Comparative Studies on Seismic Incoherent SSI Analysis Methodologies

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Purpose of This Presentation:

To review results obtained using different incoherent SSI approaches, with focus on the approaches benchmarked and validated by EPRI (TR# 1015110, November, 2007)

Addressed Issues:

- The impact on incoherent SSI response of considering a limited number of incoherent modes and zeroing complex response phases. *All the EPRI validated methods use the complex response phase adjustment/zeroing.*

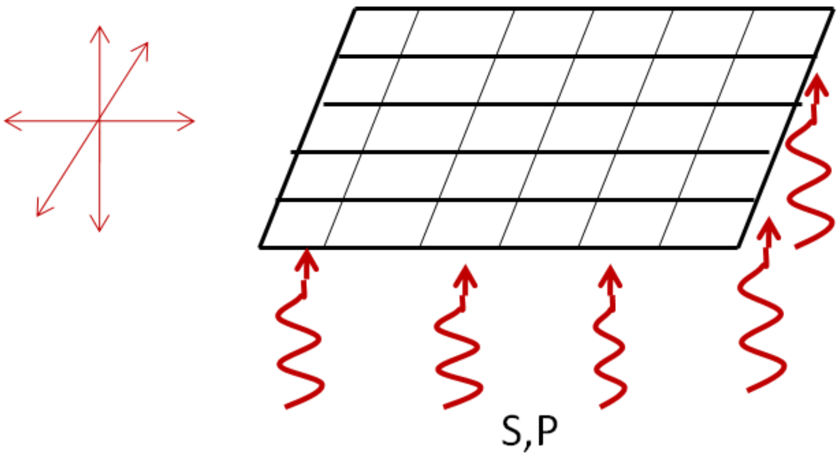
- Influence of basemat flexibility on incoherent ISRS

- Effects of motion incoherency on basemat bending moments.

ACS SASSI NQA code was used for these studies.

Wave Propagation Models: Coherent vs. Incoherent

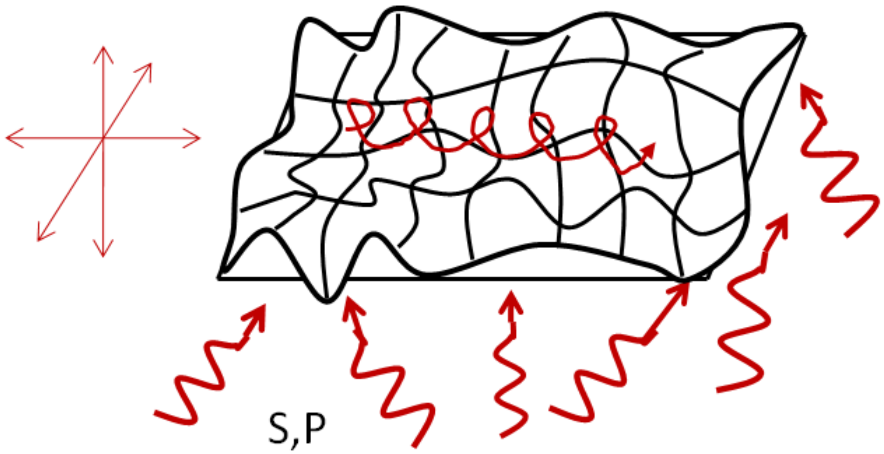
3D Rigid Body Soil Motion (Idealized)



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

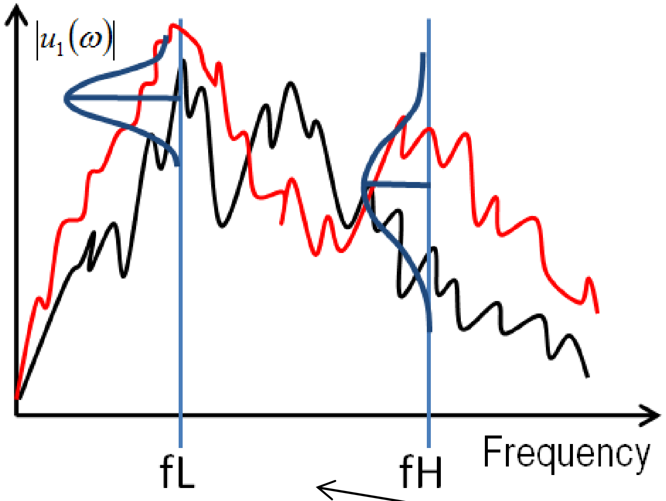
3D Random Wave Field Soil Motion (Realistic)

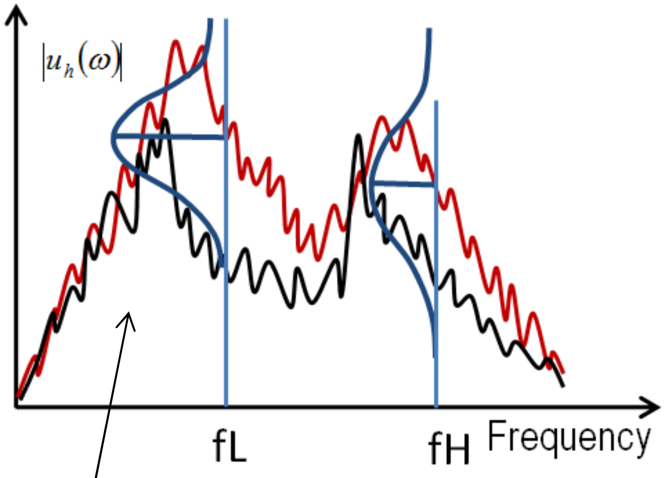


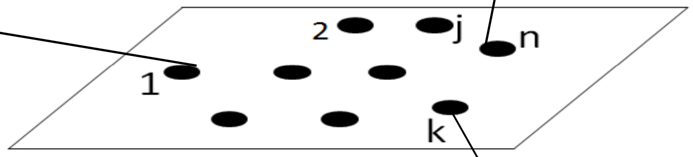
3D Wave Propagation Data-Based Model
(Incoherent – Database-Driven Adjusted Coherent)
Amplitude of vertically propagating S and P wave motions are adjusted based on the statistical models derived from various field dense-arrays record databases (plane wave coherency models, plus wave passage – Abrahamson's models)
- Includes real field records information, including implicitly motion field heterogeneity, random arrivals of different wave types under random incident angles

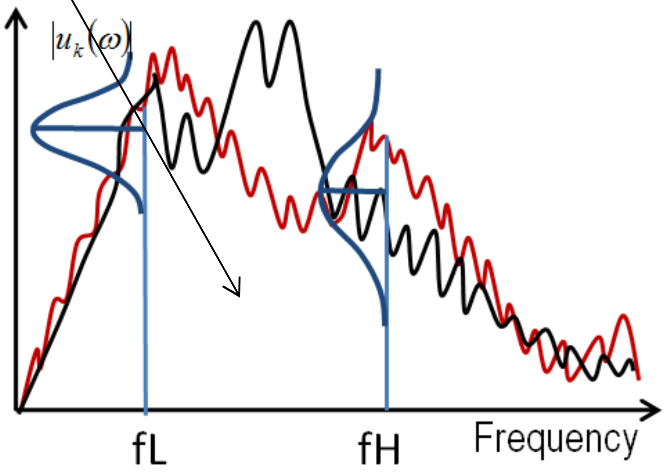
ANIMATIONS

3D Stochastic Wave Model: Incoherent Motion Field









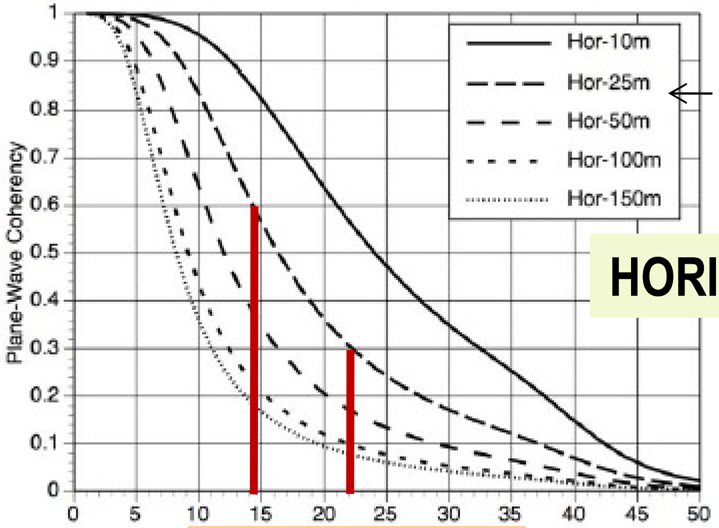
Coherence Function

$$\Gamma_{Uj,Uk}(\omega) = \frac{S_{Uj,Uk}(\omega)}{[S_{Uj,Uj}(\omega)S_{Uk,Uk}(\omega)]^{1/2}}$$

$$\Gamma_{U\,Ui,Uk}(\omega) = \Gamma_{L\,Ui,Uk}(\omega)\exp\,[i\omega(X_{D,i} - X_{D,k})/V_D]$$

$$\gamma_{ij}(\omega) = \frac{E\left[|u_i(\omega)||u_j(\omega)|\right]}{E\left[|u_i^2(\omega)|\right]^{1/2} E\left[|u_j^2(\omega)|\right]^{1/2}}\exp\left(i\omega\frac{\Delta_{ij}}{V_a}\right)$$

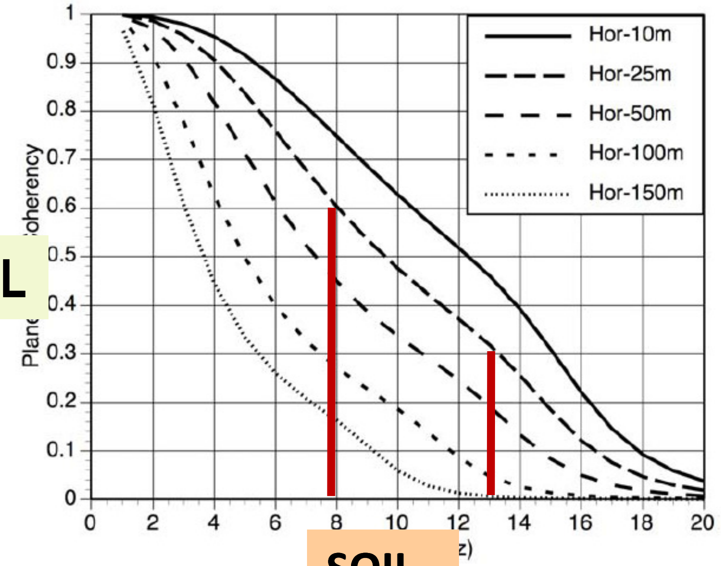
2007 Abrahamson Coherence for Hard-Rock and Soil Sites



