ASCE 4-16 STANDARD-BASED PROBABILISTIC SEISMIC SSI ANALYSIS; PART 2 APPLICATION FOR BEYOND DESIGN-BASIS LEVEL (BDBE)

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

DOE/NRC Natural Phenomena Hazards Meeting
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Case Study No. 1:
ASCE 4-16 Probabilistic SSI Simulation-Based Fragility Analysis

Low-Rise Reinforced Concrete Shearwall Building Example
Probabilistic SSI Analysis Performed Twice at Review Level(s) for Random and Composite Variations

Two probabilistic SSI analysis input sets are required for PSA investigations.

1) All the randomness and the epistemic uncertainty variations to get the total variability \( (\beta_C) \)
2) All the randomness variations to get the randomness variability \( (\beta_R) \)

Compute epistemic uncertainty variability from Steps 1 and 2 – using physics-based models.
ACS SASSI Main Software
Option A-AA (Integration with ANSYS)
Option PRO (Probabilistic SRA and SSI)
Option NON (Nonlinear Structure)

Option A-AA (ANSYS)
Option PRO (PSSI)
Option PRO (PSRA)
Option NON (Nonlinear SSI)

ACS SASSI Toolboxes

Future/Options HAZ and FRAG

Present/Options A-AA, NON and PRO,
Future/Options HAZ and FRAG

Future On--going
ASCE 4-16 Probabilistic SSI Based Fragility Analysis of Low-Rise RC Shearwall Building

Nuclear building model split in nonlinear panels; done semi-automatically using ACS SASSI UI

Using ACS SASSI Option NON the effective stiffness and damping is automatically computed for each LHS probabilistic simulation

Wood 1990 Panel Shear Capacity, and Cheng-Mertz Hysteretic Model
Rock Hazard Curve - Using 7, 3 and 1 Review Levels

0.25g GRS Simulations Using ASCE 4-16 Method 2

Horizontal
Spectral Amplitude
c.o.v. = 28%
c.l. = 10Hz

Vertical
**Random Soil Profiles:**

V1: $V_s$ c.o.v. = 15% and c.l. = 1,000 ft

V2: $V_s$ c.o.v. = 14% and c.l. = 100 ft

Total $V_s$ c.o.v = 20%

$\text{Corr}(V_s, D) = -0.40$

**Uncertain Scaling Factor:**

Means = 1;

$V_s$ c.o.v = 30%;

$D$ c.o.v. = 40%;
Random BBC Variations for Nonlinear Wall Panels

Panel 17

Random

Panel 25

BBC Variations:
Mean = Wood 1990 shear capacity
Random: c.o.v. = 15%
Composite: c.o.v. = 33.5%
Wall Panel Hysteretic Behavior for 0.95g Level

Panel 17

Random

Composite

Panel 25
Computed 84% NEP Shear Strain and Pf/a in Panels

- **0.10g Level (Uncracked)**
- **1.25g Level (Highly Nonlinear)**

84% NEP Shear Strains For Random Variations

Ln R/S Reliability Model to Build Fragility Curve (Pf/a Data)

Computed Pf/a for a=0.95g Level
Fitting Lognormal Models for Fragility Curves

\[
\ln(a) = \ln(\bar{a}) + K_p \Phi_{x}^{-1}(P_f)
\]

Linear Regression in Normal Space

Panel 17

\[
P_f(a) = \Phi\left(\frac{\ln(a/\bar{a})}{K_p}\right)
\]

Fitted Lognormal Models

Panel 25
Computation of Overall Risk, Unconditional $P_{\text{fail}}$

- Simulate Hazard Curves
- Simulate Fragility Curves
- Compute Simulated Total Risks
- Compute Overall $P_{\text{fail}}$ Probability Distribution
## Pfail for 7, 3 and 1 Level Seismic Hazard Levels

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<th>Displacement</th>
<th>pf mean</th>
<th>pf C.O.V.</th>
<th>pf 90%CDF</th>
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### 7 ZPGA Levels

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### 1 ZPGA Level; 1e-4 or 0.25g

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How good is Lognormal Model for Equipment Fragility Curves?

