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

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DOE/NRC Natural Phenomena Hazards Meeting

US NRC Headquarters, Rockville, MD

October 23-24, 2018

Case Study No. 1: ASCE 4-16 Probabilistic SSI Simulation-Based Fragility Analysis

Low-Rise Reinforced Concrete Shearwall Building Example

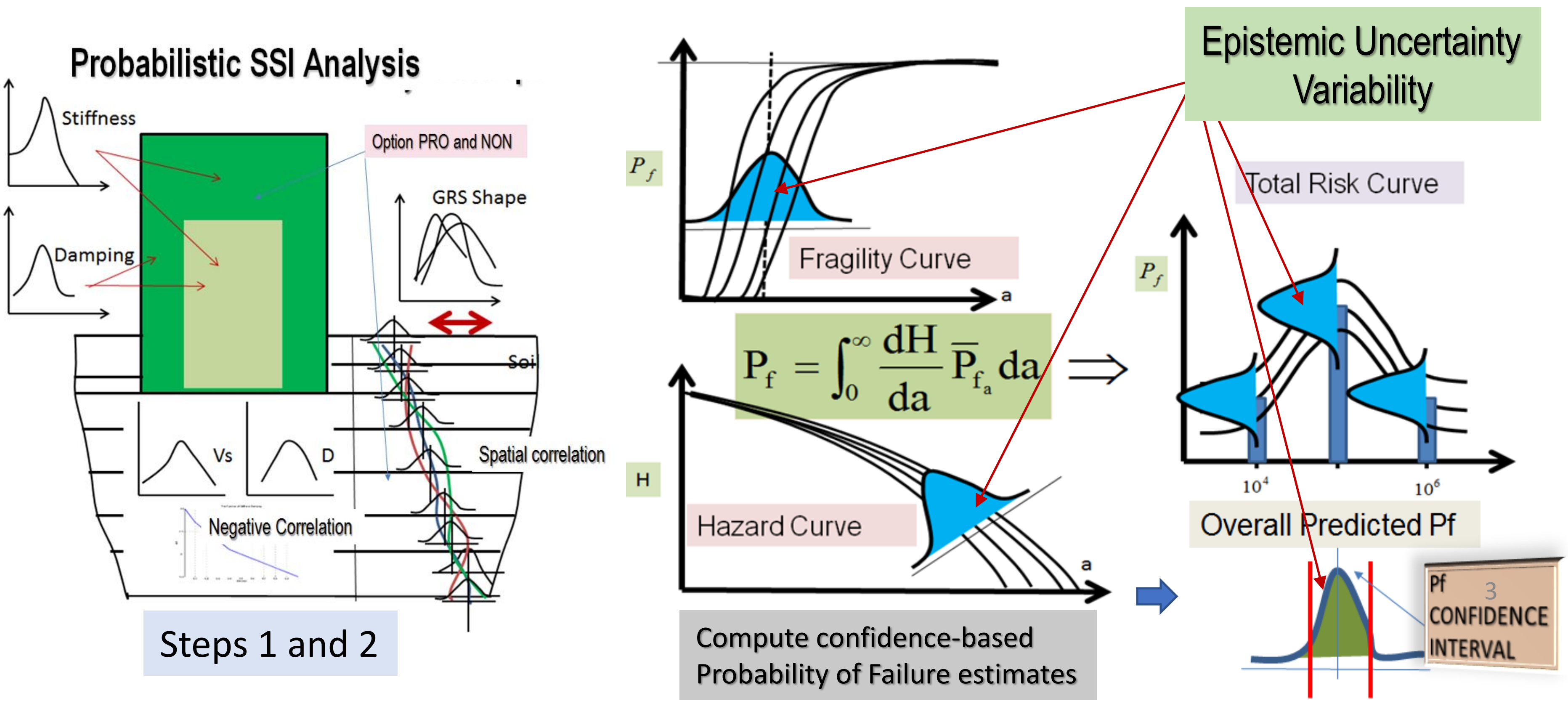
Probabilistic SSI Analysis Performed Twice at Review Level(s) for Random and Composite Variations

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 (β_C)

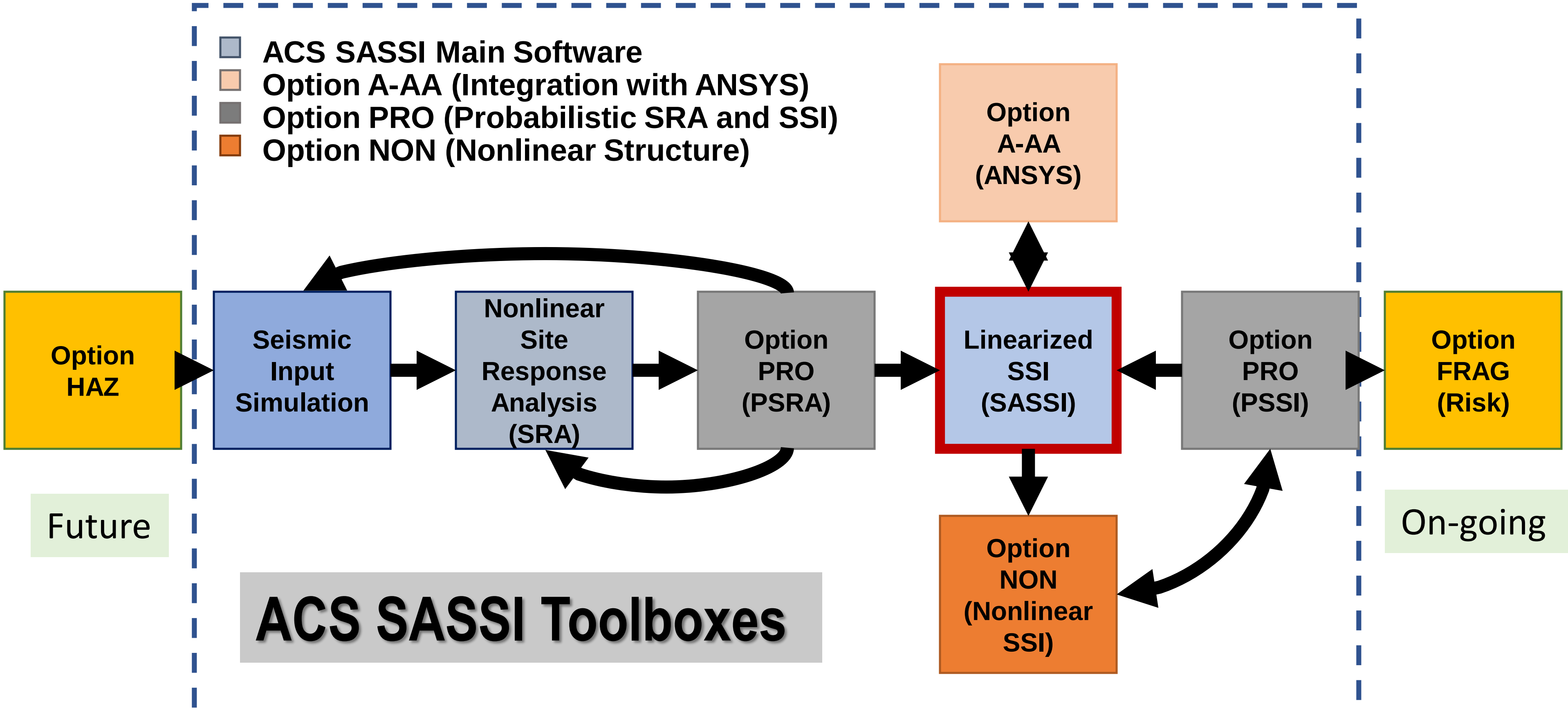
2) All the randomness variations to get the randomness variability (β_R)

Compute epistemic uncertainty variability from Steps 1 and 2 – *using physics-based models.*

