Probabilistic Seismic SSI Analysis Sensitivity Studies for Base-Isolated Nuclear Structures Subjected to Coherent and Incoherent Motions

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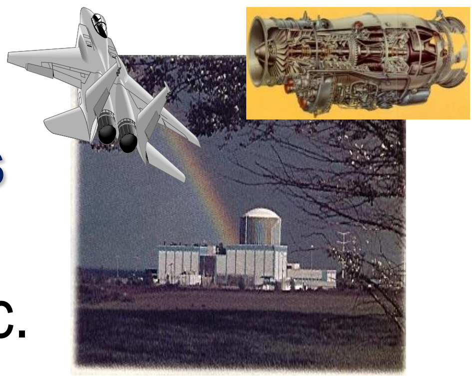

SMiRT25 Conference, Division III

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Purpose of Presentation:

To investigate the effects of base isolation on seismic SSI response of a typical NI complex under coherent and incoherent motions using probabilistic and deterministic SSI analyses and different base-isolation systems, LRBs and HVDs.

The probabilistic and deterministic SSI analyses follow the recommendations of the ASCE 4-16 standard.

Sensitivity Studies

The presentation illustrate key results of a series of sensitivity studies, in two project phases, in 2015 (LRBs) and in 2019 (HVDs) to investigate

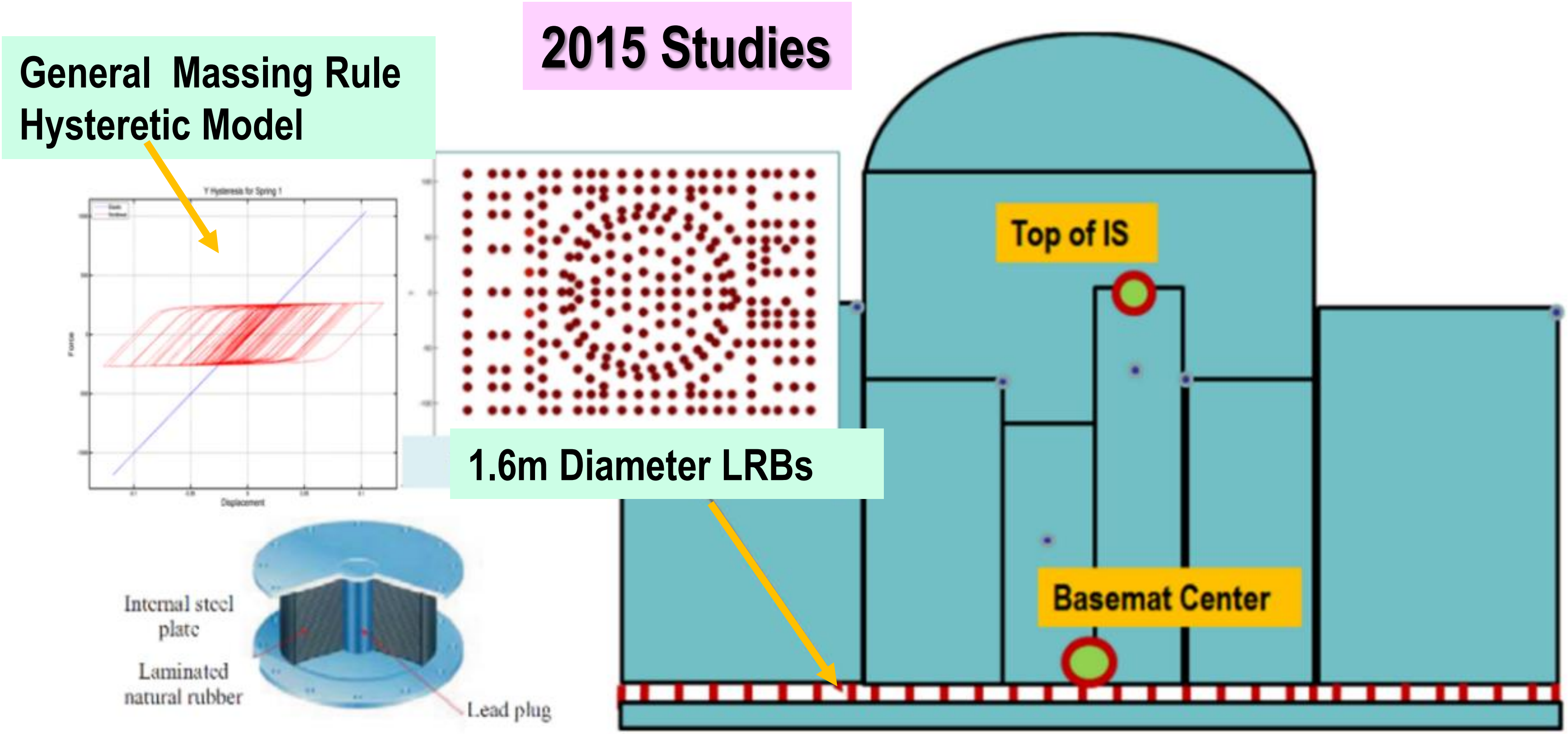
1) the effects of the base-isolation against no base-isolation for rock sites and soil sites,

2) the effects of motion incoherency on SSI responses

3) the use of probabilistic SSI vs. deterministic SSI analysis

4) the effects of using the 3D HVD base-isolators against the 2D LRB base-isolators.

1. Effects of Seismic Base-Isolation on ISRS for Soil and Rock Sites and Coherent Motion



Soil Layering:

SOIL: Uniform with Vs = 1000 fps
ROCK: Uniform with Vs = 6000 fps

Seismic Input:

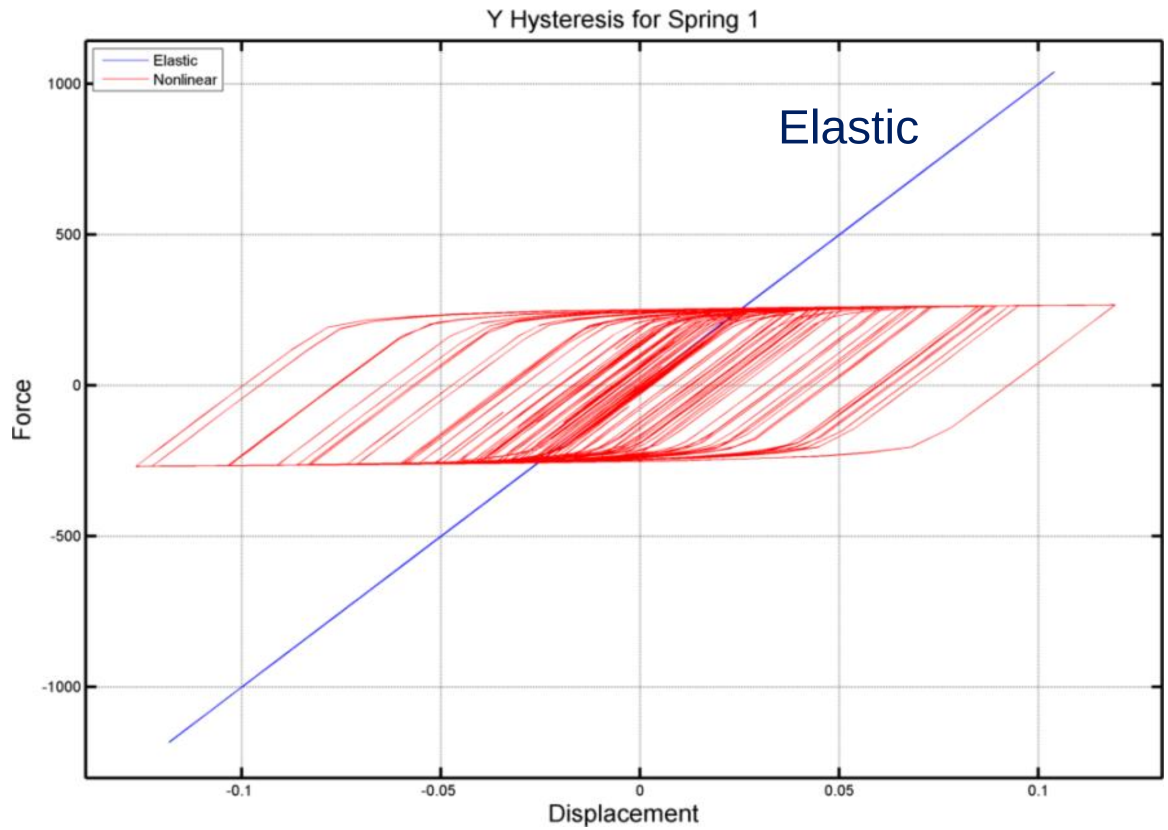
RG1.60 Input with 0.30g

Used ACS SASSI software with Option NON (nonlinear springs via iterative EQL SSI analysis)

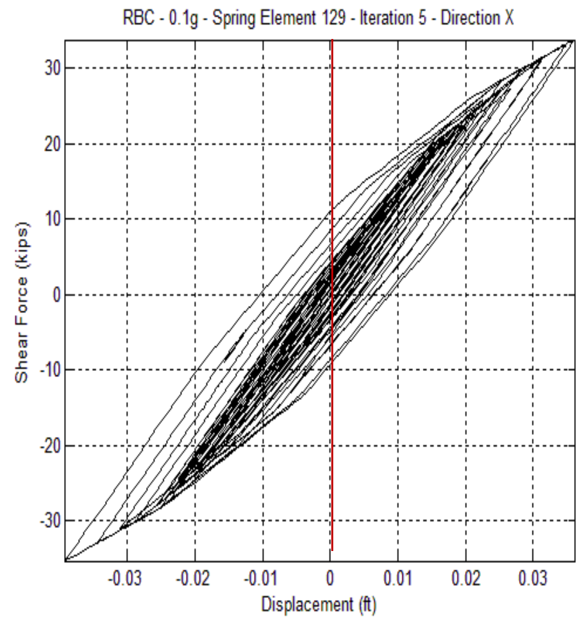
Modelling of the Hysteretic LRB Isolators

An efficient seismic SSI analysis was based on computing iteratively the SSI response for the equivalent-linearized system in complex frequency, coupled with an evaluation the local nonlinear spring behaviour in time domain for the simultaneous X, Y and Z inputs based on which the equivalent-linear spring is determined.

