Comparative Probabilistic-Deterministic Studies and RVT-based SASSI Analyses of Nuclear Structures for Soil and Rock Sites

Ghiocel Predictive Technologies Inc.

Dr. Dan M. Ghiocel

Email: dan.ghiocel@ghiocel-tech.com

Phone: 585-641-0379

Ghiocel Predictive Technologies Inc.

http://www.ghiocel-tech.com

2014 U.S. Department of Energy Natural Phenomena Hazards Meeting

Germantown, MD, October 21-22, 2014

Purpose of This Presentation:

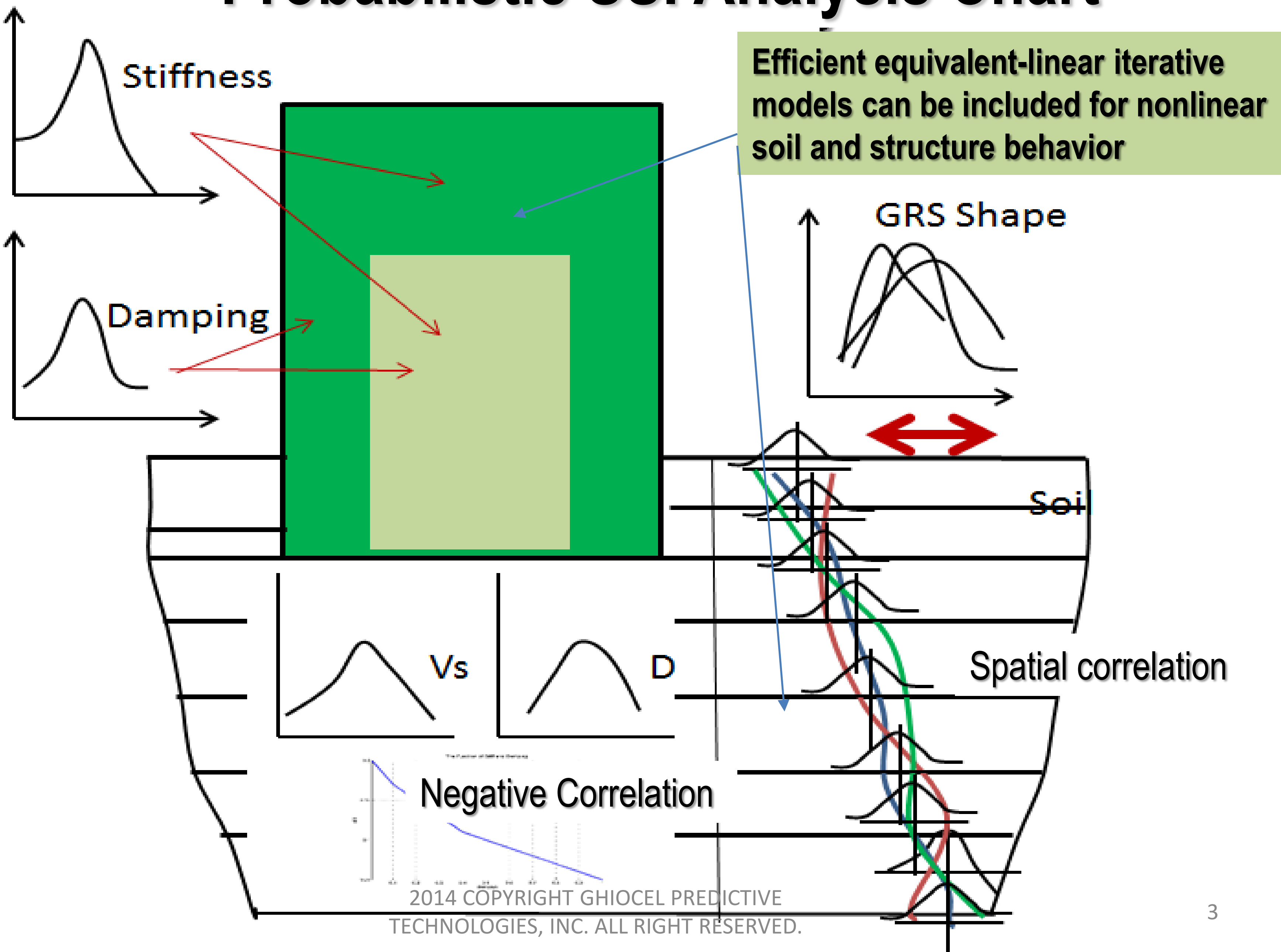
To disseminate results of some internal multiyear research projects done in GP Technologies for a better understanding of the accuracy and limitations of the probabilistic and RVT-based SSI approaches for nuclear structures.

To answer to the following key questions:
- Is probabilistic SSI more accurate than deterministic SSI? Yes, but….
- Is deterministic SSI analysis providing the same non-exceedance probability level for soil and rock sites?
- Are the RVT SSI approaches based on RS-PSD transformation sufficiently accurate for application to complex nuclear structures?

Discuss the methodology effects the ISRS…

The *ACS SASSI Version 3.0 with new Options PRO and RVT* was used.

Probabilistic SSI Analysis Chart



ASCE 04-2014 Draft Probabilistic SSI Analysis

The new ASCE 04-2014 draft standard states that the purpose of the analytical methods included in the standard is to provide reasonable levels of conservatism to account for uncertainties.

More specifically, in the same section is written that given the seismic design response spectra input, the goal of the standard is based on a set of recommendations to develop seismic *deterministic SSI responses* that correspond approximately to a 80% non-exceedance probability level.

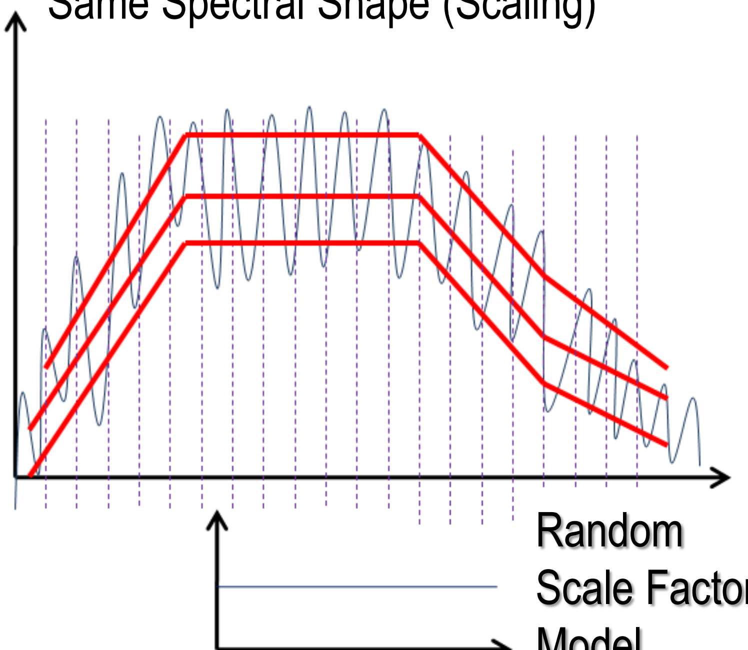
For probabilistic seismic analyses, *probabilistic SSI responses* defined with the 80% non-exceedance probability level are considered adequate.

Section 5.5 of the standard provides guidelines for the acceptable probabilistic SSI approaches. The GRS spectral shape could be considered with variable shape or not (Methods 1 and 2). Soil profiles, Vs and D, should include spatial correlation with depth. Structural stiffness and damping should be also modeled by dependent or negatively correlated random variables.

Probabilistic Seismic Input Ground RS

Method 1

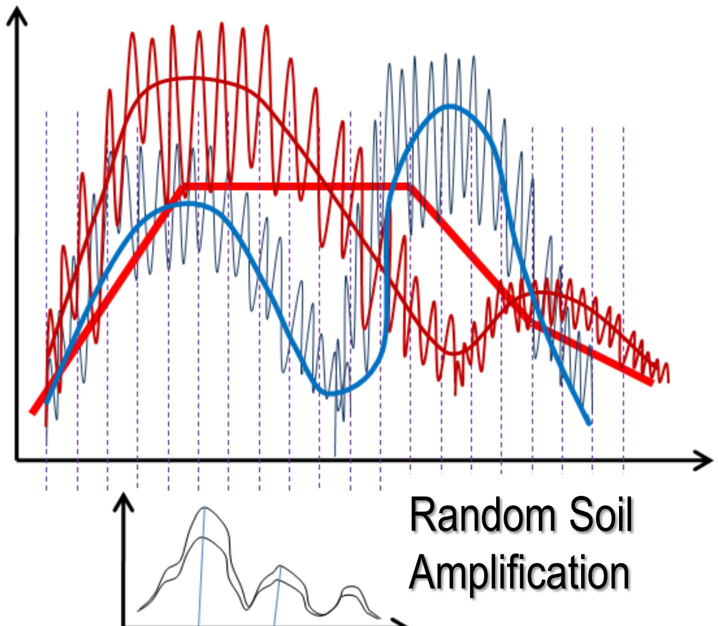
Same Spectral Shape (Scaling)



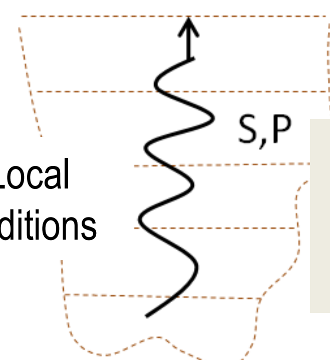
Full Correlation in Frequency….
Simpler...
Less information required….

Method 2

Random Spectral Shape



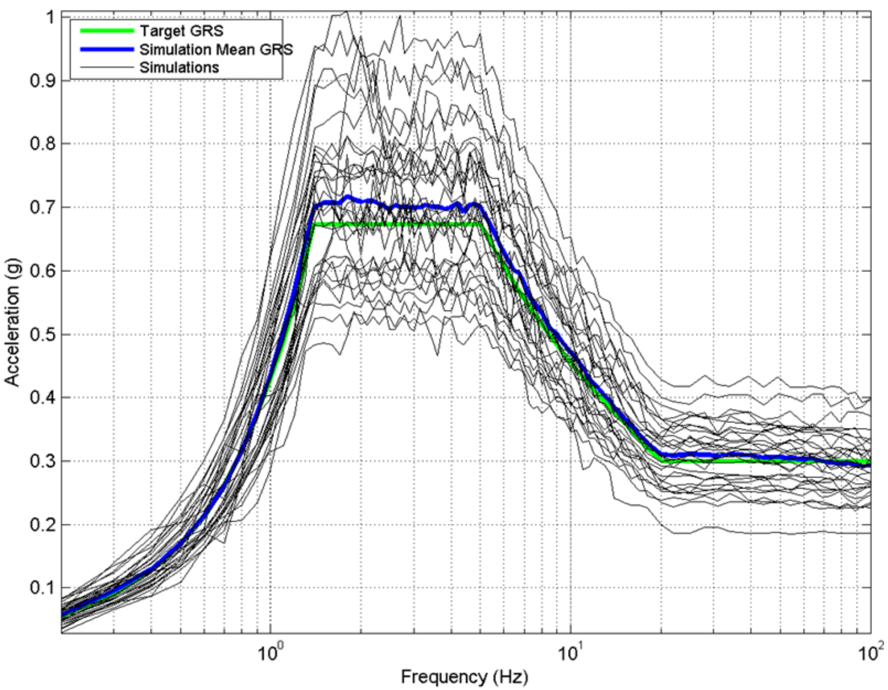
Include Local
Soil Conditions



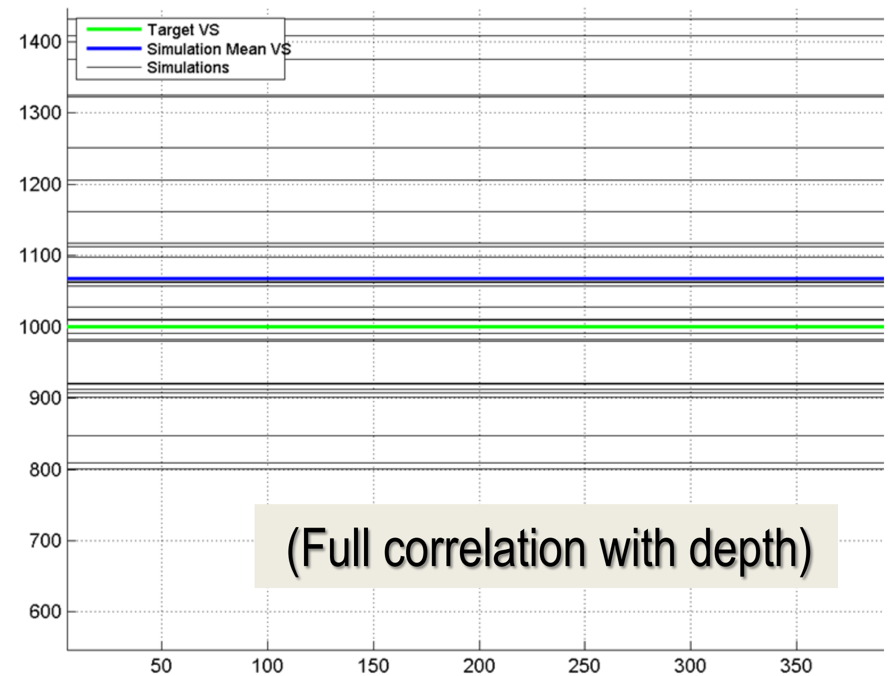
Correlation in Frequency….
More physics-based…
More information required….

