LIMITATION OF THE RVT SASSI APPROACH FOR APPLICATION TO SEISMIC SSI ANALYSIS OF NUCLEAR STRUCTURES

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Purpose of This Presentation:

The RVT SASSI approach as currently implemented is some SASSI versions has the apparent advantage that computes the seismic responses of the SSI system using directly the ground response spectra (GRS) input without the need of developing spectrum compatible input acceleration time histories.

The presentation discusses the theoretical basis of the RVT SASSI approach and explains why this approach can fail to provide reasonably accurate results for seismic SSI analyses.

Case studies include surface and embedded RB models, and deeply embedded SMR founded on rock and soil sites.

RVT SASSI Approach for Seismic SSI Analysis

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

$S_X(\omega) = |H_{SSI}(\omega)|^2 |H_0(\omega)|^2 S_u(\omega)$ or $S_X(\omega) = |H_X(\omega)|^2 S_u(\omega)$

ISRS Responses:

XPSD = H2SSIX * H2SDOF * GPSD

Other SSI Responses:

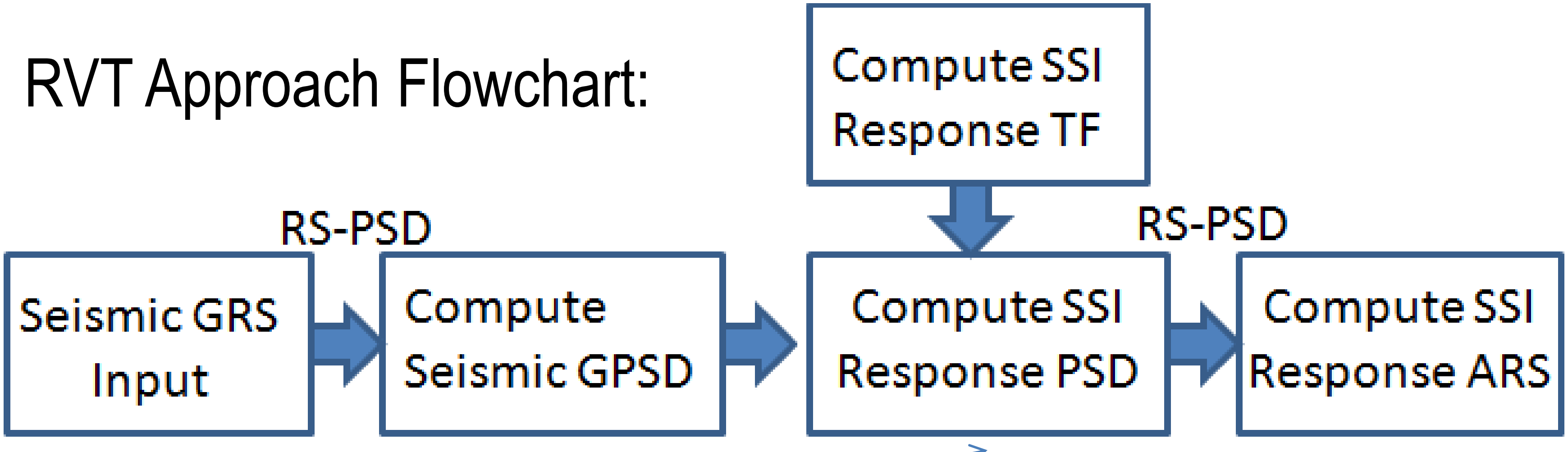
XPSD = H2SSIX * GPSD

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

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

RVT SASSI Approach for ISRS Responses

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)

Maximum SSI Response Based on RVT Solution

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

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) (1980,1981)

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

Basic Assumptions for (Linear) RVT Solution

1) It is based on the assumption that the seismic ground motion is a Gaussian stationary stochastic process.

This assumption might not be true if highly non-Gaussian "seed" records are used to generate the design-basis input time histories. More generally, real earthquake motion are not Gaussian.

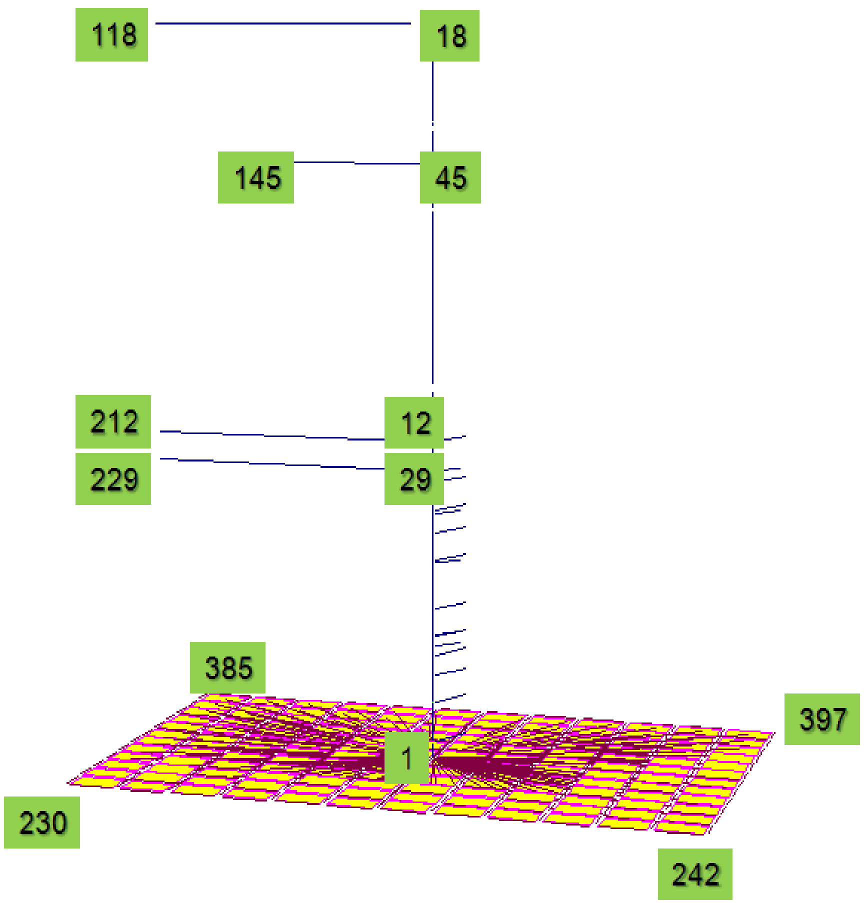
If the Gaussianity aspect is ignored, the RVT-based approach application becomes quite arbitrary, with results based on a case-by-case luck, and without a sound theoretical basis.

2) The ASCE 4-16 referenced RVT SASSI approach does not include the cross-correlations between the SSI response motions at different locations and between X, Y and Z components.

