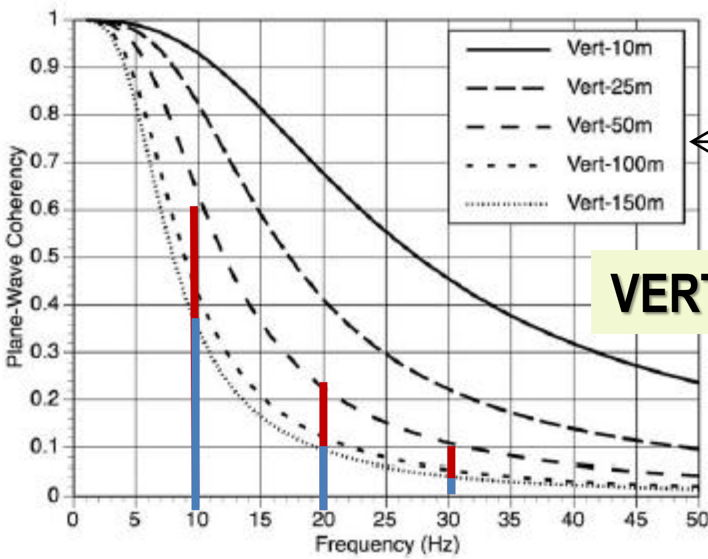
Figure 6-1
Plane-Wave Coherency for the Horizontal Component



SOIL

Figure 7-1
Plane-Wave Coherency for the Horizontal Co

Larger differential displacements for soils. May affect SSSI..?



VERTICAL

Figure 6-2
Plane-Wave Coherency for the Vertical Component

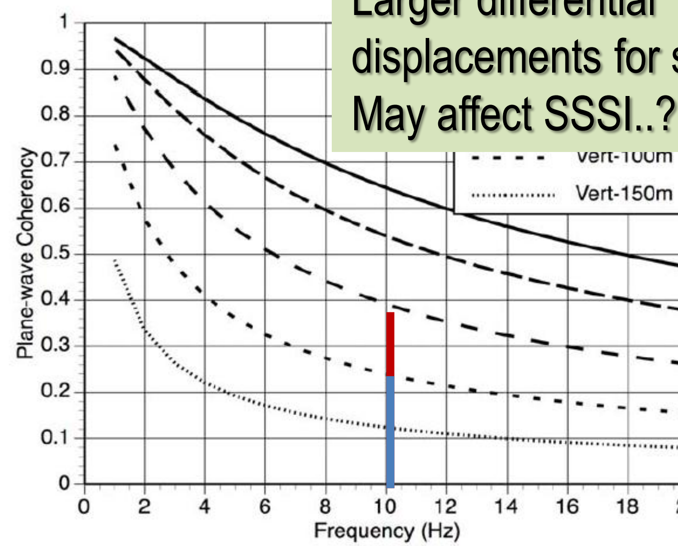
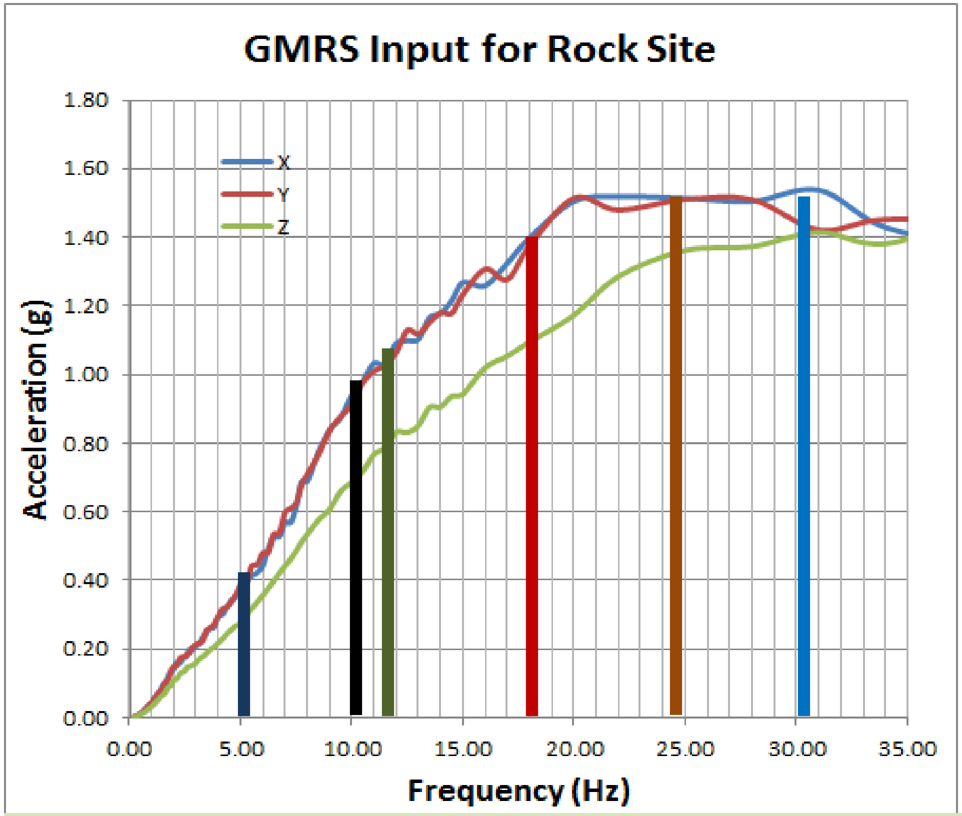


Figure 7-2
Plane-Wave Coherency for the Vertical Component for Soil Sites

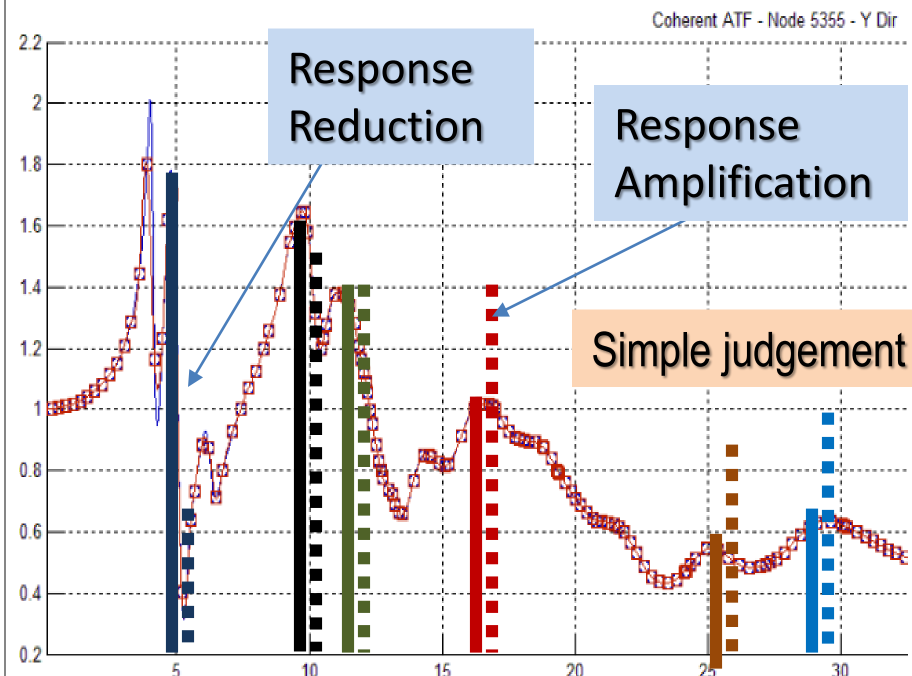
(EPRI TR # 1015110, December 2007)

Incoherency Effects on Multiple Mode SSI Responses

Seismic Motion Amplitude Shape

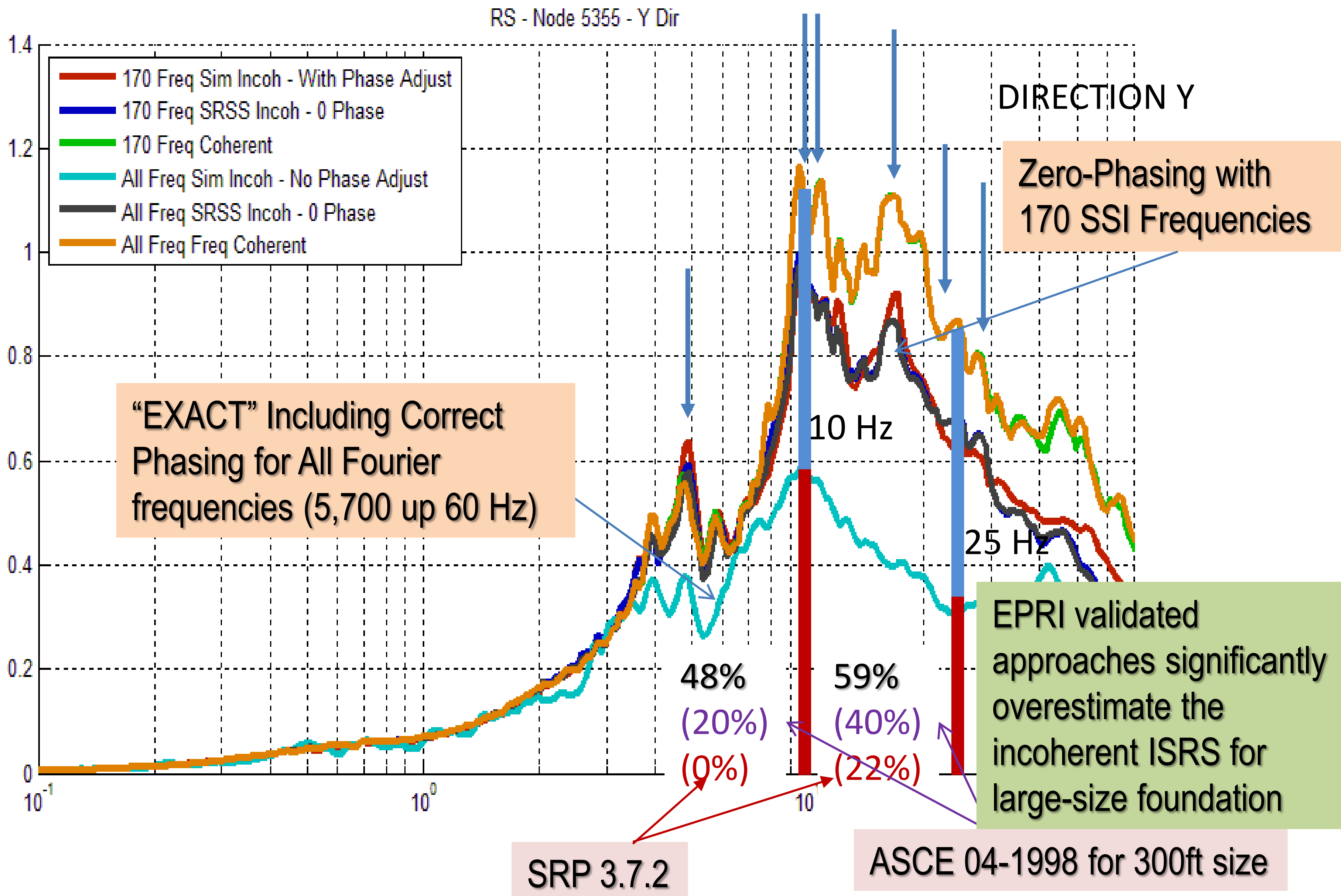


ATF Amplitude Spectral Shape

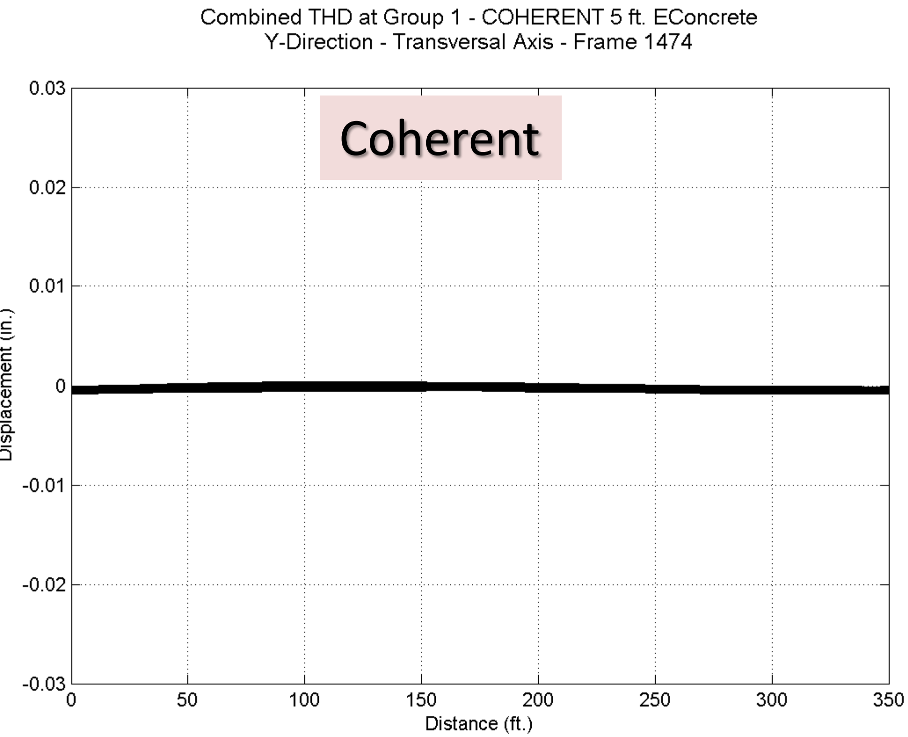


Remark: For the above GMRS, the ISRS at the selected location will be dominated by the 10 Hz, 12 Hz and 17 Hz mode responses. The 5 Hz component will be much lower. Incoherent ISRS reductions will correspond to a mix of components in the 10-17 Hz range.