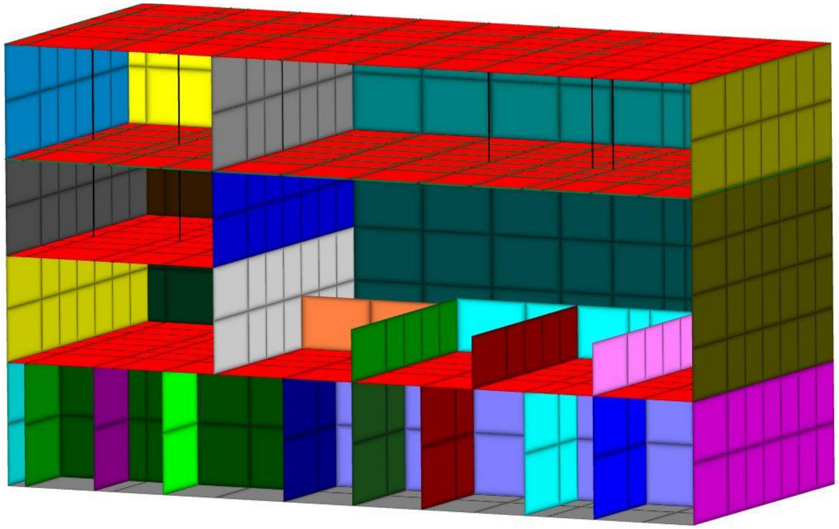


ACS SASSI Framework Development

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



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

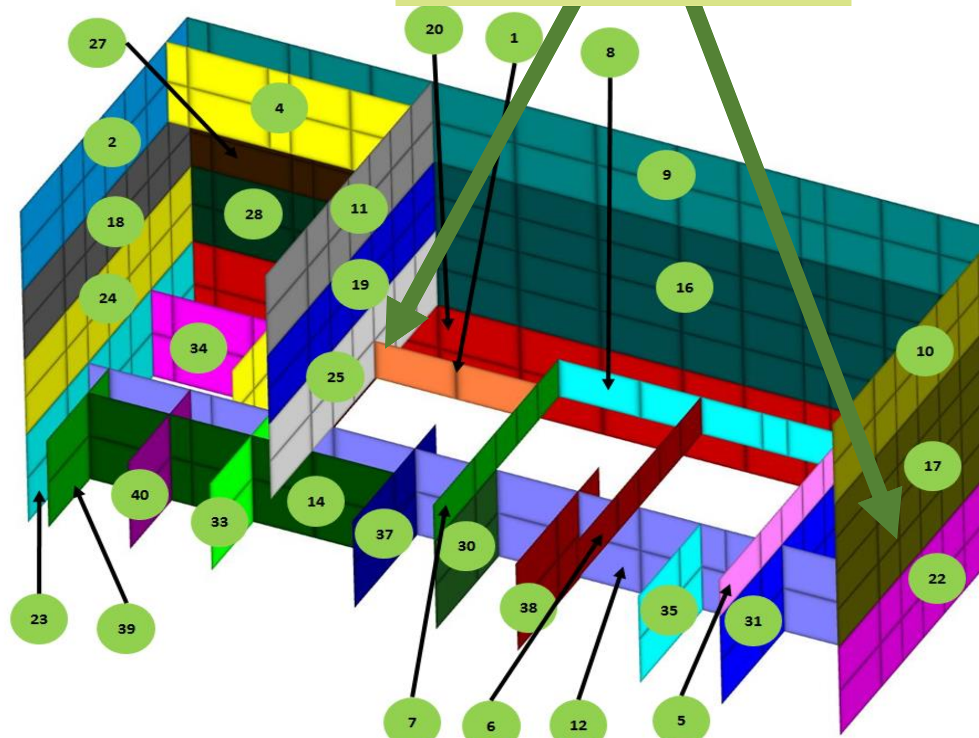


Nuclear building model split in nonlinear panels; done semi-automatically using ACS SASSI UI

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

Selected Panels



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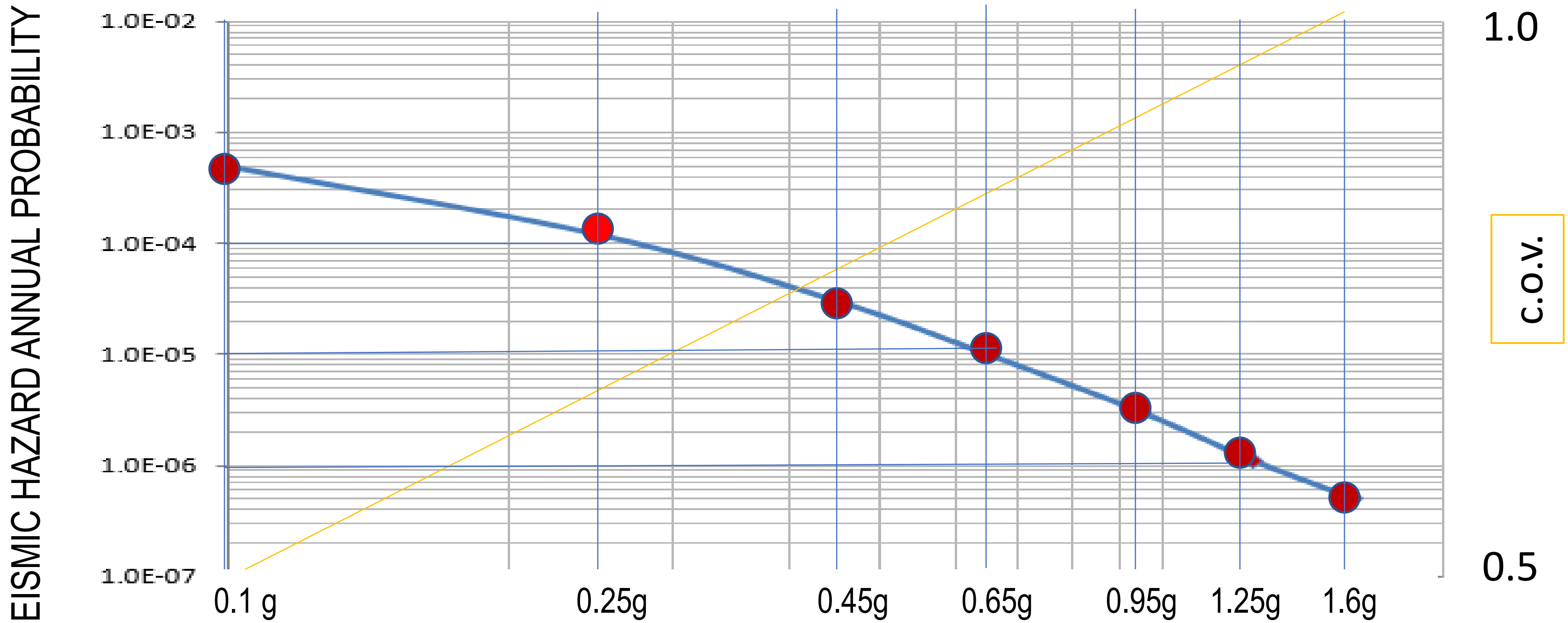
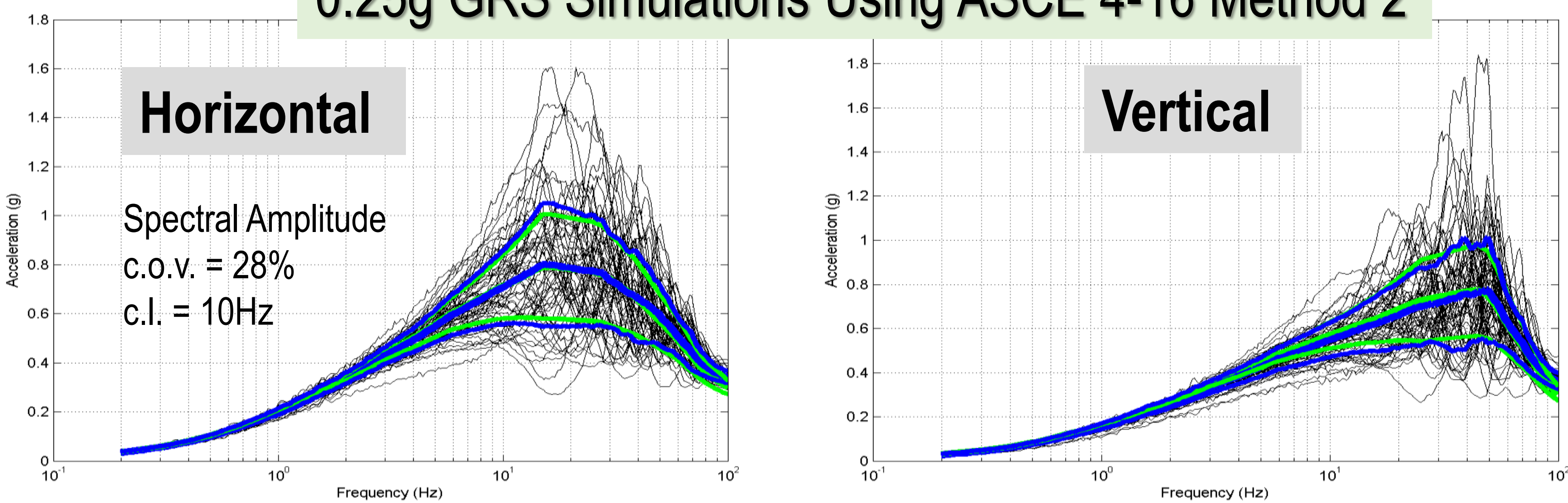
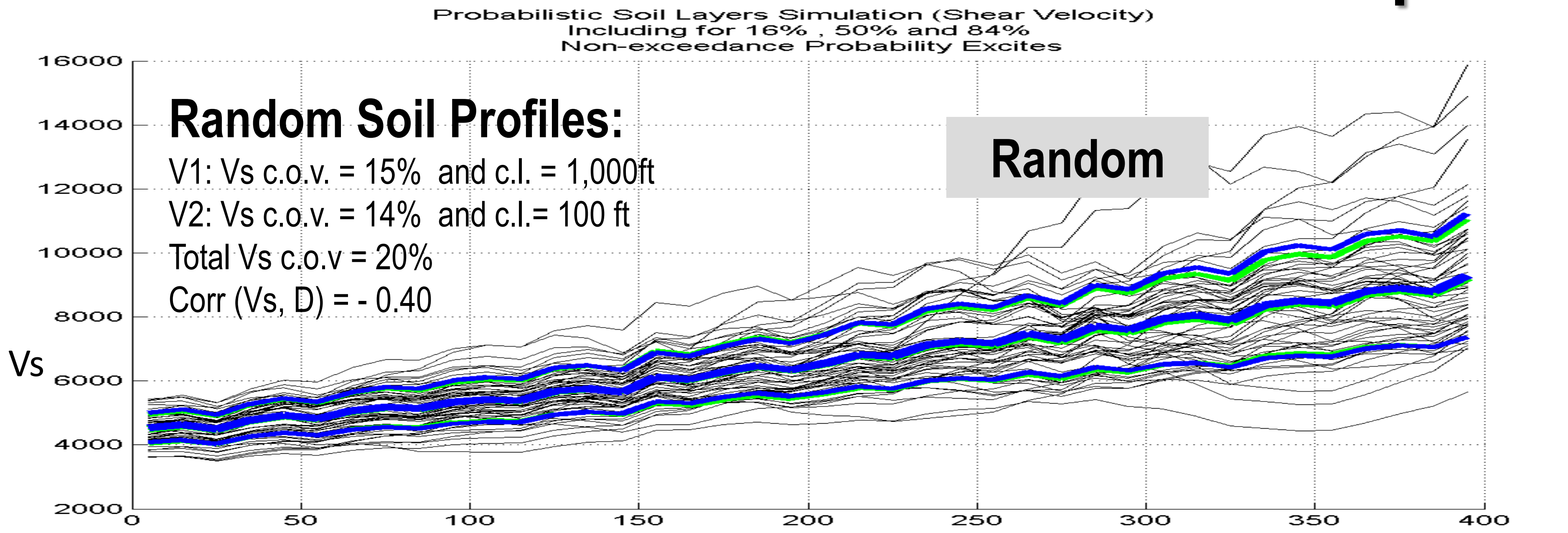
Rock Hazard Curve - Using 7, 3 and 1 Review Levels