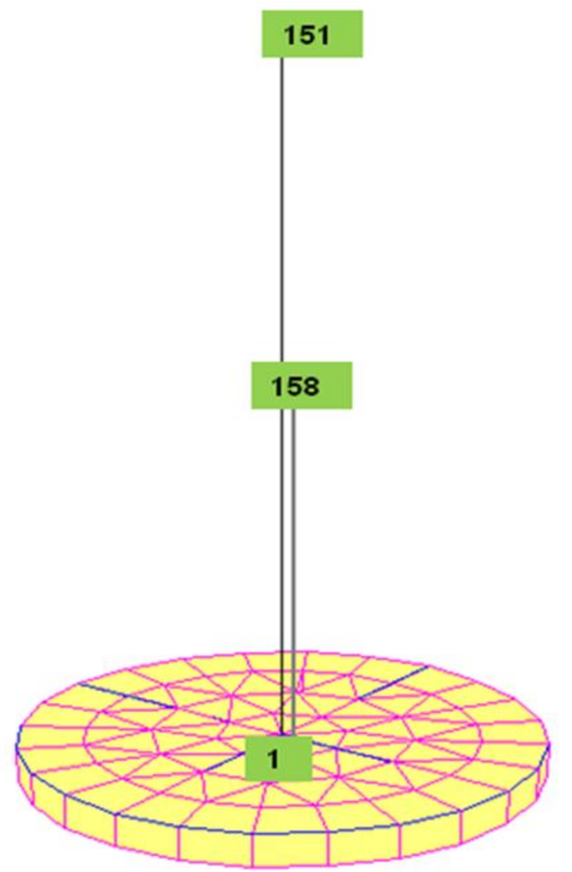
Inapplicable to multiple support time domain analysis of secondary systems.