Simulated Probabilistic Seismic GRS (Method 1) and Soil Profile (Vs and D) Using Random Variables

Simulated GRS Inputs



Simulated Soil Profiles

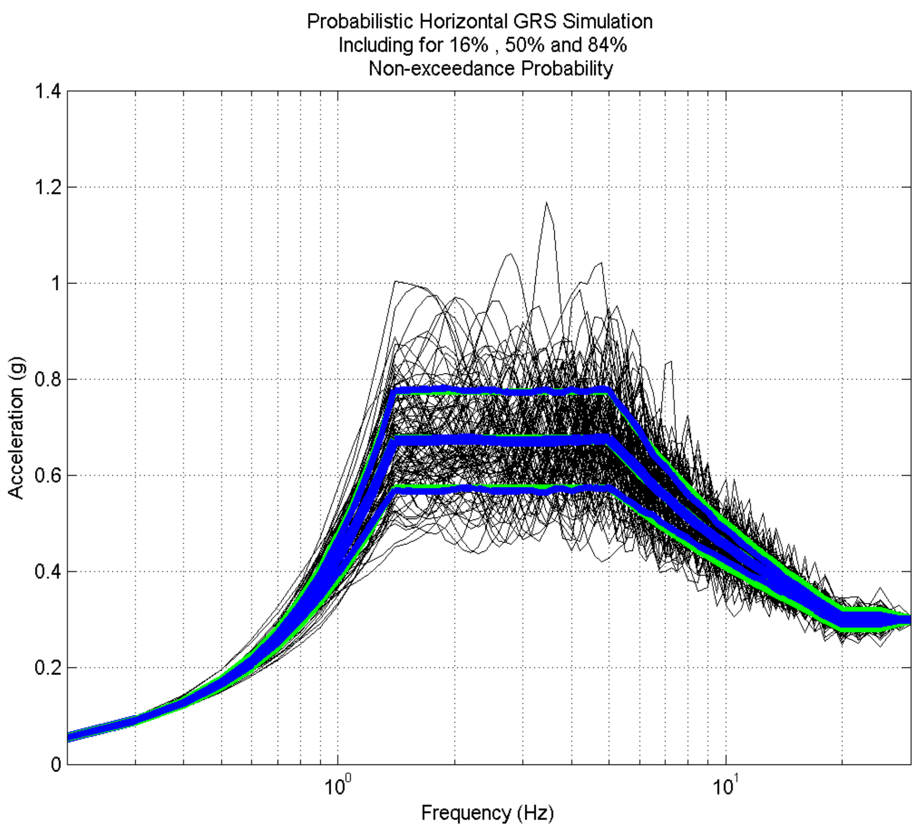


(Full correlation with depth)

Note: Only 30 LSH simulations were used

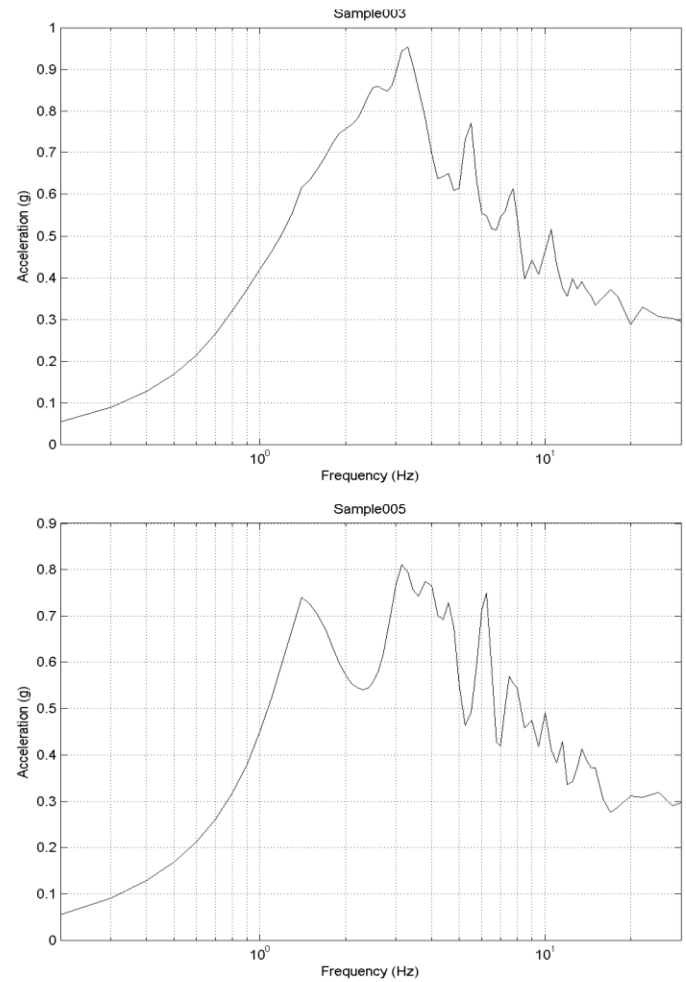
Simulated Probabilistic Seismic GRS (Method 2)

Probabilistic UHRS Input
0.30 ZPGA



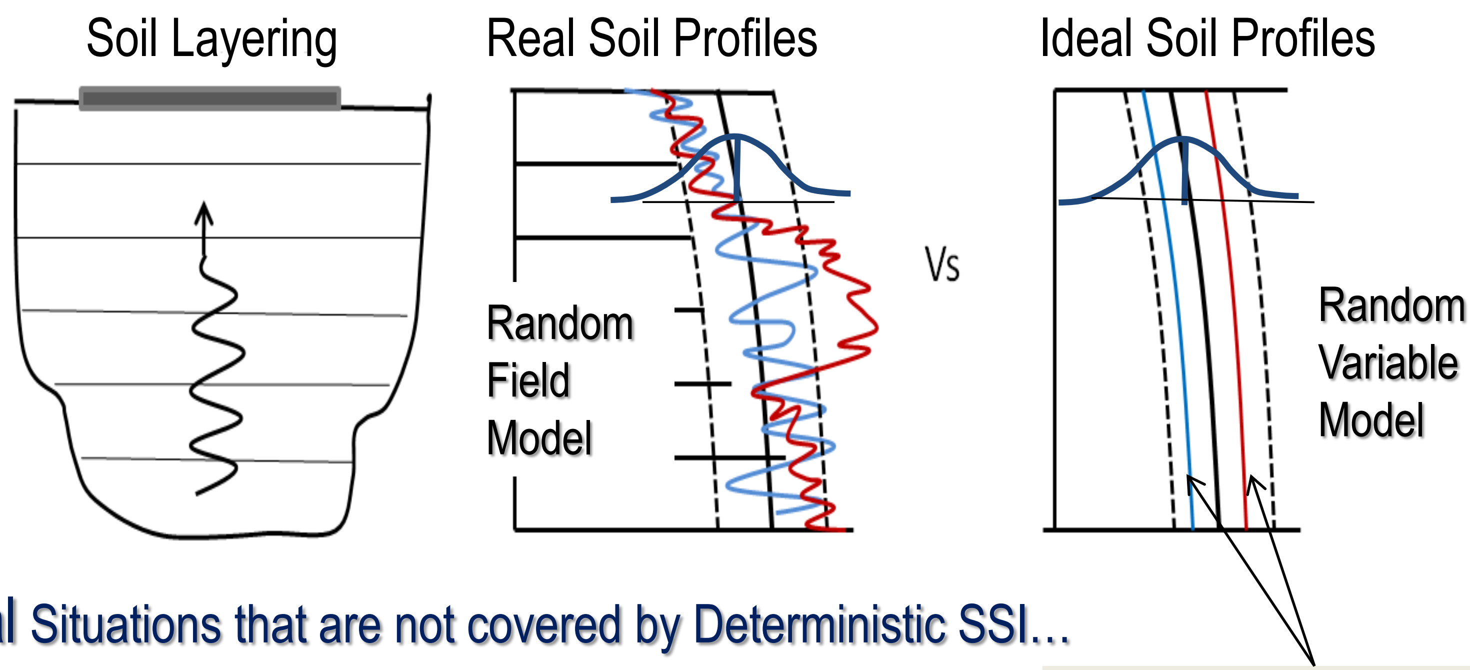
c.o.v. = 15%; Spectral Correl. Length = 1 Hz
(based on probabilistic site response simulations)

Simulated GRS

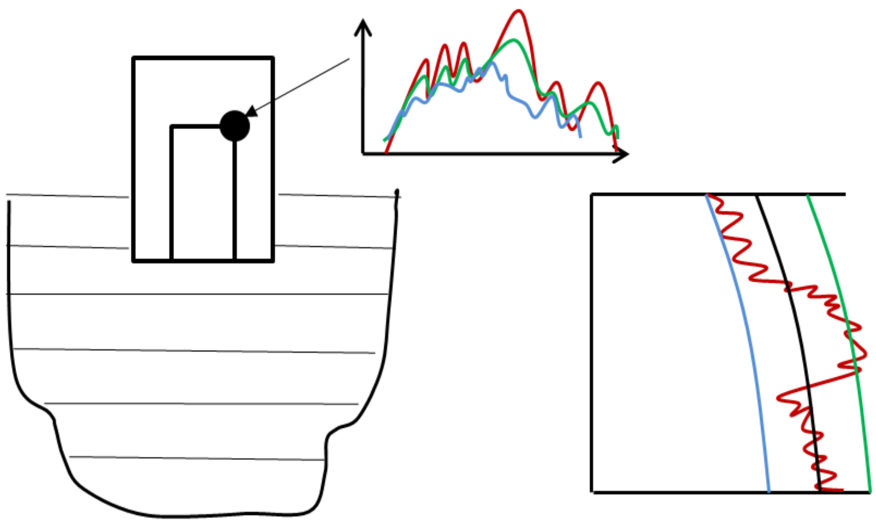


Random Samples

Probabilistic Soil Profiles (at Low Shear Strains)



