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)

CLASSIinco and CLASSIinco-SRSS

- CLASSI, a program for SSI analysis of surface founded structures on a rigid basemat has been modified to treat incoherent ground motion
- CLASSIinco assumes deterministic phasing of FIM components of motion
- CLASSIinco-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

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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 $[S_{UoI}] = [F]\,[SUGI]\,[F^C]^T$ 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 $[S_{UoI}]$

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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 (CLASSIinco)
  - Most applicable to cases where the phase relationship is known (e.g., wave passage)
- Random (CLASSIinco-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
- CLASSIinco-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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CLASSIinco 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)

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CLASSIinco-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.

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Validation

CLASSIinco 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

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

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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 ft*ft)
  - Luco and Mita (1987)
  - Veletsos and Prasad (1989)
- Square foundation 150 ft on a side
  - Luco and Wong (1986)

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Validation of CLASSIinco: Key Parameters

- Visco-elastic half-space
  - Shear Wave Velocity, Vs = 6300 ft/sec = 1920.24 m/sec
  - Mass Density, ρ = .004969 k-sec2/ft4
  - Poisson's Ratio, ν = 0.33
  - Damping, ξ = 0.01

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Coherency Ground Motion Function

- Coherency ground motion function (vertically incident waves)

$$\Gamma(|r1 - r2|,\omega) = \exp[-(\gamma\omega|r1 - r2|/Vs)^{**}2]$$

where

|r1 - r2| is the distance between points on the foundation (subregion centroids)

γ is a dimensionless incoherence parameter,

ω is the angular frequency (radians/sec),

Vs is the representative shear wave velocity of the soil profile

- CLASSIinco was modified to include the Luco and Wong representation of the coherency ground motion
- Values of γ = 0.1, 0.2, 0.3, 0.4, and 0.5 were benchmarked
- Luco and Wong provide the following guidance

  Vs * 2 x 10-4 sec/m $\leq \gamma \leq$ Vs * 3 x 10-4 sec/m

  γ = 0.5 approximates this recommendation for Vs = 1920 m/sec

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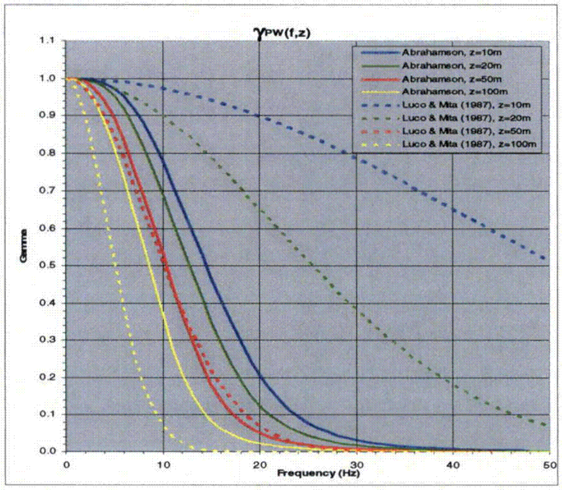
Coherency Ground Motion Function: Abrahamson vs. Luco and Wong ($\gamma = 0.5$)



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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 a0

Frequency (Hz)	a0
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. γ * a0

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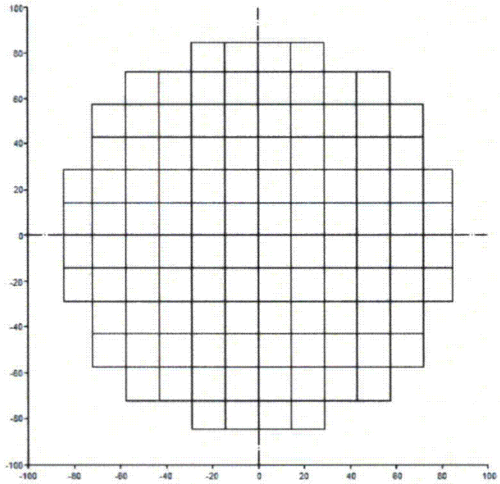
Circular Disk: CLASSIinco Discretization