Earlier Studies: 1) EPRI AP1000 NI & 2) RB Sticks

EPRI AP1000 NI Stick Model



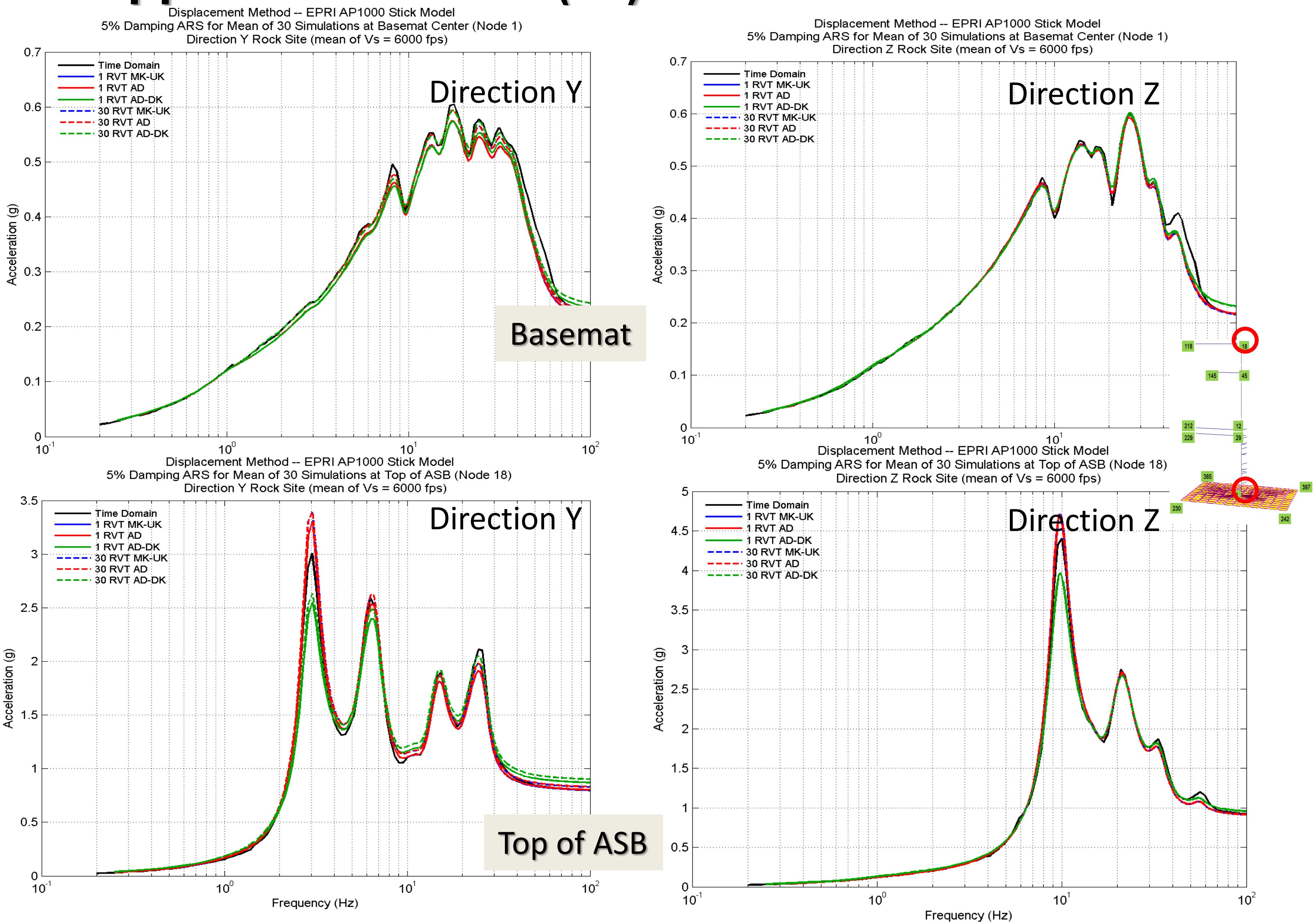
PWR RB Stick Model



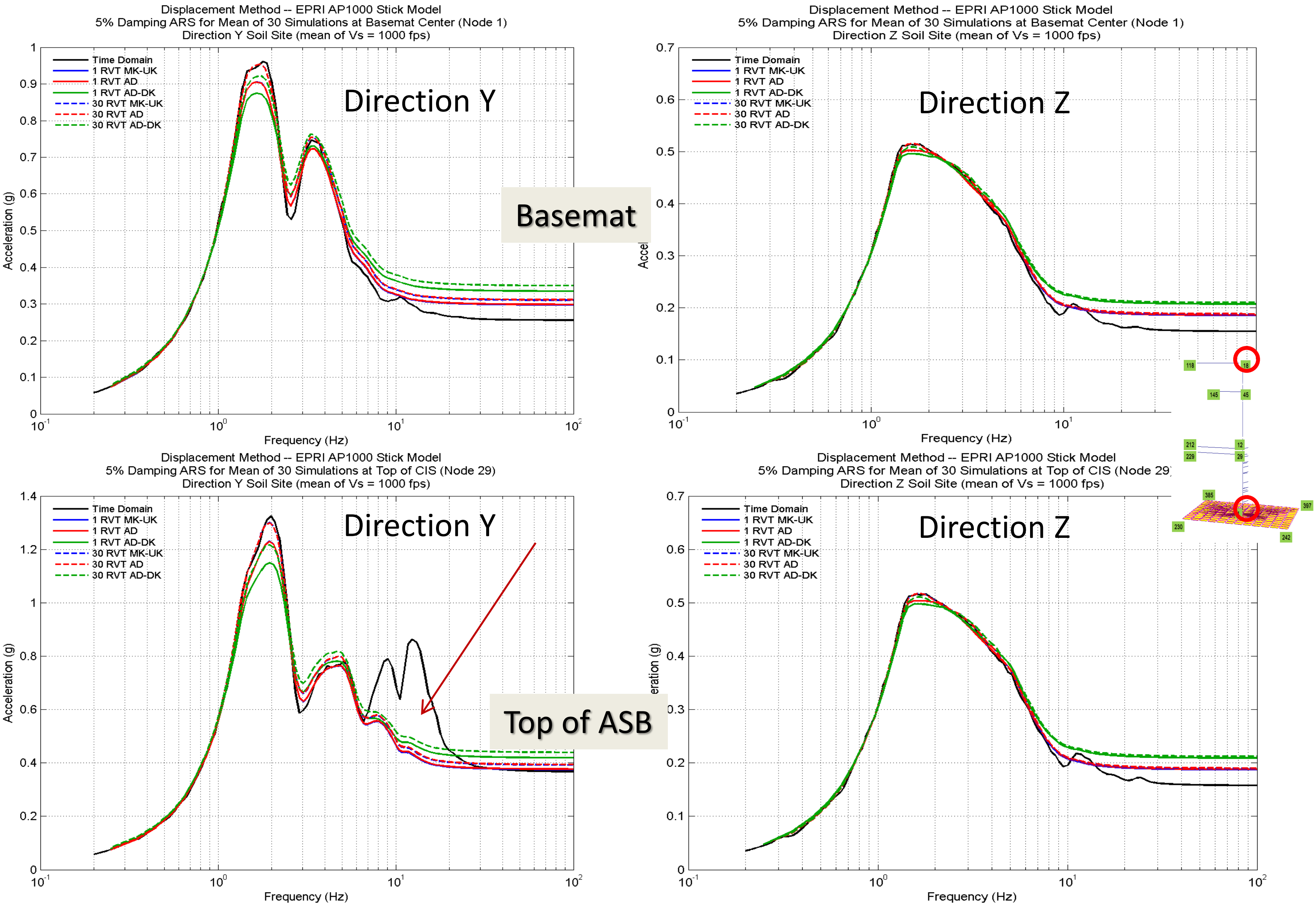
Case 1: Soil Site (BE Soil and Random Soil), Vs = 1,000 fps
Case 2: Rock Site (BE Soil and Random Soil), Vs = 6,000 fps