HORIZONTAL

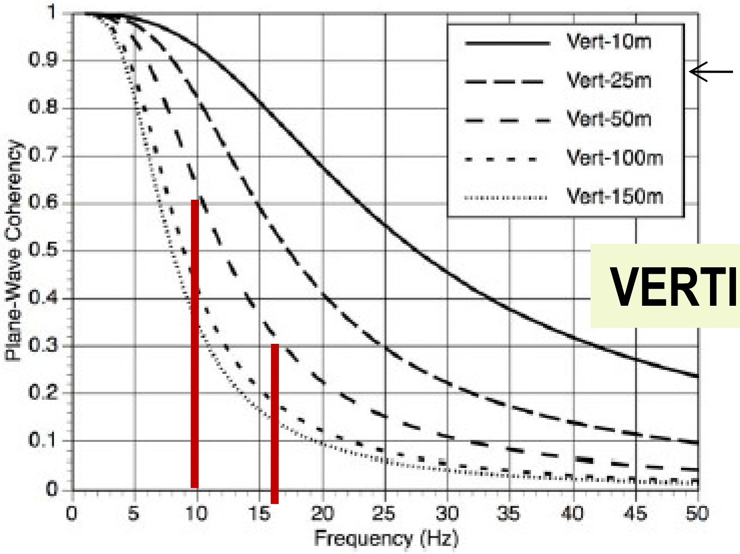
HARD-ROCK

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



SOIL

Figure 7-1
Plane-Wave Coherency for the Horizontal Component for Soil Sites



VERTICAL

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

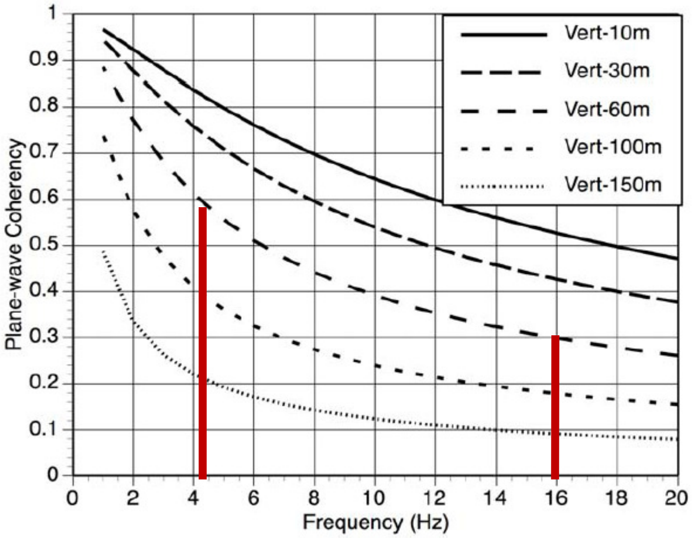


Figure 7-2
Plane-Wave Coherency for the Vertical Component for Soil Sites

(EPRI TR # 1015110, December 2007)

Seismic SSI Analysis Using 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)

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

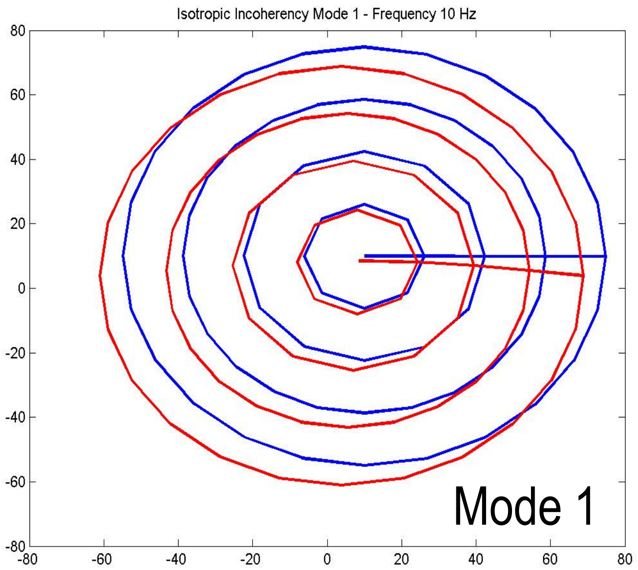
Complex Fourier transform of relative spatial variations of motion at interaction nodes that is stochastic by nature

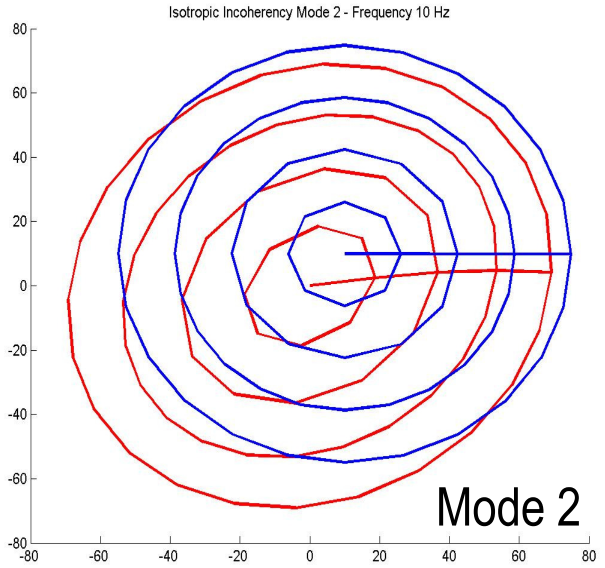
$$S_g(\omega) = [\Phi(\omega)][\lambda(\omega)]\{\eta_\theta\}$$

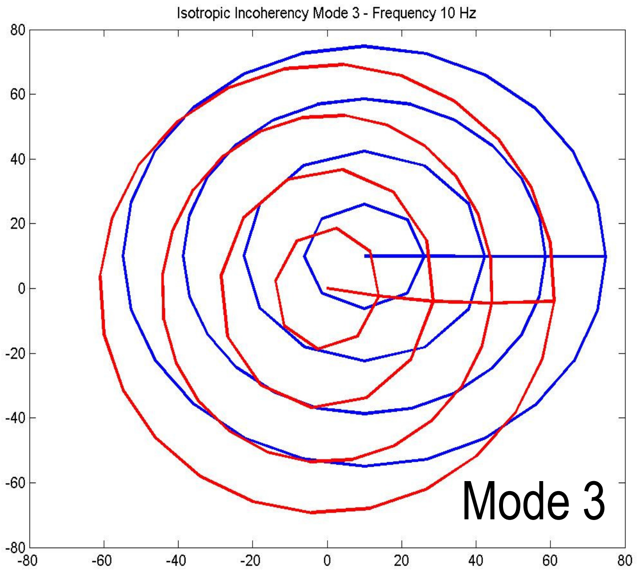
Spectral factorization of coherency kernel

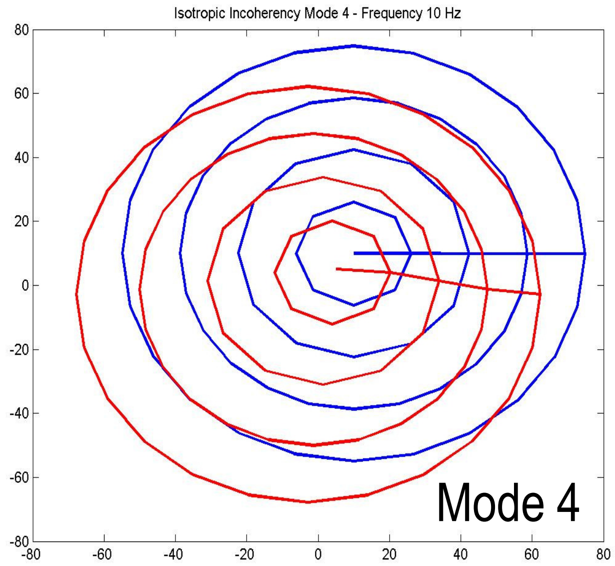
Random phases (stochastic part)

Motion Incoherency Modes of Basemat at 10 Hz


Isotropic Incoherency Mode 1 - Frequency 10 Hz


Isotropic Incoherency Mode 2 - Frequency 10 Hz


Isotropic Incoherency Mode 3 - Frequency 10 Hz


Isotropic Incoherency Mode 4 - Frequency 10 Hz

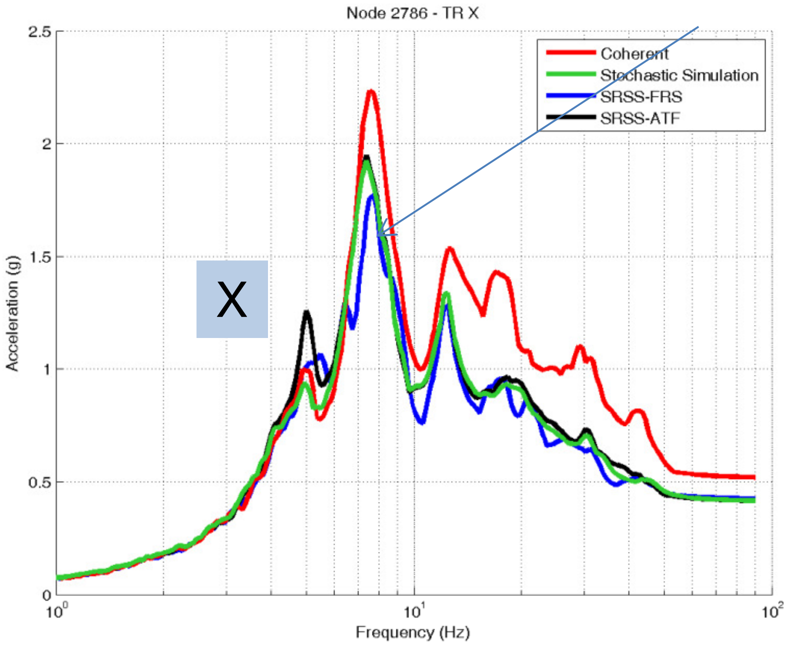
REMARKS:

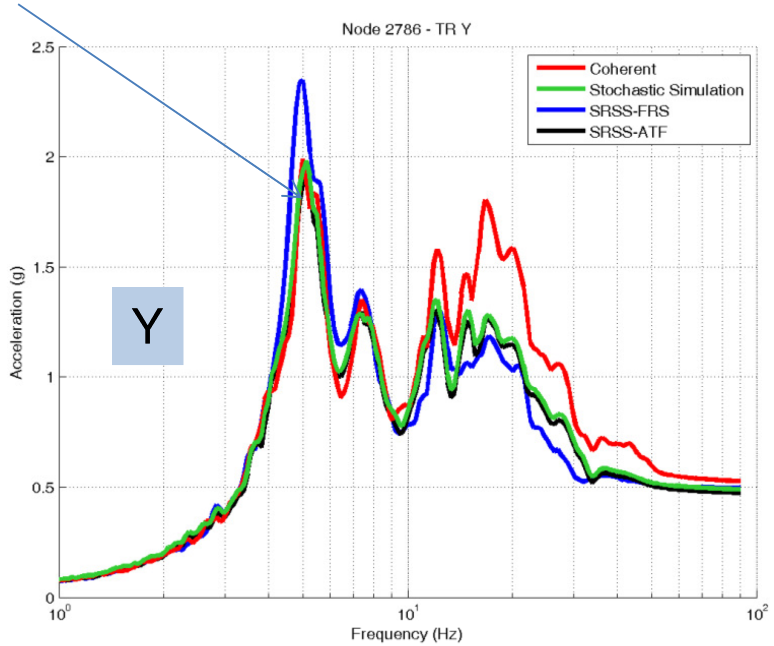
1) For low frequencies or rigid basemats only a number of few incoherency modes are sufficient.

