Critical Modeling and Implementation Aspects for Seismic Incoherent SSI Analysis of Nuclear Structures with Surface and Embedded Foundations for Rock and Soil Sites

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Complementary to 2014 DOE NPH SSI Presentation

2016 DOE Natural Phenomena Hazards Meeting
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Purpose of This Presentation:

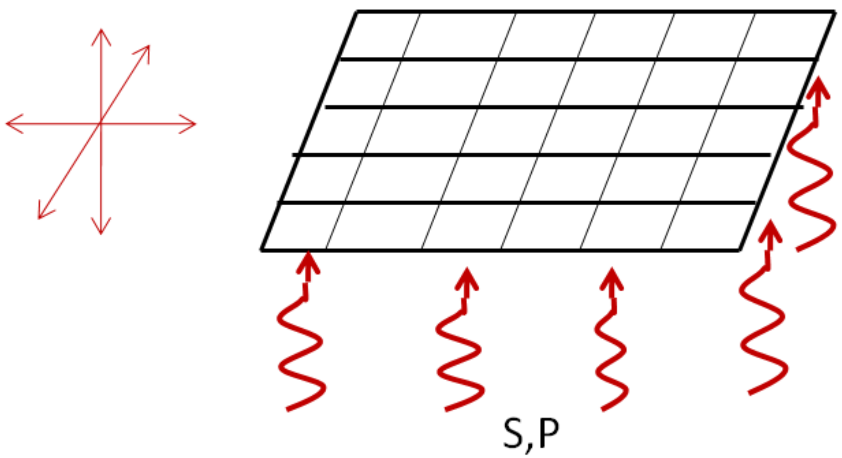
To answer to the following important questions:

- What is the meaning of “incoherent motion”?
- How important is the foundation size influence on ISRS?
- How important is the seismic input directionality on ISRS?
- Is incoherency influencing the SSSI effects on ISRS, inter-building gap sizing, and computed soil pressures?
- How significant are incoherency effects on the o-p bending moments of foundation mats and walls?

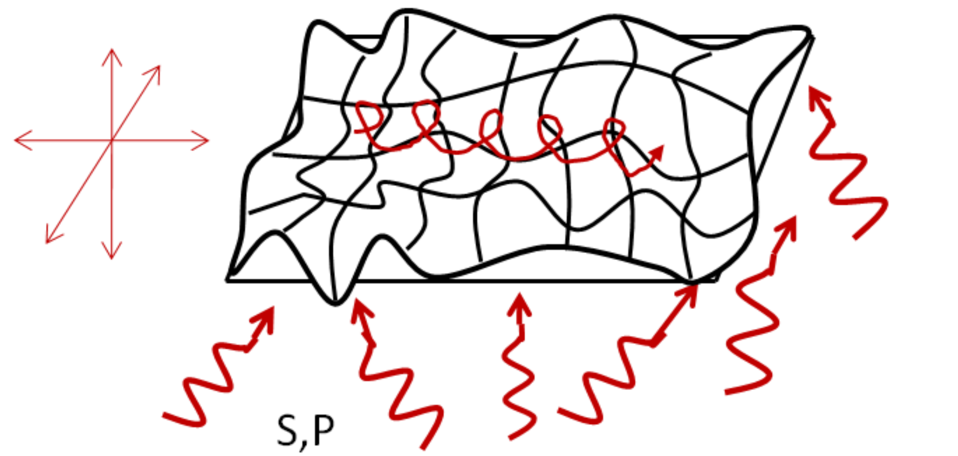
The 2016 ACS SASSI NQA V3 software was used.
The new version can run 20-25 incoherent stochastic simulations in a single SSI run for all X, Y and Z directions. This is 15-20 times faster than using a SSI restart for each simulation. What took 8 months for the APR1400 NI incoherent SSI project using the simple EPRI INCOH SRSS approach, can take only 8 days or less, using also a much more rigorous simulation approach.

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:

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

Structural transfer function given input at interaction nodes

Coherent ground transfer function at interface nodes given control motion

Complex Fourier transform of control motion

- Incoherent SSI response:

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

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

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

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)

Background on 2007 EPRI Validated Incoherent SSI Approaches Based on "*Industry Consensus*"

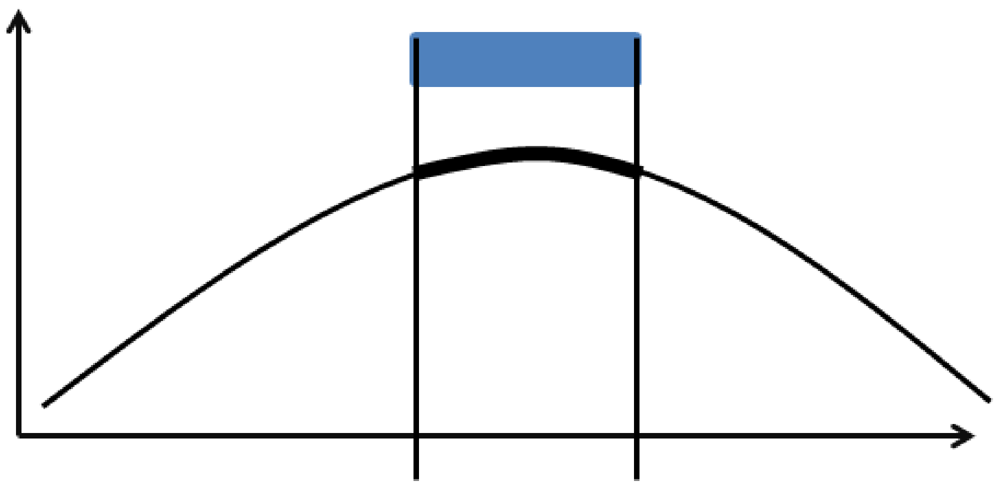
The 2007 EPRI validated approaches were based on industry *consensus*. The EPRI industry team uses three codes: ClassiInco, ACS SASSI and SASSI Bechtel codes. The industry *consensus* was built around the SRSS approach that assumes zero phasing for the SSI complex responses.

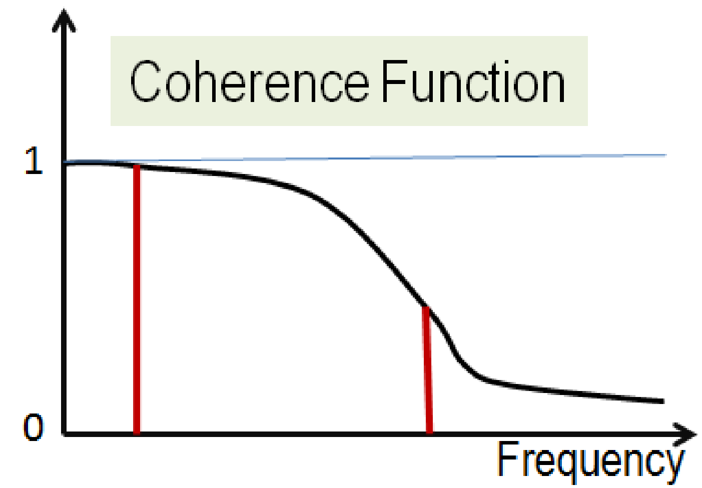
To match the team *consensus results* based on SRSS approaches, the Stochastic Simulation approach was used only with the "phase adjustment" option, that basically is zeroing the complex response phasing. *The "theoretically exact" solution should include no phase adjustment*

It should be understood that *by neglecting the complex random phasing, the incoherent SSI responses are less incoherent*, and by this creates a bias toward coherent responses, that most likely is conservative for practical applications, but this is not always the case, as discussed herein.

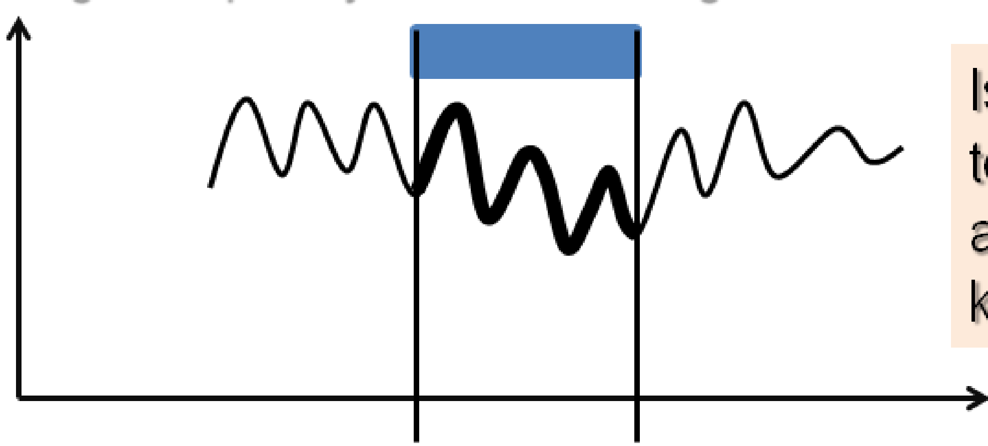
How Many Modes Should Be Considered for SRSS Approaches? SS Considers All!

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



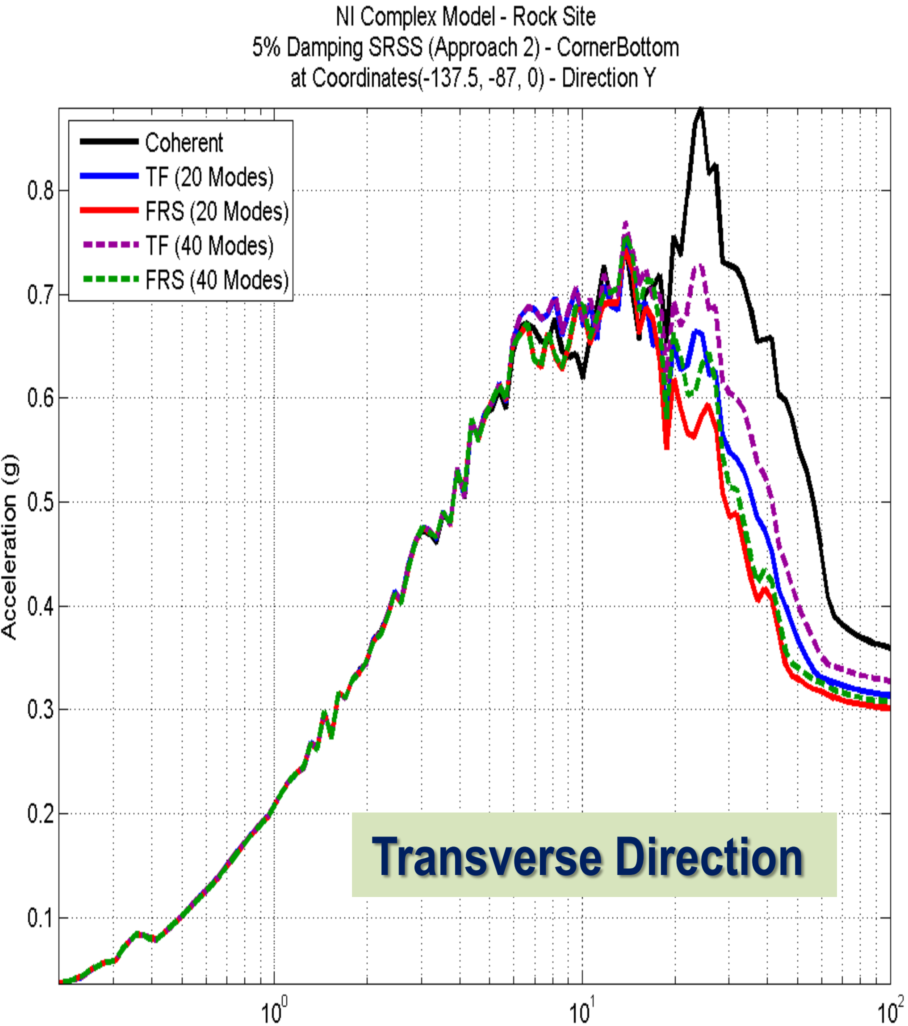


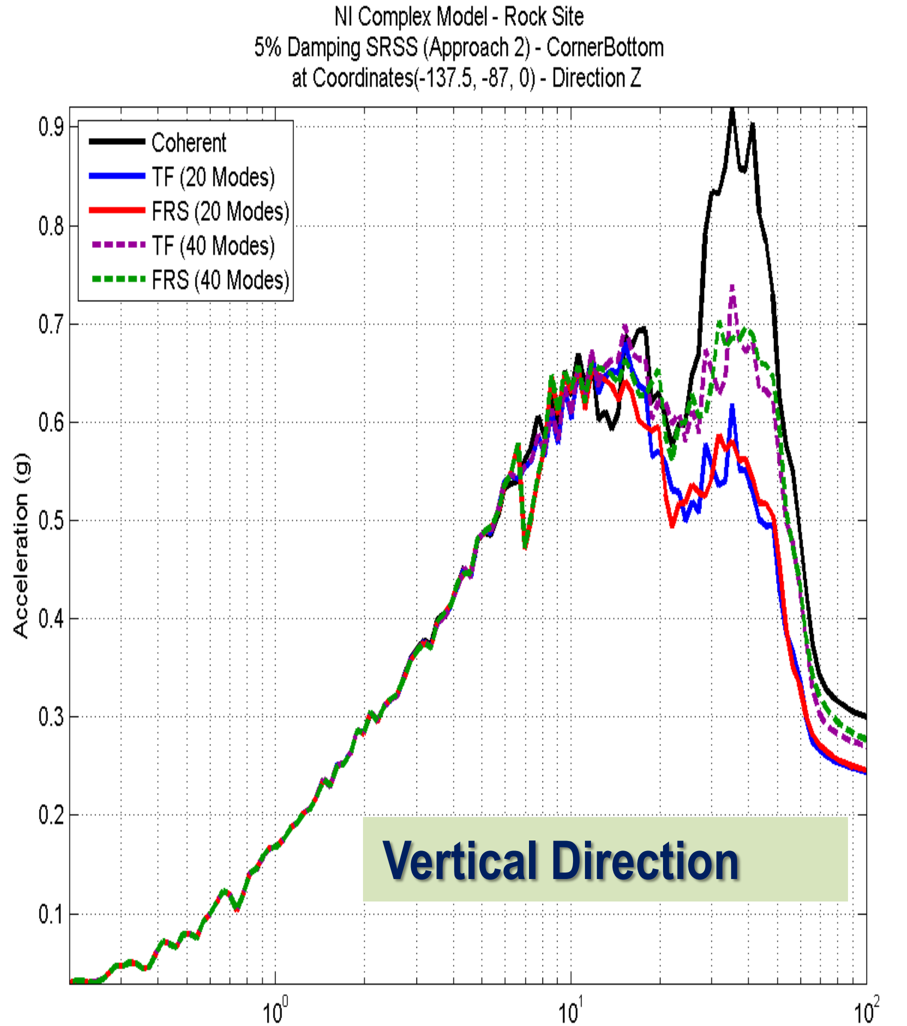
High Frequency/Short Wavelengths/Low and High Order Incoherency Modes