Potential Situations that are not covered by Deterministic SSI…

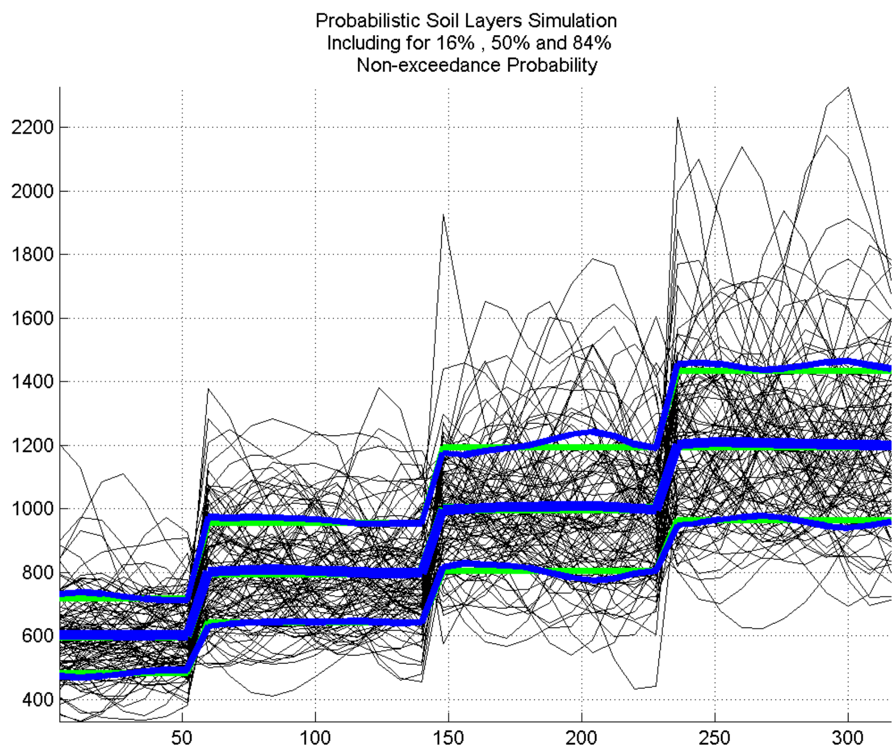


Perfect Correlation with depth looses physics…

No Correlation with depth looses physics…

Simulated Probabilistic Soil Layer Profiles

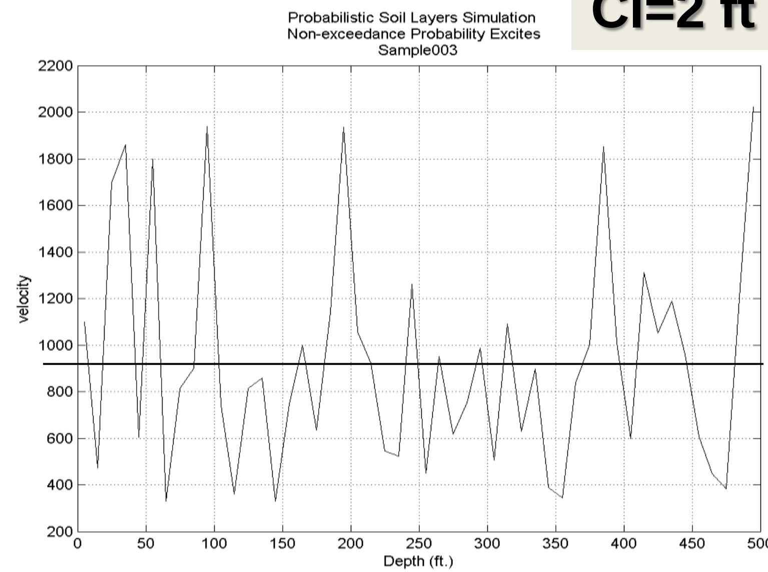
Probabilistic Soil Profile



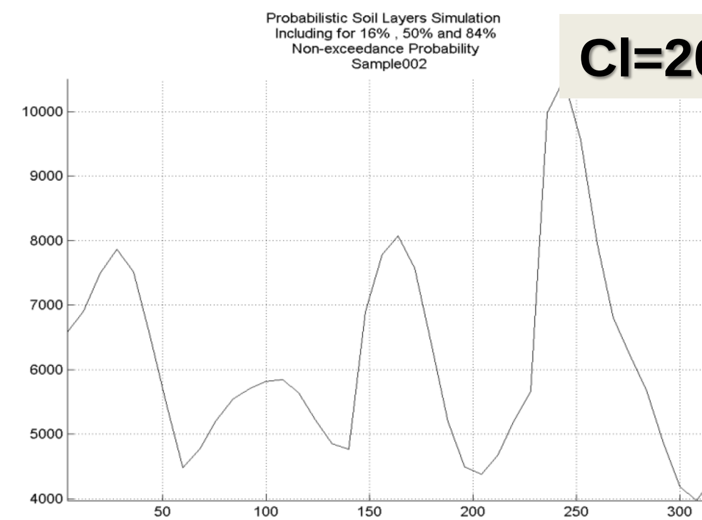
c.o.v. = 20%; Correl. Length = 20 ft

Simulated Soil Profiles

Cl=2 ft



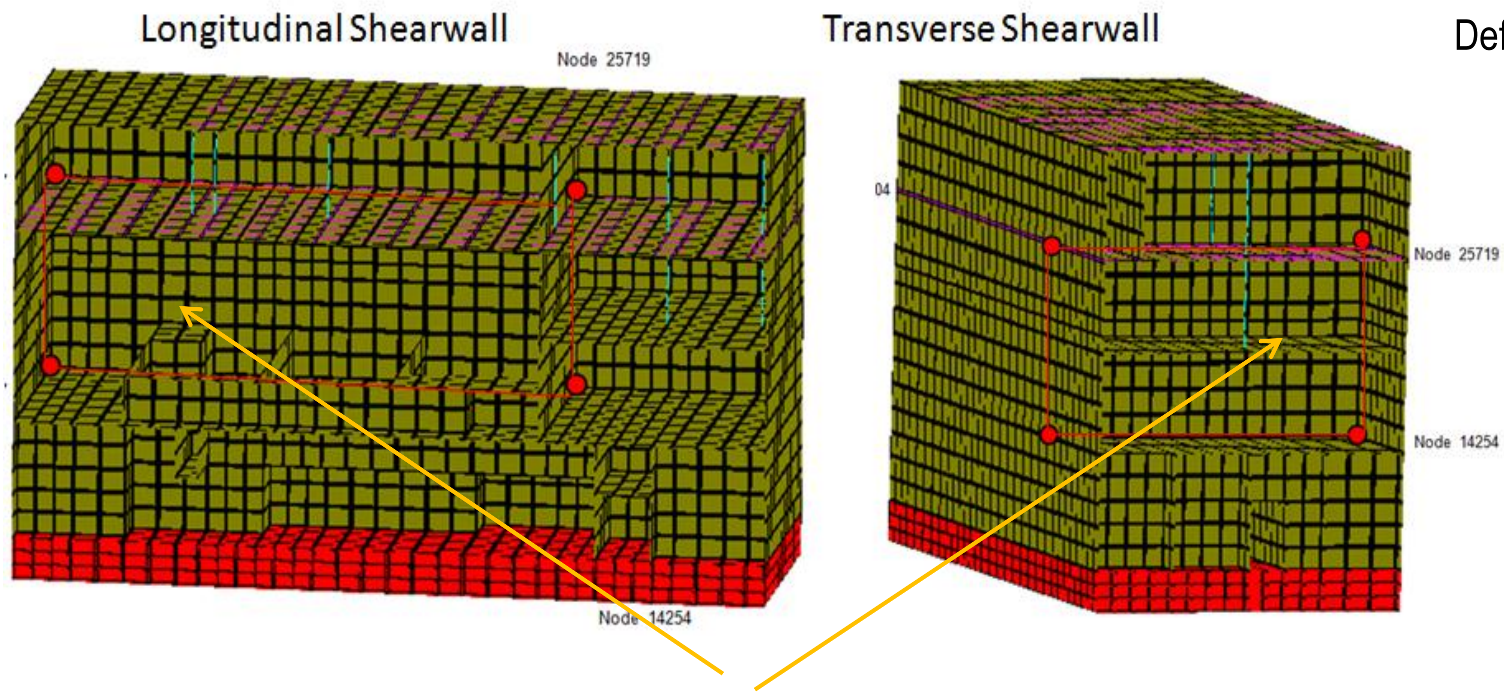
Cl=20 ft



Probabilistic Structural Modeling (Stiffness & Damping)

- *Effective or iterated* stiffness ratio Keff/Kelastic and damping ratio, Deff, are modeled as statistically dependent pair of random variables for each element group (with different stress levels).

- Keff/Kelastic and Deff can be considered negatively correlated, or having a complementary probability relationship, or Deff be a *response function* of Keff/Kelastic based on experiments



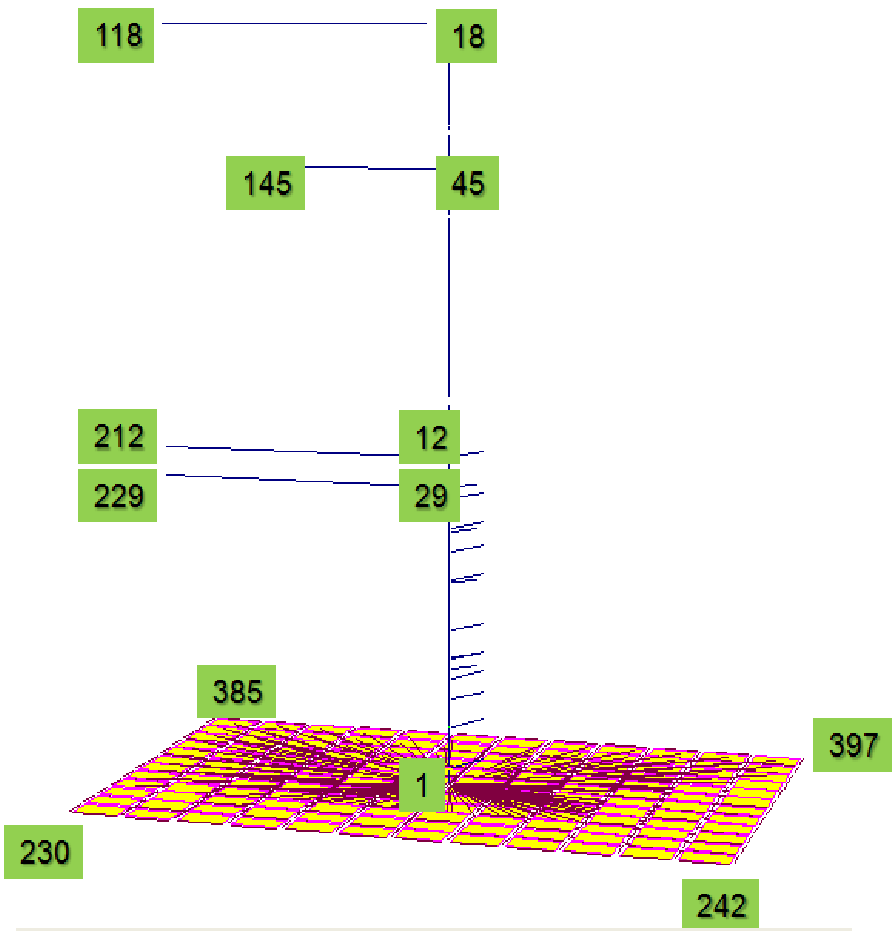
Deff = f (Keff/Elastic)

Stiff	Damp
0.01	0.20
0.10	0.17
0.20	0.15
0.30	0.13
0.40	0.11
0.50	0.10
0.60	0.09
0.70	0.08
0.80	0.07
0.90	0.06
1.00	0.05

- Keff and Deff are defined separately for each element group.

