

Session 6: CLASSI Approach to Incoherency SShort 2:30 to 3:00

Technical Approach

- Key elements of the CLASSI approach are to determine:
 - The incoherency transfer function (ITF) or scattering function due to kinematic interaction
 - The corresponding foundation input motion (FIM) given by the inverse Fast Fourier Transform of the product of the free field Fourier spectra and the ITF
- The ITF and FIM are the effects of incoherency or random horizontal spatial variation of ground motion
 - Reduction of translation compared to the free field motion
 - Induced rotation (torsion and rocking)

CLASSlinco and CLASSlinco-SRSS

- CLASSI, a program for SSI analysis of surface founded structures on a rigid basemat has been modified to treat incoherent ground motion
- CLASSlinco assumes deterministic phasing of FIM components of motion
- CLASSlinco-SRSS assumes random phasing of FIM components of motion
- For either approach, a new CLASSI module, CLAN6 has been developed to compute ITF and FIM

CLAN6 – Evaluation of Incoherency Transfer Function (ITF)

Define soil profile and specify properties by soil layers Define foundation footprint and specify as n sub-regions
Input coherency function, $\gamma(f,s)$ as a function of frequency, f and separation distance, s. At each frequency, evaluate $[\gamma]$ at the n separation distances
Run CLASSI modules to evaluate the impedance matrix and Green's function matrix
From Green's function matrix and rigid foundation assumption, evaluate the traction matrix, $[T]$. Invert the impedance function to evaluate the compliance function, $[C]$
Evaluate $[S_{UoI}]$, the cross PSD matrix of rigid massless foundation motion subjected to unit PSD input $[S_{UoI}] = [F] [S_{UGI}] [F^c]^T$ where $[F] = [C] [T]^T$ and $[S_{UGI}] = [I] [\gamma] [I]$
Evaluate the incoherency transfer function, $ITF(f)$ as the amplitude of the complex square root of the diagonal terms of $[S_{UoI}]$

Kinematic Interaction is the Key Element of the Incoherence Problem for CLASSI

- Each component of free-field motion (x, y, z) could produce six components of foundation input motion (FIM)
 - Square foundation – three important components of FIM per direction of excitation
 - X (free-field) → X, Y, Z, XX, YY, ZZ
 - Y (free field) → X, Y, Z, XX, YY, ZZ
 - Z (free-field) → X, Y, Z, XX, YY, ZZ
- For a given direction of input (X, Y, or Z), what is the phase relationship between the three FIM components?
 - Deterministic
 - Random

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Phase Relationship of the FIM Components

- Deterministic (CLASSlinco)
 - Most applicable to cases where the phase relationship is known (e.g., wave passage)
- Random (CLASSlinco-SRSS)
 - Assume each component of FIM has random phase vs. the other components
 - E.G., X-input → (X, Y, Z, XX, YY, ZZ) FIM randomly phased
- CLASSlinco-SRSS
 - Perform six analyses with input for each defined by the individual FIM components
 - SSI analysis
 - Repeat process until all FIM analyzed
 - Repeat for all directions
 - SRSS responses for each direction ground motion input and all combined

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CLASSlinco Analysis Steps

- GLAY (same as for coherent analysis)
- CLANINCO (creates input file for CLAN6; otherwise same as for coherent analysis)
- CLAN6 (new module for incoherence)
- Replace IMPFN with an incoherent IMPFN created by CLAN6 as input to SSIN
- SAP (same as for coherent analysis)
- INSSIN (same as for coherent analysis)
- SSIN (same as for coherent analysis)

CLASSlinco-SRSS Analysis Steps

- GLAY (same as for coherent analysis)
- CLANINCO (creates input file for CLAN6; otherwise same as for coherent analysis)
- CLAN6-SRSS (new module for incoherence)
- Replace IMPFN with incoherent IMPFNs created by CLAN6 as input to SSIN. Six IMPFN files are created for each foundation degree of freedom, 3 translations and 3 rotations.
- SAP (same as for coherent analysis)
- INSSIN (same as for coherent analysis)
- SSIN (same as for coherent analysis, except that six SSIN runs are performed for each of the six IMPFN files)
- Generate six response spectra for each of the foundation degrees of freedom and combine by SRSS to obtain the in-structure response spectra for incoherent motion.