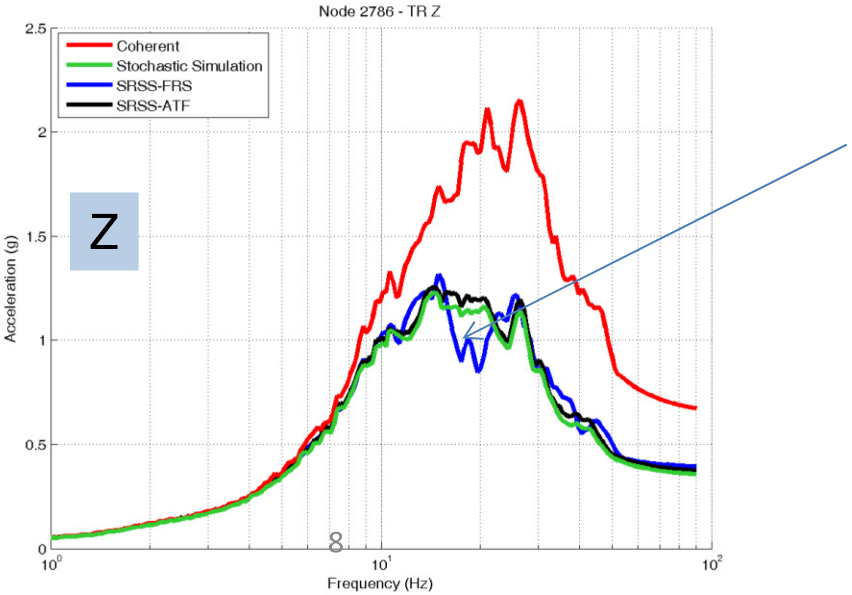
2) Incoherent motion is obtained by combining stochastically the coherency matrix modes.

3) EPRI validated for stick/rigid basemat models simple superposition rules, as SRSS and ACS *(zeroing ATF phases).*

Comparative Results for RB Stick Model

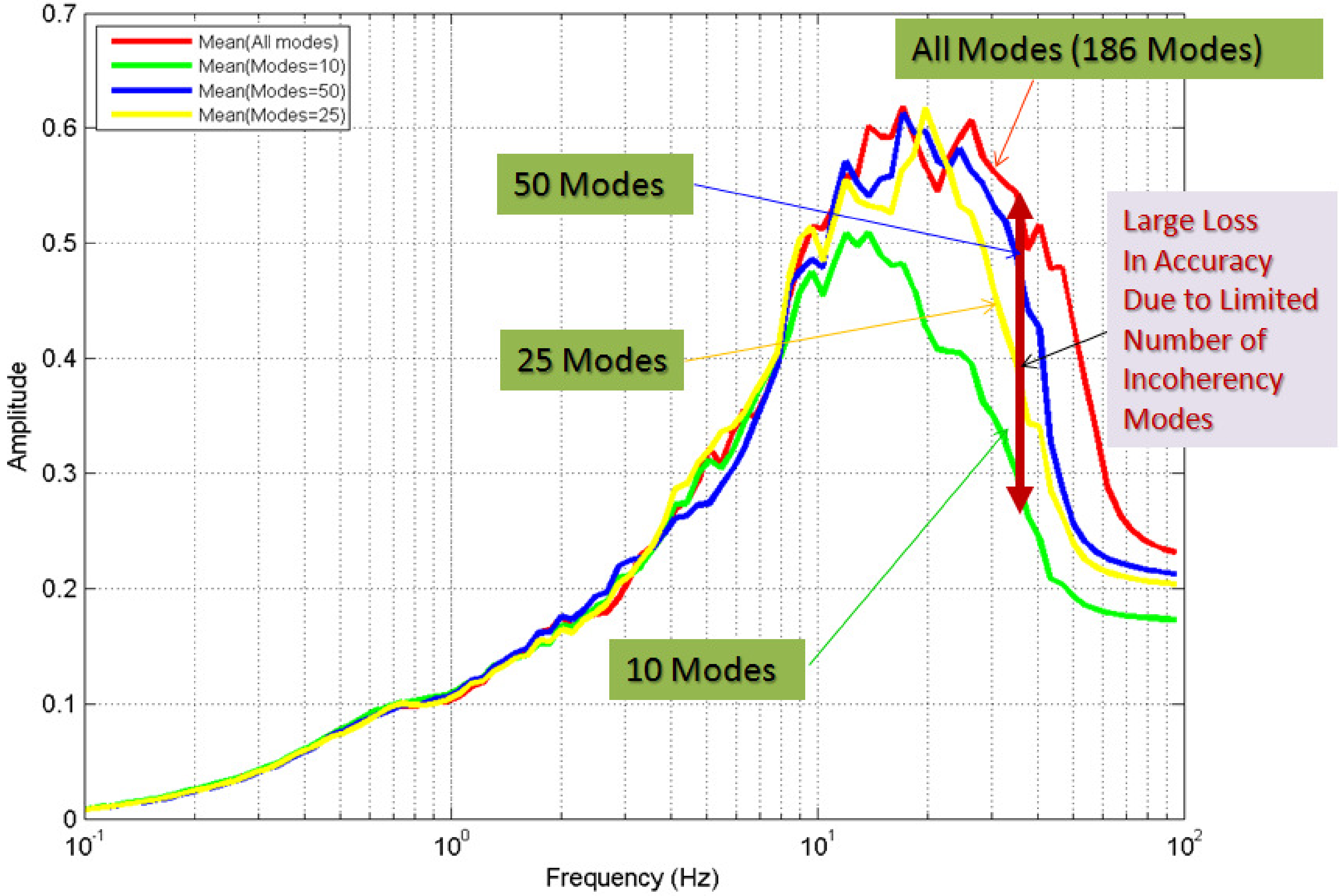






Effects of Number of Incoherent Modes for RB FEA Model

Elastic Basemat Corner -- XINPUT -- RS at Node 1047X



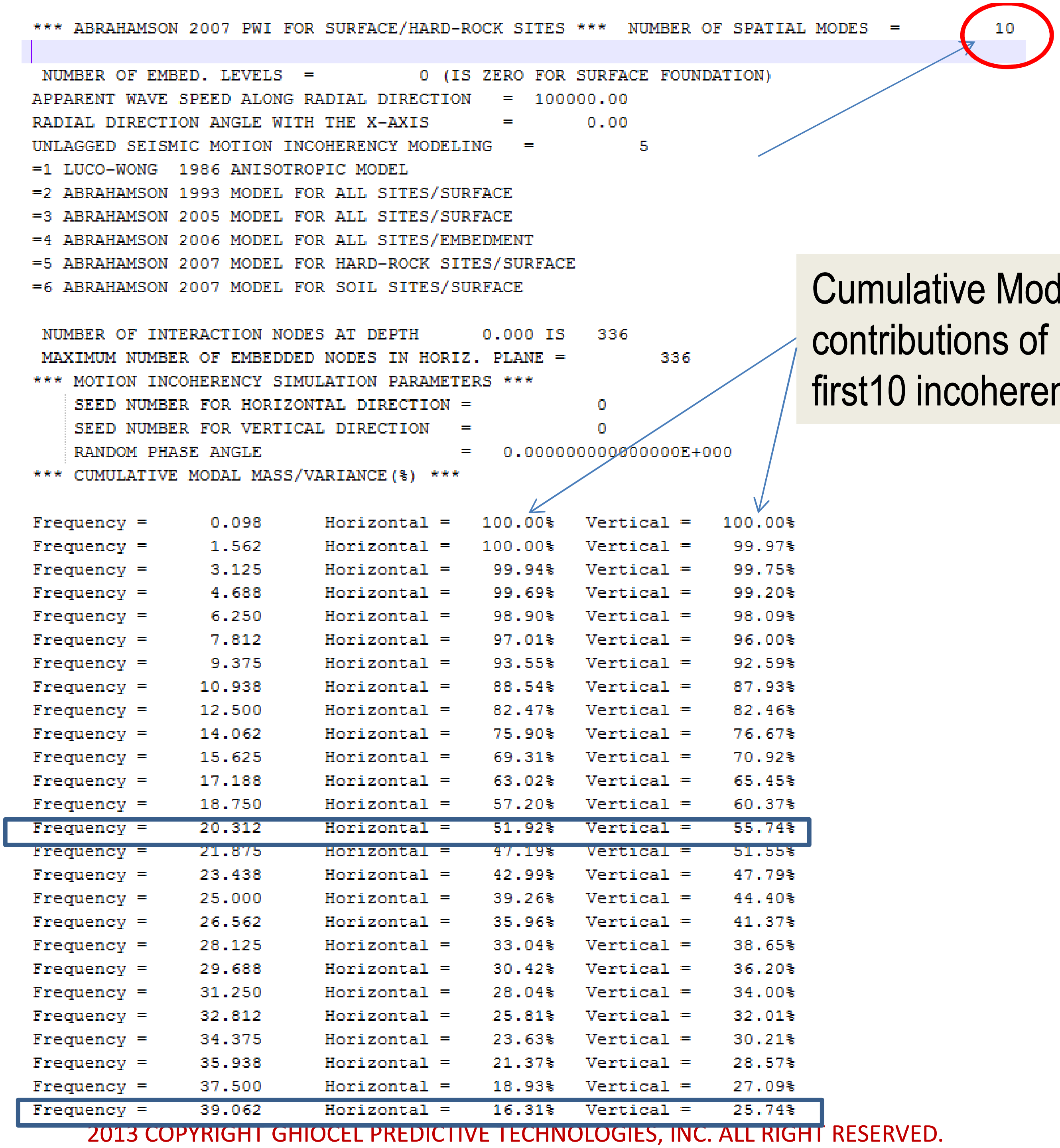
All Modes (186 Modes)

50 Modes

25 Modes

10 Modes

Large Loss In Accuracy Due to Limited Number of Incoherency Modes



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*** ABRAHAMSON 2007 PWI FOR SURFACE/HARD-ROCK SITES ***  NUMBER OF SPATIAL MODES  =       10

 NUMBER OF EMBED. LEVELS  =          0 (IS ZERO FOR SURFACE FOUNDATION)
APPARENT WAVE SPEED ALONG RADIAL DIRECTION   =  100000.00
RADIAL DIRECTION ANGLE WITH THE X-AXIS       =       0.00
UNLAGGED SEISMIC MOTION INCOHERENCY MODELING   =          5
=1 LUCO-WONG  1986 ANISOTROPIC MODEL
=2 ABRAHAMSON 1993 MODEL FOR ALL SITES/SURFACE
=3 ABRAHAMSON 2005 MODEL FOR ALL SITES/SURFACE
=4 ABRAHAMSON 2006 MODEL FOR ALL SITES/EMBEDMENT
=5 ABRAHAMSON 2007 MODEL FOR HARD-ROCK SITES/SURFACE
=6 ABRAHAMSON 2007 MODEL FOR SOIL SITES/SURFACE