Effects of Random Phasing on ISRS for Large-Size 420 ft x 330 ft RB Complex



Effects of Incoherency on Basemat Bending



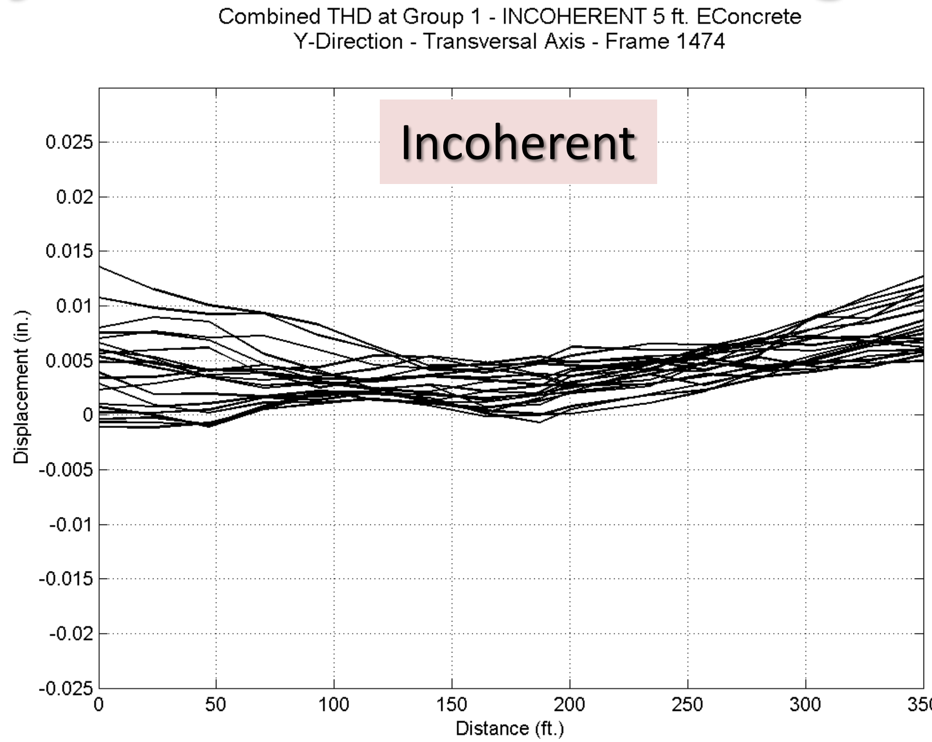


Table 1: Baseslab Bending Moments for A Soil Deposit with Vs = 3,300 ft/s

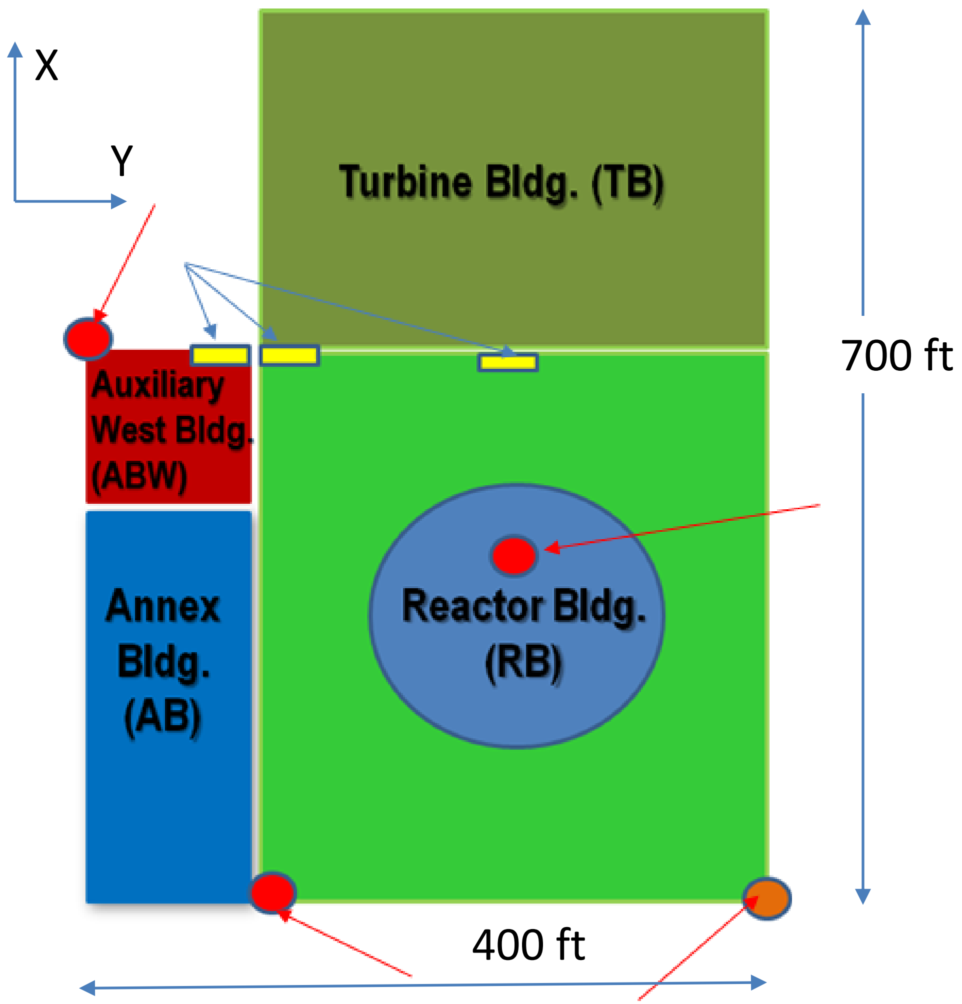
Zone #	Coherent MXX	Incoherent MXX	Ratio Inc/Coh MXX	Coherent MYY	Incoherent MYY	Ratio Inc/Coh MYY
1	10.293	15.196	1.476	9.567	14.812	1.548
2	8.345	19.986	2.395	7.197	14.901	2.070
3	10.291	13.499	1.312	9.695	15.475	1.596
[illegible]	[illegible]	[illegible].859	2.007	8.386	17.199	2.051
[illegible]	[illegible]	[illegible].618	1.986	7.124	14.879	2.089
[illegible]	[illegible]	[illegible].503	2.375	8.354	14.293	1.711

Remark: Incoherent bending moments are 130%-240% of coherent bending moments.

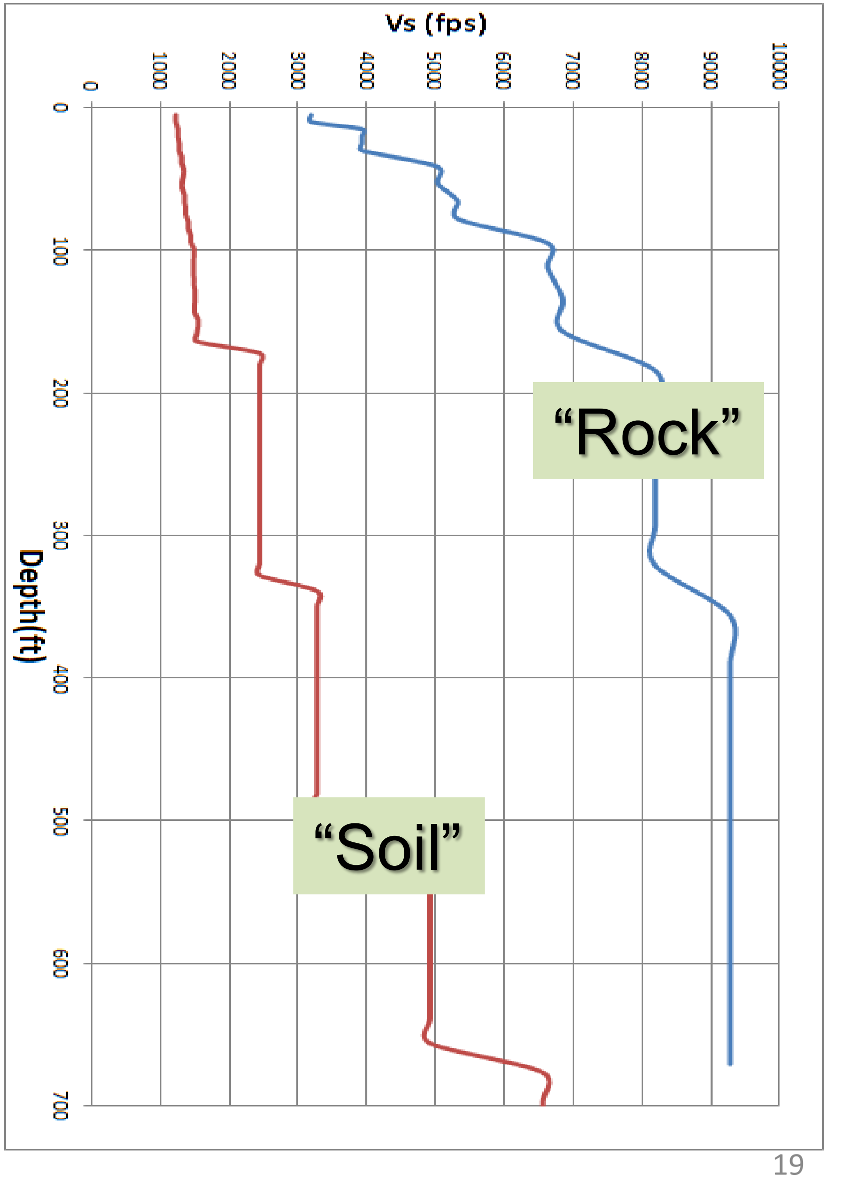
Incoherent vs. Coherent Seismic SSSI Effects

Generic NPP SSSI Model 1

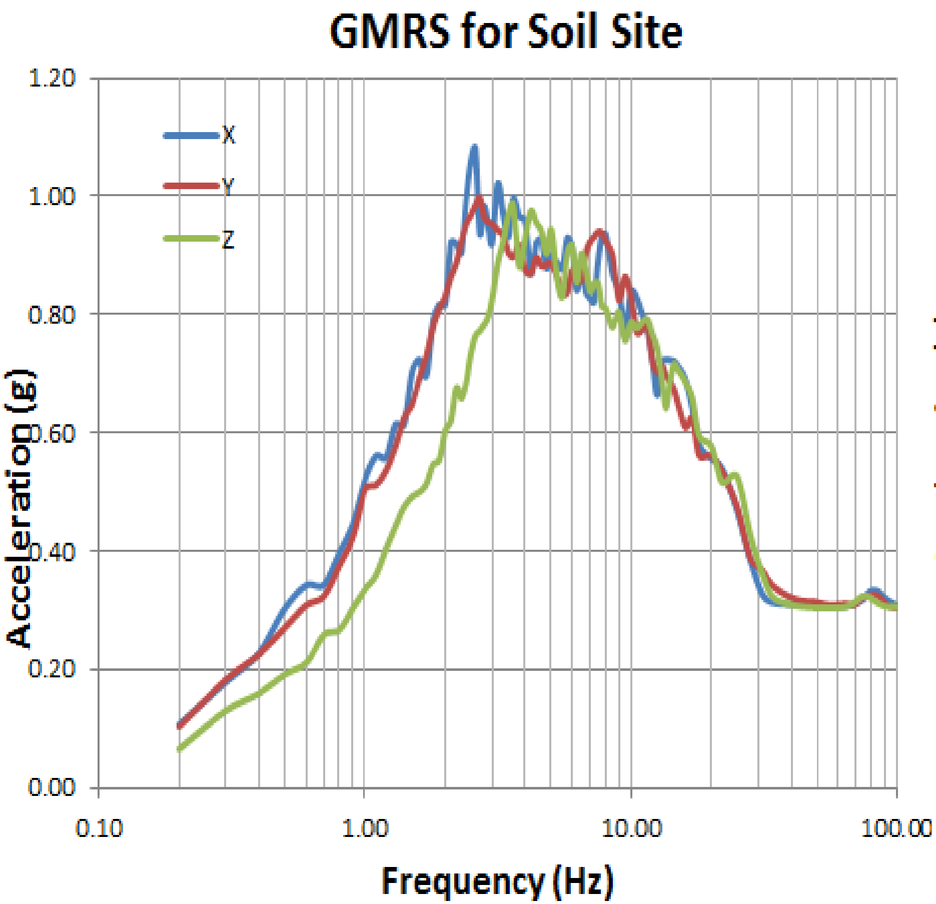
(55,000 nodes with 5,000 int. nodes, 27,000 shells, 13000 solids, 11000 beams)