Validation

CLASSlinco has been validated by comparison of computed response to that from published literature

- Incoherency transfer functions computed for rigid massless foundations
- Incoherency transfer functions computed for a structure with outriggers on a rigid foundation

CLASSlinco-SRSS has been validated by comparison of computed response with that from several SASSI approaches

Rigid Massless Foundation Cases

- Rigid, massless foundations on a visco-elastic half-space
 - Kinematic interaction
 - Incoherency transfer functions (CLASSI scattering functions)
- Circular disk of radius 84.63 ft (Area = 22,500 ft²)
 - Luco and Mita (1987)
 - Veletsos and Prasad (1989)
- Square foundation 150 ft on a side
 - Luco and Wong (1986)

Validation of CLASSlinco: Key Parameters

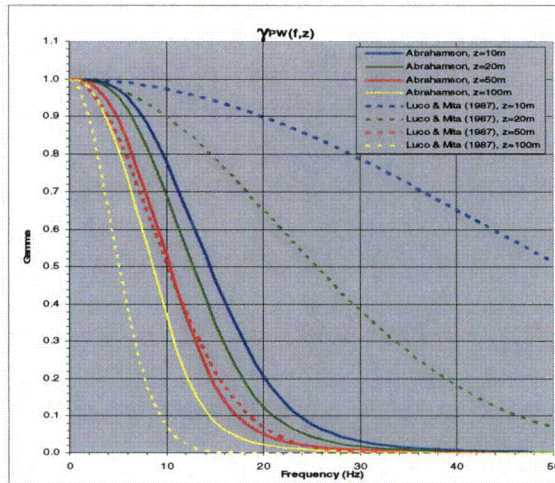
- Visco-elastic half-space
 - Shear Wave Velocity, $V_s = 6300 \text{ ft/sec} = 1920.24 \text{ m/sec}$
 - Mass Density, $\rho = .004969 \text{ k-sec}^2/\text{ft}^4$
 - Poisson's Ratio, $\nu = 0.33$
 - Damping, $\xi = 0.01$

Coherency Ground Motion Function

- Coherency ground motion function (vertically incident waves)

$$\Gamma(|r_1 - r_2|, \omega) = \exp[-(\gamma\omega|r_1 - r_2|/V_s)^2]$$
 where
 - $|r_1 - r_2|$ is the distance between points on the foundation (subregion centroids)
 - γ is a dimensionless incoherence parameter,
 - ω is the angular frequency (radians/sec),
 - V_s is the representative shear wave velocity of the soil profile
- CLASSlinco was modified to include the Luco and Wong representation of the coherency ground motion
- Values of $\gamma = 0.1, 0.2, 0.3, 0.4$, and 0.5 were benchmarked
- Luco and Wong provide the following guidance
 - $V_s * 2 \times 10^{-4} \text{ sec/m} \leq \gamma \leq V_s * 3 \times 10^{-4} \text{ sec/m}$
 - $\gamma = 0.5$ approximates this recommendation for $V_s = 1920 \text{ m/sec}$

Coherency Ground Motion Function: Abrahamson vs. Luco and Wong ($\gamma = 0.5$)



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Circular Disk

- Luco and Mita (1987)
 - Solution in terms of Bessel functions
 - Horizontal and induced torsion
 - Vertical and induced rocking
 - Results plotted vs. dimensionless frequency a_0

Frequency (Hz)	a_0
10	0.84404123
20	1.68808245
25	2.11010307
30	2.53212368
50	4.22020613

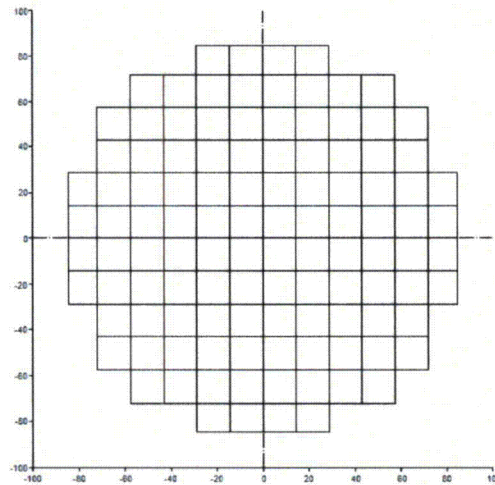
- Veletsos and Prasad (1989)
 - Reduced the number of independent variables
 - Horizontal and induced torsion plotted vs. $\gamma * a_0$

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Circular Disk: CLASSlinco Discretization