 NUMBER OF INTERACTION NODES AT DEPTH      0.000 IS   336
 MAXIMUM NUMBER OF EMBEDDED NODES IN HORIZ. PLANE =         336
*** MOTION INCOHERENCY SIMULATION PARAMETERS ***
    SEED NUMBER FOR HORIZONTAL DIRECTION =            0
    SEED NUMBER FOR VERTICAL DIRECTION   =            0
    RANDOM PHASE ANGLE                   =   0.000000000000000E+000
*** 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%
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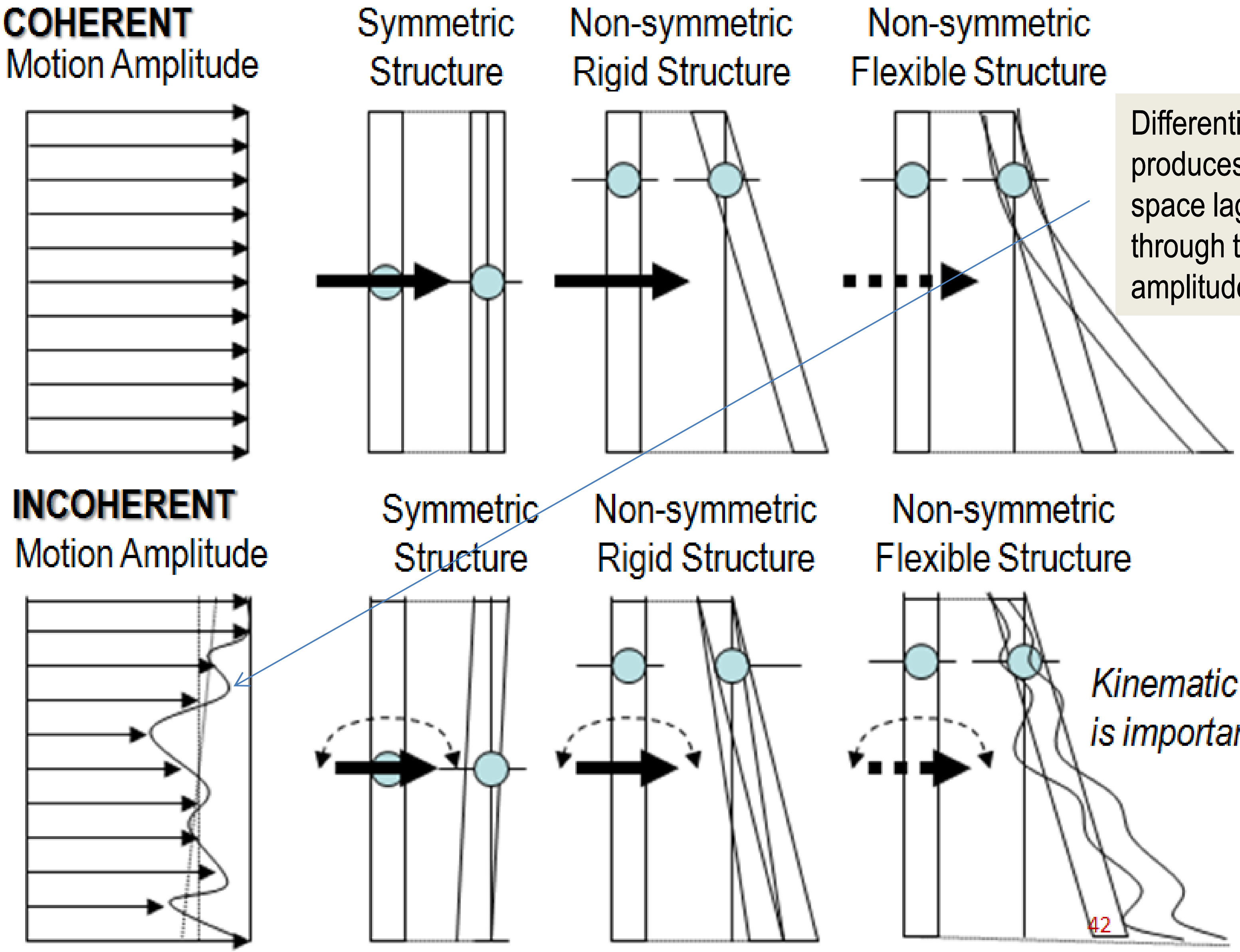
Cumulative Modal contributions of the first10 incoherent modes

Effect of Motion Incoherency Differential Phasing

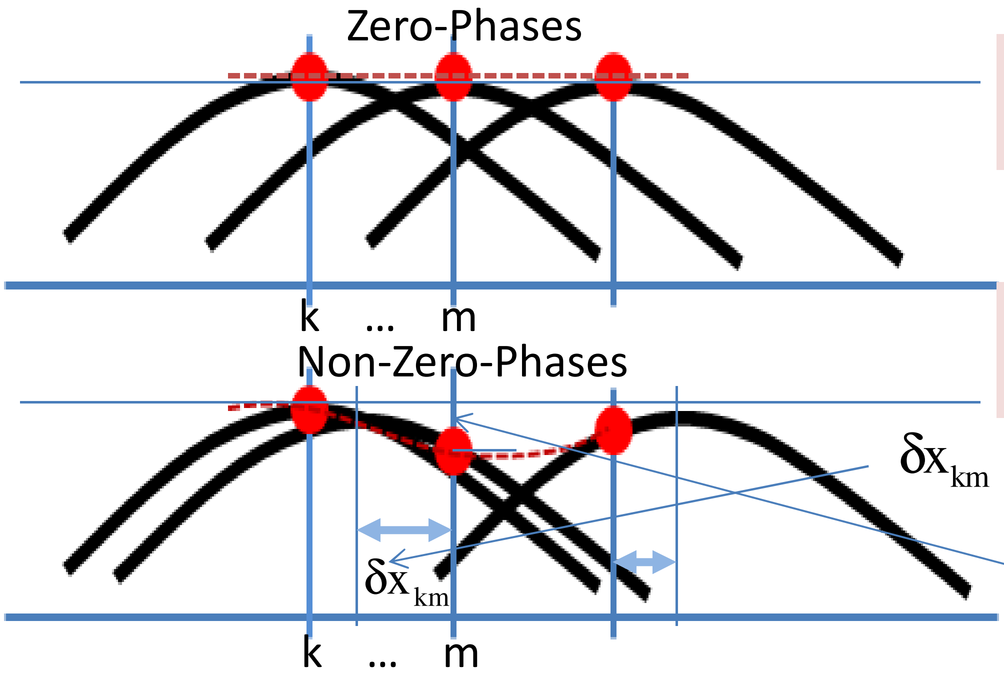


Differential phasing produces time and space lags, and through these, amplitude variations

Kinematic SSI is important

Effect of Zeroing Differential Phases at Lower Frequencies

At a given frequency, 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

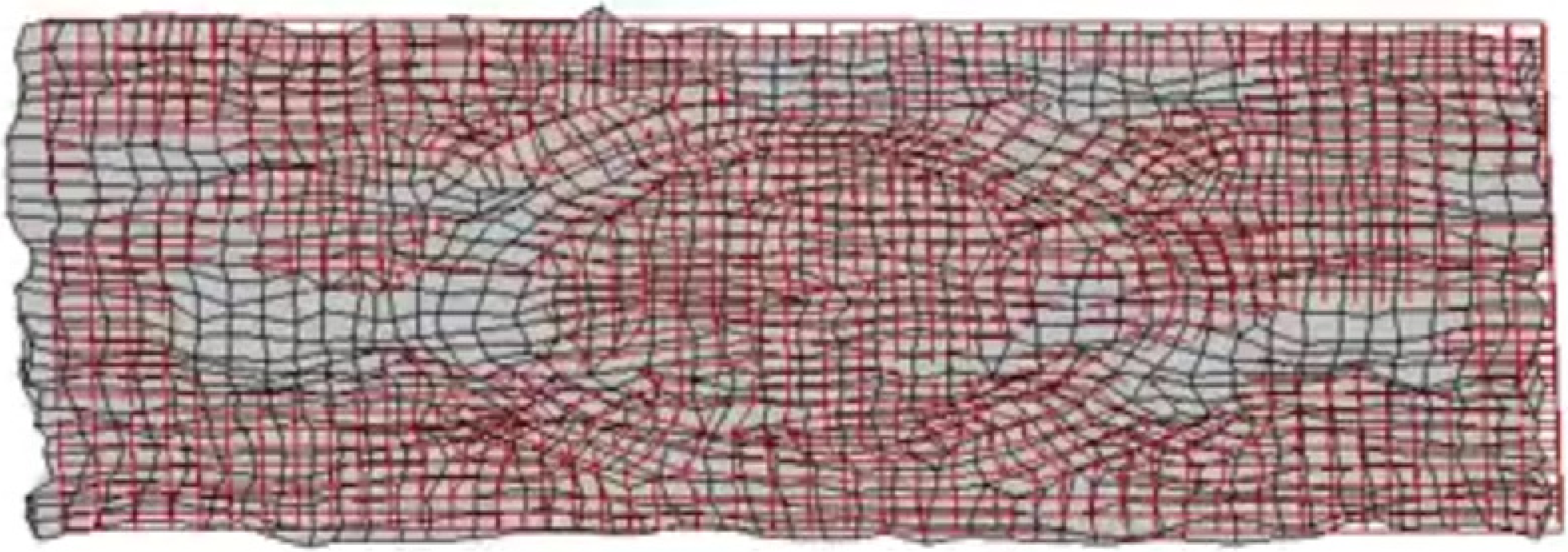
$$\delta x_{km} = (\psi_{j,k} - \psi_{j,m}) / k_j \quad \text{(space lag)}$$

Differential Amplitude Variations due to Differential Random Phasing

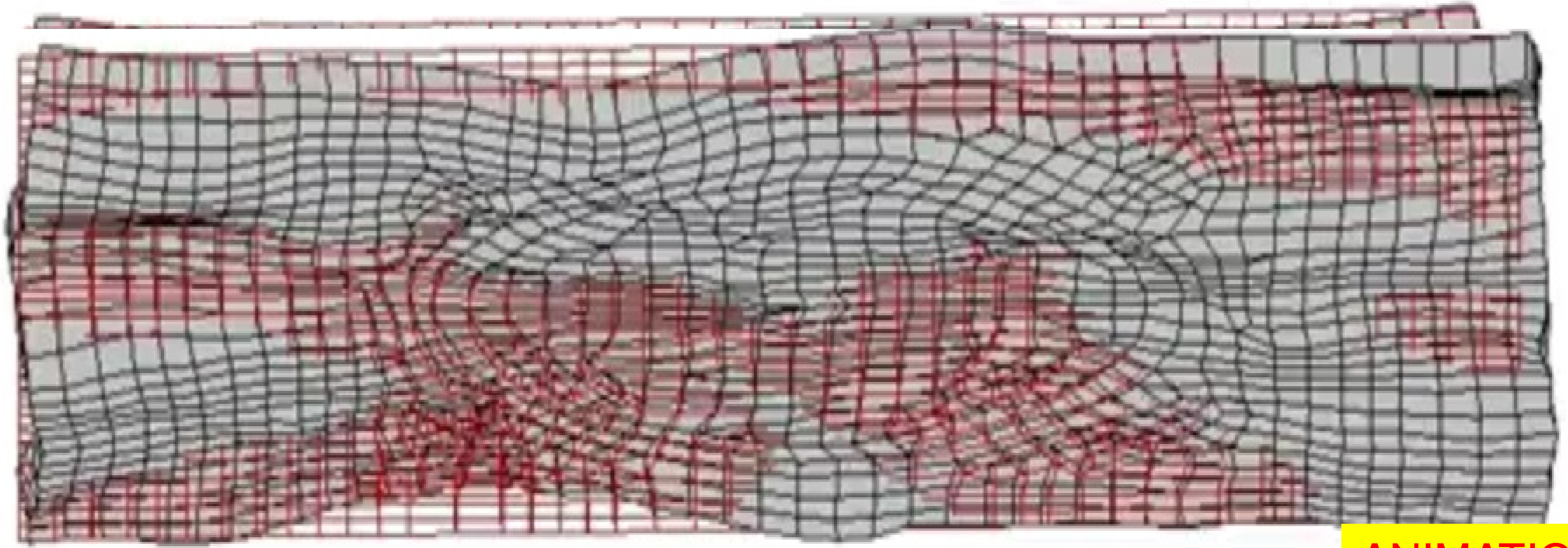
Mode 1 Contribution		
Freq	Part H	Part V
1 Hz	100%	98.2
8 Hz	84%	67%
25 Hz	7%	21%