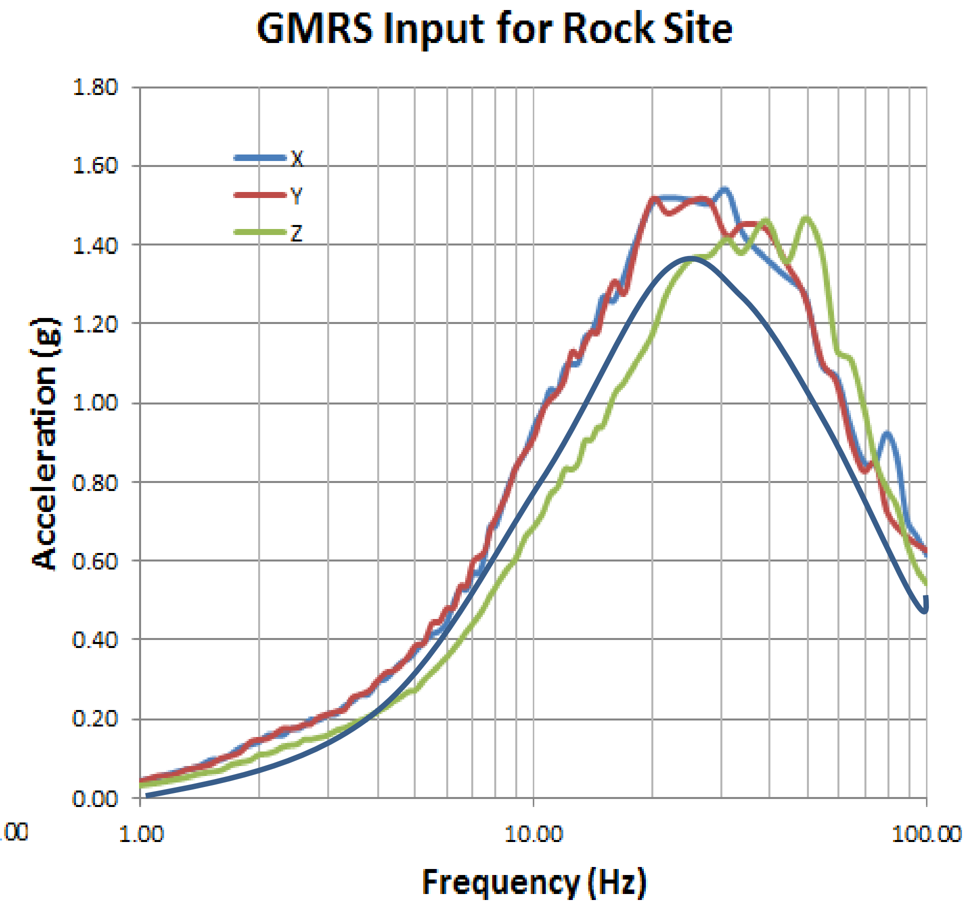


Soil Profiles

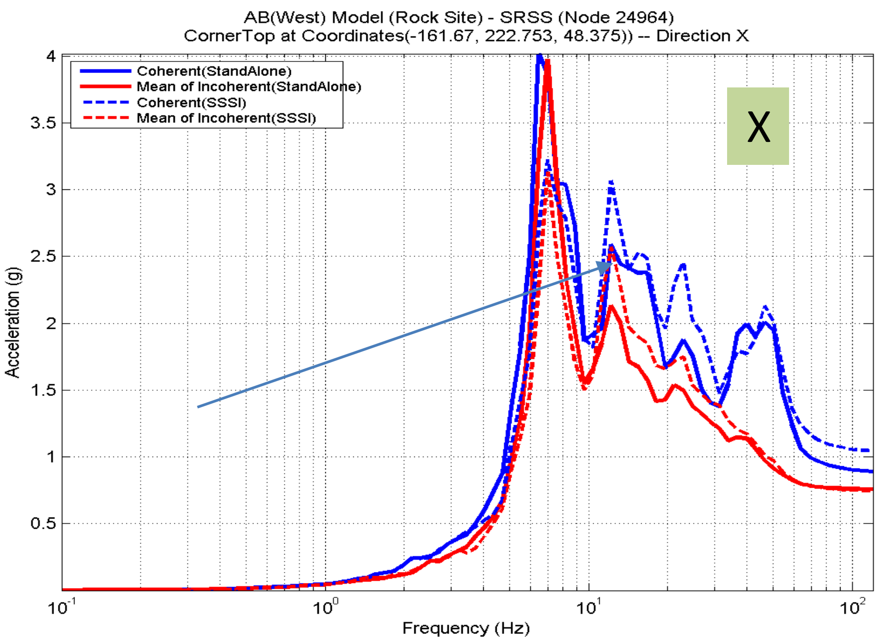


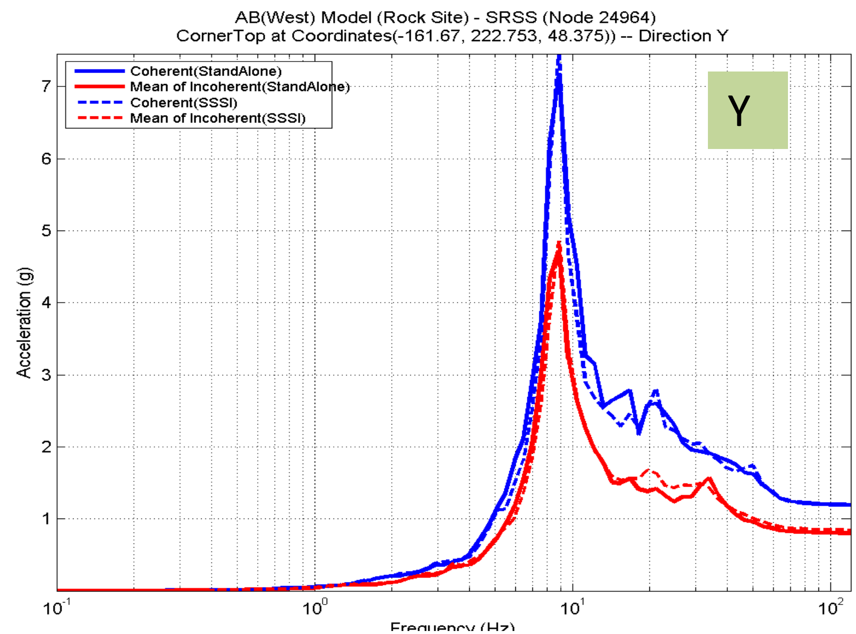
Seismic GMRS Surface Input for Soil and Rock Sites

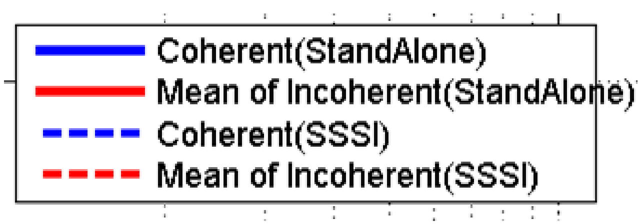


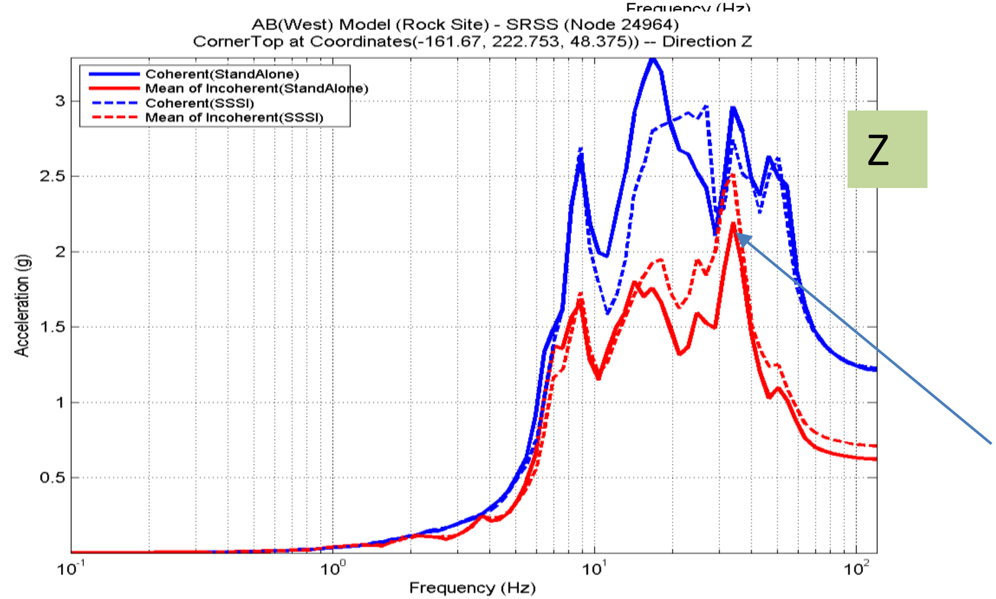


ABW Bldg. Coherent vs. Incoherent SSI and SSSI Effects for Roof Corner ISRS for Rock Site