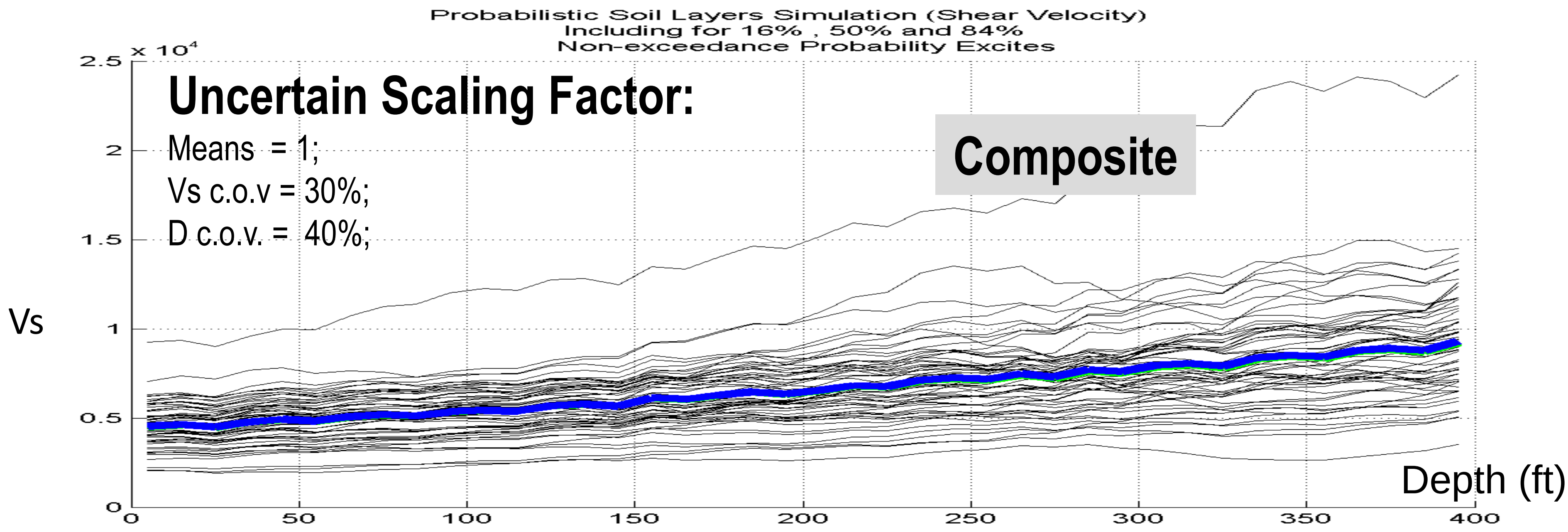


0.25g GRS Simulations Using ASCE 4-16 Method 2

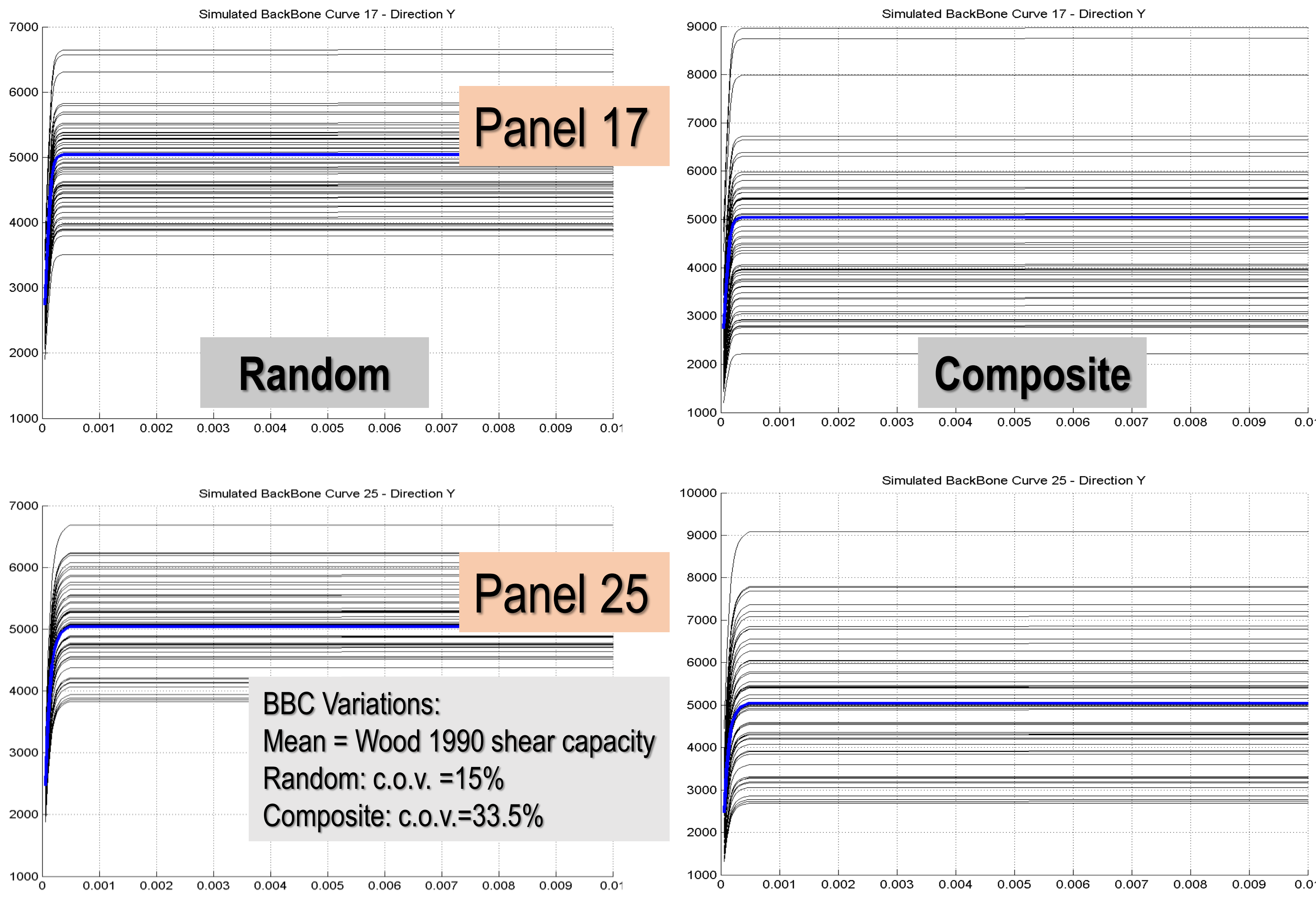


Simulated Soil Profiles for Random and Composite

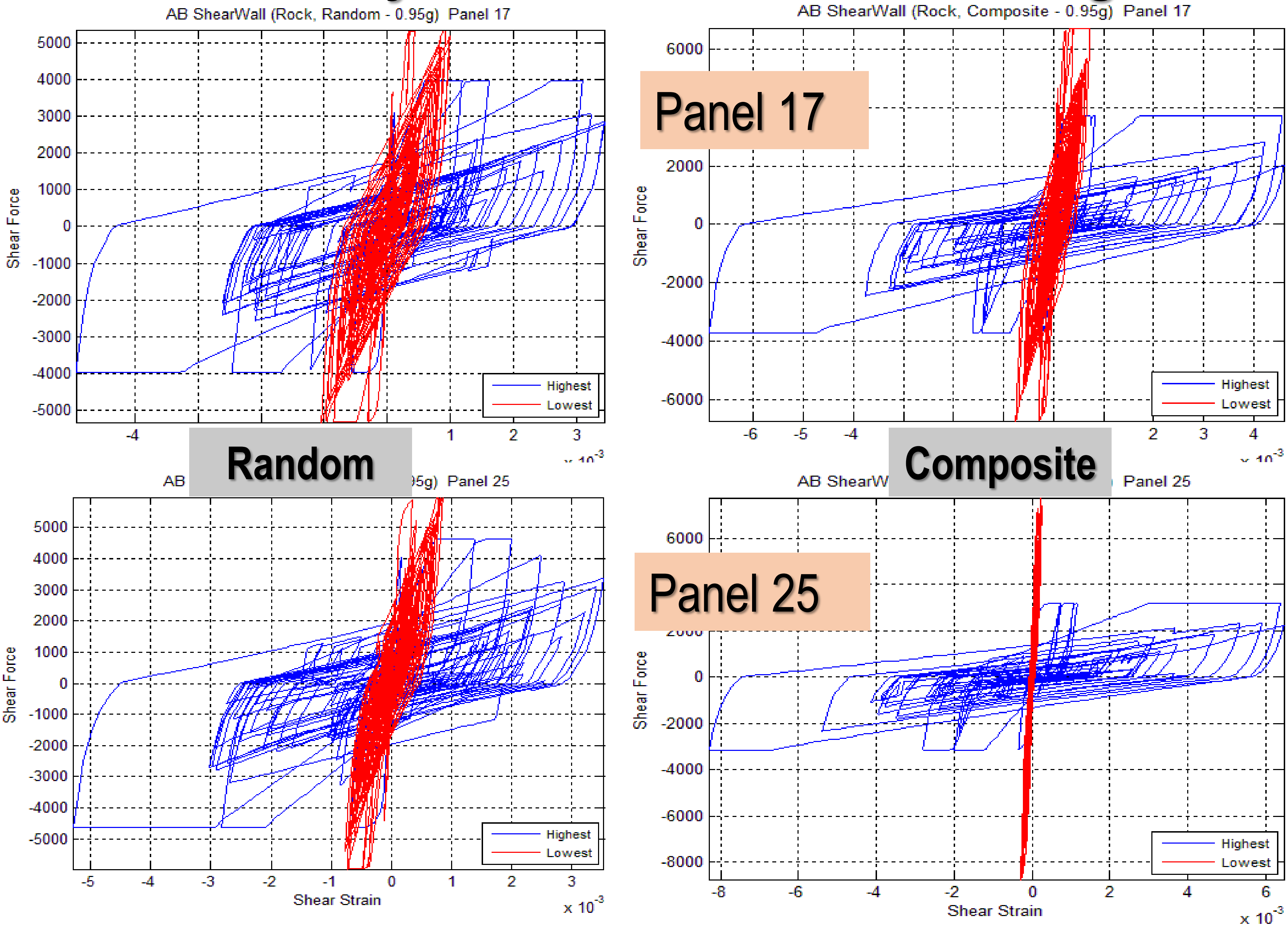




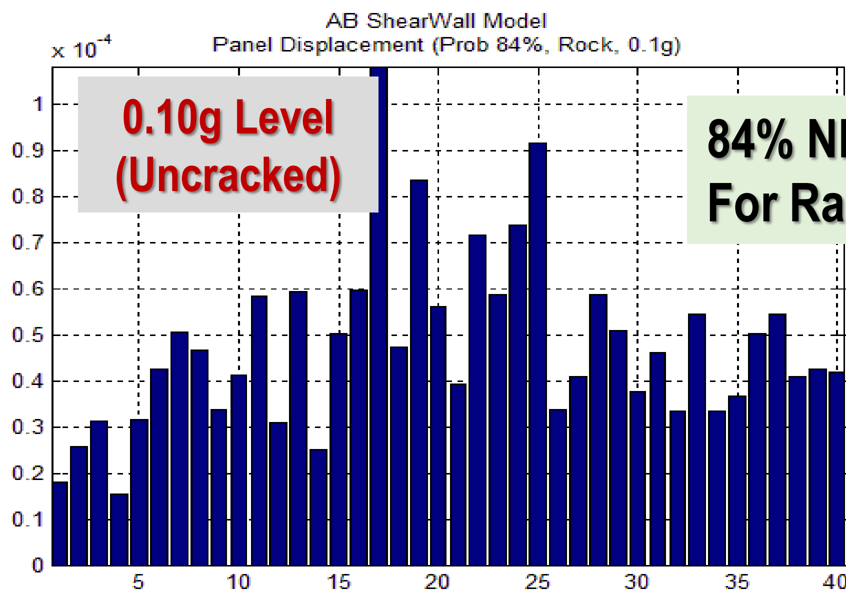
Random BBC Variations for Nonlinear Wall Panels