Ghiocel and Grigoriu, SMIRT22, 2013

RVT Approach vs. LHS (30) for Rock Site – Mean ISRS



RVT Approach vs. LHS (30) for Soil Site – Mean ISRS

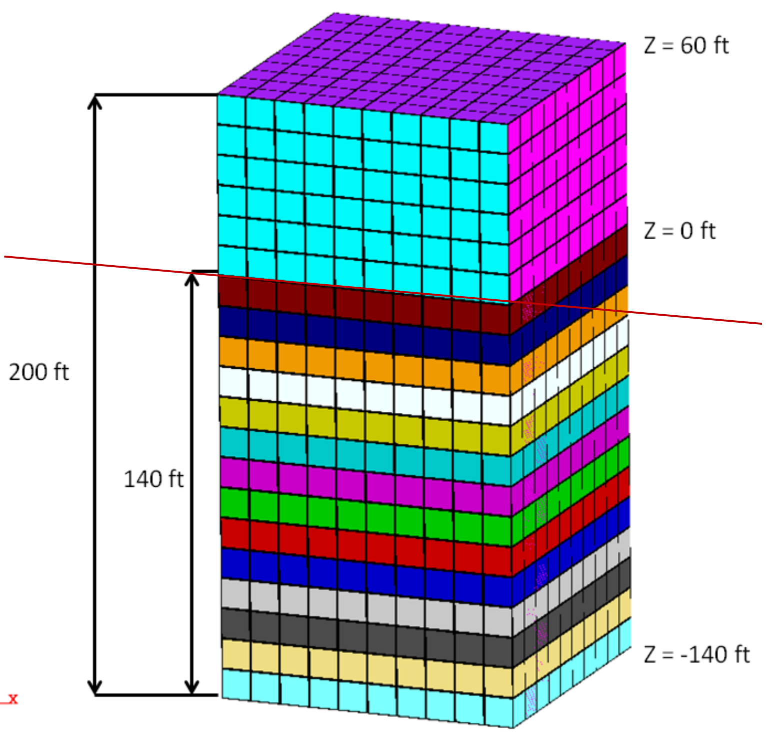


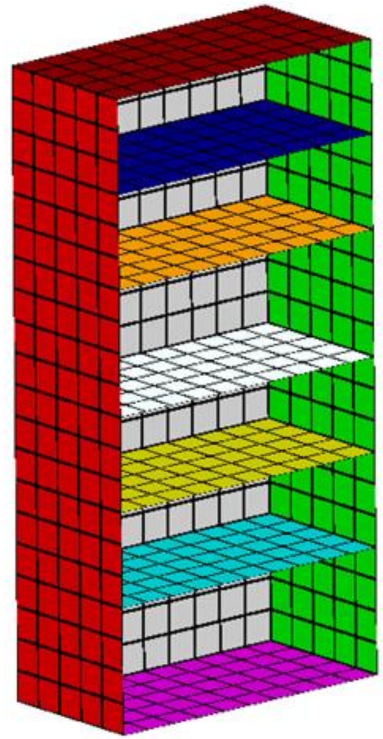
 DOE/NRC NPH Meeting, Oct 23-24, 2018

Deeply Embedded SMR RVT SSI Analysis Study

Volume Size: 200 ft x 100 ft x 100 ft

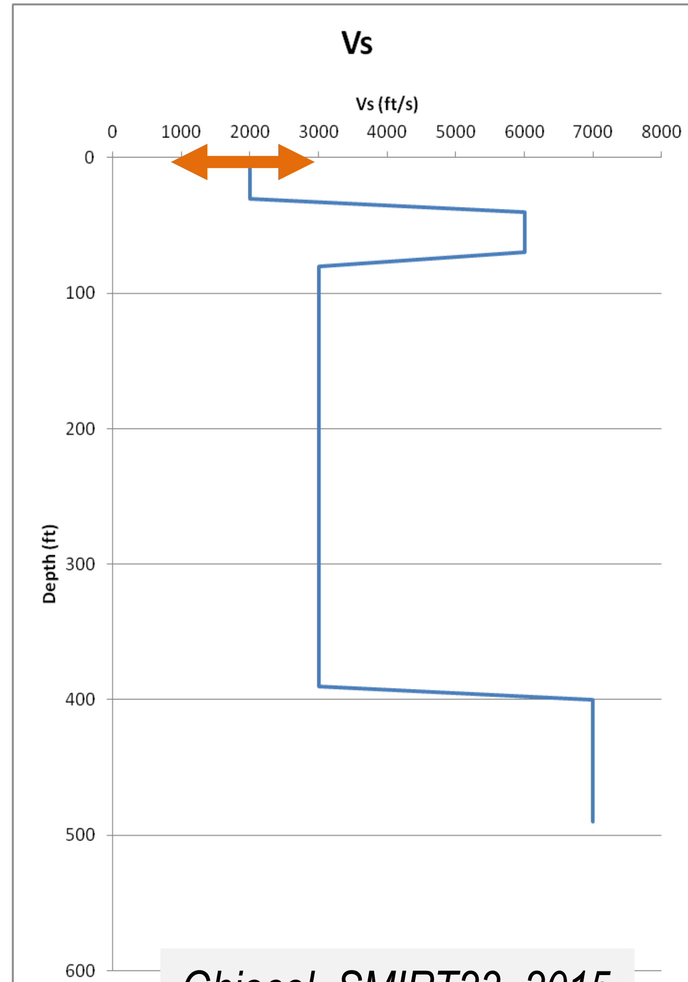
140 ft Embedded SMR Model





SMR size: 100 ft x 100 ft X 200 ft
Embedment: 140 ft
Mesh size: 10 ft X 10 ft X 10 ft
Number of Nodes: 2,580
Interaction Nodes: 1,815

Vs Soil Profile (fps)

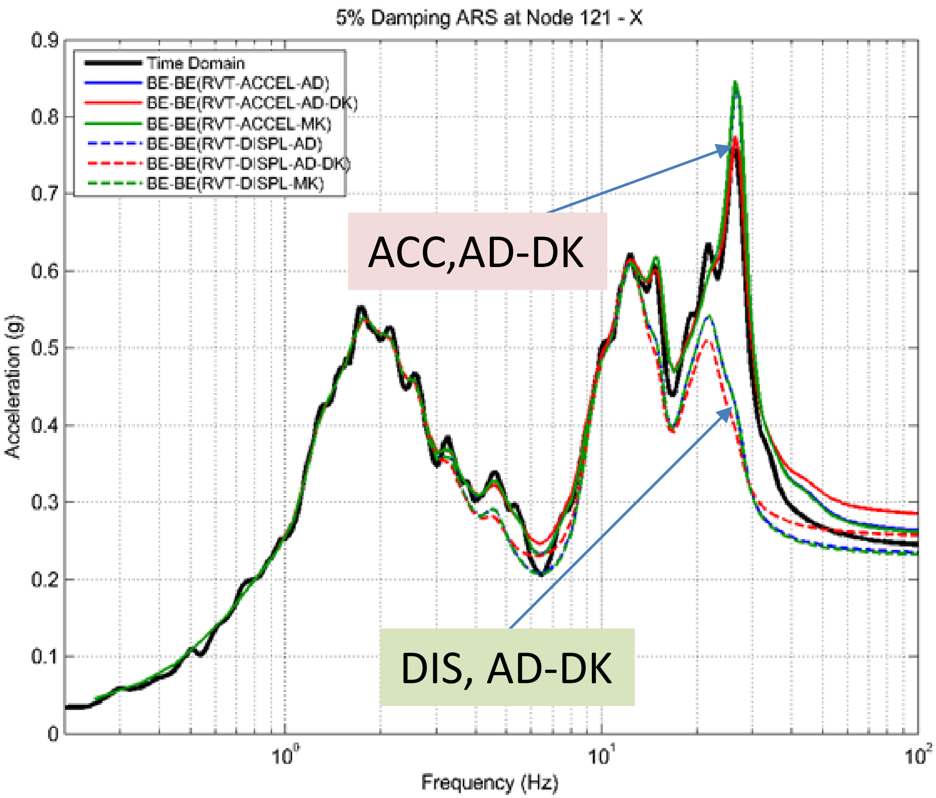


Ghiocel, SMIRT23, 2015

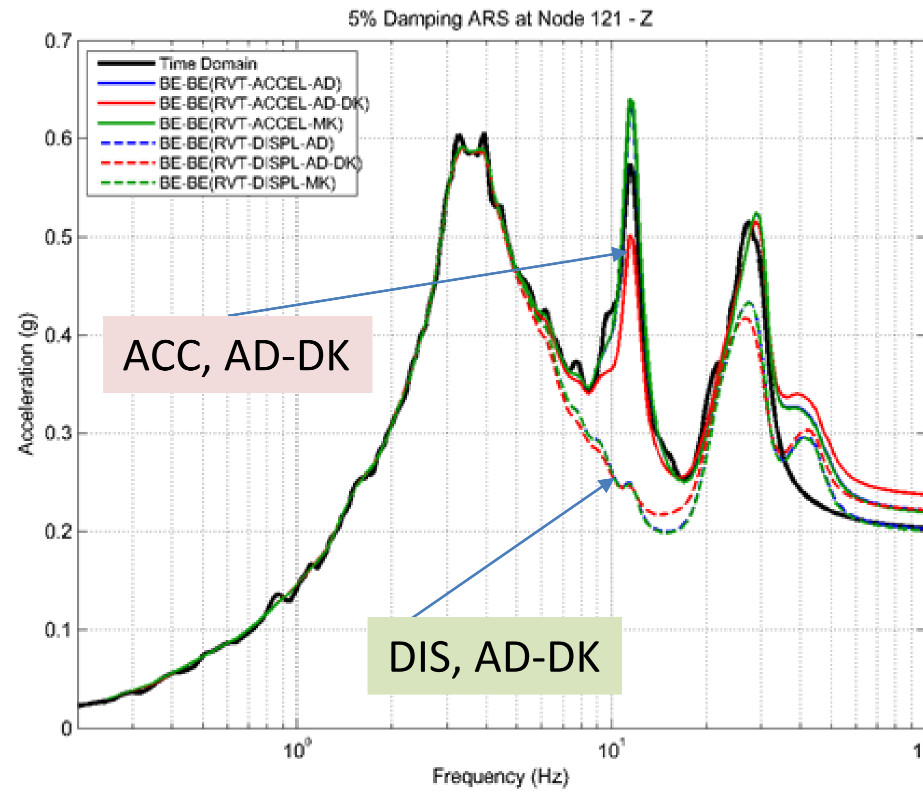
RVT vs. Deterministic SSI (5) for Nonuniform Soil ISRS at Basemat Level (Elevation 0ft)