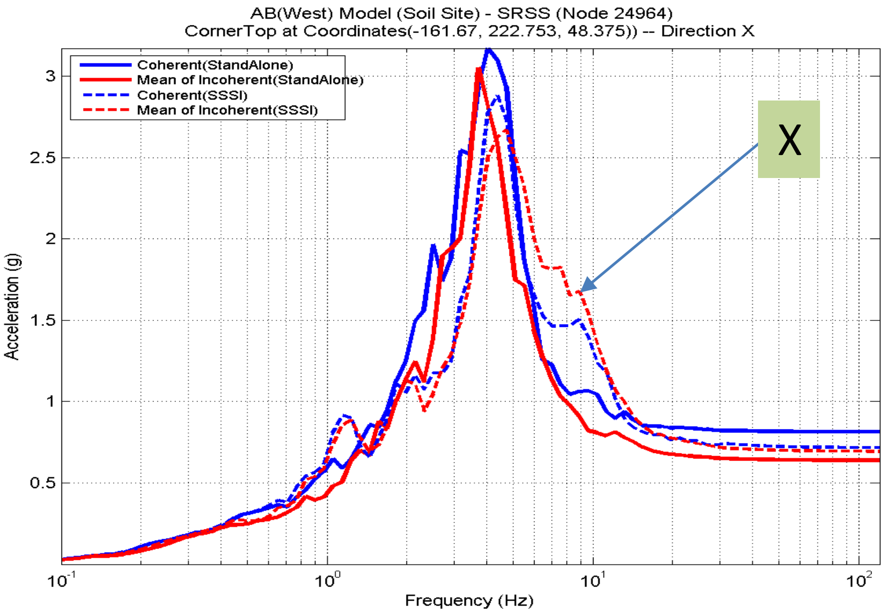


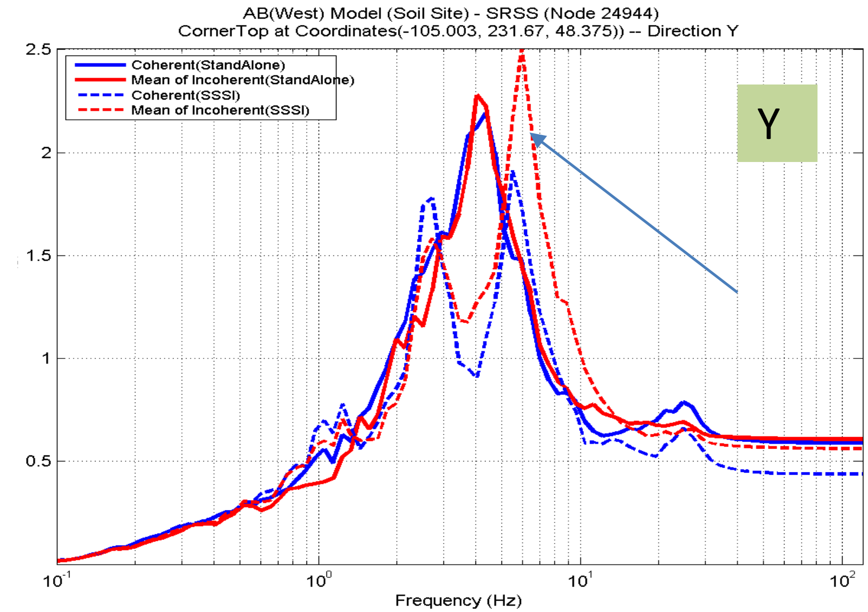


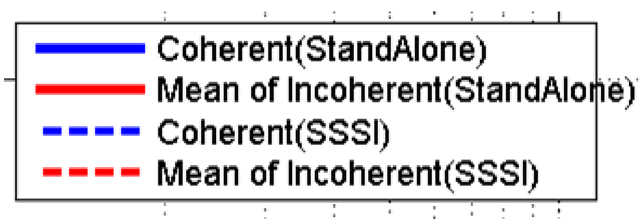


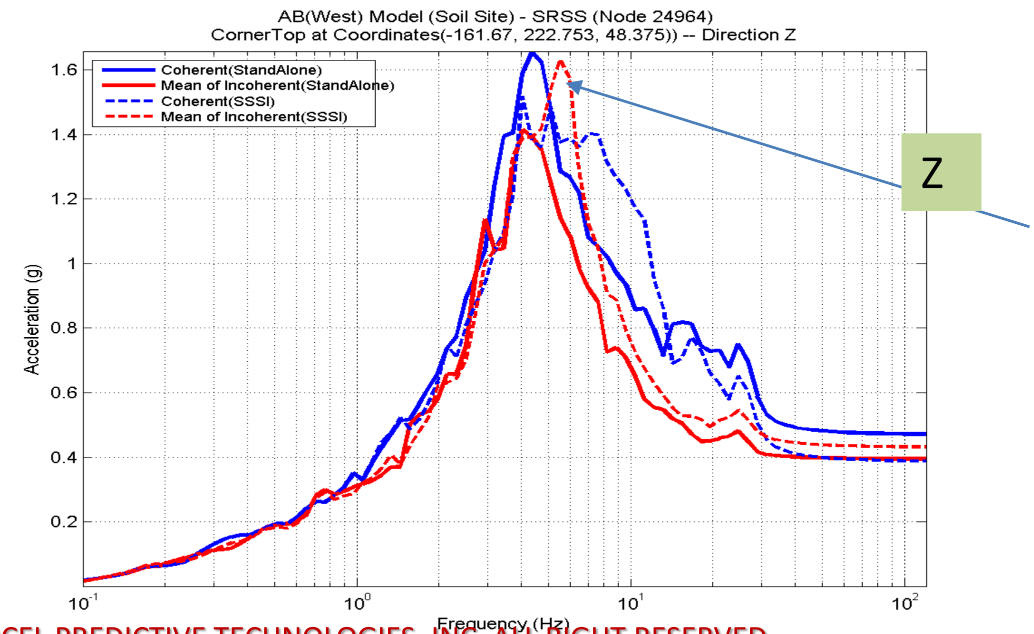


ABW Bldg. Coherent vs. Incoherent SSI and SSSI Effects for Roof Corner ISRS for Soil Site

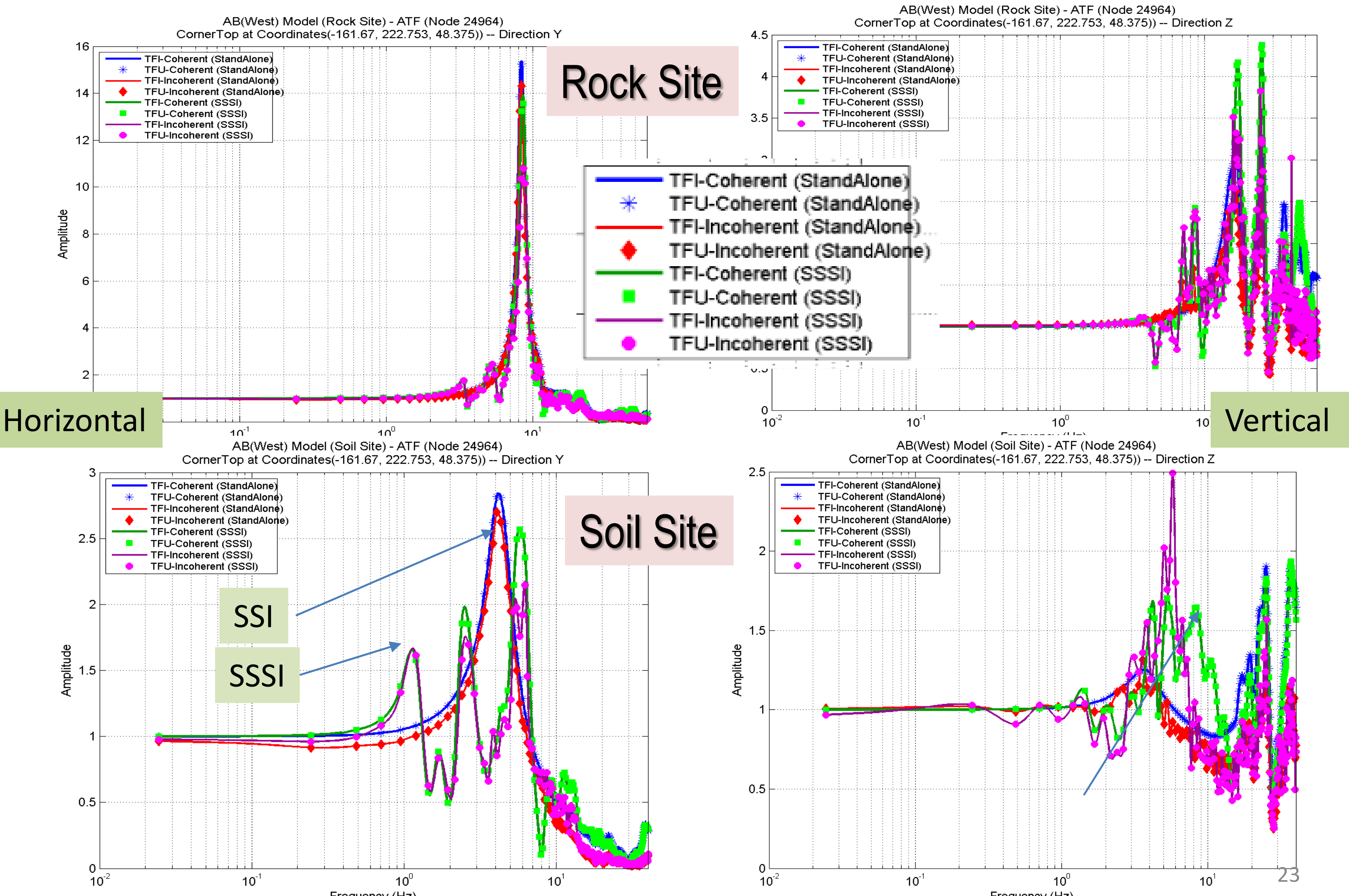




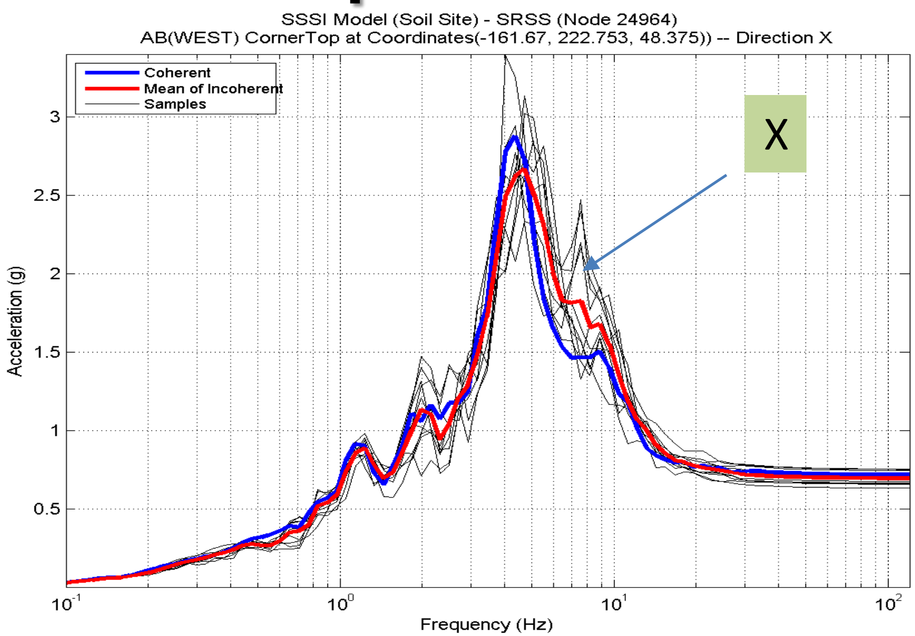


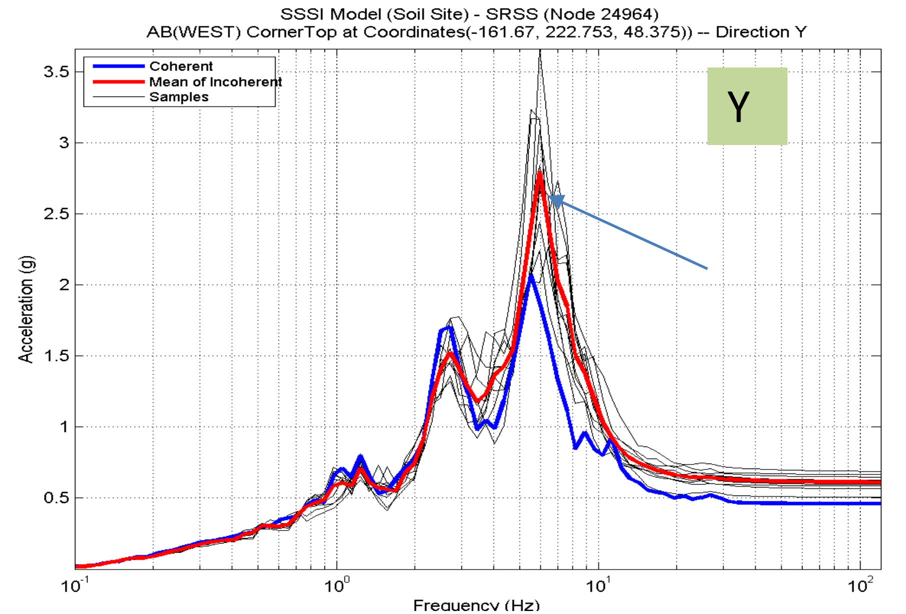


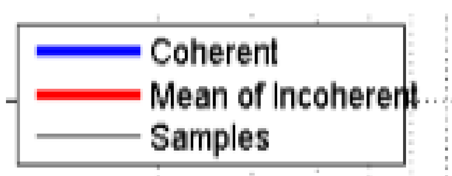
ABW Bldg. Coherent vs. Incoherent SSI and SSSI ATF for Roof Corner ISRS for Rock and Soil Sites