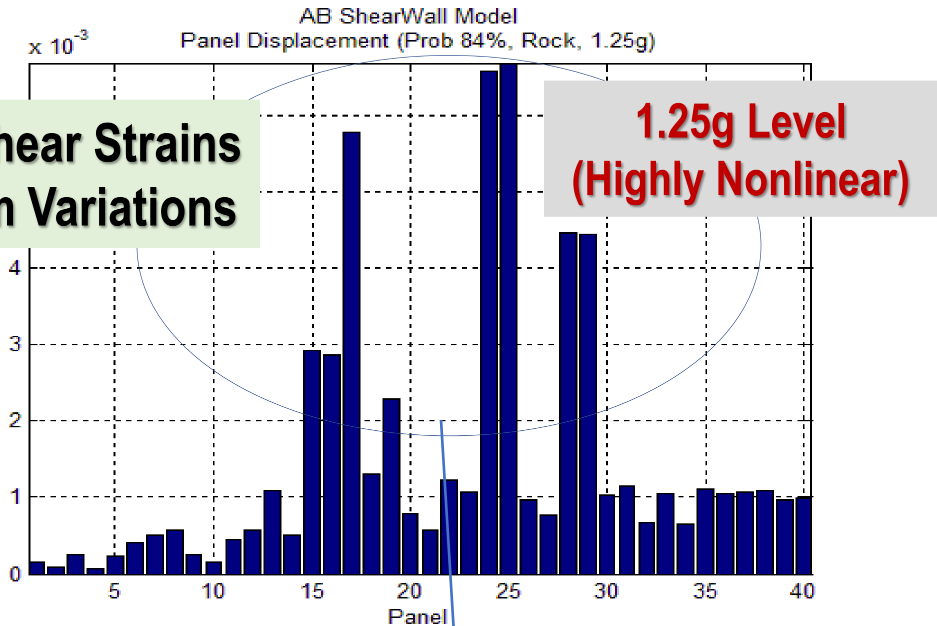
Wall Panel Hysteretic Behavior for 0.95g Level



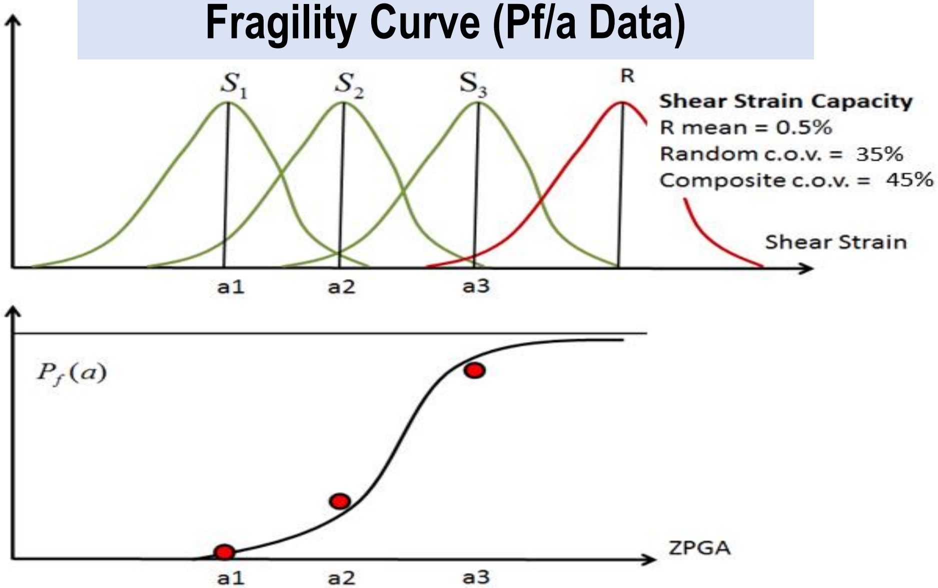
Computed 84% NEP Shear Strain and Pf/a in Panels



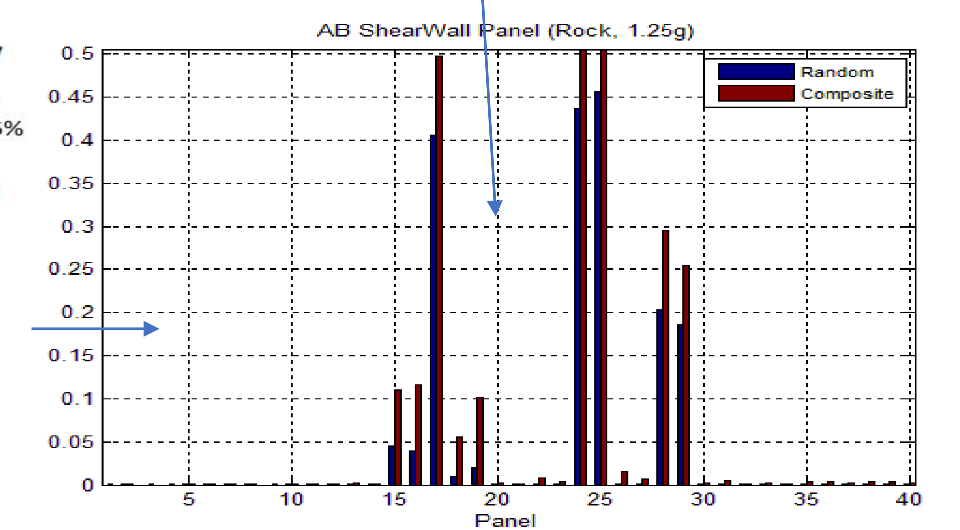
84% NEP Shear Strains For Random Variations



