Sensitivity Studies for Evaluating SSI Effects for Seismically Base-Isolated NPP Structures. PART 1:Deterministic SSI Analysis

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Purpose of This Presentation:

To investigate the effects of base isolation on seismic SSI response of a typical NI complex under coherent and incoherent motions.

How are the base-isolation effects different for soft soil sites and rock site?

How are the base-isolation effects different for coherent and incoherent motions?

Which are the base-isolation effects on the NI complex ISRS?

Which are the base-isolation effects on the relative displacements at the RCL system supports?

Presentation Content

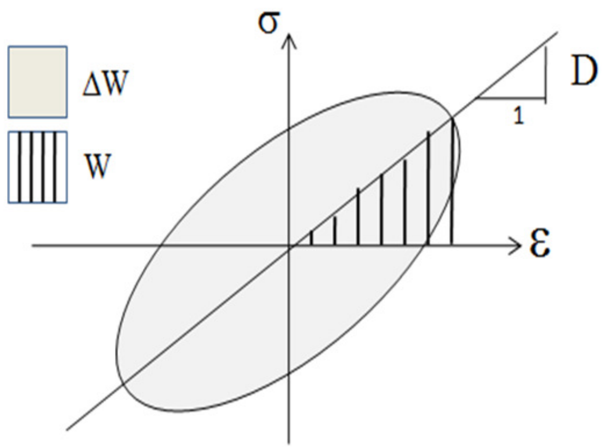
1. Investigate the seismic SSI effects for the base-isolated NI complex for different soil conditions, for a *rock site and soft soil site*. Compare NI responses *with and without LRB isolators. Case study 1.*

2. Investigate the seismic SSI effects for the base-isolated NI complex response for *coherent and incoherent* input motions. *Case study 2.*

Compare accelerations, displacements and ISRS within the NI complex and computed displacements and forces in isolators.

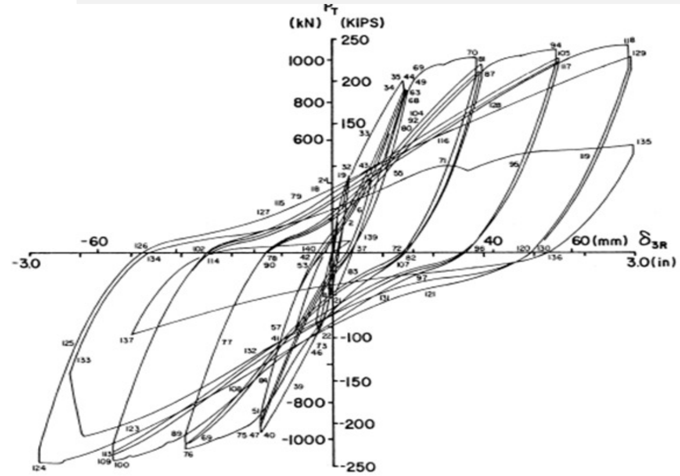
ACS SASSI NON Modeling of Hysteretic Behavior

Linearized Hysteretic Model



Frequency Domain
Linearized Hysteretic Model

Experimental Hysteretic Model



Time Domain
Hysteretic Model

Comparative nonlinear SSI analysis results of the hybrid approach and the "*true*" nonlinear time-integration approach showed a very good matching.

The new nonlinear SSI approach can be used to perform *fast and accurate* nonlinear SSI analyses at a small fraction of the runtime of a time domain nonlinear SSI analysis, about 2-3 times the linear analysis runtime.

Seismic Nonlinear SSI Analysis Methodology

Base isolators are modeled as nonlinear spring elements.

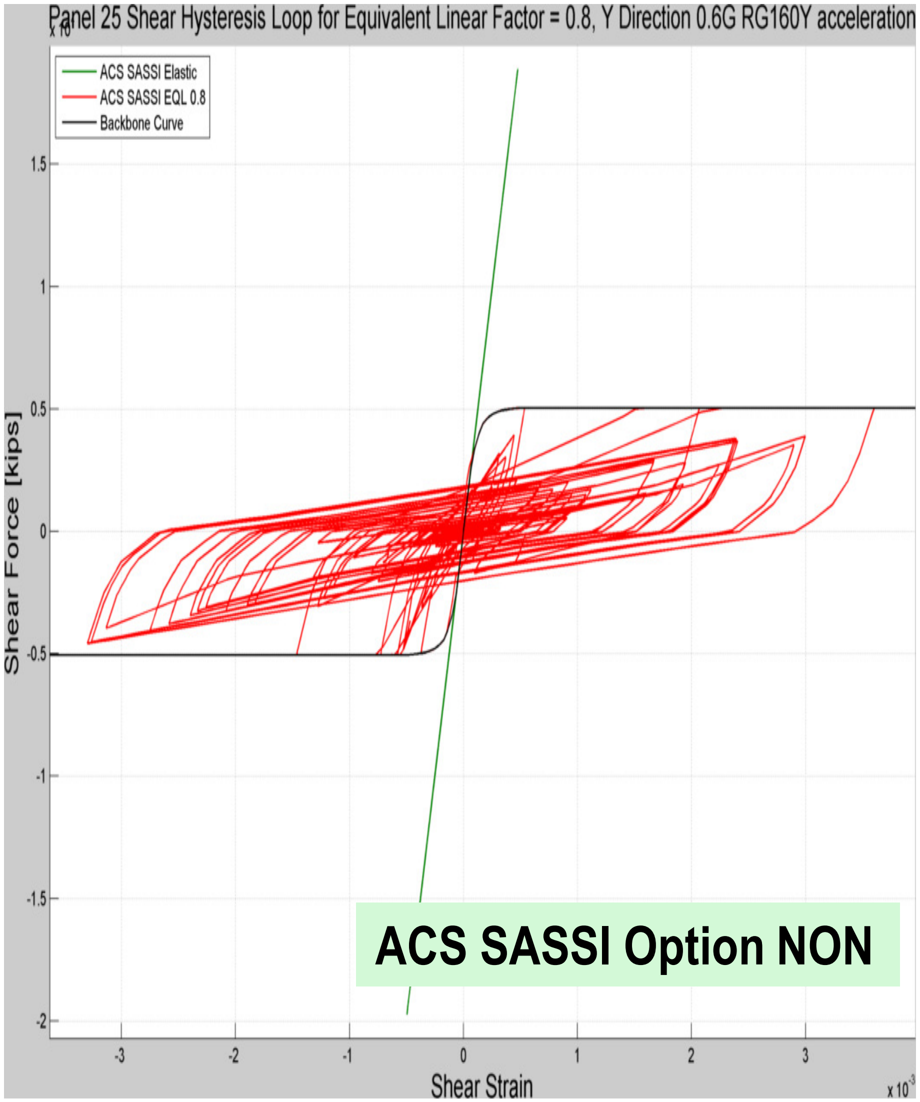
ACS SASSI NON extended the SASSI subtructuring methodology to nonlinear SSI using an iterative equivalent linear procedure. Includes shells and springs.

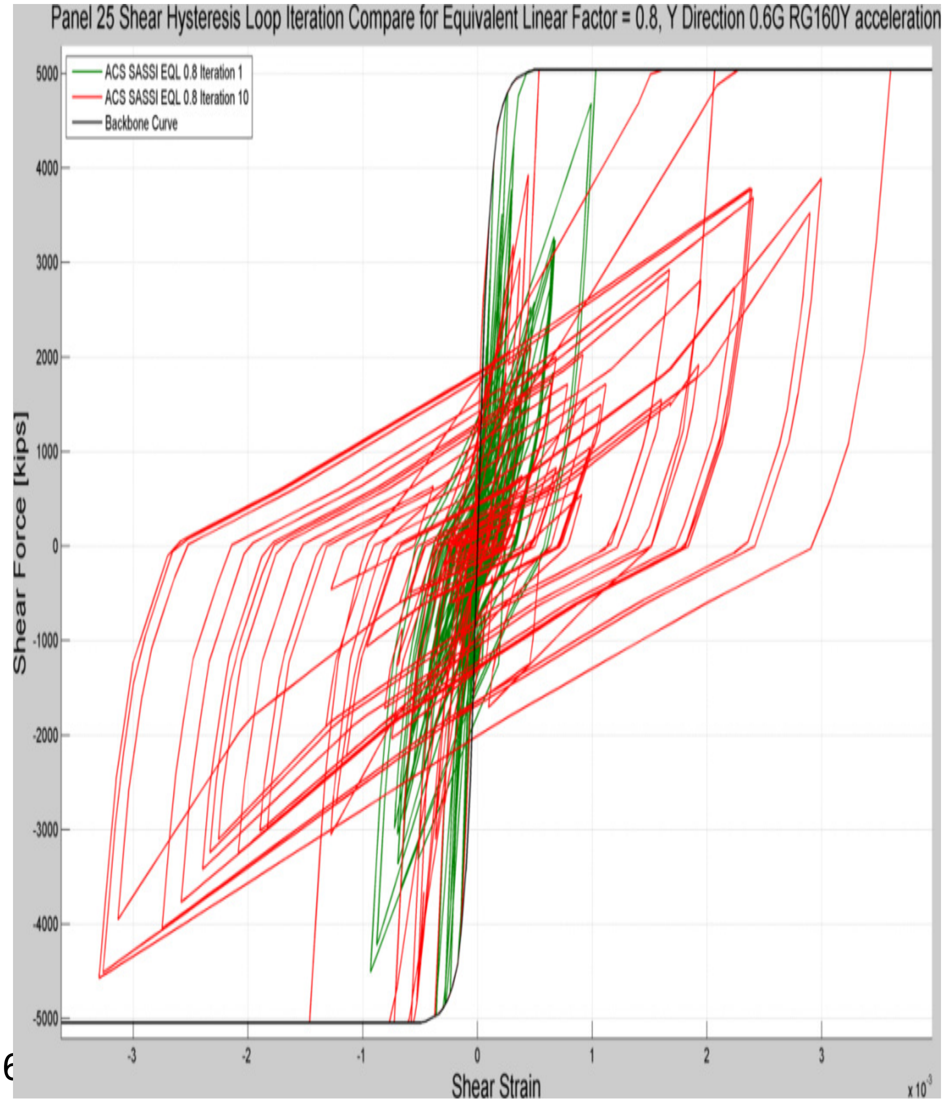
Computational steps:

- For the initial iteration, perform a linear SSI analysis using the initial elastic properties for the nonlinear elements
- Compute the local behavior of nonlinear elements in time domain based on the local relative displacements, that is then used to calibrate the local linearized hysteretic models associated to each nonlinear element in complex frequency
- Perform a new SSI analysis iteration using a fast SSI restart analysis in the complex frequency domain using the linearized hysteretic models computed in Step 2 for nonlinear elements
- Check convergence after new SSI iteration to stop or continue.

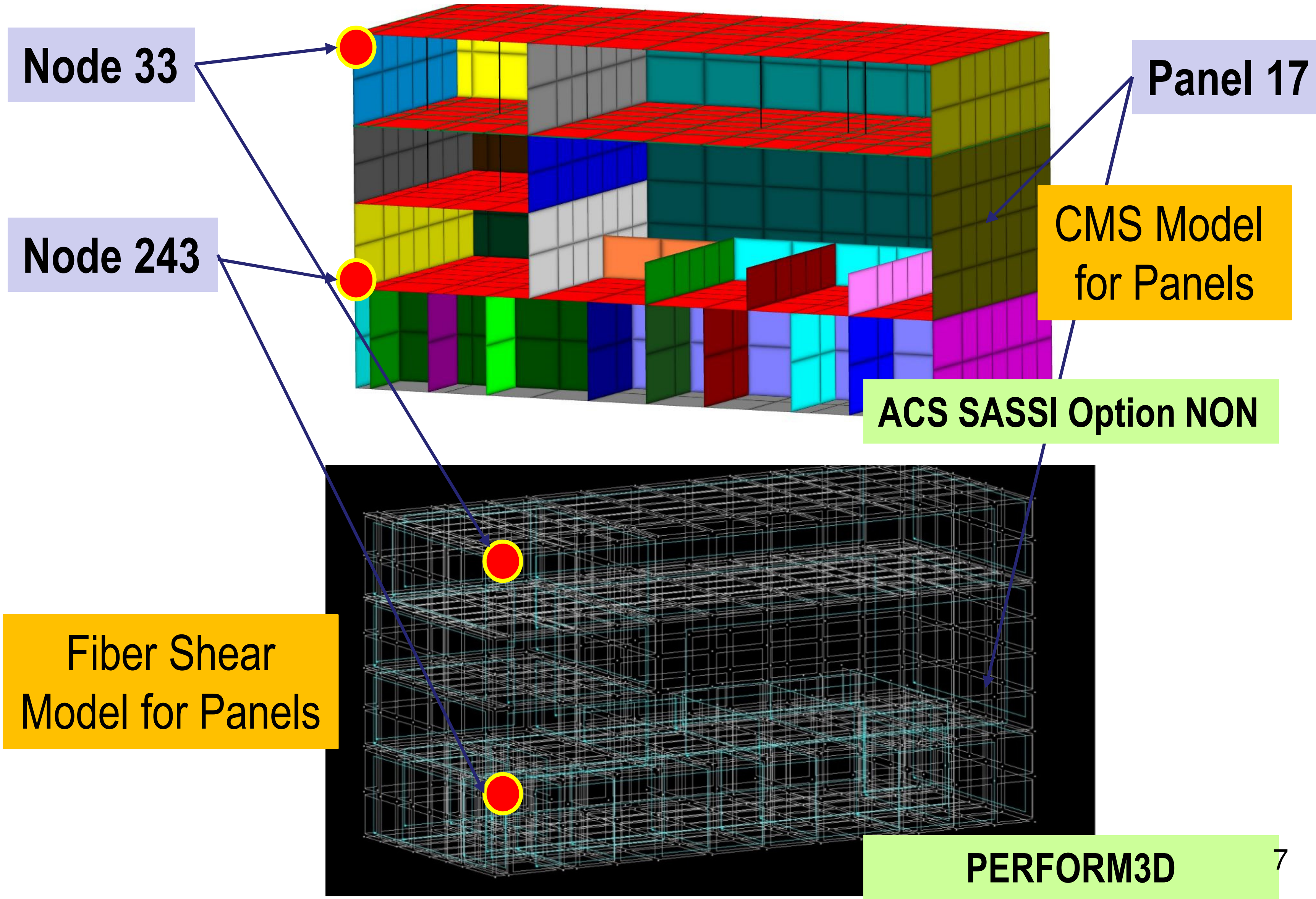
Reinforced Concrete Structure SSI Analysis

Elastic vs. Nonlinear	1st Iteration vs. Last Iteration

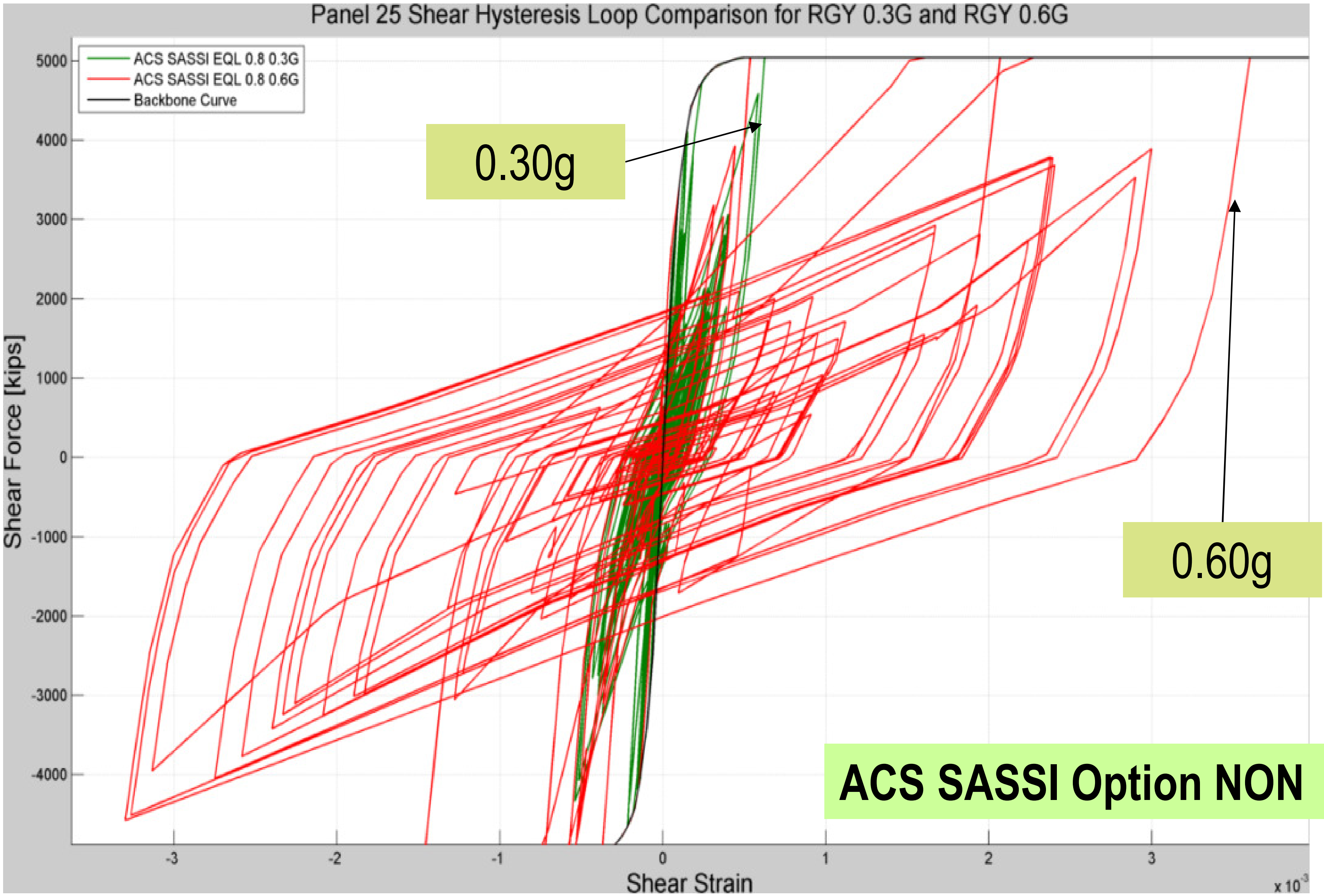




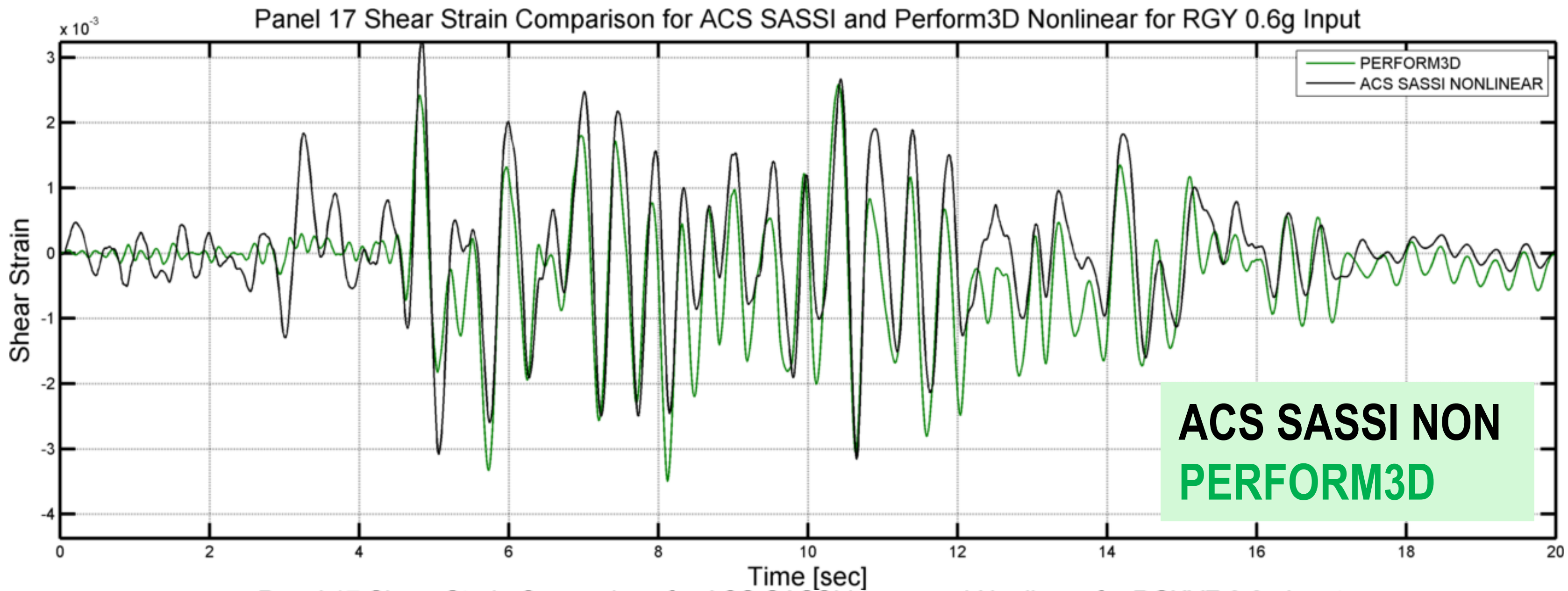
ACS SASSI Opt NON vs. PERFORM3D Fixed-Base Analysis. Comparative Study Results.