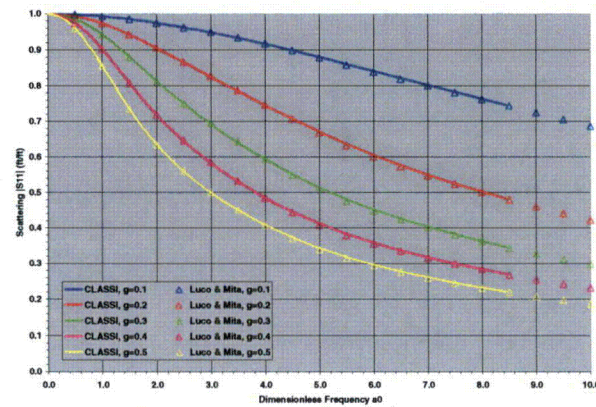


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CLASSlinco vs. Luco and Mita (1987): Horizontal ITF

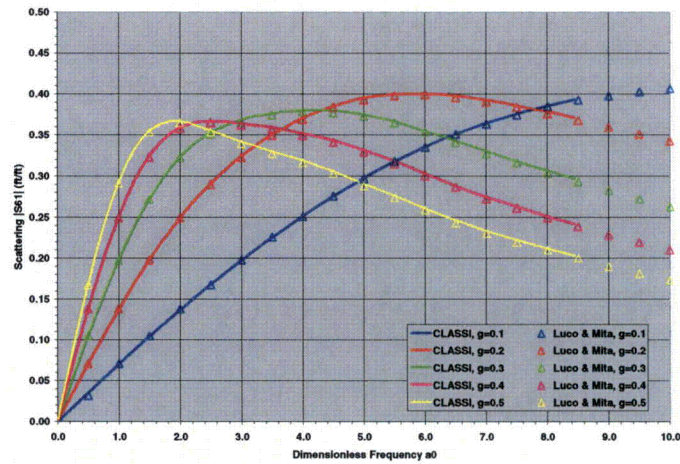


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CLASSlinco vs. Luco and Mita (1987): Induced Torsion ITF

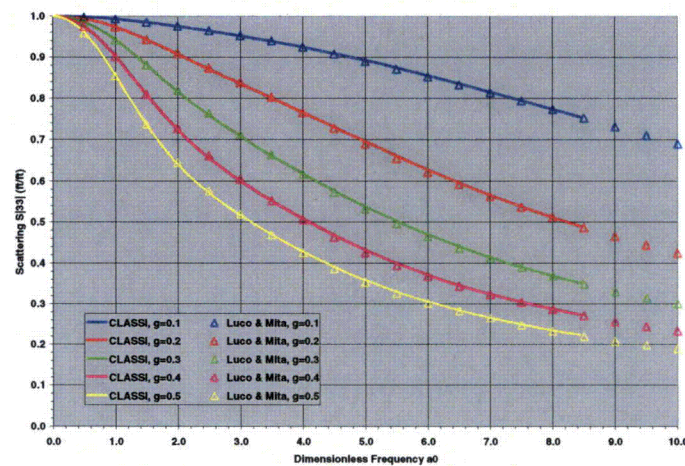


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CLASSlinco vs. Luco and Mita (1987): Vertical ITF

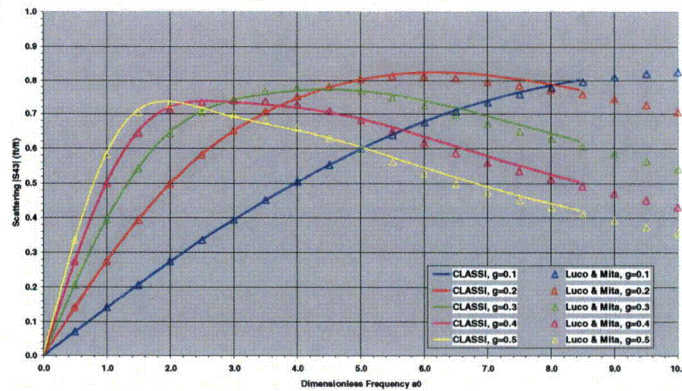


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CLASSlinco vs. Luco and Mita (1987): Induced Rocking ITF

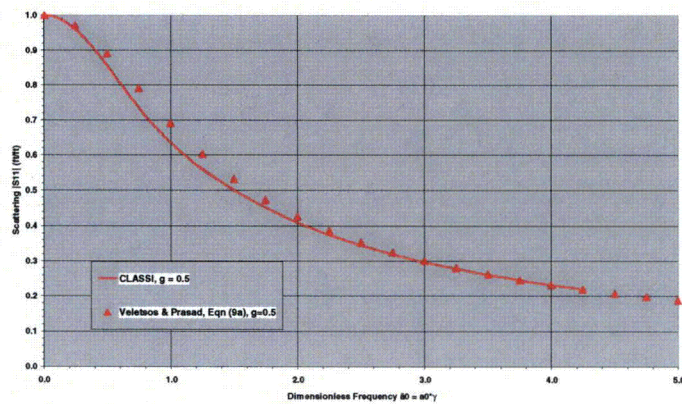


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CLASSlinco vs. Veletsos and Prasad (1989) ($\gamma = 0.5$): Horizontal ITF