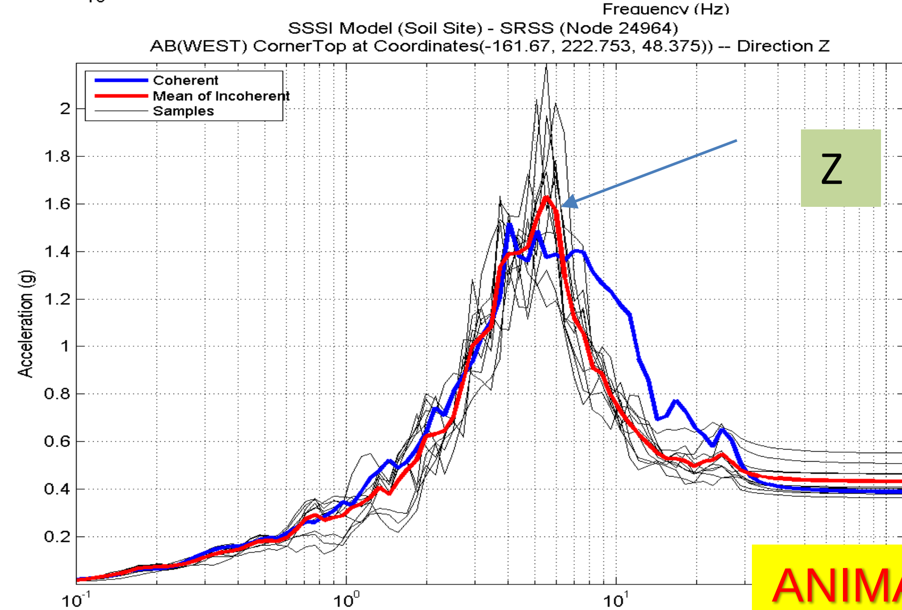


ABW Bldg. Coherent vs. Incoherent SSSI Simulated Responses for Roof Corner ISRS for Soil Site



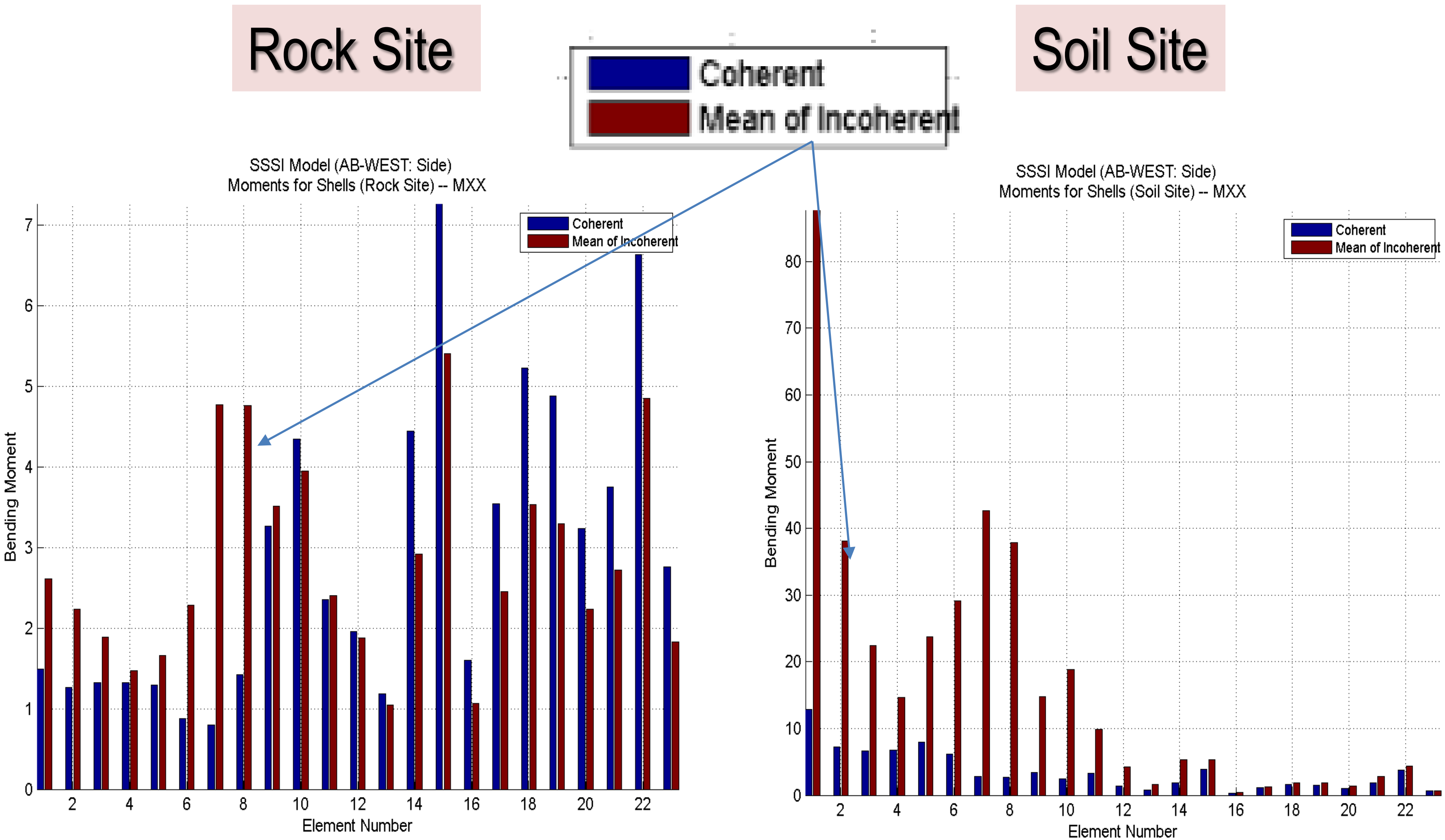




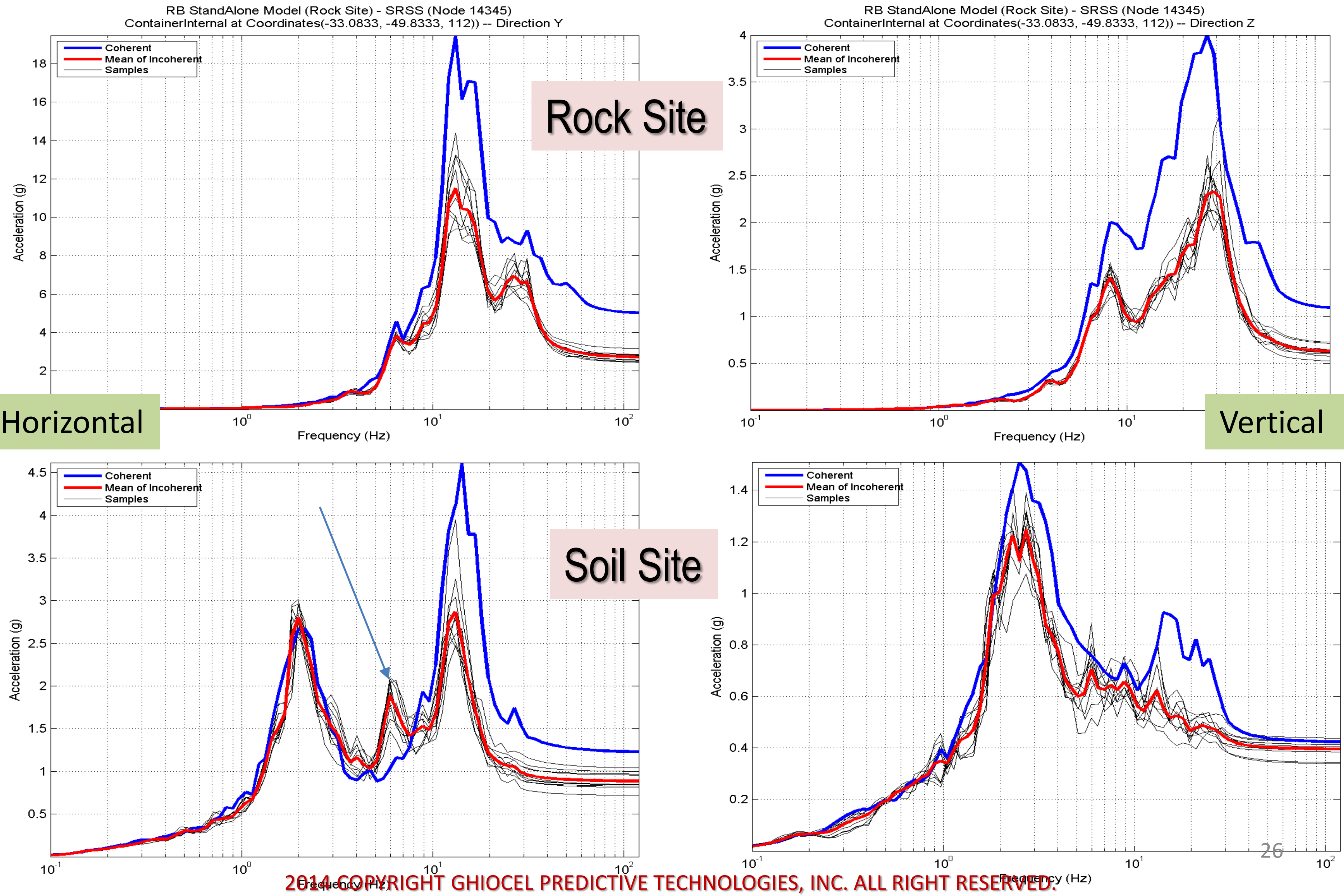


ANIMATIONS

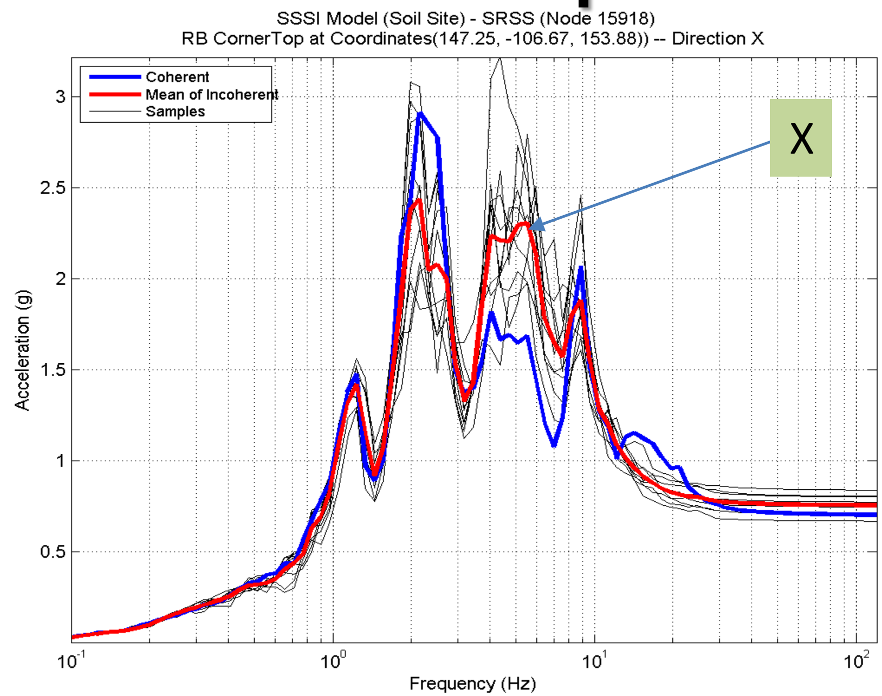
ABW Bldg. Coherent vs. Incoherent SSSI Effects on Bending Moments in Corner Walls Near RB Complex

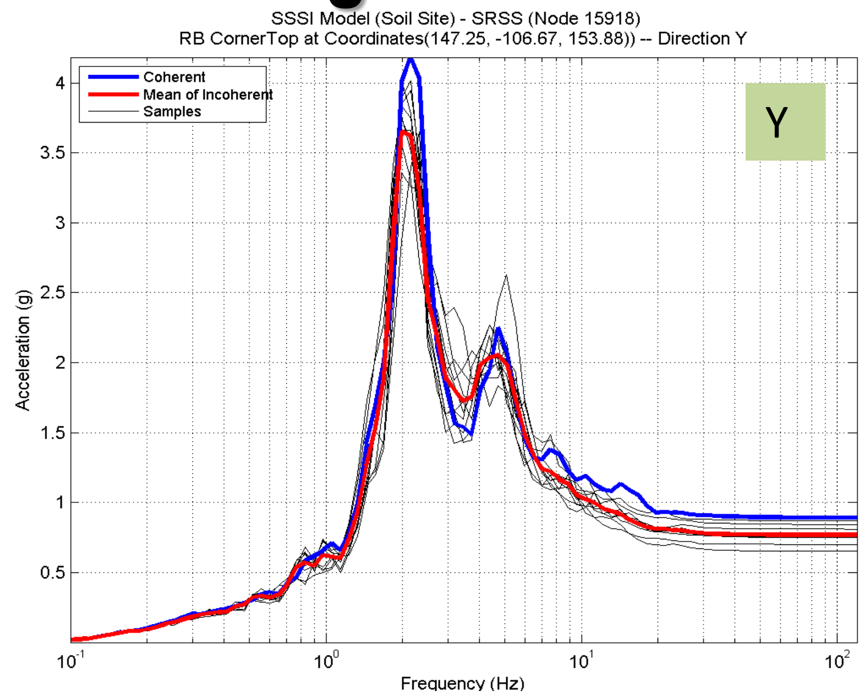


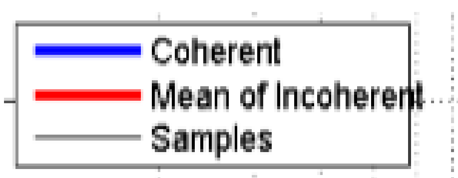
RB Complex Coherent vs. Incoherent SSSI Effects on ISRS on Top of Internal Structure – Y and Z Directions