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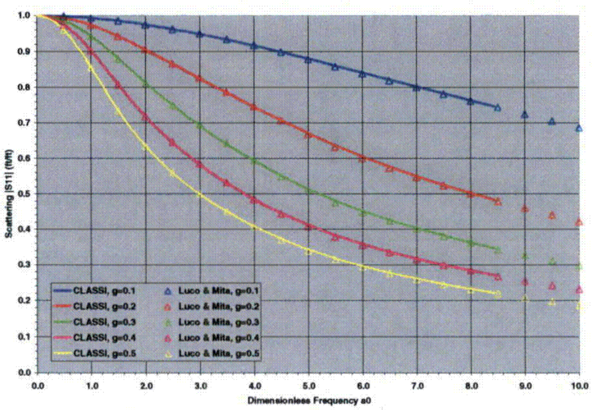
CLASSIinco vs. Luco and Mita (1987): Horizontal ITF



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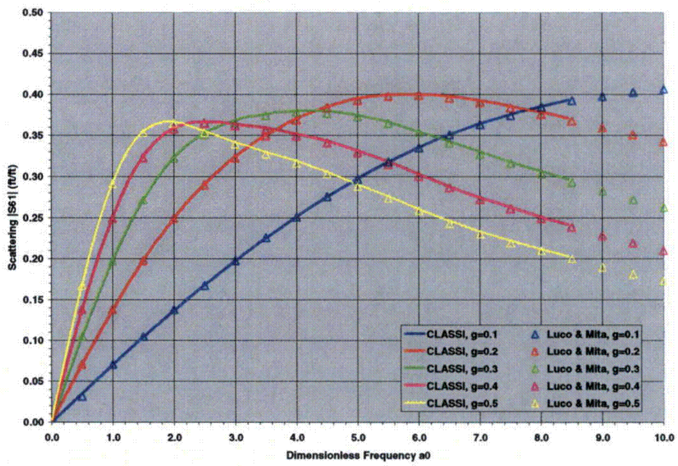
CLASSIinco vs. Luco and Mita (1987): Induced Torsion ITF



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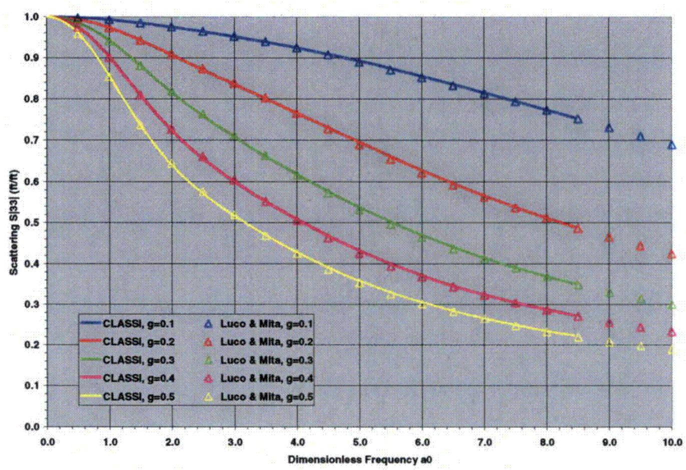
CLASSIinco vs. Luco and Mita (1987): Vertical ITF



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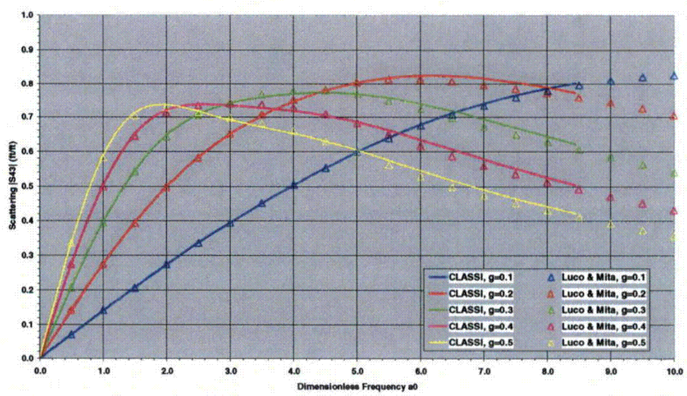
CLASSlinco vs. Luco and Mita (1987): Induced Rocking ITF



