Comparative Probabilistic-Deterministic Investigations for Evaluation of Seismic SSI Response

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Purpose of This Presentation:

*To present comparative probabilistic vs. deterministic SSI analysis results for nuclear structures.*

The applied Probabilistic SSI approaches are those recommended by the new ASCE 04-2013 standard.

Both soil and rock sites are considered.

Comparisons are made in ISRS.

ACS SASSI Option Pro was used for probabilistic SSI analyses.
ASCE 04-2013 Probabilistic SSI Analysis

The new ASCE 04-2013 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 random variables.
Probabilistic Seismic Input

Method 1

Same Spectral Shape (Scaling)

Random Scale Factor Model

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

Method 2

Random Spectral Shape

Random Soil Amplification

Include Local Soil Conditions

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

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

Simulated GRS Inputs

Simulated Soil Profiles

 Note: Only 30 LSH simulations were used

(Full correlation with depth)
Simulated Probabilistic Seismic GRS (Method 2)

Probabilistic UHRS Input
0.30 ZPGA

Probabilistic Horizontal GRS Simulation
Including for 16%, 50% and 84%
Non-exceedance Probability

c.o.v. = 15%; Correl. Length = 1 Hz

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

Random Samples
Effect of Spatial Correlation Length on Simulated Soil Profiles

![Graph of soil profiles for Sample 1 with a correlation length of 2 ft.]

![Graph of soil profiles for Sample 2 with a correlation length of 20 ft.]

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Probabilistic Structural Modeling (Stiffness & Damping)

- Effective stiffness ratio $K_{eff}/K_{elastic}$ and damping ratio, $D_{eff}$, are modeled as statistically dependent random variables.

- $K_{eff}/K_{elastic}$ and $D_{eff}$ can be considered negatively correlated, or having a complementary probability relationship, or $D_{eff}$ be a response function of $K_{eff}/K_{elastic}$ based on experiments.

$D_{eff} = f(K_{eff}/K_{elastic})$

- $K_{eff}$ and $D_{eff}$ are defined separately for each element group. Statistical correlation between different group $K_{eff}$ variables can be included.

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Case Studies: 1) EPRI AP1000 NI & 2) PWR RB Sticks

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

Deff = f (Keff)

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

- Horizontal, Y (c.o.v.=20%)
- Vertical, Z (c.o.v.=25%)
- Vs Profile (c.o.v.=20%)
- D Profile (c.o.v.=30%, correl. = -60)

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

Horizontal, Y (c.o.v.=20%)
Deterministic vs. Probabilistic SSI Analysis for Soil Site

CASE A: Deterministic Mean (Mean GRS, Soil LB, BE, UB, and Struct Mean $K_{eff}=0.90$ and $D_{eff}=6\%$)

Direction Y

Det ranges Prob 60\%-80\%

Direction Z

Det ranges Prob 85\%-95\%

UB role
Deterministic vs. Probabilistic SSI Analysis for Rock Site

CASE A: Deterministic Mean (Mean GRS, Soil LB, BE, UB, and Struct Mean $K_{eff} = 0.90$ and $Deff = 6\%$)

- **Direction Y**: Basemat
  - Det ranges: Prob 65%-80%

- **Direction Z**: Top of ASB
  - Det ranges: Prob 65%-95% (UB role)
Deterministic vs. Probabilistic SSI Analysis for Soil Site

CASE B: Deterministic ASCE (Mean GRS, Soil LB, BE, UB, and Struct Code Keff=1.00 and Deff=4%)

Det ranges Prob 85%-80% (Basemat)

Det ranges Prob 85%-95% (UB role)
Deterministic vs. Probabilistic SSI Analysis for Rock Site

CASE B: Deterministic ASCE (Mean GRS, Soil LB, BE, UB, and Struct Code Keff=1.00 and Deff=4%)

Direction Y (Transversal)

Direction Z (Vertical)

NOTE: 229 node location sensitive to torsional and rocking motion components
Probabilistic SSI Using Alternate Simulation Approaches

60 LHS Simulations

30 LHS Simulations

Same GRS Shape (Method 1)

Independent Vs per layer

Same GRS Shape (Method 1)

Fully correlated Vs per layer

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Comparative Results for Probabilistic SSI Approaches

Direction Y

Direction Z

Basemat

Top of ASB

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Conclusions

• The ASCE 04-2013 standard goal, that Deterministic SSI produces SSI responses that correspond to approximately 80% NEP, is accomplished in an overall, average sense.

• Exceptions appear to correspond to particular cases of large mass eccentricity structures that are more sensitive to rotational motions, including torsional and rocking motions. More investigations are needed, and currently underway.

• Using lower damping in structure in Deterministic SSI analysis impacts larger for the rock sites for which radiation damping is much lower. More investigations are needed, and currently underway.