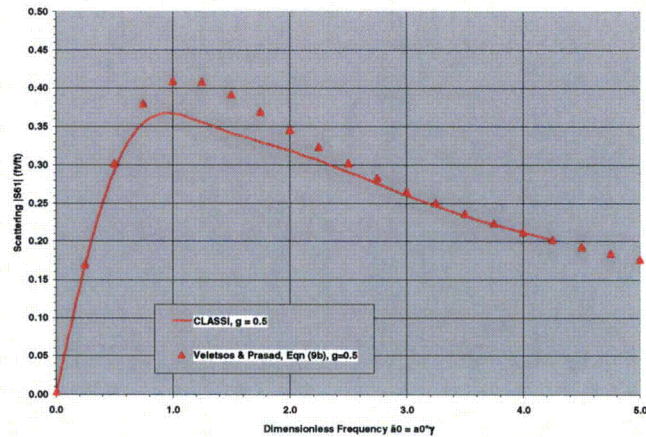


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CLASSlinco vs. Veletsos and Prasad (1989) ($\gamma = 0.5$): Induced Torsion ITF

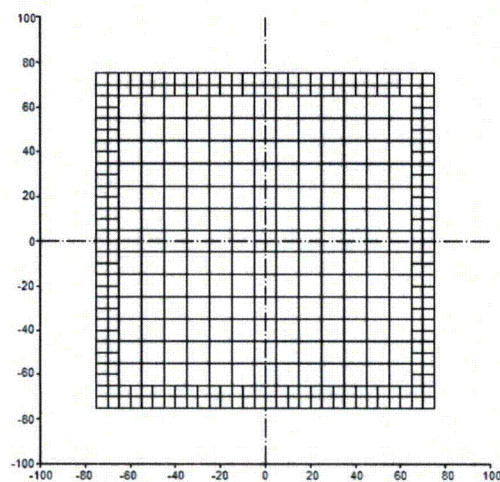


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Square Foundation: CLASSlinco Discretization

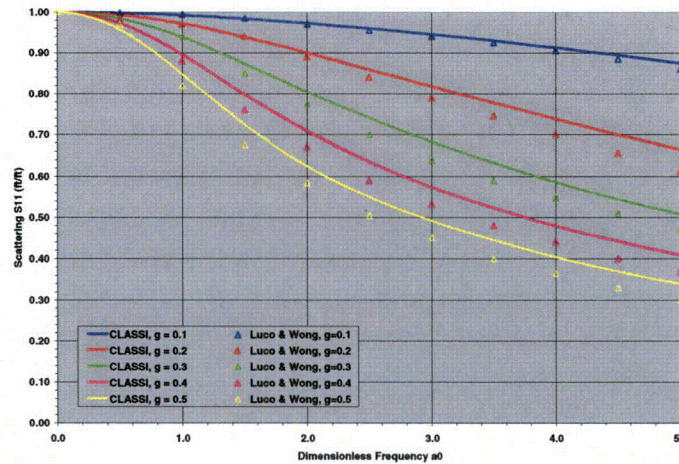


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CLASSlinco vs. Luco and Wong (1986): Horizontal ITF

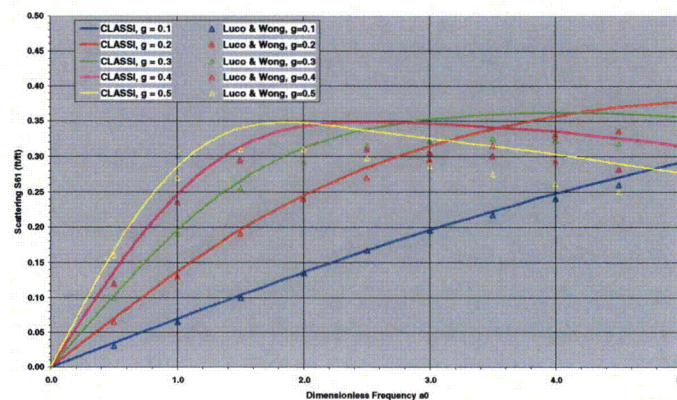


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CLASSlinco vs. Luco and Wong (1986): Induced Torsion ITF