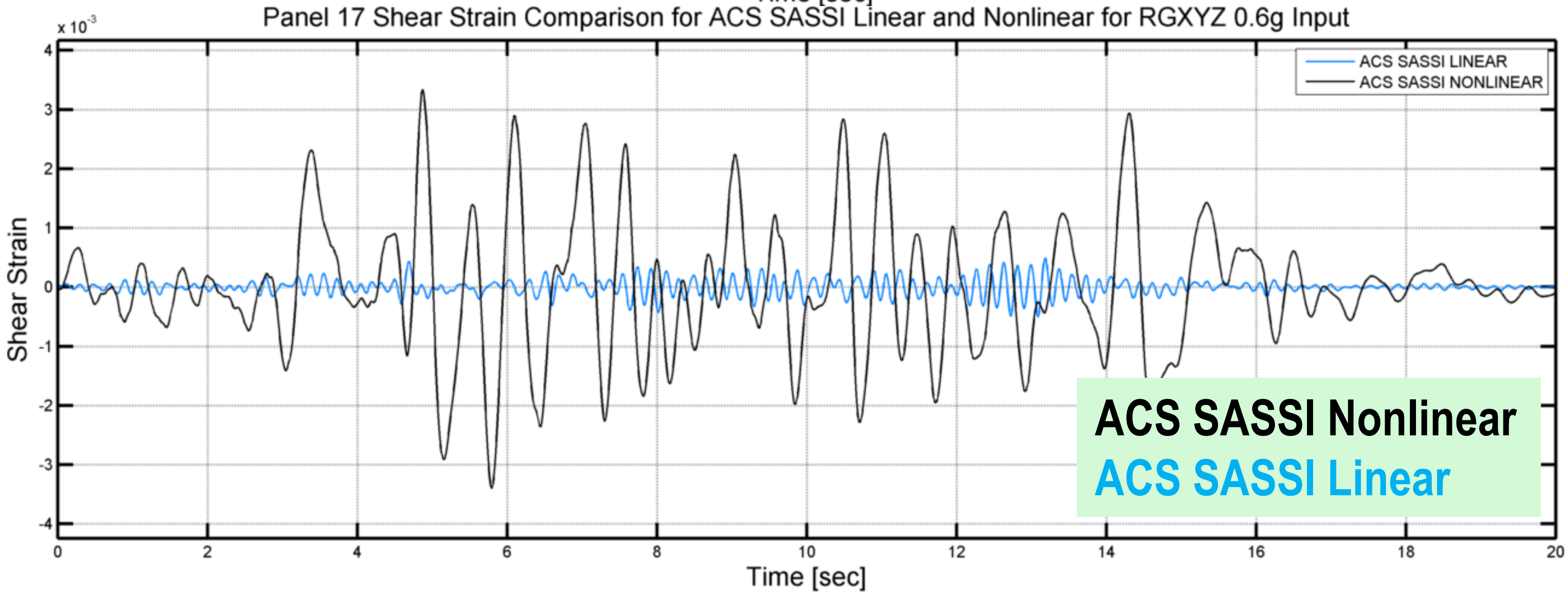


Nonlinear SSI Analysis for 0.30g and 0.60g Inputs. Panel 17 Cheng-Mertz Shear Hysteretic Model



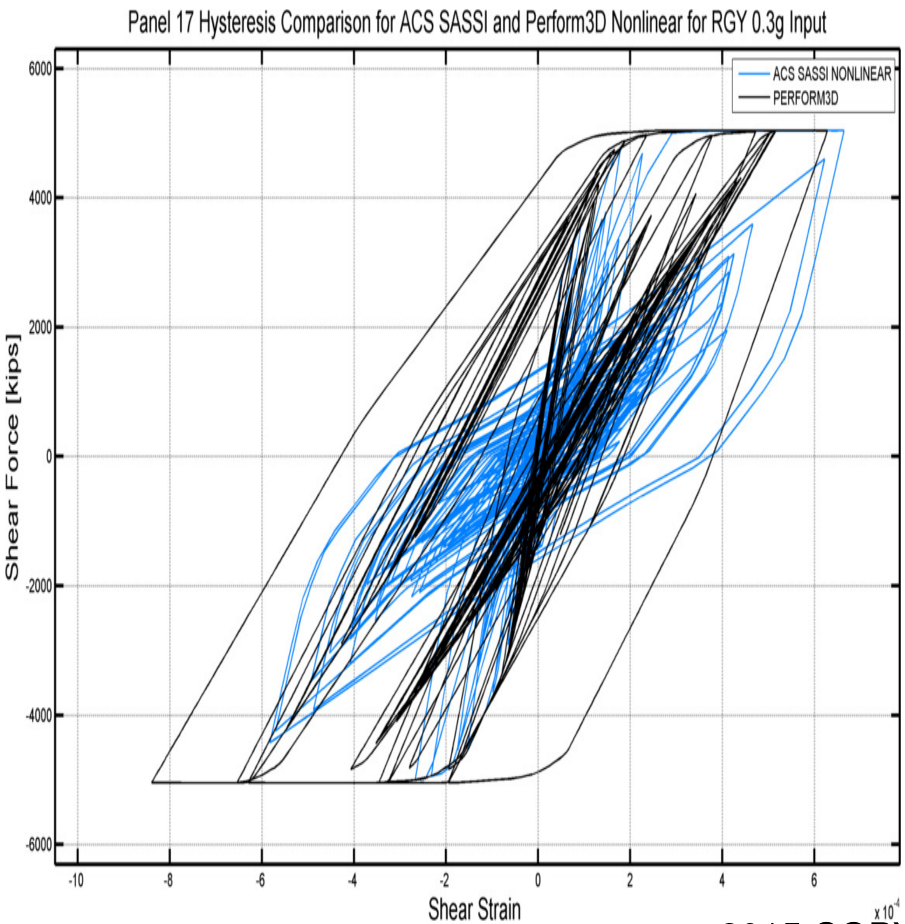
Panel 17 Shear Strains for 0.60g Input



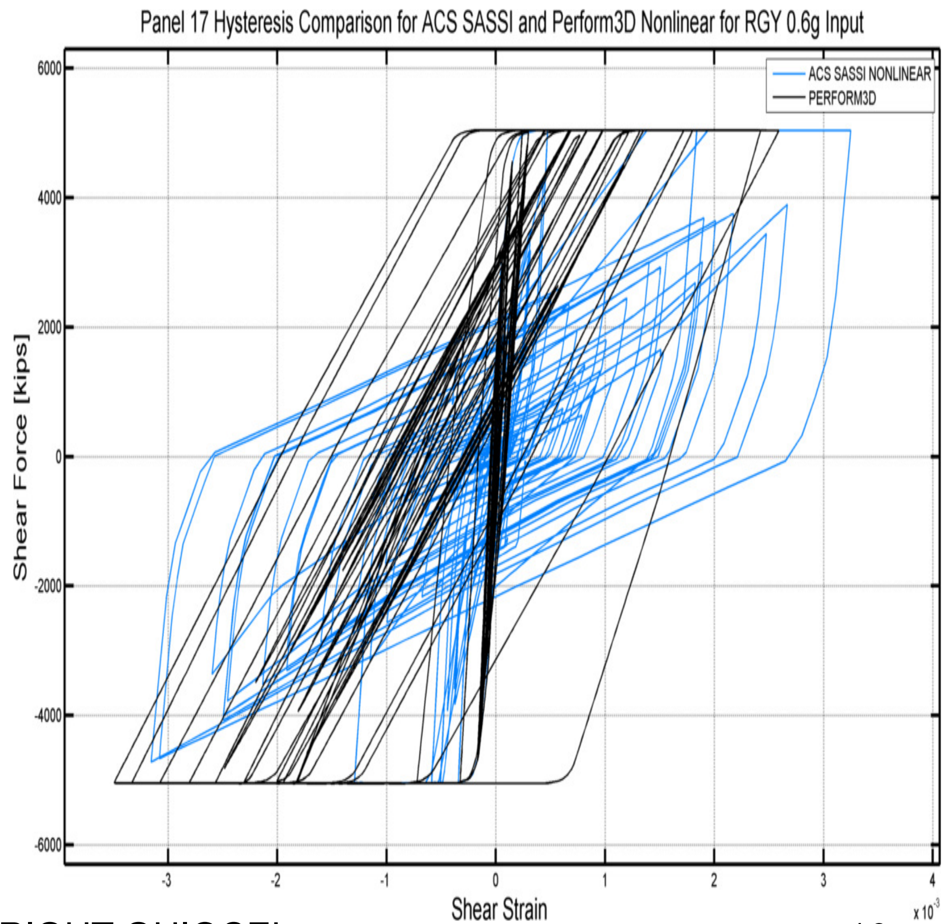


ACS SASSI Opt NON vs. PERFORM3D Fixed-Base Panel 17 Hysteretic Loops for 0.30g and 0.60g

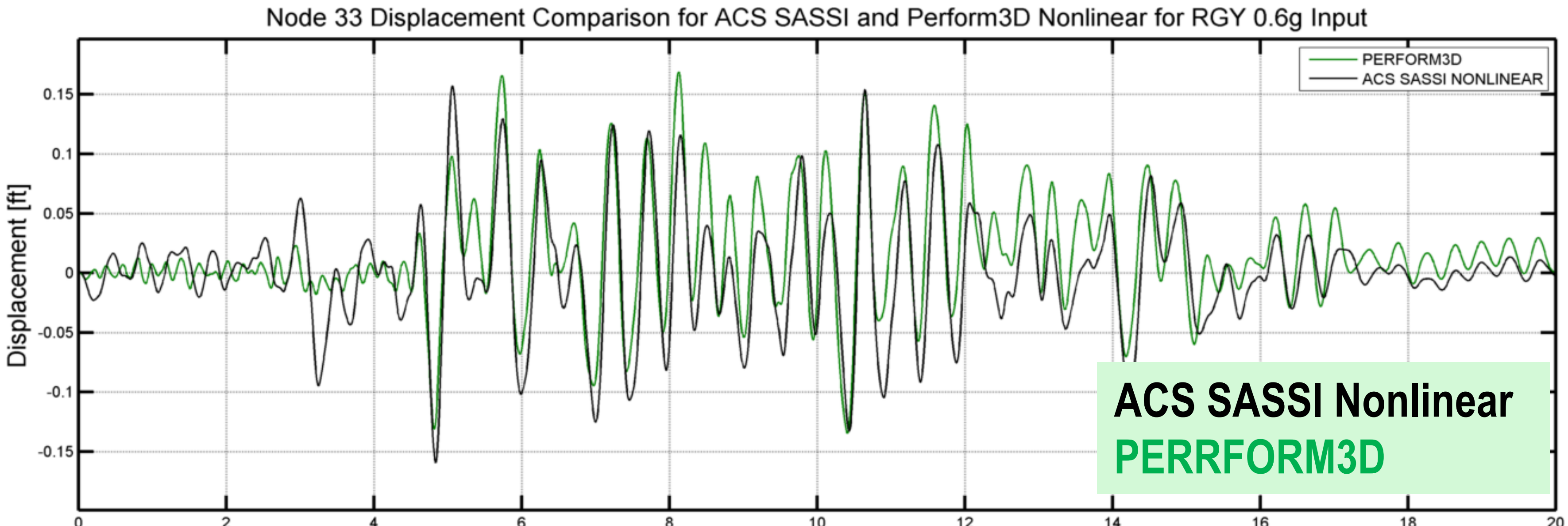
0.30g

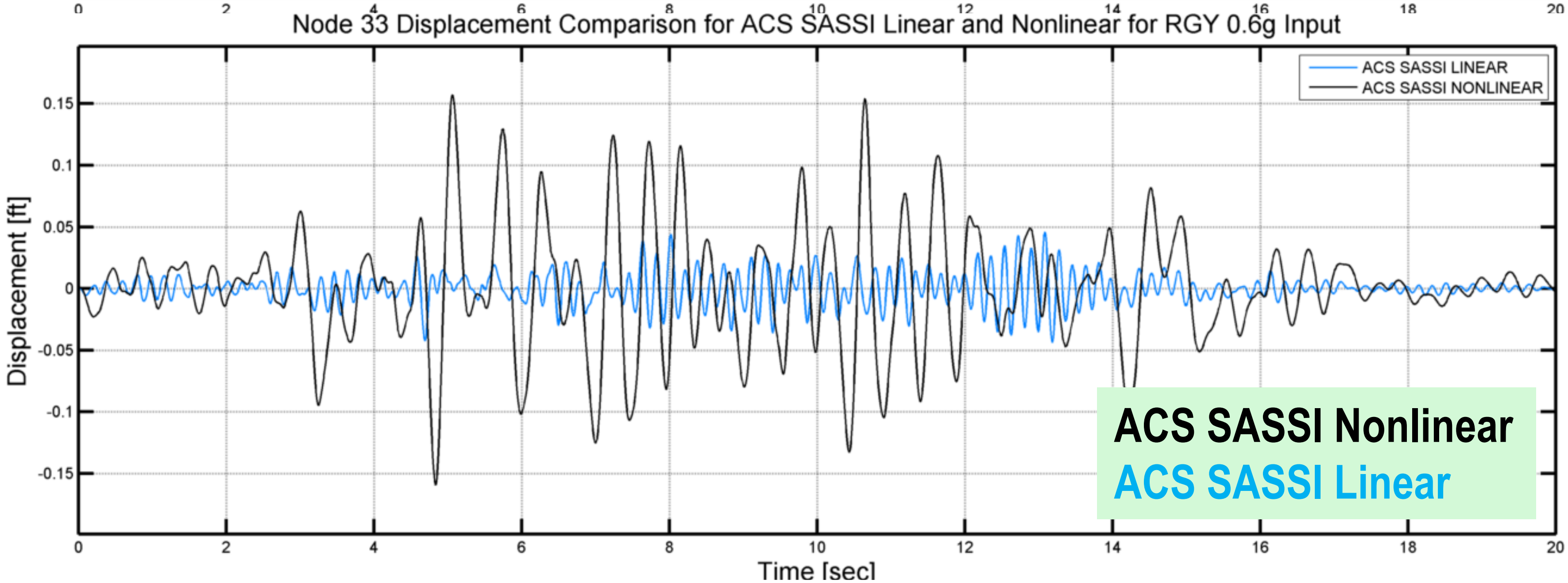


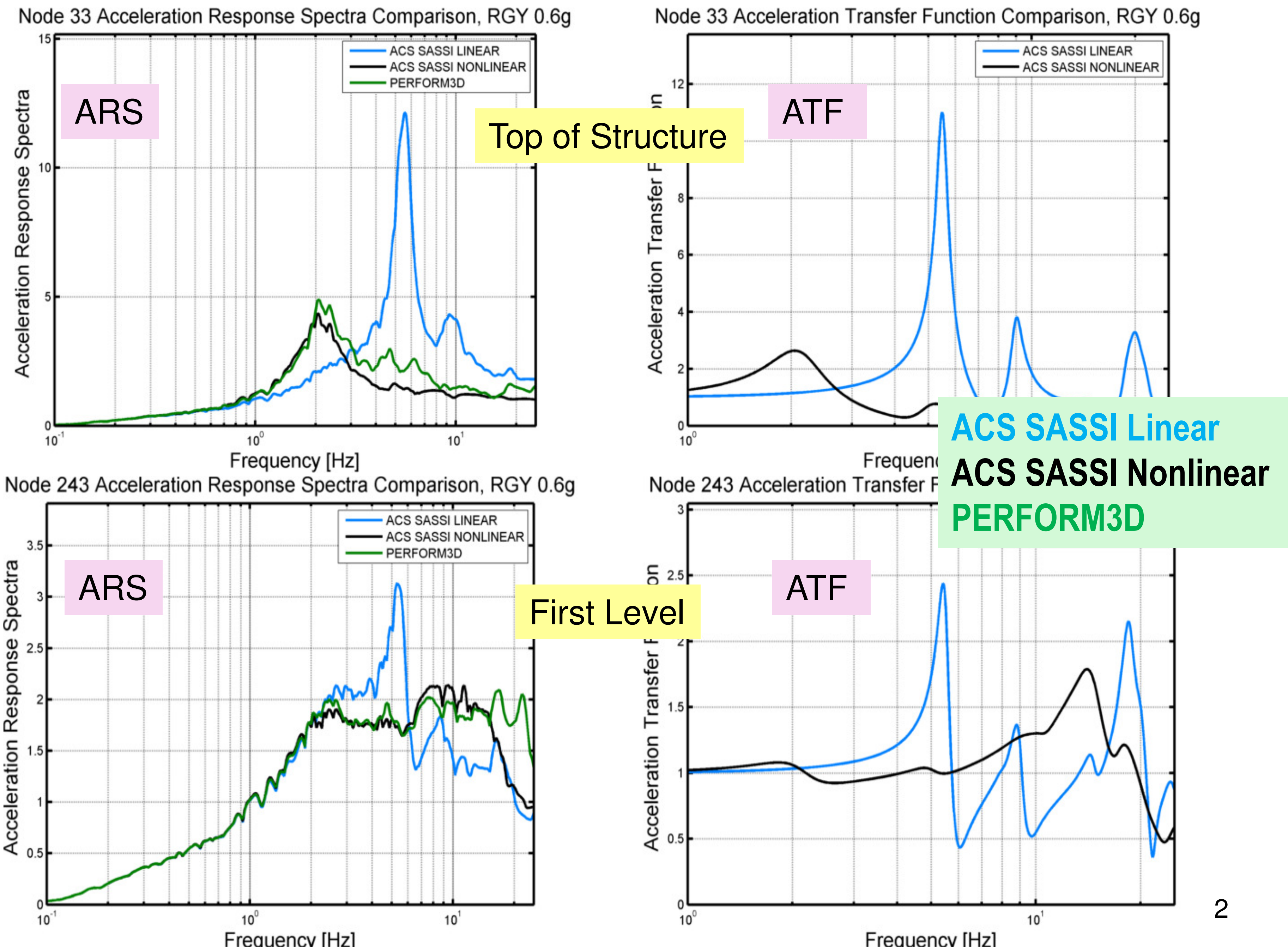
0.60g



Top of Structure Displacements for 0.60g Input



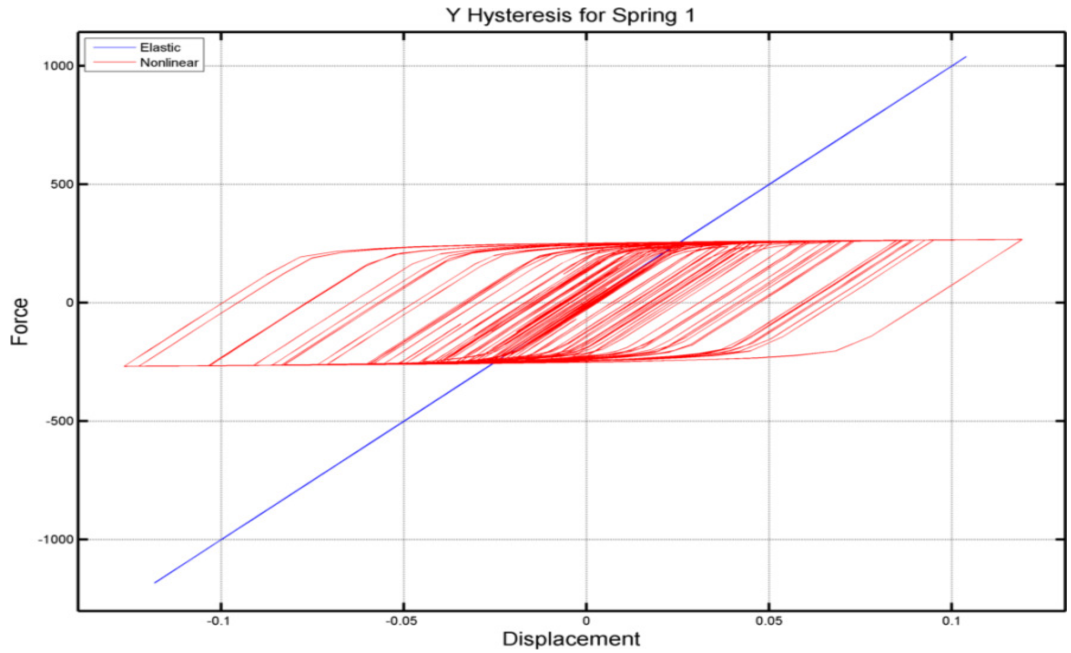


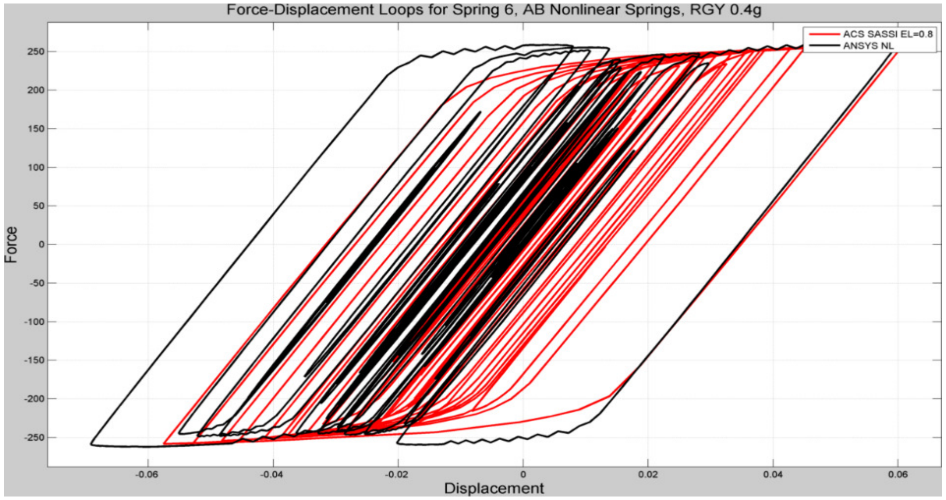

Node 33 Acceleration Response Spectra Comparison, RGY 0.6g
ACS SASSI LINEAR
ACS SASSI NONLINEAR
PERFORM3D
ARS
Acceleration Response Spectra
Frequency [Hz]
Top of Structure
Node 33 Acceleration Transfer Function Comparison, RGY 0.6g
ACS SASSI LINEAR
ACS SASSI NONLINEAR
ATF
ACS SASSI Linear
ACS SASSI Nonlinear
PERFORM3D
Node 243 Acceleration Response Spectra Comparison, RGY 0.6g
ACS SASSI LINEAR
ACS SASSI NONLINEAR
PERFORM3D
ARS
Acceleration Response Spectra
Frequency [Hz]
First Level
ATF
Frequency [Hz]

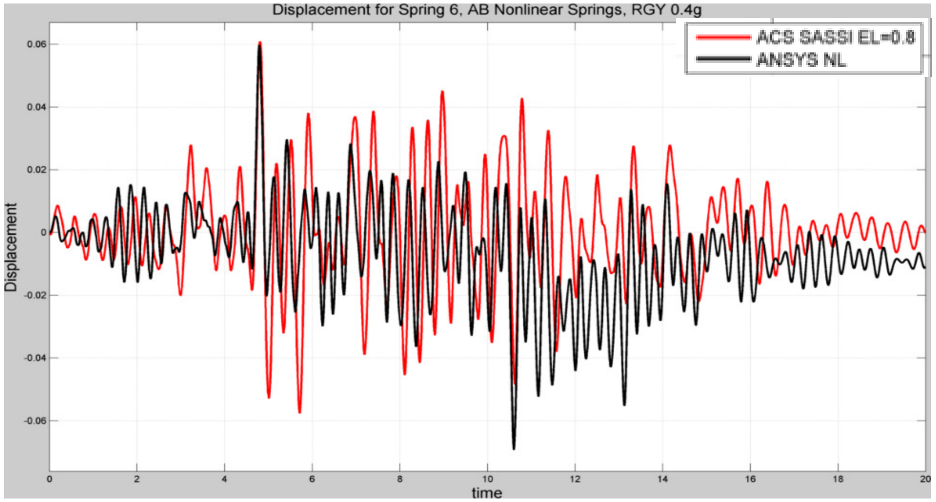
Nonlinear Springs for Modeling Base-Isolators and/or Moderate Building Sliding

Base-Isolators

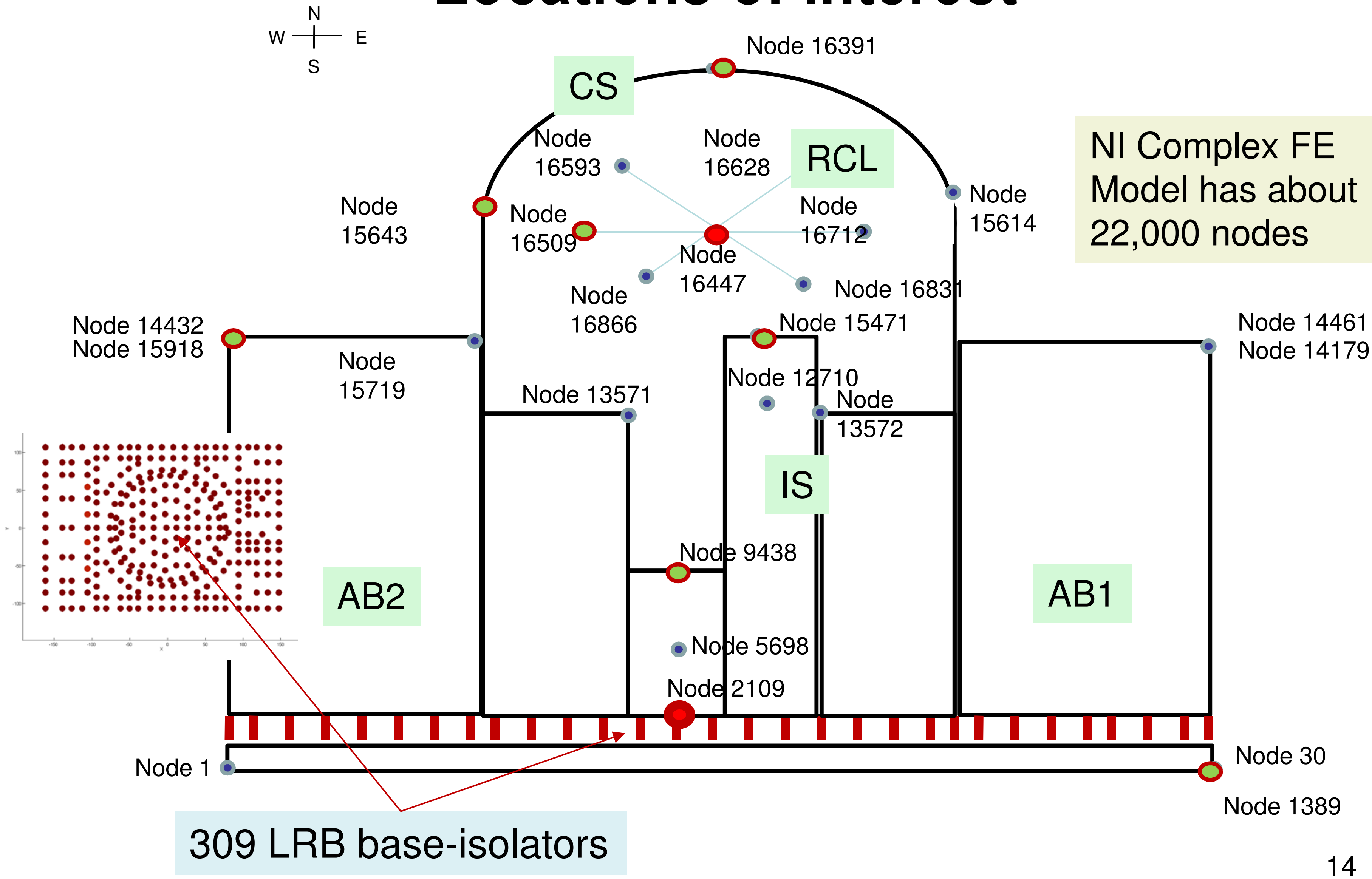
Small-Moderate Sliding







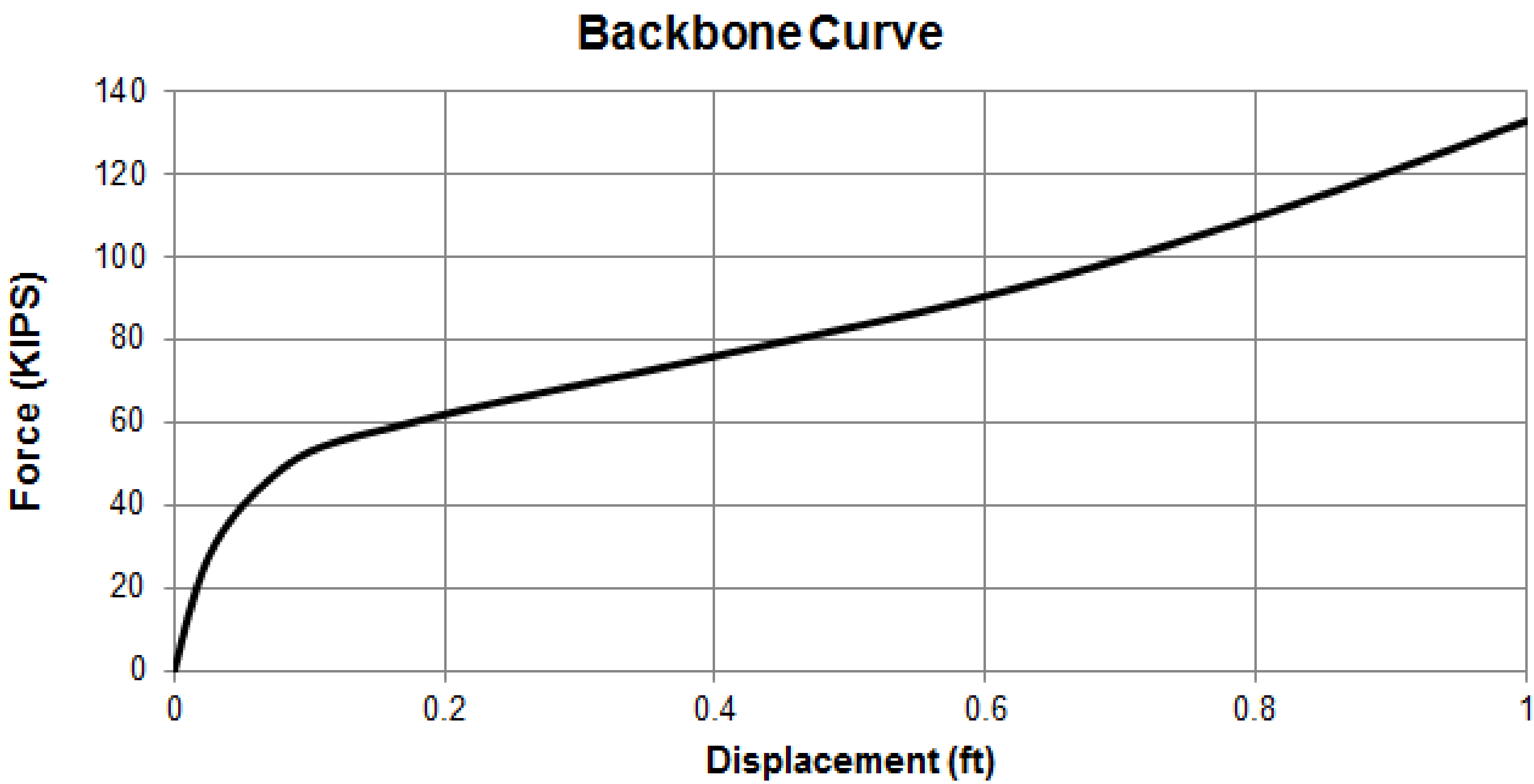
Typical Nuclear Island Complex Model. Locations of Interest