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

Comparative 20 vs. 40 Incoherent Mode Solution Using SRSS Deterministic Approach

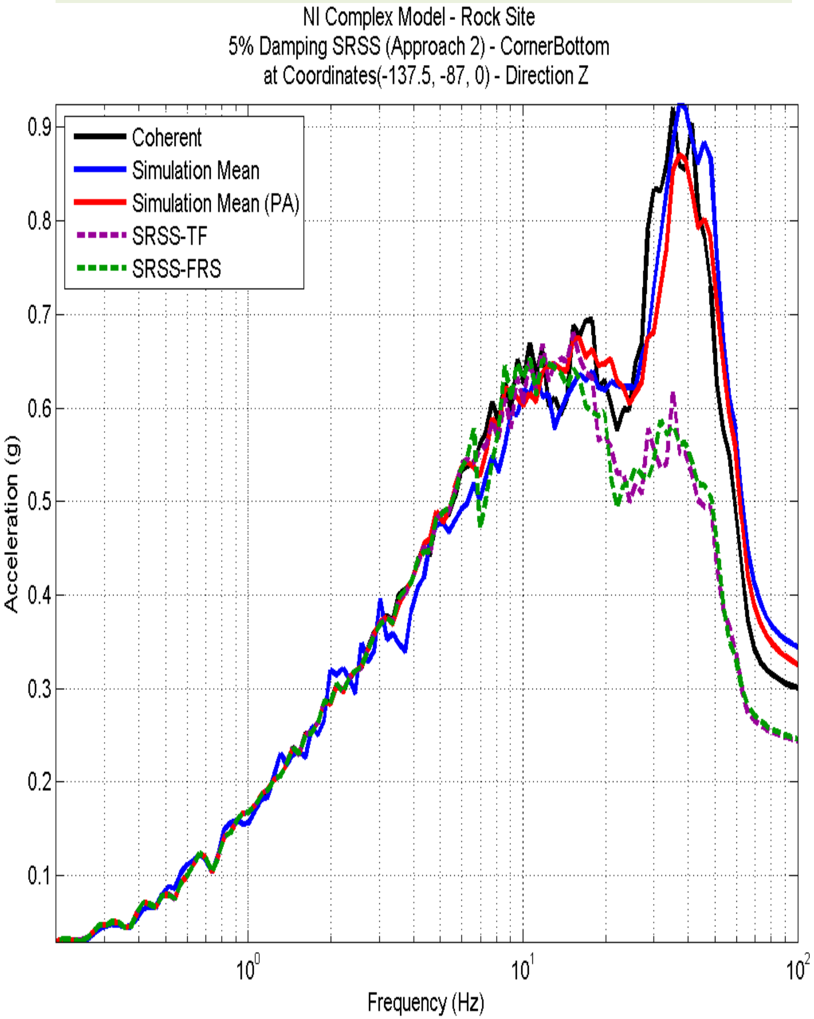




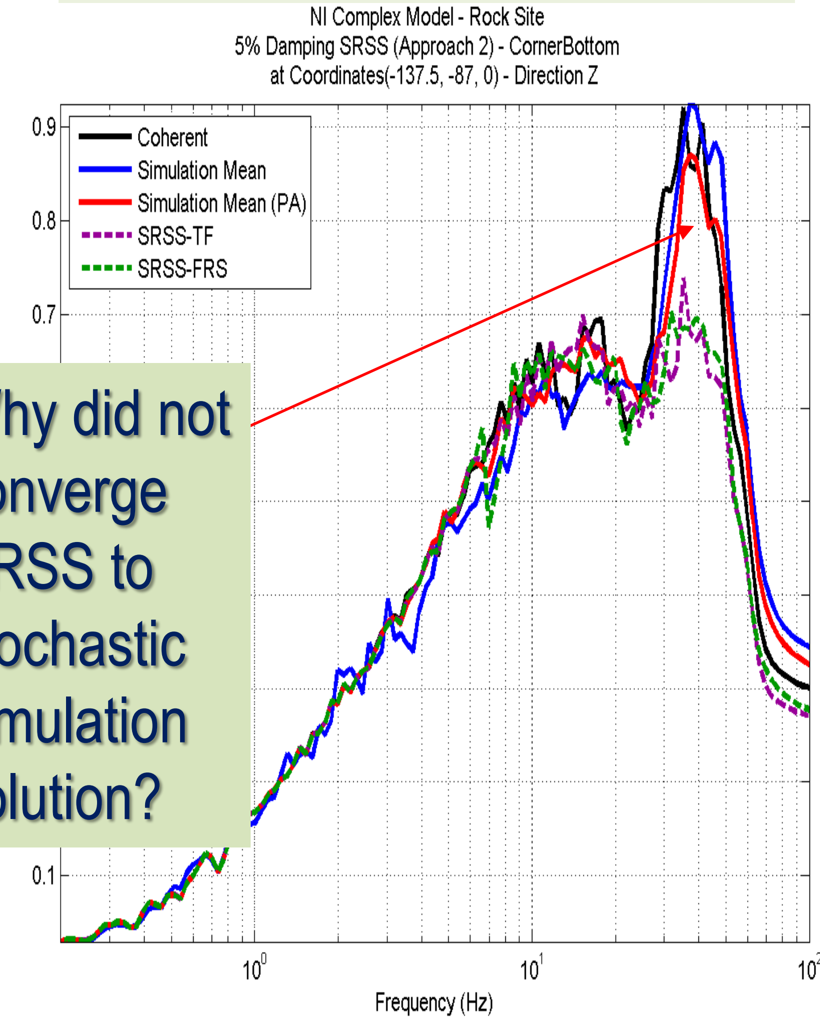
Basemat Corner ISRS of NI Complex with 50m Width

Is the 40 Modes SRSS Solution Convergent?

20 Incoherent Modes



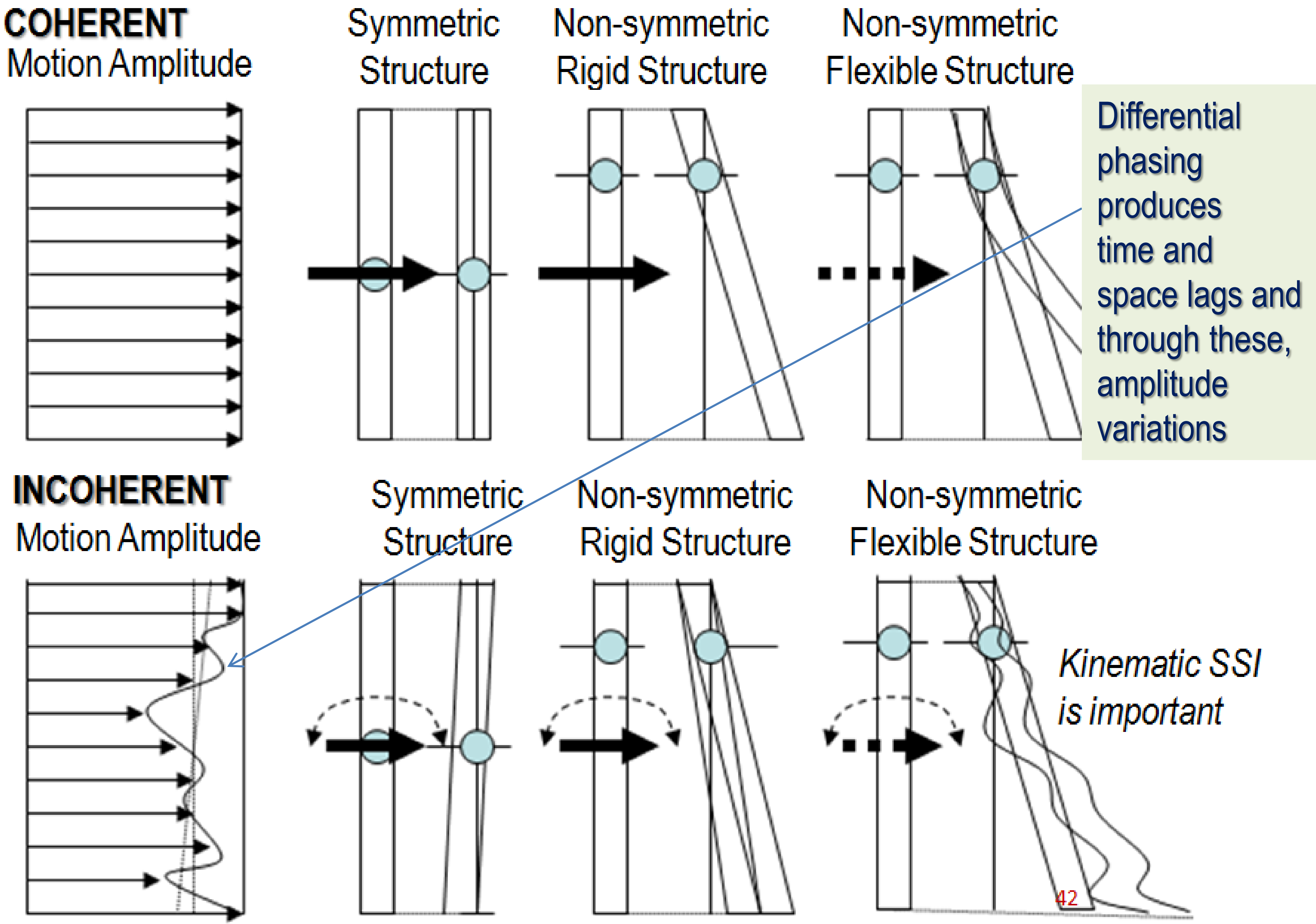
40 Incoherent Modes



Why did not converge SRSS to stochastic simulation solution?

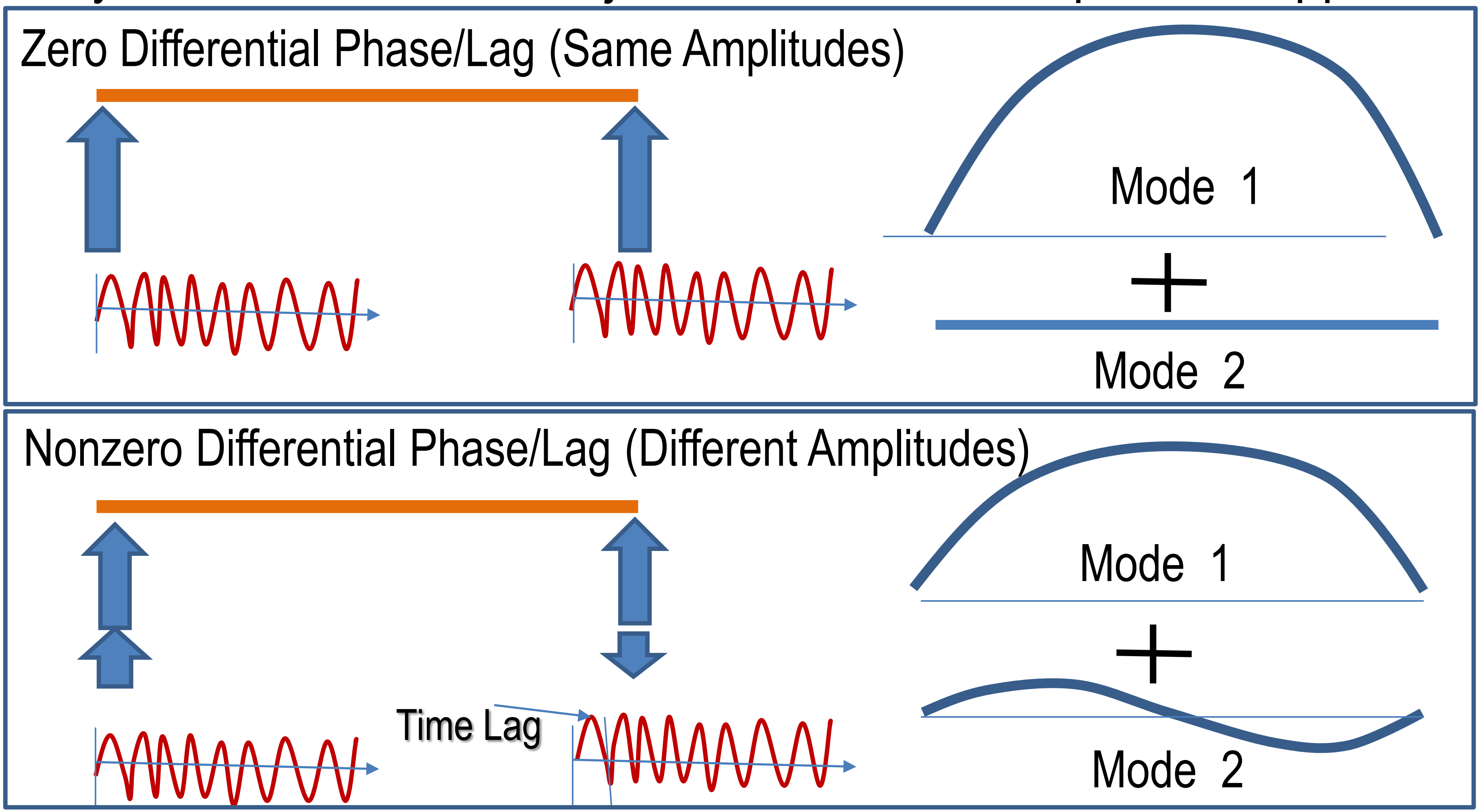
Basemat Corner Vertical ISRS of NI Complex with 50m Width