EPRI AP1000 Stick Probabilistic SSI Study

EPRI AP1000 NI Stick Model



Case 1: Soil Site, Vs = 1,000 fps
Case 2: Rock Site, Vs = 6,000 fps

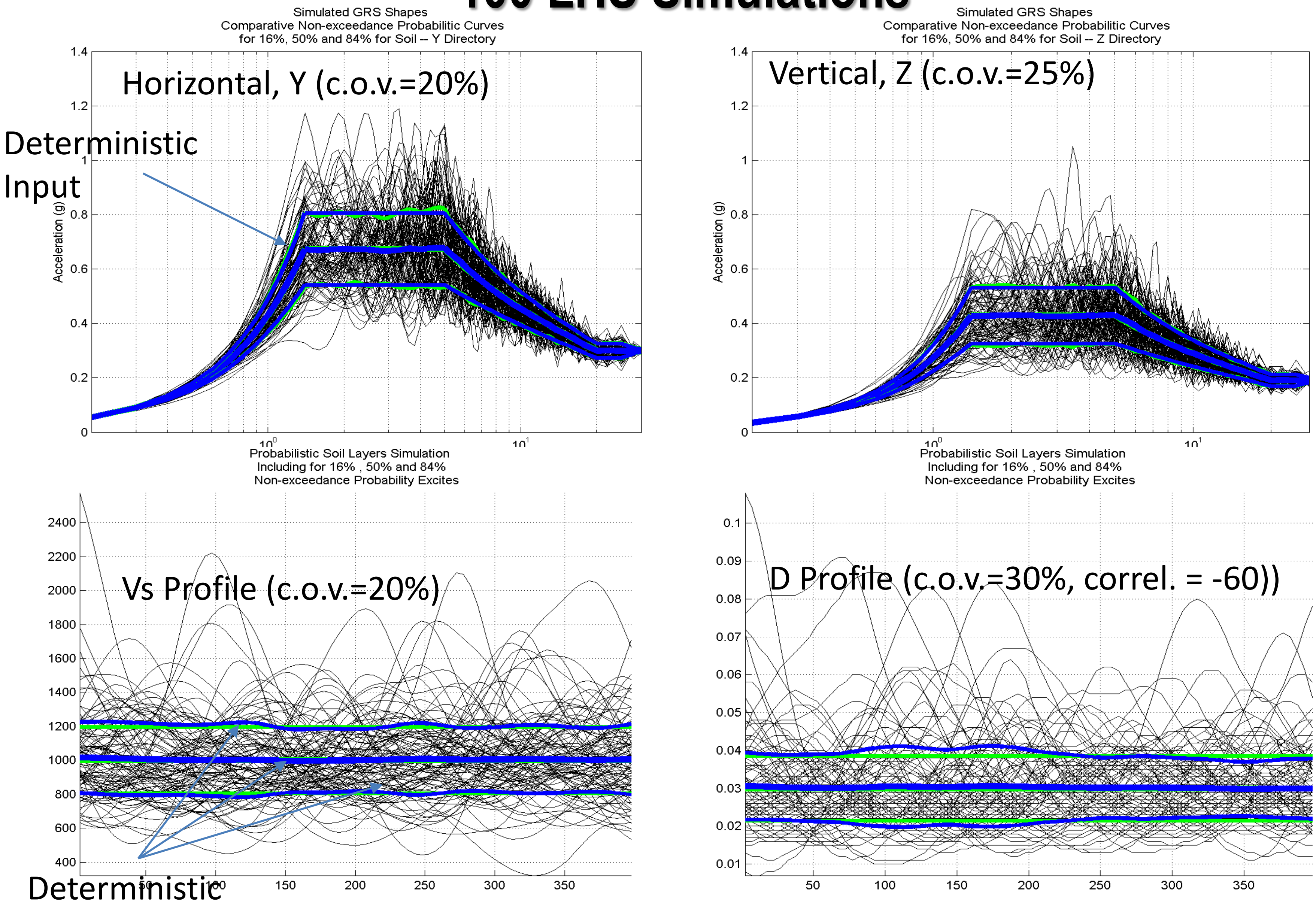
Experimental RS

Stiff	Damp
0.01	0.20
0.10	0.17
0.20	0.15
0.30	0.13
0.40	0.11
0.50	0.10
0.60	0.09
0.70	0.08
0.80	0.07
0.90	0.06
1.00	0.05

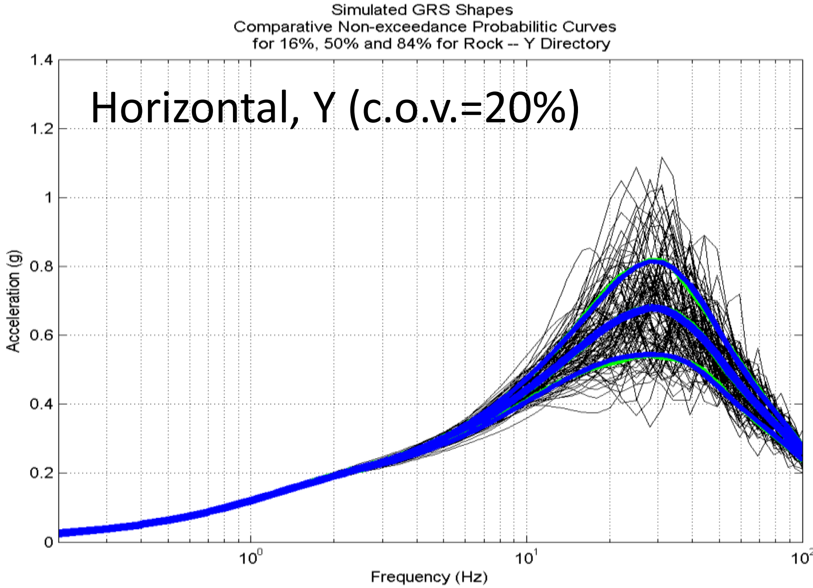
Mean Values not Allowable Values

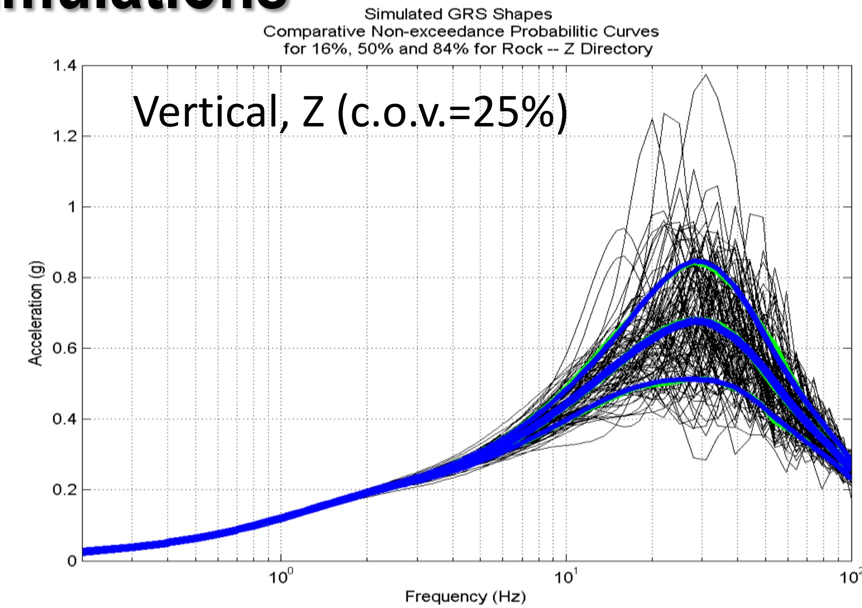
Seismic GRS (Method 2) and Soil Profiles for Soil Site