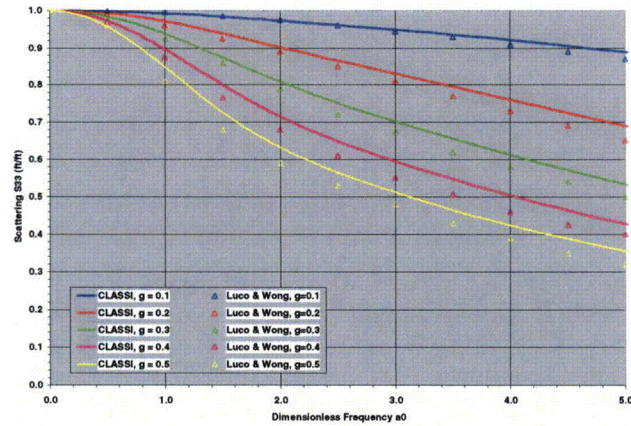


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CLASSlinco vs. Luco and Wong (1986): Vertical ITF

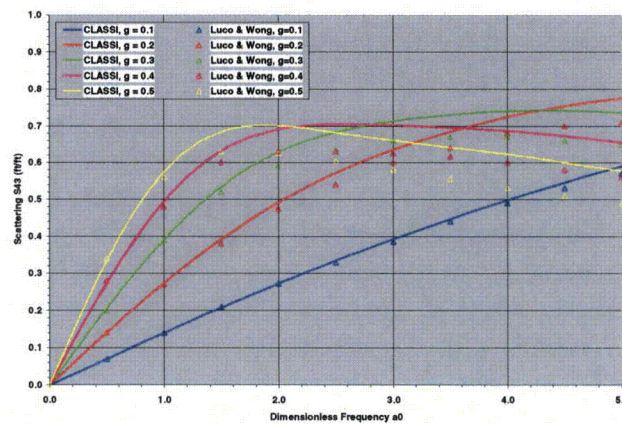


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CLASSlinco vs. Luco and Wong (1986): Induced Rocking ITF



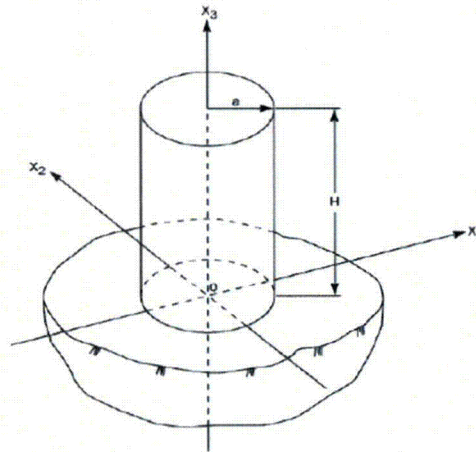
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Structure with Outriggers Case

- Mita & Luco, 1986
 - 40 m high, 10 m radius cylindrical structure represented by stick model
 - Foundation has 10 m radius on 400 m/s halfspace
 - Transfer functions evaluated at base center and edge and top center and edge



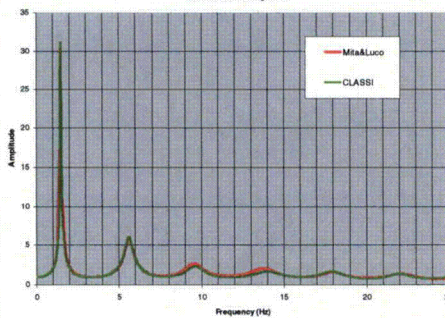
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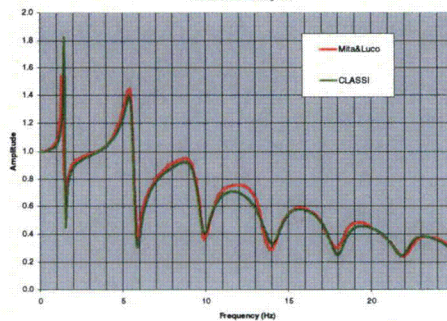
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Bottom Center Response – Horizontal due to Horizontal

Horizontal Top Edge Response due to Horizontal Excitation
Coherent Motion, $g = 0.0$



Horizontal Base Center Response due to Horizontal Excitation
Incoherent Motion, $g = 0.5$