Motion Incoherency Differential Phasing Effects



Differential Phasing Effects for Same Harmonic Inputs at Supports with Zero and Nonzero Time Lags

Symmetric Structure Subjected to Harmonic Inputs at Supports

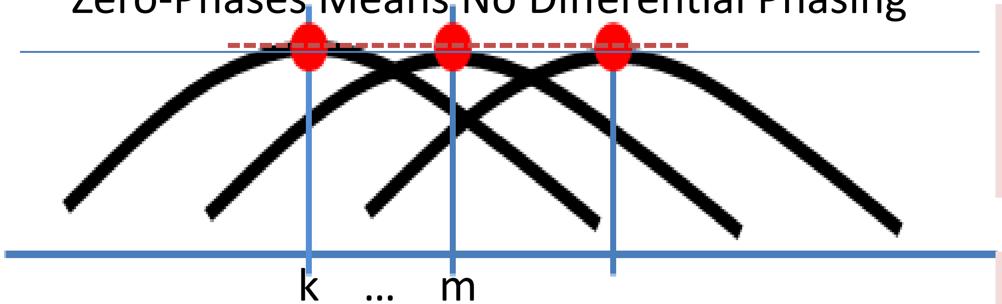


(inspired by Greg Mertz's 2014 DOE NPH example)

Effect of Zeroing Phases for Low-Mid Frequencies

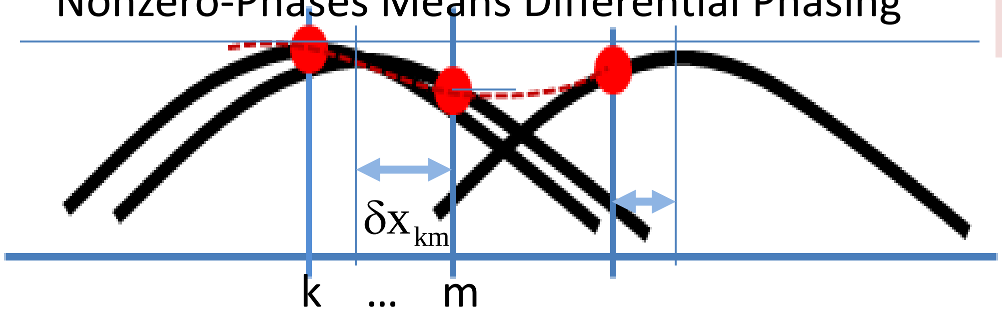
For dominant single mode situations (in lower frequency range), the *neglect of the (differential) phases* that produce random amplitude variations in frequency space, *basically changes the problem and departs from reality.*

Zero-Phases Means No Differential Phasing



Single Mode "Zero-Phase" Motion produces a "deterministic" motion closer to coherent

Nonzero-Phases Means Differential Phasing



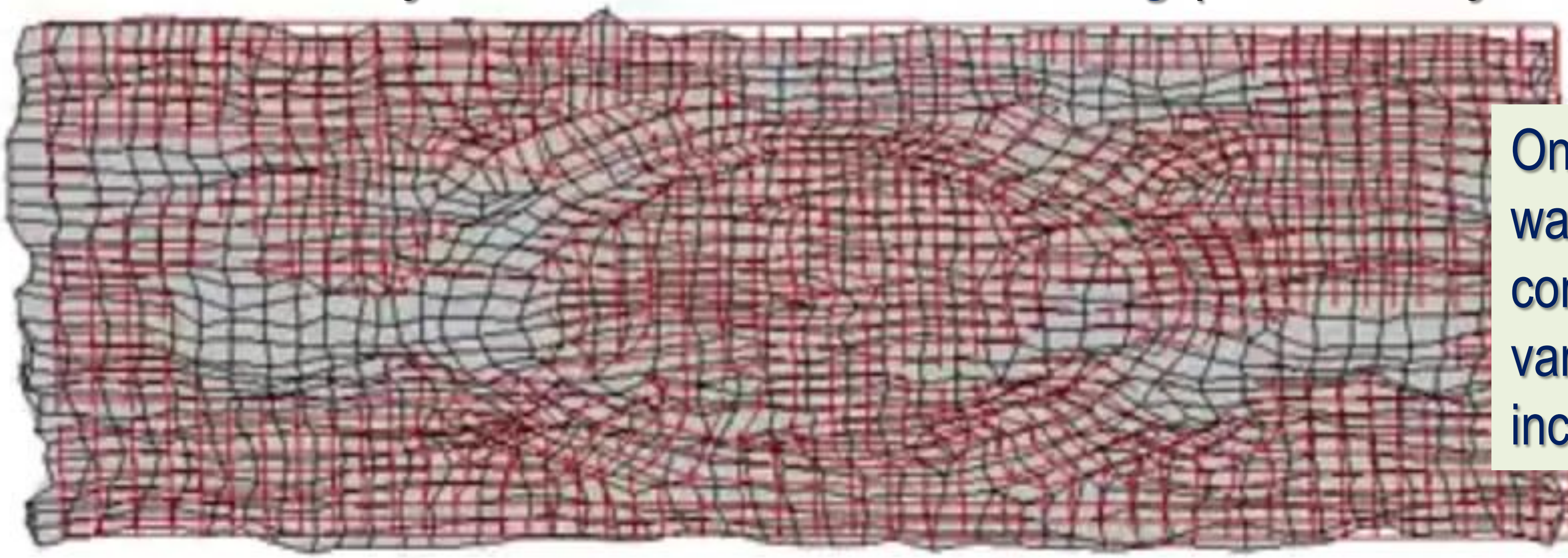
Single Mode "Non-Zero-Phase" Motion produces a realistic "random field" motion

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%

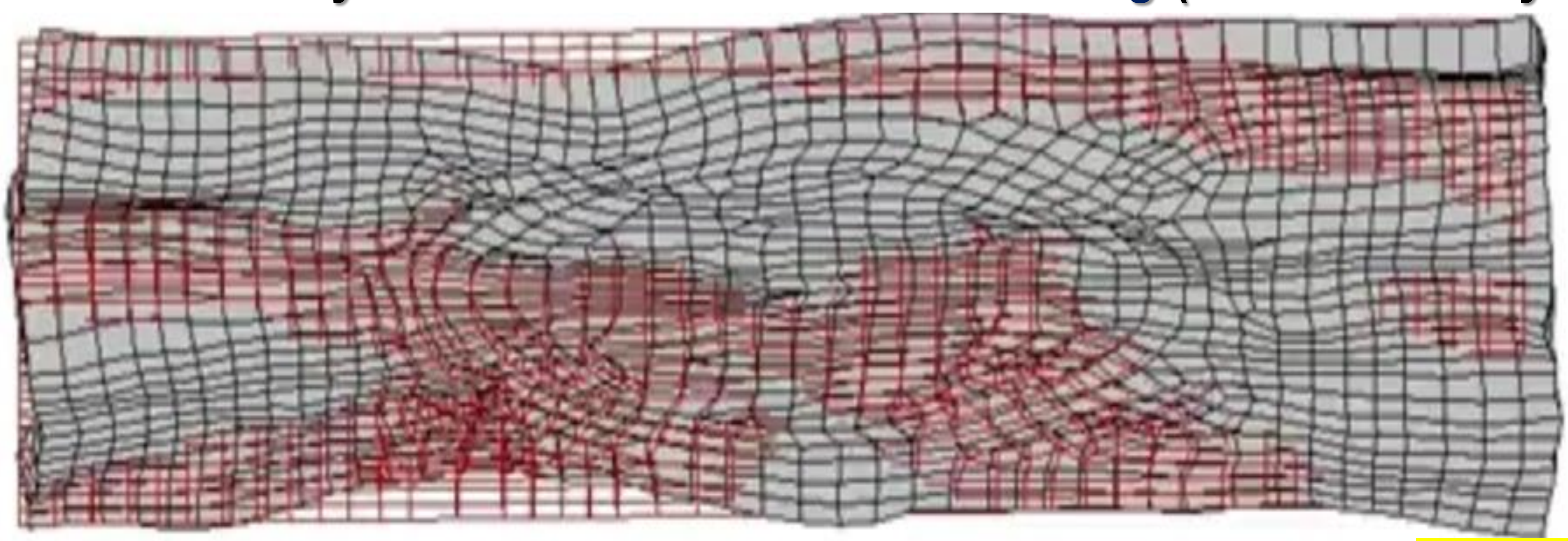
At the lower frequencies, below 10 Hz, where a single mode (Mode 1) is governing, the zero-phase assumption practically neglects the differential phase variations between motion components due to incoherency.

Incoherency Simulation *With Zero-Phasing* (Loss of Physics)



Only small wavelength component variations included !

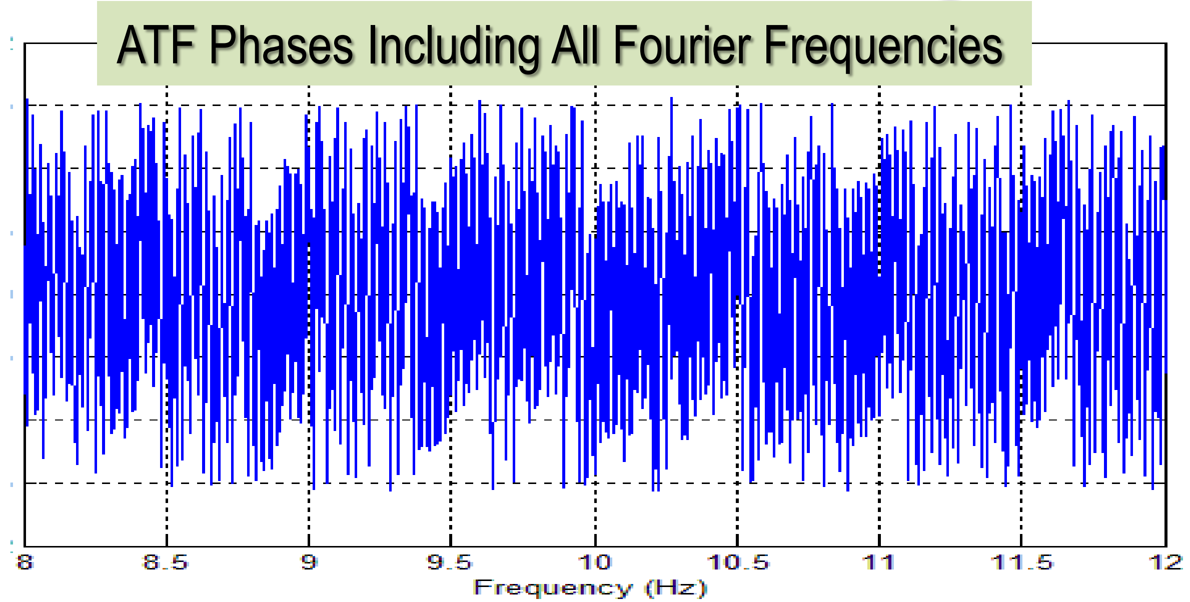
Incoherency Simulation *With Random Phasing* (No Loss of Physics)