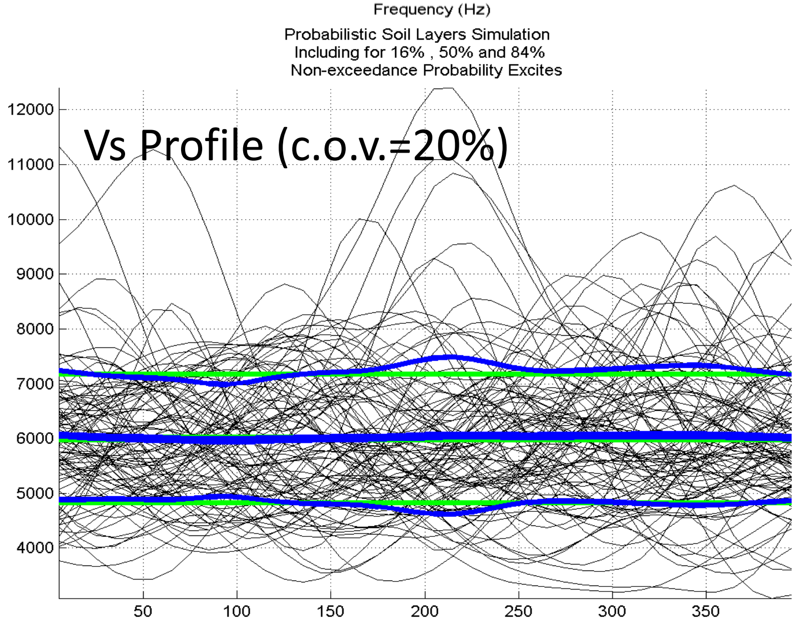
100 LHS Simulations

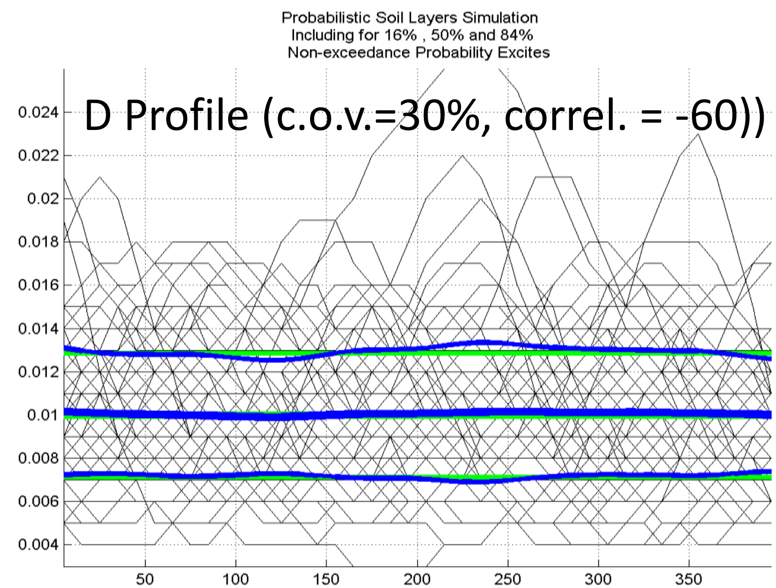


Seismic GRS (Method 2) and Soil Profiles for Rock Site
100 LHS Simulations



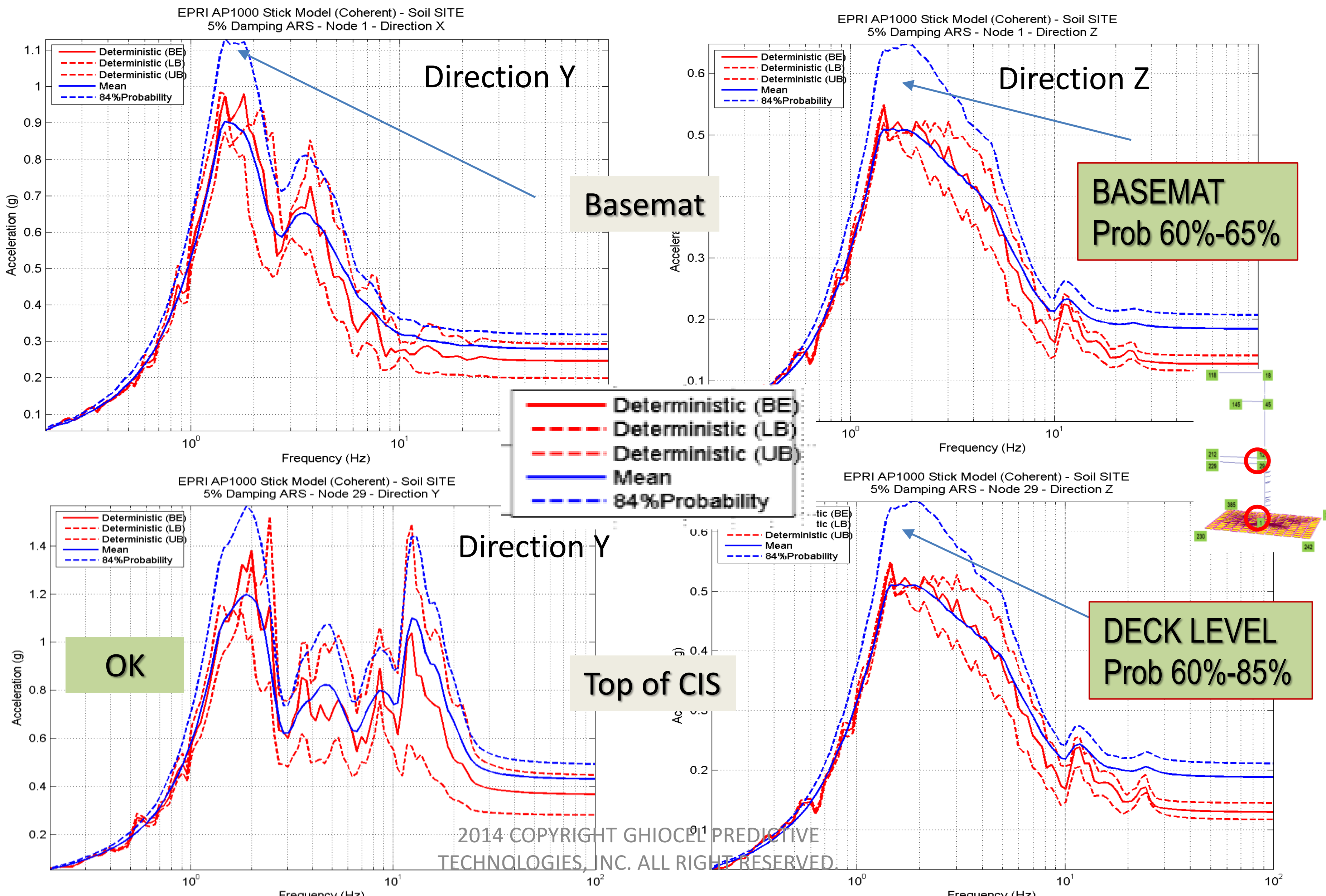






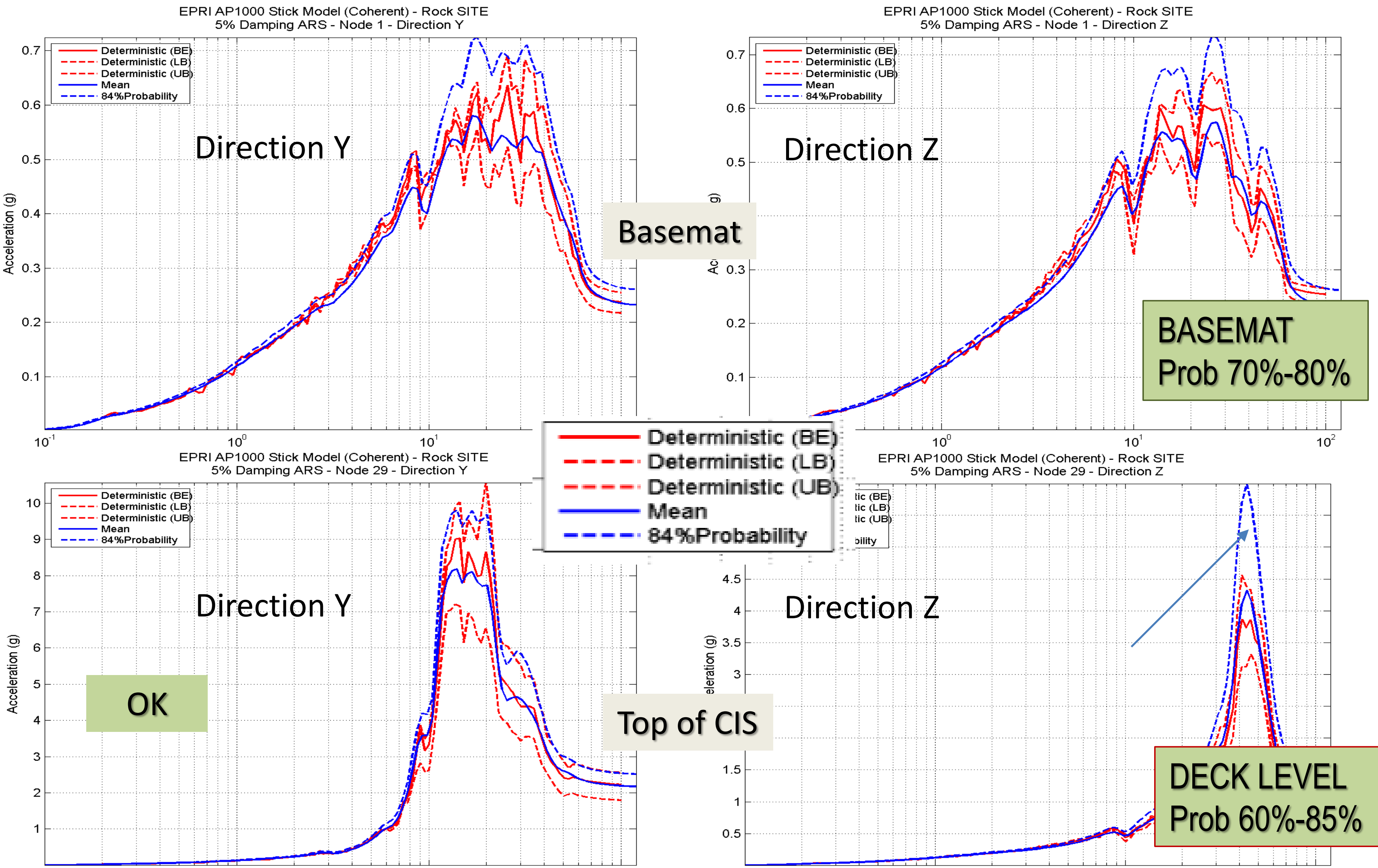
Deterministic vs. Probabilistic SSI Analysis for Soil Site

DETERMINISTIC (UNCRACKED) STRUCTURE – Keff/Kel=1.0 and Deff=4%



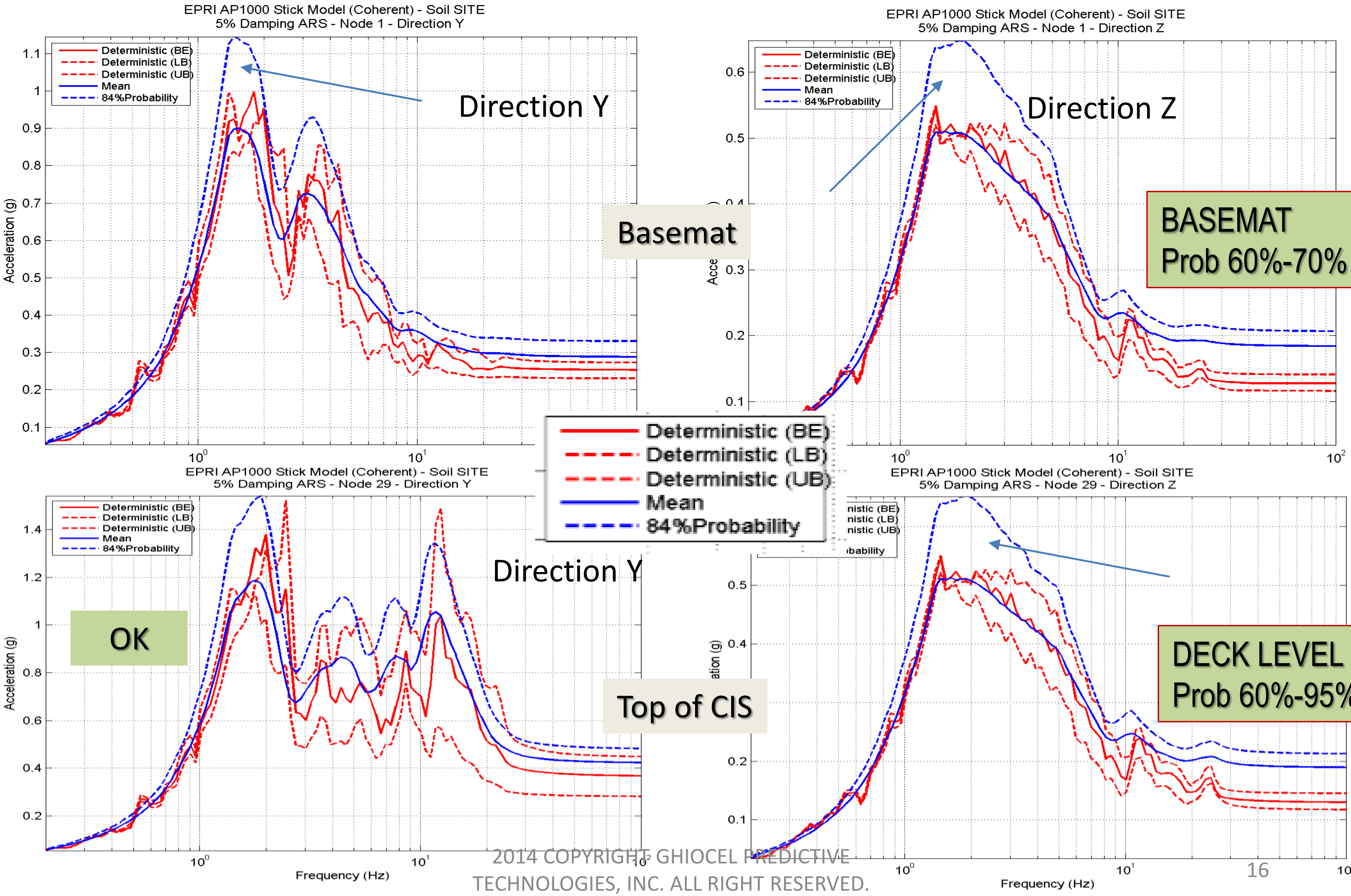
Deterministic vs. Probabilistic SSI Analysis for Rock Site

DETERMINISTIC (UNCRACKED) STRUCTURE – Keff/Kel=1.0 and Deff=4%



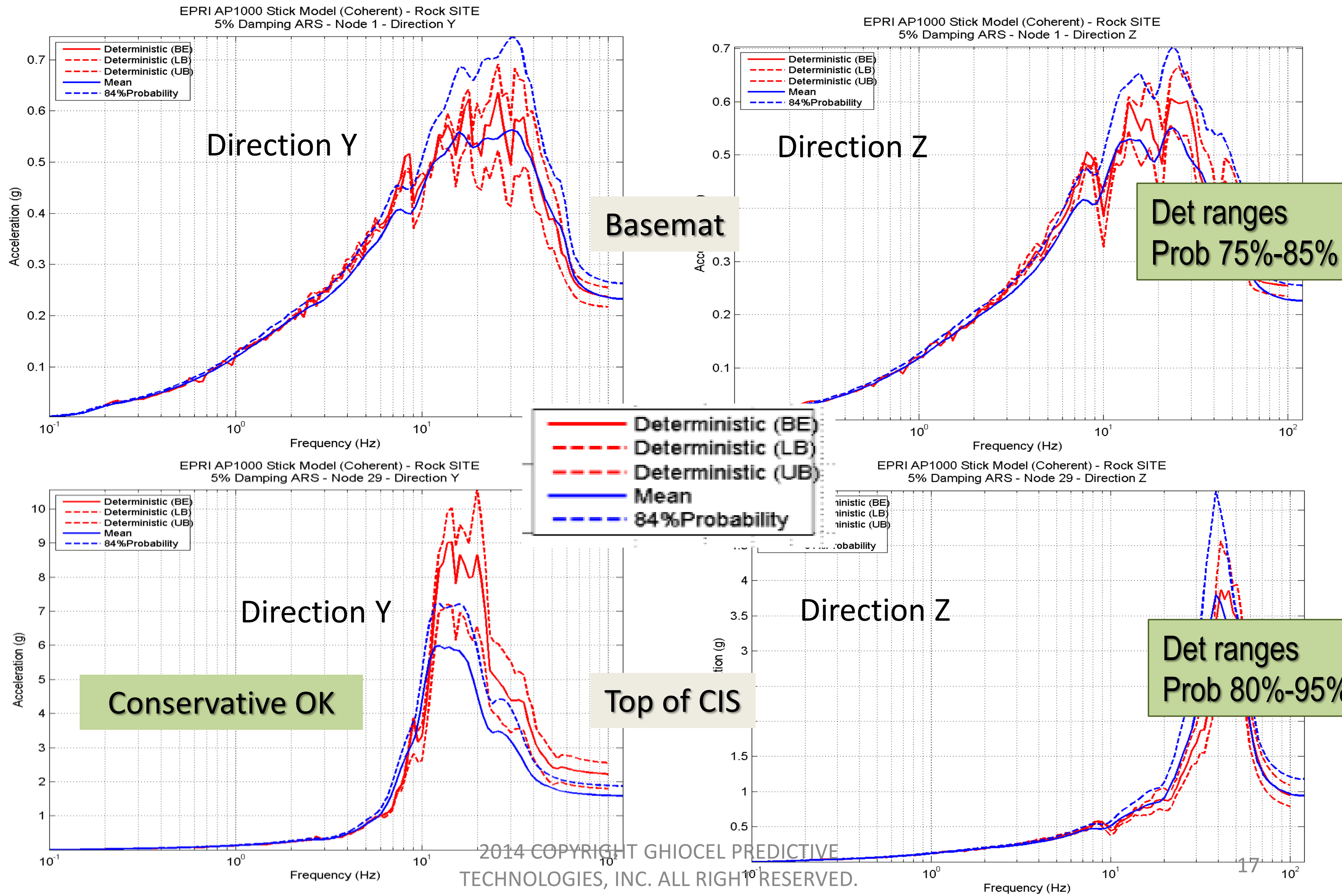
Deterministic vs. Probabilistic SSI Analysis for Rock Site