Mean ISRS

Direction X



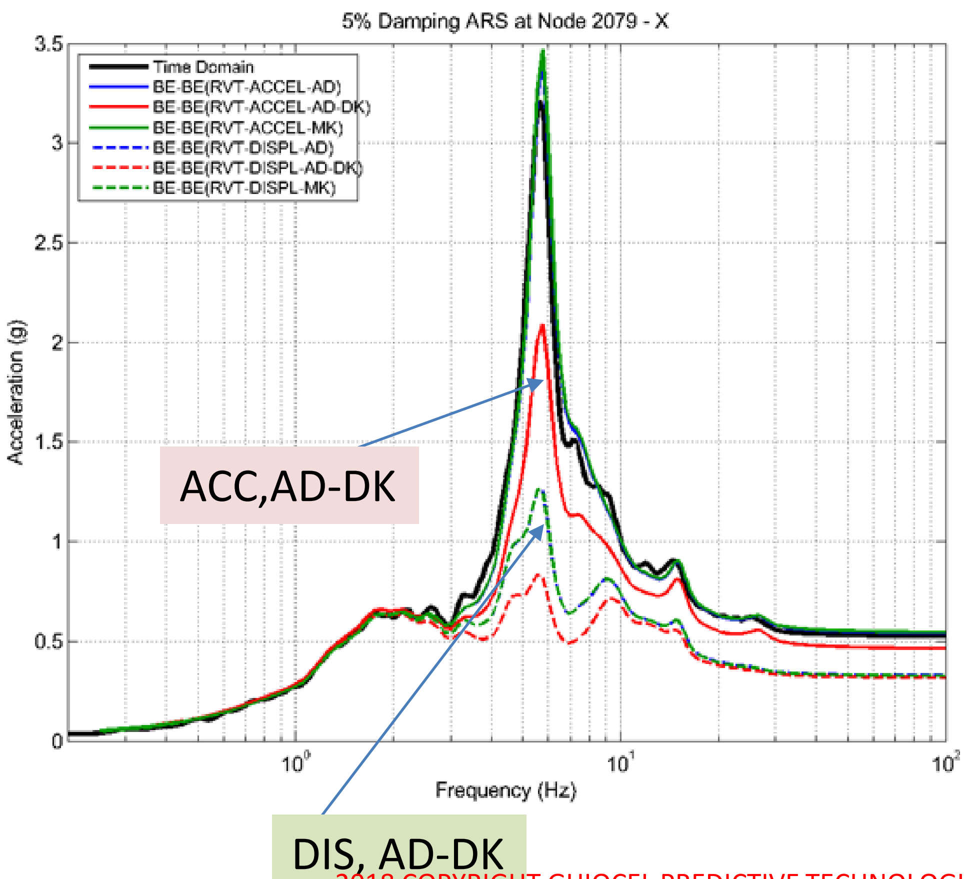
Direction Z



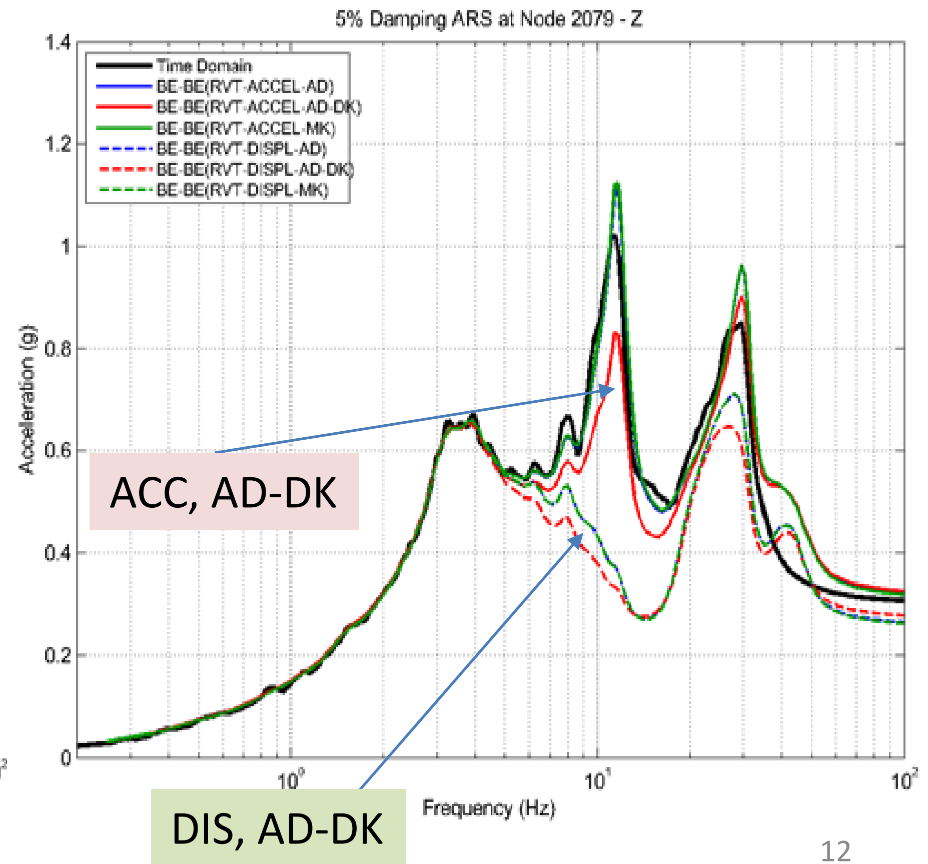
RVT vs. Deterministic SSI (5) for Nonuniform Soil at Roof Level (Elevation 200 ft)

Mean ISRS

Direction X



Direction Z



Concluding Remarks from Earlier Studies

The RVT SSI approach accuracy varies widely on a case-by-case basis.

- When the SSI responses are dominated by a single mode contribution, the RVT SASSI approach perform quite well.

- When multiple spectral peaks are present, then, there is a good chance of having missing ISRS peaks at higher frequencies (the 2nd or 3rd ISRS peak)

- The RVT SASSI approach is more accurate for the rock sites that have less SSI effects than for the soil sites that have larger SSI effects.