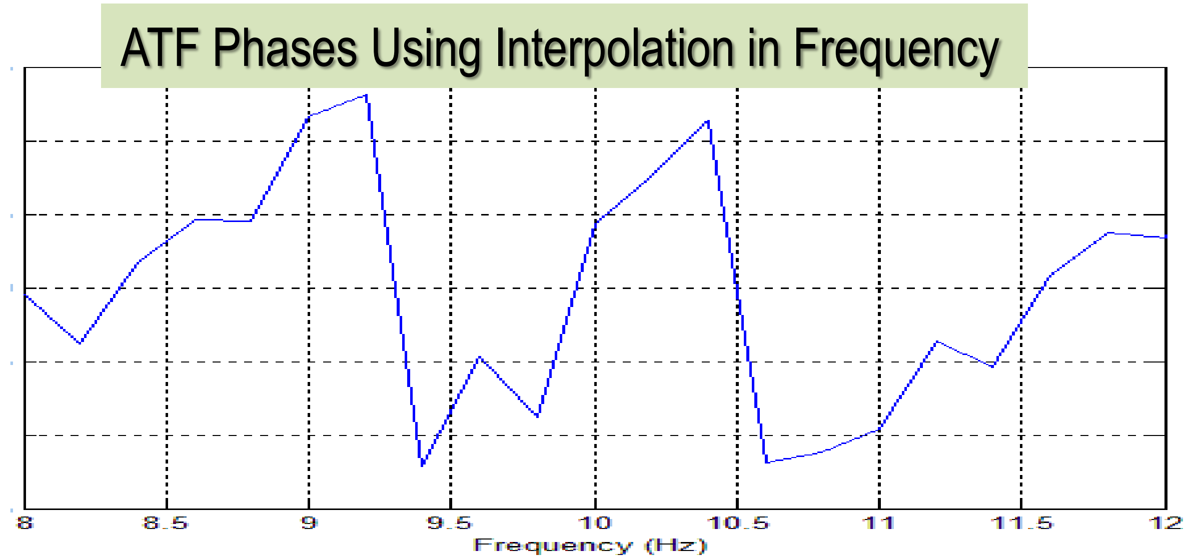
ANIMATIONS

Effects of Number of SSI Frequencies on Simulated Random Phasing

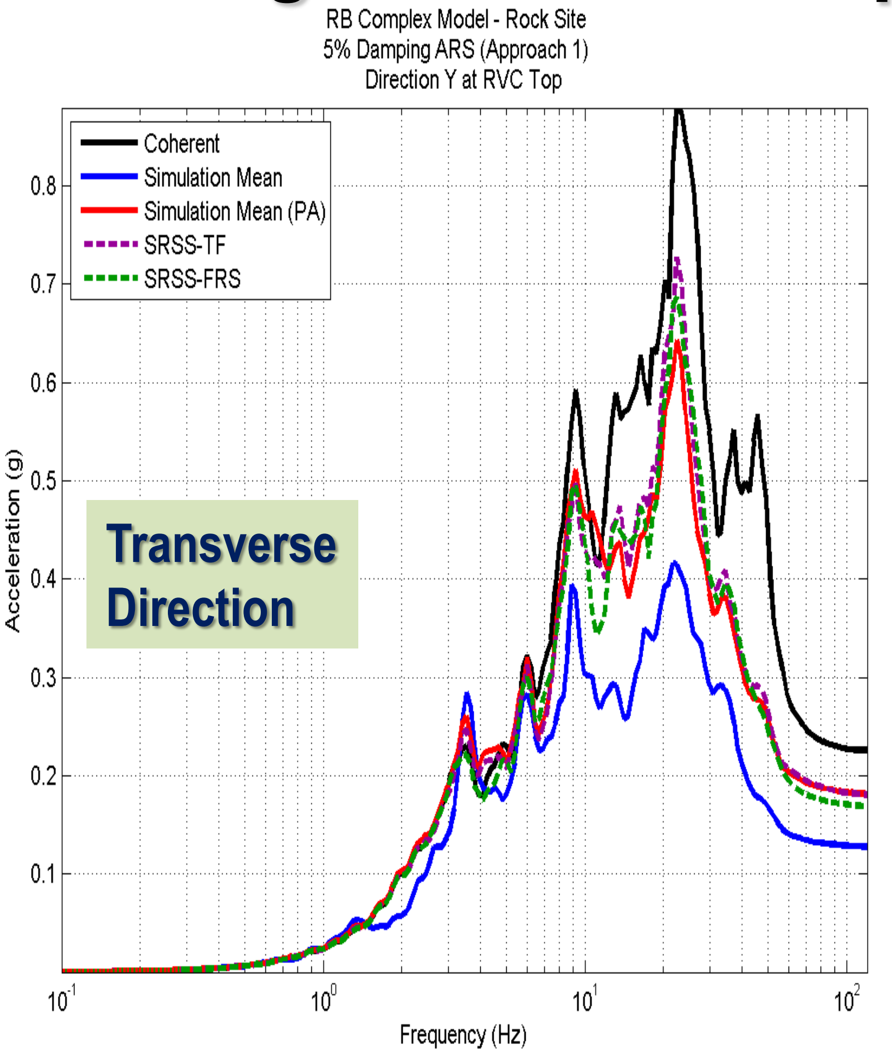
Records show significant *Differential Phases (low-correlated)* for closely-spaced SSI frequencies

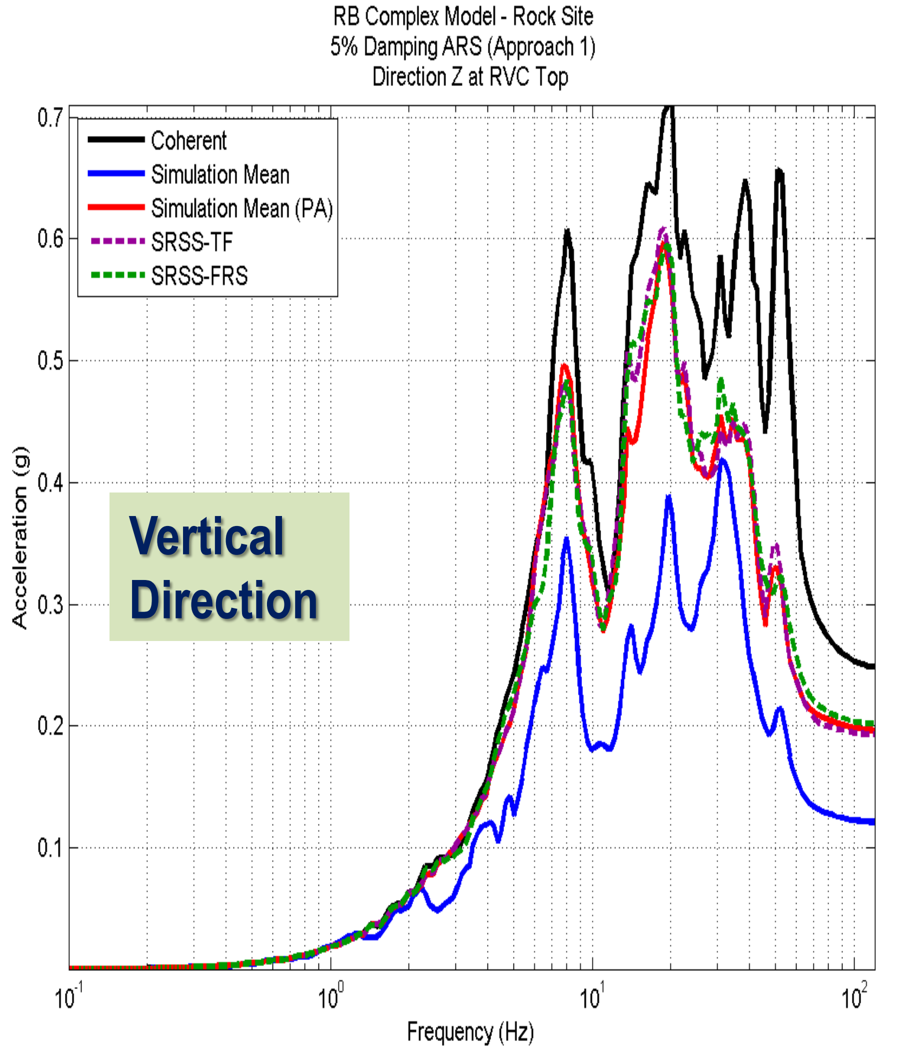


Typical SSI analysis interpolation filters *Differential Phases (high-correlated)* for closely-spaced SSI frequencies.
We suggest use 200-300 SSI frequencies in the ACS SASSI manual.



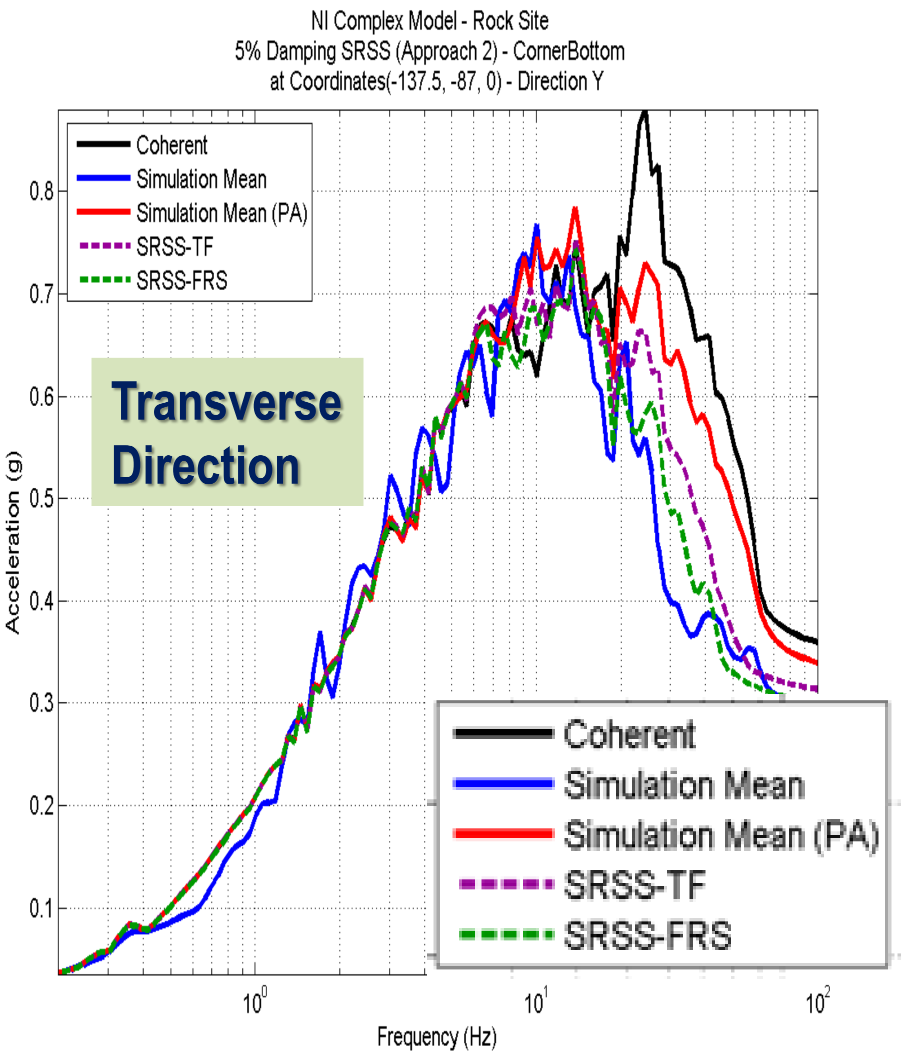
Incoherent SSI Response Phasing Effects on Large-Size RB Complex with 105m Width