NI Complex FE Model has about 22,000 nodes

LRB Base-Isolator Dynamic Properties

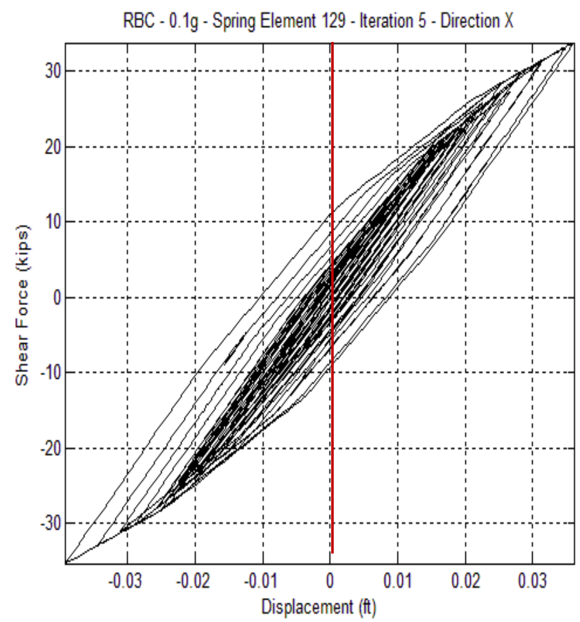
Horizontal Nonlinear Springs: Stiffness defined by backbone curve



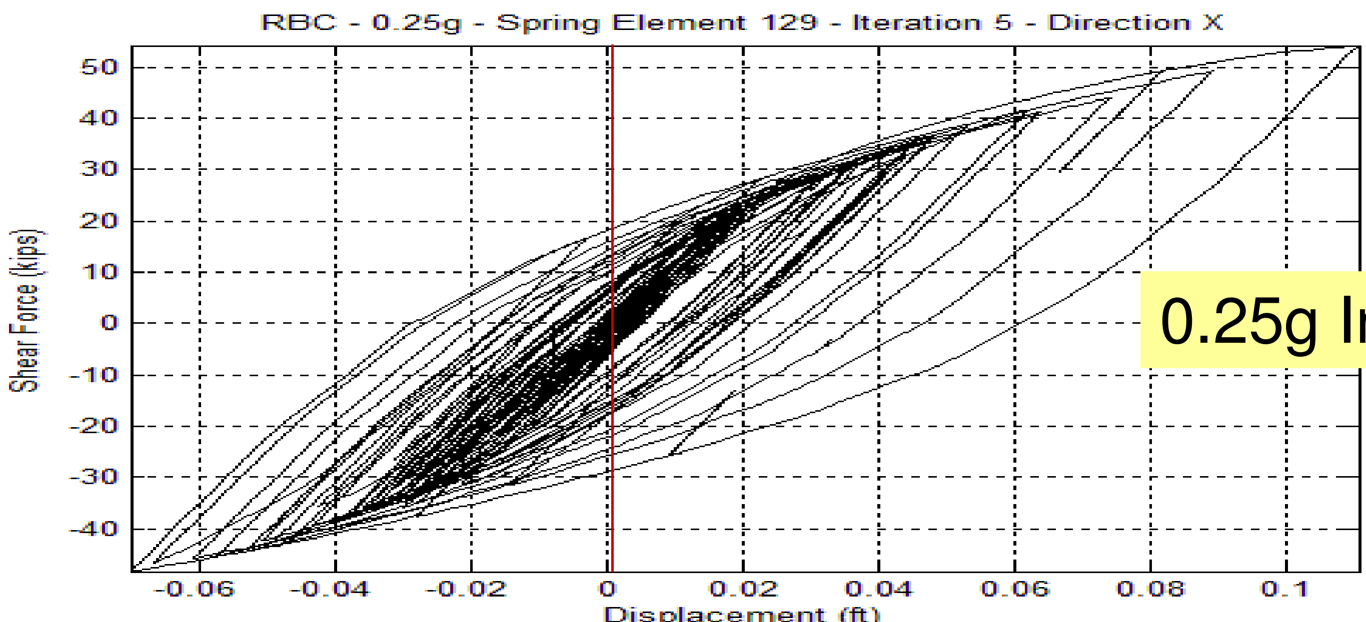
(close to 1.60 diameter LRB base-isolators used in Japan; see SMiRT23 Papers presented in Division V)

Vertical Linear Springs: With an axial stiffness of 600,000 kips/ft

General Hysteretic Model for LRB Isolators

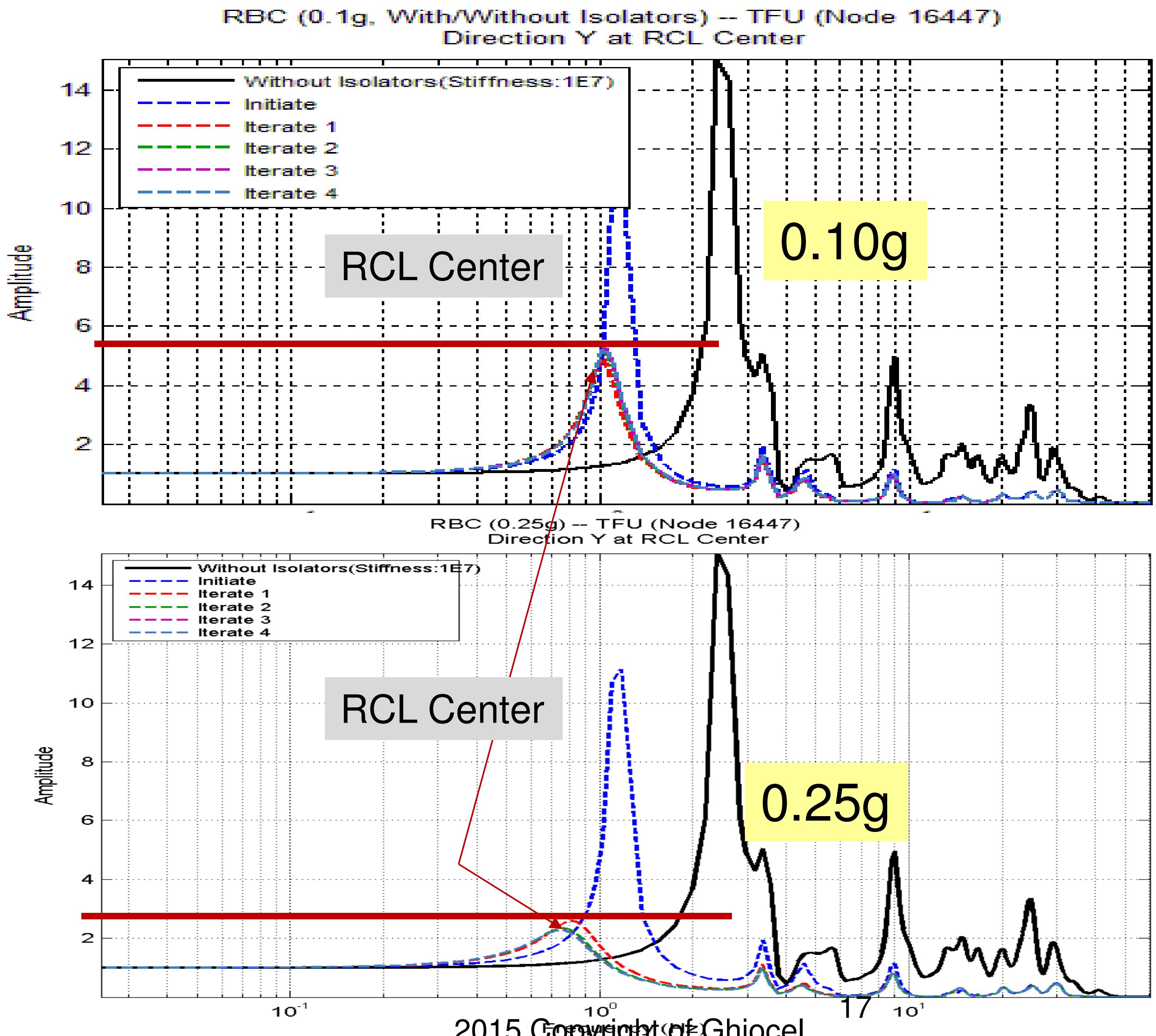


0.10g Input

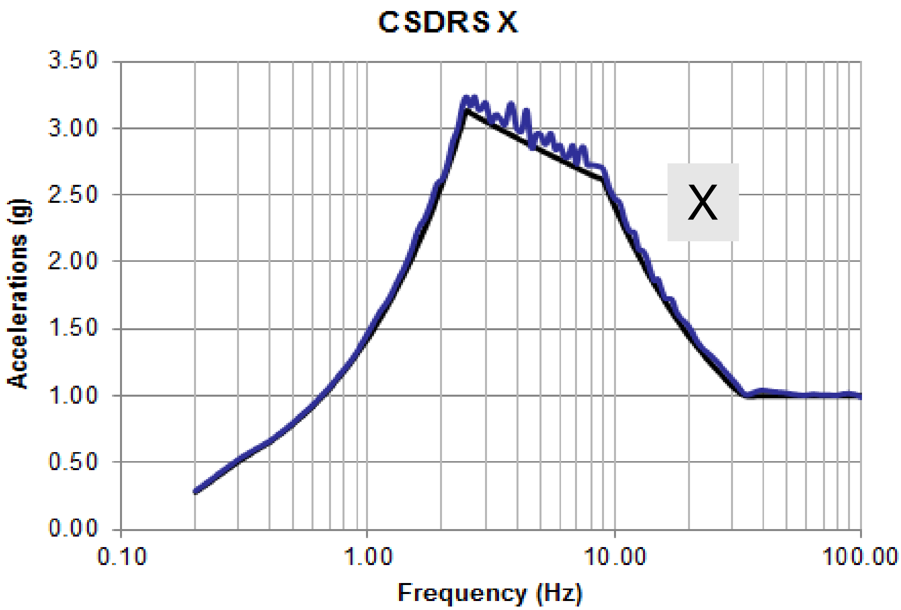


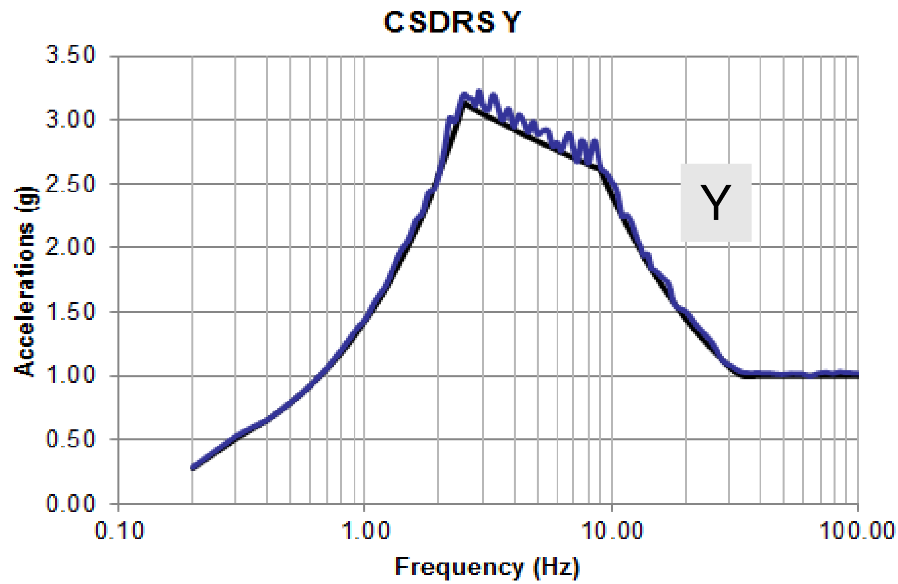
0.25g Input

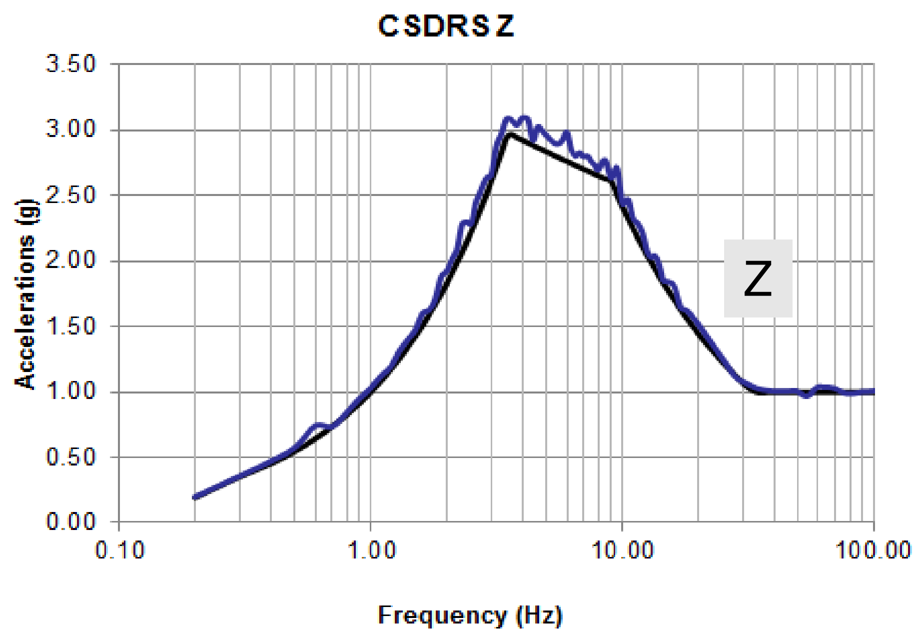
Equivalent Linear Iteration Convergence in ATF



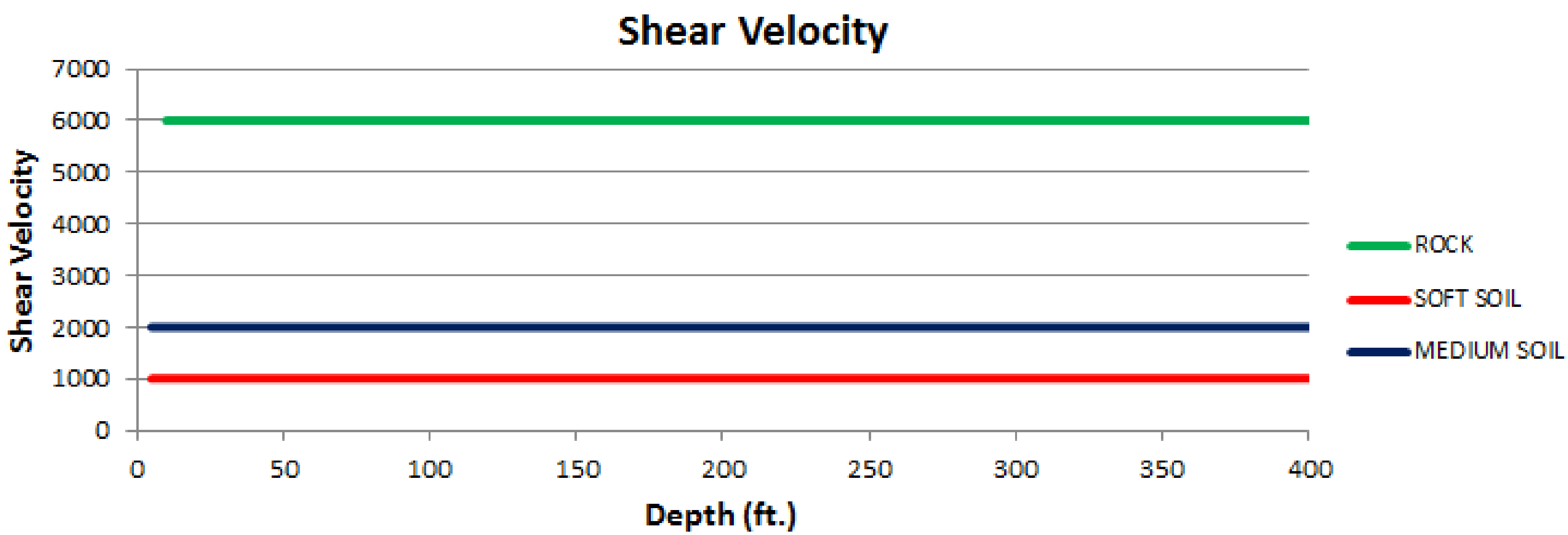
Seismic Input: 0.30g RG 1.60 Seismic Input at Surface

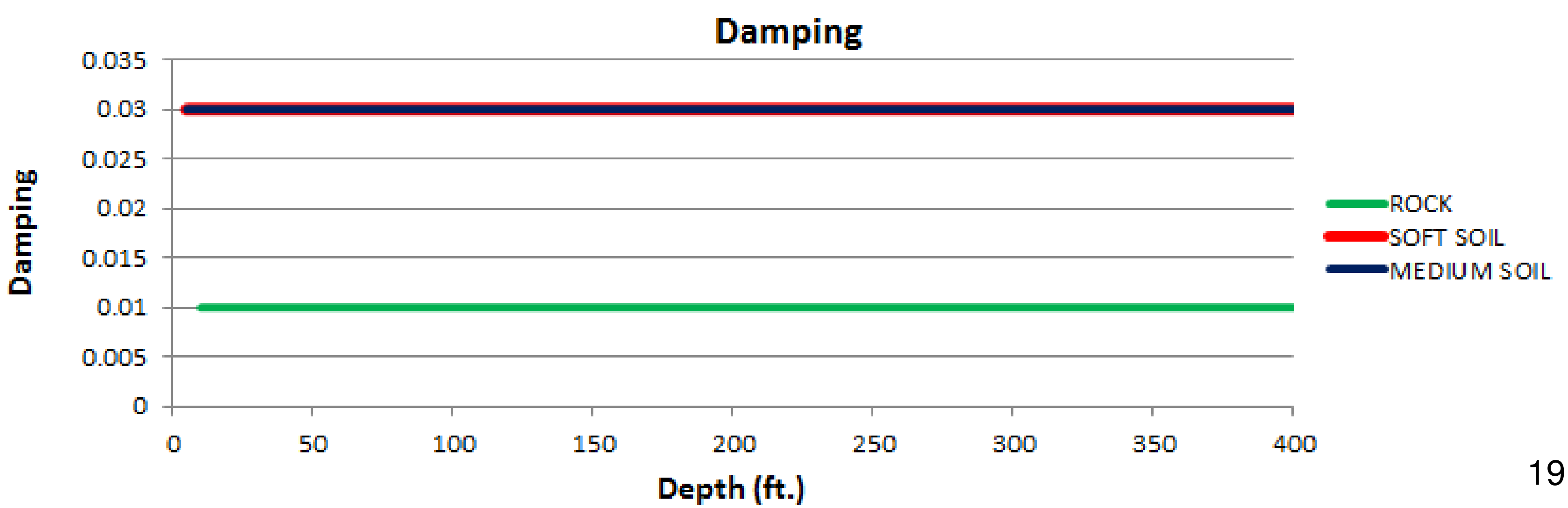






Soil Profiles: Soft Soil (Vs=1,000fps), Rock (Vs = 6000 fps), and Medium Soil (Vs = 2,000 fps)



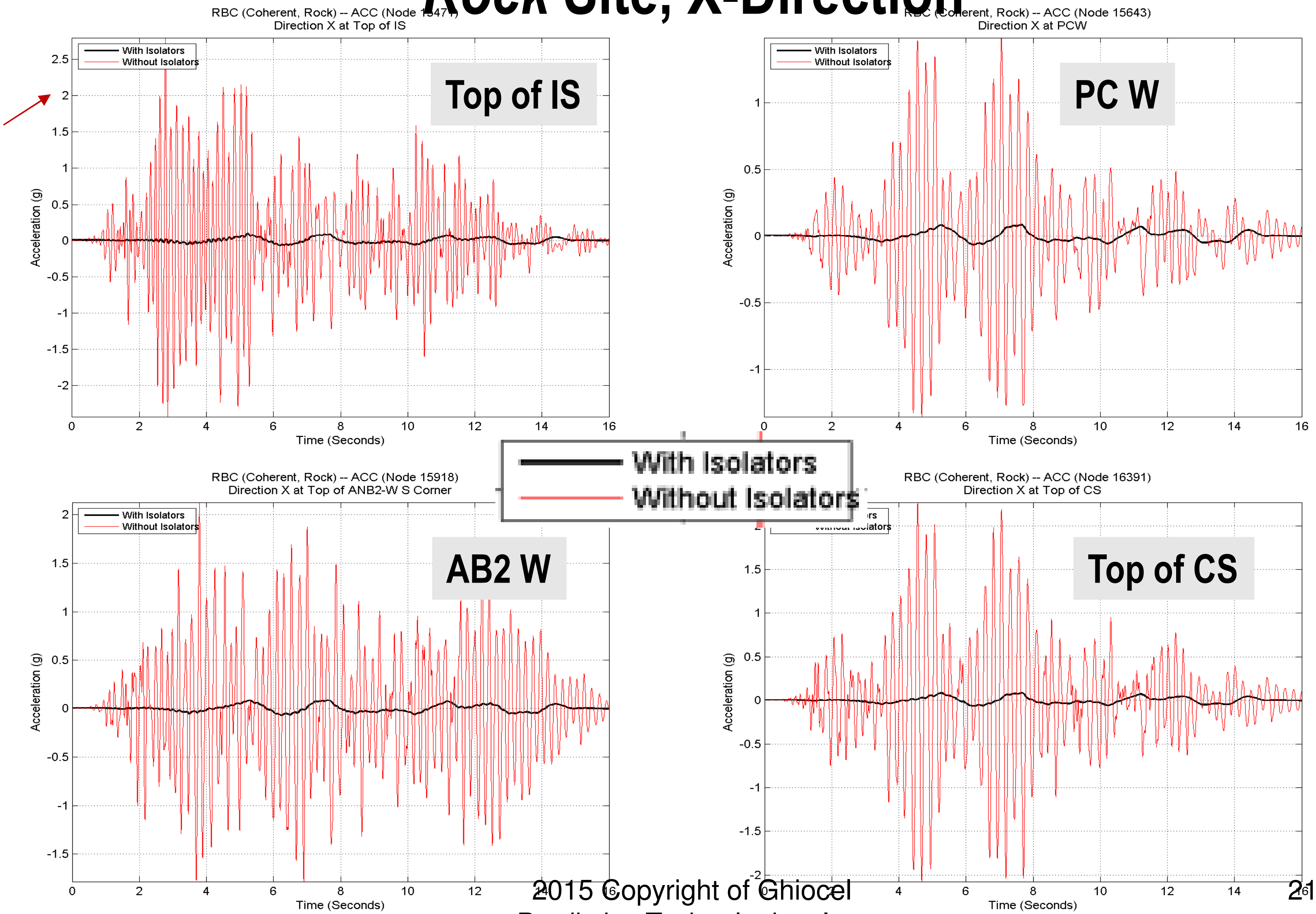


Case Study 1: *Coherent Input*

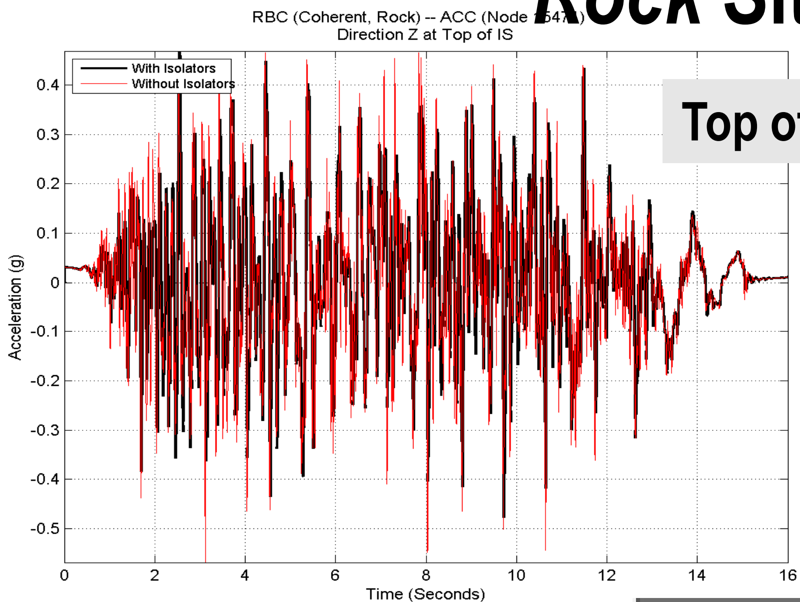
Base-Isolated NI Complex Behavior
for Rock Site (Vs=6000 fps) and Soft Soil Site (Vs=1000fps)