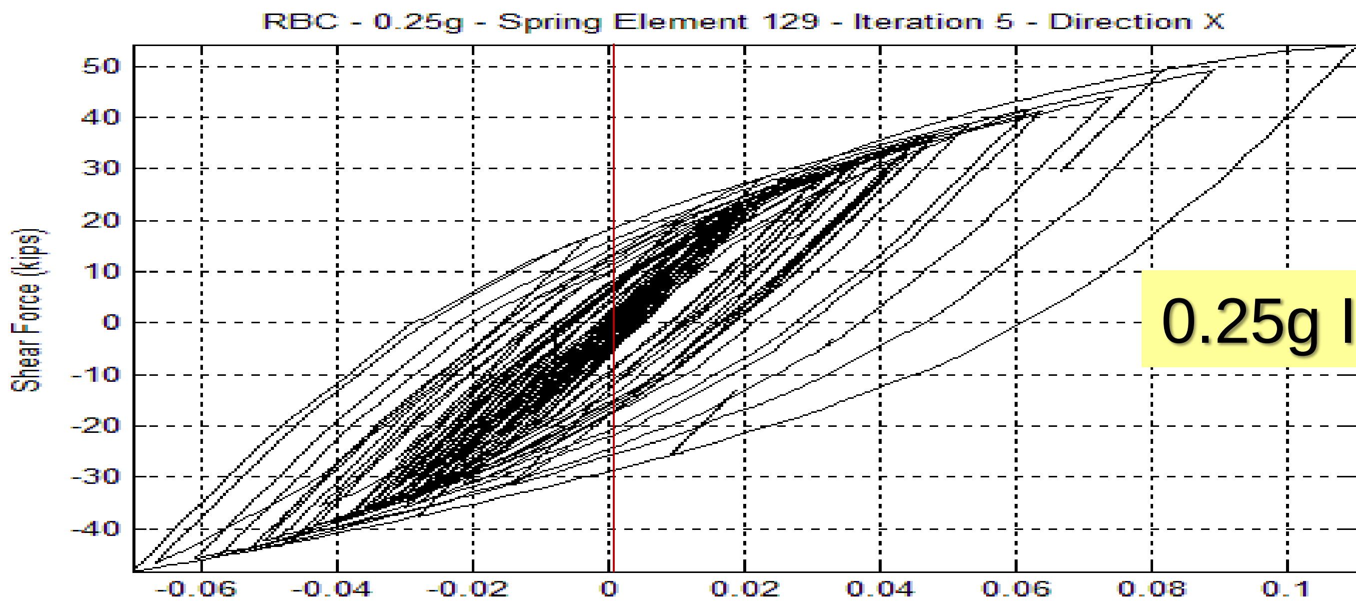
LRB Base-Isolator Hysteresis Loop



General Hysteretic Model for LRB Isolators

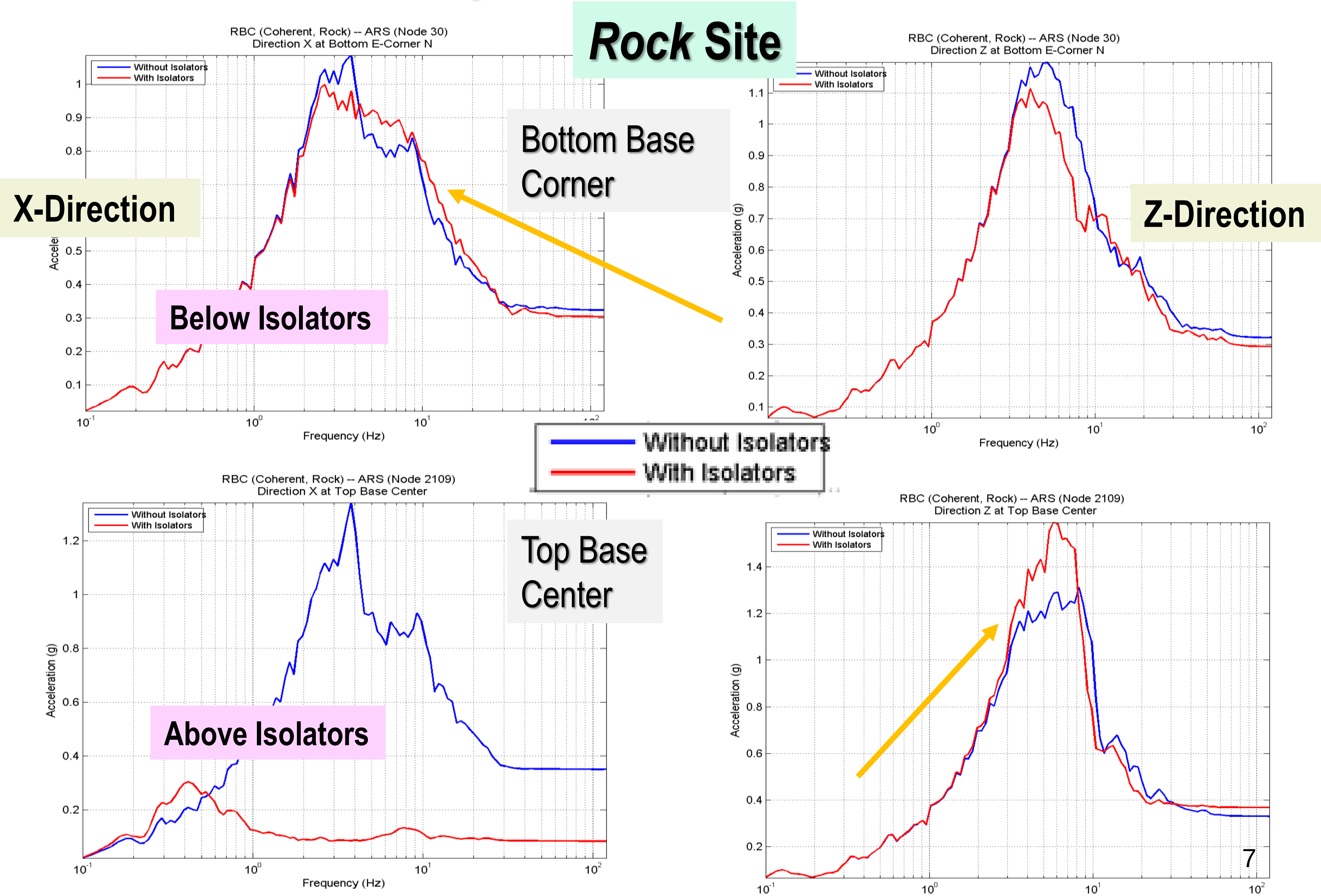


0.10g Input



0.25g Input

ISRS for NI Complex With and Without Isolators



ISRS for NI Complex *With* and *Without Isolators*

***Soil* Site**

X-Direction

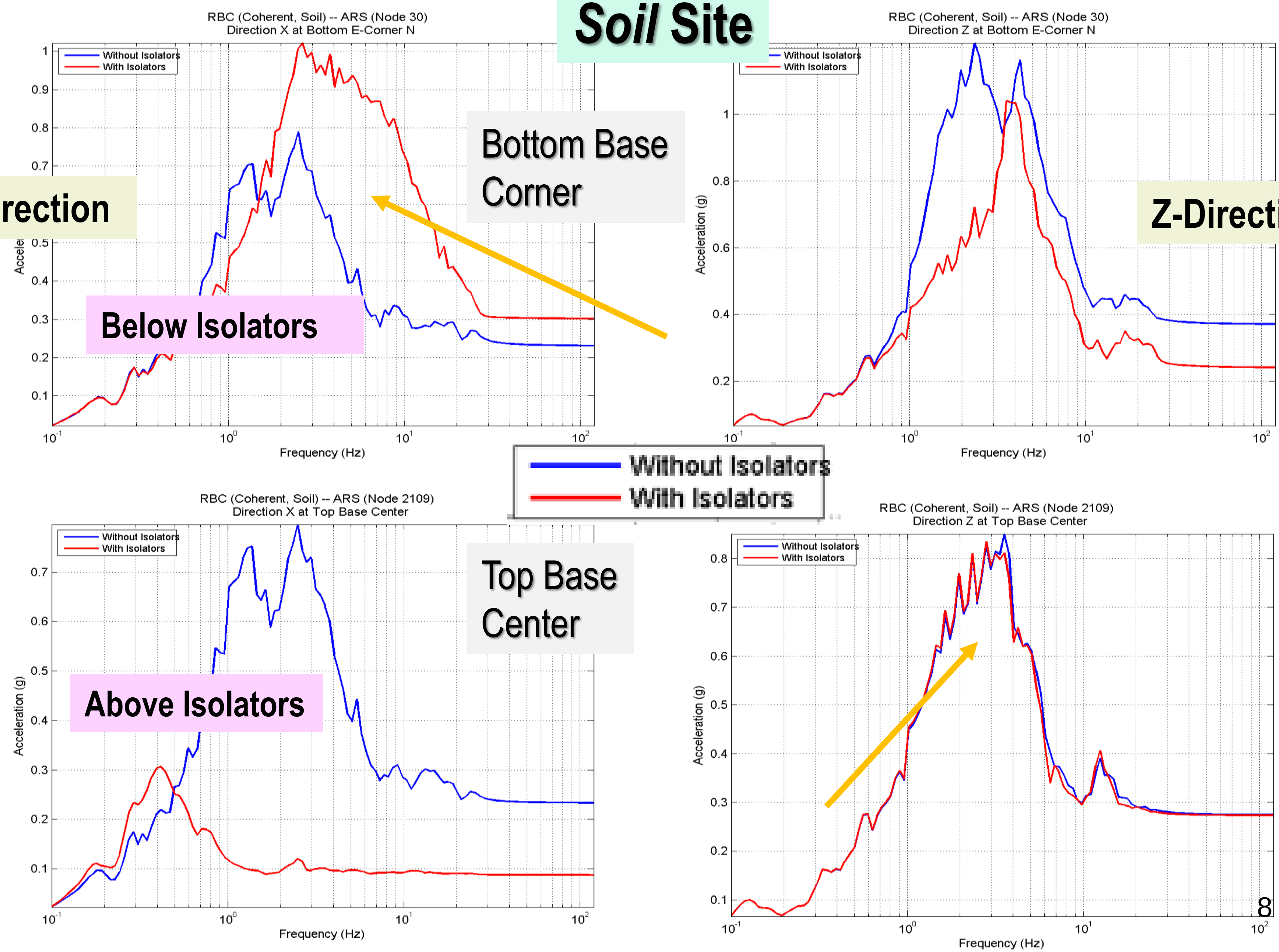
Z-Direction

Bottom Base Corner

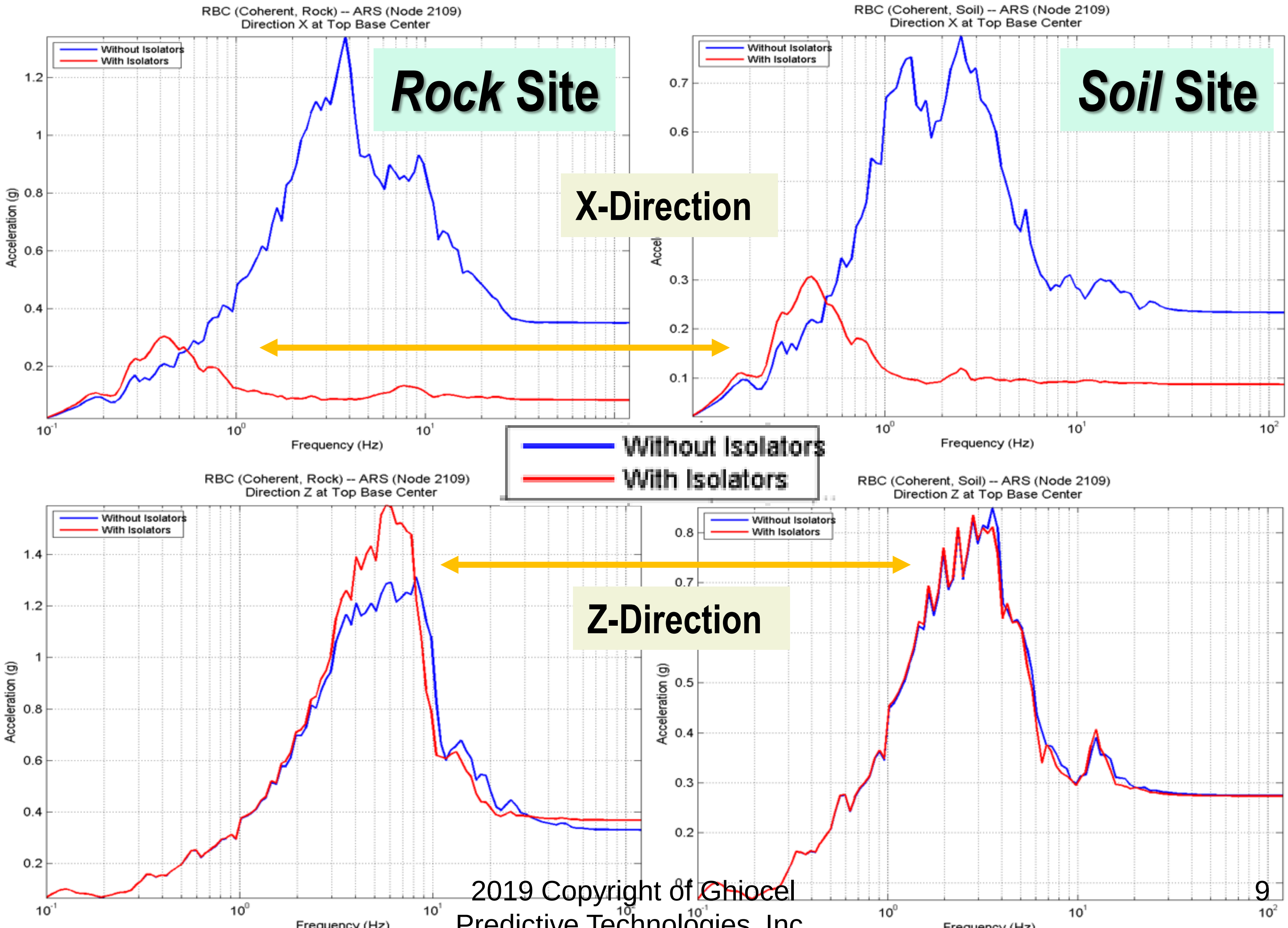
Below Isolators

Top Base Center

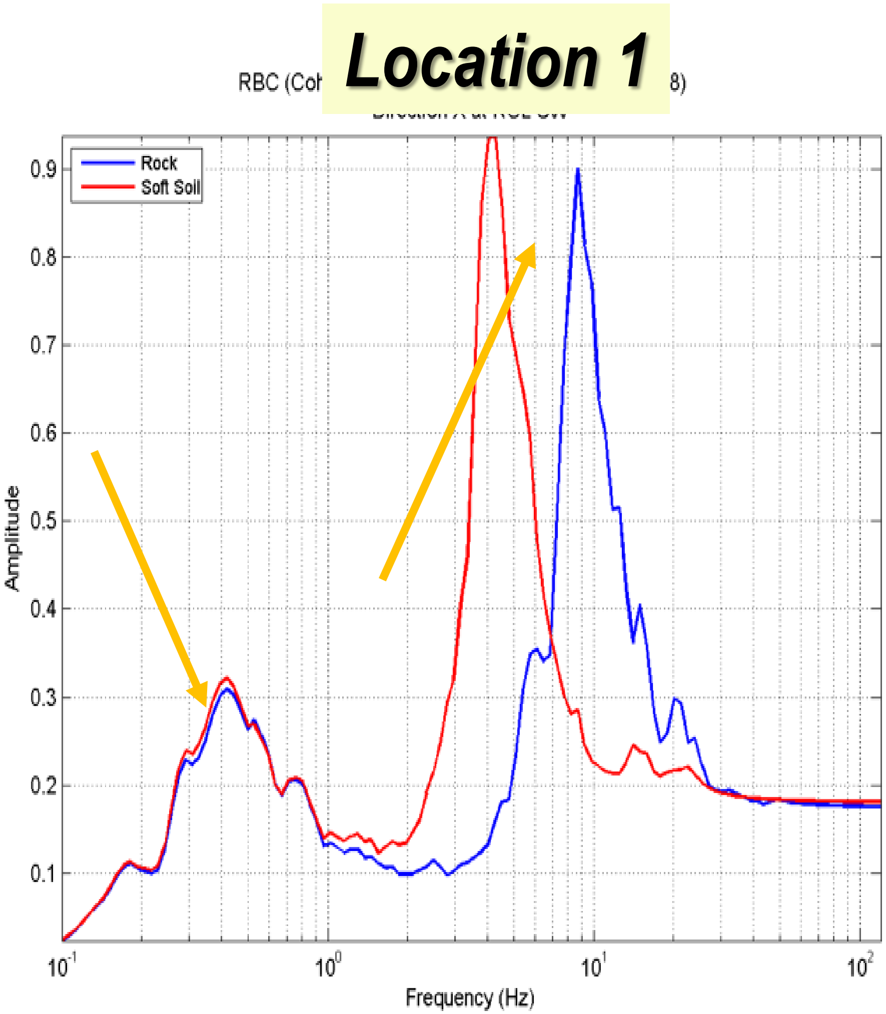
Above Isolators

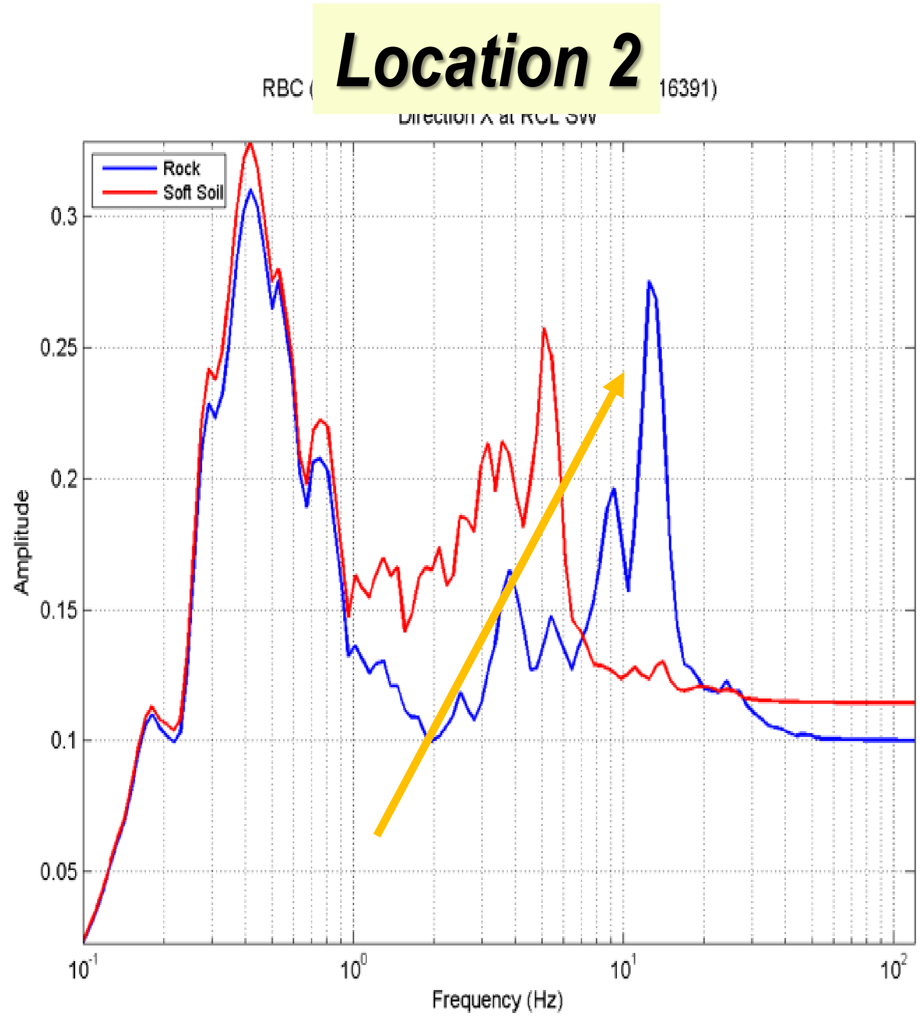


Top Basemat ISRS *With* and *Without Isolators*



High-Elevation Horizontal ISRS *With Isolators* for Rock and Soil Sites





2. Effects of Motion Incoherency on ISRS