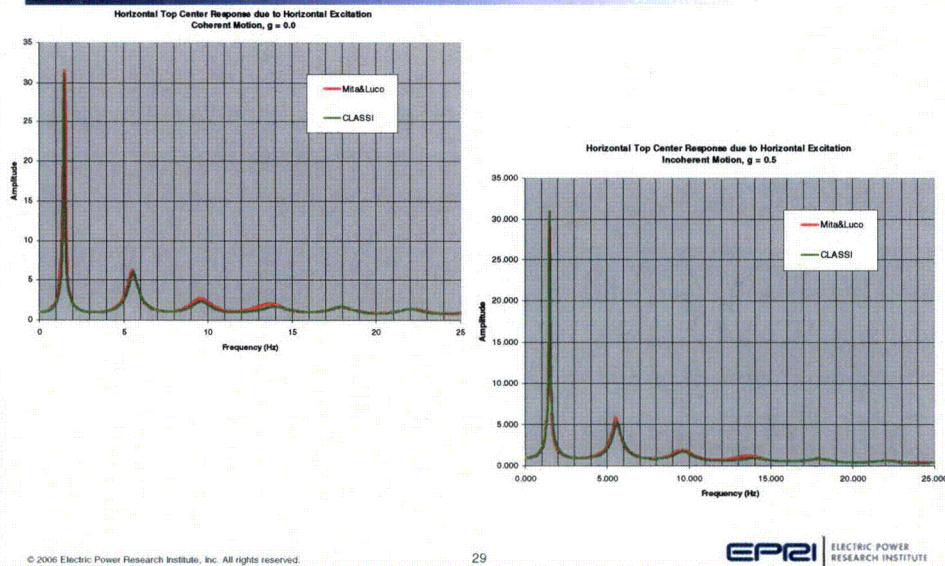


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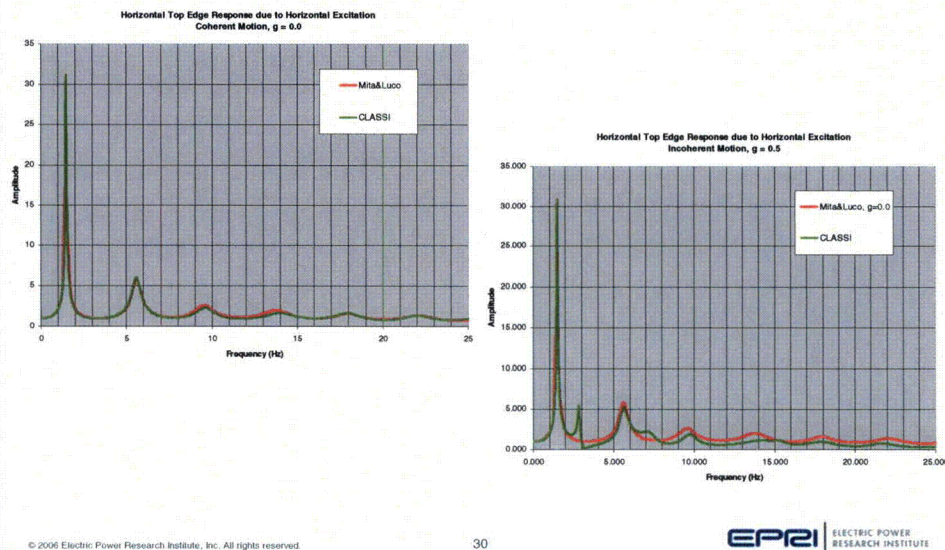
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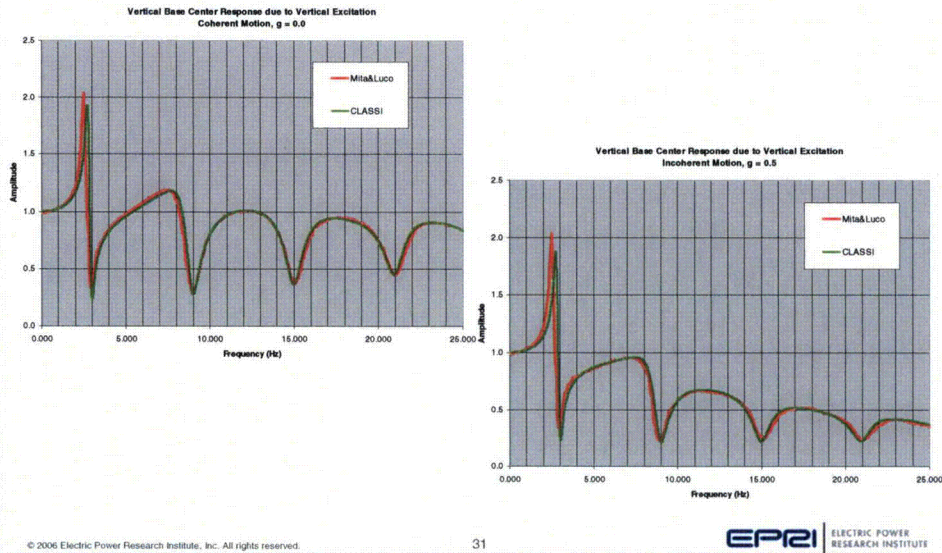
Top Center Response – Horizontal due to Horizontal