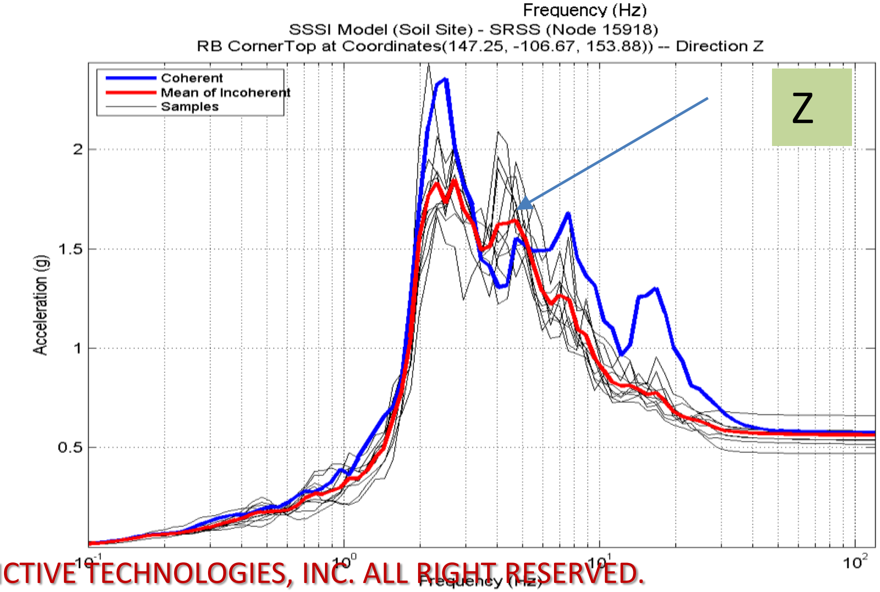


RB Complex Coherent vs. Incoherent SSSI Effects on ISRS at Top Corner Near AB Bldg. for Soil Site





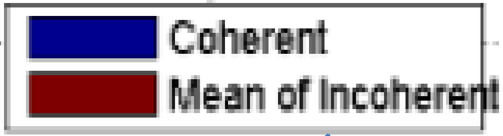


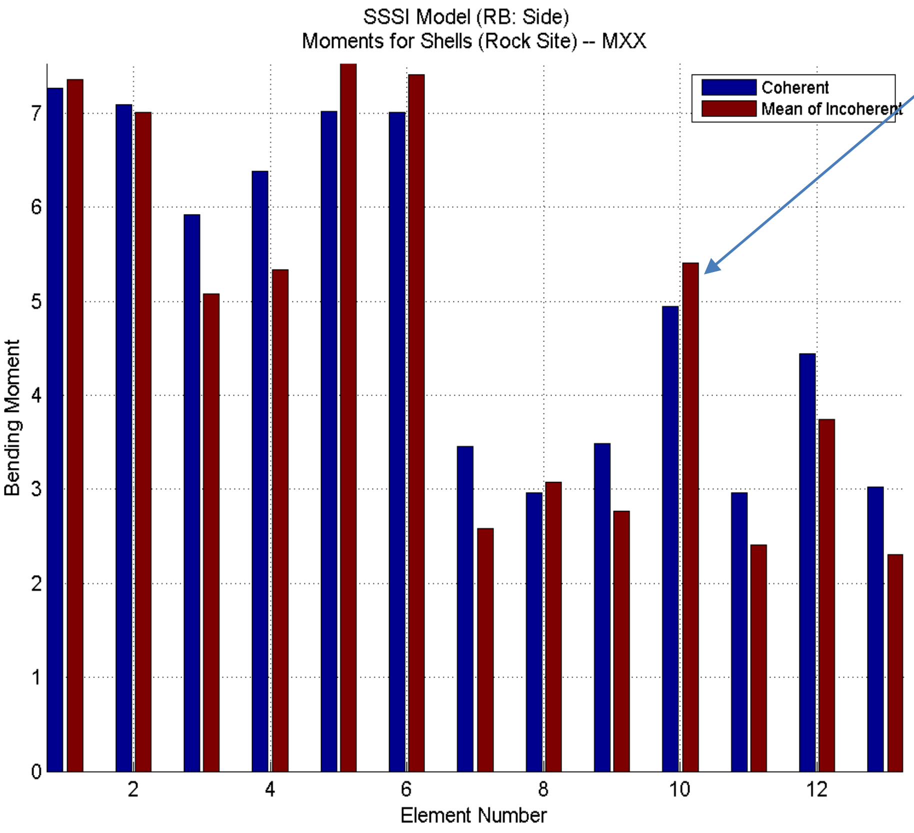


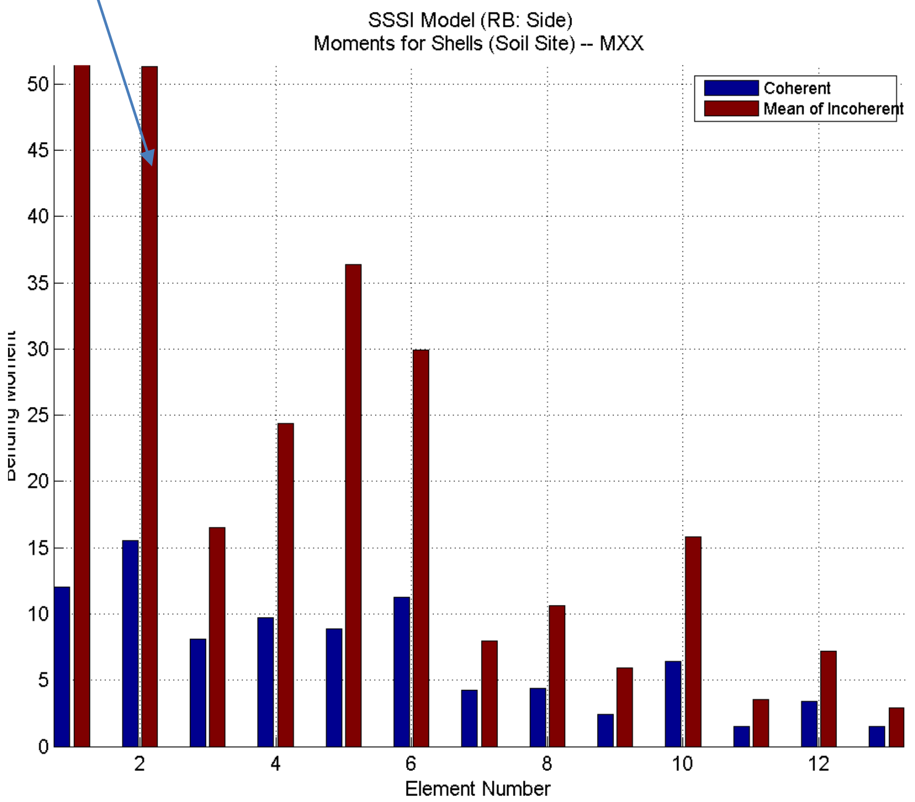
RB Complex Coherent vs. Incoherent SSSI Effects on Bending Moments in Corner Wall Near ABW Bldg.

Rock Site

Soil Site





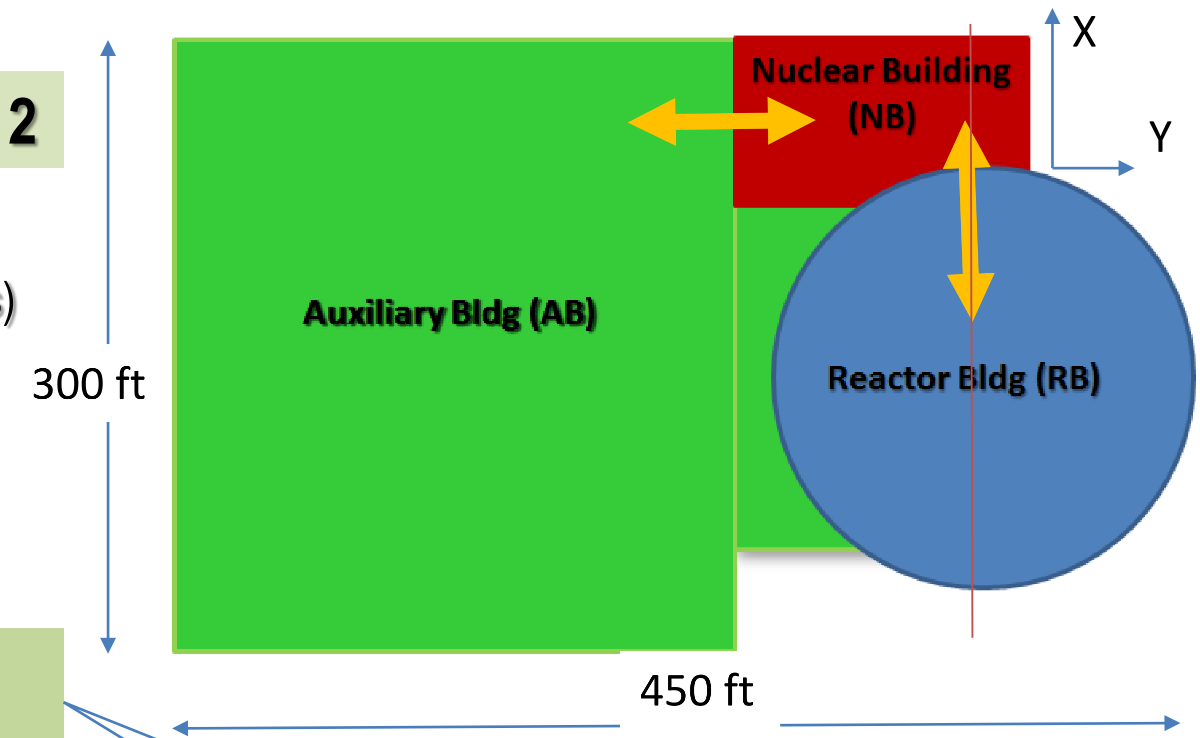


Incoherent vs. Coherent Seismic SSSI Effects

Generic NPP SSSI Model 2

(75,000 nodes with 11,000 int. nodes,45,000 solids, 11,000 shells)

Compute relative displacements between NB and RB buildings:

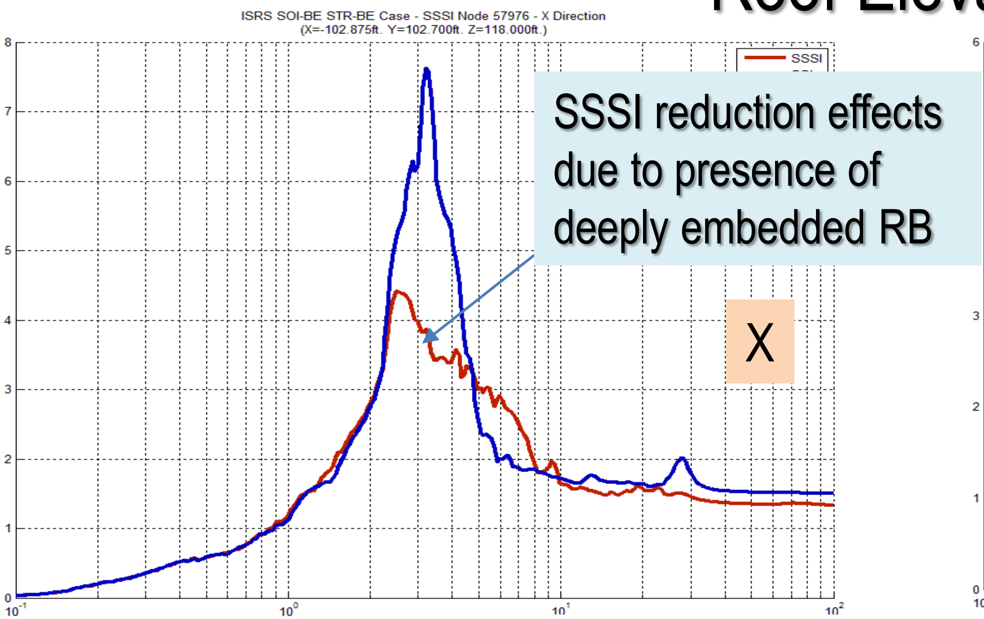


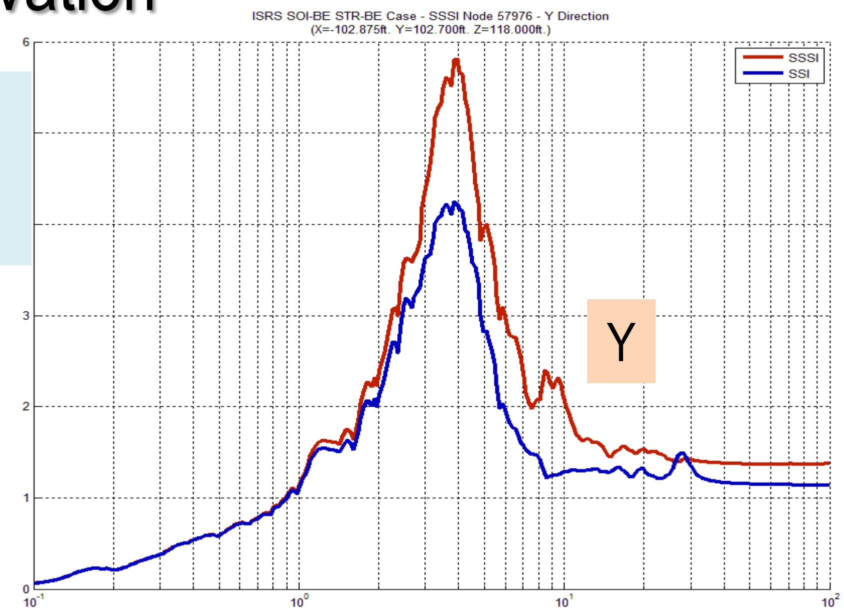
Differential motion amplitude is twice larger for incoherent input

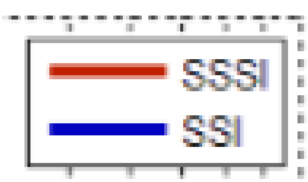
		Displacements									Absolute Difference of Displacements					
		Coordinates			Coherent			Incoherent-Sample1			Coherent			Incoherent-Sample1		
Node Number	Model	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
49678	RB	-75.615	27	30	0.012455	0.012657	0.004428	2.22419	2.62085	1.51993						
49760	FHB	-76.67	26.922	30	0.073812	0.033553	0.152572	2.35583	2.65359	1.65843	0.061357	0.020896	0.148144	0.13164	0.03274	0.1385
14966	RB	-72.881	33.75	30	0.012455	0.012657	0.004428	2.22419	2.62085	1.51993						
32740	FHB	-73.941	33.611	30	0.072556	0.035056	0.133265	2.35014	2.65559	1.62887	0.060101	0.022399	0.128837	0.12595	0.03474	0.10894

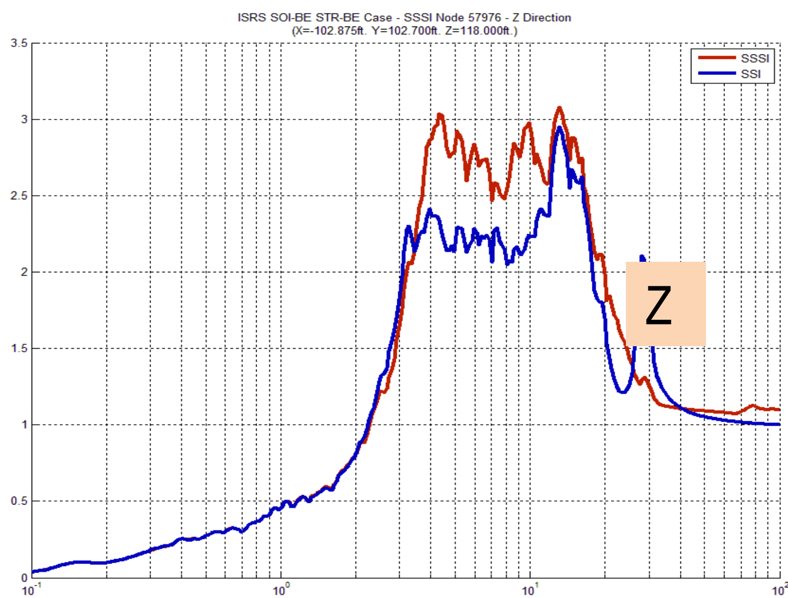
Seismic SSSI Effects on the Adjacent NB ISRS

Roof Elevation



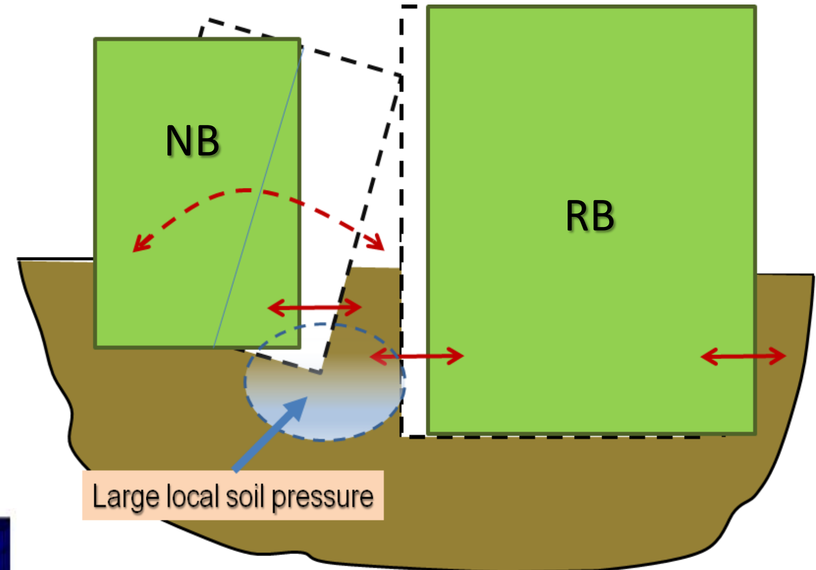






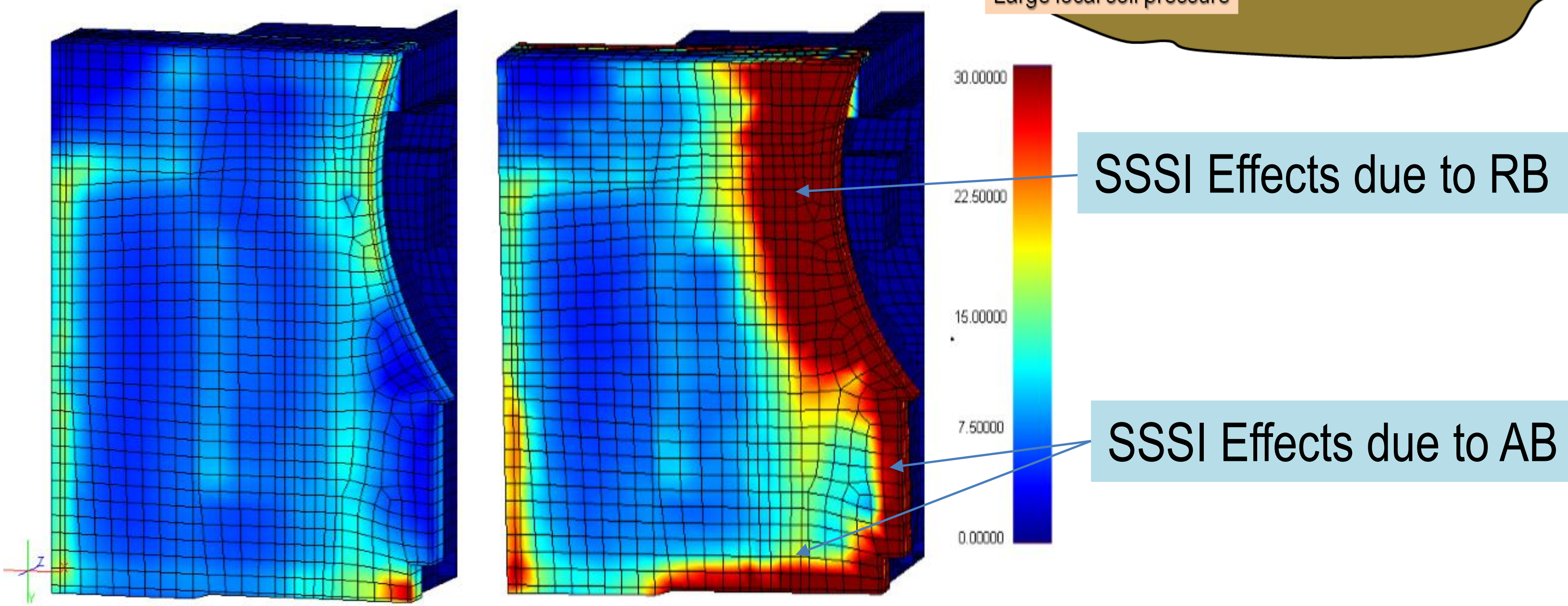
Seismic SSSI Effects on NB Basemat Pressures

SSSI Effects may increase severely seismic pressures on foundation walls and basemat. Suggestion to include local nonlinear soil behavior (only 2-3 iterations)