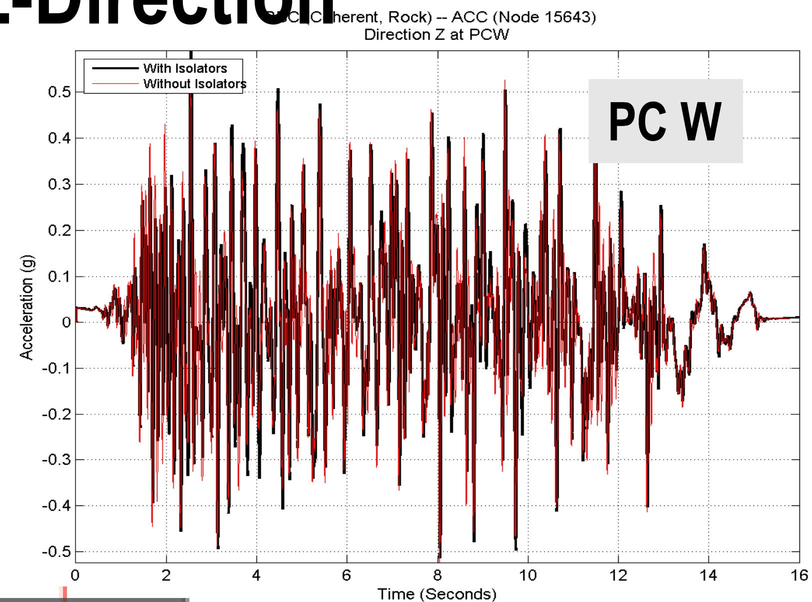
Comparisons for NI complex with and without LRB isolators for accelerations and ISRS

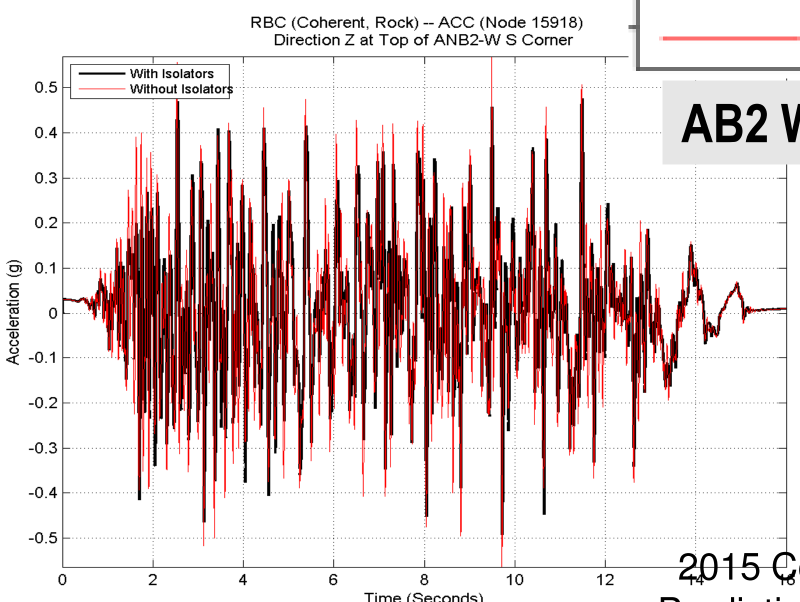
Accelerations in NI Complex With and Without Isolators
Rock Site, X-Direction

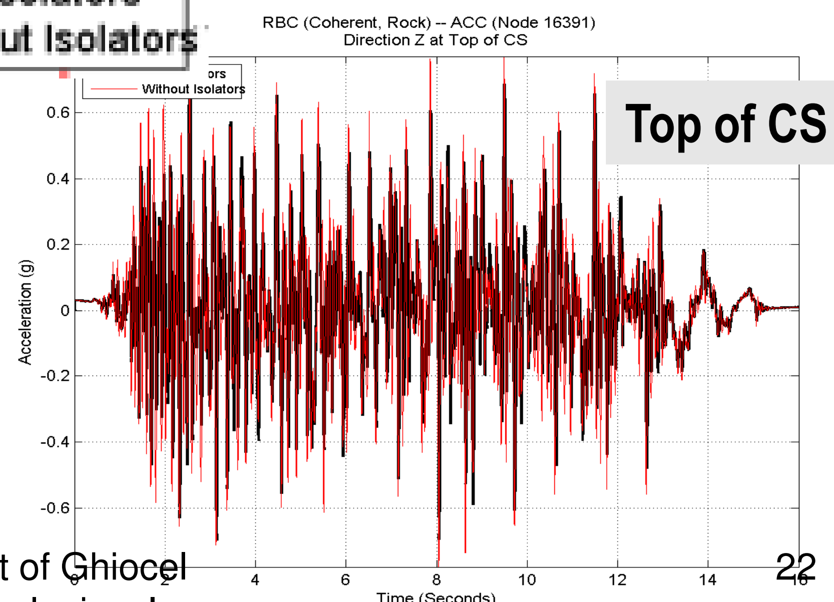


Accelerations in NI Complex With and Without Isolators
Rock Site, Z-Direction



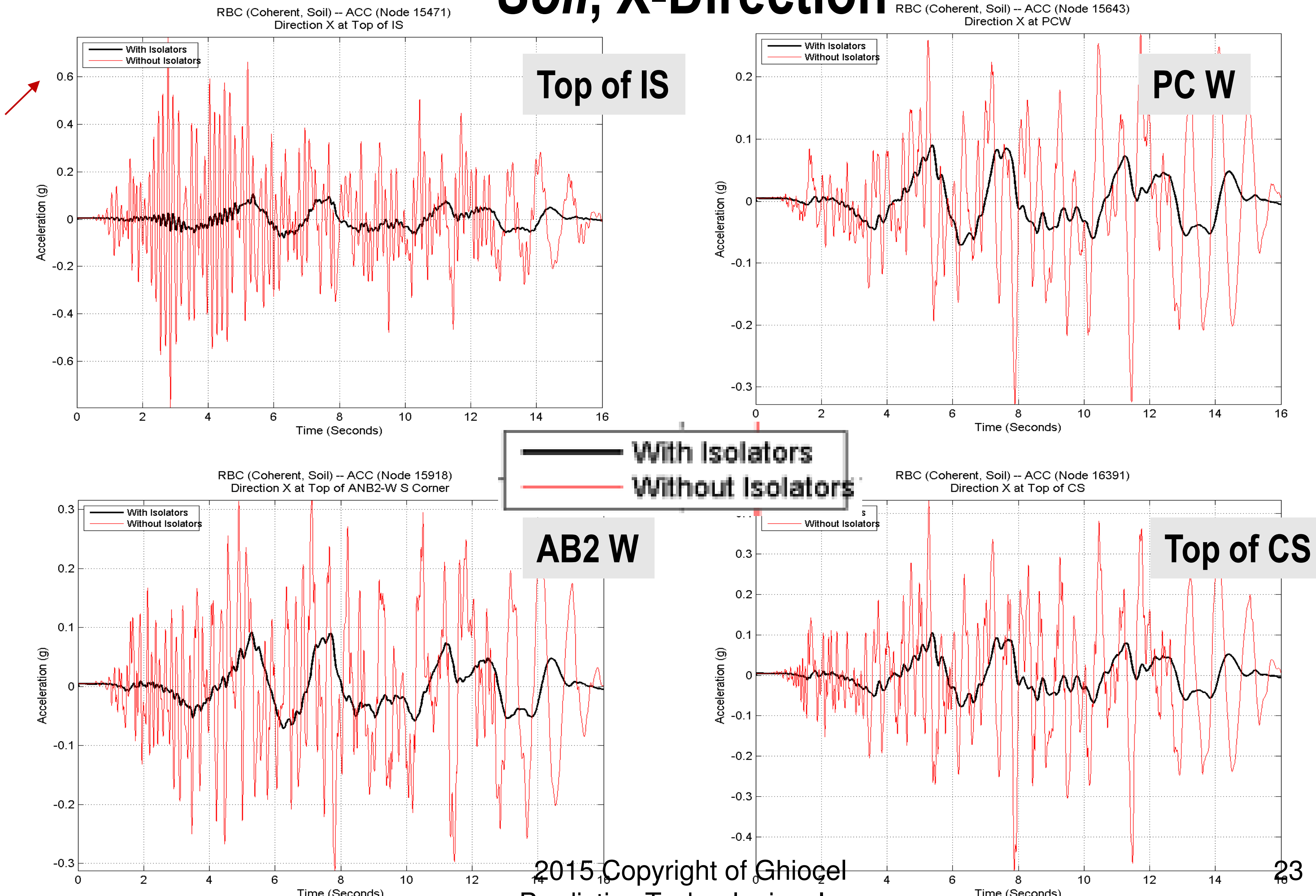




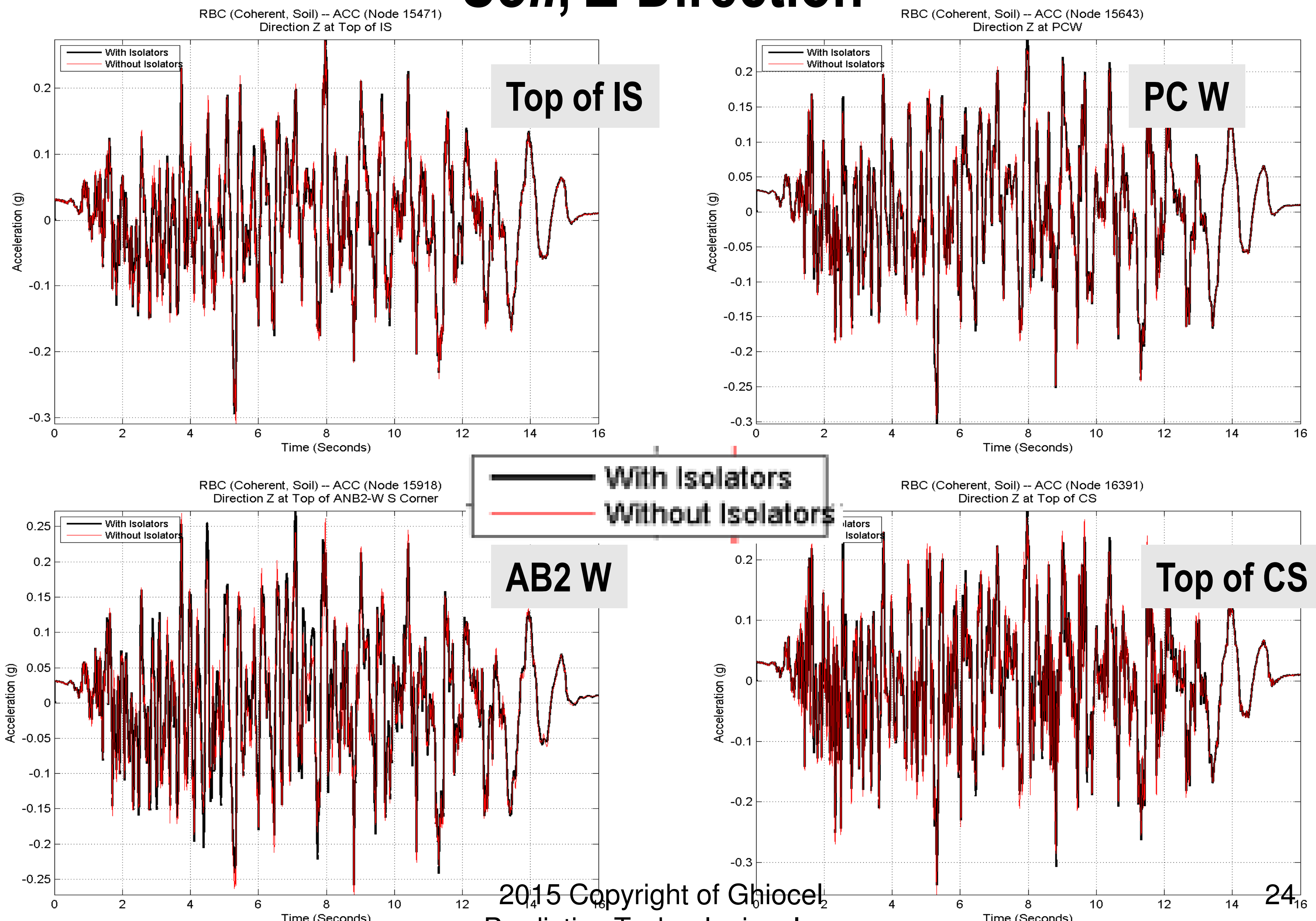


With Isolators
Without Isolators

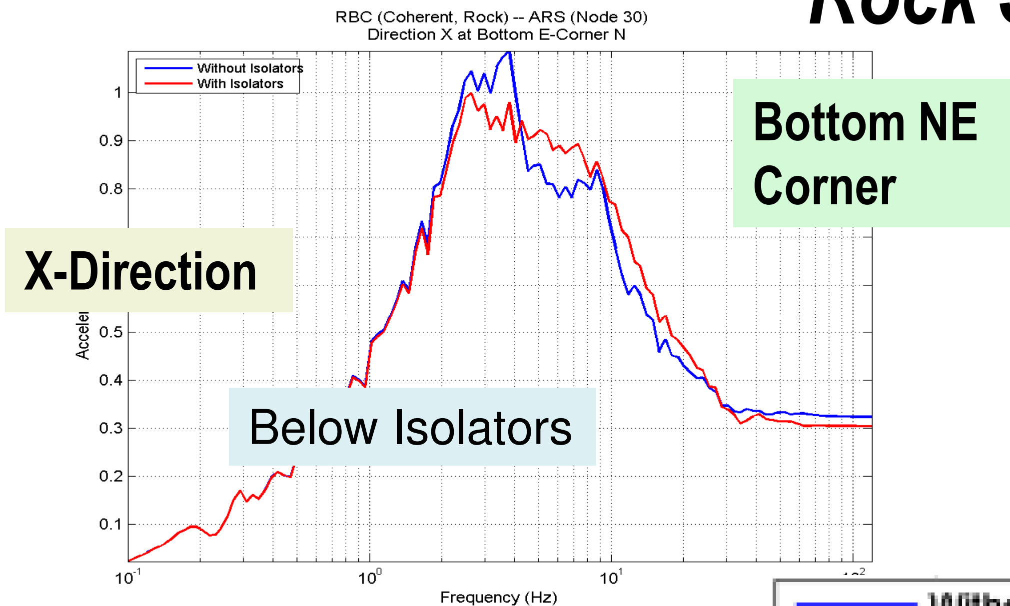
Accelerations in NI Complex With and Without Isolators
Soil, X-Direction

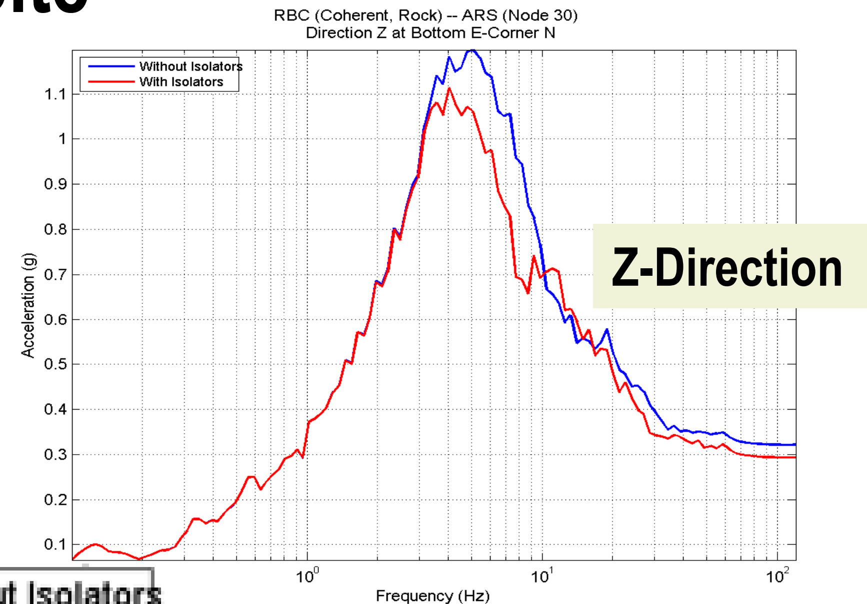


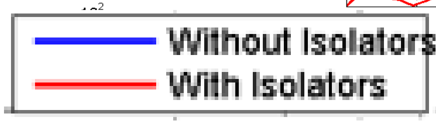
Accelerations in NI Complex With and Without Isolators
Soil, Z-Direction

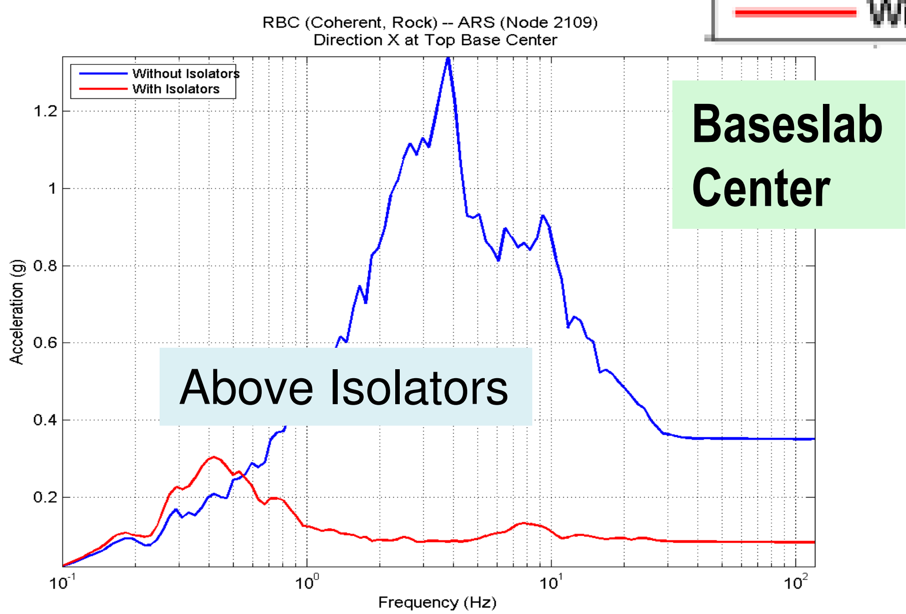


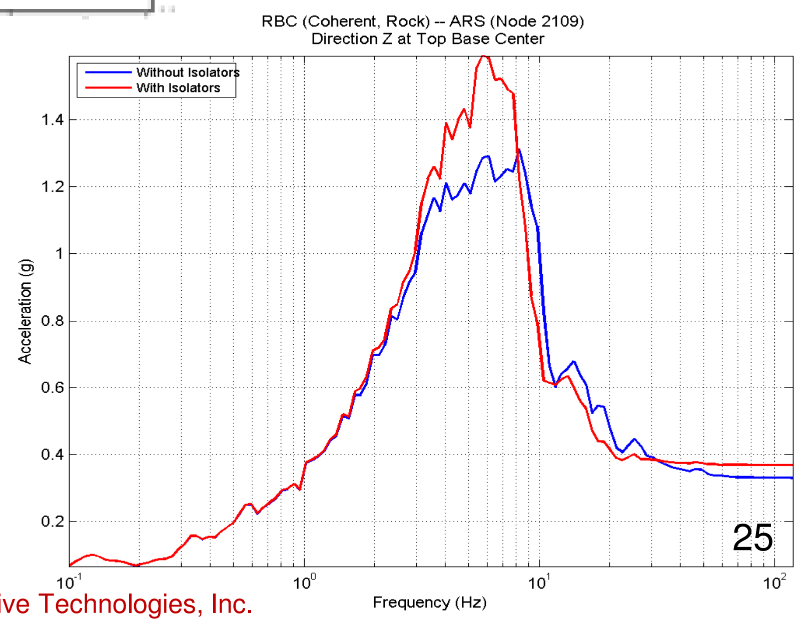
ARS in NI Complex With and Without Isolators, *Rock* Site