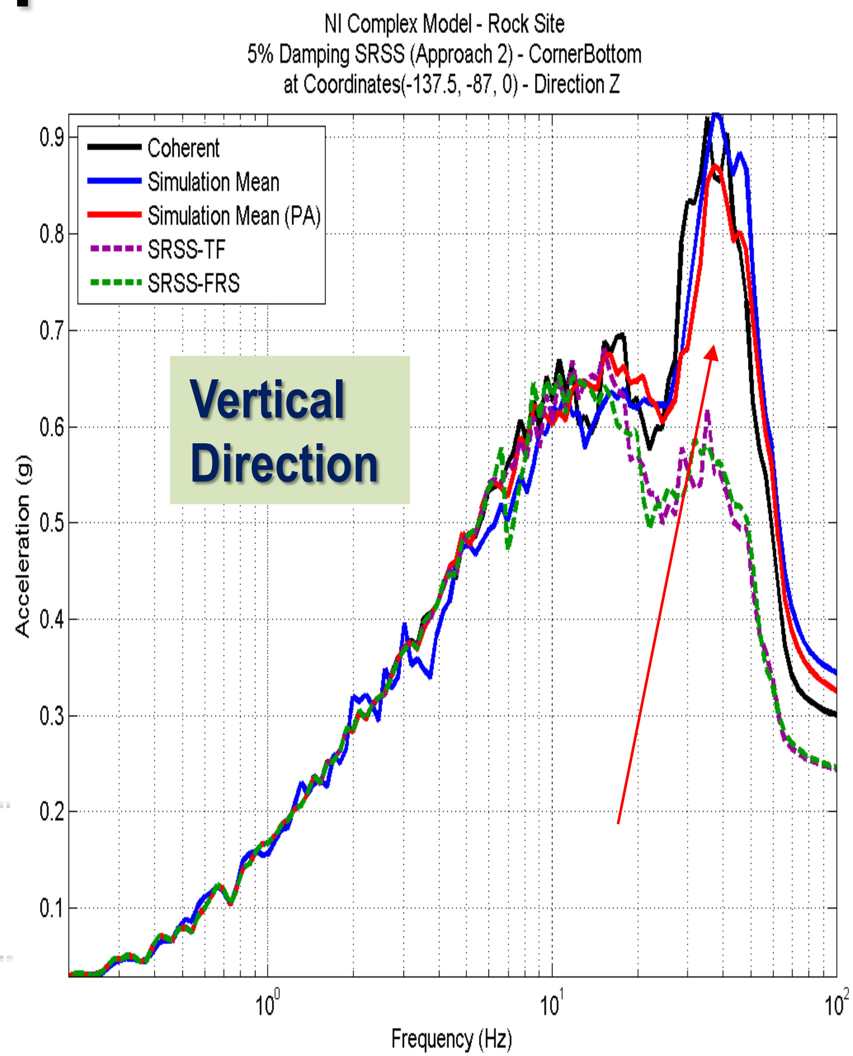




Top of RVCC ISRS of NI Complex

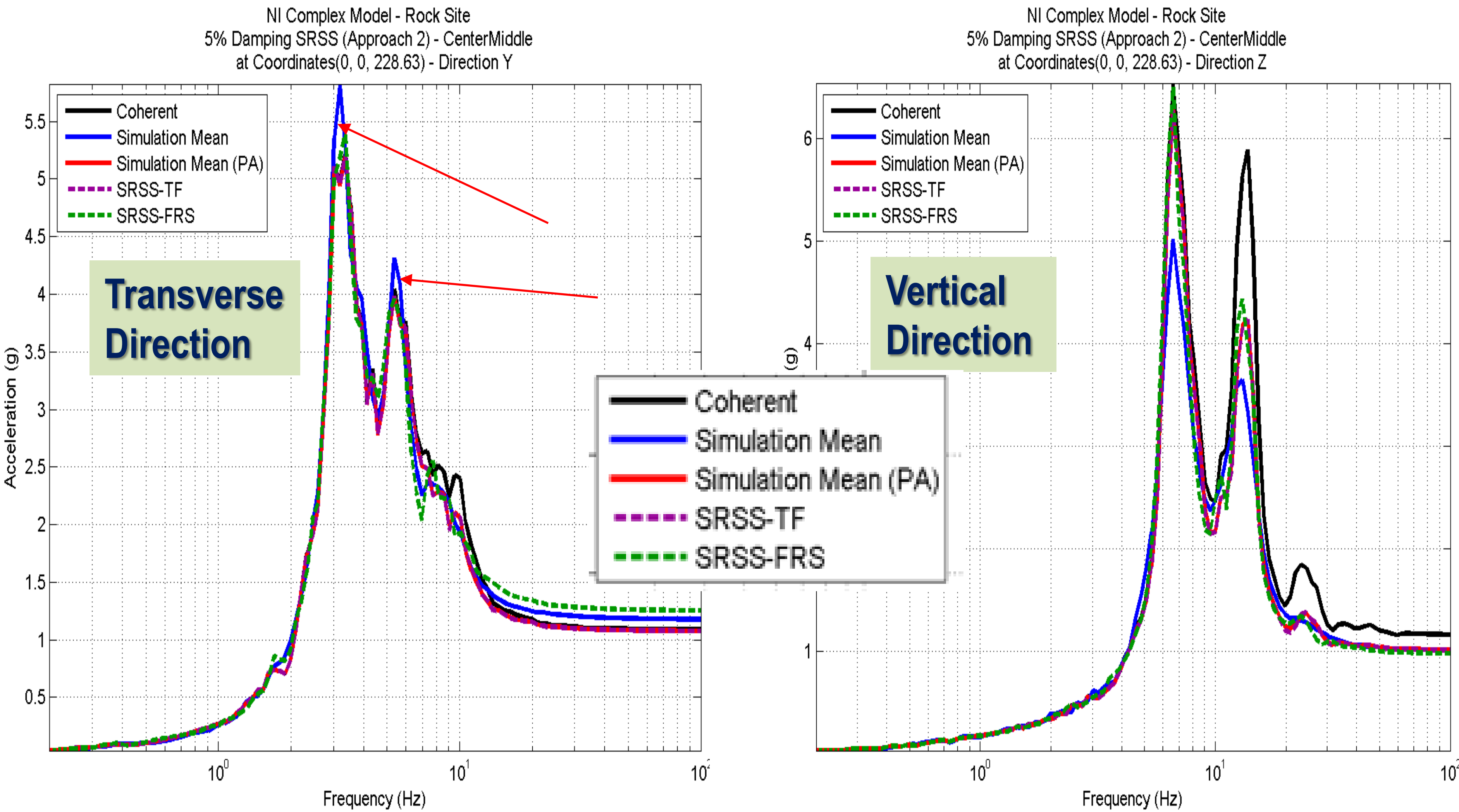
Incoherent SSI Response Phasing Effects on Reduced-Size RB Complex with 50m Width





Basemat Corner of NI Complex

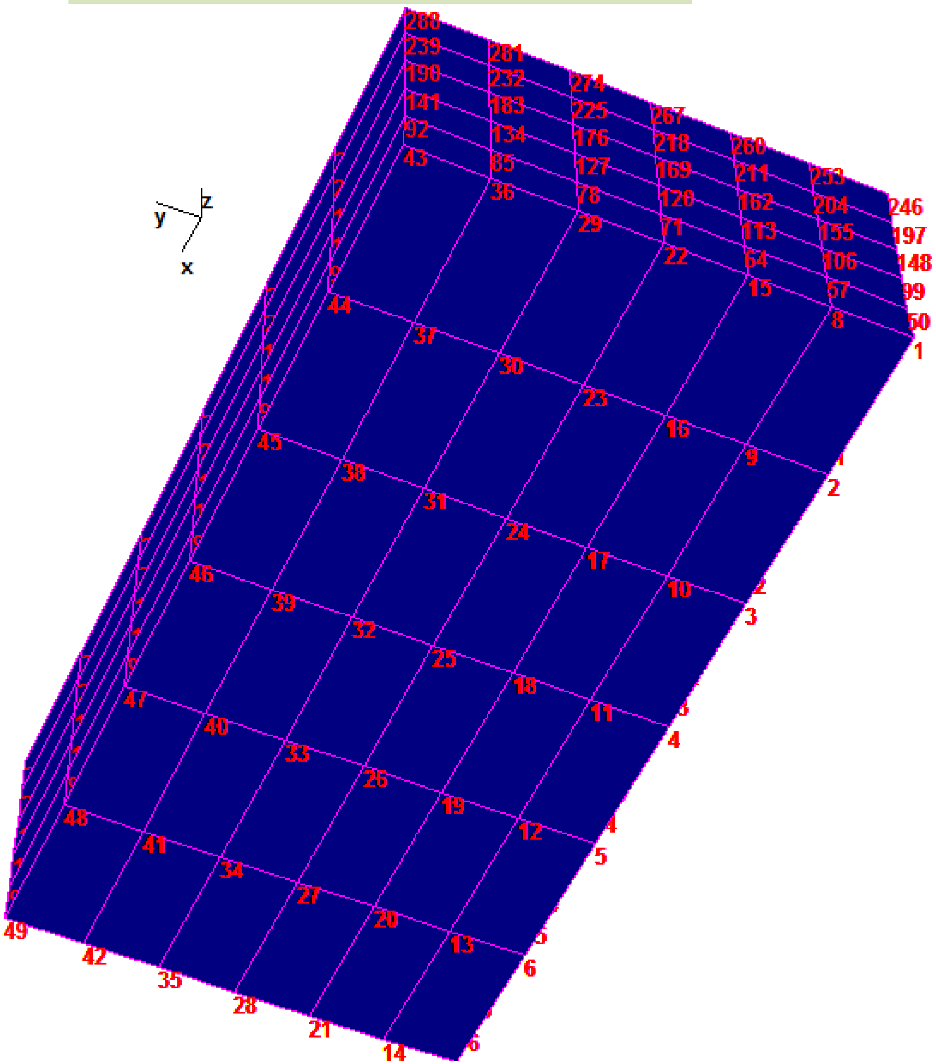
Incoherent SSI Response Phasing Effects on Reduced-Size RB Complex with 50m Width



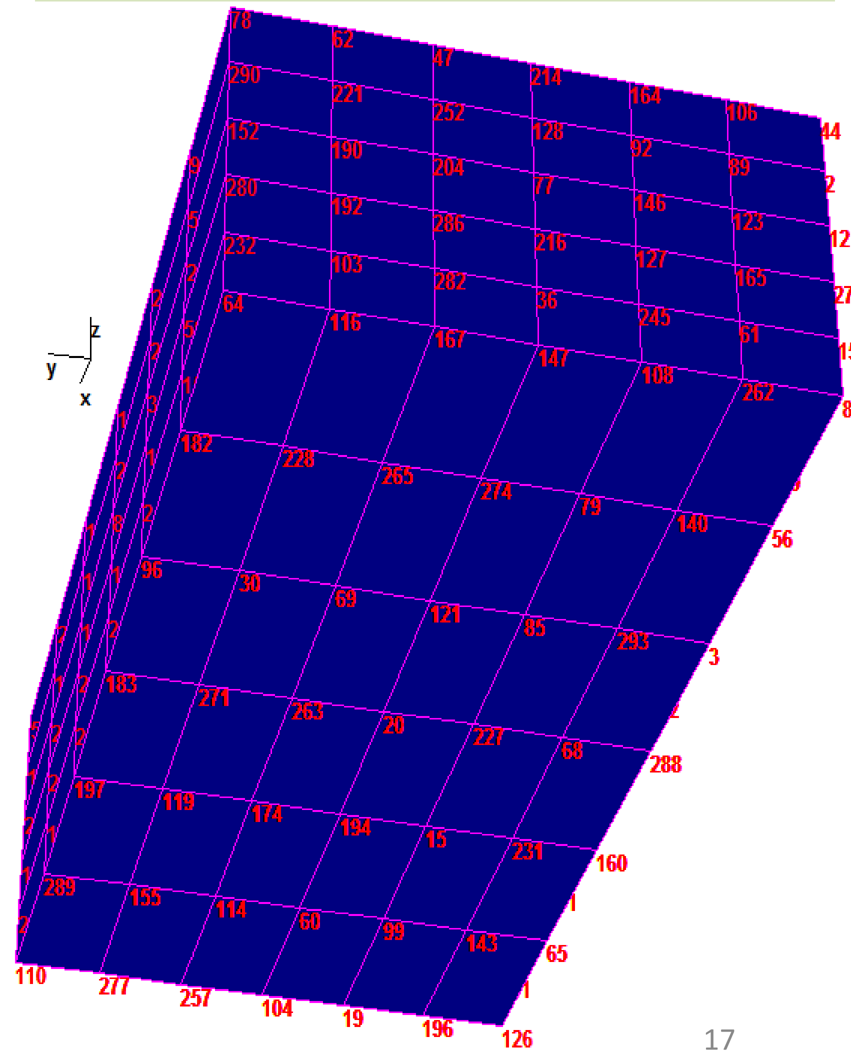
High Elevation Center of NI Complex

Embedded SSI Models – Node Numbering Issue

SAME node numbering order for all levels



DIFFERENT node numbering order for all levels

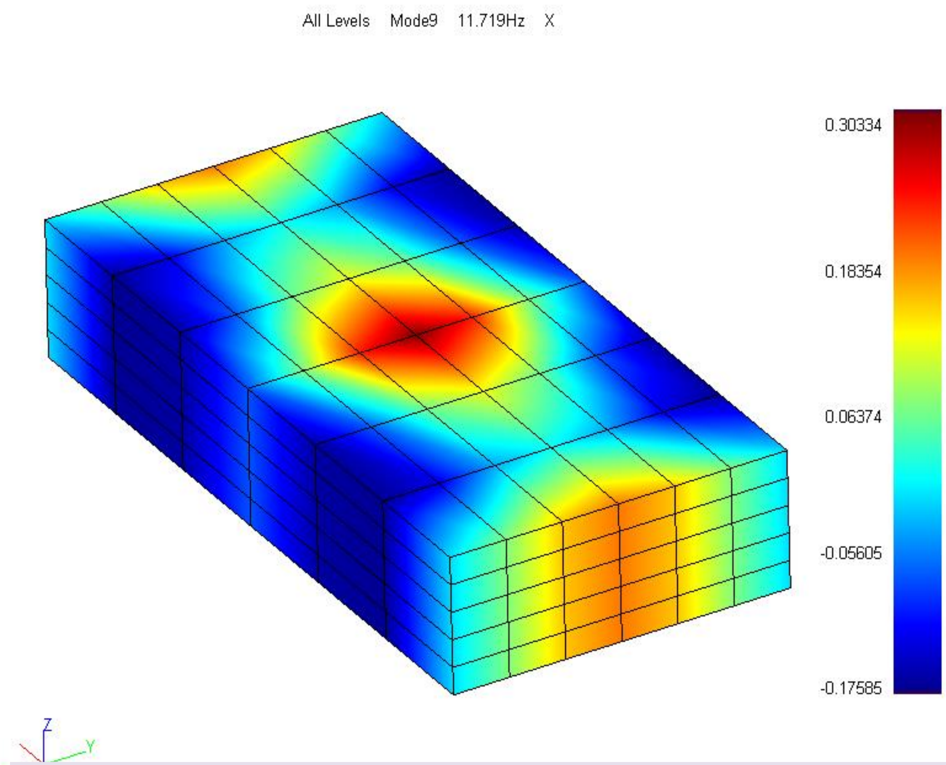


Embedded SSI Models – Node Numbering Issue

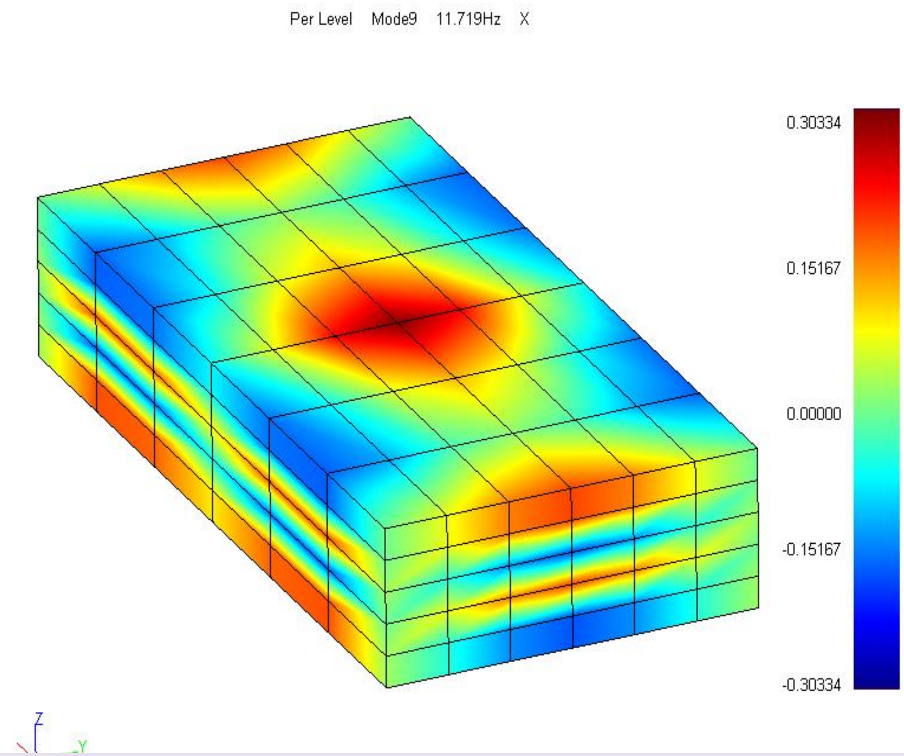
SAME node numbering order for all levels