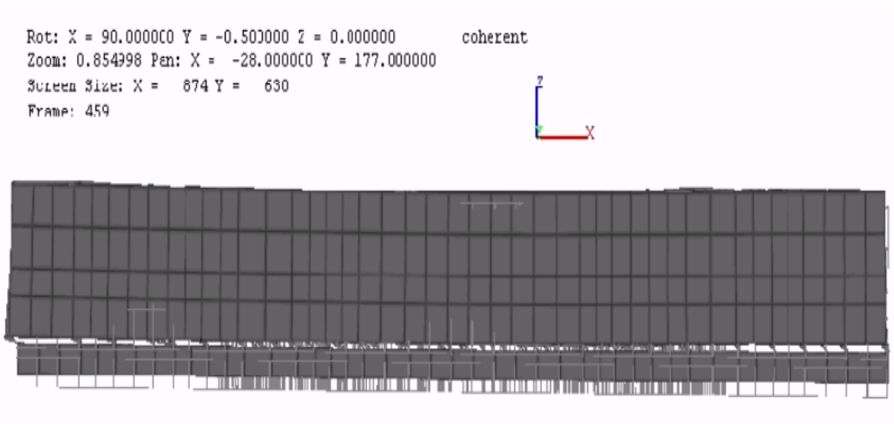
Incoherent Seismic Input:

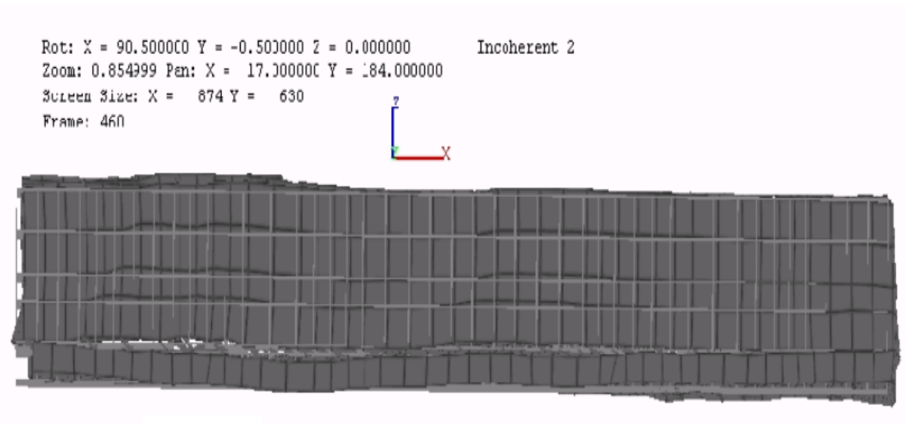
- For the comparative coherent vs. incoherent deterministic SSI analysis study, a uniform soil deposit with a Vs of 2,000 fps was considered.
- The incoherent motion was defined based on the Abrahamson coherence function for soil sites (Abrahamson, 2007).
- Additionally, an apparent traveling wave velocity of 6,000 fps was included to simulate the wave passage effects in the X-longitudinal direction.
- For the incoherent SSI analysis, the rigorous stochastic simulation approach (with no phase adjustment) based on a clean Monte Carlo wavefield simulations was used.
- Several incoherent seismic wavefields were simulated.