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

Incoherency Simulation With Phase Adjustment (Underestimate Incoherency)



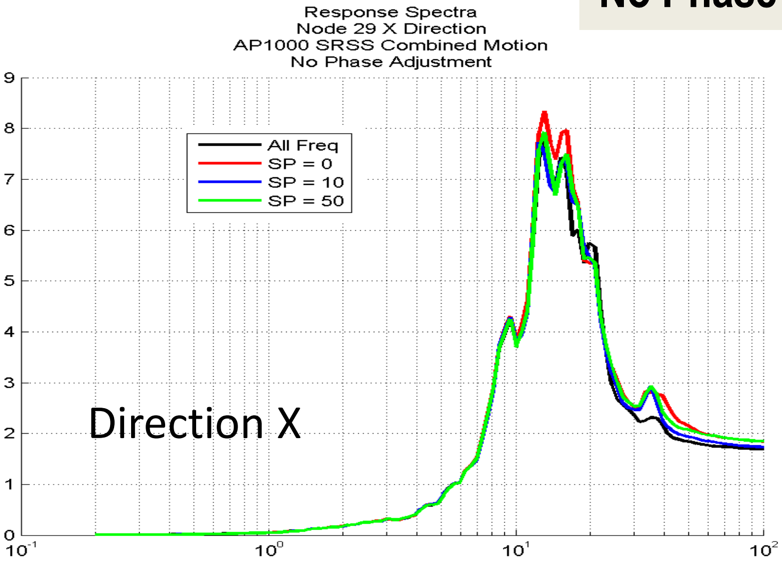
Incoherency Simulation Without Phase Adjustment (Unbiased Estimation)

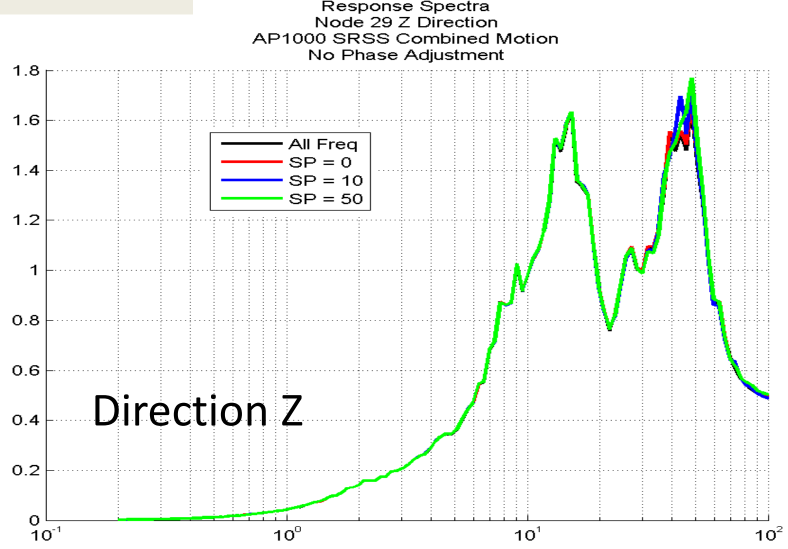


ANIMATIONS

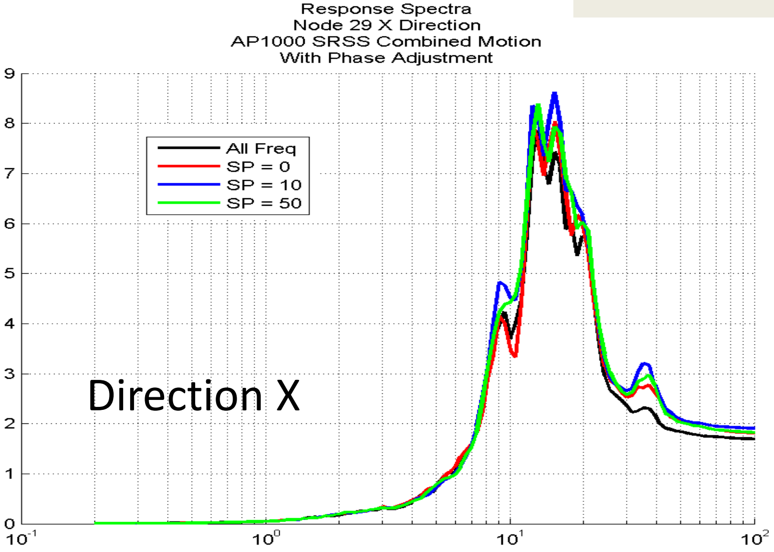
Effects of Phase Adjustment (Zeroing) for a RB Stick Model

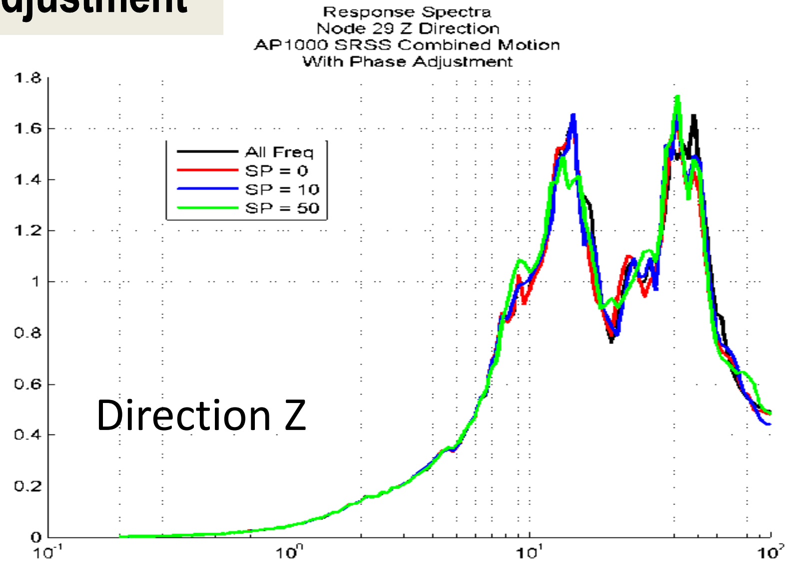
No Phase Adjustment


Response Spectra
Node 29 X Direction
AP1000 SRSS Combined Motion
No Phase Adjustment


Response Spectra
Node 29 Z Direction
AP1000 SRSS Combined Motion
No Phase Adjustment

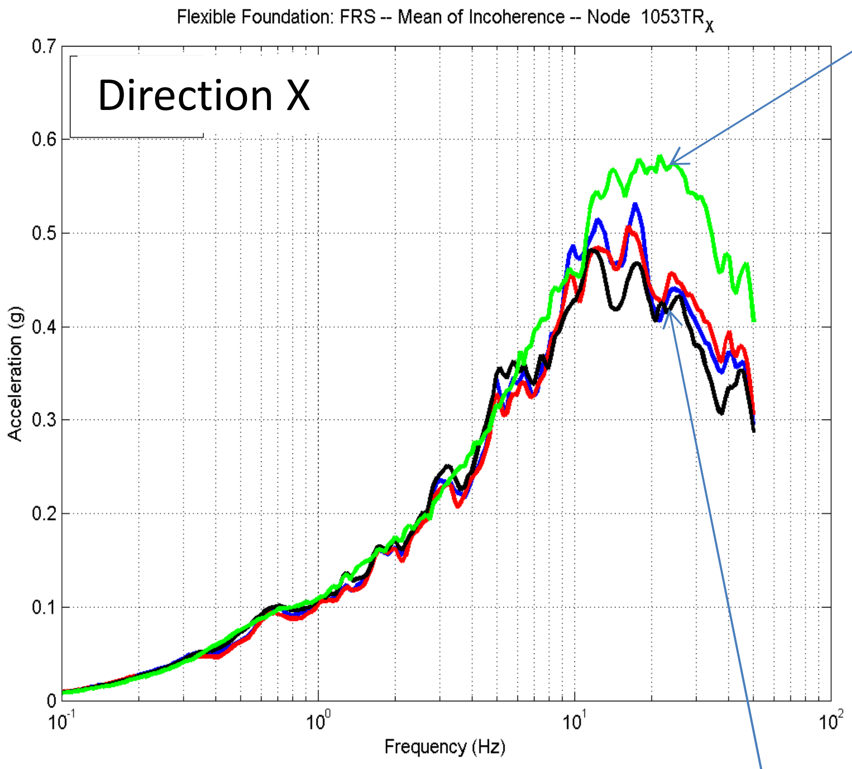
With Phase Adjustment

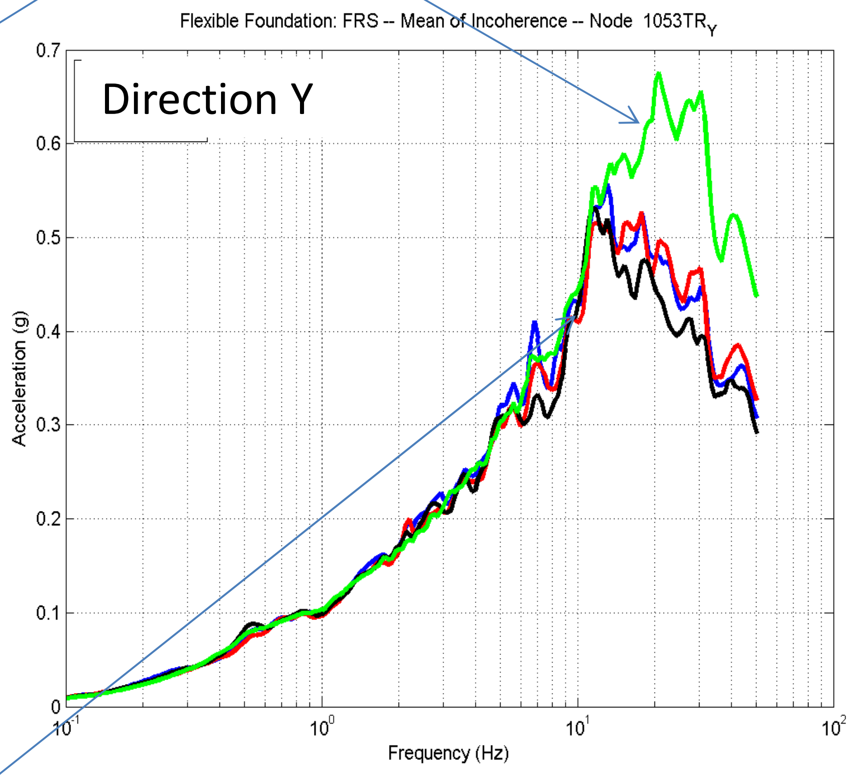

Response Spectra
Node 29 X Direction
AP1000 SRSS Combined Motion
With Phase Adjustment


Response Spectra
Node 29 Z Direction
AP1000 SRSS Combined Motion
With Phase Adjustment