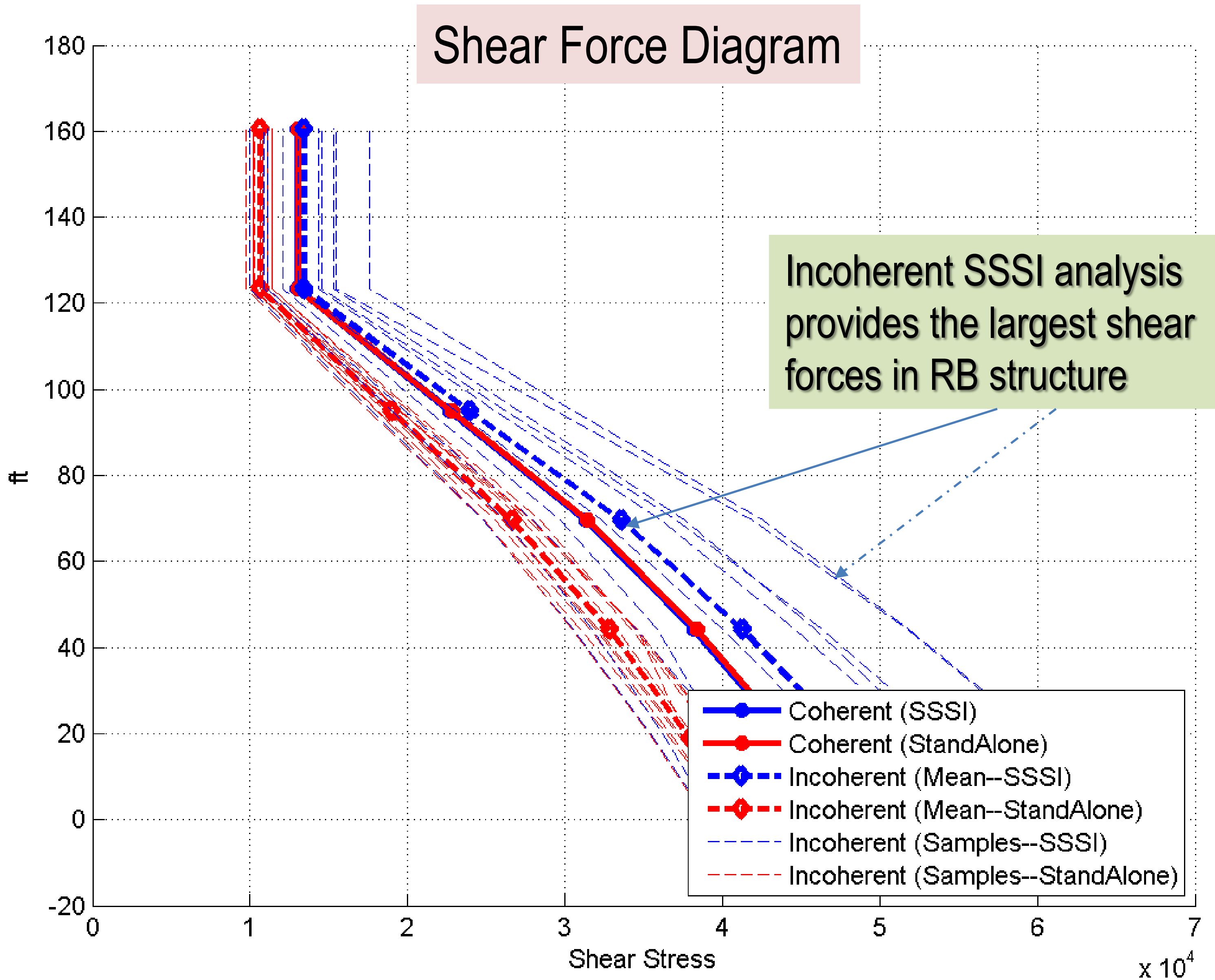


SSI Pressures

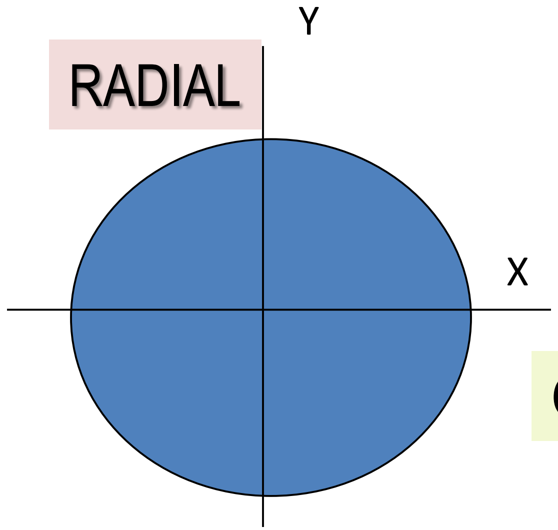
SSSI Pressures



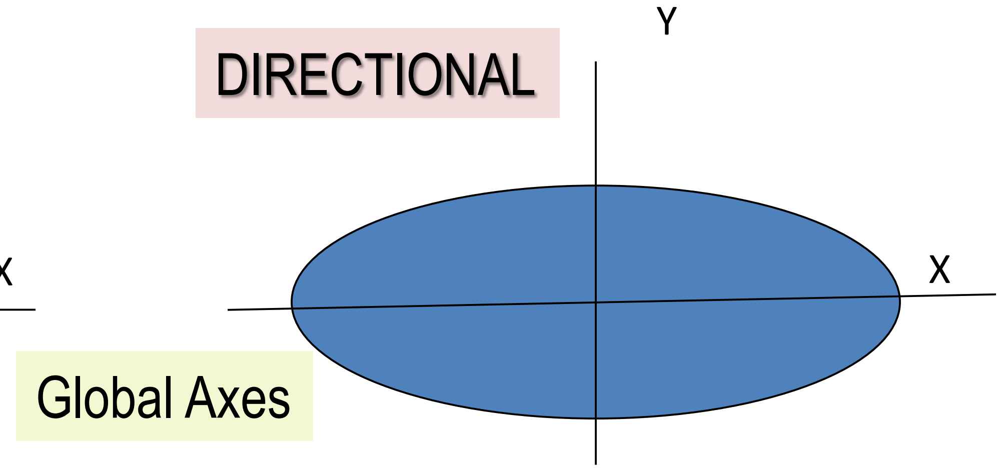
Seismic SSSI Effects on Shear Forces in RB



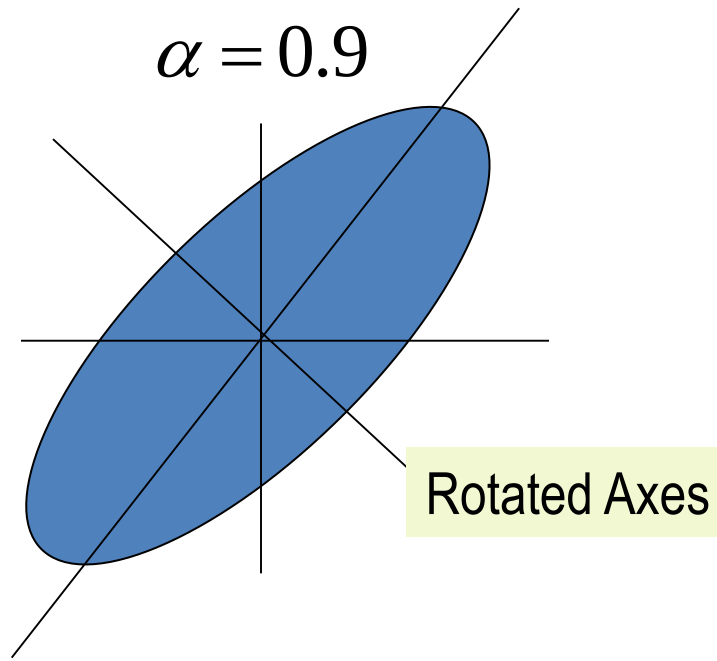
Abrahamson Radial vs. Directional Coherency Models



$\alpha = 0.5$



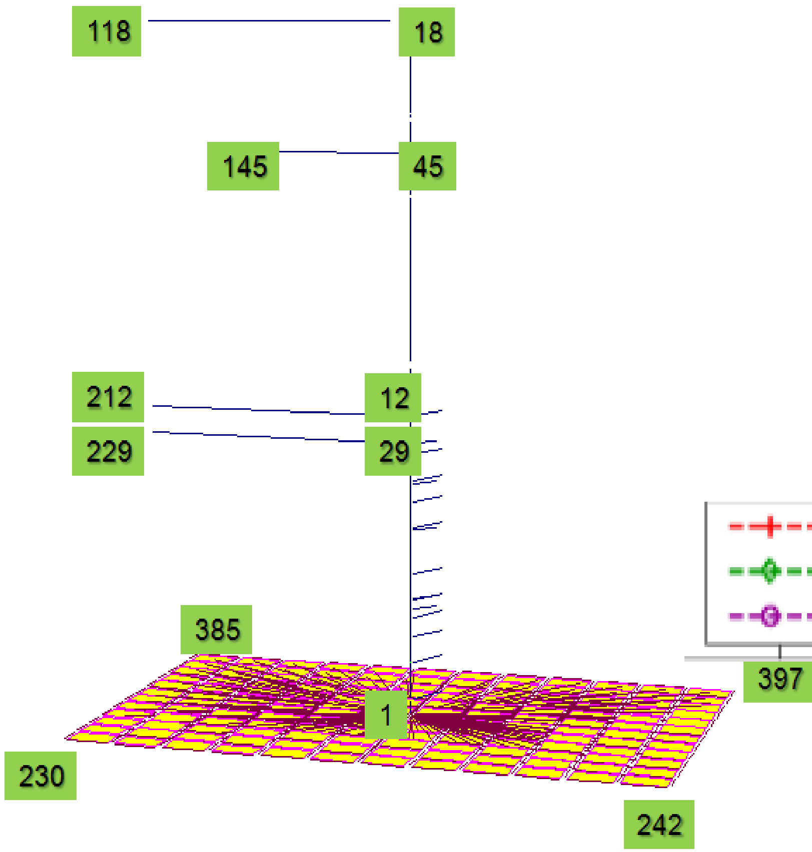
$\alpha = 0.9$

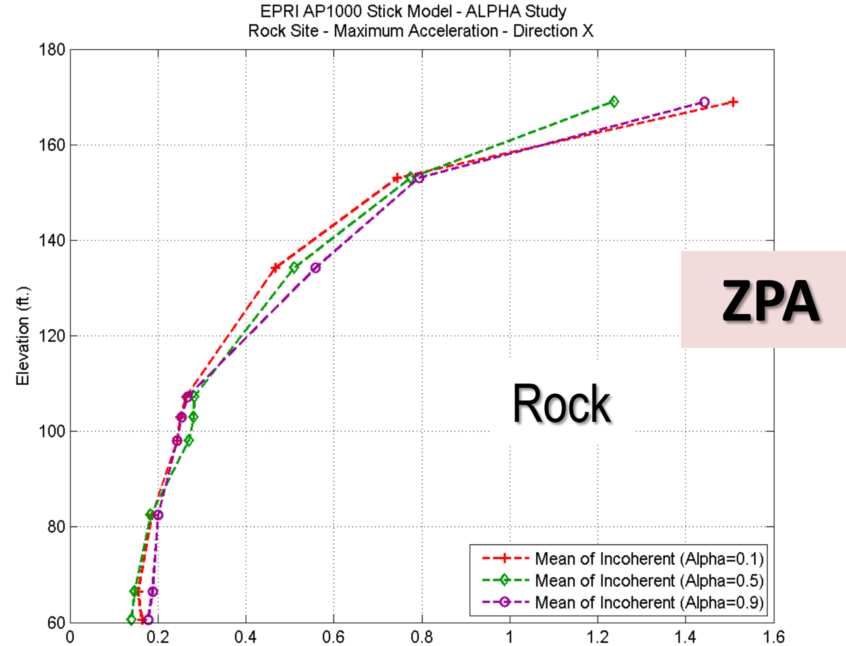


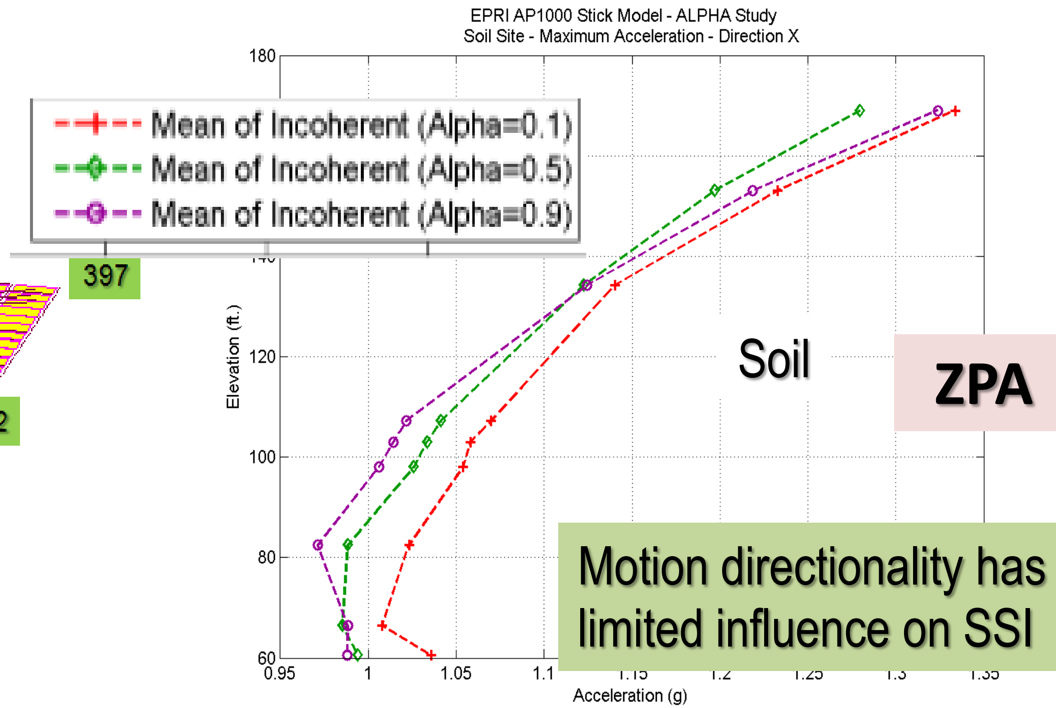
Incoherency distance is

$$D\vee\varsigma = \varsigma[(\mathrm{I} - \alpha)D^{x}{}_{\vee}\varsigma + \alpha D^{\lambda}{}_{\vee}\varsigma]$$

EPRI AP1000 NI Stick Model Study







- Soil Site, Vs = 1,000 fps, CSDRS, AB2007Soil
- Rock Site, Vs = 6,000 fps, EPRIRockRS, AB2007Rock

Motion directionality has limited influence on SSI

Conclusions for Investigated Cases

- Incoherent motion describes a realistic, 3D random wave field motion.
- For realistic, elastic foundations, truncating the number of incoherent modes produces unconservative results in the high-frequency range.
- Zeroing the incoherent motion phasings produces overly conservative results in mid-frequency range at the price of the loss of physics – spatial correlation between support motions is neglected. Not applicable to the multiple time history analysis of RCL system.
- SSSI effects are significant for soil sites and possibly non-negligible for rock sites. Affect ISRS, soil pressures, foundation wall bending. Affect less the shear forces in the structure.
- Incoherent SSI effects are larger or different than the coherent SSSI effects.
- Incoherency model directionality, radial vs. directional, produces less significant effects on SSI response.