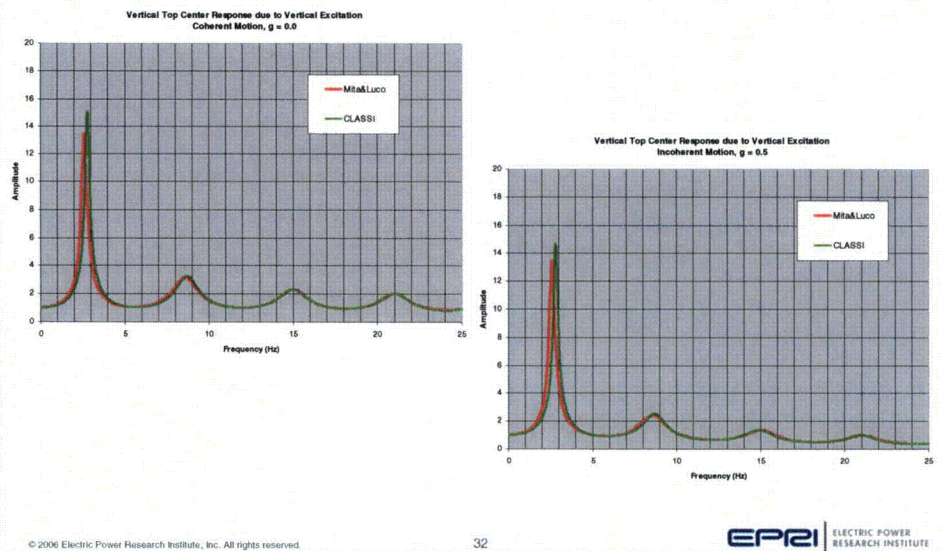
Top Edge Response – Horizontal due to Horizontal



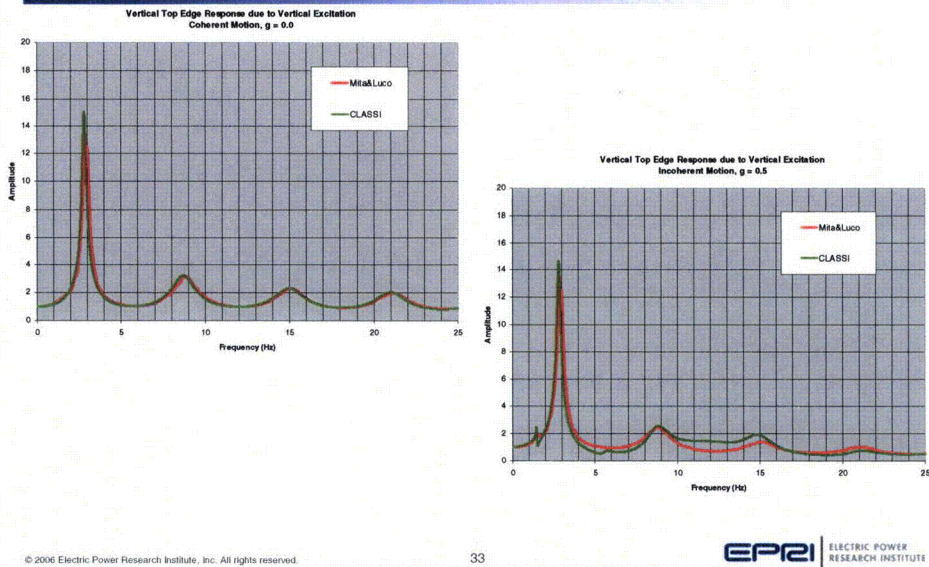
Bottom Center Response – Vertical due to Vertical