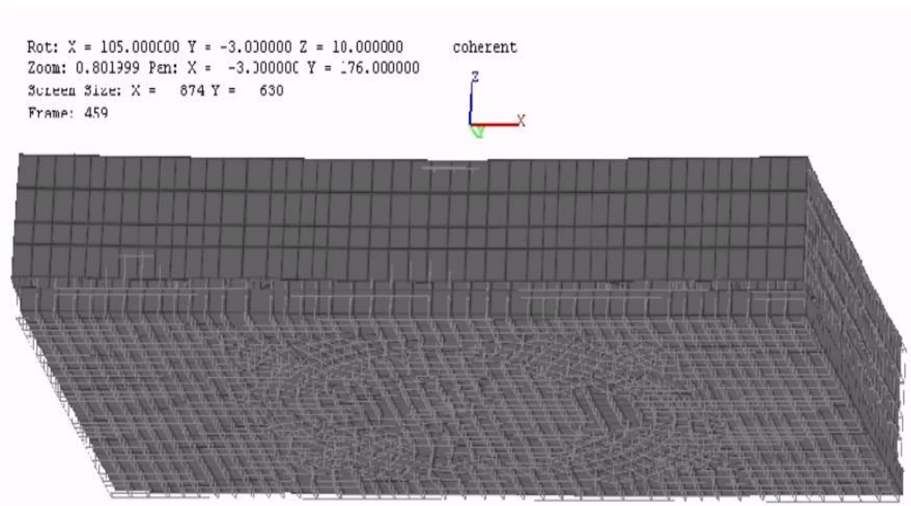
Coherent and Incoherent SSI Responses

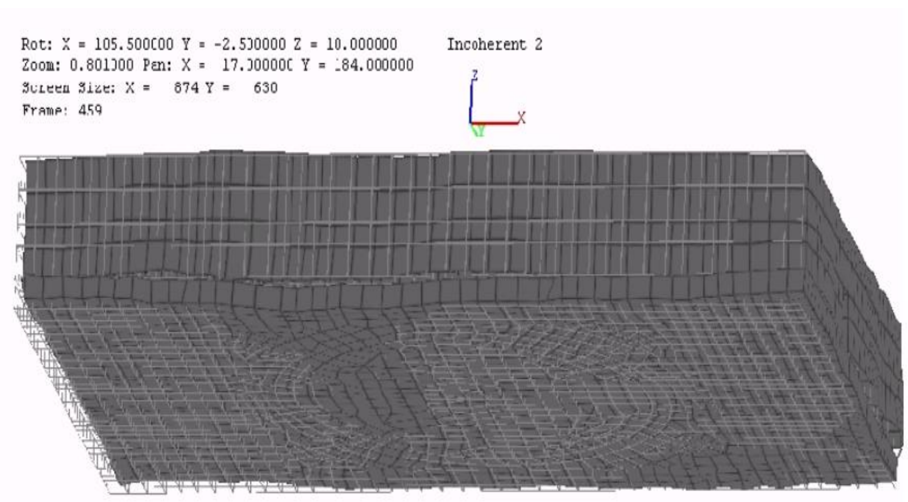
Coherent Accelerations

Incoherent Accelerations



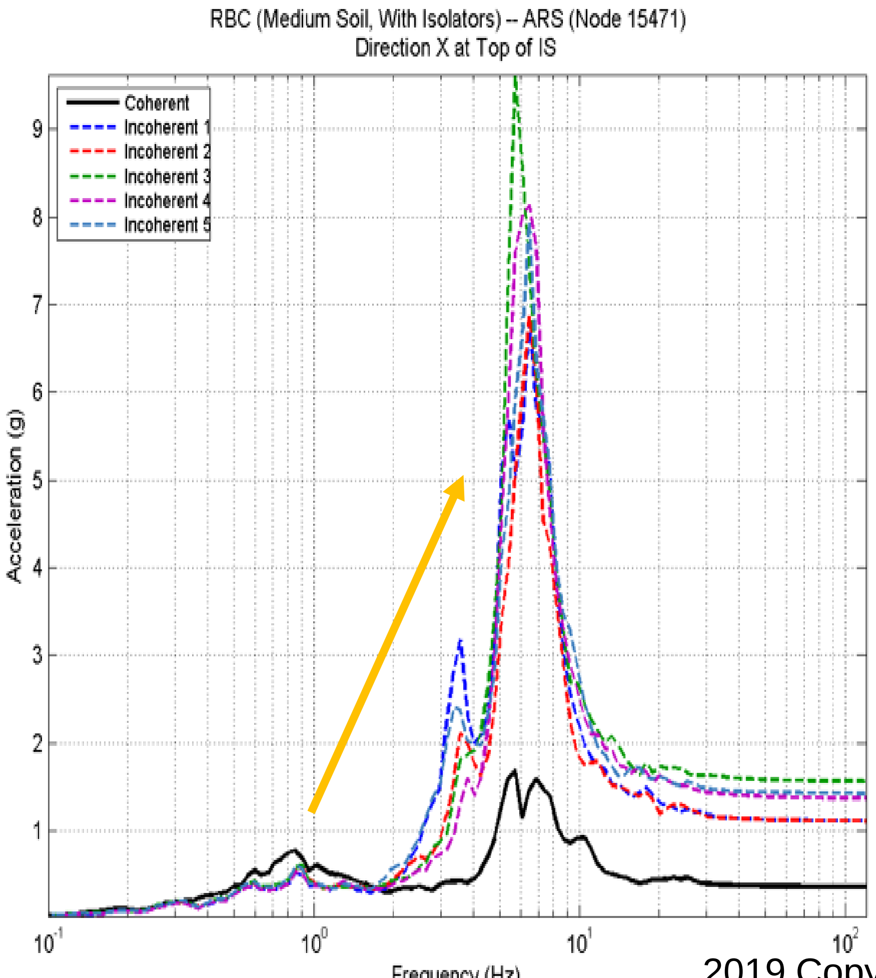




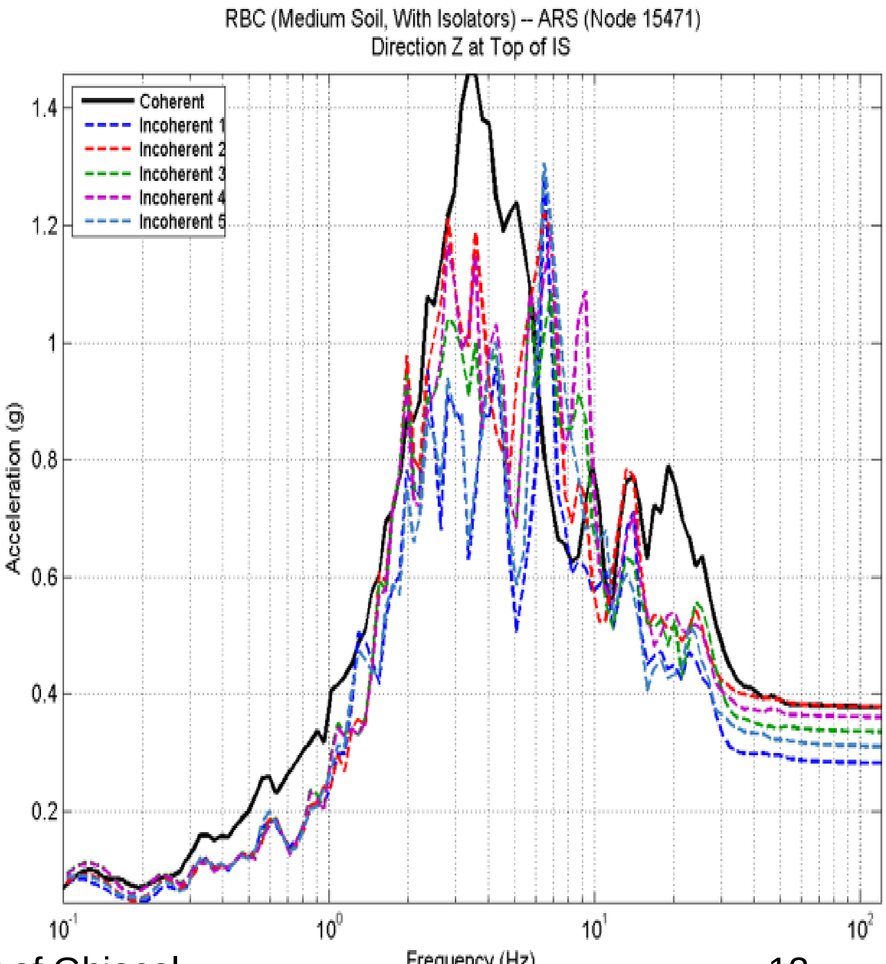


Horizontal and Vertical ISRS at Top of IS

Horizontal

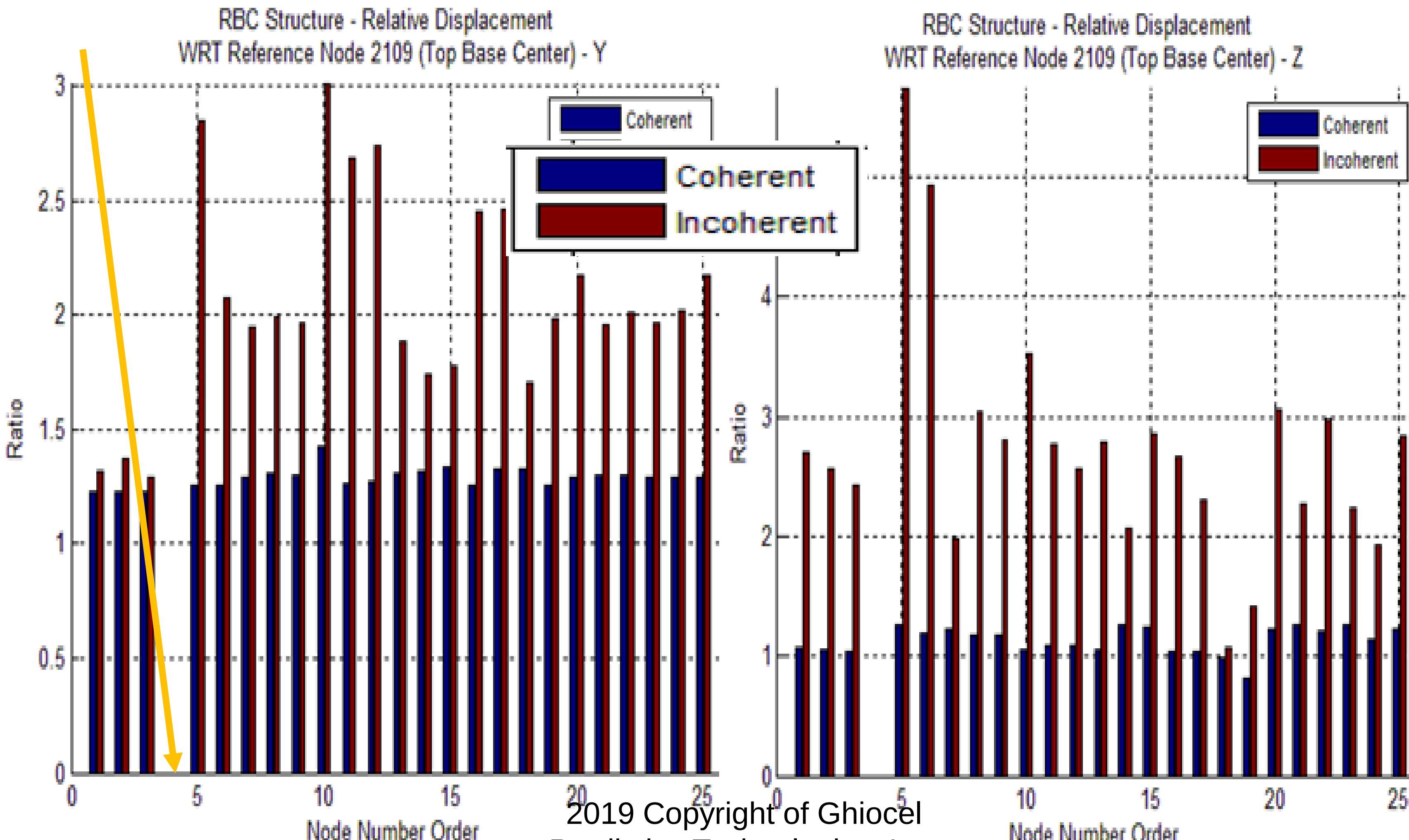


Vertical

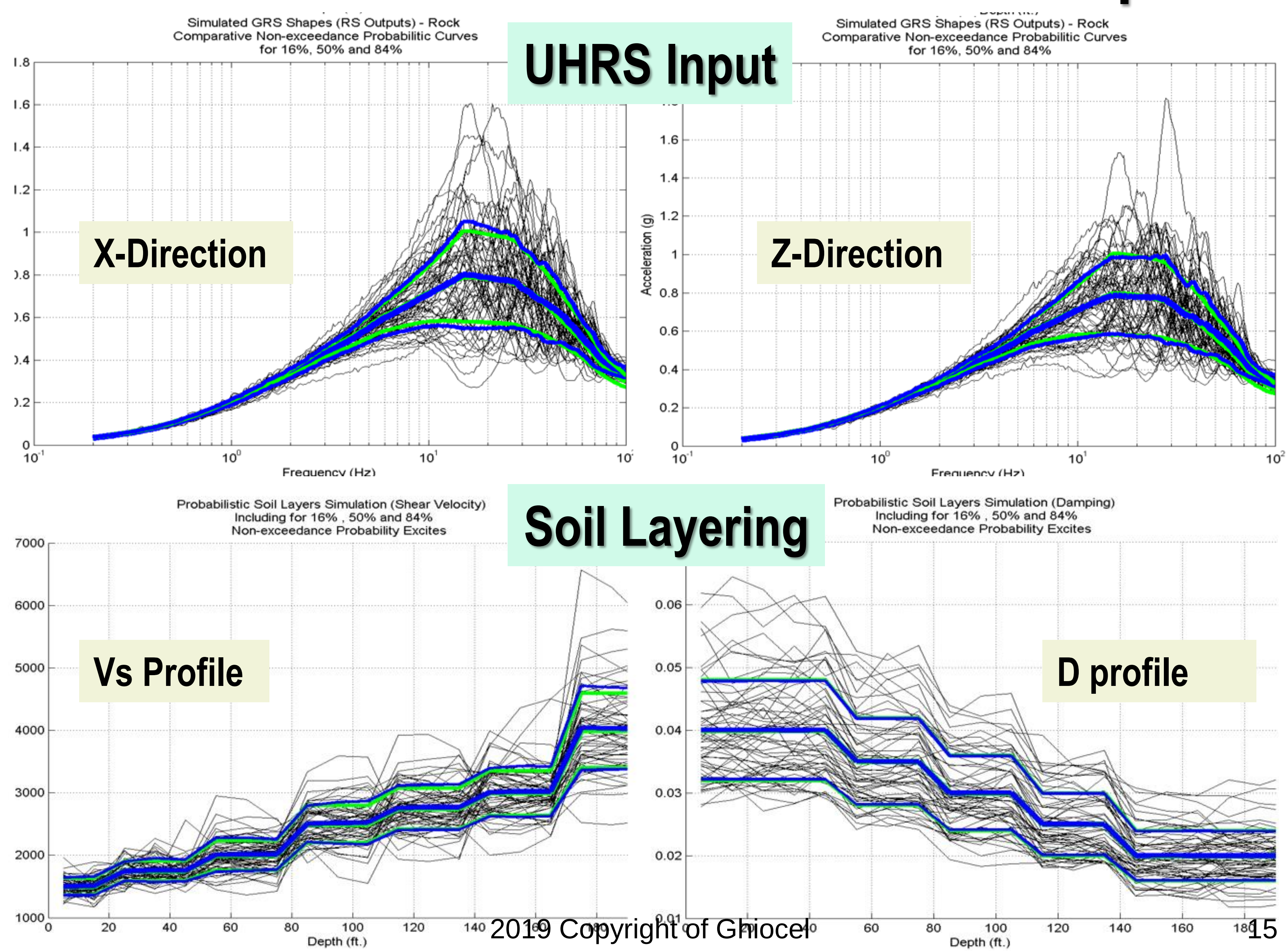


Effect of Motion Incoherency on Relative Displacements at NI Complex Critical Locations

