ASCE 4-16 STANDARD-BASED PROBABILISTIC SEISMIC SSI ANALYSIS; PART 1 APPLICATION FOR DESIGN-BASIS LEVEL (DBE)

Dr. Dan M. Ghiocel
Email: dan.ghiocel@ghiocel-tech.com
Phone: 585-641-0379
Ghiocel Predictive Technologies Inc.
http://www.ghiocel-tech.com

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Purpose of This Presentation:

To show the application of the ASCE 4-16 based probabilistic SSI analysis for *Design-level (DBE) applications*.

To answer to a question:

Is the ASCE 4-16 probabilistic SSI responses with 80% NEP more conservative or less conservative than the ASCE 4-16 deterministic SSI responses for the *design-level* analyses?

To be able to answer to this question, we investigated a number of case studies. Herein, we show few representative results from four SSI case studies including surface and deeply embedded structures on rock and soil sites.

*ACS SASSI V3 with Options PRO and NON* was used.
ASCE 4-16 Based Probabilistic vs. Deterministic SSI Analysis Case Studies

RB Complex Case 1: RC Uncracked PRO Linear
- 160 ft
- Rock, Vs=6000 fps
- Soil, Vs=1000 fps

RB Complex Case 2: RC Uncracked DET Linear
- 350 ft
- Rock, Vs=6000 fps
- Soil, Vs=1000 fps

SMR Case 3: RC Uncracked PRO Linear
- 100 ft
- Nonuniform Soil
- Vs=2000-7000 fps

Aux Bldg. Case 4: RC Cracked Nonlinear
- 260 ft
- Rock, Vs=5000-7000 fps
- Nonuniform Soil, Vs=800-3500 fps
ASCE 4-16 Probabilistic Site Response Analysis (PSRA) and Probabilistic SSI Analysis (PSSIA)

Based on the new ASCE 04-2016 recommendations:

- Probabilistic SSI analyses should be performed using at least 30 LHS randomized simulations.

- For the design-level applications, probabilistic SSI responses should defined for the 80% non-exceedance probability (NEP).

- Probabilistic modeling should minimally include:
  - SEISMIC INPUT: GMRS/UHRS amplitude assumed to randomly varying (Methods 1 and 2).
  - SOIL PROFILE: Vs and D soil profiles
  - STRUCTURE: Effective stiffness and damping, as functions of stress/strain level in different parts of structure.
ASCE 4-16 Probabilistic SSI Simulation Concept

Negative Correlation

Stiffness

Damping

ACS SASSI with Options PRO and NON

GRS Shape

Spatial correlation

2D Soil Profiles

Negative Correlation

Vs

D

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Probabilistic Seismic Input Models

**ASCE 04 Method 1**

*No variation of spectral shape*

**ASCE 04 Method 2**

*Include variation of spectral shape*
Vs and D Soil Profile Probabilistic Models Using Multiple Segments Split

Different statistical properties for different soil profile segments in depth
Vs and D Soil Profile Probabilistic Models.

Two Variation Scale Models Based on Field Data

Model 1 (Simple)

Model 2 (Composite)

(Popescu, 1996)
Probabilistic Simulations of Soil Profiles & Curves

Model 1

Model 2

Simulated vs. Target Soil Vs Profiles Using Method 1 (left) and Method 2 (right)

Soil G/Gmax and D Curve Random Variations (left); Simulated G/Gmax for 4 Soil Curves (right). The Mean Values of 4 Soil Curves Are Plotted with Green Lines.
Probabilistic Linear Structural Models; Effective Stiffness and Damping Depend on Wall Strain Levels

- Keff/Kel and Deff variables should be defined by user for each element group.

- Effective stiffness ratio Keff/Kelastic and damping ratio, Deff, should be modeled as statistically dependent random variables. They can be considered negatively correlated, or Deff defined as a response function of Keff/Kelastic based on experimental tests.