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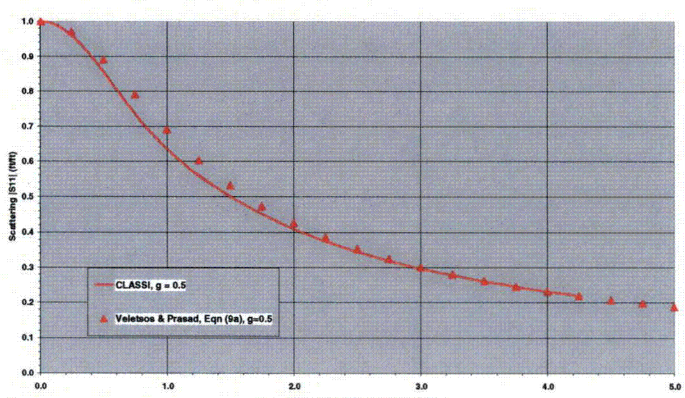
CLASSlinco vs. Veletsos and Prasad (1989) (γ = 0.5): Horizontal ITF



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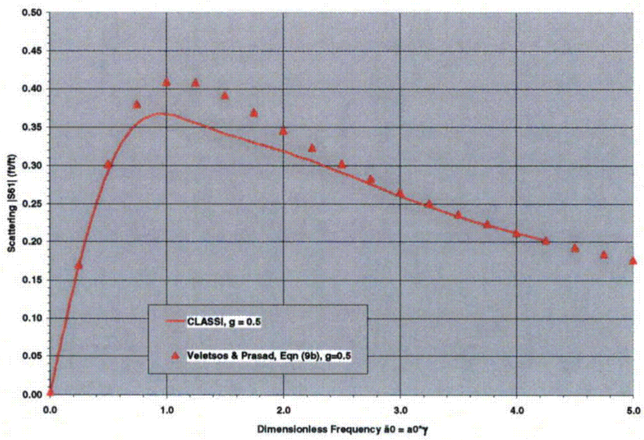
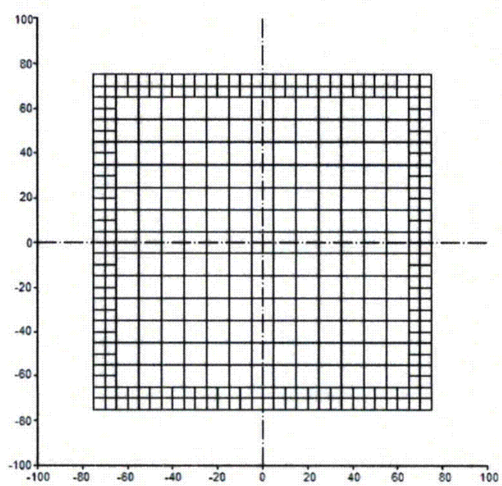
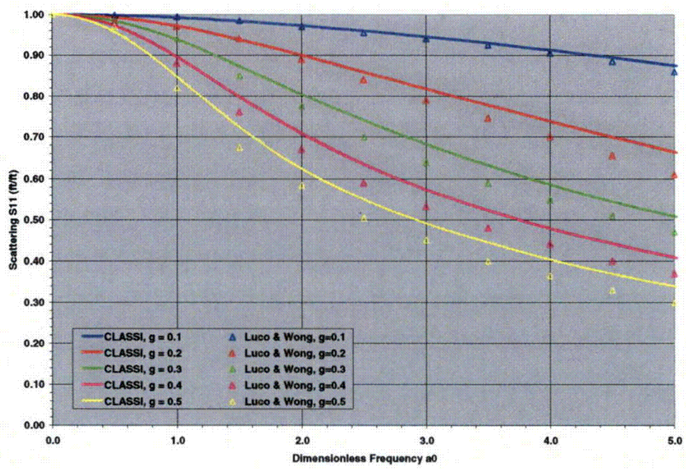
CLASSIinco vs. Veletsos and Prasad (1989) ($\gamma = 0.5$): Induced Torsion ITF



Square Foundation: CLASSIinco Discretization



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



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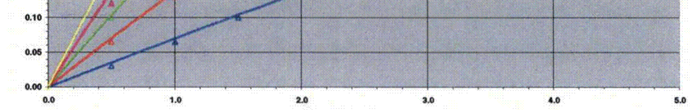
CLASSIinco vs. Luco and Wong (1986): Induced Torsion ITF