Earlier study results rised concerns on the RVT SASSI approach accuracy and its validation for SSI analysis. We decided not to include any RVT SSI analysis capability in our ACS SASSI software.

The Pitfall of RVT SASSI Approach: Single Peak Factor Used for MDOF SSI Systems

The RVT SASSI approach uses a single peak factor and single set of spectral moments based on AD-DK, which is applicable to *broad band spectra and SDOF responses to WN/FWN input motions* (Der Kiureghian's, 1980, 1981)

In the EERC 80-15 report, pages 8-9, the Der Kiureghian uses for MDOF systems separate peak factors for each system vibration mode. These modal *peak factors* (see eqs. 16-17) depend on the computed mean crossing rates that are *a function of the mode frequency and damping*.

Each mode that produce a resonant spectral peak has its own peak factor.

Using a *single peak factor* is *accurate only for broad band ISRS that behave close to SDOF systems, not for MDOF systems for which ISRS might have multiple peaks.*

Computation of SSI Response Peak Factors Using AD-DK SDOF System Solution Under WN/FWN Inputs

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

AD-DK Peak factors for mean (p) and std. dev. (q) of the maximum response, Xmax:

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

Mean-crossing rate for Gaussian process X

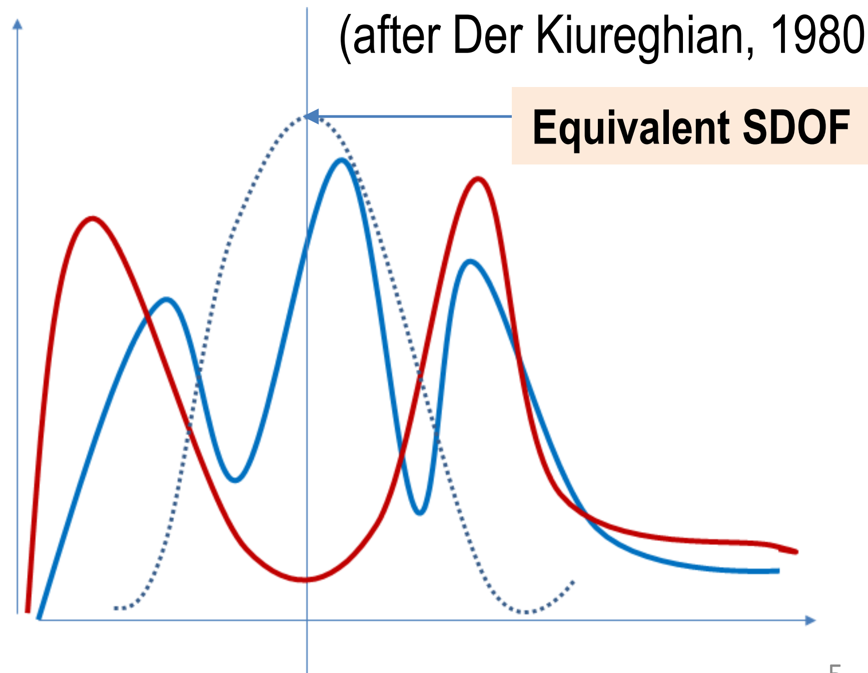
$$\nu_0 = \frac{1}{\pi}\frac{\sigma_{\dot{X}}}{\sigma_X} = \frac{1}{\pi}\sqrt{\frac{\lambda_2}{\lambda_0}}$$

Where spectral moments are defined by

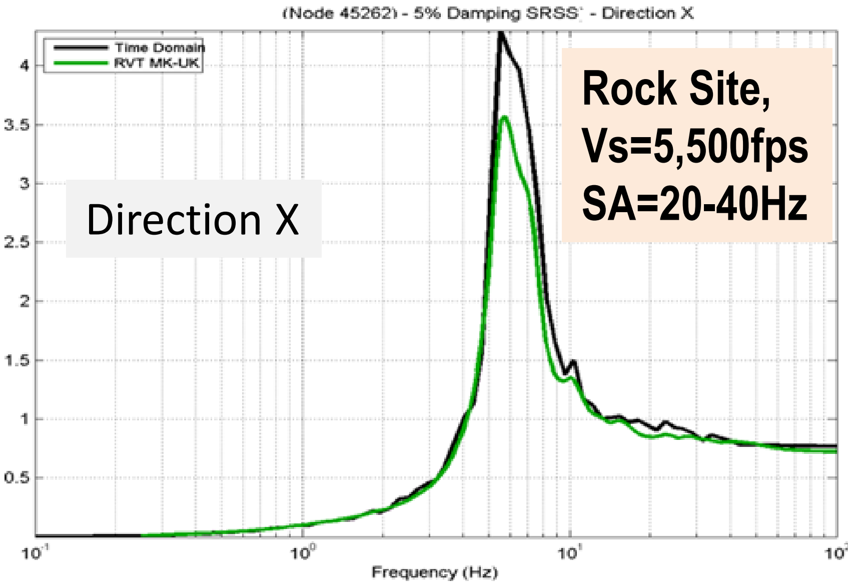
$$\lambda_i = \int_0^\infty \omega^i S(\omega)\, d\omega$$

Only the 0 and 2nd order spectral moments are considered, so that PSD shape details are lost

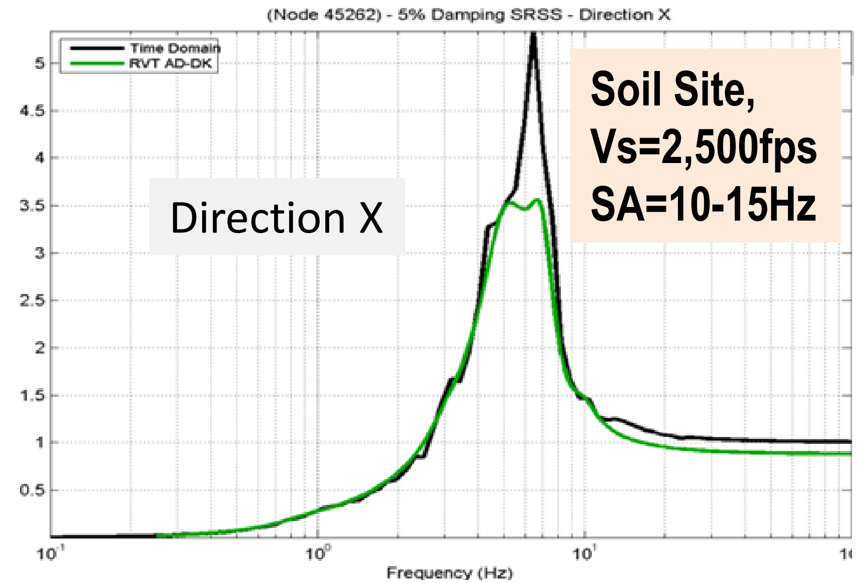
(after Der Kiureghian, 1980)