Top Center Response – Vertical due to Vertical



Top Edge Response – Vertical due to Vertical

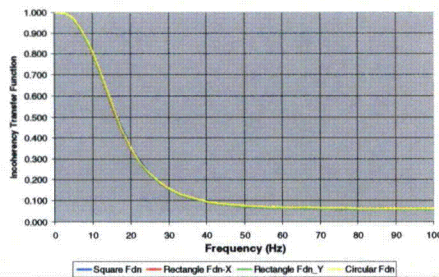


Demonstration of Incoherency Effects

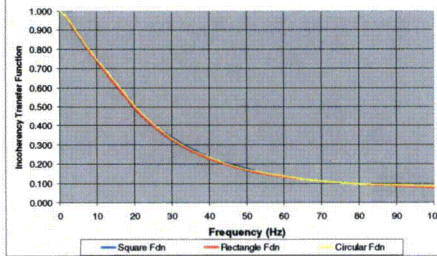
- Rapid run times for CLASSlinco enabled the study of incoherency effects
 - Foundation Shape
 - Foundation Area
 - Site conditions

Effect of Foundation Shape

Effect of Foundation Shape on Horizontal Motion
150 ft square & 100x225 ft rectangle, circle of same area
Rock Site Profile



Effect of Foundation Shape on Vertical Motion
150 ft square & 100x225 ft rectangle, circle of same area
Rock Site Profile



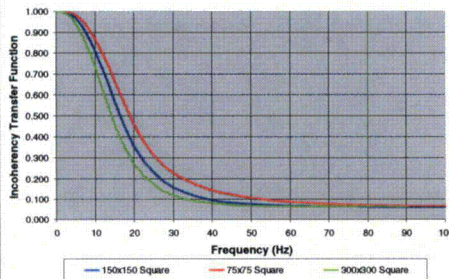
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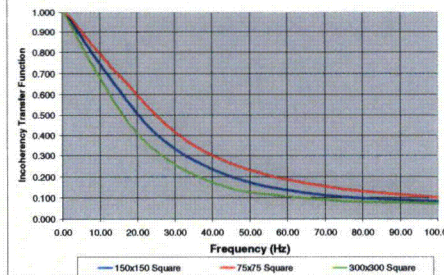
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Effect of Foundation Area

Effect of Foundation Area on Horizontal Motion
Rock Site Profile



Effect of Foundation Area on Vertical Motion
Rock Site Profile



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Effect of Site Conditions and Spectral Reductions due to Incoherency

- The incoherency transfer functions are independent of site conditions (i.e., soil or rock stiffness)
- However, the reductions to spectra from incoherency are quite different for free field spectra from soil and rock sites
- This demonstrates that the spectral reduction factor approach in ASCE 4, the effective ground motion NUREG, and the seismic margins report is not generally an appropriate way to account for incoherency
 - The spectra reduction factor approach does not work well for high frequency sites
 - The spectra reduction factor approach appears adequate for lower frequency soil sites

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Spectral Reduction due to Incoherency

Frequency	ASCE 4 – 150ft	ASCE 4 – 300ft	Rock – 150ft	Rock – 300ft	Soil – 150ft	Soil – 300ft
5	1.00	1.00	0.93	0.89	0.97	0.95
10	0.90	0.80	0.78	0.71	0.85	0.79
15	0.86	0.71	0.59	0.49	0.71	0.63
20	0.82	0.65	0.41	0.33	0.62	0.56
25	0.80	0.60	0.30	0.24	0.60	0.55
30	0.80	0.60	0.25	0.20	0.60	0.56
40	0.80	0.60	0.22	0.19	0.62	0.59

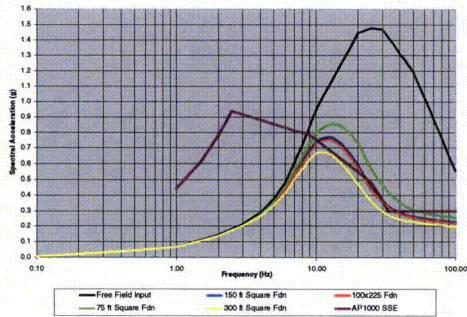
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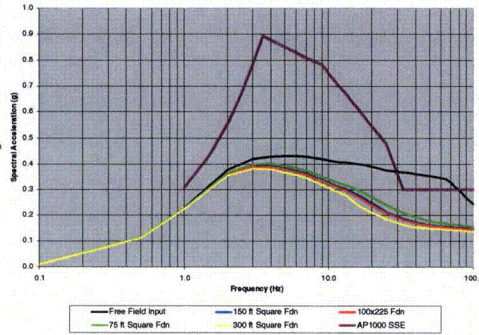
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Spectral Reduction due to Incoherency

Horizontal Spectra Reduction due to Incoherency, Rock Site Profile



Vertical Spectra Reduction due to Incoherency, Soil Site Profile



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