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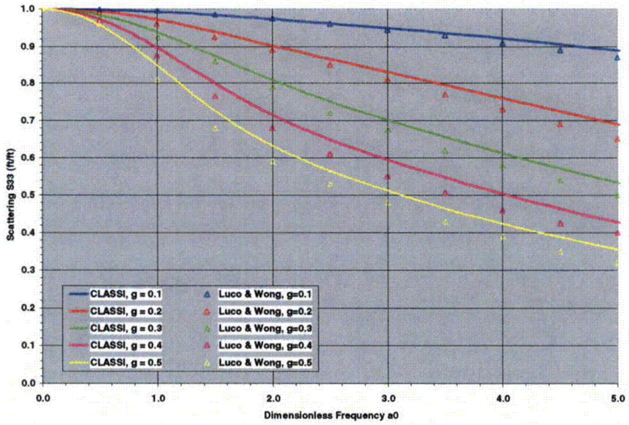
CLASSIinco vs. Luco and Wong (1986): Vertical ITF



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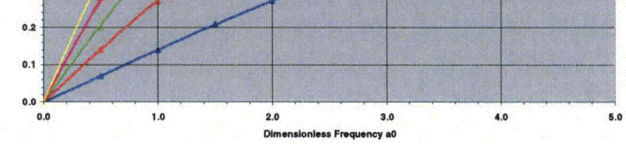
CLASSIinco vs. Luco and Wong (1986): Induced Rocking ITF



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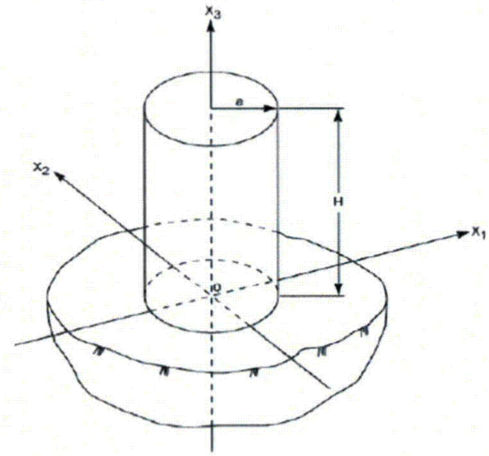
Structure with Outriggers Case

- 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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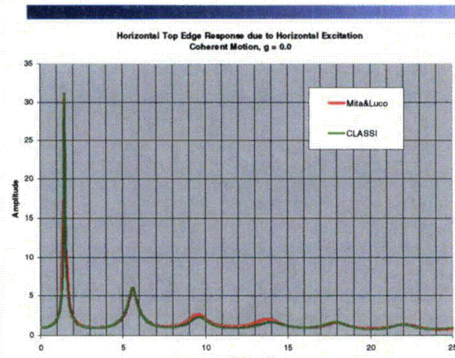
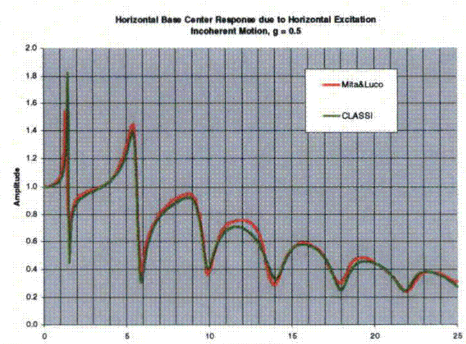
Bottom Center Response – Horizontal due to Horizontal





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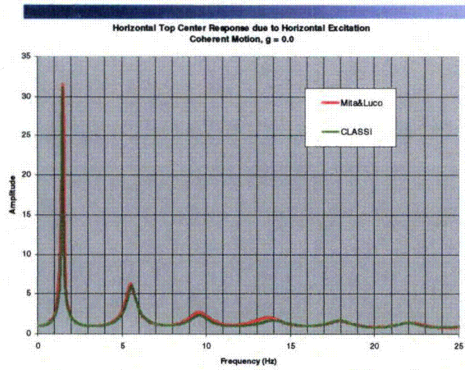
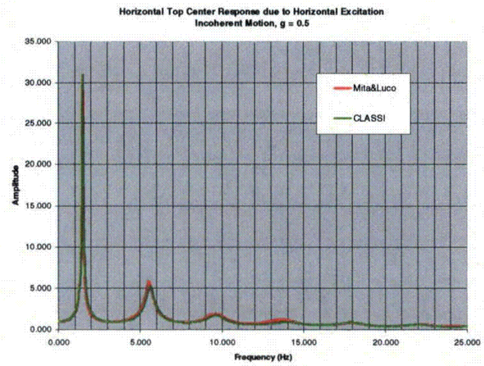
Top Center Response – Horizontal due to Horizontal