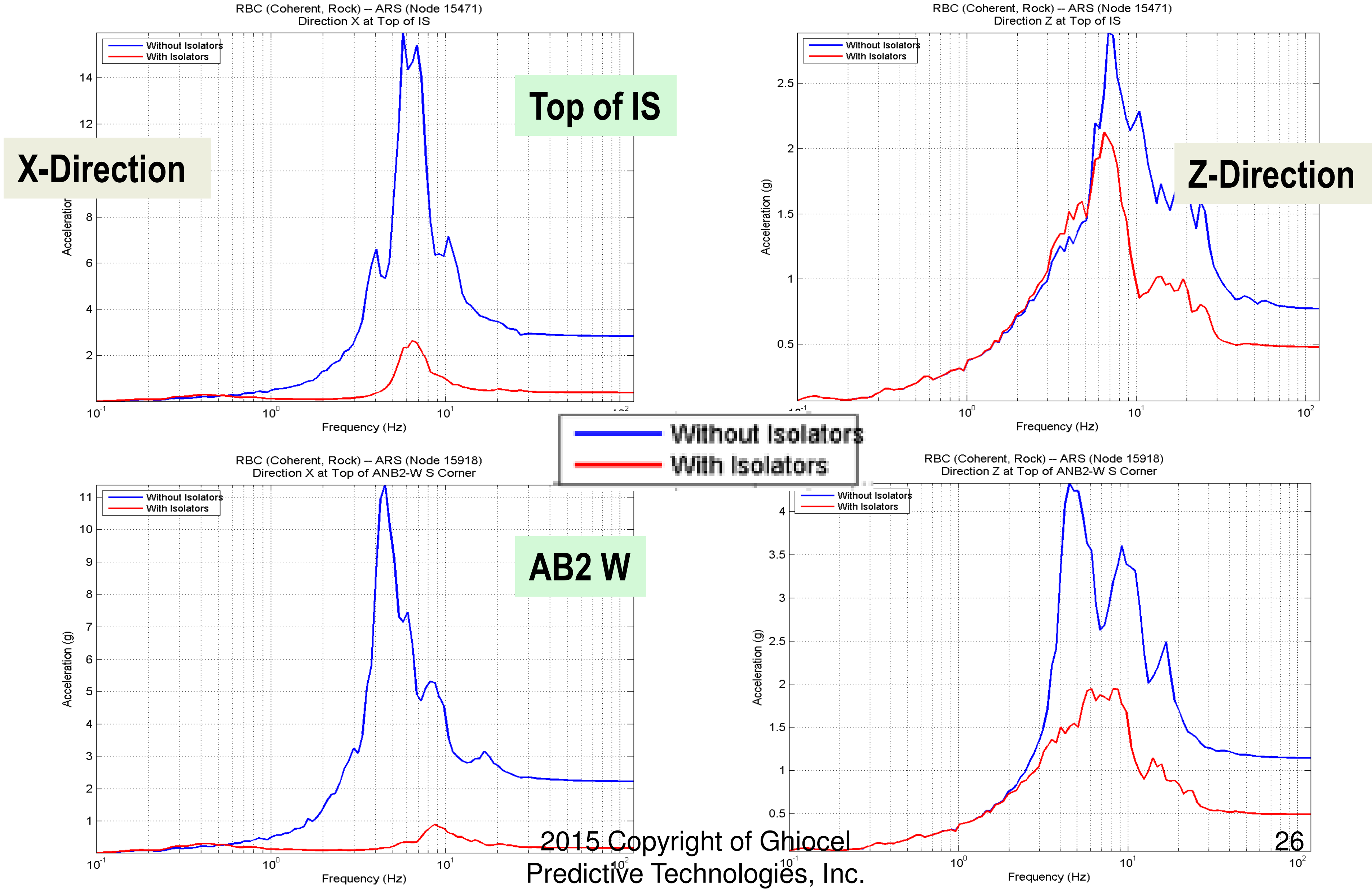




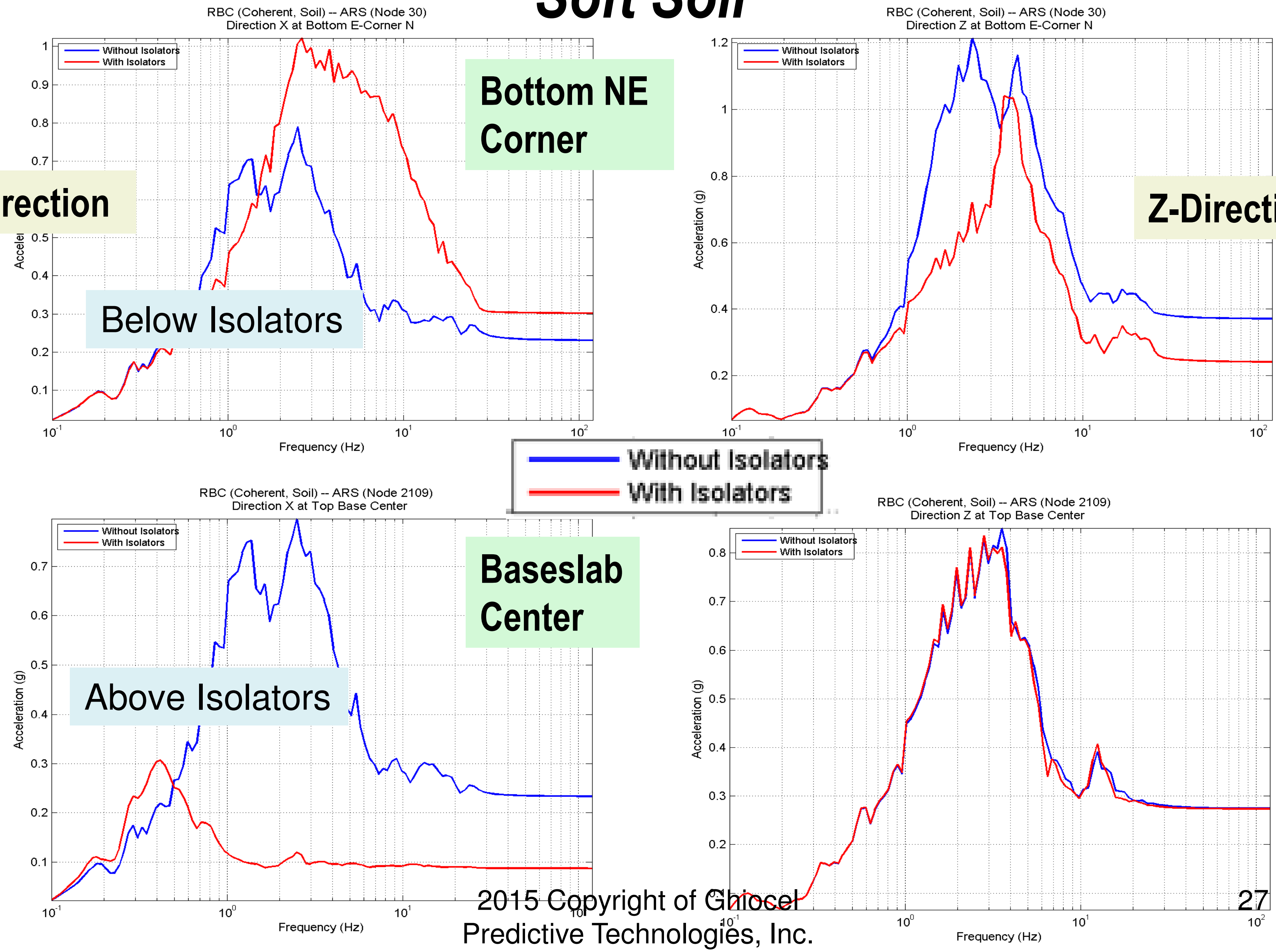




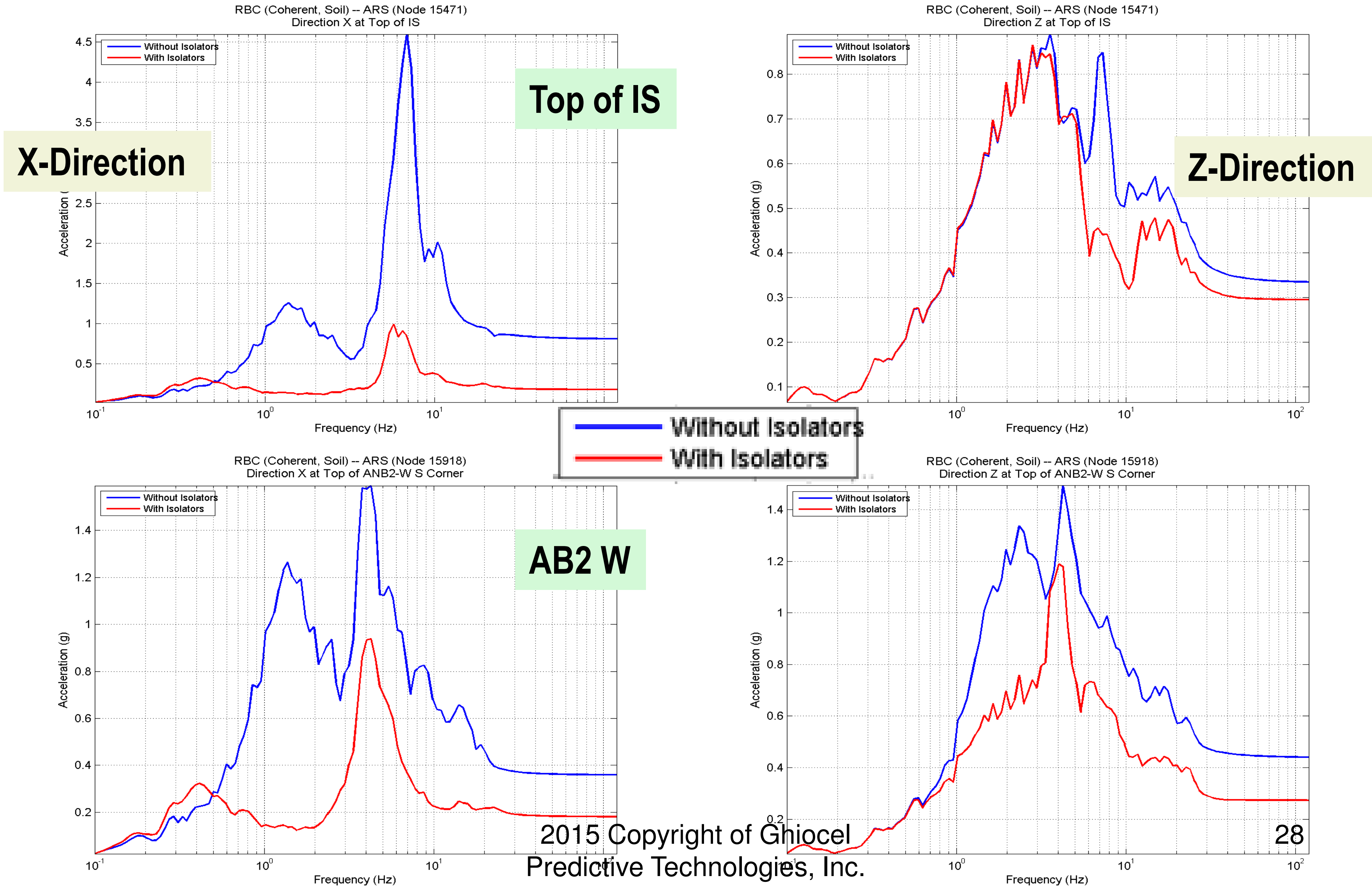
ARS in NI Complex With and Without Isolators, *Rock* Site



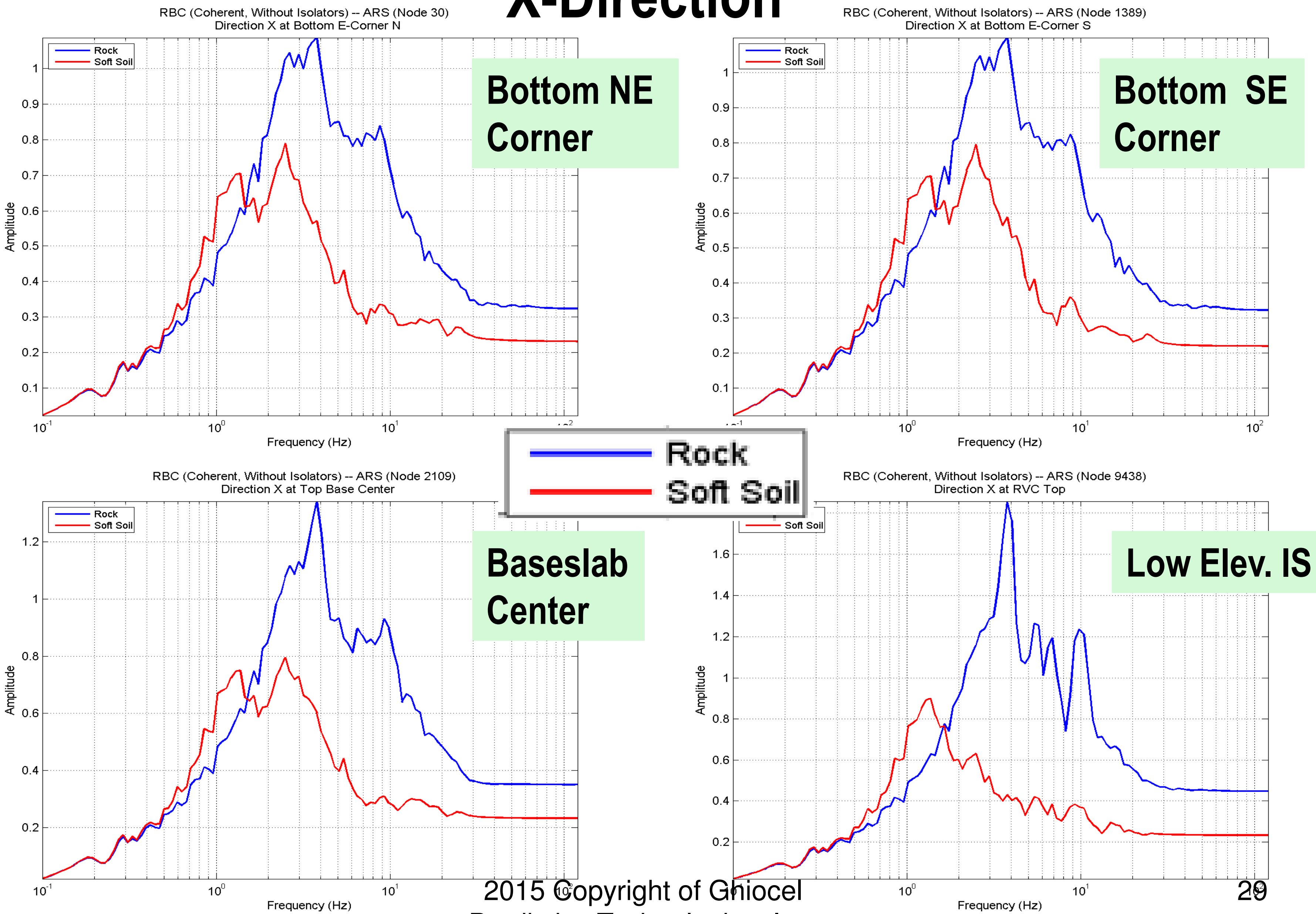
ARS in NI Complex With and Without Isolators, *Soft Soil*



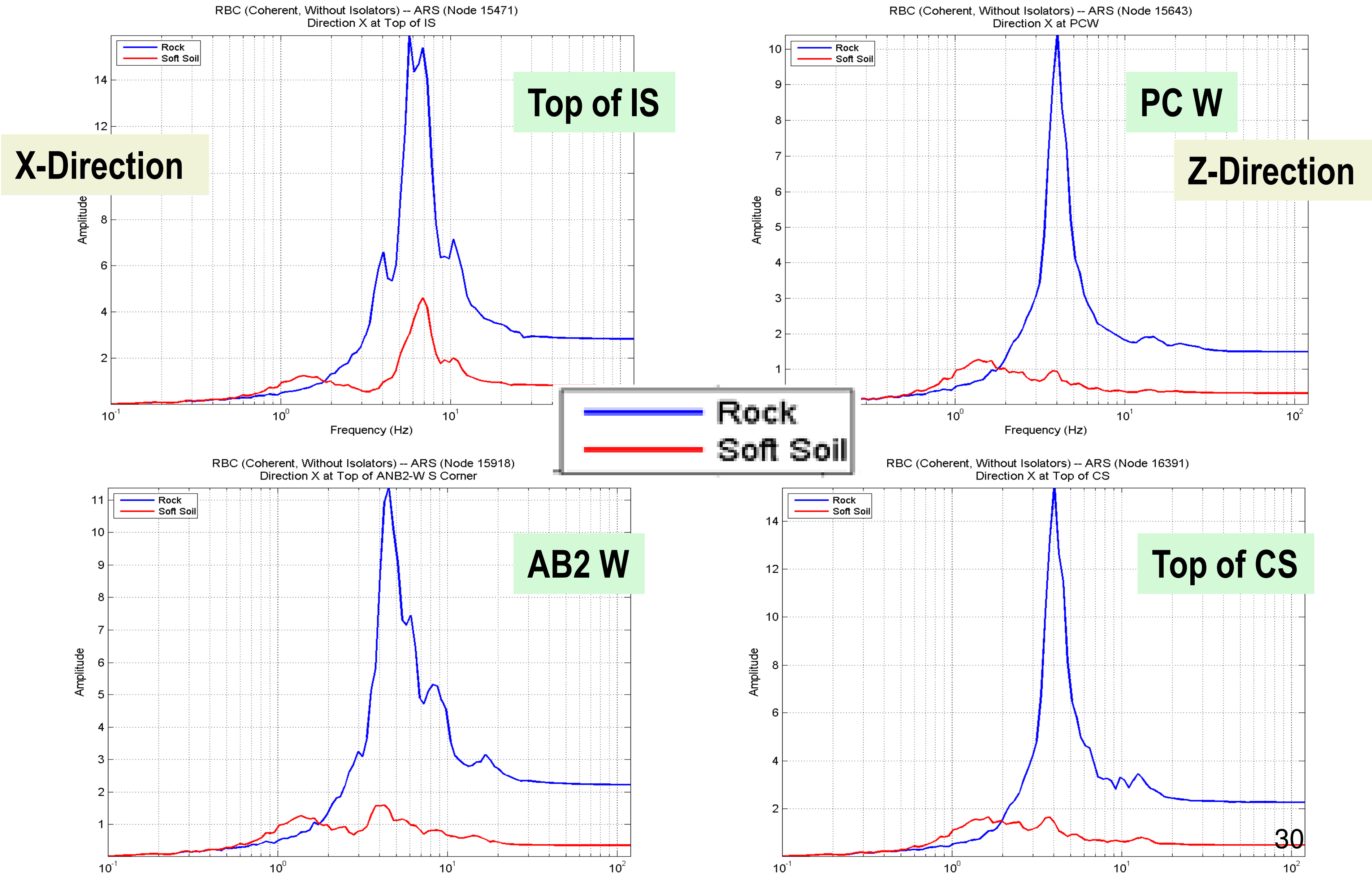
ARS in NI Complex With and Without Isolators, *Soft Soil*



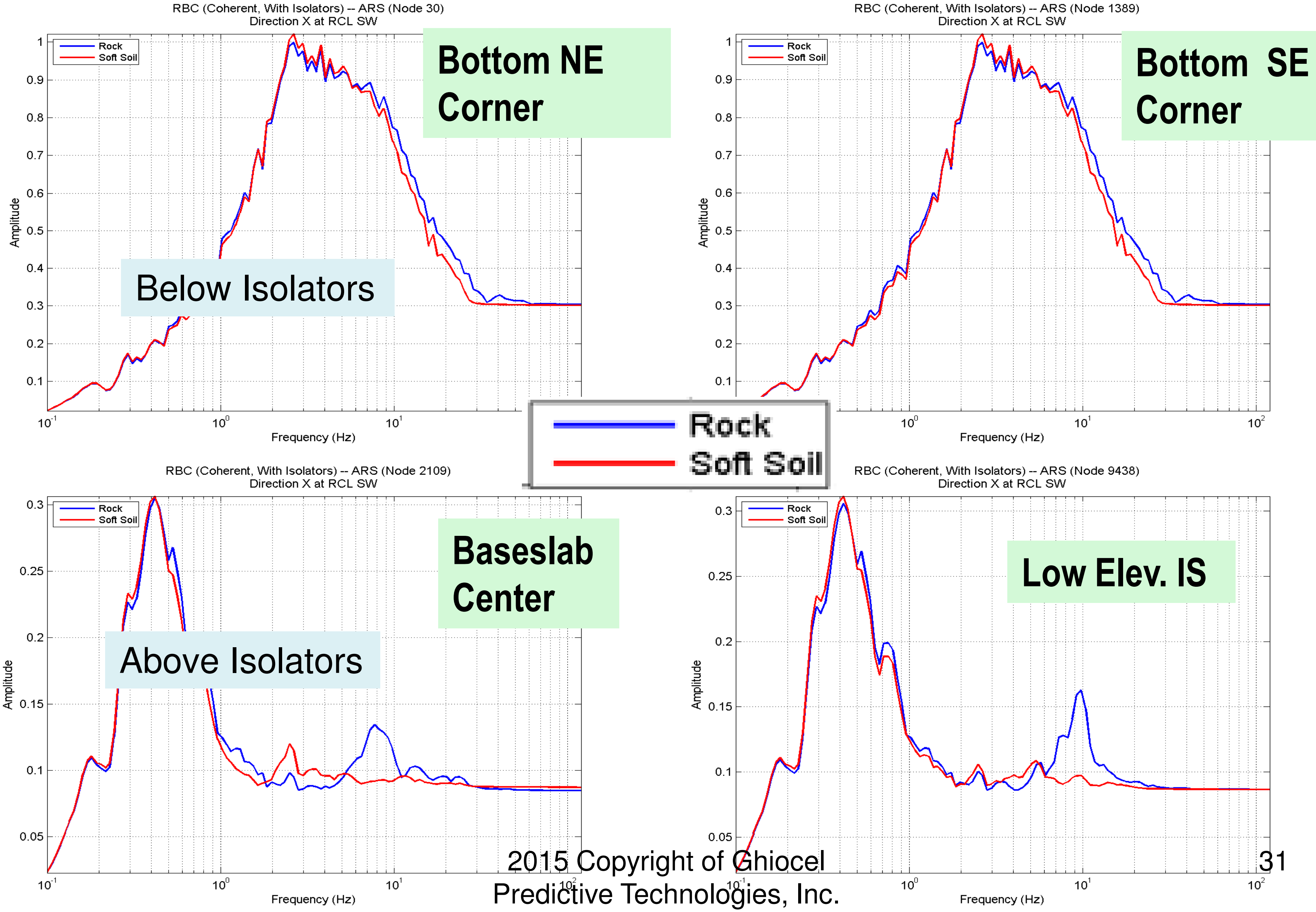
ARS in NI Complex *Without Isolators* for Rock vs. Soil X-Direction



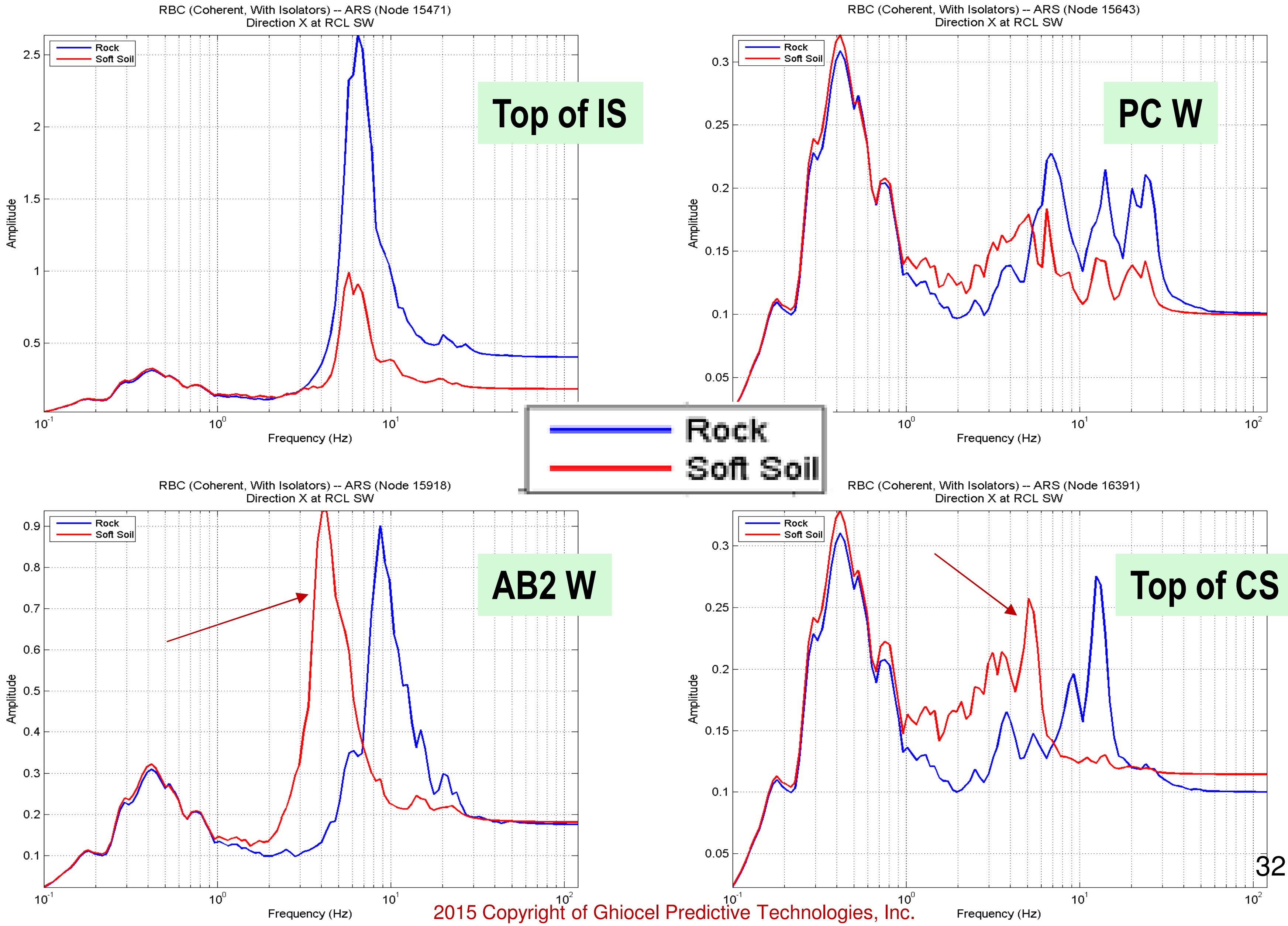
ARS in NI Complex *Without Isolators* for Rock vs. Soil X-Direction