UNCERTAIN STRUCTURE – Means: Keff/Kel=0.8 and Deff=7%



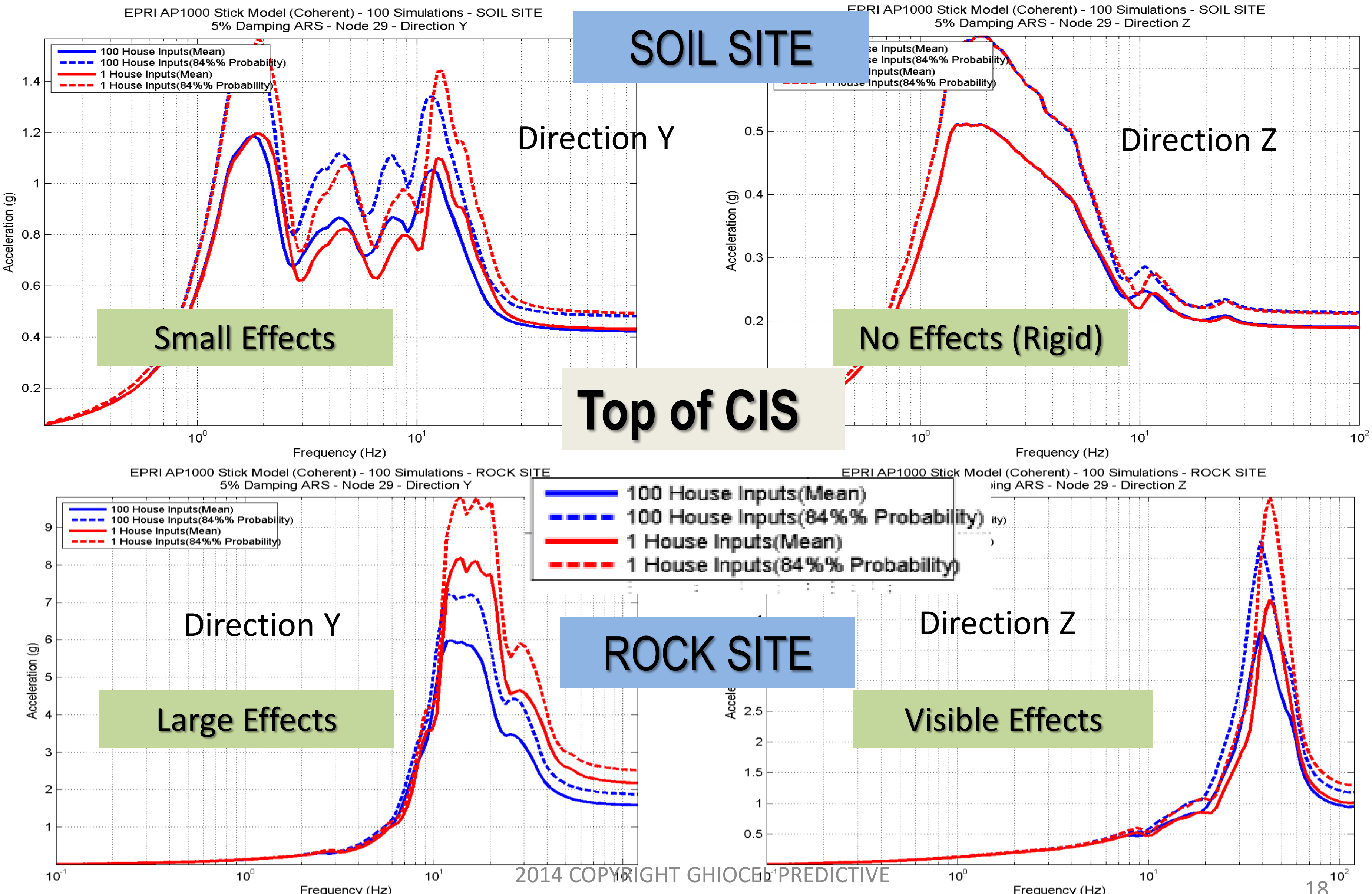
Deterministic vs. Probabilistic SSI Analysis for Rock Site

UNCERTAIN STRUCTURE – Means: Keff/Kel=0.8 and Deff=7%



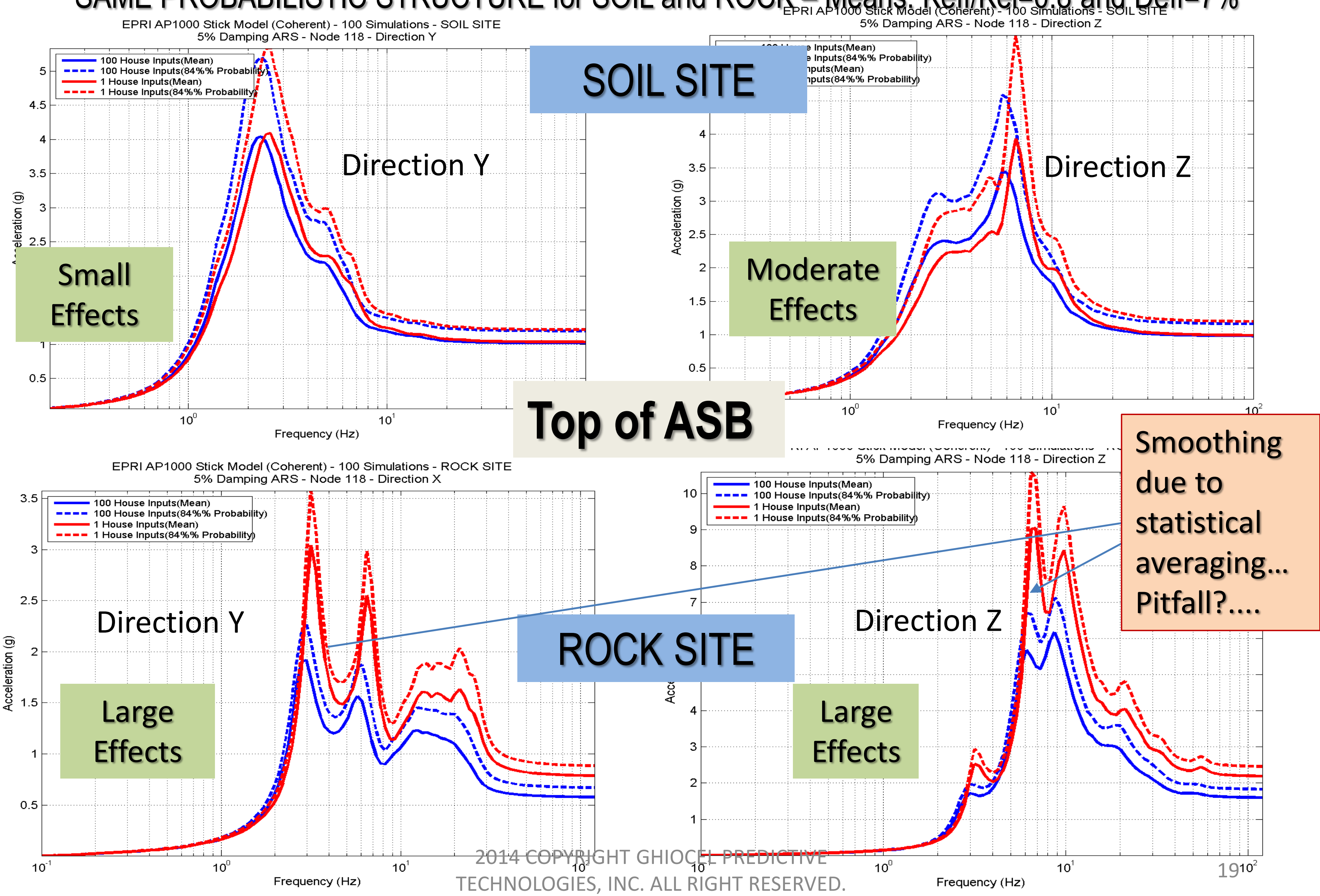
Structure Property Uncertainty Effects on ISRS

SAME STRUCTURE for SOIL and ROCK – Means: Keff/Kel=0.8 and Deff=7%



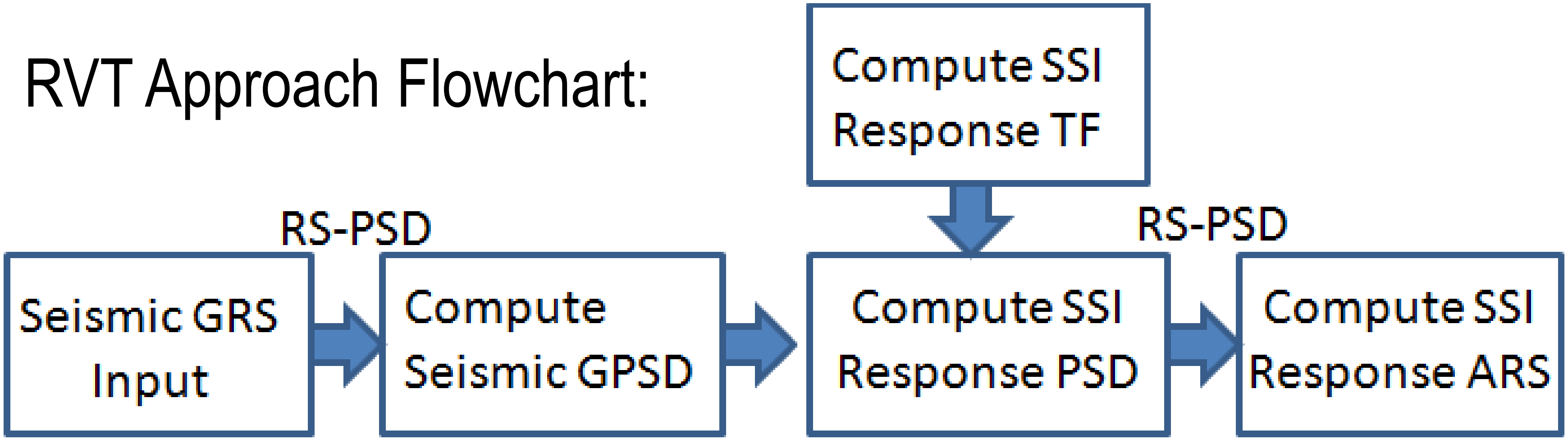
Structure Uncertainty Effects on ISRS

SAME PROBABILISTIC STRUCTURE for SOIL and ROCK – Means: Keff/Kel=0.8 and Deff=7%



RVT Approach for Seismic SSI Analysis

RVT Approach Flowchart:



SDOF Transfer Functions:

$$H_0(\omega) = \frac{\omega_0^2 + 2i\omega_0\xi_0\omega}{\left(\omega_0^2 - \omega^2\right) + 2i\omega_0\xi_0}$$

Absolute Accelerations (ARS-APSD)

$$H_0(\omega) = \frac{\omega}{\left(\omega_0^2 - \omega^2\right) + 2i\omega_0\xi_0}$$

Relative Velocities (VRS-VPSD)

$$H_0(\omega) = \frac{1}{\left(\omega_0^2 - \omega^2\right) + 2i\omega_0\xi_0}$$

Relative Displacements (DRS-RPSD)

RVT Approach for SSI Analysis (Only Seismic Input)

The RVT based approach uses frequency domain convolution computations (no need to use time-histories) assuming a *linear system under a Gaussian seismic input:*

$$S_X(\omega) = |H(\omega)|^2 |H_0(\omega)|^2 S_u(\omega)$$

Response SSI SDOF Input

The RVT-based approaches include several options related to the *PSD-RS transformation*. These options are related to the stochastic approximation models used for computing the maximum SSI response overt a time period T, i.e. during the earthquake intense motion time interval.

The maximum SSI response can be expressed by using peak factors that are applied to the stochastic motion standard deviation (RMS). These quantities depend on the duration T, the mean crossing rate of the motion and probability level associated to the maximum response ("first passage problem").