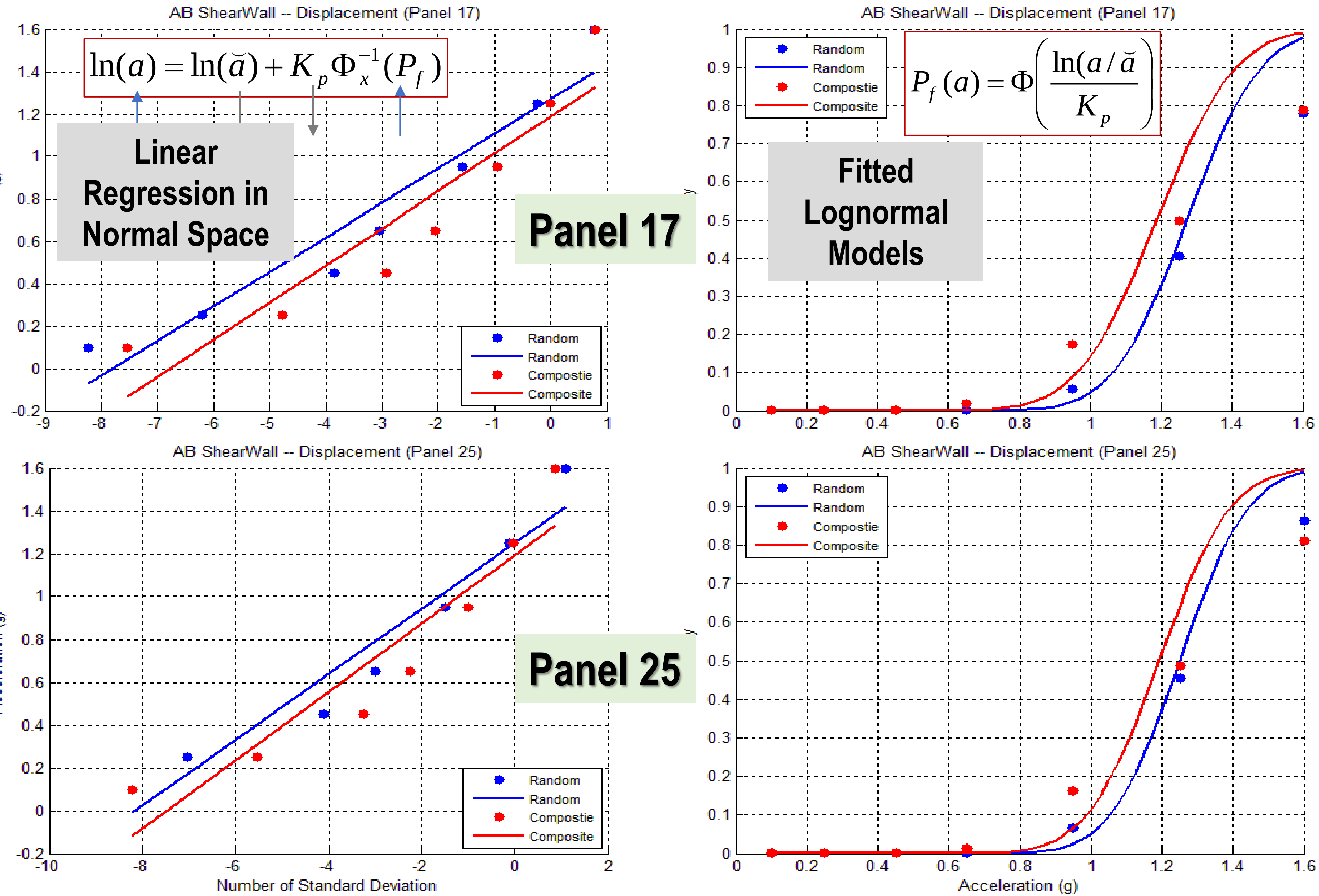
Ln R/S Reliability Model to Build Fragility Curve (Pf/a Data)



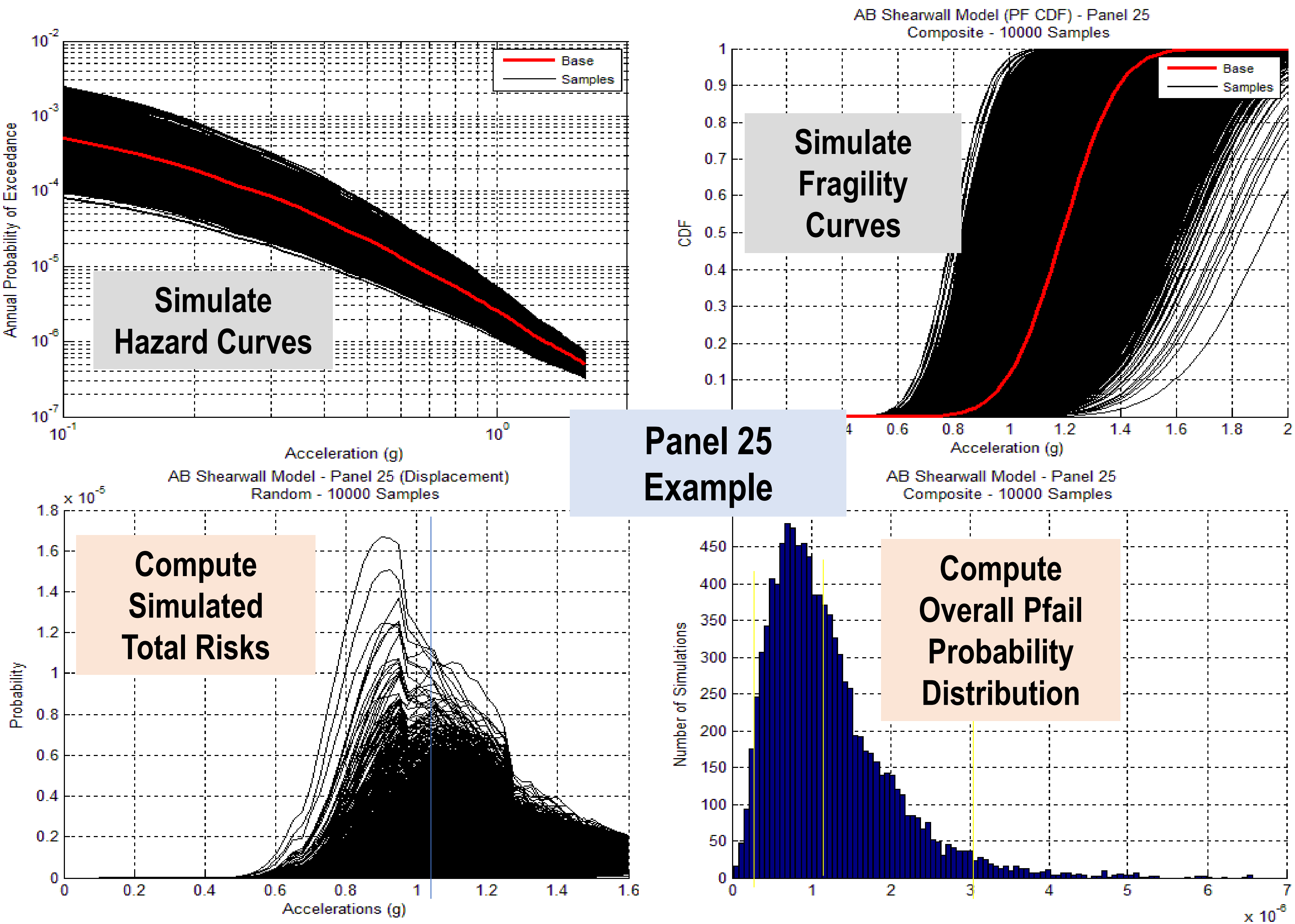
Computed Pf/a for a=0.95g Level



Fitting Lognormal Models for Fragility Curves



Computation of Overall Risk, Unconditional Pfail



Pfail for 7, 3 and 1 Level Seismic Hazard Levels

Displacement

Panel #	pf mean	pf C.O.V.	pf 90%CDF	pf 90%LOGN	pf 95%CDF	pf 95%LOGN
15	1.82E-007	0.71	3.60E-007	3.38E-007	4.27E-007	4.27E-007
16	2.40E-007	1.06	5.48E-007	5.02E-007	7.17E-007	6.88E-007
17	7.80E-007	0.49	1.26E-006	1.27E-006	1.48E-006	1.50E-006
24	8.78E-007	0.60	1.55E-006	1.53E-006	1.85E-006	1.87E-006
25	9.22E-007	0.68	1.71E-006	1.68E-006	2.11E-006	2.10E-006
28	4.59E-007	0.24	6.04E-007	6.04E-007	6.53E-007	6.58E-007
29	4.16E-007	0.46	6.65E-007	6.65E-007	7.72E-007	7.81E-007