Effects of Phase Adjustment (Zeroing) for RB Complex FEA Model

With Phase Adjustment

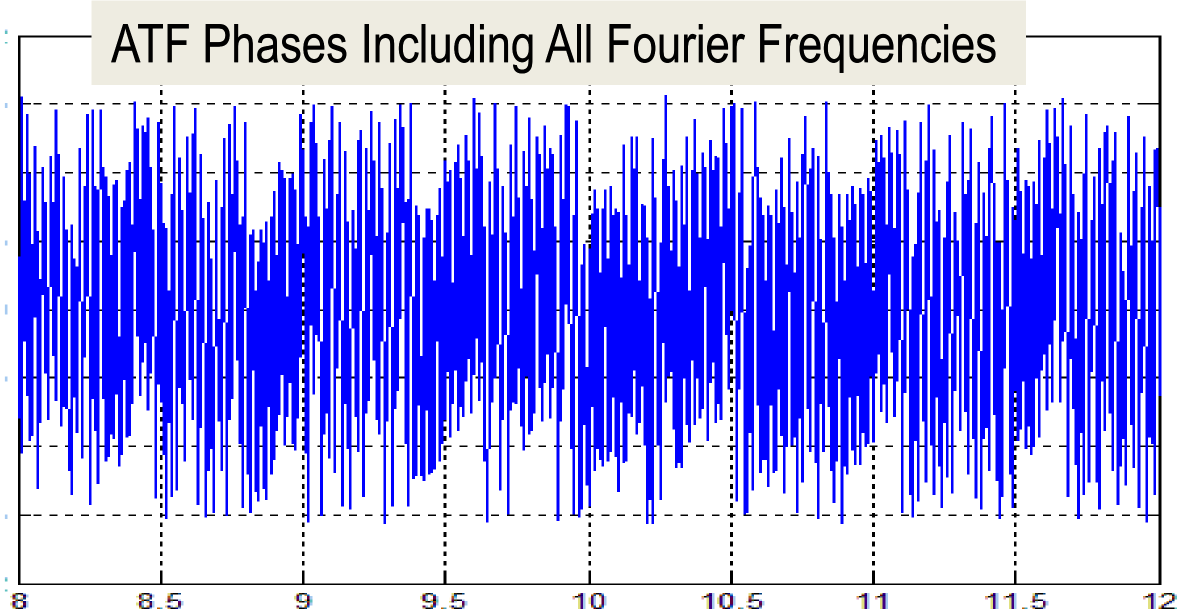




No Phase Adjustment

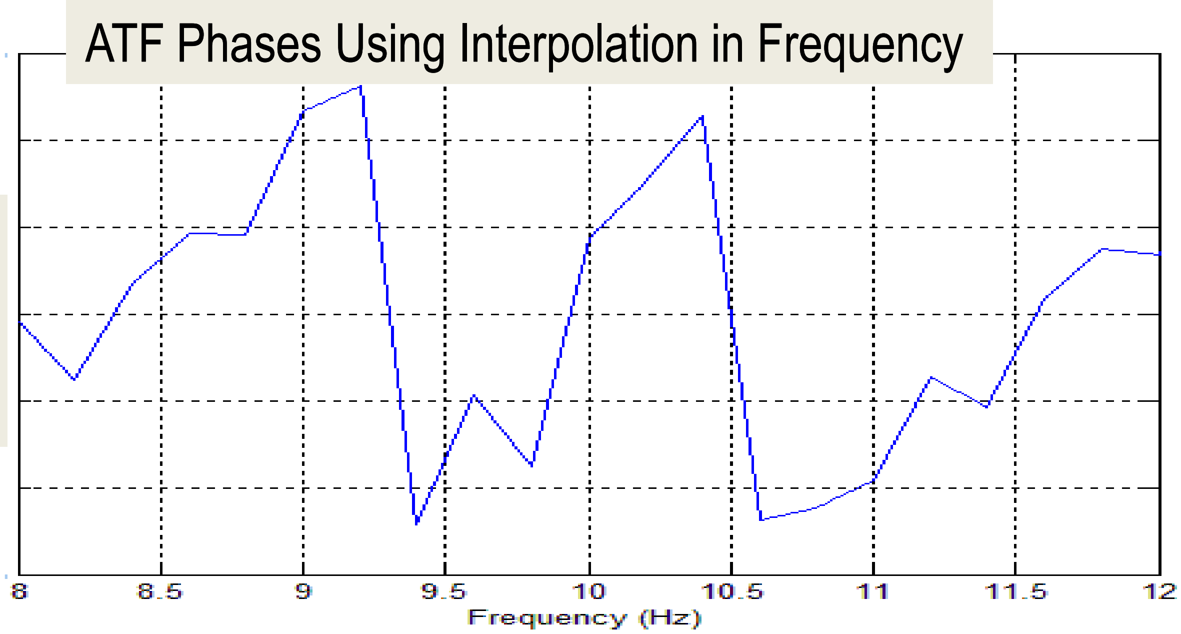
Effects of Complex Response Interpolation on Differential Phases

Records show Significant *Differential Phases (Incoherency)* for Neighbor Frequencies



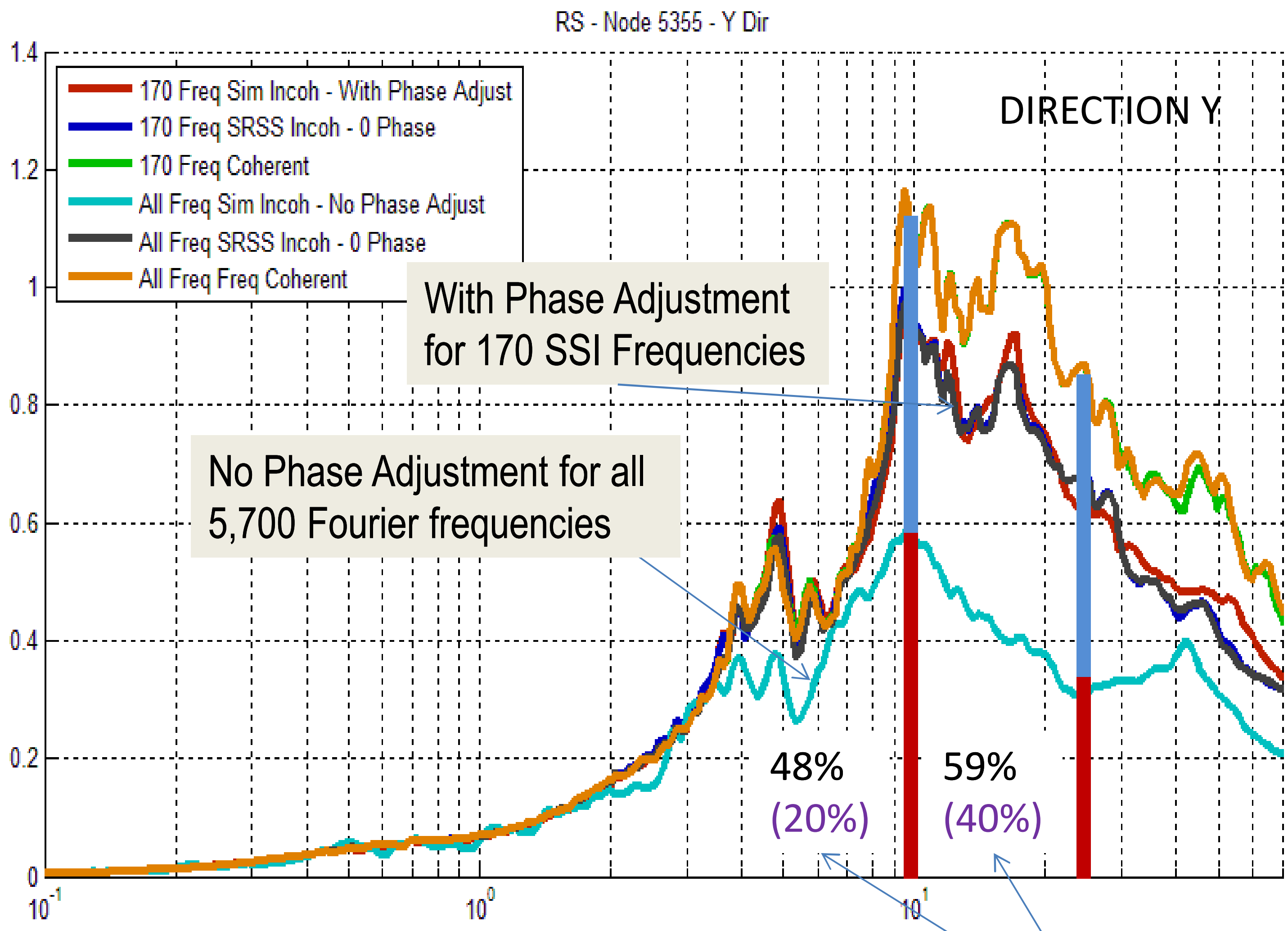
ATF Phases Including All Fourier Frequencies

Interpolation smoothes, reduces *Differential Phases (Incoherency)* for Neighbor Frequencies



ATF Phases Using Interpolation in Frequency

Comparative ISRS for Different Modeling Assumptions

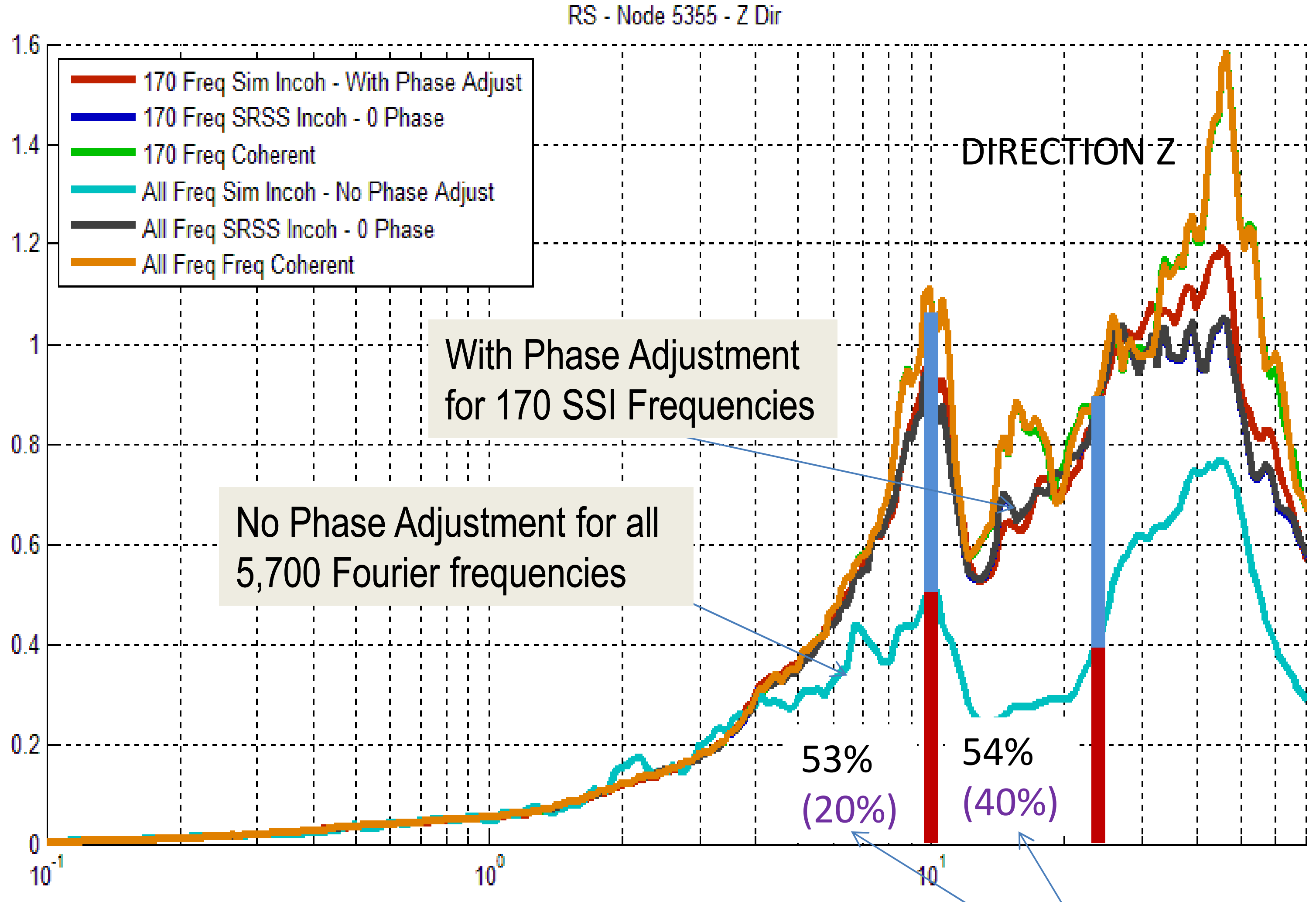


With Phase Adjustment for 170 SSI Frequencies

No Phase Adjustment for all 5,700 Fourier frequencies

ASCE 04-1998 for 300ft size

Comparative ISRS for Different Modeling Assumptions



DIRECTION Z

With Phase Adjustment for 170 SSI Frequencies

No Phase Adjustment for all 5,700 Fourier frequencies

53%
(20%)