DIFFERENT node numbering order for all levels

Mode 9 at 11.72 Hz

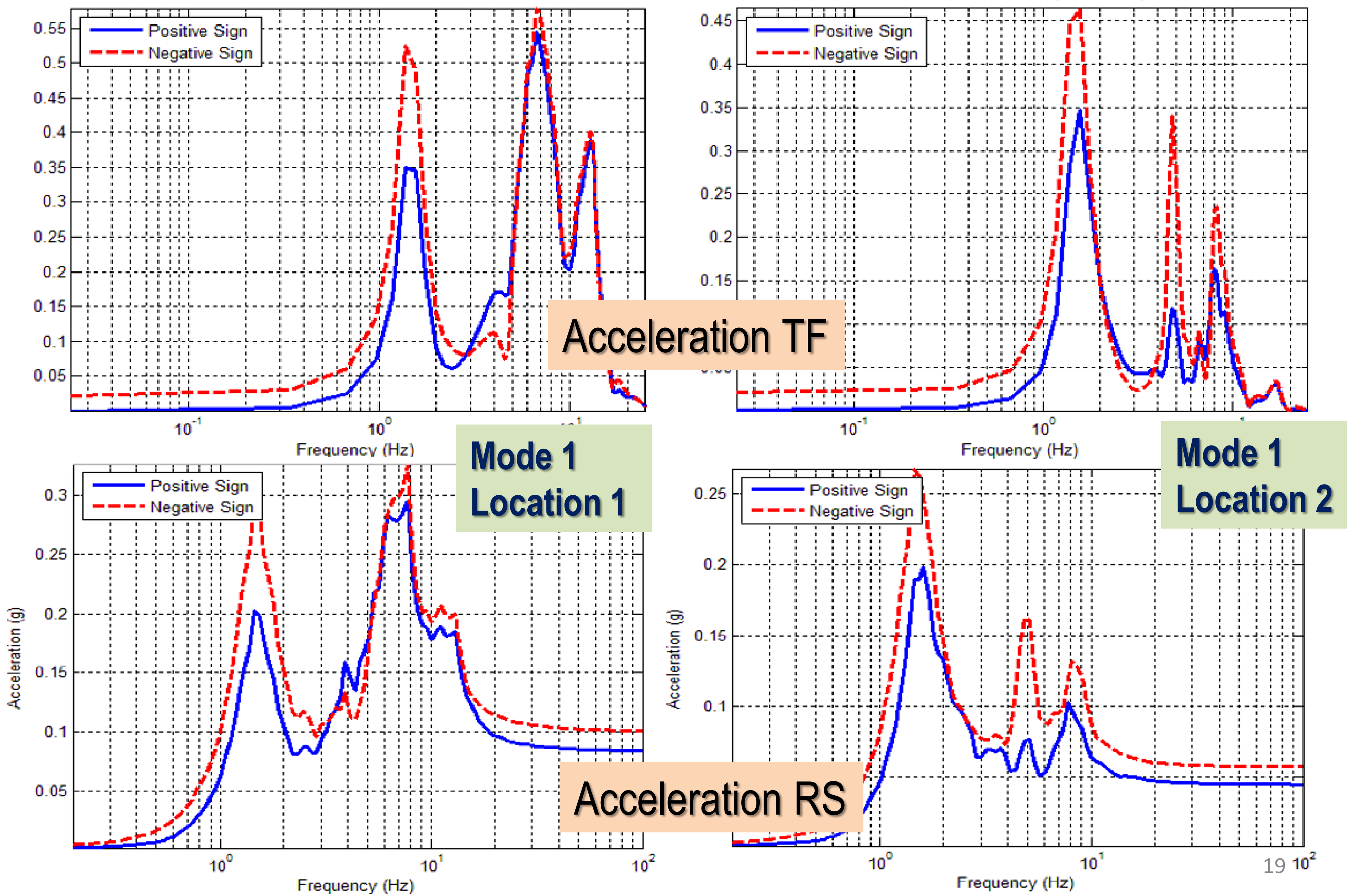


Mode 9 at 11.72 Hz

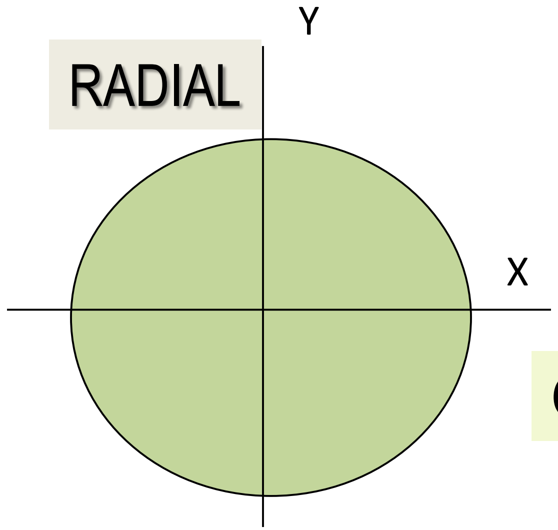


REMARK: The sign of the mode shapes is random, + or -, depending on the node numbering. Deterministic SRSS approach uses "arbitrary" criteria to maintain consistency between levels.

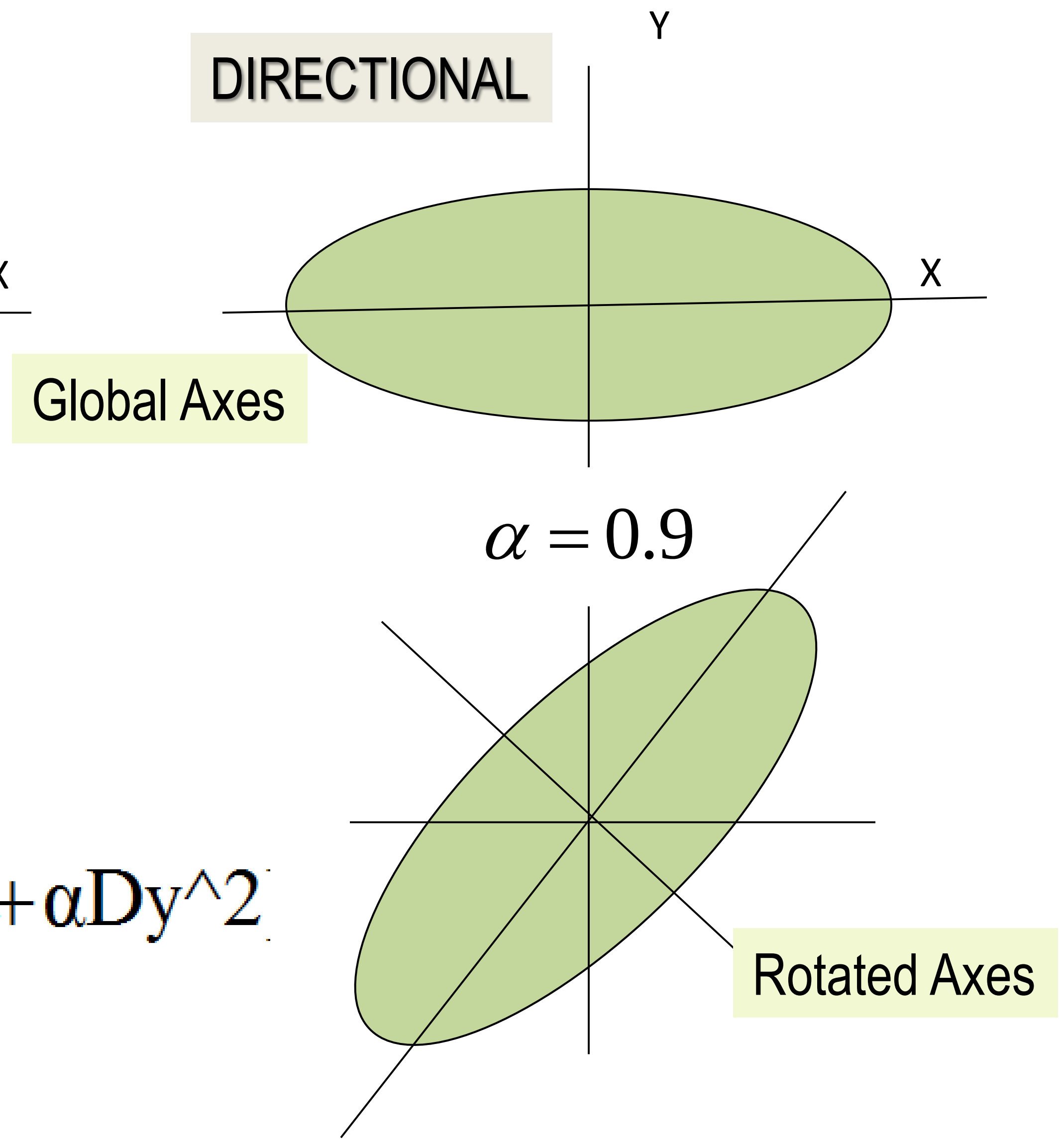
Mode 1 Sign Effect on Modal ATF & ISRS for X-Dir



Radial vs. Directional Coherency Models



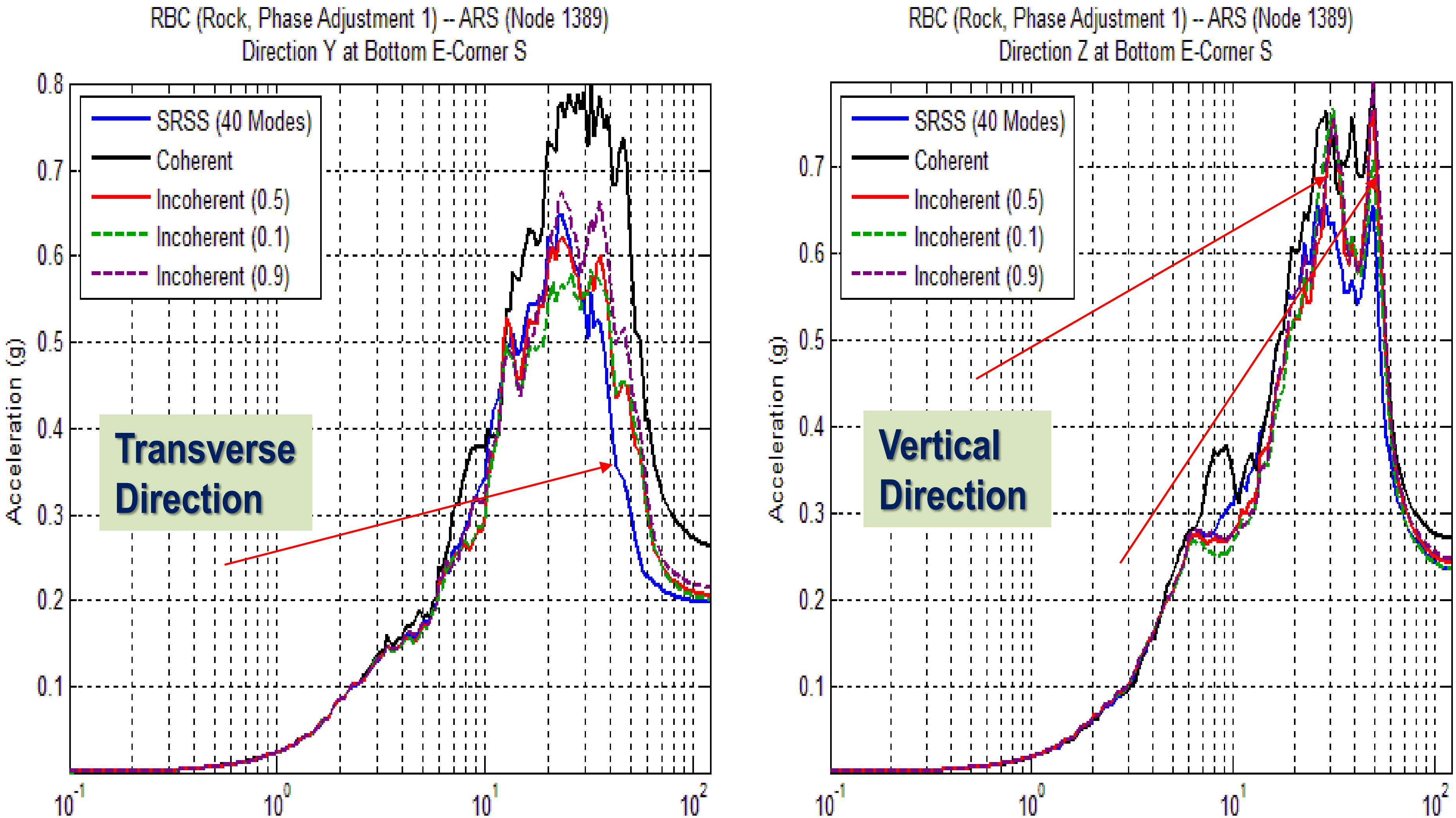
$\alpha = 0.5$



Incoherency distance is

$$D^2 = 2[(1-\alpha)Dx^2 + \alpha Dy^2$$

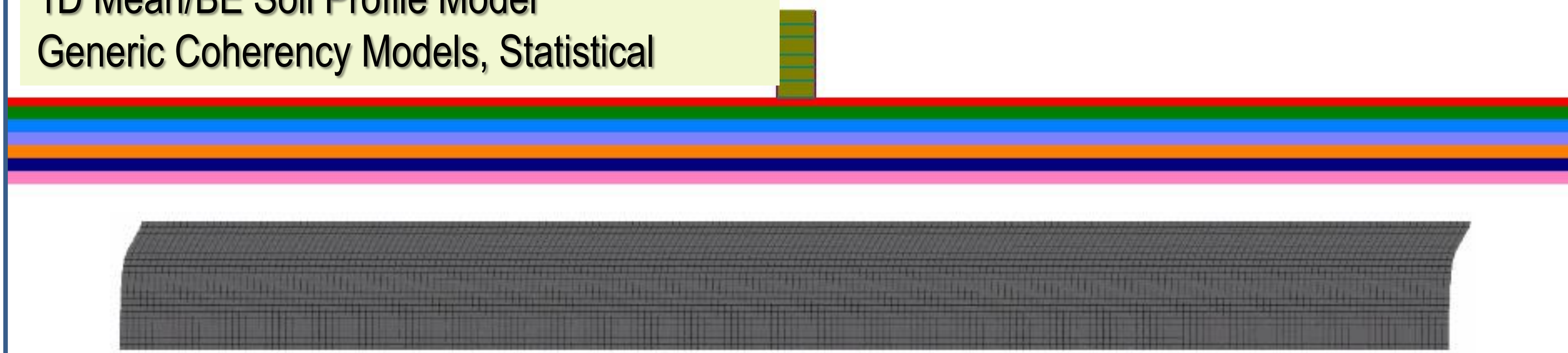
Incoherent Motion Directionality Effects on ISRS for Large-Size RB Complex W/ Zeroing Phase