7 ZPGA Levels

Displacement Random

Panel #	pf mean	pf C.O.V.	pf 90%CDF	pf 90%LOGN	pf 95%CDF	pf 95%LOGN
15	3.94E-008	0.54	6.85E-008	6.63E-008	7.61E-008	7.96E-008
16	4.34E-008	0.81	8.95E-008	8.39E-008	1.10E-007	1.09E-007
17	6.67E-007	1.06	1.52E-006	1.39E-006	1.97E-006	1.91E-006
24	6.56E-007	0.80	1.35E-006	1.26E-006	1.64E-006	1.63E-006
25	6.17E-007	0.70	1.18E-006	1.13E-006	1.43E-006	1.42E-006
28	2.98E-007	0.96	6.65E-007	6.06E-007	8.61E-007	8.13E-007
29	2.30E-007	0.87	4.87E-007	4.54E-007	6.09E-007	5.96E-007

3 ZPGA Levels

Displacement Random

Panel #	pf mean	pf C.O.V.	pf 90%CDF	pf 90%LOGN	pf 95%CDF	pf 95%LOGN
15	5.20E-006	2.79	1.39E-005	1.16E-005	2.77E-005	1.98E-005
16	1.51E-005	4.66	2.72E-005	3.13E-005	6.61E-005	5.85E-005
17	4.39E-008	1.17	1.03E-007	9.38E-008	1.38E-007	1.32E-007
24	8.14E-008	3.34	2.14E-007	1.79E-007	3.88E-007	3.17E-007
25	3.26E-008	2.66	8.74E-008	7.34E-008	1.52E-007	1.24E-007
28	2.61E-005	3.96	4.82E-005	5.54E-005	1.25E-004	1.01E-004
29	4.49E-007	4.33	8.83E-007	9.40E-007	2.00E-006	1.74E-006

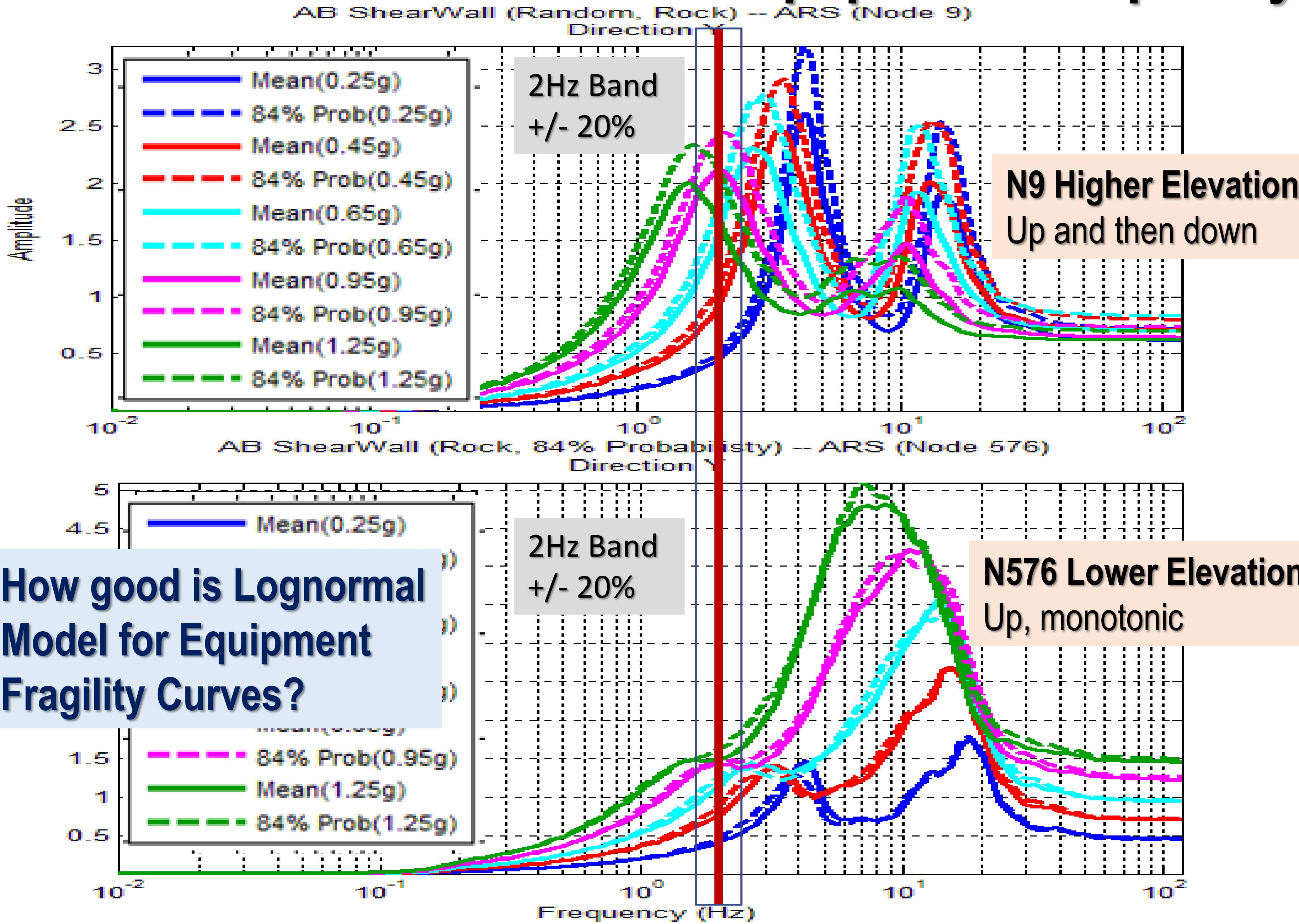
1 ZPGA Level; 1e-4 or 0.25g

Displacement Random

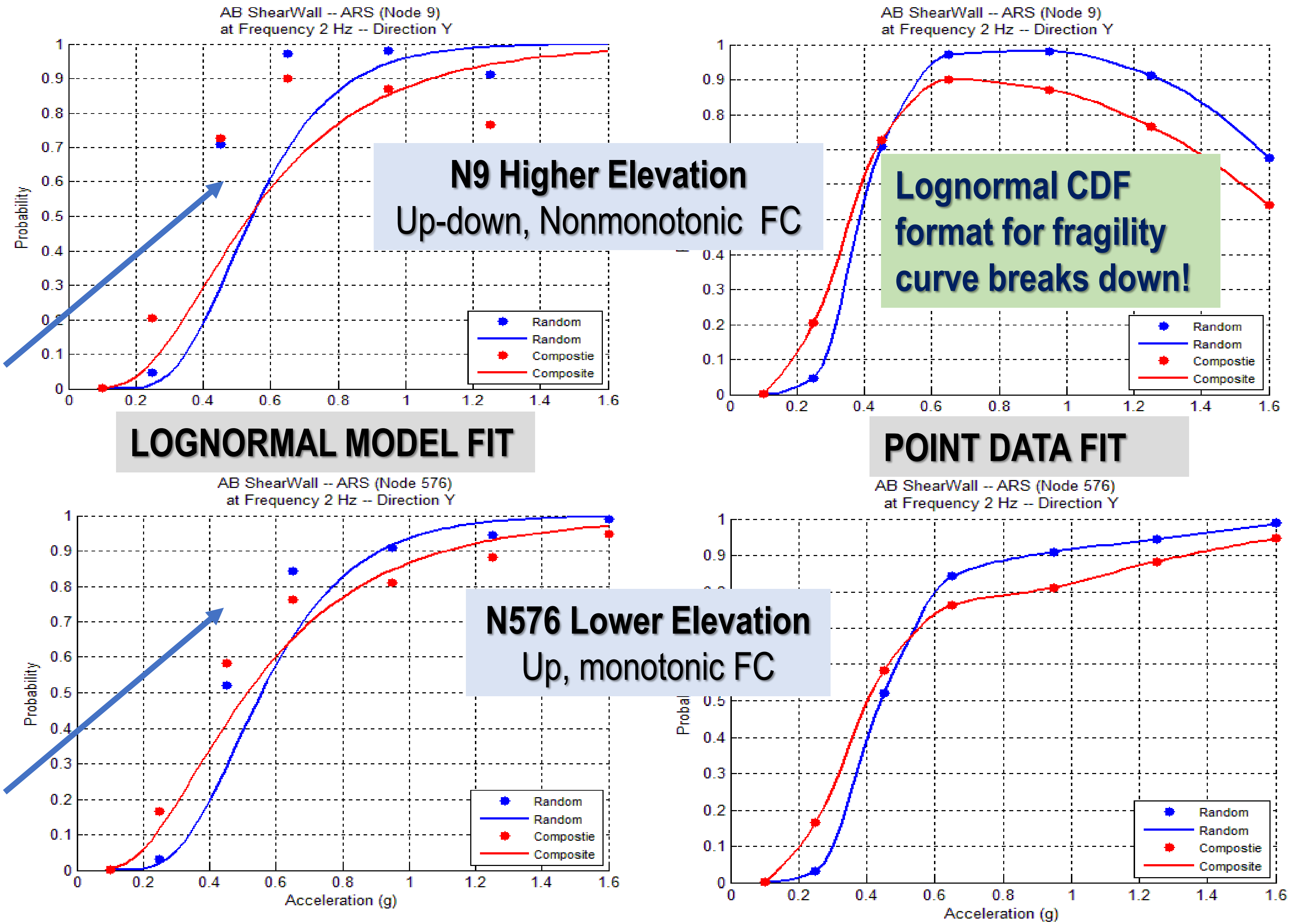
Panel #	pf mean	pf C.O.V.	pf 90%CDF	pf 90%LOGN	pf 95%CDF	pf 95%LOGN
15	1.41E-008	0.95	3.21E-008	2.85E-008	4.08E-008	3.81E-008
16	2.47E-008	1.35	6.05E-008	5.43E-008	8.45E-008	7.85E-008
17	3.48E-007	1.11	7.90E-007	7.34E-007	1.06E-006	1.02E-006
24	2.46E-007	1.10	5.68E-007	5.18E-007	7.52E-007	7.17E-007
25	2.22E-007	1.02	4.87E-007	4.59E-007	6.50E-007	6.23E-007
28	7.78E-008	1.02	1.71E-007	1.61E-007	2.31E-007	2.18E-007
29	4.98E-008	0.94	1.06E-007	1.00E-007	1.38E-007	1.34E-007