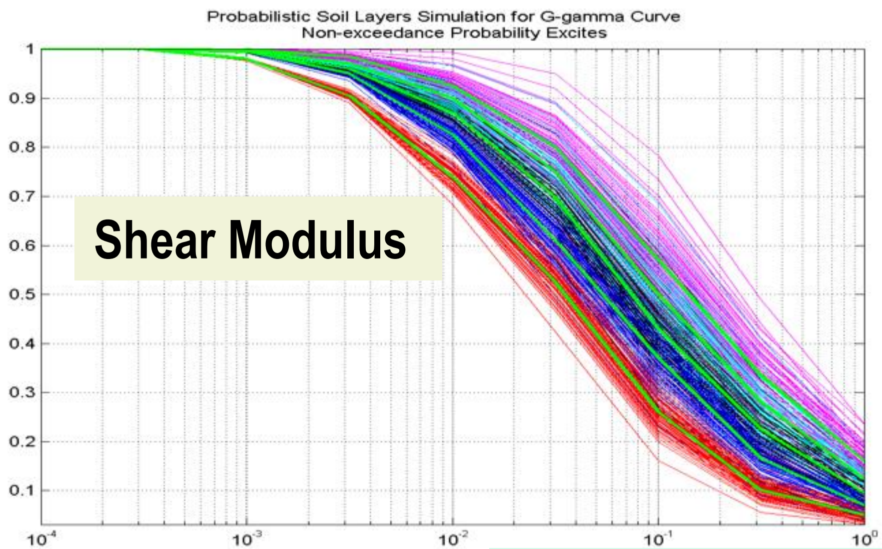
Reference Location is Top Slab Center

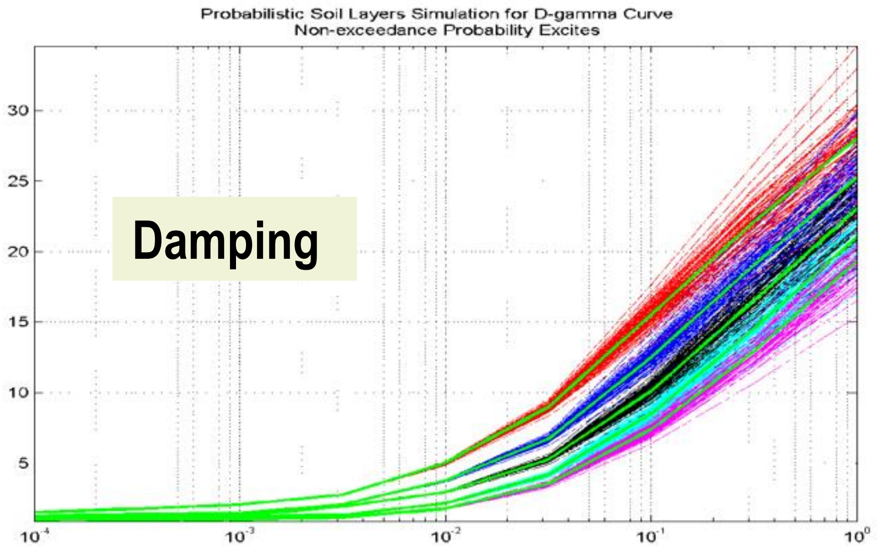


3. Probabilistic vs. Deterministic SSI Responses

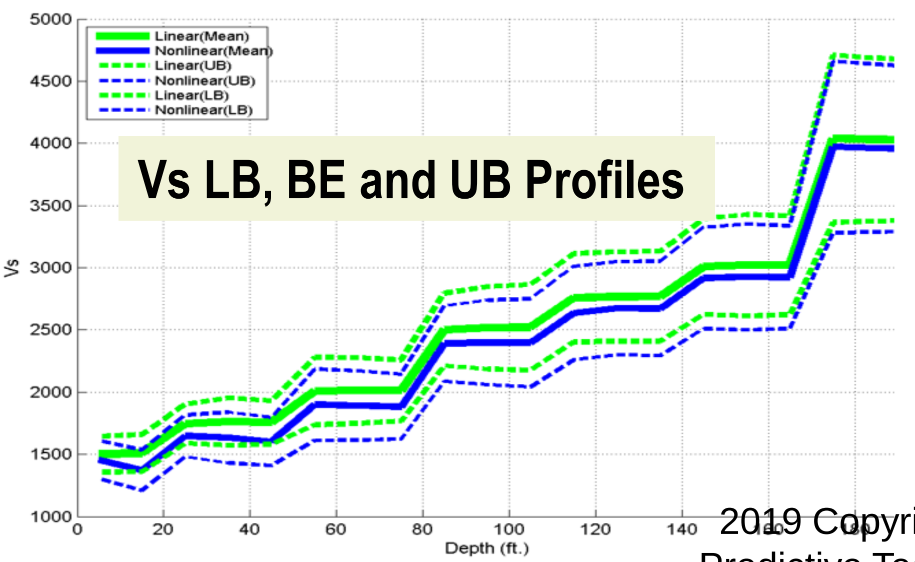


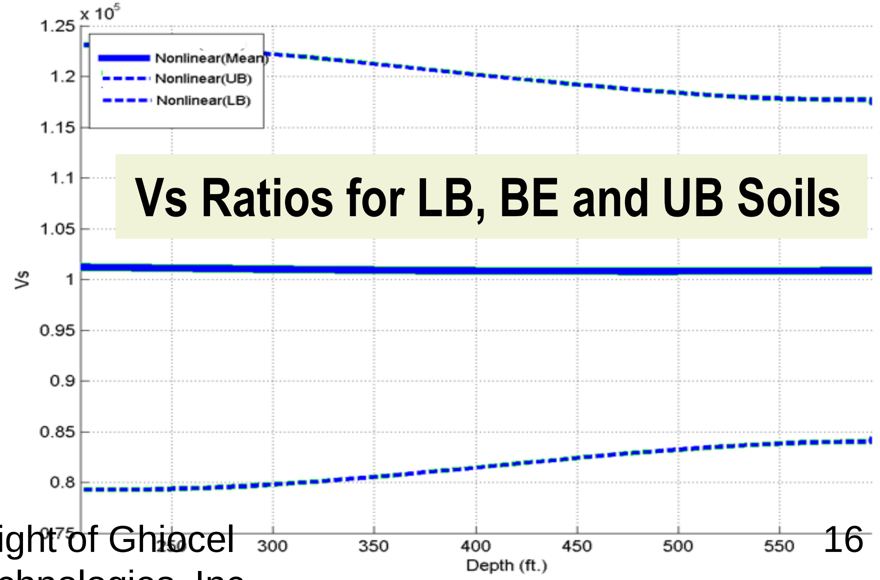
Soil Material Curves



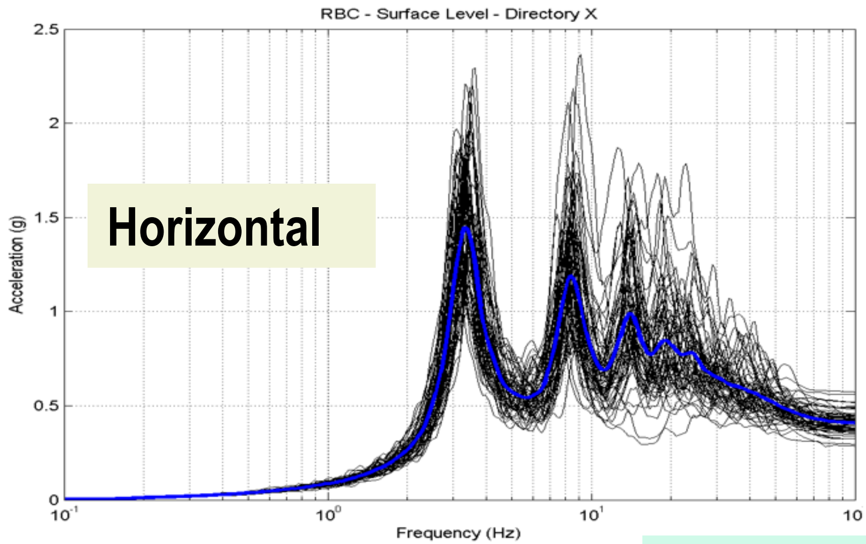


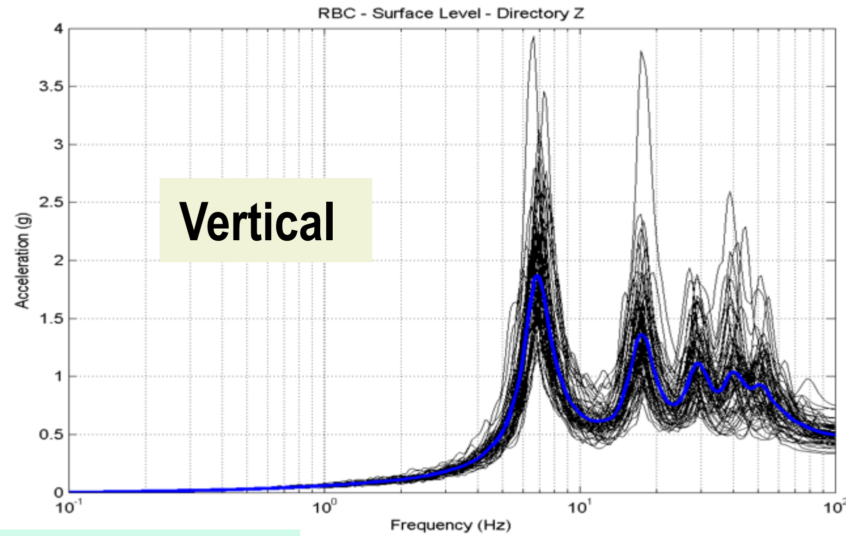
Deterministic Soil Profiles



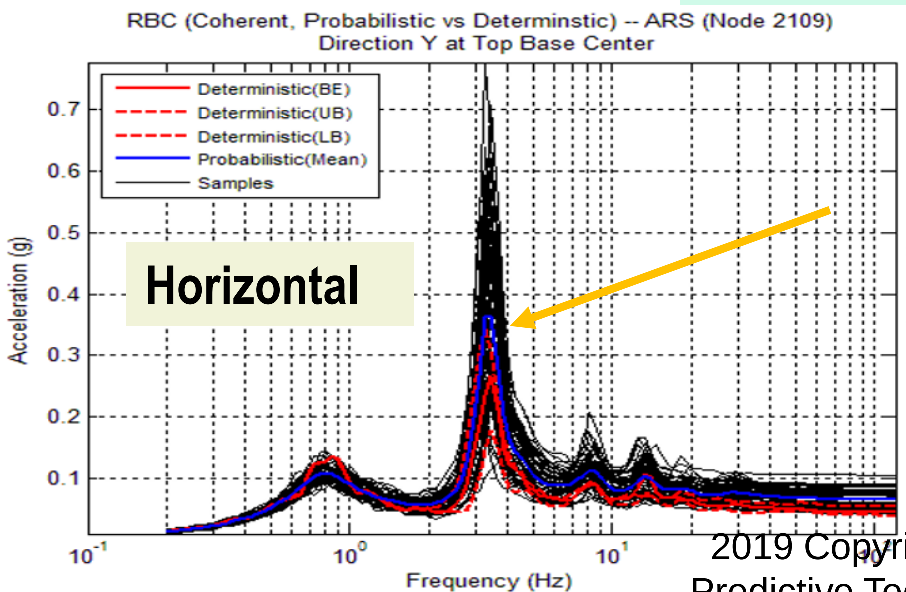


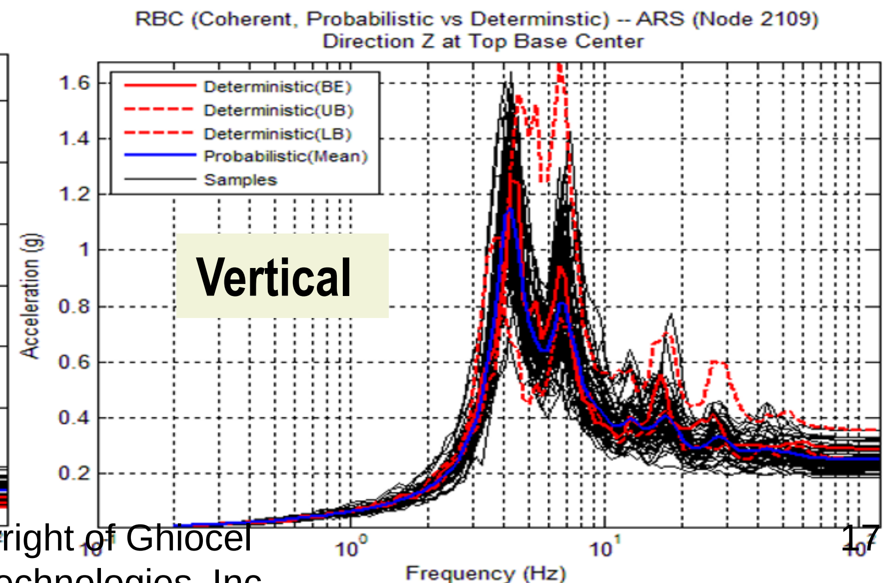
Surface GRS



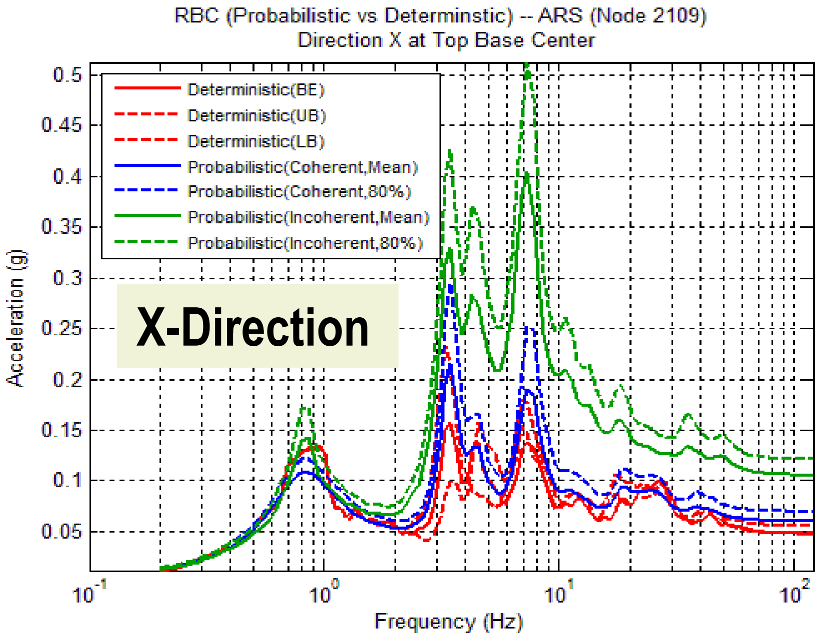


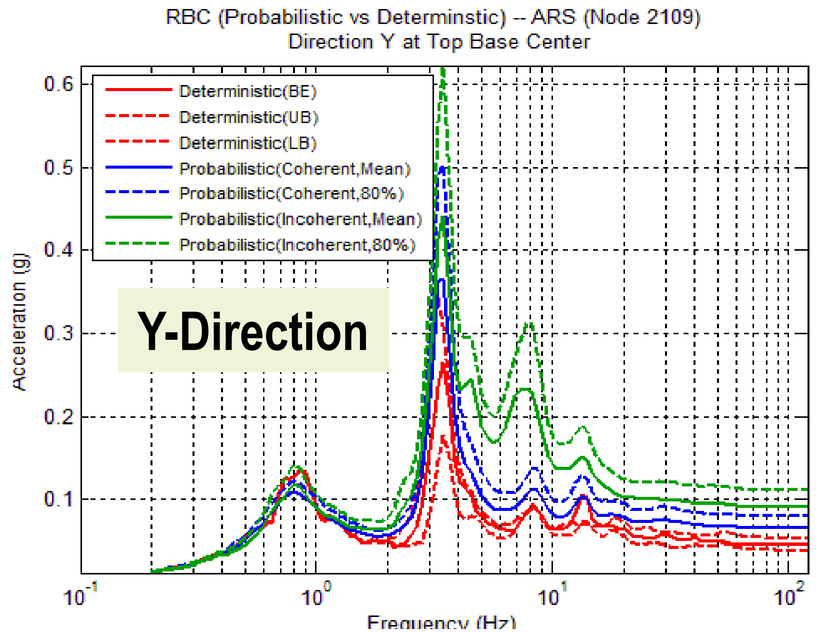
Top Base Center



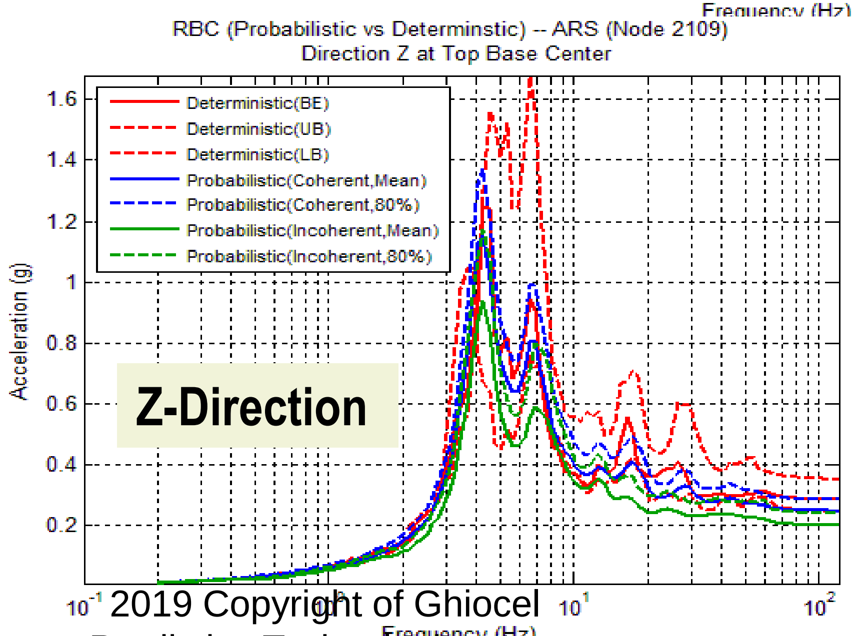


Probabilistic-Deterministic ISRS for NI Complex

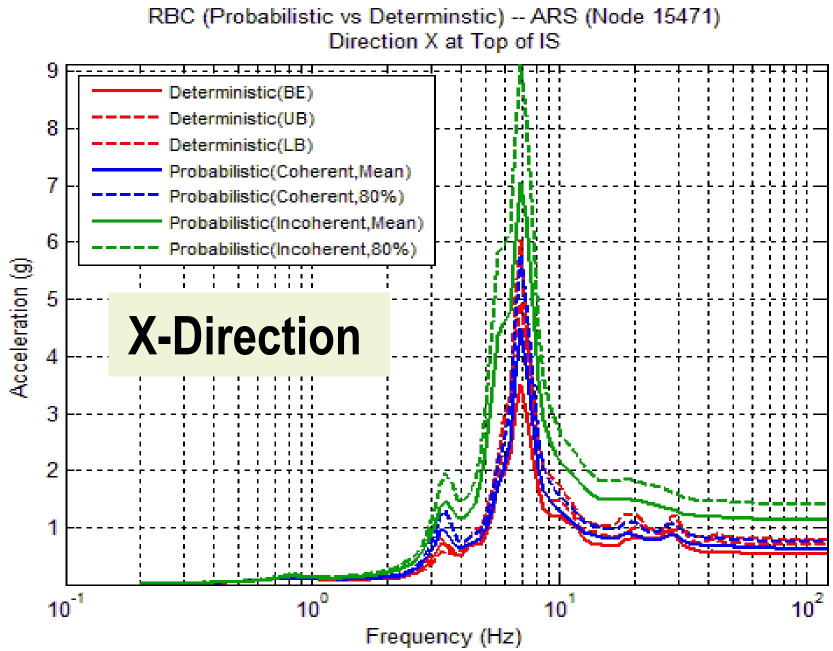


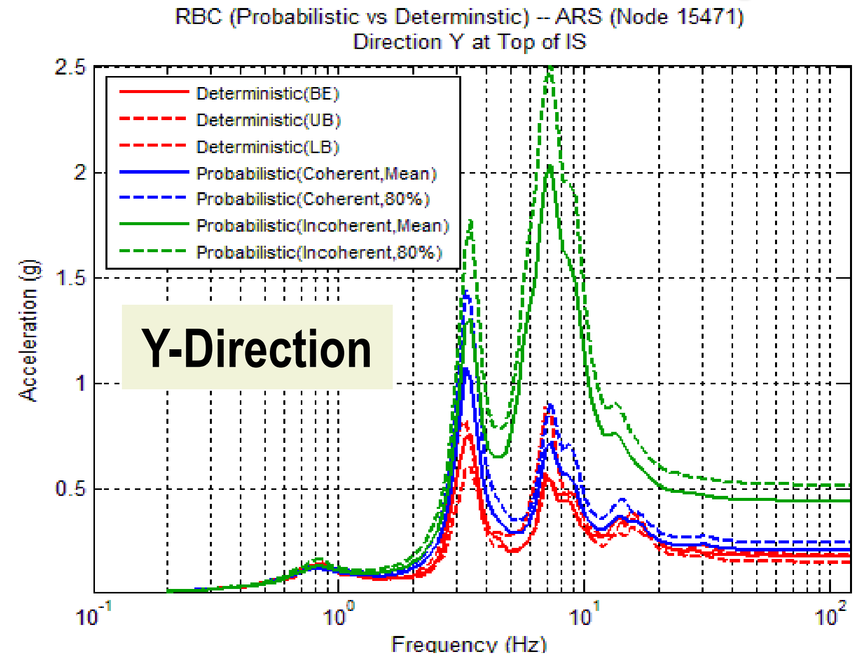


Top Base Center

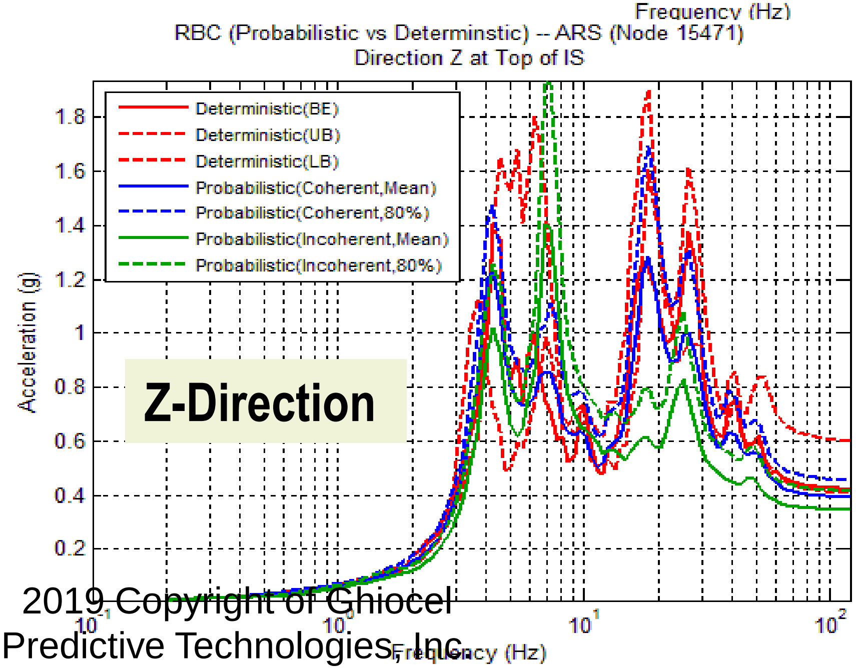


Probabilistic-Deterministic ISRS for NI Complex