ARS in NI Complex *With Isolators* for Rock vs. Soil X-Direction



ARS in NI Complex *With Isolators* for Rock vs. Soil X-Direction



Case Study 2: Coherent vs. Incoherent Inputs

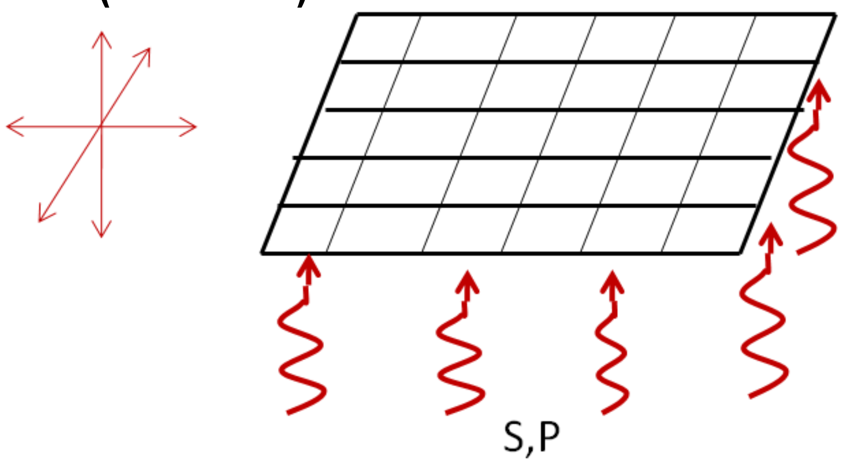
Base-Isolated NI Complex Behavior
for Coherent and Incoherent Motions
for the Medium Soil Site (Vs = 2,000 fps);

Used 2007 EPRI/Abrahamson Incoherency Model
for Soil Sites including wave passage with Va = 2km/s

Comparisons for accelerations, ISRS, relative displacements and LRB forces

Coherent vs. Incoherent Wave Propagation Models

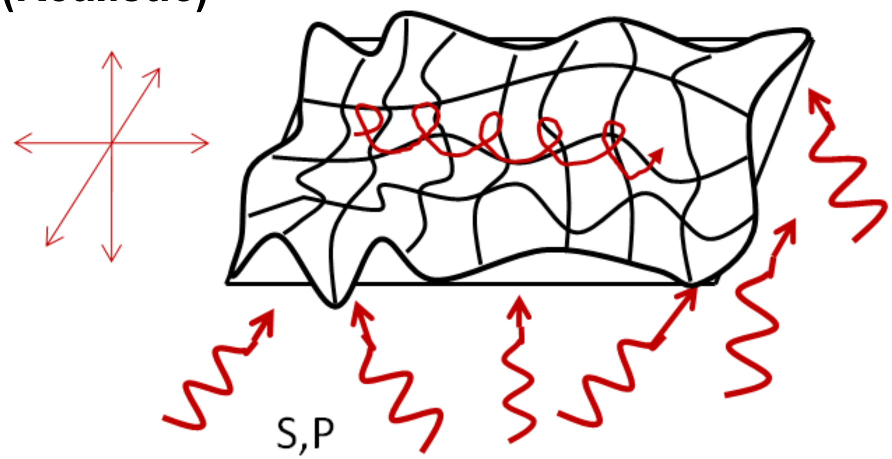
3D Rigid Soil Surface Motion (Idealized)



1D Wave Propagation Analytical Model
(**Coherent** – Simplified Modeling)

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

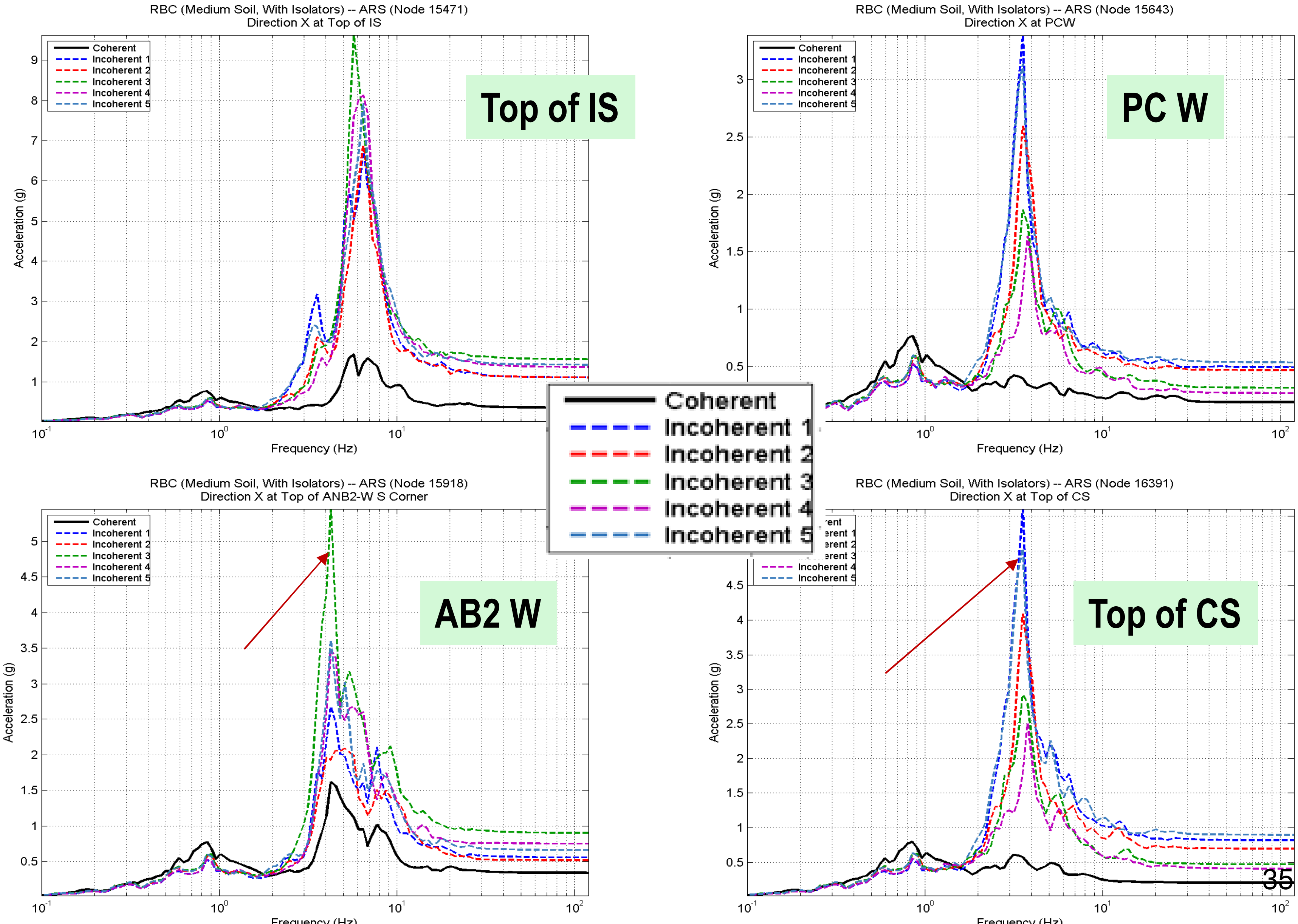
3D Random Wave Field Soil Motion (Realistic)



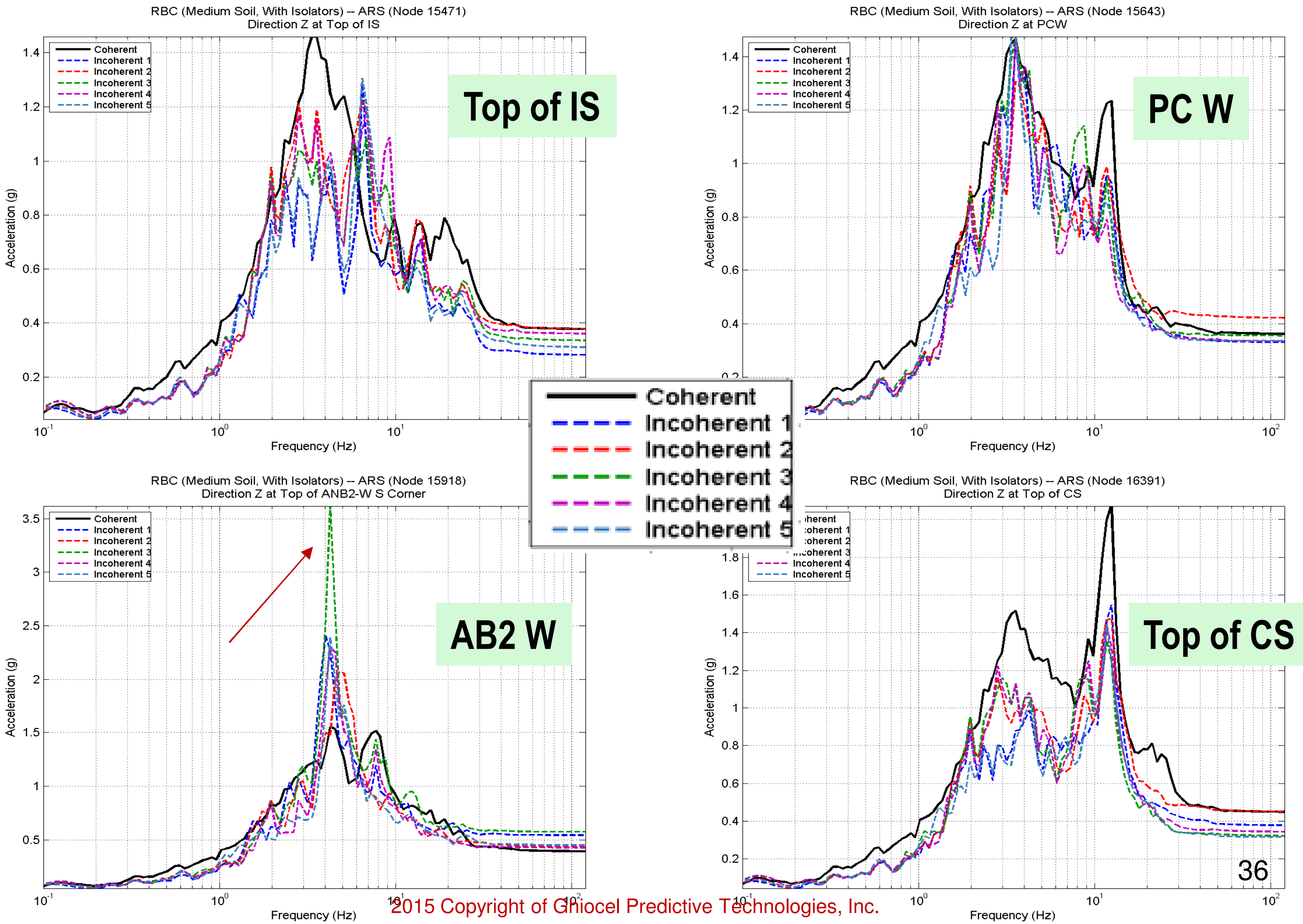
3D Wave Propagation Data-Based Model
(**Incoherent** – Database-Driven Modeling)

Includes real field records information, including implicitly motion field heterogeneity, random arrivals of different wave types under random incident angles.

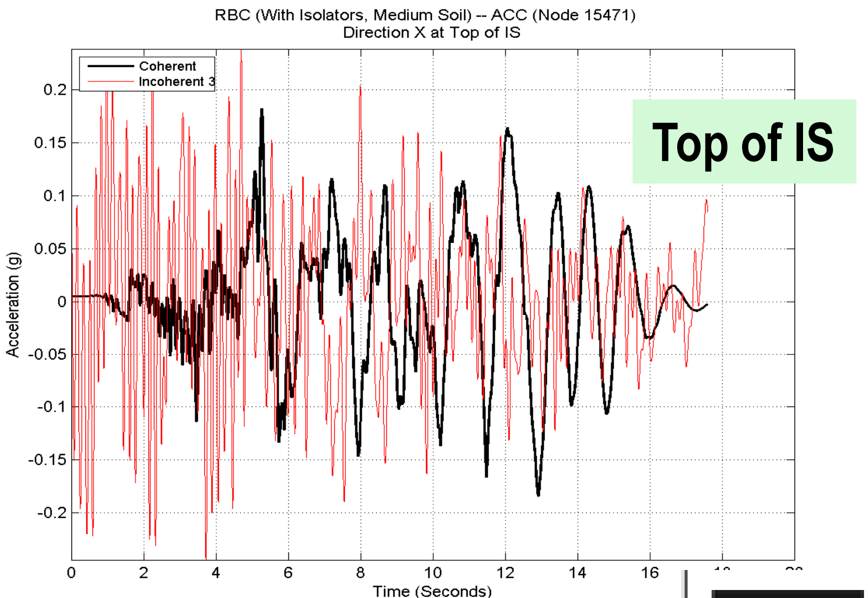
Coherent and Incoherent ARS in NI Complex
With Isolators, Medium Soil, X-Direction

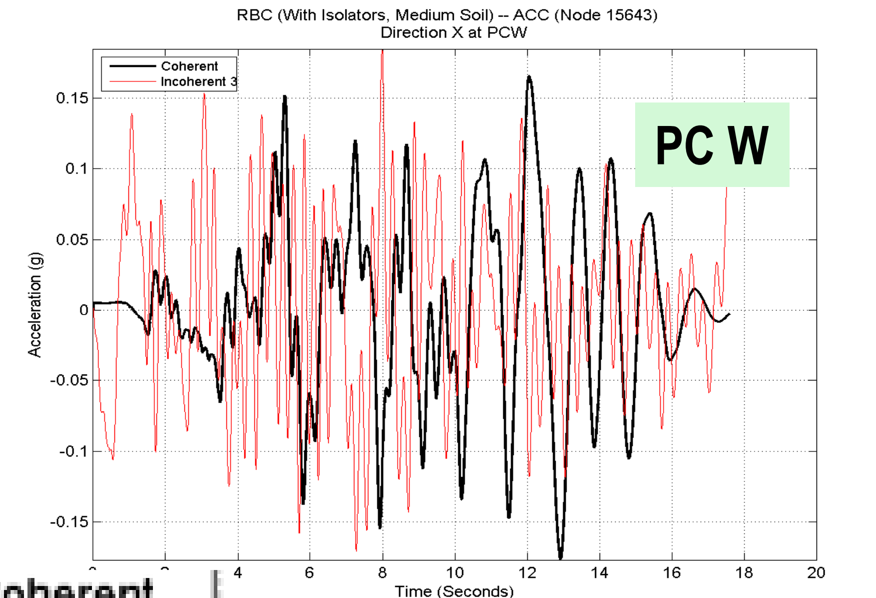


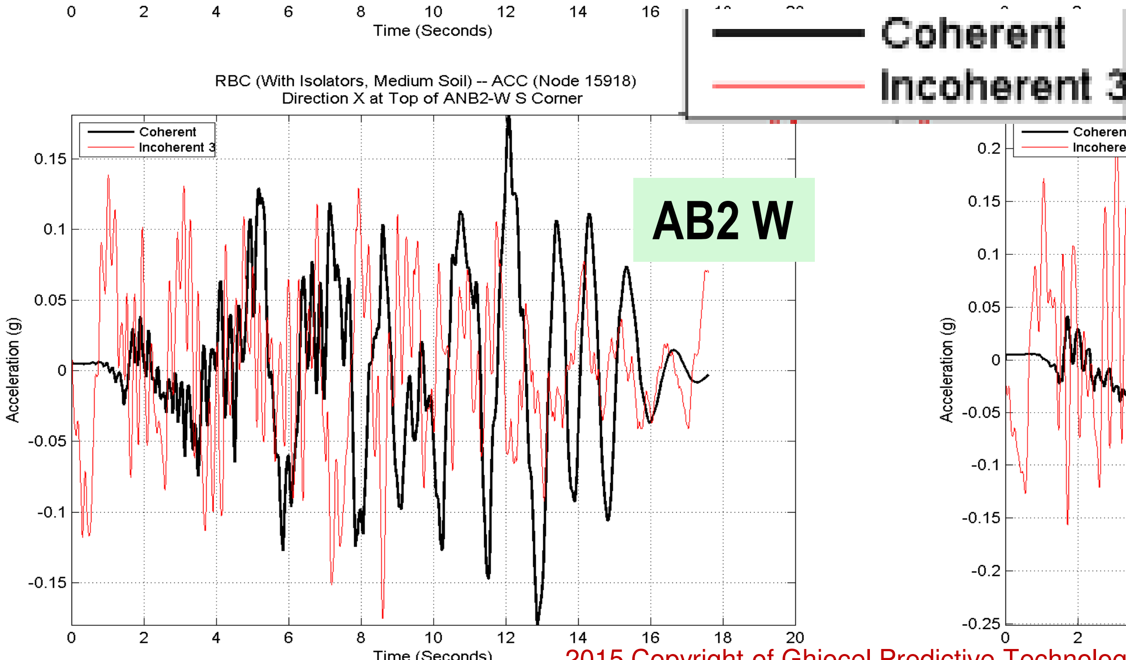
Coherent and Incoherent ARS in NI Complex *With Isolators,* Medium Soil, Z-Direction

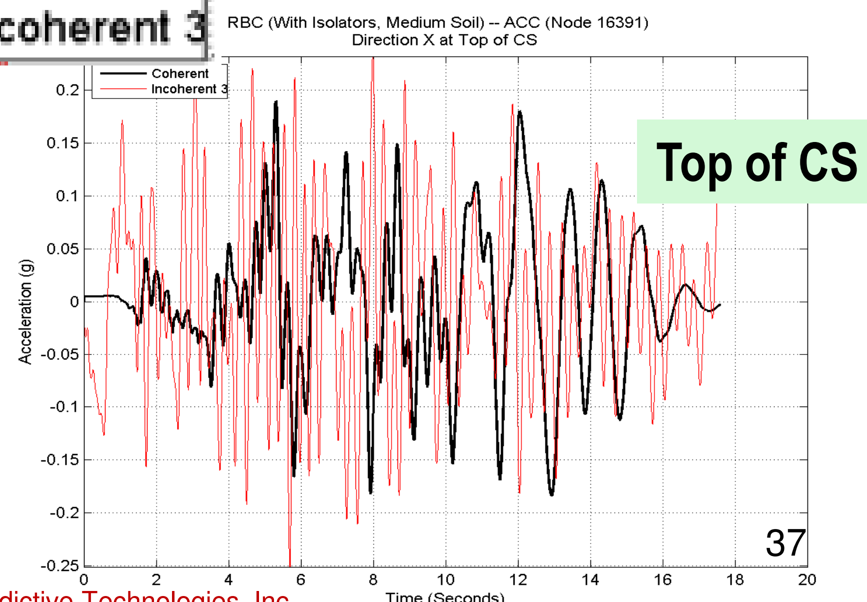


Coherent and Incoherent Accelerations in NI Complex
With Isolators, Medium Soil, X-Direction

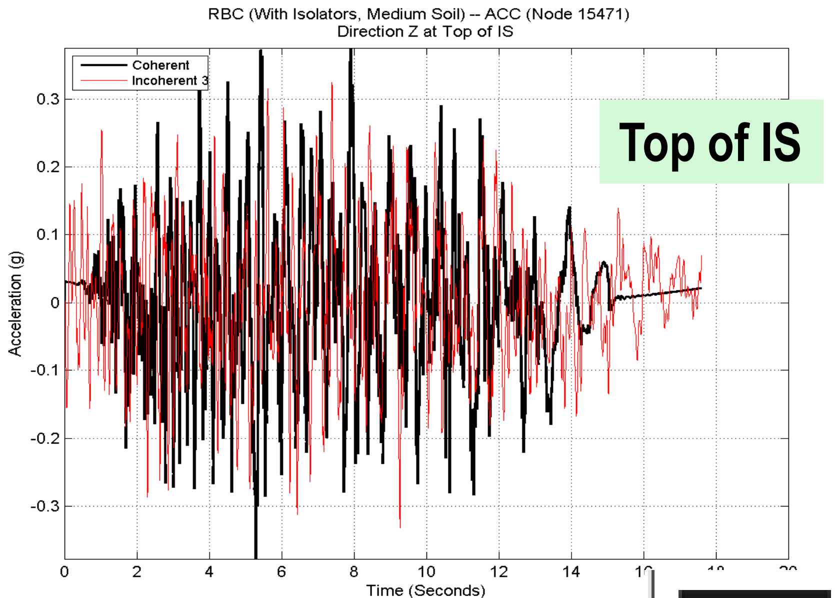


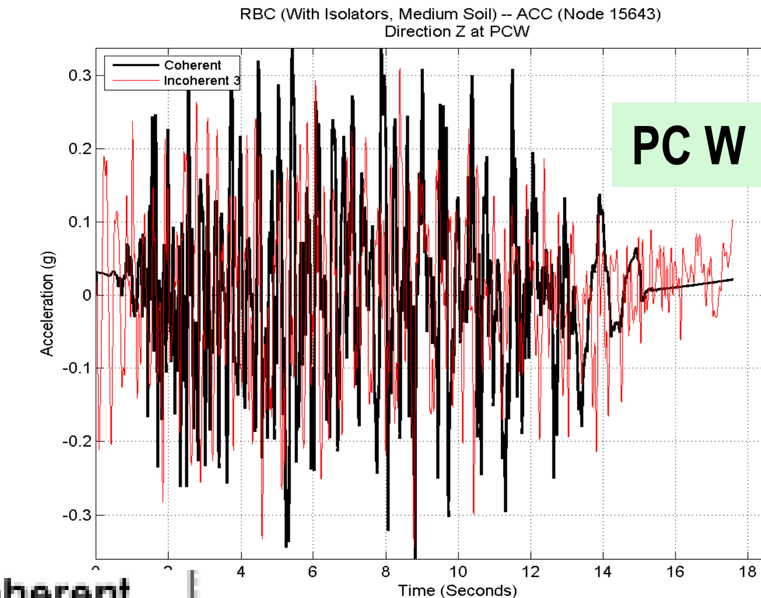


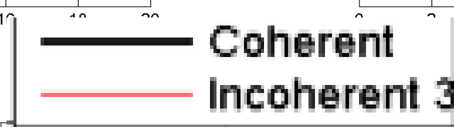


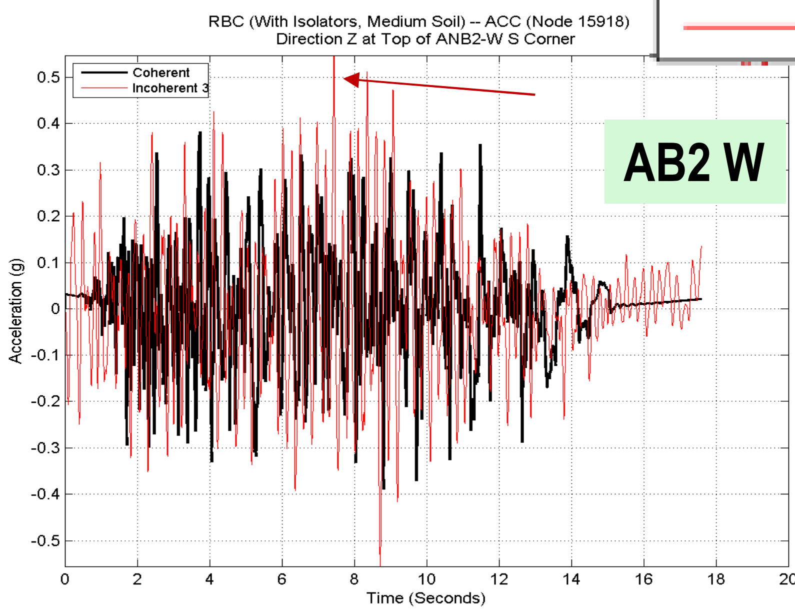


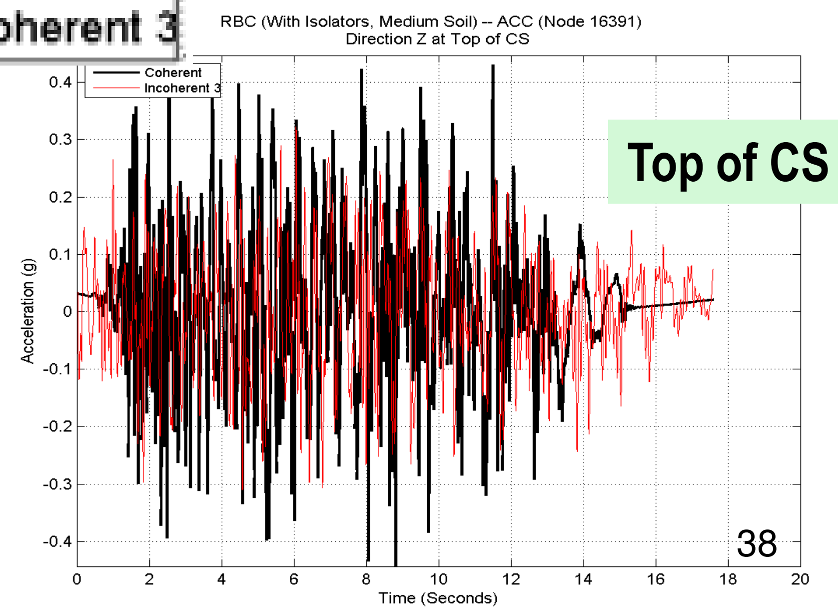
Coherent and Incoherent Acceleration in NI Complex *With Isolators*, Medium Soil, Z-Direction