1 ZPGA Level; 1e-5 or 0.65g

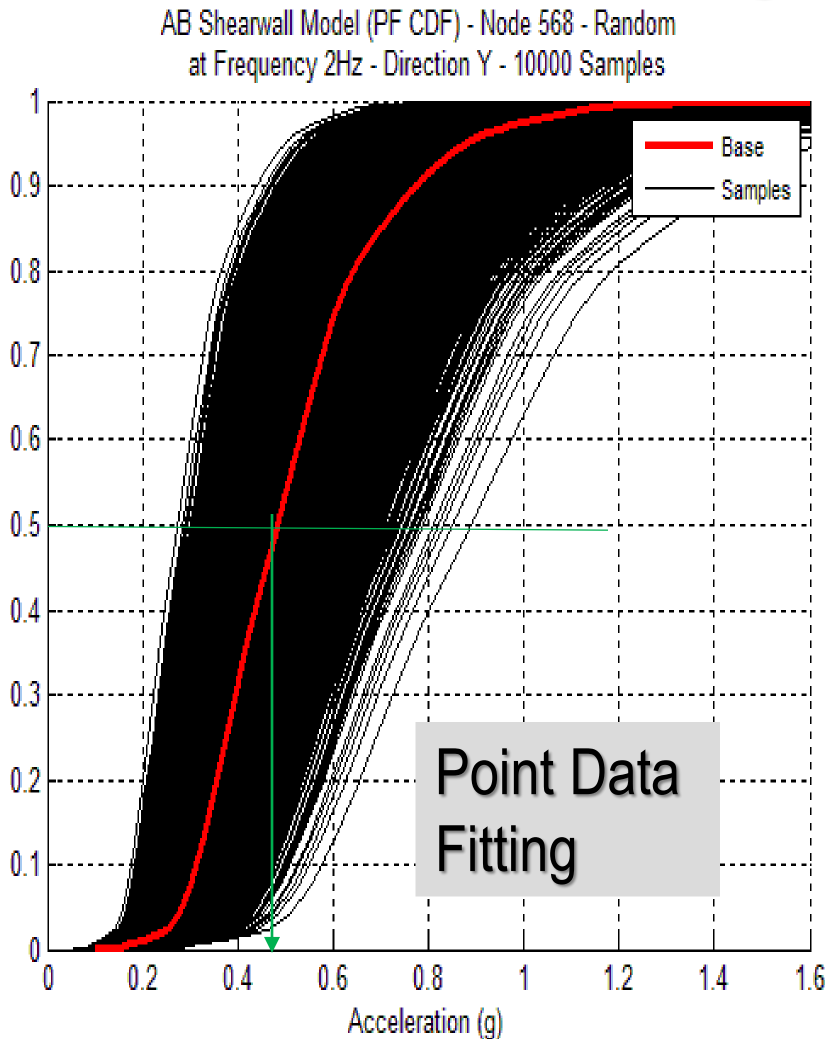
ARS for 5 Seismic Levels/2Hz Equipment Frequency



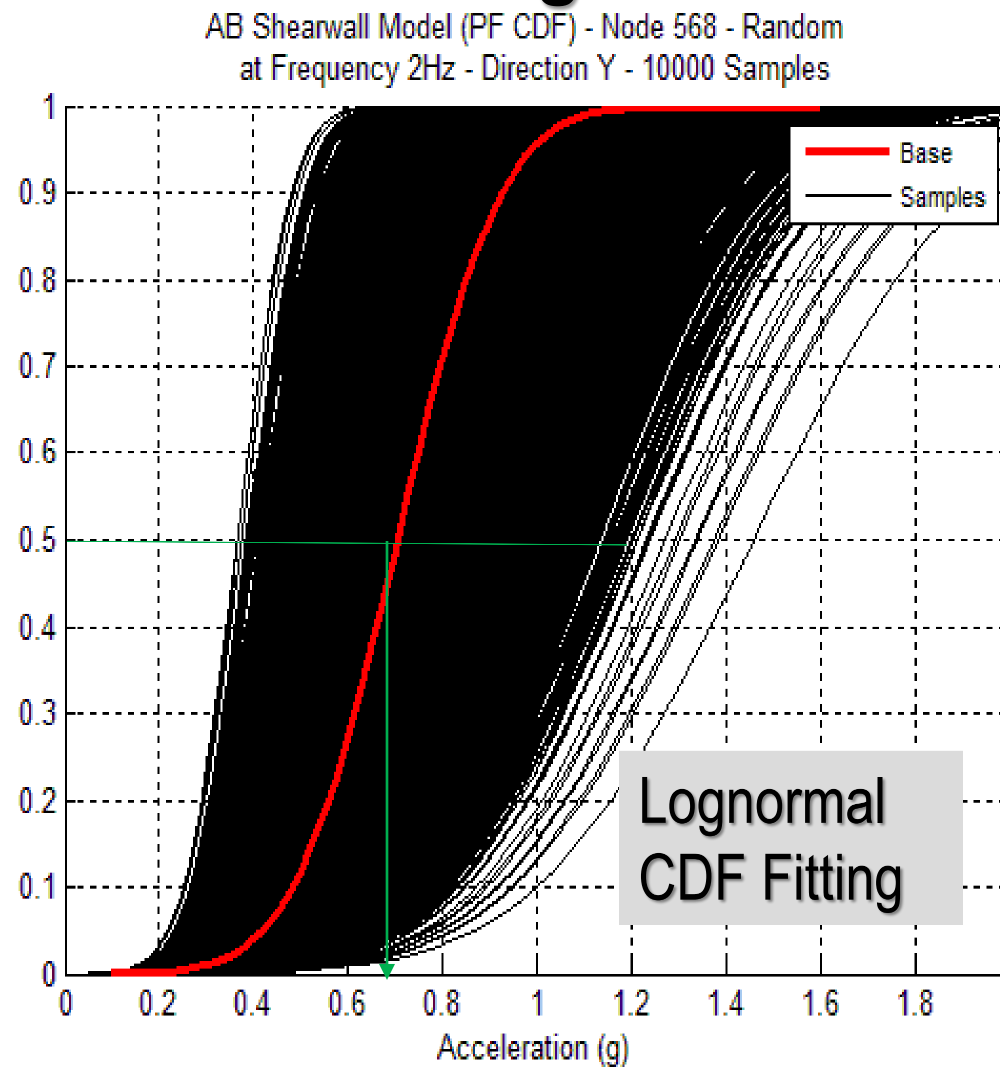
Lognormal Model for Fragility Curve Could Fail!



Pf for N568 Y Using Point Data vs. Lognormal Fit



ISRS Node #	Random pf mean	2Hz pf C.O.V.
482	3.81E-005	0.53
568	3.89E-005	0.57
570	3.97E-005	0.59
576	5.17E-005	0.79