Top of IS



Some Remarks from 2015 Studies:

- Probabilistic SSI analysis results are significantly larger than Deterministic SSI analysis results for coherent inputs.
- Probabilistic SSI analysis produces significantly larger ISRS amplifications for higher frequency modes.
- Motion incoherency increases significantly the relative displacements within the NI complex
- LRB isolator axial forces are largely increased due to motion incoherency *(not shown)*

4. Frequency-Dependent 3D HVD isolators

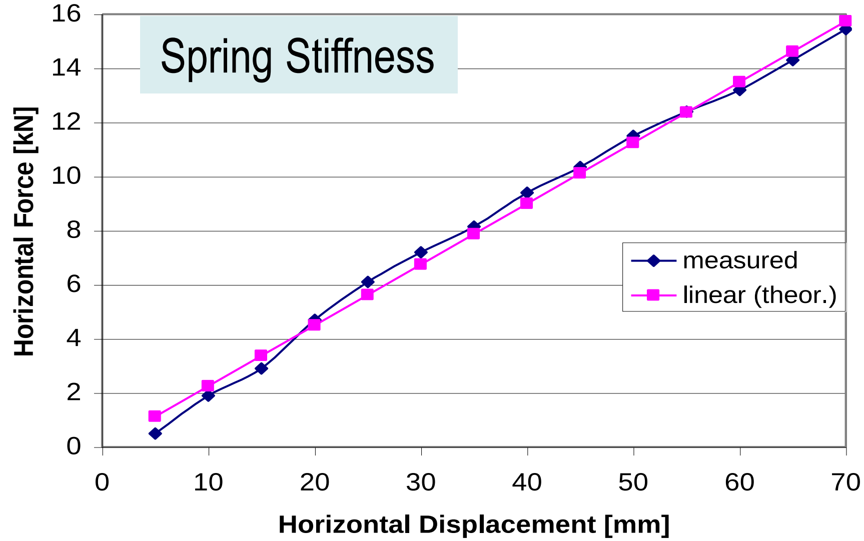
GERB BCS

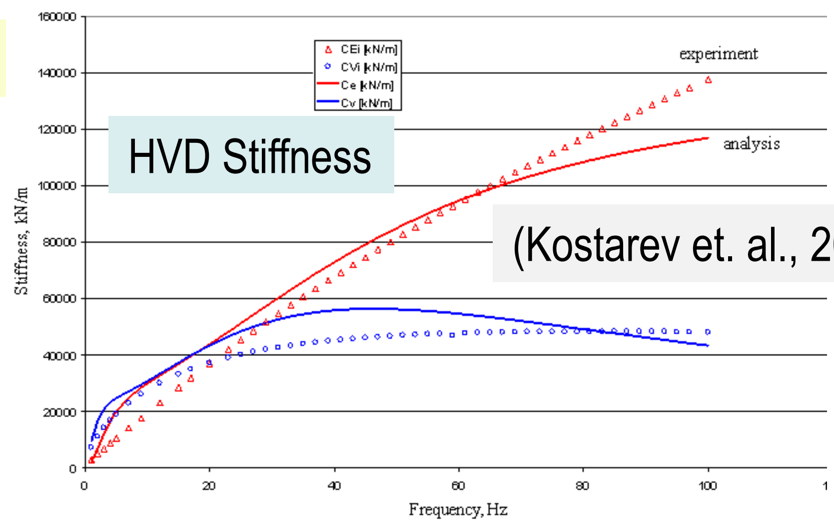
2019 Studies

3D Springs

(Nawrotzki et al., 2018)

3D HV Dampers





(Kostarev et. al., 2018)

3D HVD is a new ACS SASSI element

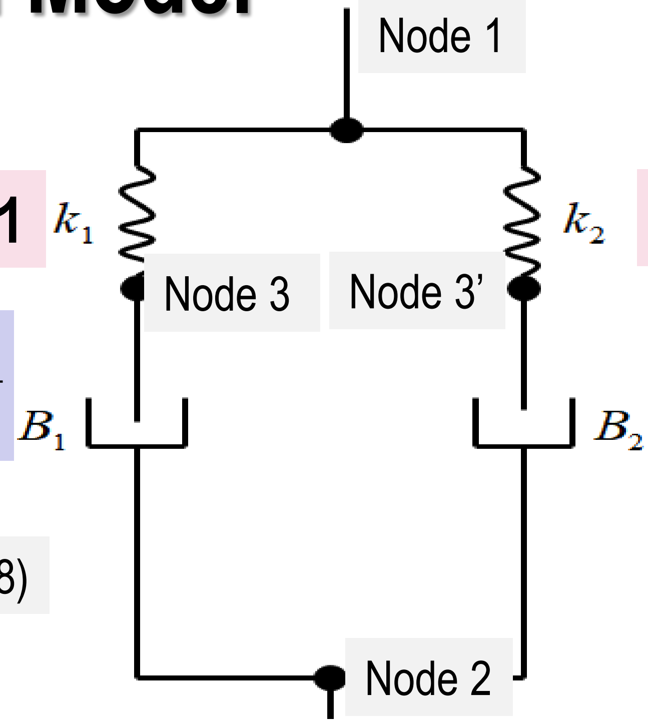
3-Node HVD Element is Based on 4-Parameter Maxwell Model

GERB BCS/HVD

(Nawrotzki, Kostarev et al, 2018)