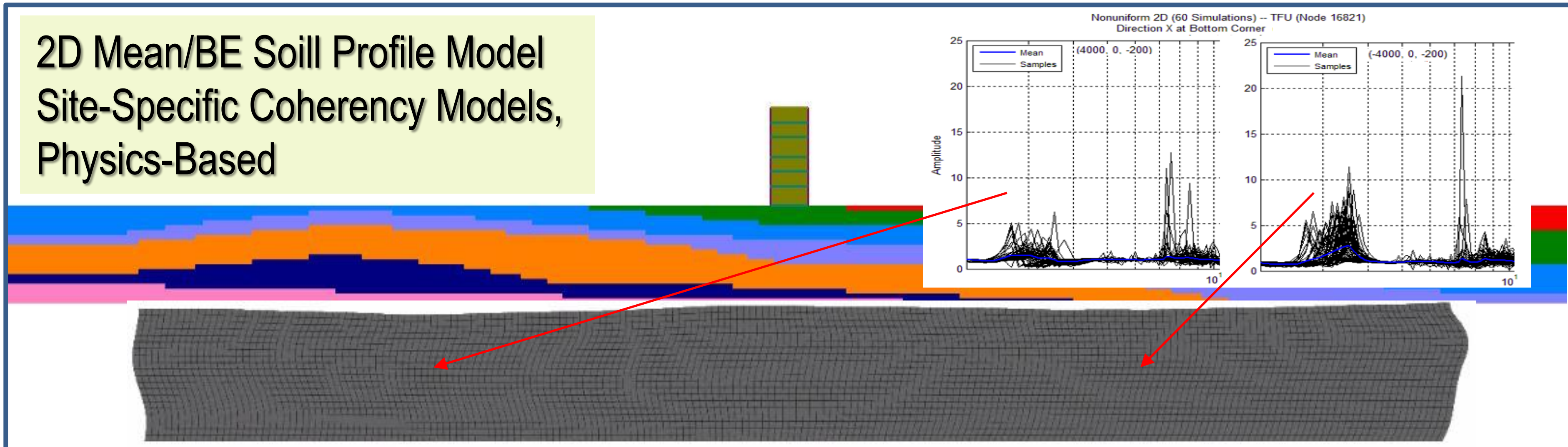
Bottom Basemat Corner

2D Probabilistic Nonlinear Site Response (ACS SASSI OptionPRO & NON) for Site-Specific Coherency Models

1D Mean/BE Soil Profile Model
Generic Coherency Models, Statistical



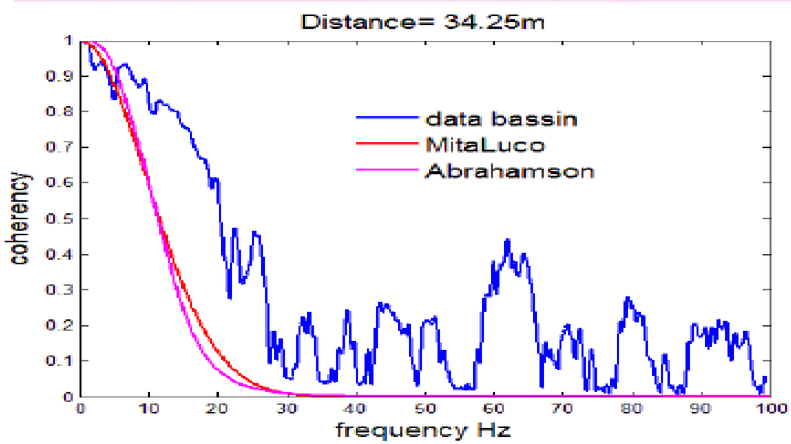
2D Mean/BE Soill Profile Model
Site-Specific Coherency Models,
Physics-Based

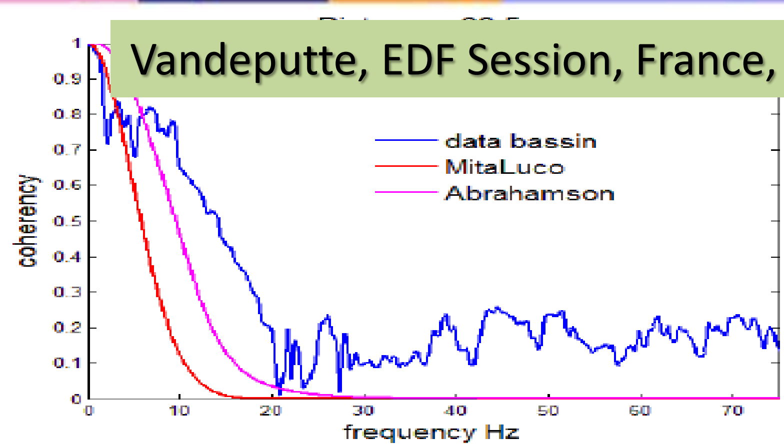


Developing *Site-Specific* Incoherency Models for NPP Area Using 2D/2V Probabilistic Soil Profiles (Vs, D)

Horizontal Mean Soil Layering (2D/2V Homogeneus Correlated Fields)
>>> Generic Coherency Models, Statistical, as Abrahamson, Luco,others

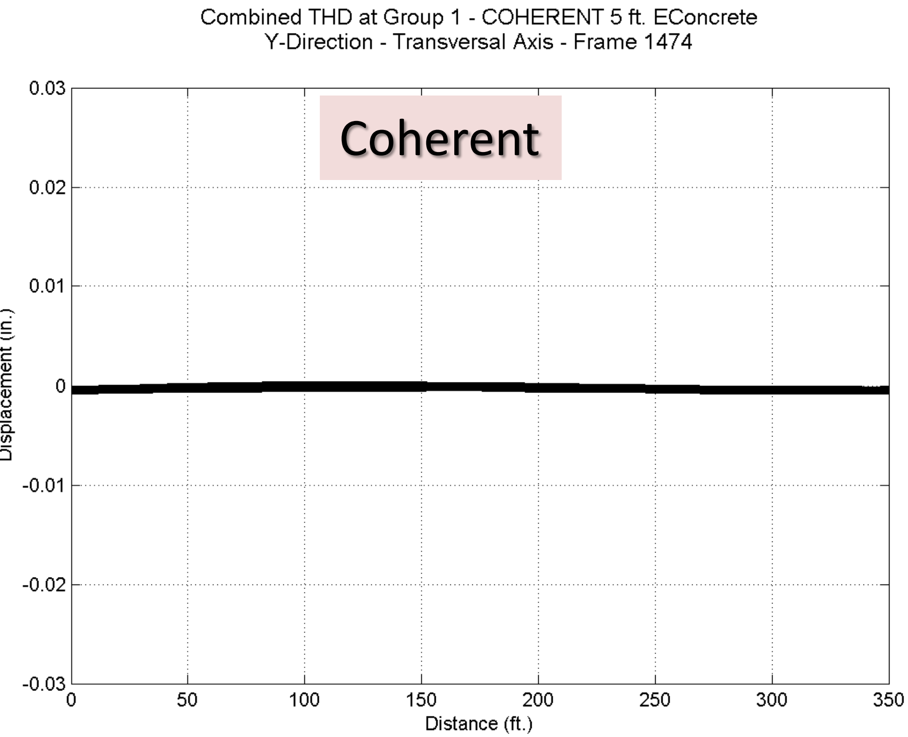
Slopped Mean Soil Layering (2D/2V NonHomogeneus Correlated Fields)
>>> Site-Specific Coherency Models, Physics-based Modeling





Vandeputte, EDF Session, France, 2016

Effects of Incoherency on Basemat Bending



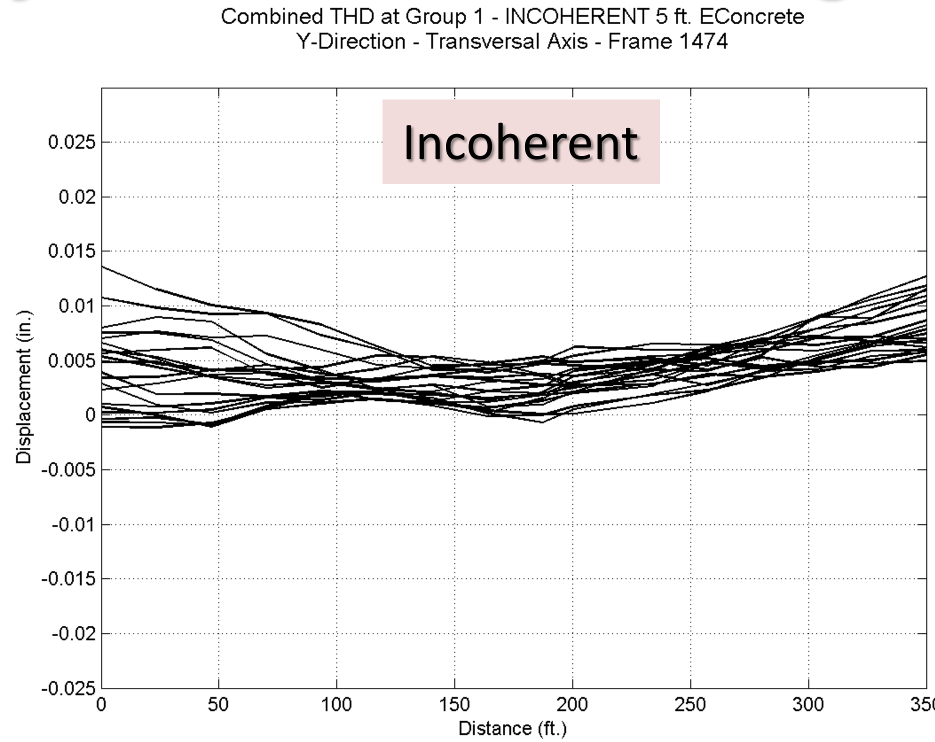


Table 1: Baseslab Bending Moments for A Soil Deposit with Vs = 3,300 ft/s

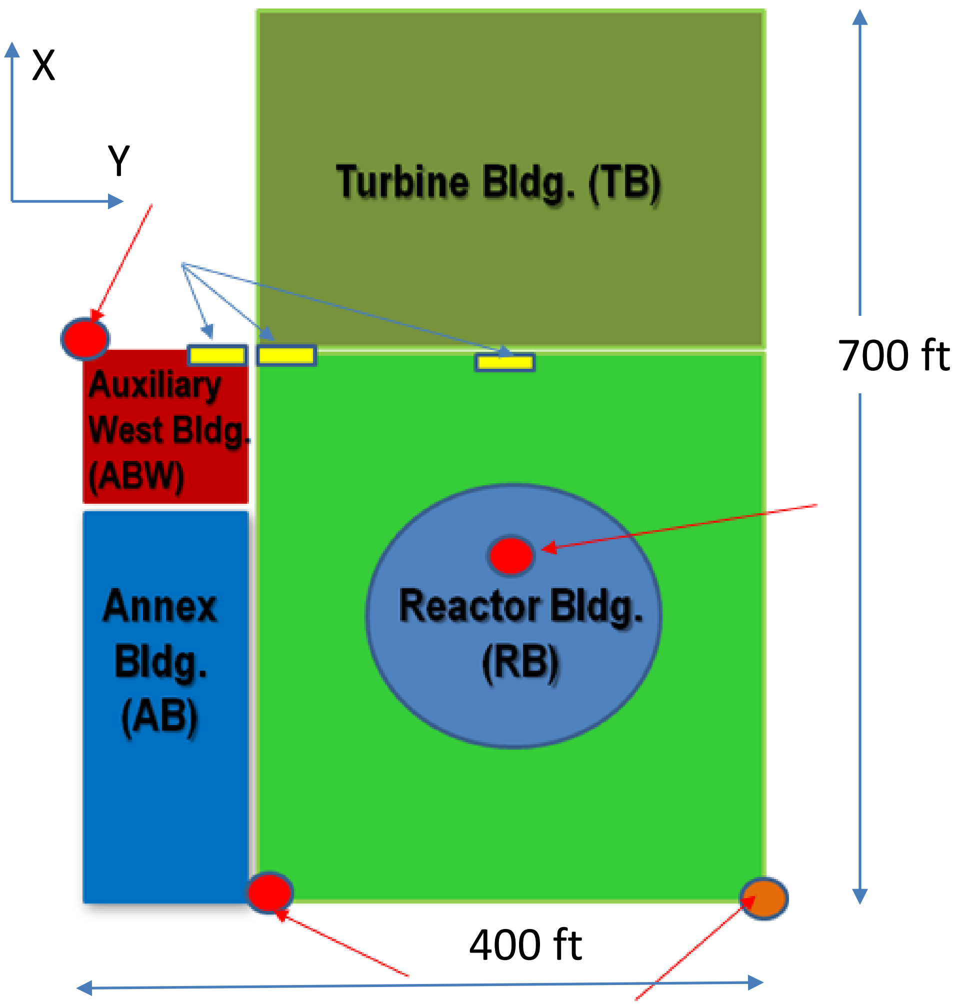
Zone #	Coherent MXX	Incoherent MXX	Ratio Inc/Coh MXX	Coherent MYY	Incoherent MYY	Ratio Inc/Coh MYY
1	10.293	15.196	1.476	9.567	14.812	1.548
2	8.345	19.986	2.395	7.197	14.901	2.070
3	10.291	13.499	1.312	9.695	15.475	1.596
[illegible]	[illegible]	[illegible].859	2.007	8.386	17.199	2.051
[illegible]	[illegible]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