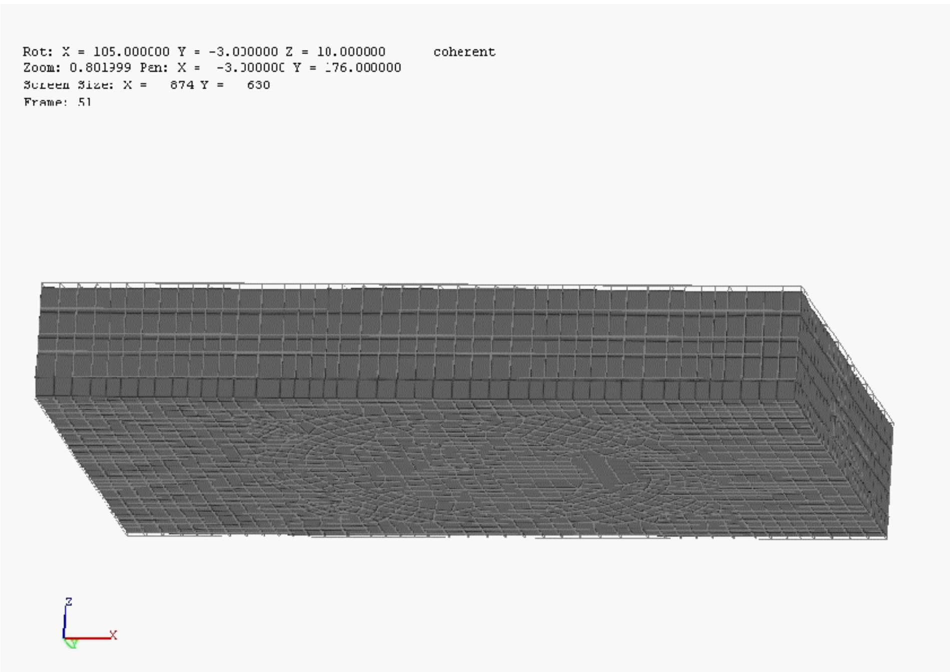




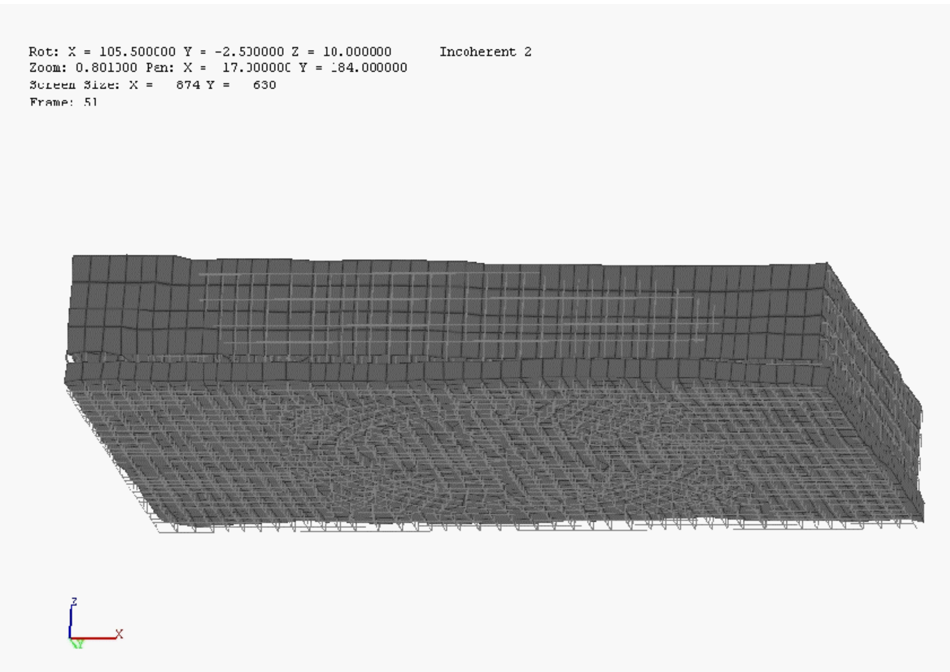
Base-Isolated NI Complex Behavior for Coherent and Incoherent Motions

Accelerations

Coherent



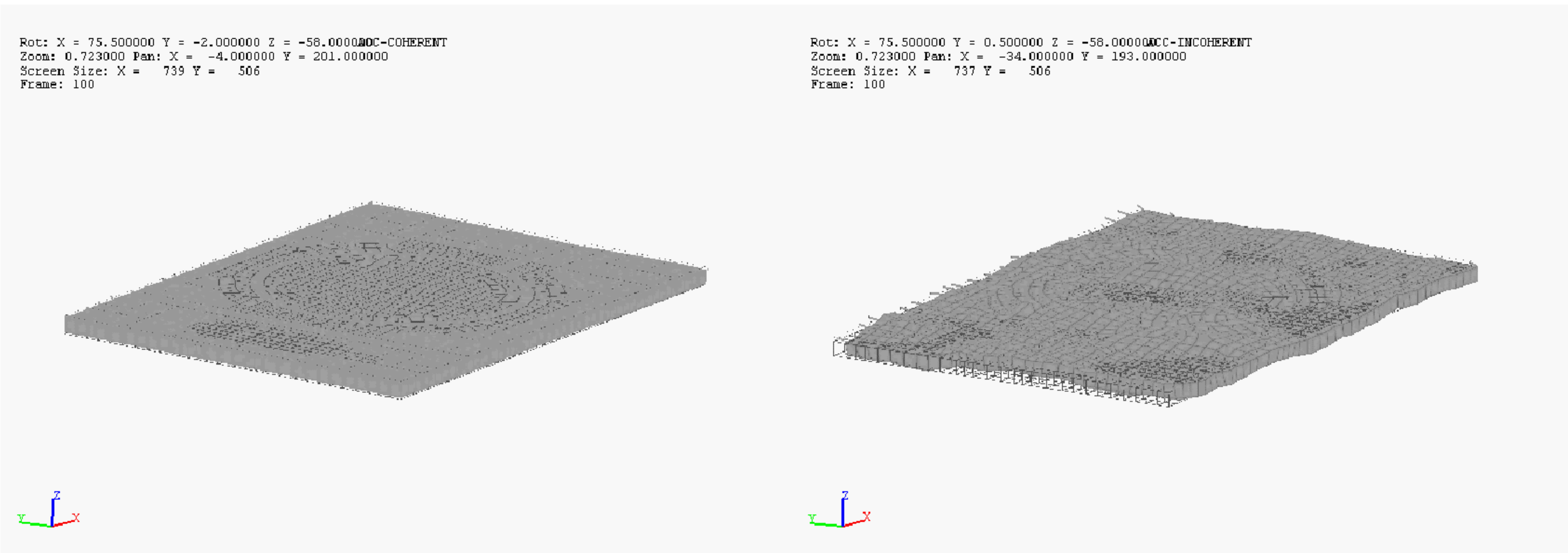
Incoherent



Base-Isolated NI Complex Behavior for Coherent and Incoherent Motions

Accelerations

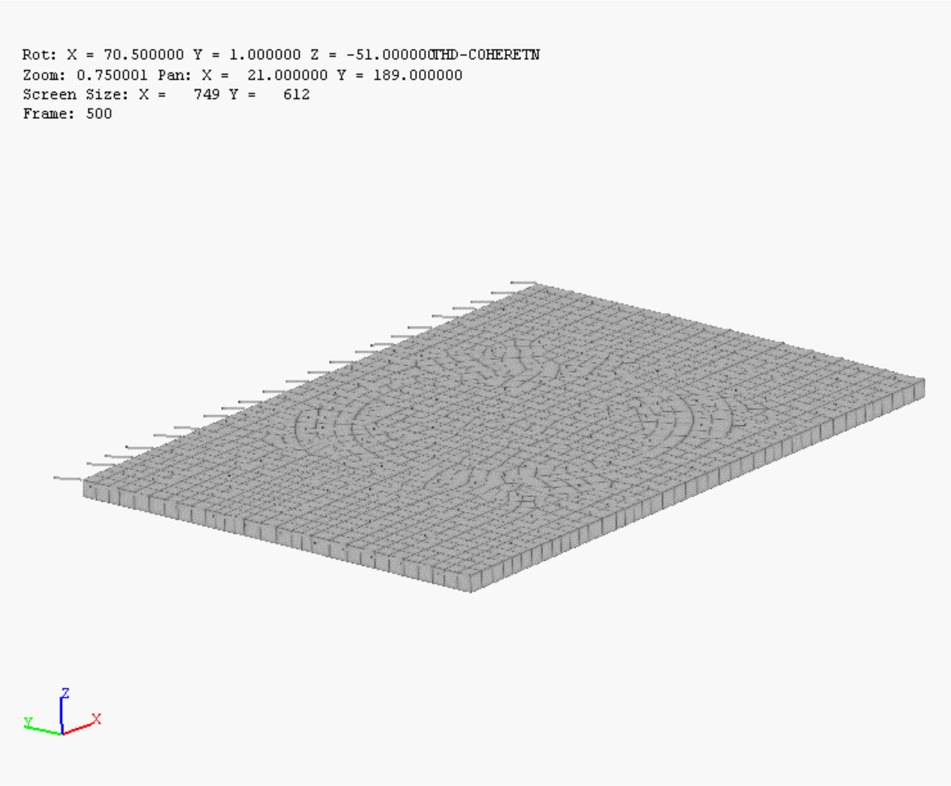
Coherent | Incoherent



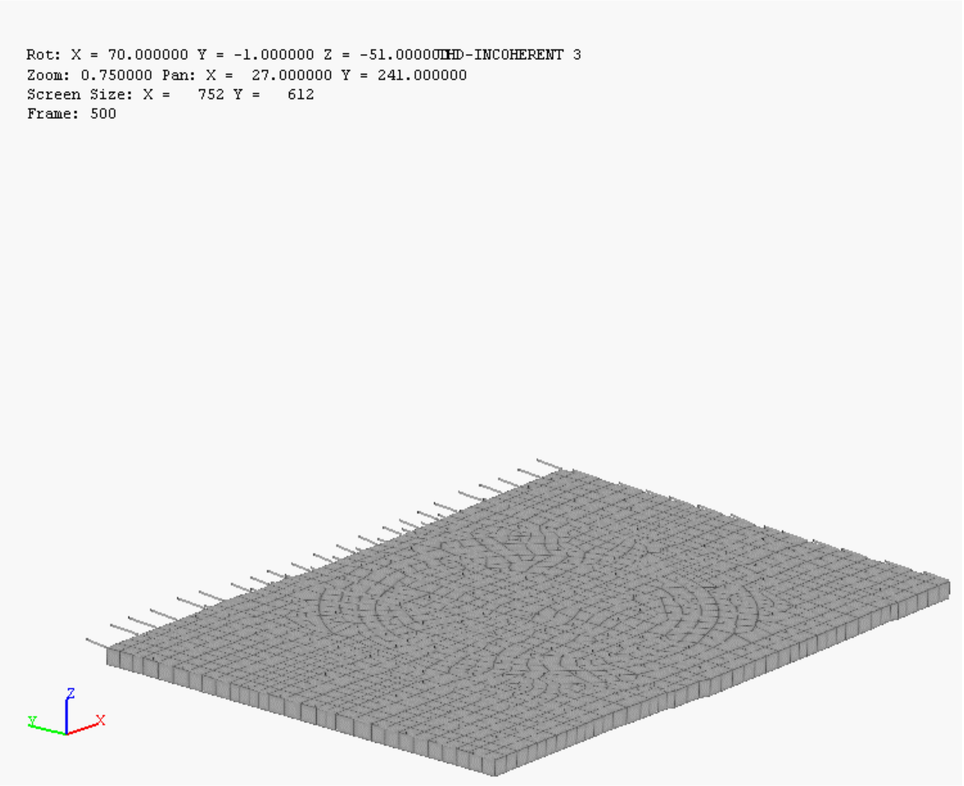
Base-Isolated NI Complex Behavior for Coherent and Incoherent Motions

Relative Displacements wrt Control Motion in Free-Field

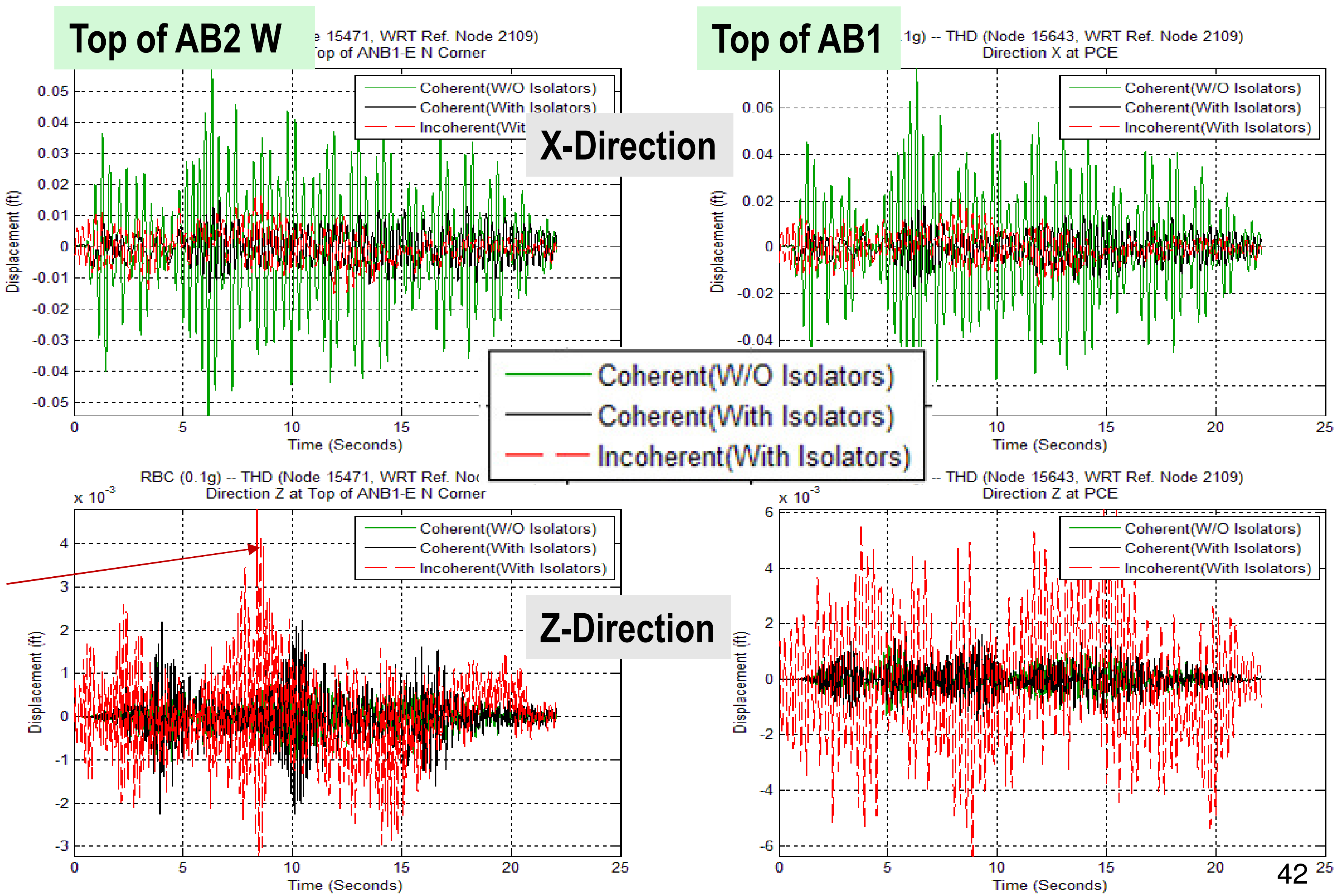
Coherent



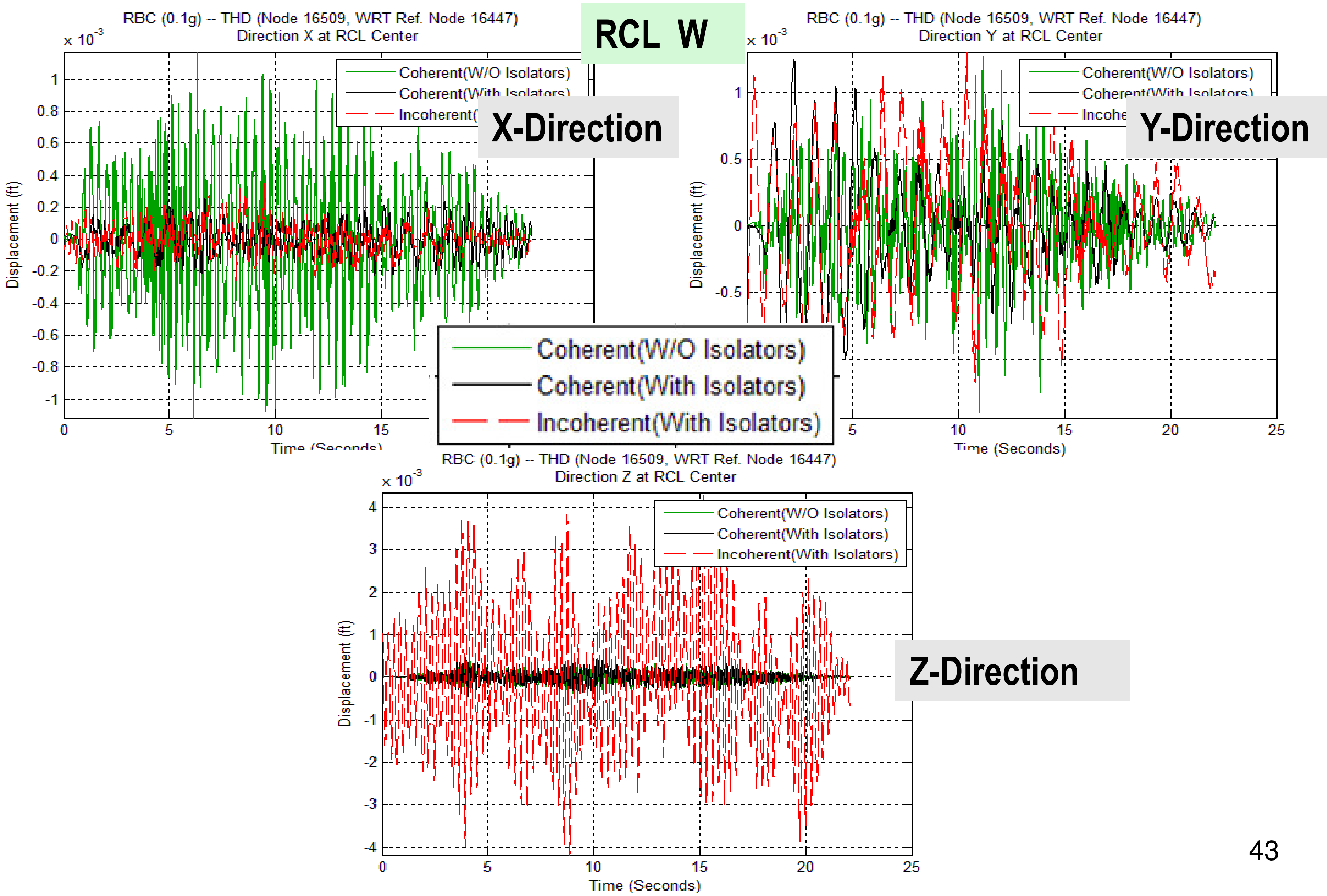
Incoherent



Coherent and Incoherent Structure Displacements wrt Base Center (above), NI *With Isolators*, Medium Soil

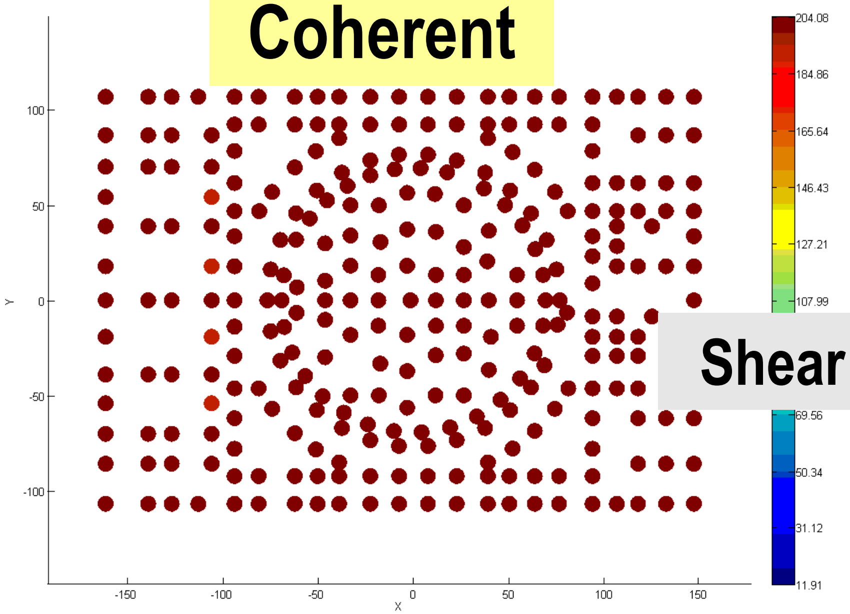


Coherent and Incoherent RCLS Displacements wrt RCL Center Location, NI *With Isolators*, Medium Soil

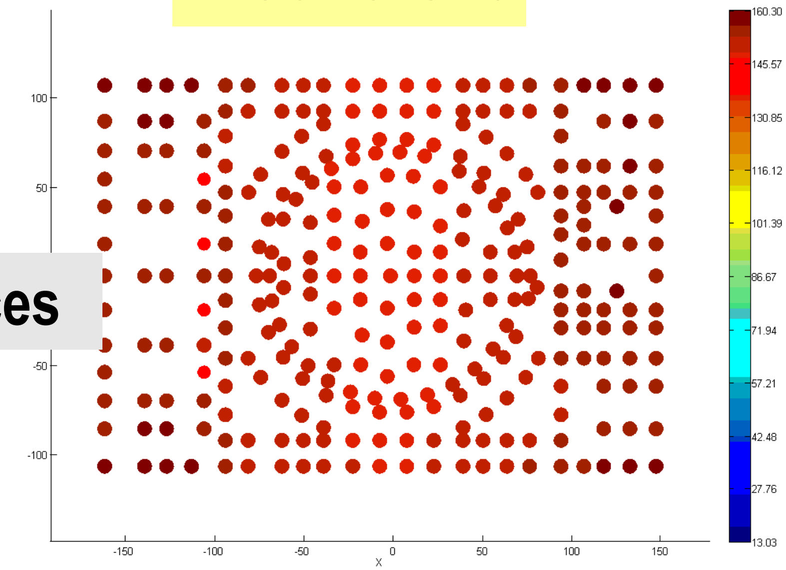


Coherent and Incoherent EQL Forces in LRB Isolators for Medium Soil

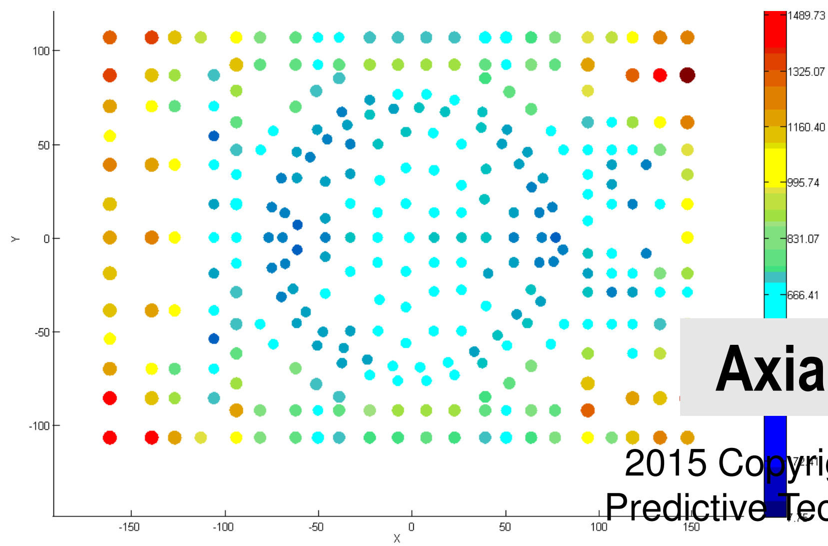
Coherent

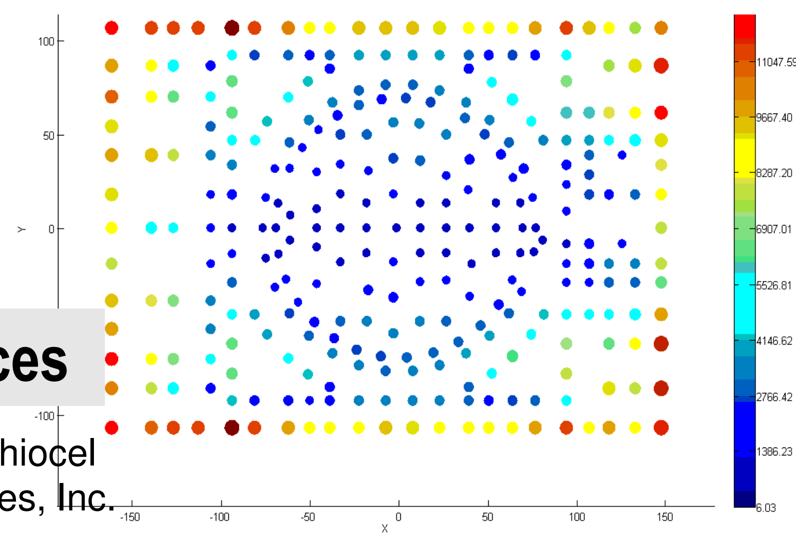


Incoherent



Shear Forces





Axial Forces

Conclusions

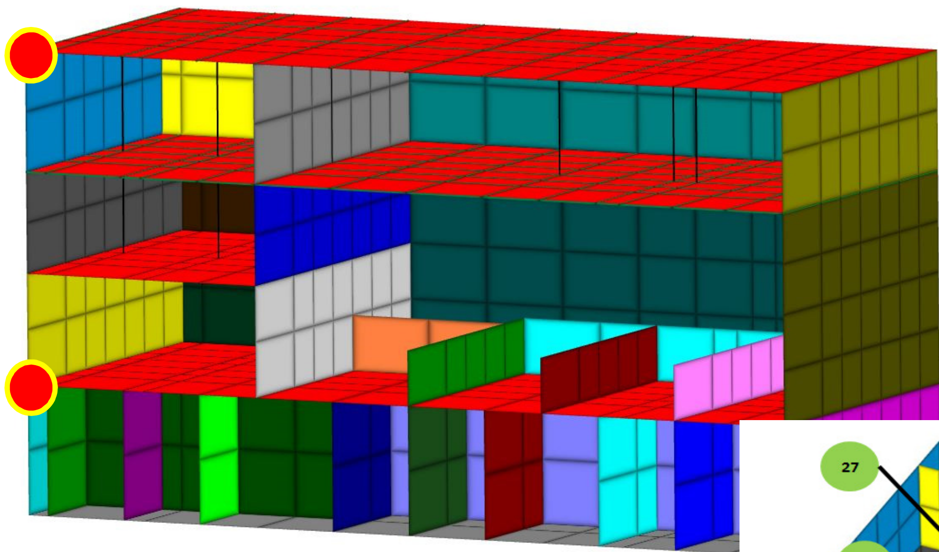
- Base-isolation largely reduces the acceleration response, and as a result of these the inertial forces in the structure. This is a great benefit of base-isolation.
- Seismic SSI effects, especially the radiation damping effects, are significantly reduced for the base-isolated NI complex. Some ISRS are larger for Soil than for Rock site. Significant frequency shifts were noticed.
- The effects of motion incoherency are largely unfavorable for base-isolated NI complex. Incoherency produced large ISRS amplifications for higher frequency modes due to the multiple excitation effects produced by incoherent differential motions.