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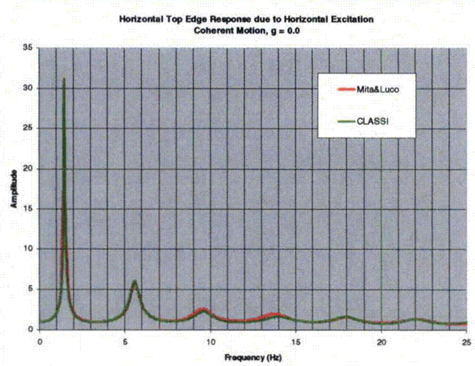
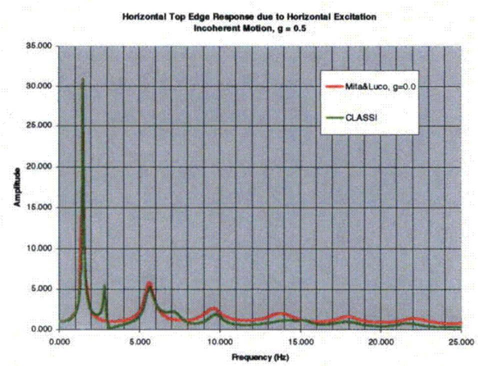
Top Edge Response – Horizontal due to Horizontal





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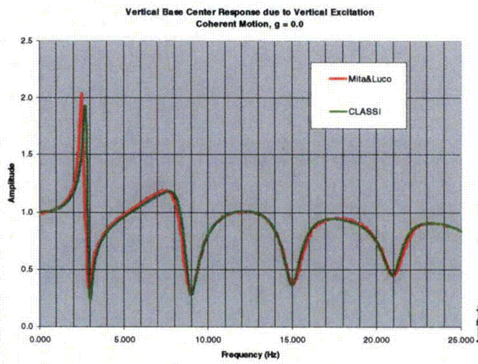
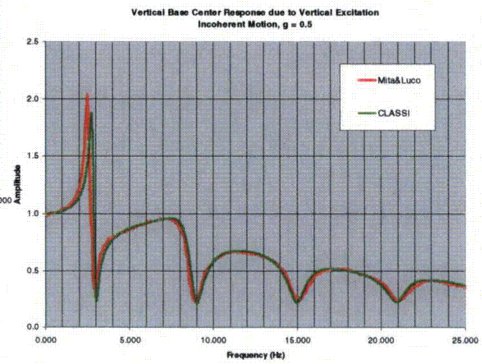
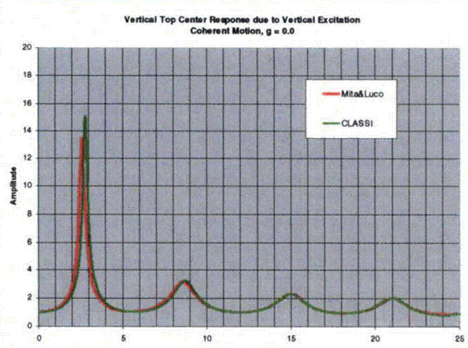
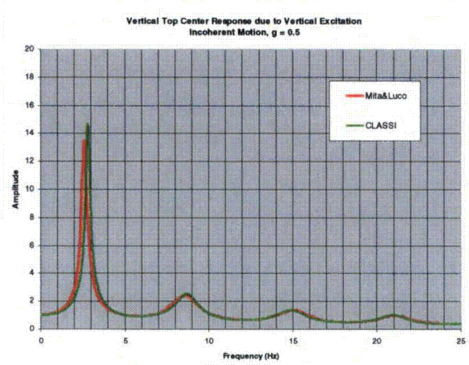
Bottom Center Response – Vertical due to Vertical