Cracked concrete stiffness and damping values computed using both Option PRO and NON capabilities.
Probabilistic Nonlinear Concrete Structural Models Based on *Wall (Panel) Strain Levels*

Structure is split in wall panels with different materials

Backbone Curves Automatically Generated

$$V = G A_{shear} \gamma$$

Iterative SSI Fast Analyses Until Convergence

Iteration 1

Iteration 6
Case Study No. 1: Surface RB Complex with 160ft Foundation Size on Rock and Soil Sites

60 Probabilistic GRS Input Simulations (ASCE 4-16, Method 2)

Rock Site

Soil Site

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60 Probabilistic Soil Layer Simulations

**Rock Site**
MODEL 1: correlation length (60ft), coefficient of variation (0.2 for Vs; 0.3 for Damping)

**Soil Site**
MODEL 1: correlation length (40ft), coefficient of variation (0.2 for Vs; 0.3 for Damping)
• Simulate 87 material types: Group 1 Solid (4); Group 2 Beam (27); Group 3 Shell (56)
• Mean of Stiffness: 0.8; Coefficient of Variation: 0.1
• Correlation Matrix: without correlation
• Damping Computation: Using a response function shown below:
ISRS for Surface RB Complex (160ft size) on Rock

**NC Complex Model (Coherent) - 60 Simulations - Rock SITE**
5% Damping SRSS - Corner/Bottom at Coordinates (118.5, 27.5, 0) - Direction X

**Deterministic (BE)**
- **Deterministic (LB)**
- **Deterministic (LB)**
- **Mean**
- **84% Probability**

**NC Complex Model (Coherent) - 60 Simulations - Rock SITE**
5% Damping SRSS - Corner/Bottom at Coordinates (118.5, 27.5, 0) - Direction Z

**Deterministic (BE)**
- **Deterministic (LB)**
- **Deterministic (LB)**
- **Mean**
- **84% Probability**

**NC Complex Model (Coherent) - 60 Simulations - Rock SITE**
5% Damping SRSS - Center/Middle at Coordinates (0, 0, 101.5) - Direction X

**Deterministic (BE)**
- **Deterministic (LB)**
- **Deterministic (LB)**
- **Mean**
- **84% Probability**

**NC Complex Model (Coherent) - 60 Simulations - Rock SITE**
5% Damping SRSS - Center/Middle at Coordinates (0, 0, 101.5) - Direction Z

**Deterministic (BE)**
- **Deterministic (LB)**
- **Deterministic (LB)**
- **Mean**
- **84% Probability**

**RC Uncracked PRO Linear**

160ft

**Elevation**

X

Z

Higher Elevation

X

Z
ISRS for Surface RB Complex (160ft size) on Soil
Case Study No. 2: Surface RB Complex with 360ft Foundation Size on Rock and Soil Sites

60 Probabilistic GRS Input Simulations (ASCE 4-16, Method 2)

Rock Site

Soil Site
60 Probabilistic Soil Layer Simulations

Rock Site

MODEL 2: correlation length (50ft), coefficient of variation (0.2 for Vs; 0.3 for Damping, correlation -0.40)

Soil Site

MODEL 2: correlation length (30ft), coefficient of variation (0.2 for Vs; 0.3 for Damping, correlation -0.40)
ISRS for Surface RB Complex (360ft size) on Rock Basemat Elevation

Y

Z

Higher Elevation

RC Uncracked DET Linear 350ft

RBC (Rock, Mean) -- ARS (Node 30)
Direction Y at Bottom E-Corner N

Mean of Coherent
84% Probability for Coherent
Mean of Incoherent
84% Probability for Incoherent
Deterministic Env. (Coherent)
Deterministic Env. (Incoherent)

Mean of Coherent
84% Probability for Coherent
Mean of Incoherent
84% Probability for Incoherent
Deterministic Env. (Coherent)
Deterministic Env. (Incoherent)

Y

Z

Amplitude

Frequency (Hz)

10^{-1} 10^{0} 10^{1} 10^{2}

10^{-1} 10^{0} 10^{1} 10^{2}
ISRS for Surface RB Complex (360ft size) on Rock
Case No. 3: Probabilistic vs. Deterministic SSI For Deeply Embedded SMR Structure

**STIFFNESS and DAMPING:**

Prob $\frac{K_{eff}}{K_{el}}$ Mean = 0.80; C.O.V. = 10%
Prob $D_{mean}$ = 6%; C.O.V. = 30%