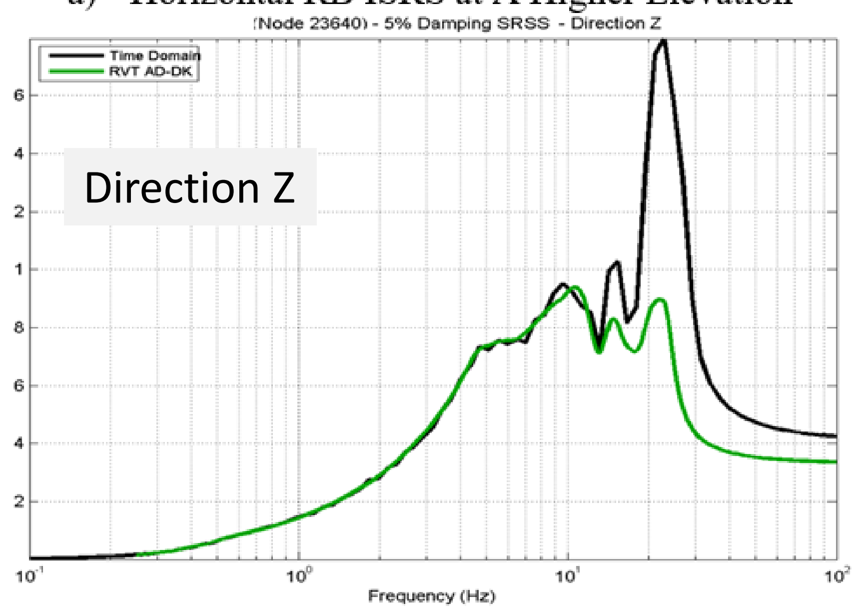
Embedded RB Complex on Rock and Soil Sites



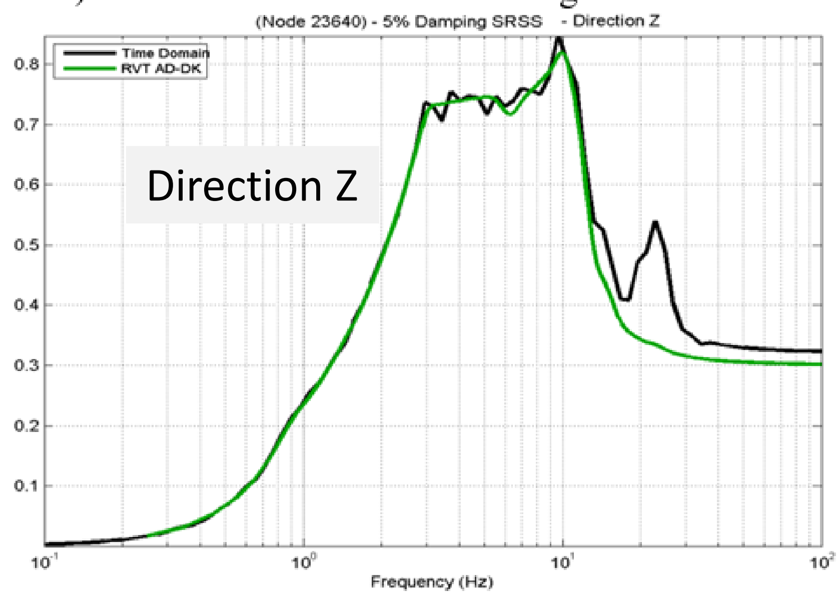
a) Horizontal RB ISRS at A Higher Elevation