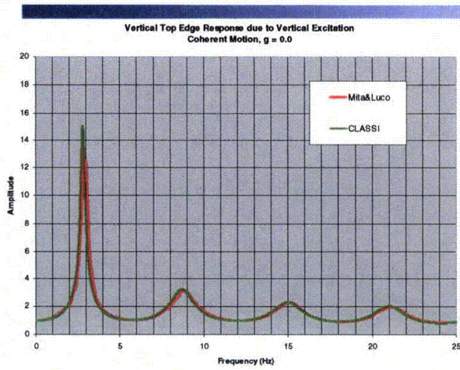


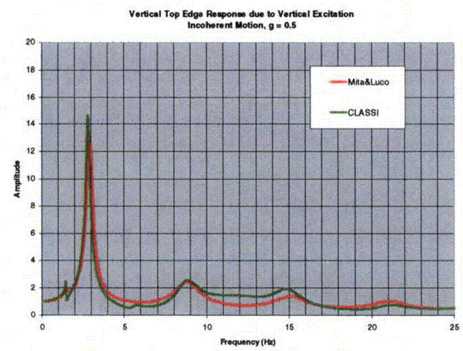
Top Center Response – Vertical due to Vertical





Top Edge Response – Vertical due to Vertical





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Demonstration of Incoherency Effects

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

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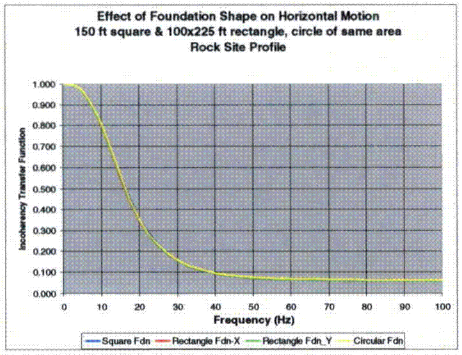
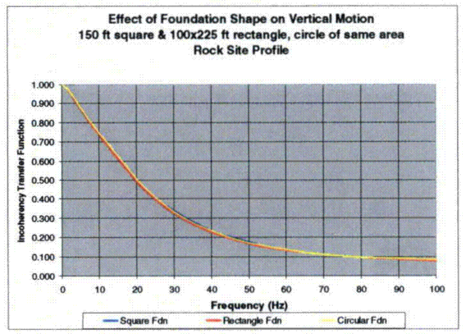
Effect of Foundation Shape





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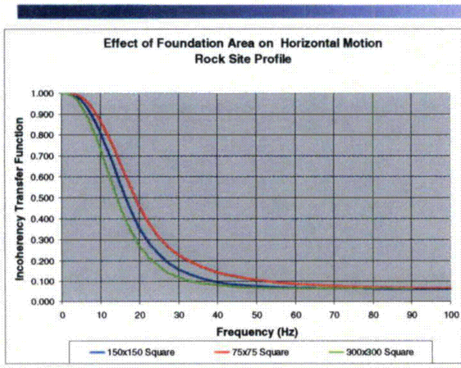
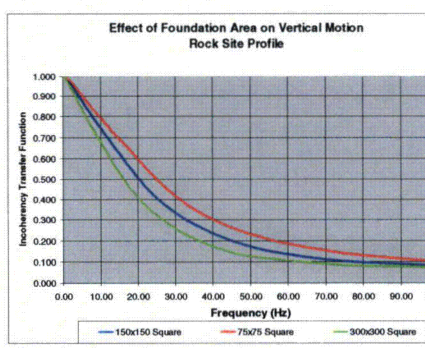
Effect of Foundation Area





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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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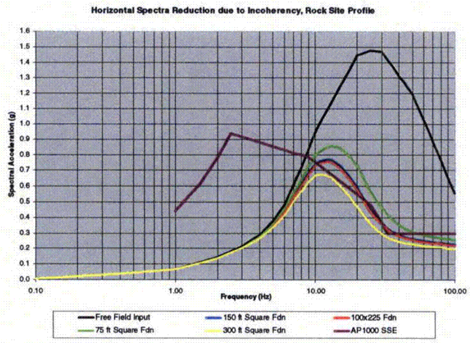
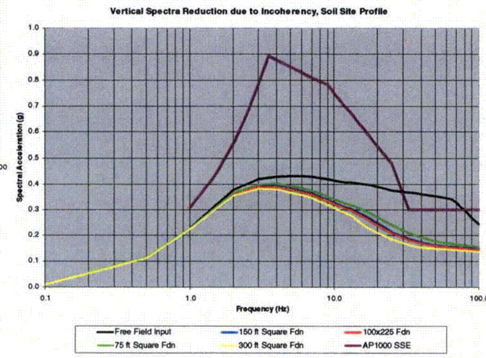
Spectral Reduction due to Incoherency





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