Chain 1

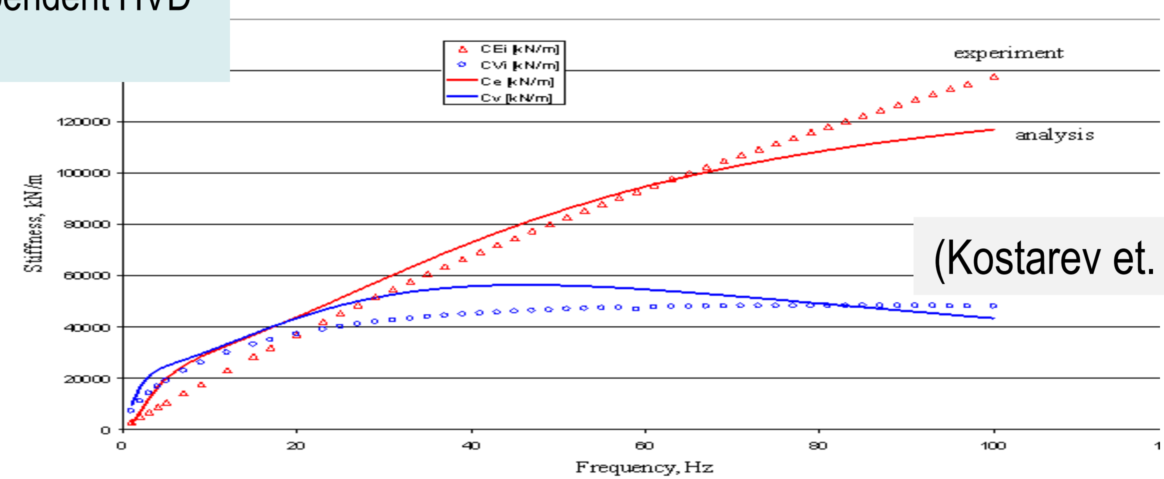
$$\omega_1 = \frac{k_1}{B_1}$$



Chain 2

$$\omega_2 = \frac{k_2}{B_2}$$

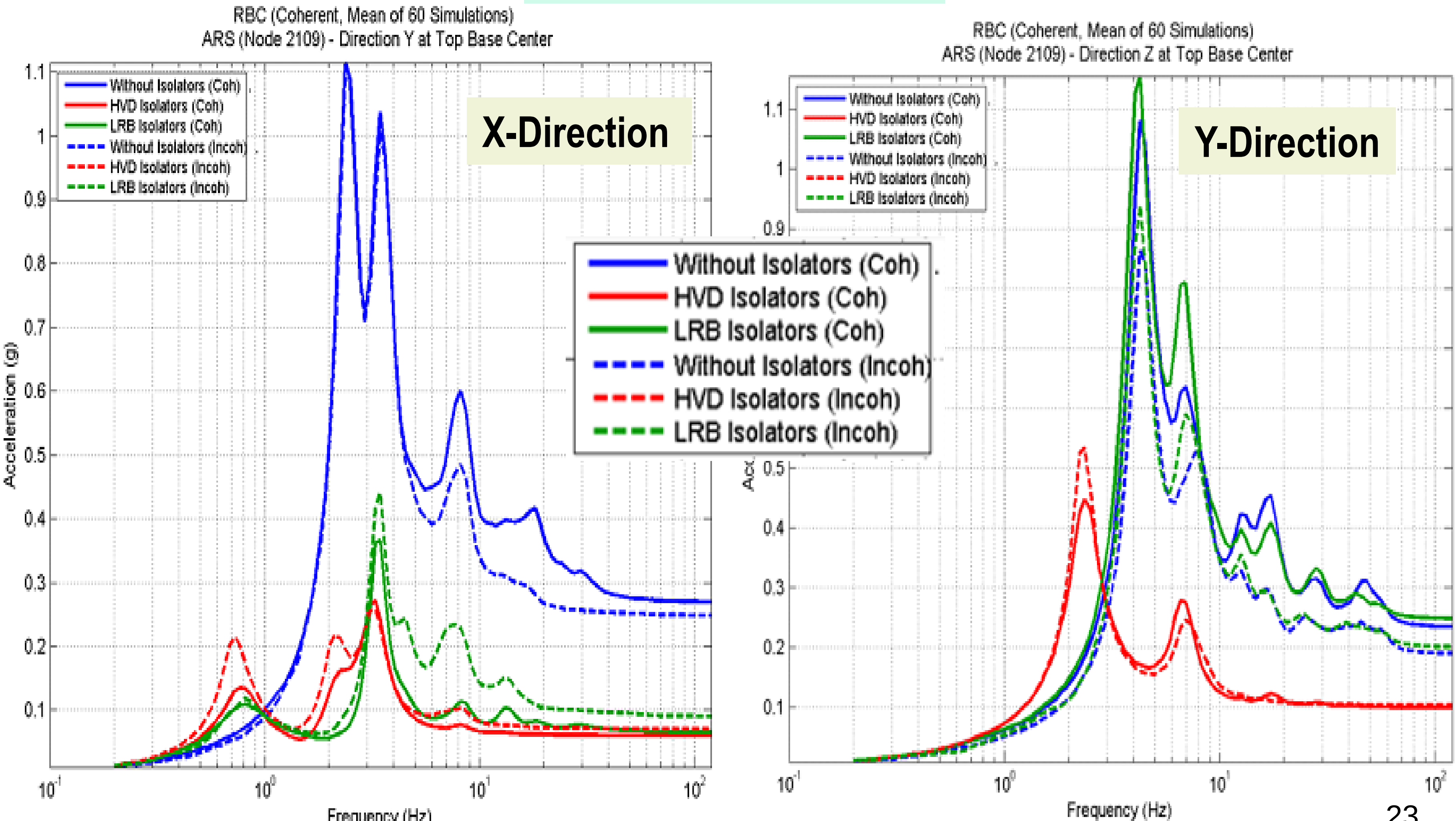
Analytical vs. Experimental Frequency-Dependent HVD Stiffnesses



(Kostarev et. al., 2018)

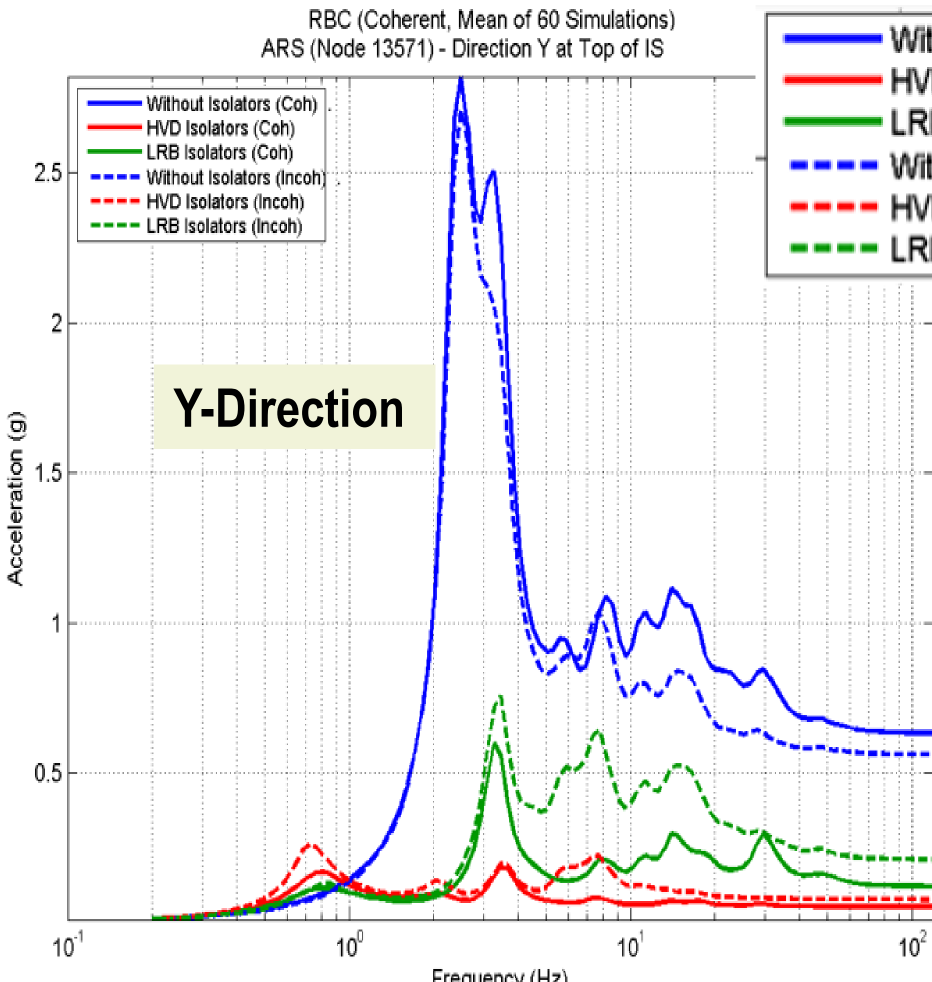
Comparative Coherent vs. Incoherent ISRS for No Isolators vs. HVD and LRB Isolators

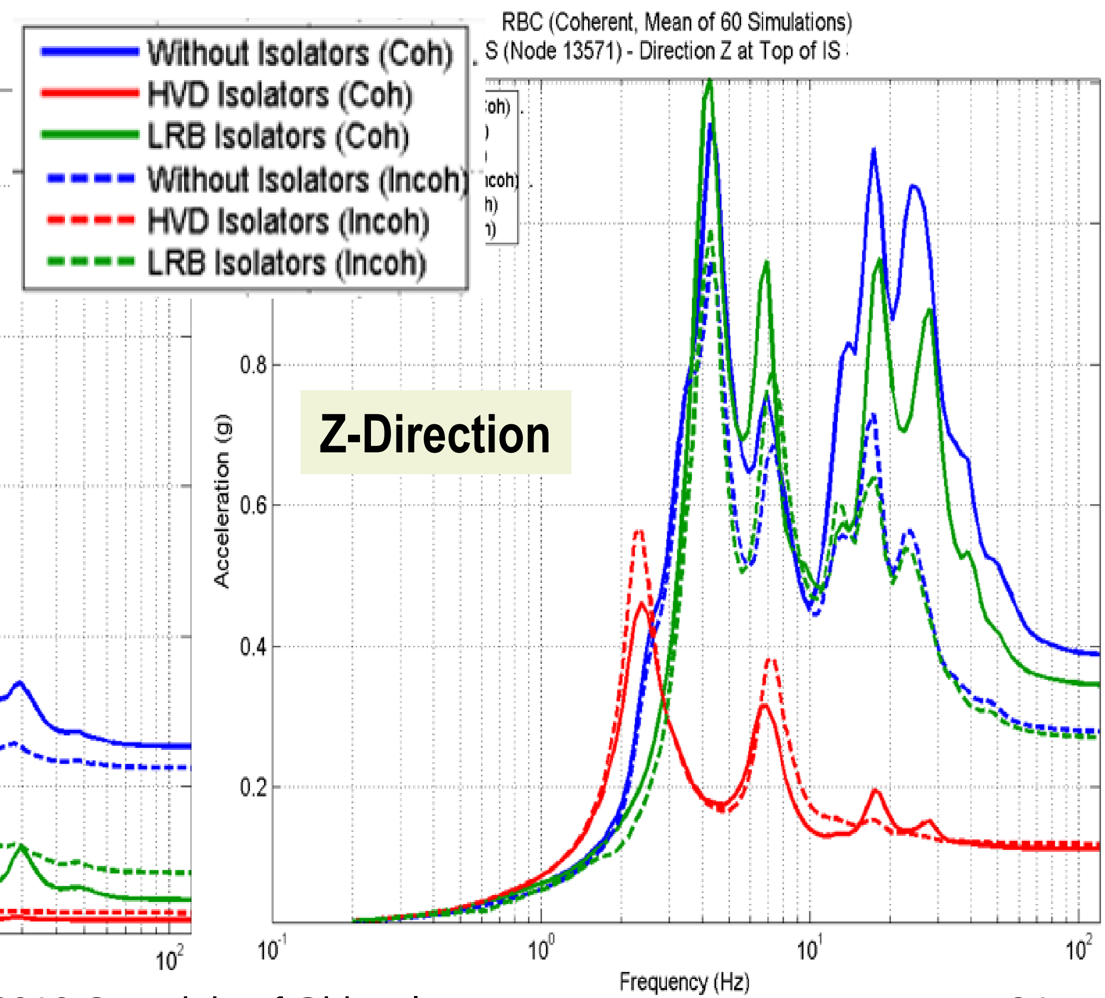
Top Base Center



Comparative Coherent vs. Incoherent ISRS for No Isolators vs. HVD and LRB Isolators