Computation of Maximum SSI Response (RS)

$$\overline{X}_{\max} = p\sigma_X$$
$$\sigma_{X_{\max}} = q\sigma_X$$

1) M Kaul-Unruh-Kana stochastic model (MK-UK) (1978, 1981) :

$$p = \left[-2\ln\left(-\left(\frac{\pi}{T}\right)\left(\frac{\sigma_X}{\sigma_{\dot{X}}}\right)\ln(P)\right)\right]^{1/2}$$

Please note that this *p* is not the mean peak factor, since it provides maximum peak factor for any given NEP P

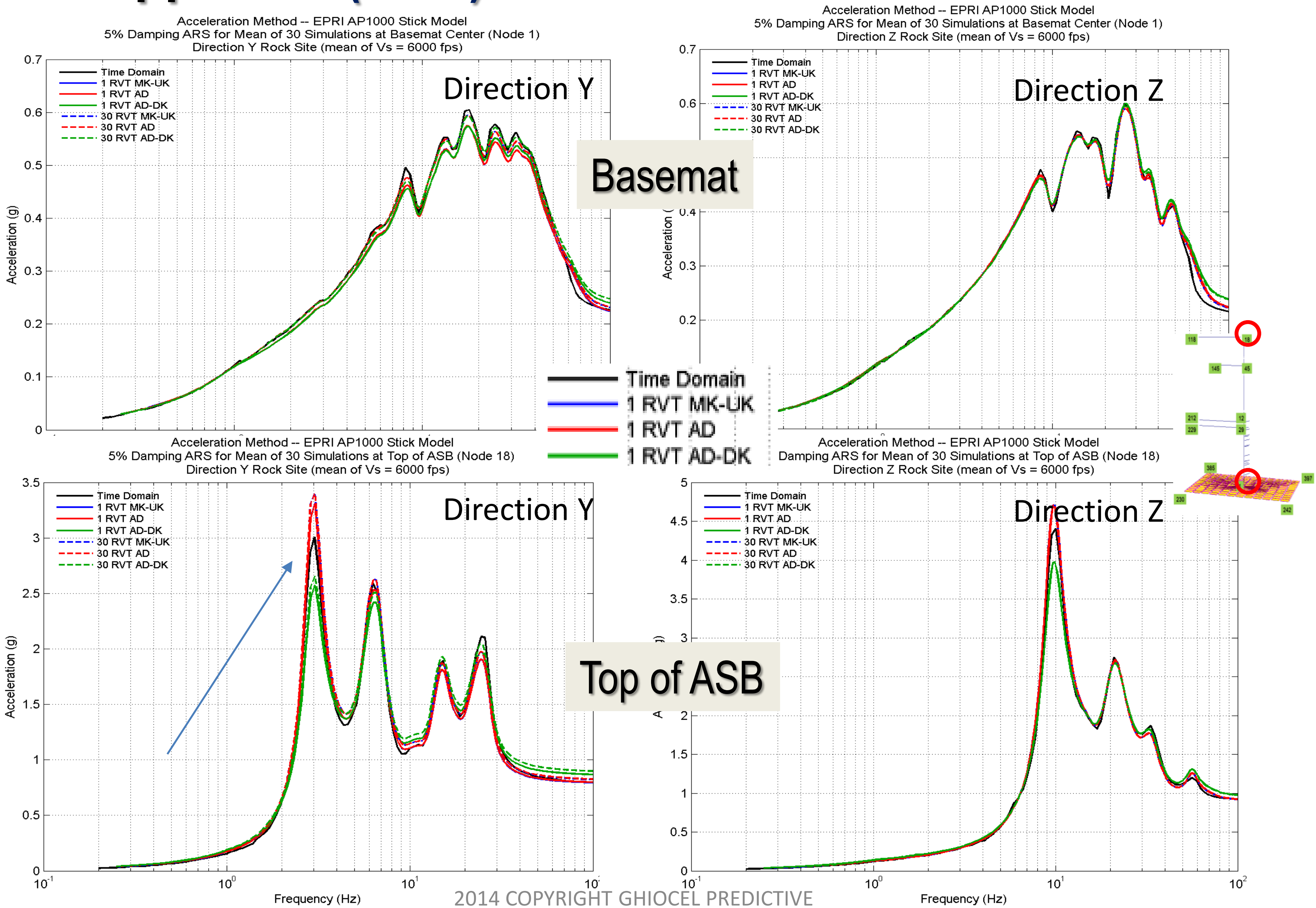
2) A Davenport (AD) (1964) for p and Der Kiureghian (1980) for q

$$p = \sqrt{2\ln(\nu_0 T)} + \frac{0.5772}{\sqrt{2\ln(\nu_0 T)}} \qquad q = \frac{1.2}{\sqrt{2\ln(\nu_0 T)}} - \frac{5.4}{\left[13 + \left(2\ln(\nu_0 T)\right)^{3.2}\right]}$$

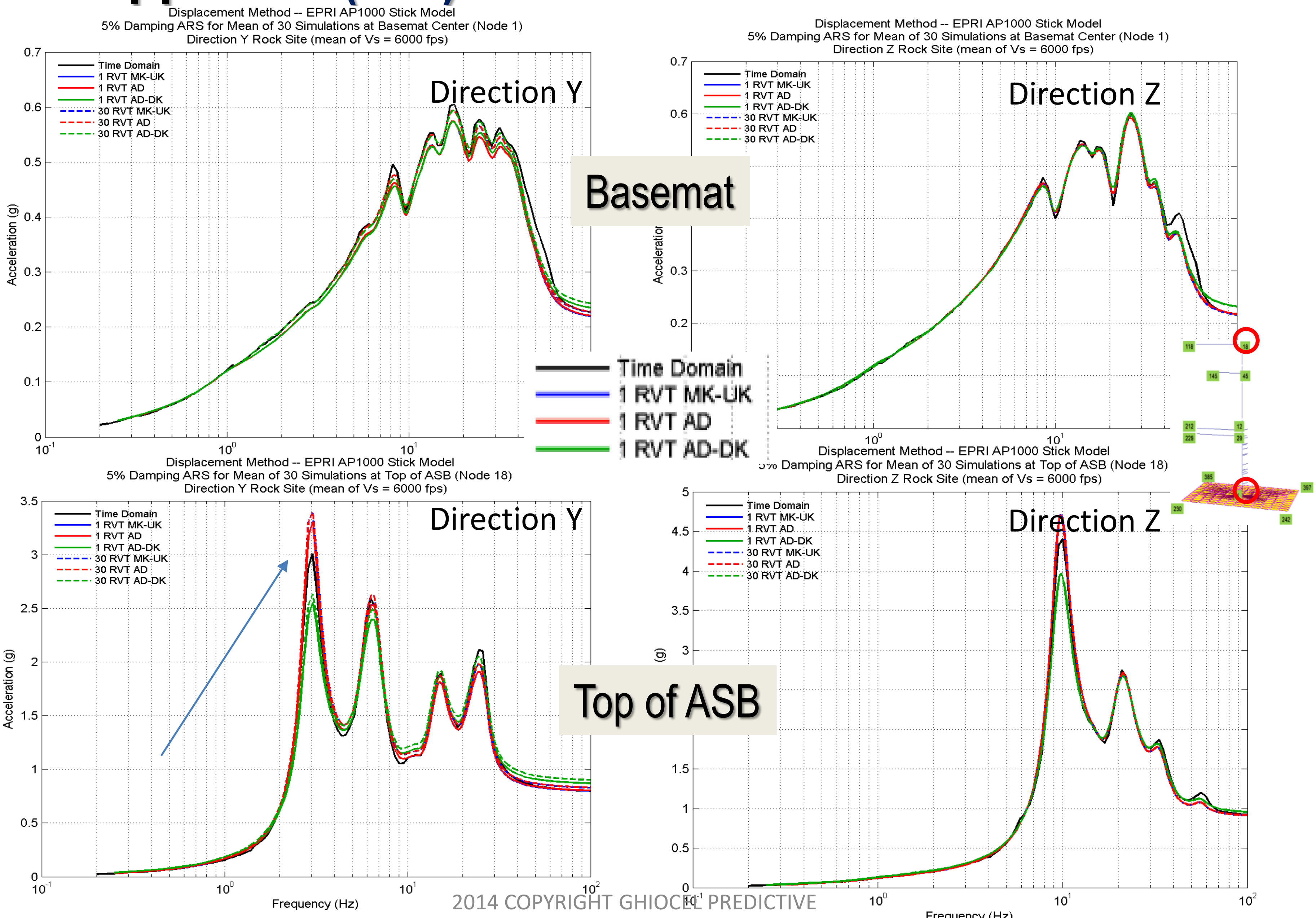
3) A Davenport Modified by Der Kiureghian (AD-DK) (1981,1983)

$$\nu_e T = \begin{cases} \max(2.1, 2\delta\nu_0 T) & ; 0 < \delta \le 0.1 \\ (1.63\delta^{0.45} - 0.38)\nu_0 T & ; 0.1 < \delta < 0.69 \\ \nu_0 T & ; 0.69 \le \delta < 1 \end{cases} \qquad \delta = \sqrt{1 - \frac{\lambda_1^2}{\lambda_0 \lambda_2}}$$

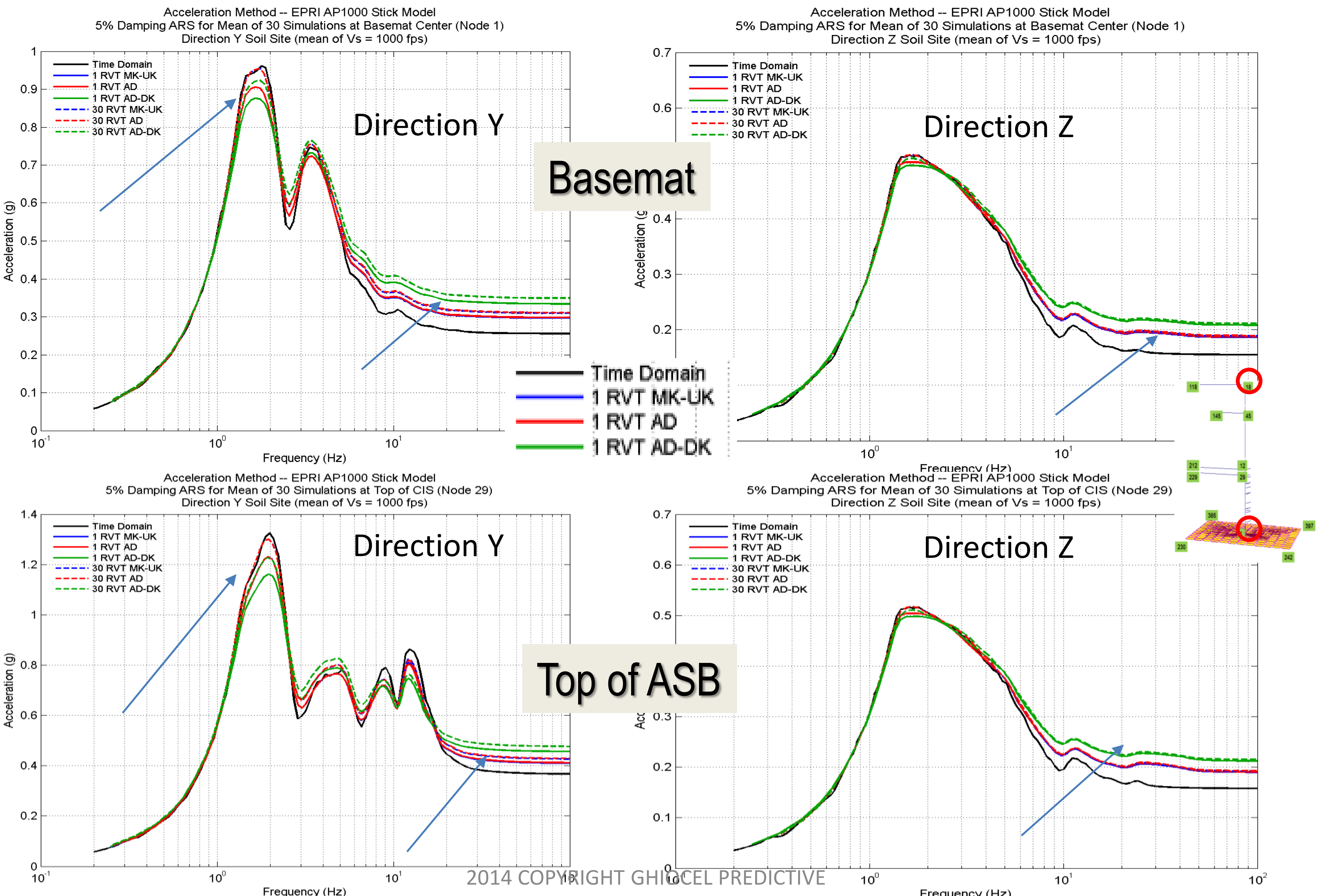
RVT Approach (ACC) vs. LHS for Rock – Mean ISRS