$\frac{K_{eff}}{K_{el}}$ and $D$ correlation -0.8

Det $\frac{K_{eff}}{K_{el}}$ = 1
Det $D$ = 4%

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

140 ft Embedment SMR SSI Model (use FV method)
Using Model 1

c.o.v. (Vs) = 20%, c.o.v. (D) = 30%, corr (Vs, D) = -0.40 plus corr. length

Using Model 2

FIRS Input

Mean UHRS Input

Vs = 9,200 fps

Probabilistic and Deterministic Soil Profiles

Vs (fps)

Depth (ft)
60 and 500 Probabilistic Simulations for Outcrop FIRS in Horizontal and Vertical Directions

Horizontal

Vertical

60 Simulations

500 Simulations
Probabilistic Horizontal ISRS (Mean and 80% NEP) vs. Deterministic (LB, BE, UB) at Elev. 0 ft (Foundation Level)
Probabilistic Vertical ISRS (Mean and 84% NEP) vs. Deterministic (LB, BE, UB) at Elev. 0 ft (Foundation Level)
Probabilistic Horizontal ISRS (Mean and 80% NEP) vs. Deterministic (LB, BE, UB) at El. 170ft (30ft above ground)
Probabilistic Horizontal ISRS (Mean and 80% NEP) vs. Deterministic (LB, BE, UB) at El. 170ft (30ft above ground)

Model 1

STIFFNESS and DAMPING:
Det $K_{eff}/K_e = 0.80$
Det $D = 6\%$

Different Deterministic Seismic Input
Case No. 4: Probabilistic vs. Deterministic SSI
Surface Concrete Structure (Nonlinear Analysis)

Structure is split in wall panels with different materials

60 Probabilistic Backbone Curve Simulations

Selected ISRS Locations

Iterative SSI with 7% Deterministic Damping Cut-off

15% c.o.v.
60 Probabilistic Simulations for Surface GRS in Horizontal and Vertical Directions

Horizontal

Vertical

Rock Site

Soil Site

Frequency (Hz)

Acceleration (g)
Soil Site

MODEL 2: correlation length (30ft), coefficient of variation (0.25 for Vs; 0.3 for Damping, correlation -0.40)

Rock Site

MODEL 2: correlation length (50ft), coefficient of variation (0.2 for Vs; 0.3 for Damping, correlation -0.40)
ISRS for Surface Shearwall Structure on Rock

Basemat Corner (N480)

260ft

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ISRS for Surface Shearwall Structure on Rock

Top of Structure (N33)

RC Cracked Nonlinear

260ft
ISRS for Surface Shearwall Structure on Soil

Basemat Corner (N480)

260ft RC Cracked Nonlinear

AB ShearWall (Soil Site) – ARS (Node 482)
Direction X

Amplitude vs Frequency (Hz)

AB ShearWall (Soil Site) – ARS (Node 482)
Direction Y

Amplitude vs Frequency (Hz)

AB ShearWall (Soil Site) – ARS (Node 482)
Direction Z

Amplitude vs Frequency (Hz)
ISRS for Surface Shearwall Structure on Soil

Top of Structure (N33)

RC Cracked Nonlinear

260ft

X

Y

Z

Mean
80% Probability
Deterministic BE
Deterministic LB
Deterministic UB

Amplitude vs Frequency (Hz)

X

Y

Z

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Conclusions

Design-Level:

PSSIA and DSSIA were compared for the same seismic (mean) GRS input:

At Basemat & Lower Elevations:
- The 80% NEP Probabilistic ISRS responses appear to be slightly larger than Deterministic ISRS responses, especially for the rock sites.

At Higher Elevations:
- Deterministic ISRS responses are significantly larger than 80% NEP Probabilistic ISRS if lower damping values for uncracked concrete are included in the DSSIA. If the cracked concrete is included for both PSSIA and DSSIA, then, differences are reduced.

Special attention is required for poor structural designs with significant mass eccentricities (Case 4 for Soil Site) which are much more sensitive to the seismic input random variations, and for which PSSIA can provide much larger ISRS responses than DSSIA.