- Incoherency increases significantly the relative vertical displacement within the NI complex structures and for the RCL system.
- The incoherent motion increases the rocking and torsional response of the base-isolated structure and resulted in much higher axial forces in the isolators, especially near the baseslab edges.

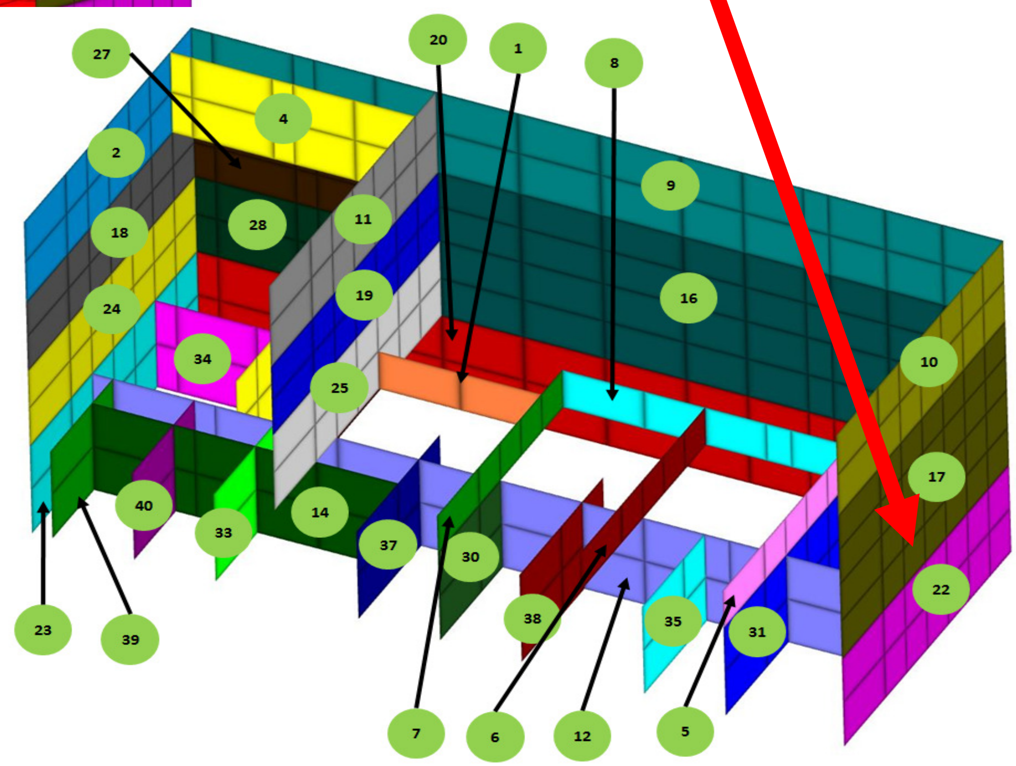
Based on these results, we recommend for base-isolated NI complexes a careful consideration of the significant SSI effects produced by the spatial variation of the ground motion.

These effects should not be neglected!

Nonlinear Concrete Shearwall Bldg. Model



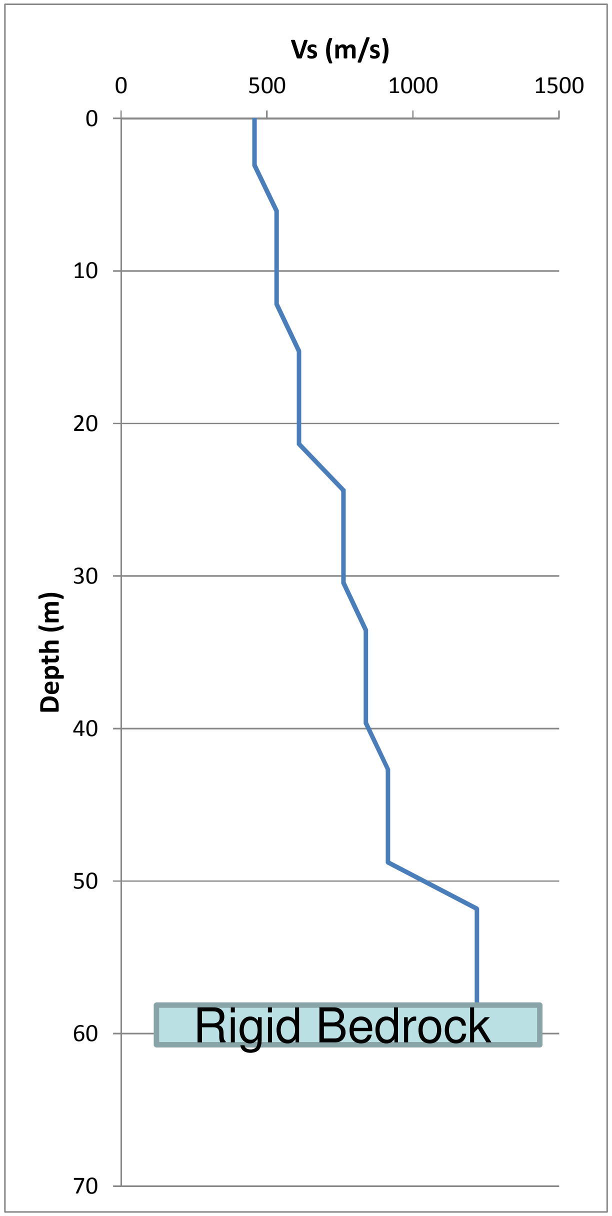
Selected Wall Panel

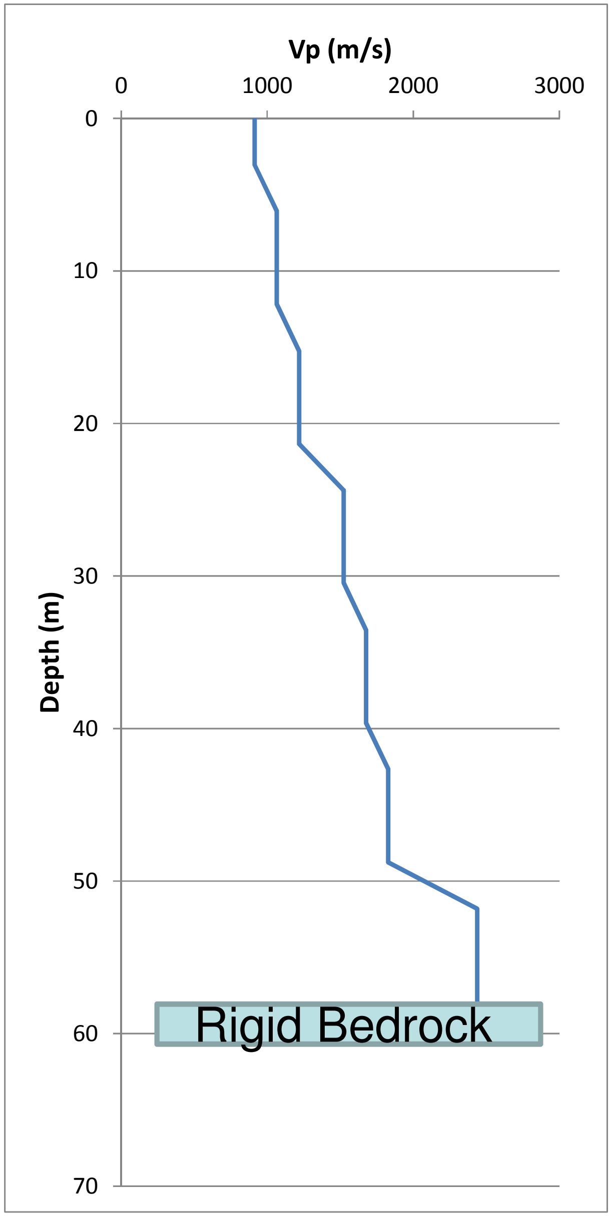


Nuclear Building Split In Nonlinear Panels

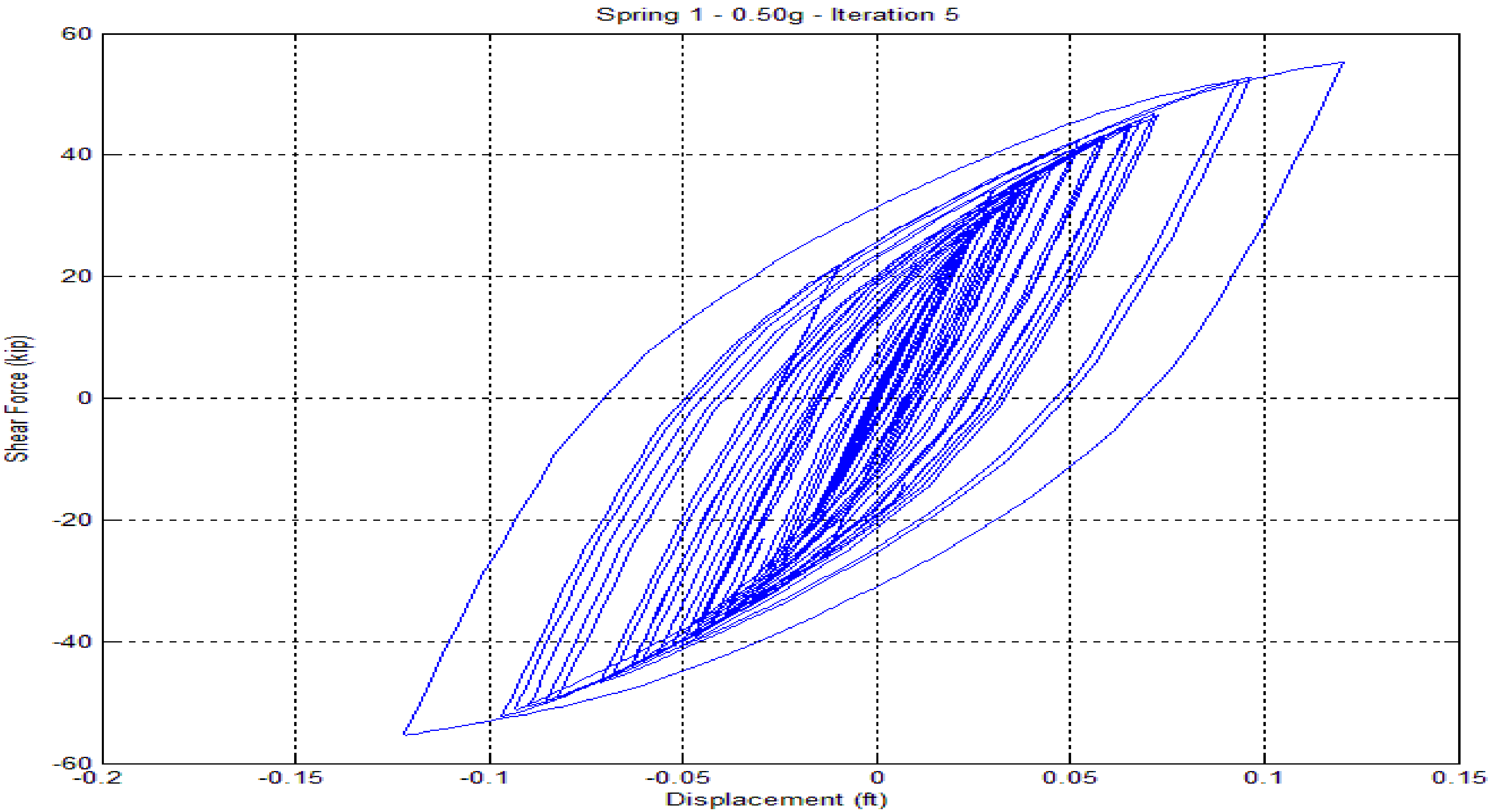
120 LRB Isolators (Diameter = 1.6m)
Used by Japan (SMiRT23 Division V papers)

V_s and V_p Soil Layer Profiles

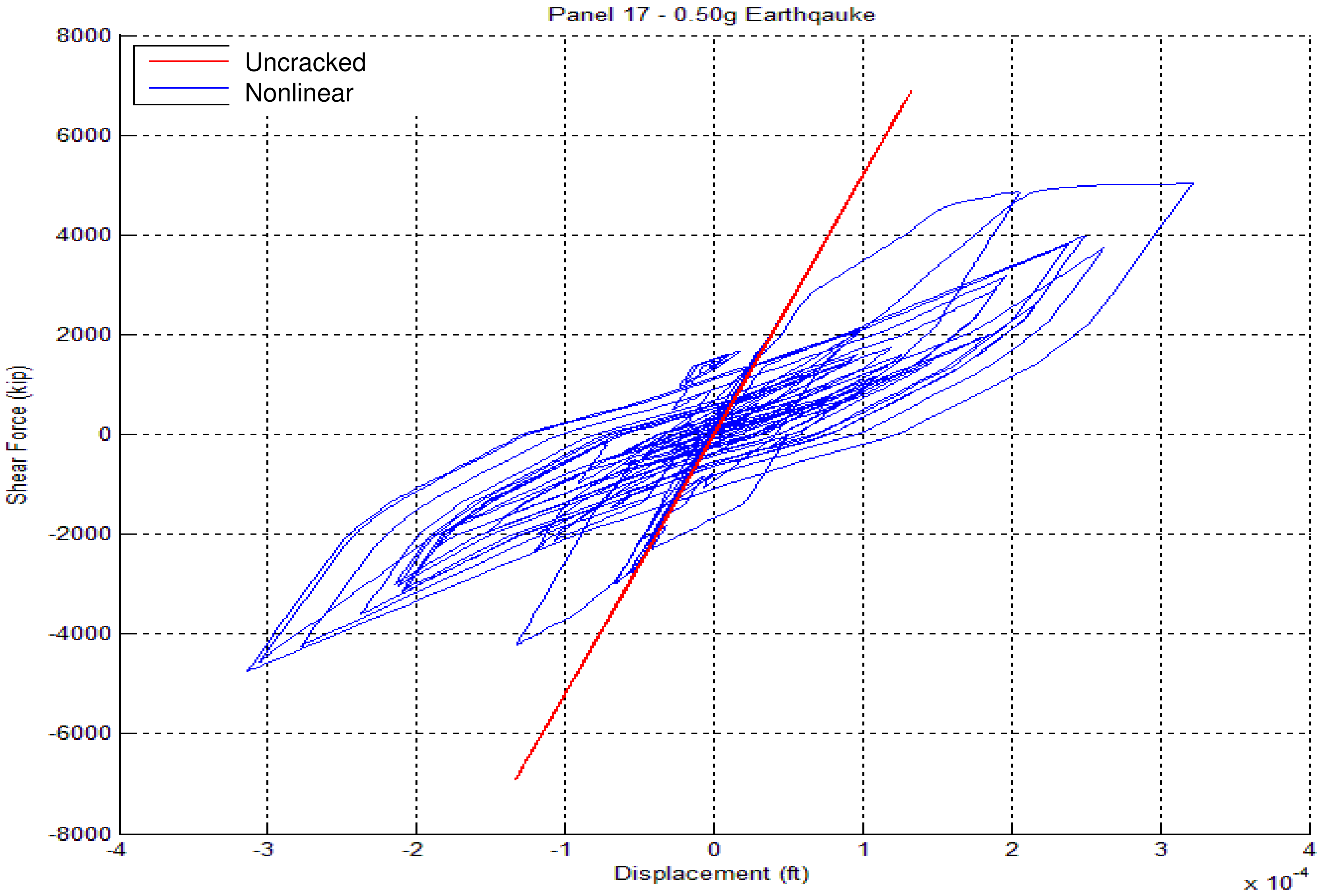




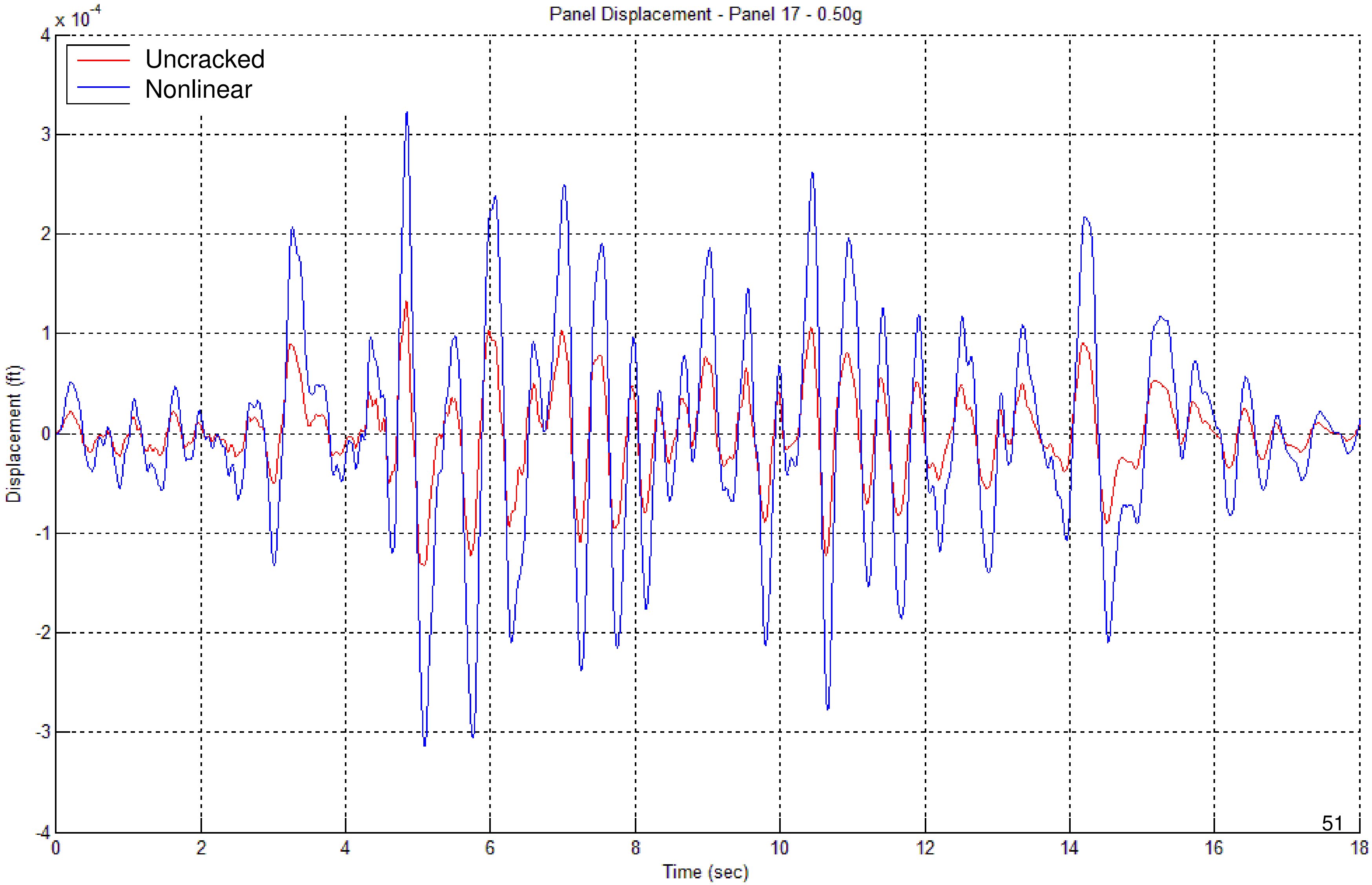
Hysteretic Loops for Base-Isolators in Transverse Direction for 0.50g RG 1.60 Input



Hysteretic Loops for Panel # 17 Transverse Direction for 0.50g RG 1.60 Input



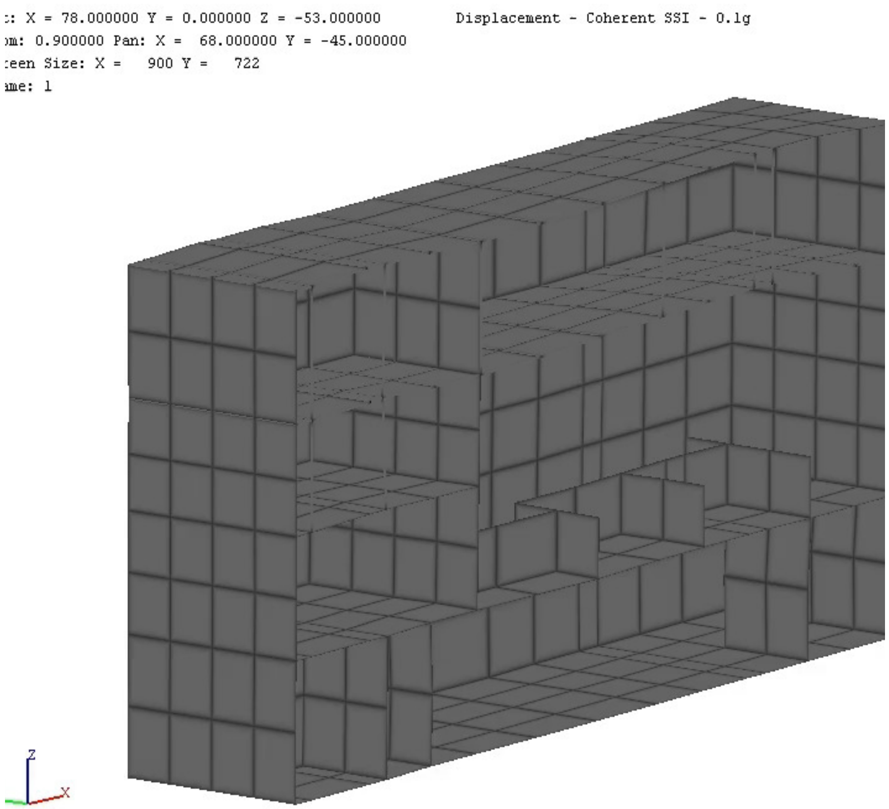
Story Drift for Wall Panel # 17 for Transverse Direction. Linear vs. Nonlinear SSI Comparisons



Base-Isolated Nuclear Building Behavior for Coherent and Incoherent Motions

Relative Displacements wrt Baseslab Center Above Isolators

Coherent



Incoherent