ARS for 5 Seismic Levels/2Hz Equipment Frequency

N9 Higher Elevation
Up and then down

N576 Lower Elevation
Up, monotonic
Lognormal Model for Fragility Curve Could Fail!

Lognormal CDF format for fragility curve breaks down!

N9 Higher Elevation
Up-down, Nonmonotonic FC

N576 Lower Elevation
Up, monotonic FC
Pf for N568 Y Using Point Data vs. Lognormal Fit

AB Shearwall Model (PF CDF) - Node 568 - Random
at Frequency 2Hz - Direction Y - 10000 Samples

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Lognormal CDF Fitting
Case Study No. 2:
ASCE 4-16 PSSI-Based Results vs.
EPRI DSSI-Based Results

Low-Rise Reinforced Concrete Shearwall Building Example
ASCE 4 Probabilistic SSI-Based Methodology

Probabilistic Simulation vs. Deterministic GMRS (Method 2)

Probabilistic Simulation vs. Deterministic Vs Profiles (LB, BE, UB)
EPRI Deterministic SSI-Based Methodology

The SSI analysis is performed for 5 SSI cases: BEstr-BEsoi, LBstr-BEsol, UBstr-BEsol, BEstr-LBsol, and BEstr-UBsoli.

The performance-based GMRS input is considered for seismic input. The ZPGA is 1g. For each SSI case, the Seismic input variability was considered by 5 sets of spectrum compatible acceleration histories based on “seed” records.

The 3 deterministic soil profiles, LB, BE and UB were obtained based on the 60 probabilistic nonlinear site response simulations assuming the UHRS inputs defined at bedrock (Vs > 9,200 fps).

The 3 deterministic structure stiffness variations included LB, BE and UB values. The concrete stiffness variations were elastic stiffness x 0.50 for BE, and -/+ 33% for LB and UB.

A total of 25 deterministic cases were considered (= 5 sets x 5 models).
Probabilistic SSI vs. Deterministic SSI Results

Mean and 84% NEP Wall Panel Shear Strain

Panel 17
Panel 28
ASCE 4 PSSI-Based ARS vs. EPRI DSSI-Based ARS

ARS at Node 482

AB ShearWall Model - 60 Simulations
5% Damping SRSS Node 482 at Direction X

AB ShearWall Model - 5% Damping SRSS
Node 482 at Direction X

Model - 60 Simulations
3S Node 482 at Direction Y

Model - 60 Simulations
3S Node 482 at Direction Y

Oct 23-24, 2018
ASCE 4 PSSI-Based ARS vs. EPRI DSSI-Based ARS

ARS at Node 568
Beyond Design-Level:

- **ASCE 4-16 provides a probabilistic physics-based modelling** for computing fragility data, reducing substantially the traditional fragility model subjectivity…. VERY IMPORTANT ASPECT

- **Traditional lognormal model for fragility curves appears to be too crude sometime when nonlinear SSI aspects are included.** This is especially true for the equipment fragility curves due to the ISRS resonant frequency shifting that is not captured by the simple lognormal probability model. *Different fragility curve models than lognormal fitted models might be needed to better fit the simulated responses.*

- **The multiple level/multipoint risk estimate approach provides significantly improved risk predictions.** Using $1e-5$ probability level with nonlinear SSI analysis as a review level is better than using $1-e4$ probability level with linear SSI analysis.
- ASCE 4-16 PSSI modelling, including the soil and nonlinear structure behaviour captures better the key physical aspects of the complex SSI phenomena

- ASCE 4-16 PSSI-based fragility results differ from the EPRI DSSI-based fragility results. Differences in the predicted risks/fragilities could be significant on a case-by-case basis. Need for more research investigations to cover many case SSI studies.

- ASCE 4-16 based probabilistic SSI analysis provides a significant improvement of the fragility calculation process based on a more refined physics-based computational SSI modeling.