54%
(40%)

ASCE 04-1998 for 300ft size

ASCE 04-1998 Incoherency Reduction Factors

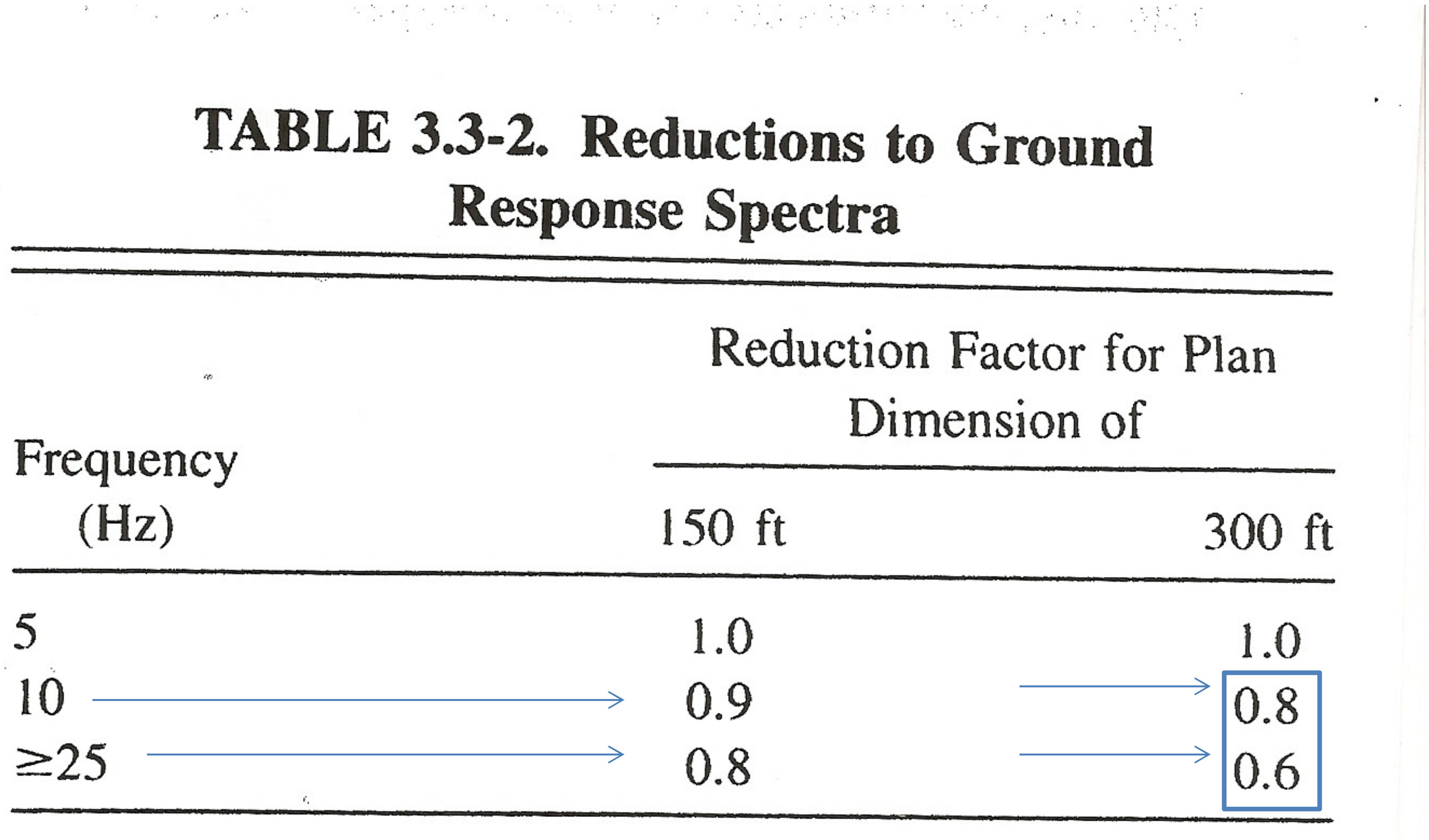
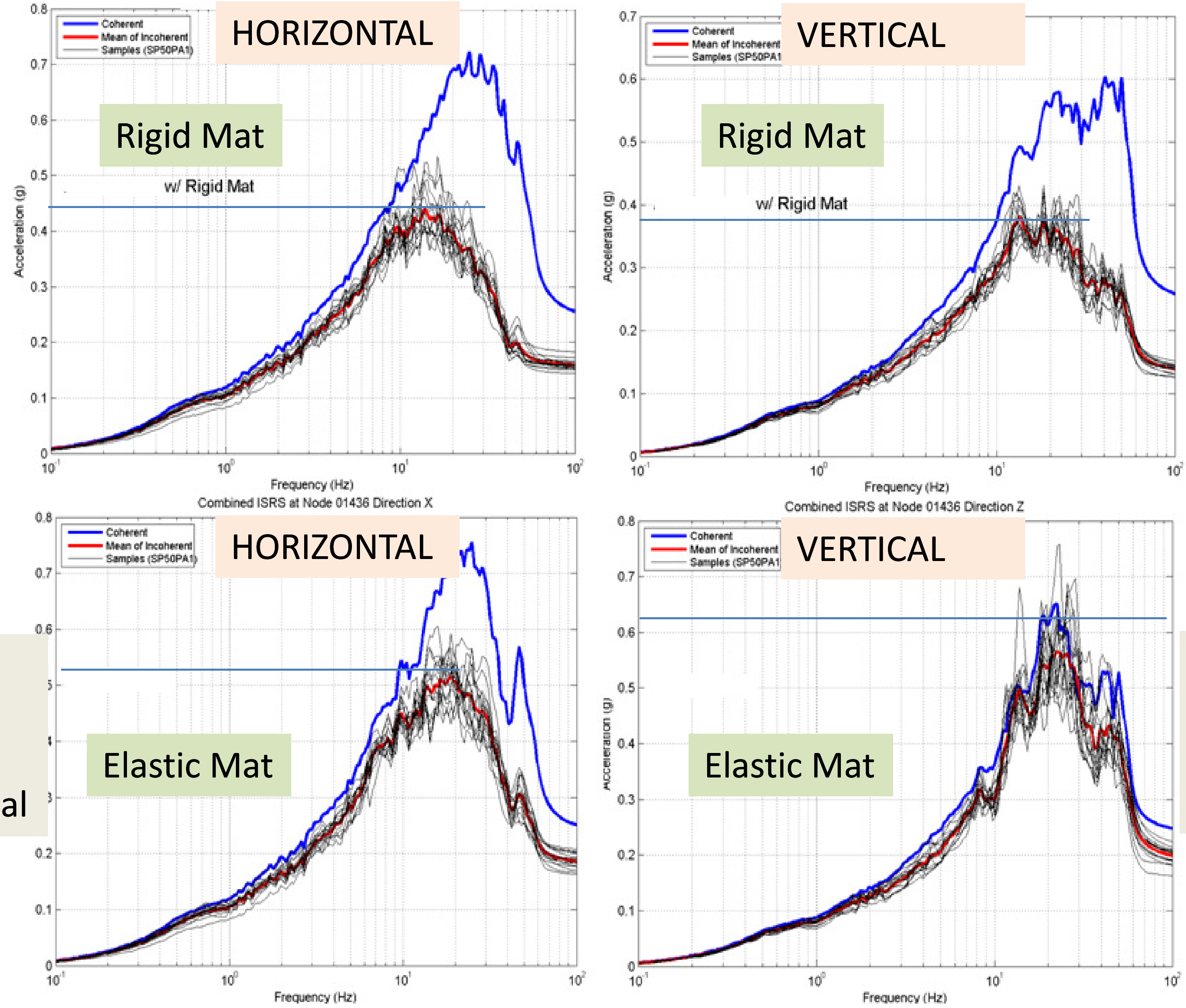