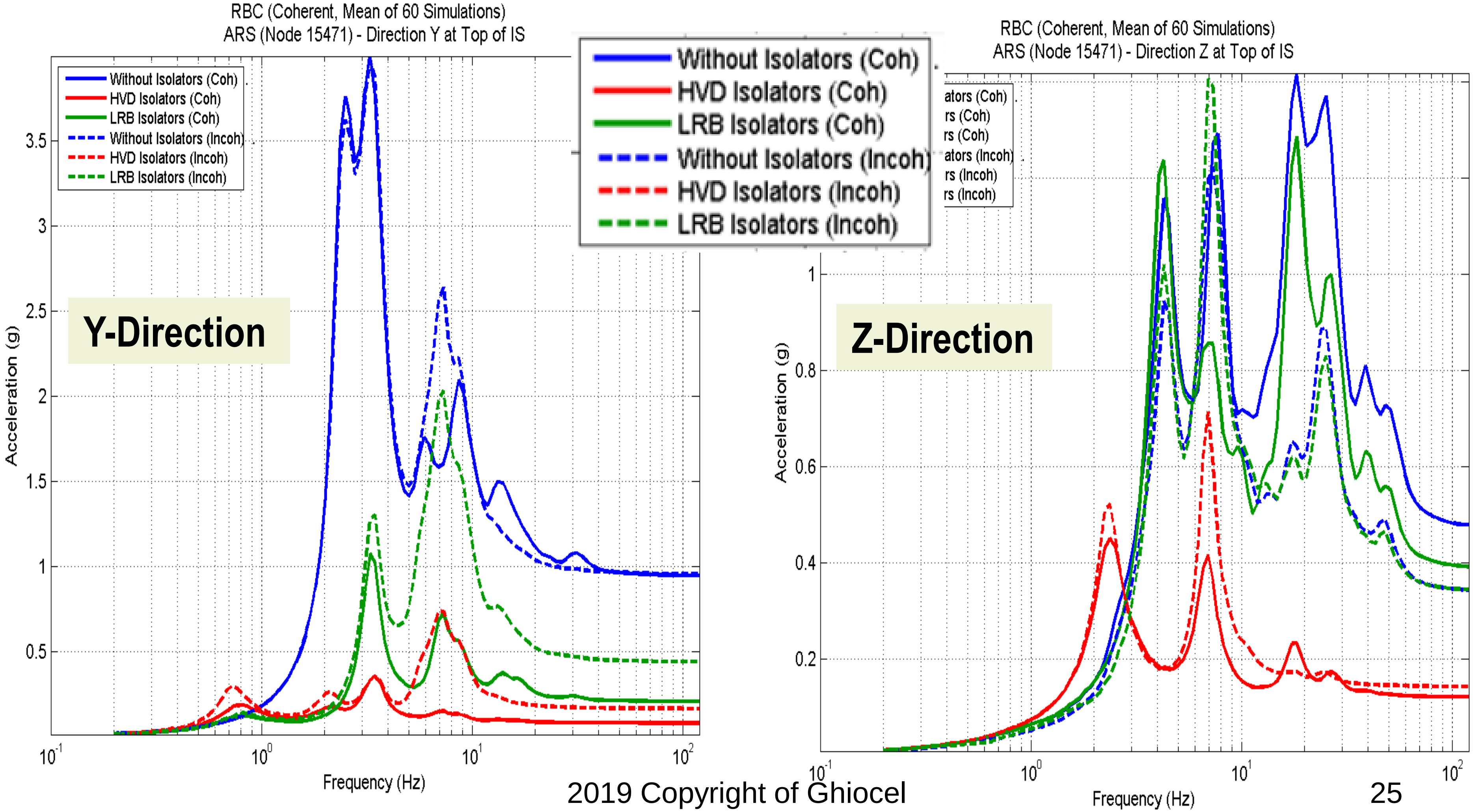
Top of IS near Center





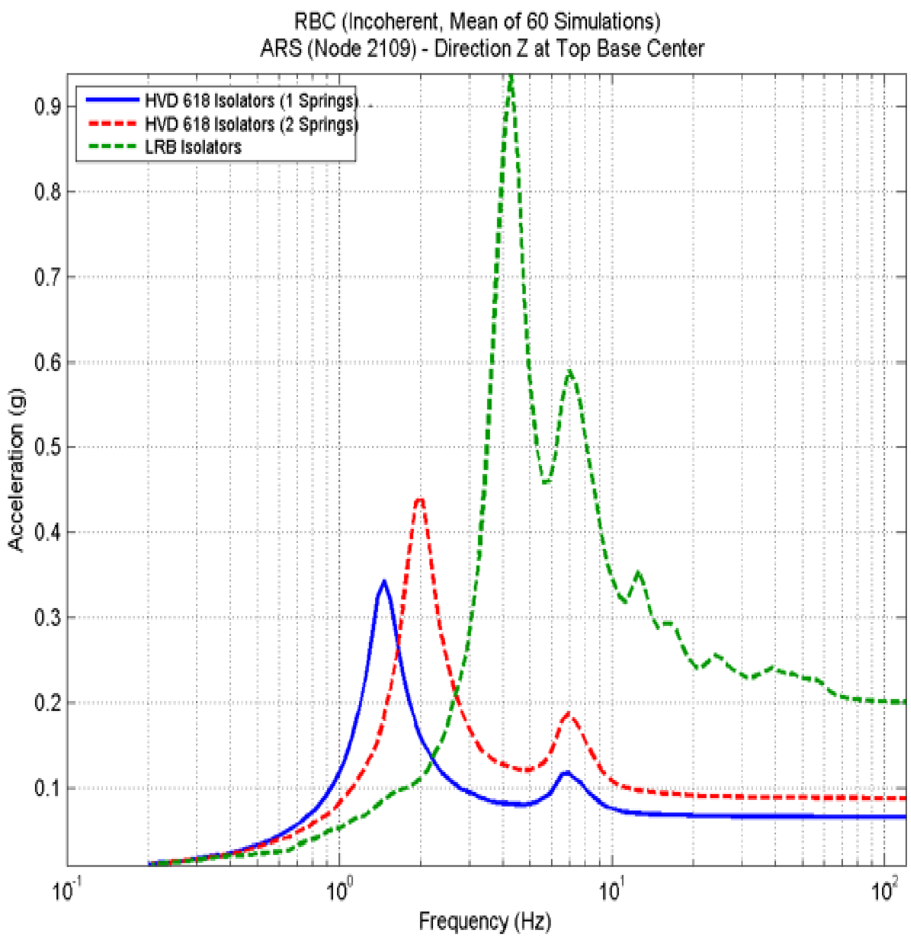
Comparative Coherent vs. Incoherent ISRS for No Isolators vs. HVD and LRB Isolators

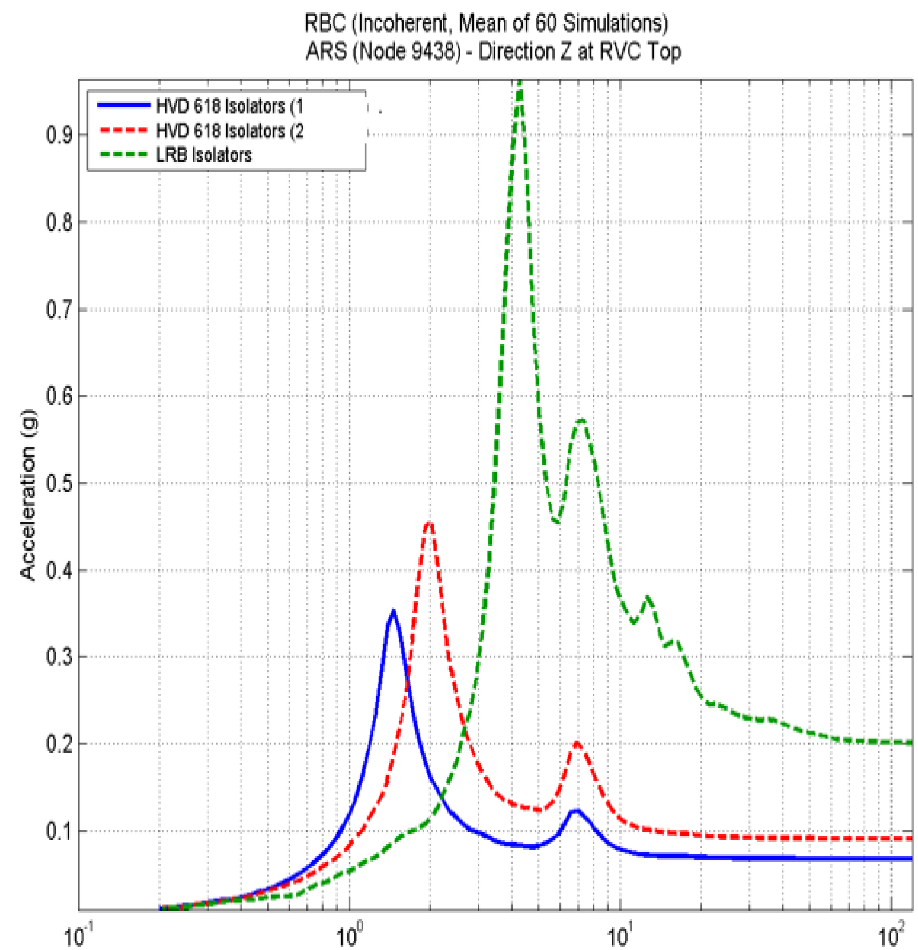
Top of IS near Edge



Comparative Coherent ISRS for Different Number of Units for HVD 1 and HVD 2 vs. LRB Isolators

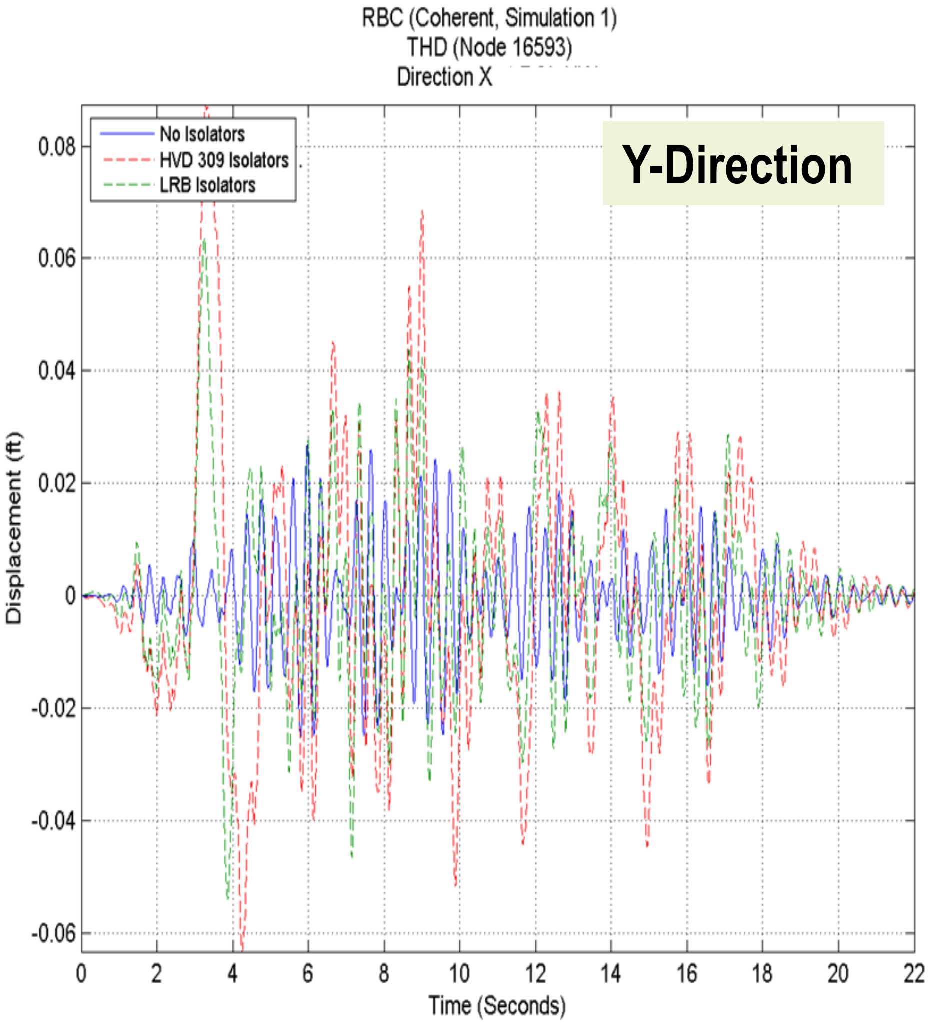
Top Base Center

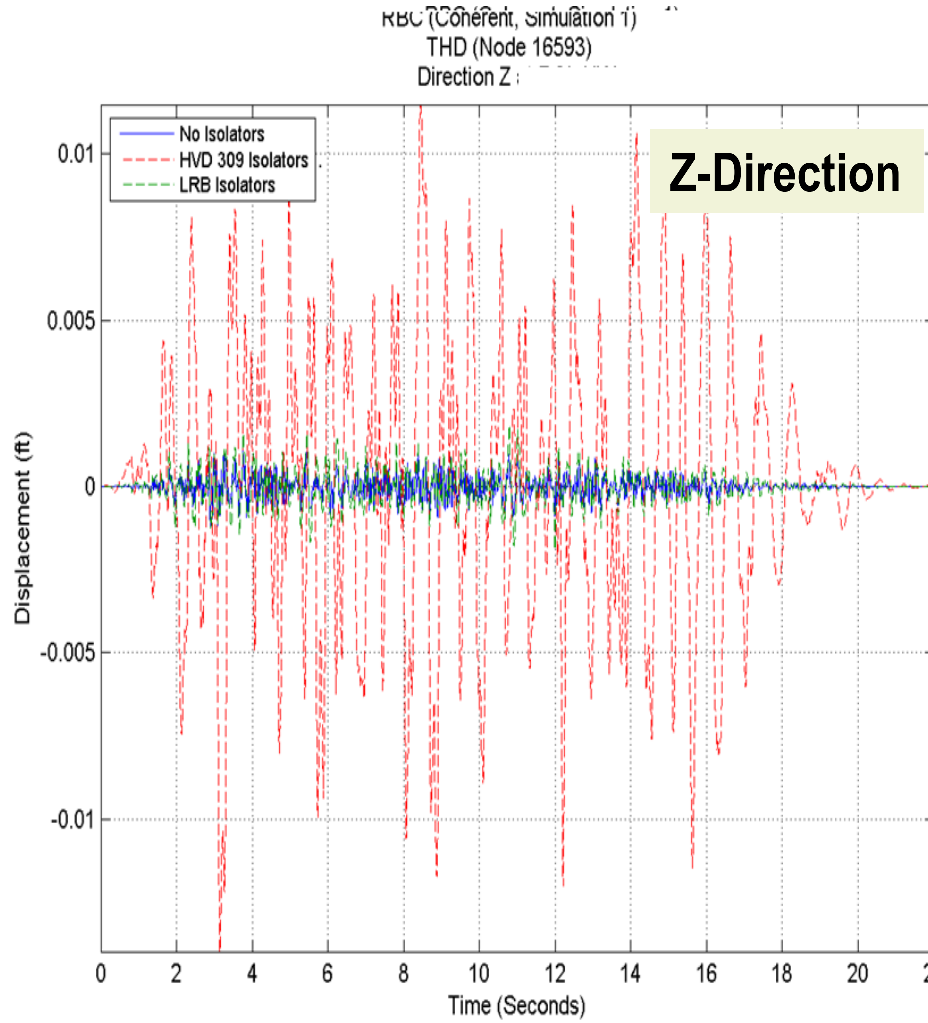




Comparative Coherent Relative Displacements wrt to Top Base Center

High Elevation Location





CONCLUDING REMARKS

The main conclusions are:

i) the RB complex base-isolation is highly effective for both the rock and soil sites,

ii) the motion incoherency largely amplifies the horizontal ISRS and relative displacements within NI complex,

iii) the 3D HVD isolators are more effective than the 2D LRB isolators, especially for the vertical motions.