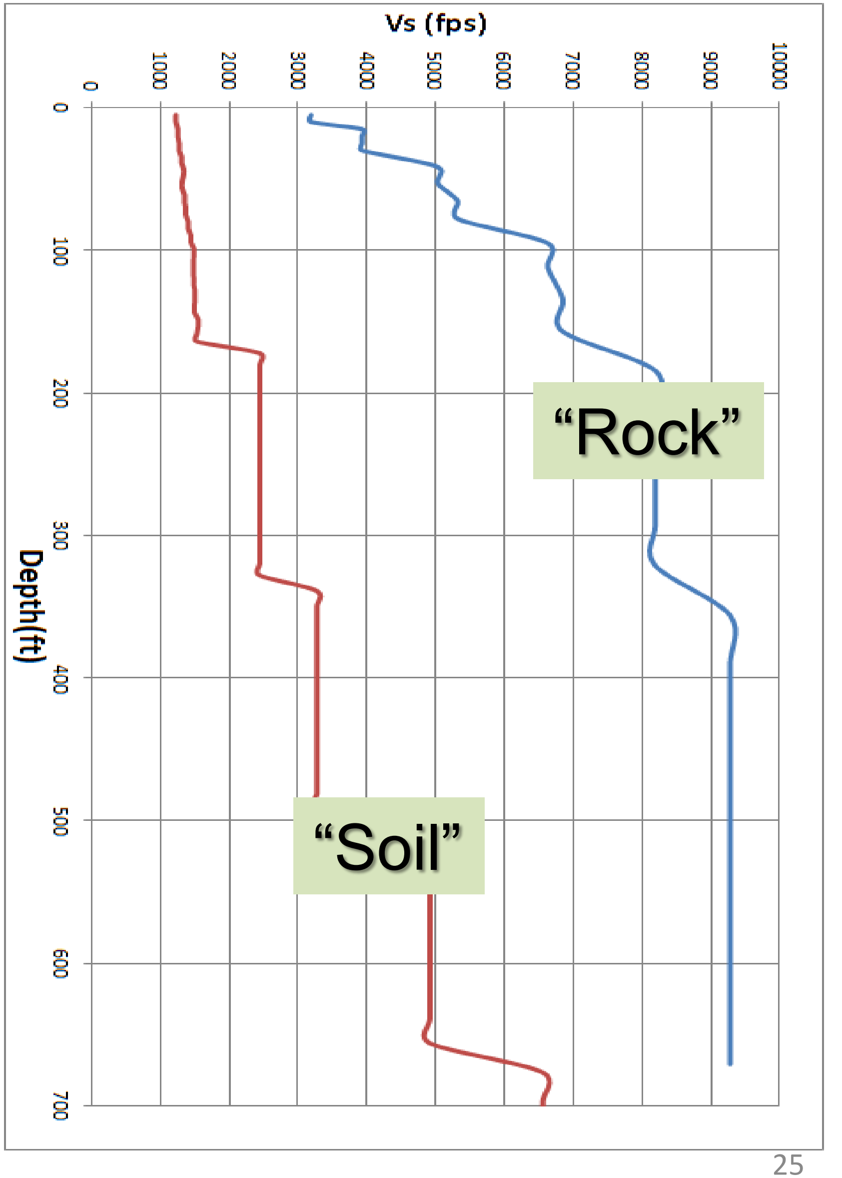
Incoherent vs. Coherent Seismic SSSI Effects

Generic NPP SSSI Model 1

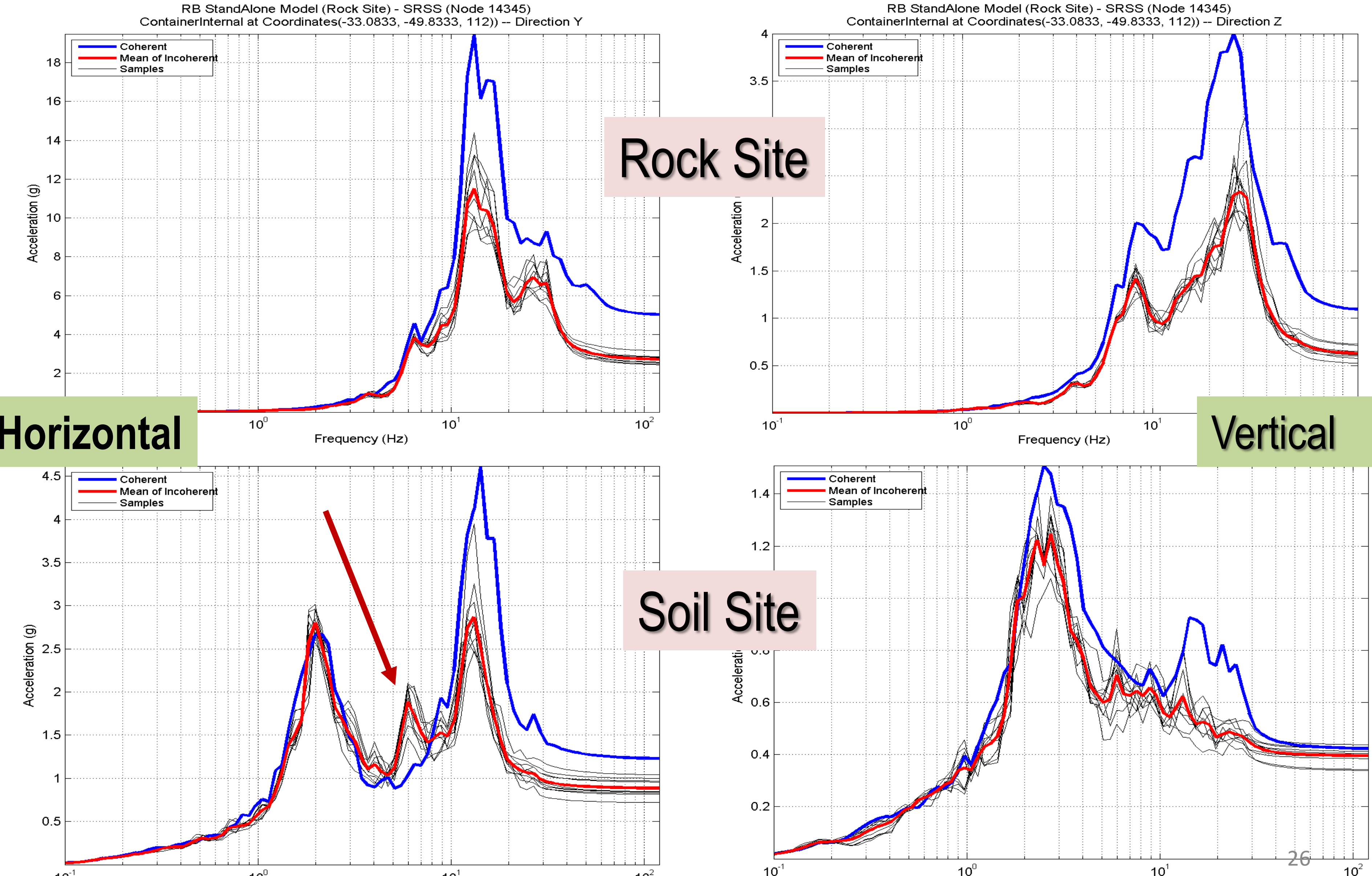
(55,000 nodes with 5,000 int. nodes,
27,000 shells, 13000 solids, 11000 beams)



Soil Profiles

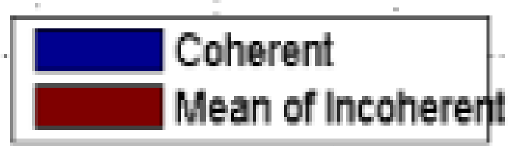


RB Complex Coherent vs. Incoherent SSSI Effects on ISRS on Top of Internal Structure – Y and Z Directions

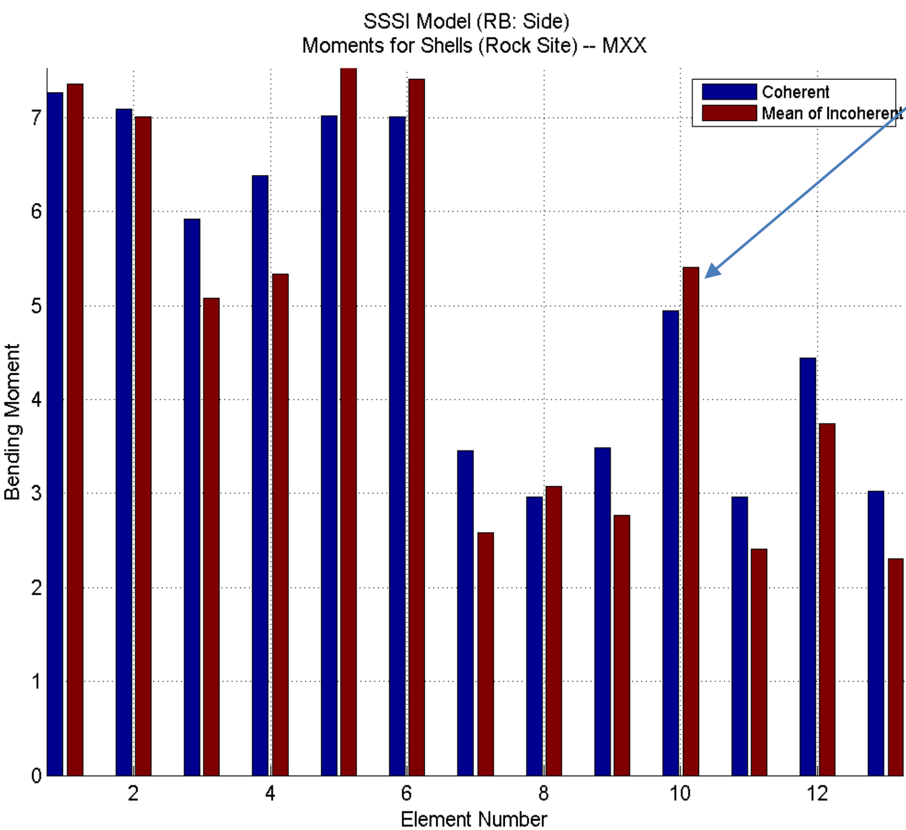


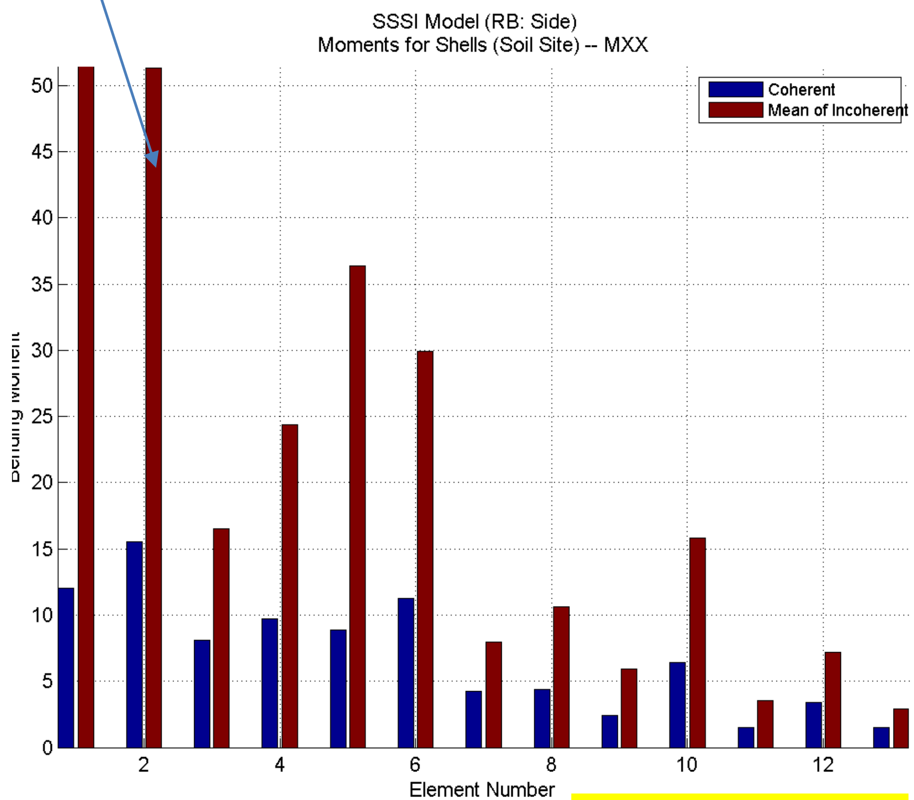
RB Complex Coherent vs. Incoherent SSSI Effects on Bending Moments in Embedded Wall Near ABW Bldg.

Rock Site



Soil Site





ANIMATIONS

Conclusions for Investigated Cases

- Incoherent motion describes a realistic, 3D random wave field motion.
- For realistic, elastic foundations, truncating the number of incoherent modes could produce unconservative results in the high-frequency range.
- Zeroing the incoherent motion phasing usually produces overly conservative results in the mid-frequency range at the price of the loss of physics. Zero-phasing approaches are not applicable to multiple time history analysis of RCL systems.
- Incoherent SSSI effects could be significant for soil sites by amplifying some SSI modes. Affect ISRS and soil pressures. SSSI results also indicate the need for larger inter-building gaps, about 2 times.
- Incoherent SSI responses produces significantly larger bending moments in the foundation mats.
- Incoherency motion directionality, radial vs. directional, produces less significant effects on SSI response.
- Incoherent SSI analysis can be improved by site-specific incoherency models