TABLE 3.3-2. Reductions to Ground Response Spectra

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

Basemat Flexibility Effects on RB Complex ISRS



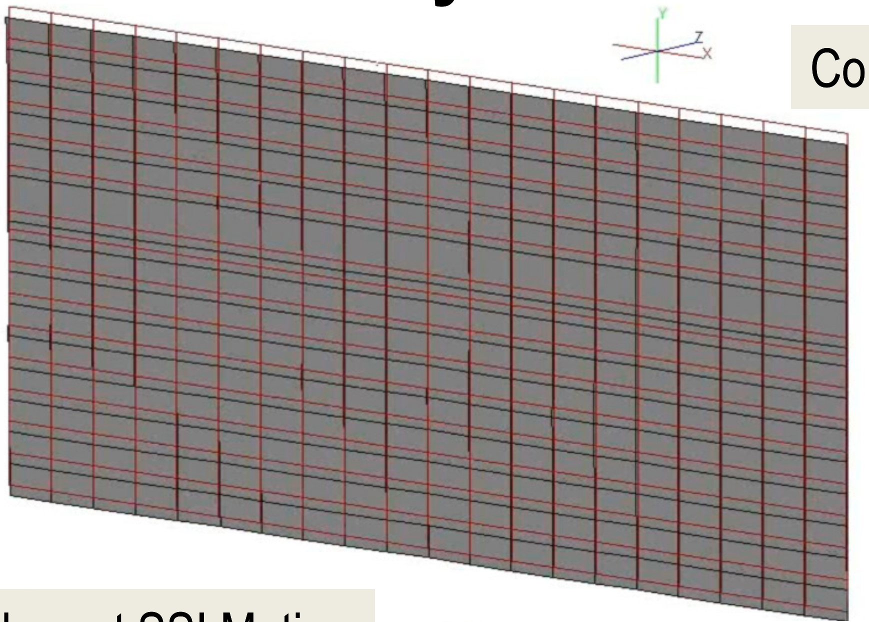
Combined ISRS at Node 01436 Direction X

Combined ISRS at Node 01436 Direction Z

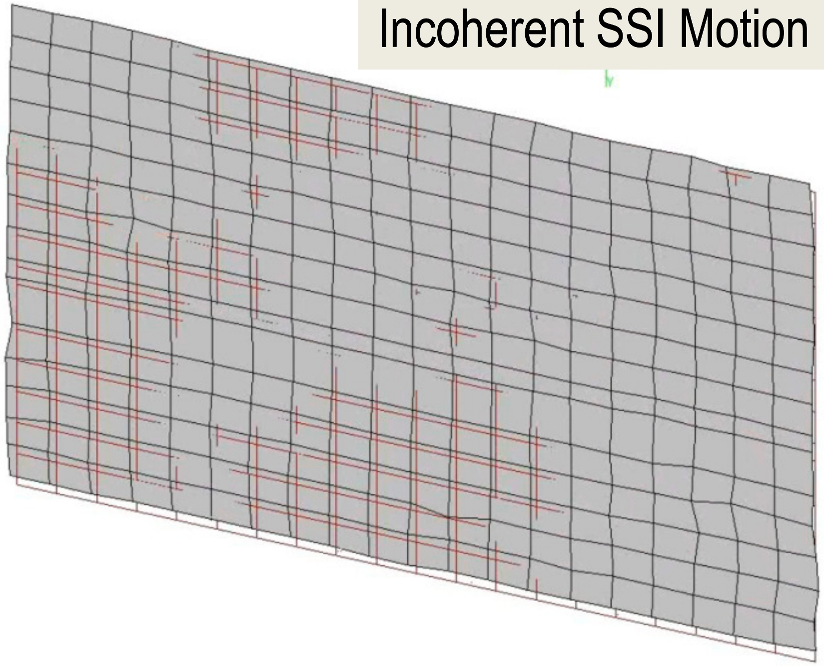
Elastic is 20% up for horizontal

Elastic is 65% (!) up for vertical

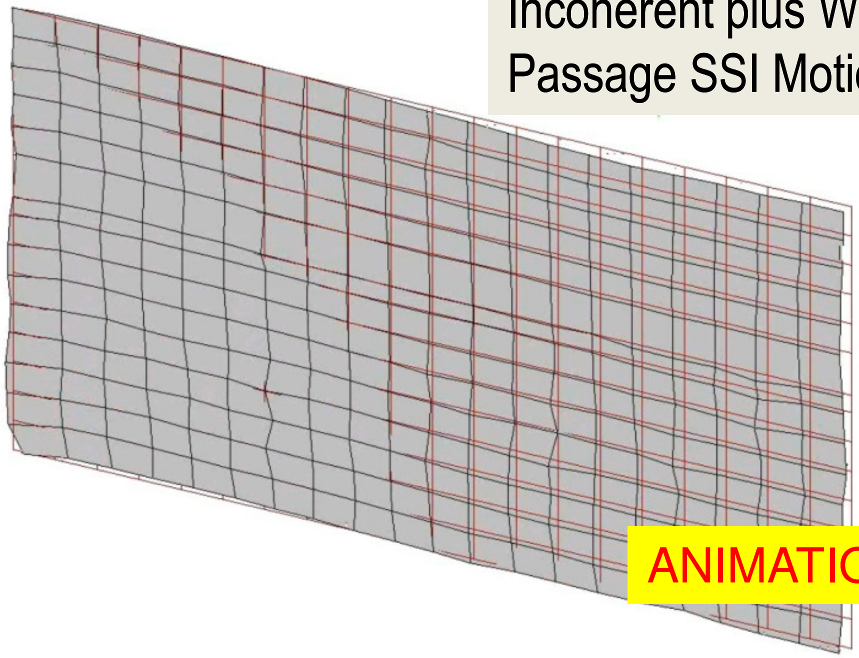
Effects of Incoherency on Basemat Bending



Coherent SSI Motion



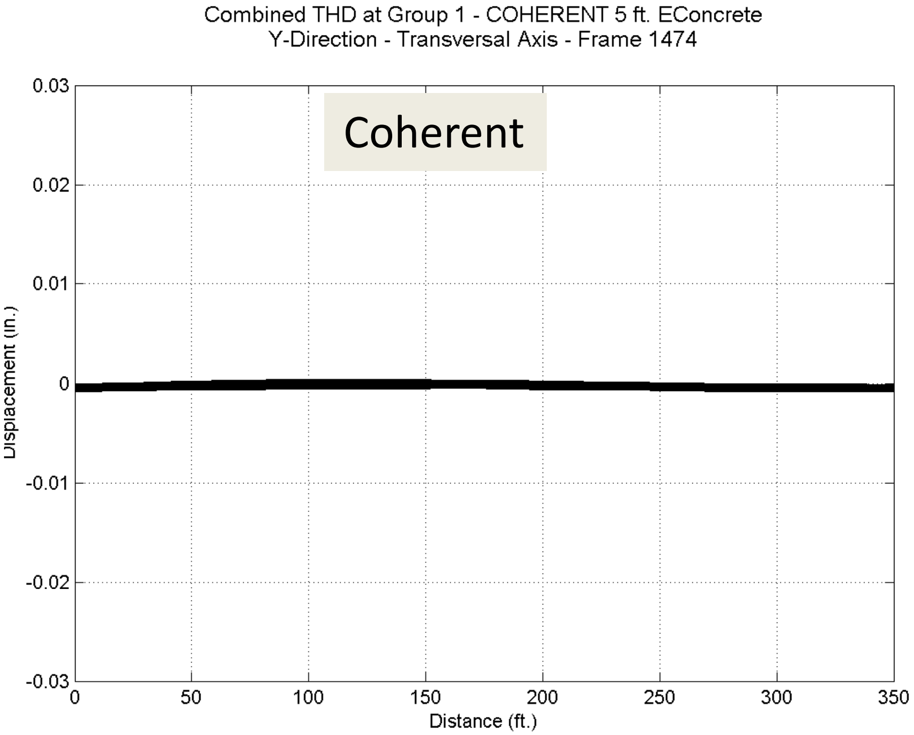
Incoherent SSI Motion



Incoherent plus Wave Passage SSI Motion

ANIMATIONS

Effects of Incoherency on Basemat Bending



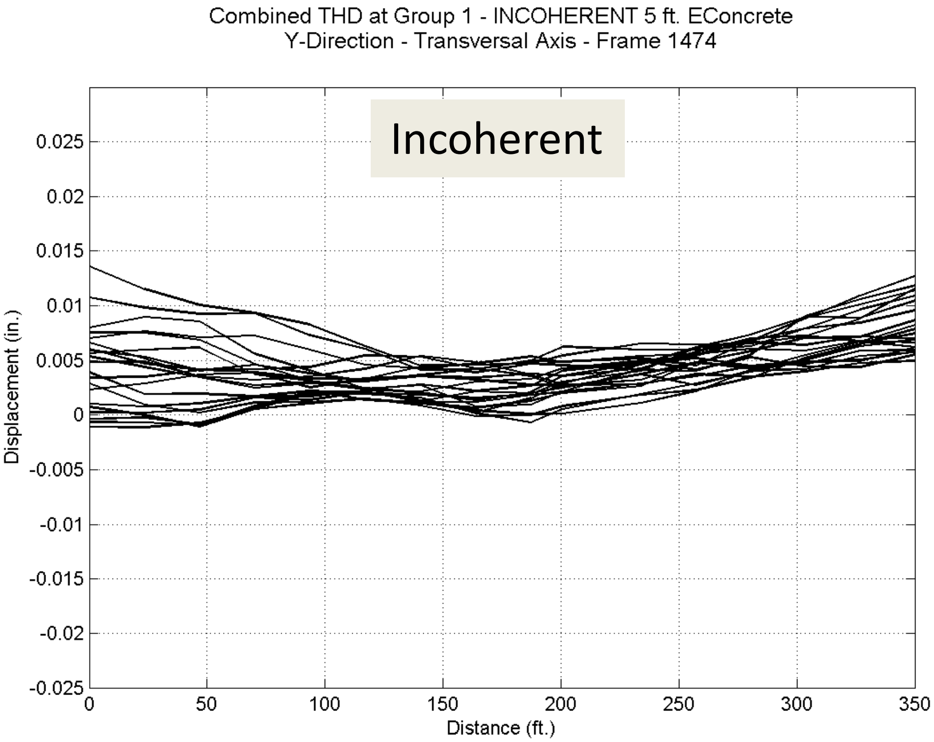
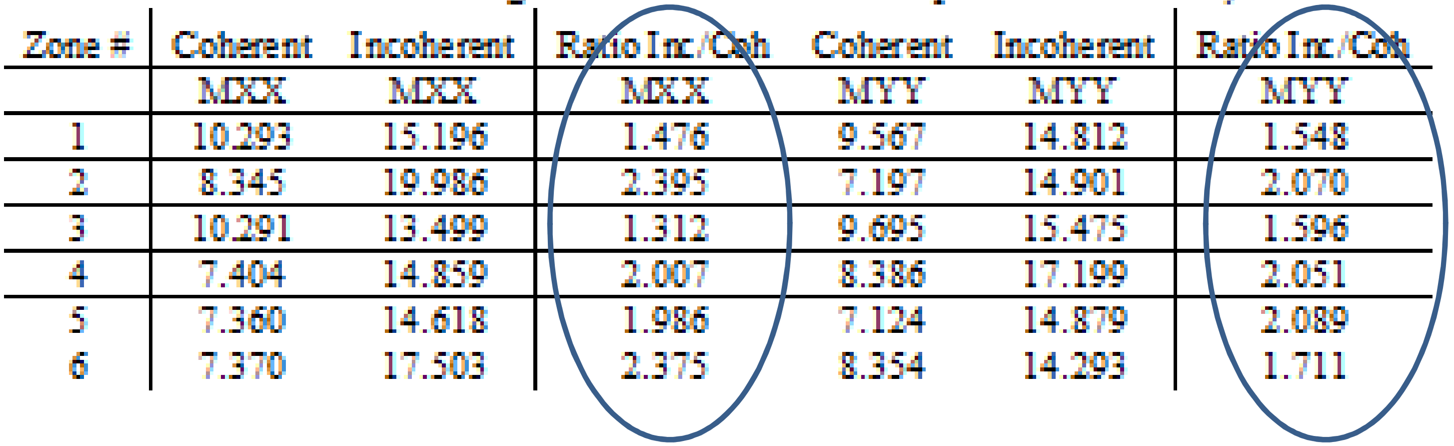


Table 1: Baseslab Bending Moments for A Soil Deposit with Vs = 3,300 ft/s



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
4	7.404	14.859	2.007	8.386	17.199	2.051
5	7.360	14.618	1.986	7.124	14.879	2.089
6	7.370	17.503	2.375	8.354	14.293	1.711

Effects of Incoherency on Basemat Bending

It should be noted that incoherent bending moments increase by 30% to 130% in comparison with coherent bending moments. The relative stiffness between baseslab and soil subgrade is an important parameter that affects the kinematic SSI effects.

It should be noted that the computed baseslab bending moments from SSI analysis include the contributions of both the primary stresses due to structural loads, and the secondary stresses due to SSI induced displacements. *The current ASCE standards do not consider in the structural design procedures for concrete footers below columns or wall lines or basemats, the effects of the secondary stresses produced by the SSI induced displacements. The neglect of the secondary stresses could produce a large under evaluation of the elastic bending moments. However, it should be noted that for the ultimate strength design approach used in the ASCE code for concrete design, the effects of the secondary stresses could be neglected if the baseslab has sufficient ductility to accommodate the SSI induced displacements.*