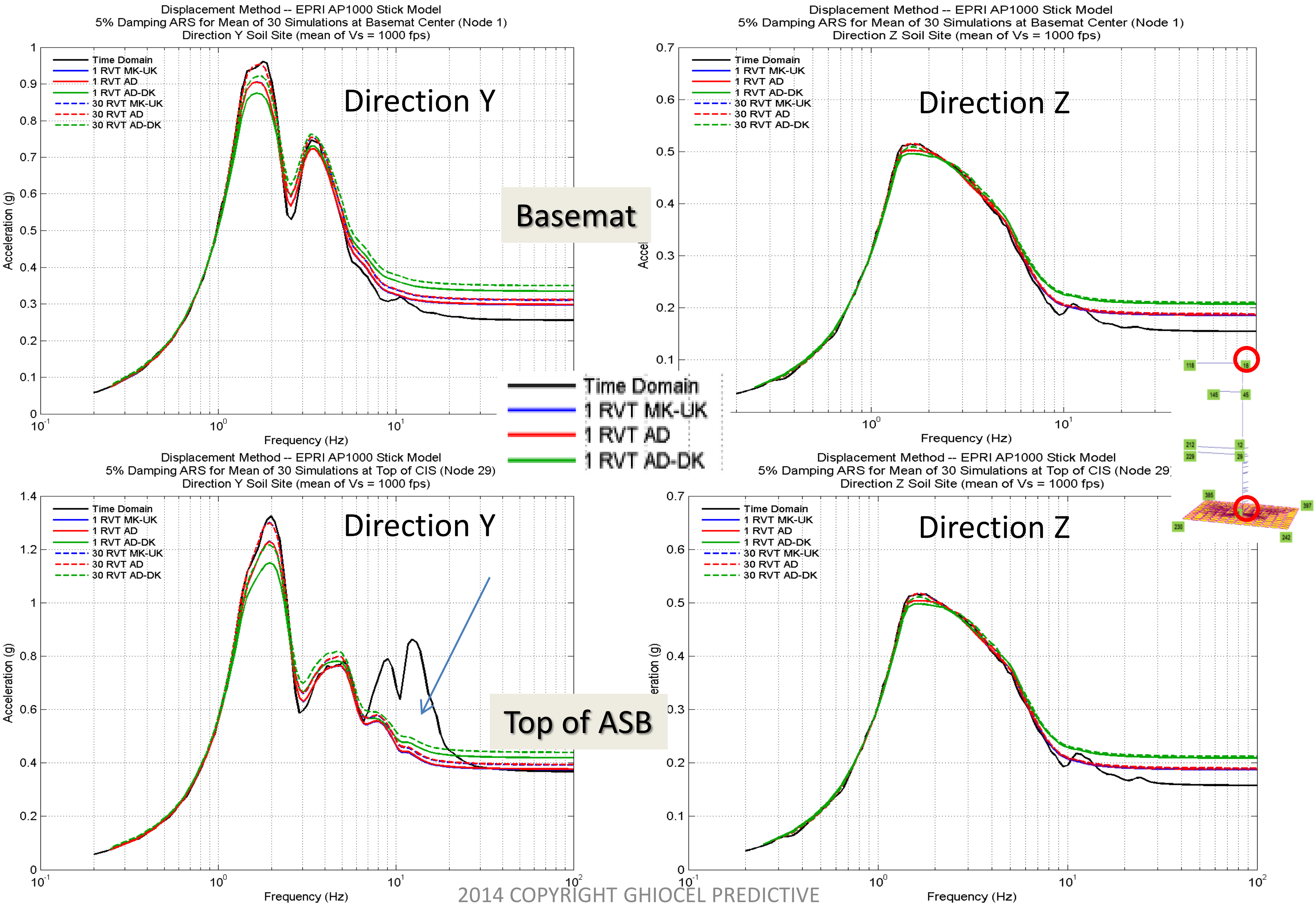
RVT Approach (DIS) vs. LHS for Rock – Mean ISRS



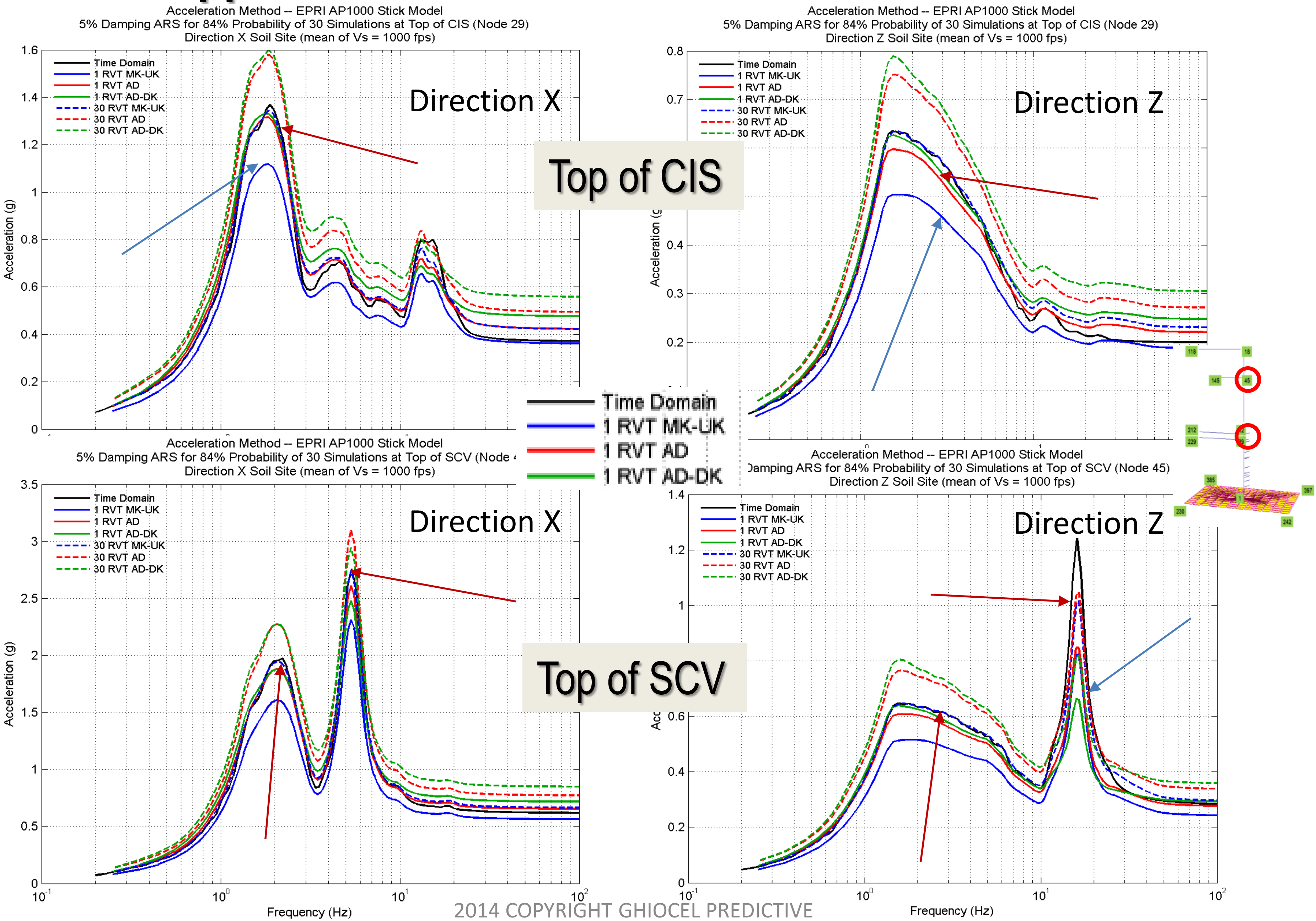
RVT Approach (ACC) vs. LHS for Soil – Mean ISRS



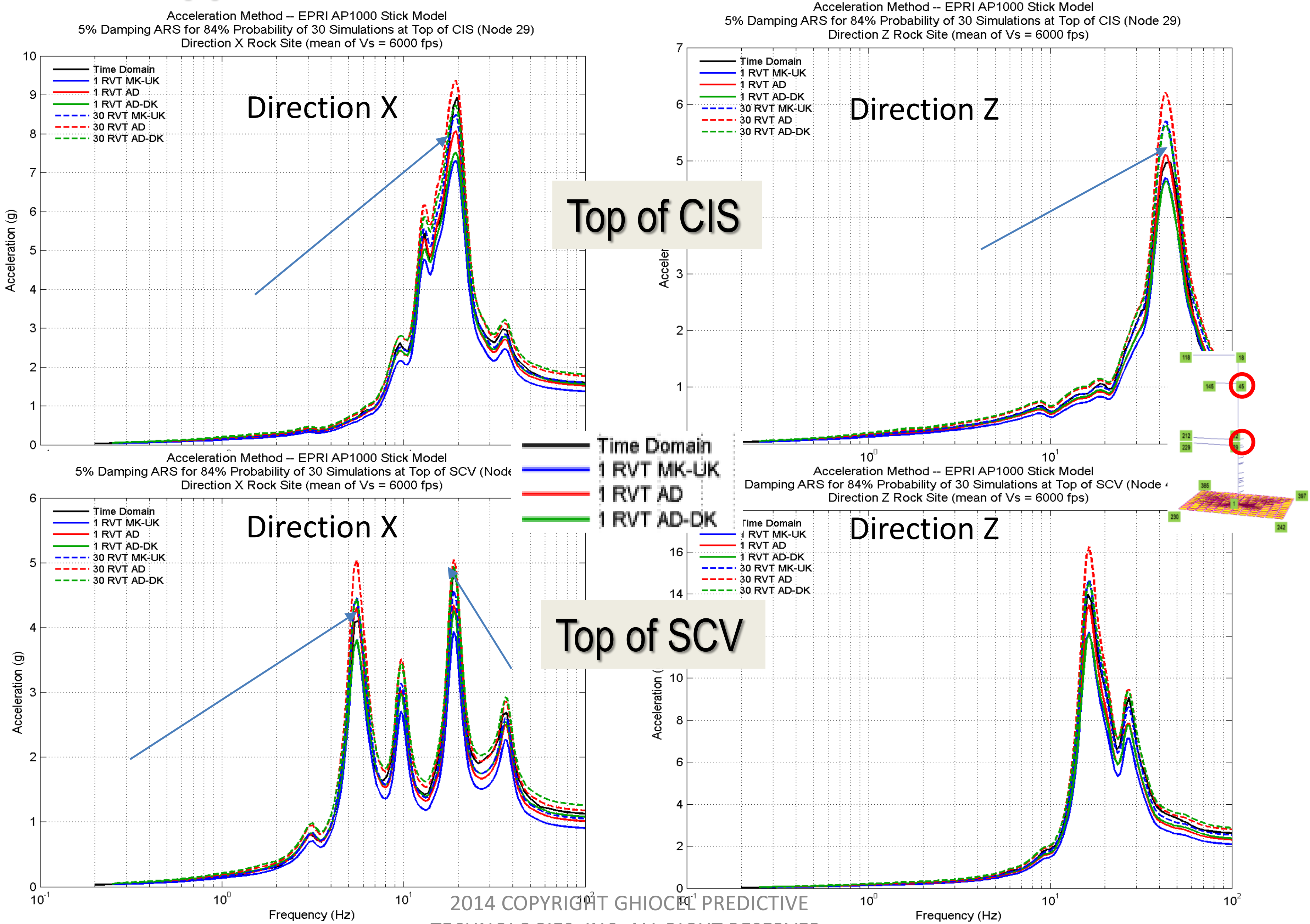
RVT Approach (DIS) vs. LHS for BE Soil – Mean ISRS



RVT Approach vs. LHS Results for Soil – 84% NEP ISRS



RVT Approach vs. LHS Results for Rock – 84% NEP ISRS



Conclusions for Investigated Cases

- For Probabilistic SSI analysis, the structure stiffness & damping uncertainties impact differently on ISRS for rock and soil sites

- For Probabilistic SSI analysis, the structure stiffness & damping uncertainties impact differently on ISRS depending on the floor elevation

- Probabilistic ISRS computed for 84% NEP show appear too low for *rock sites* due to the smoothing effect produced by statistical averaging on the sharp ISRS peaks - frequency shifts are an important parameter. *CAUTION! Guidelines needed; use higher NEP than 84%...?*

- RVT-based SSI approaches provide approximate solutions for the *mean* ISRS. However, the ISRS accuracy depend on the "*analytical equation*" used for computing maximum response (RS) of the Gaussian motion.

- RVT-based ISRS results for 84% NEP show large variations from method to method. *CAUTION! Guidelines needed..*