a) Horizontal RB ISRS at A Higher Elevation

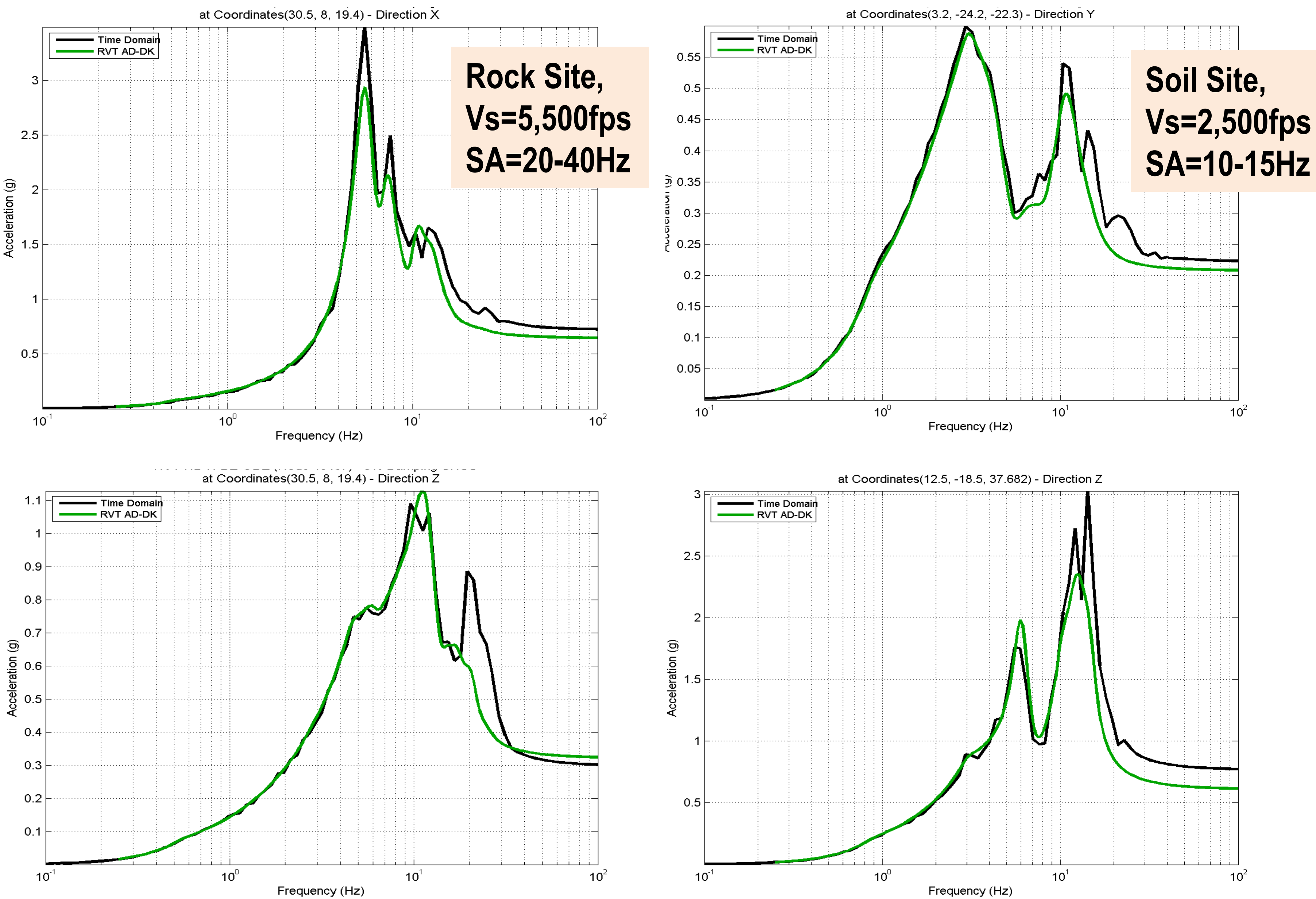


b) Vertical RB ISRS at A Higher Elevation

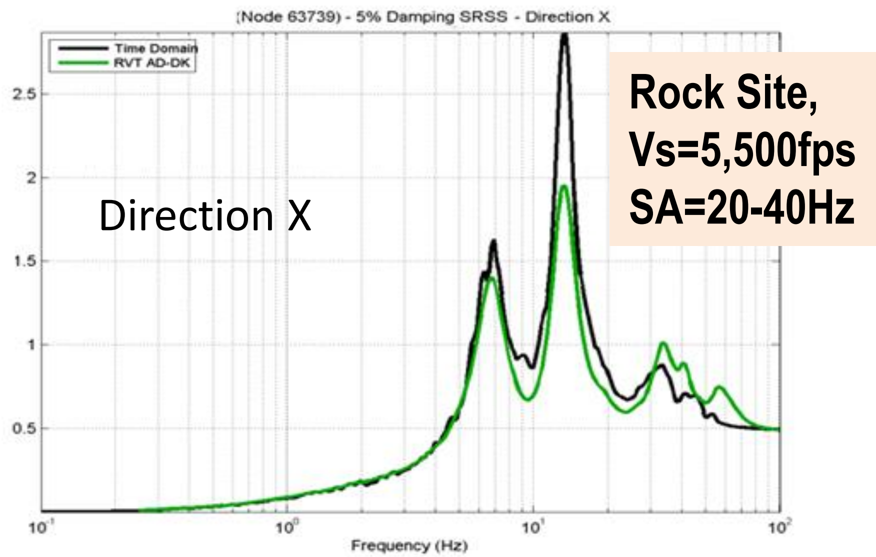


b) Vertical RB ISRS at A Higher Elevation

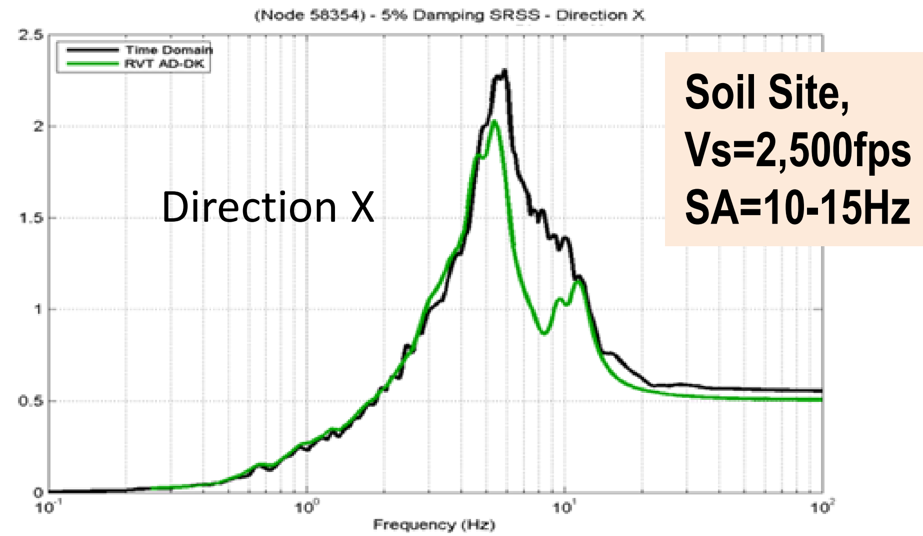
Embedded RB Complex on Rock and Soil Sites



Deeply Embedded Building on Rock and Soil Sites

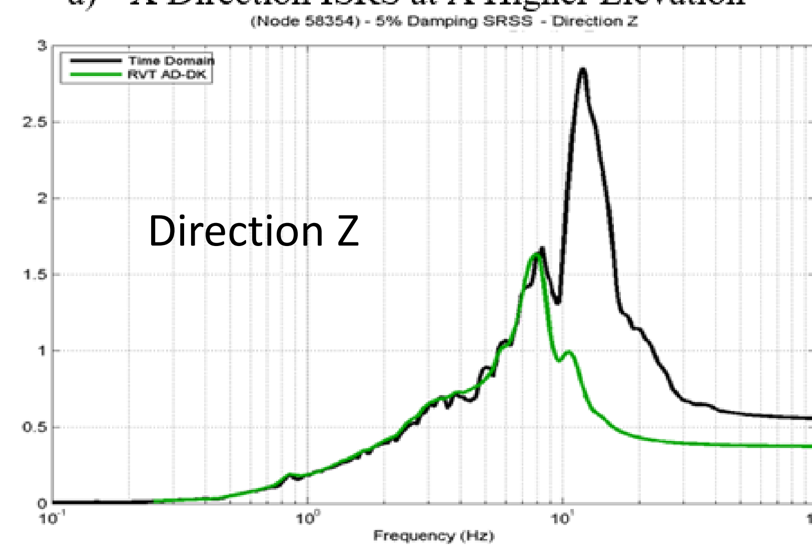


a) X Direction ISRS at A Higher Elevation



a) X Direction ISRS at A Higher Elevation

b) Y Direction ISRS at A Higher Elevation



a) Z Direction ISRS at A Higher Elevation

Conclusions

The RVT SSI approach accuracy varies widely on a case-by-case basis. In this paper *we selected on the worst case study examples*.

As explained in the paper, the theoretical basis of the RVT SASSI approach is on based on the RVT SDOF system solution.

This presentation should be considered as a warning for structural analysts, who are attracted for saving time by using the RVT SASSI approach to avoid having multiple input sets of acceleration time-histories.

I personally believe that the RVT SASSI approach, as currently implemented in some SASSI codes, *should be used very cautiously* for performing seismic SSI analysis of the nuclear safety-related structures, and only after case-by-case detailed validations are performed for all three deterministic soil profiles, LB, BE and UB soils.

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