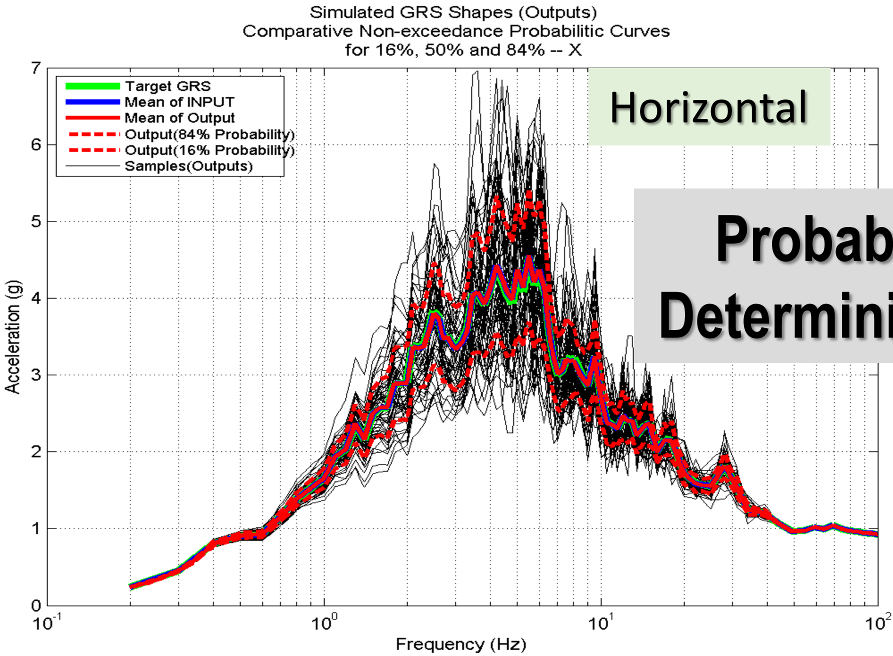


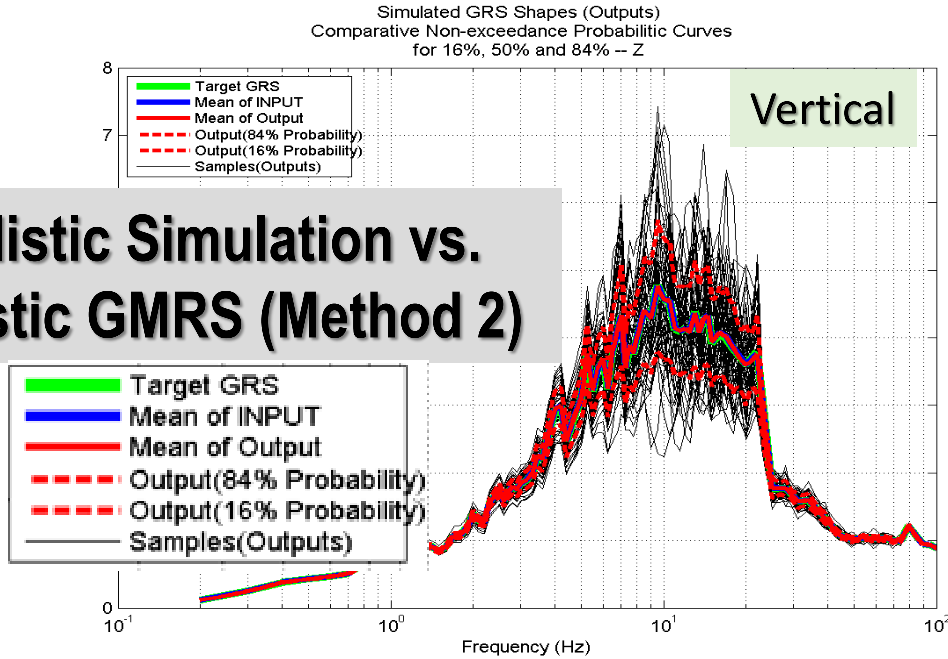
ISRS Node #	Random pf mean	2Hz pf C.O.V.
482	1.57E-005	0.67
568	1.46E-005	0.69
570	1.44E-005	0.71
576	1.24E-005	0.79

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

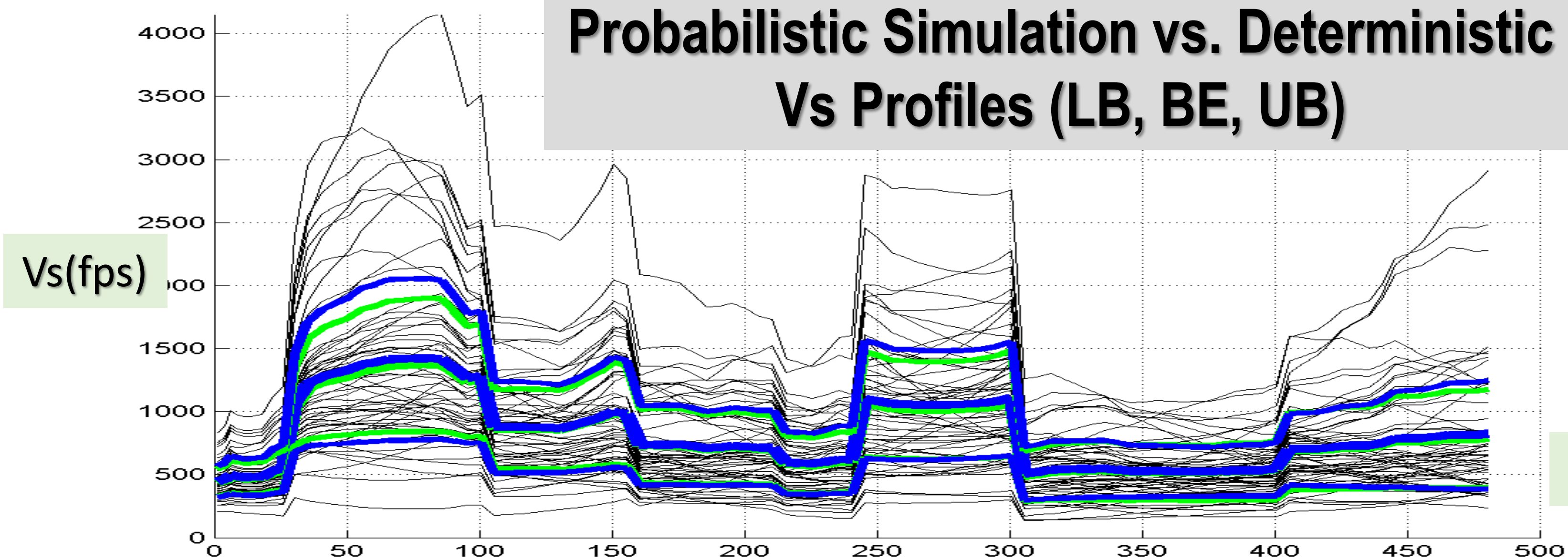
Low-Rise Reinforced Concrete Shearwall Building Example

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-BEsoi, UBstr-Besoi, BEstr-LBsoi and BEstr-UBsoi.

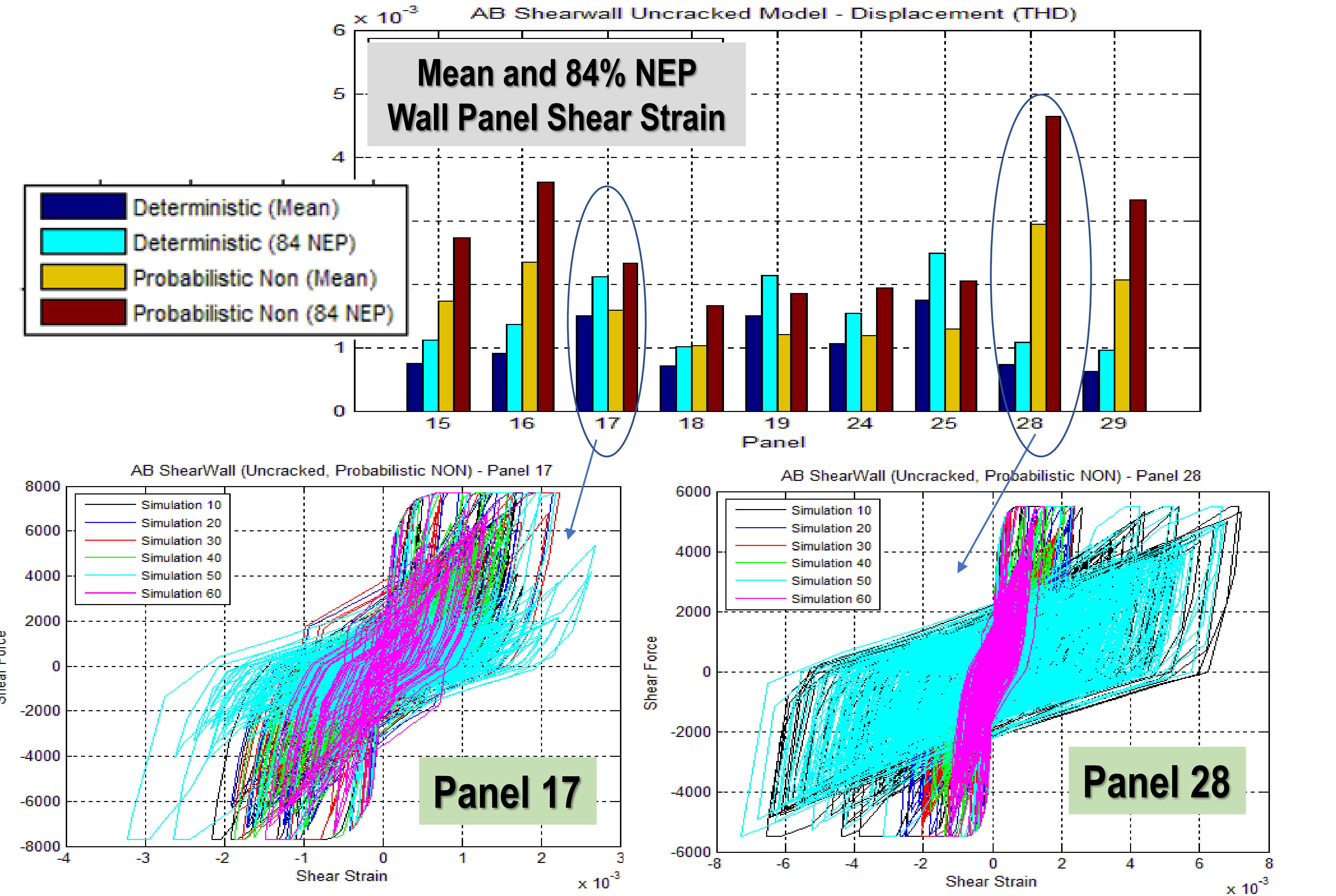
The performance-based GMRS input is considered for seismic input. The ZPGA is 1g. For each SSI case, the Seismic input variability was considered by *5 sets of spectrum compatible acceleration histories* based on “seed” records.

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



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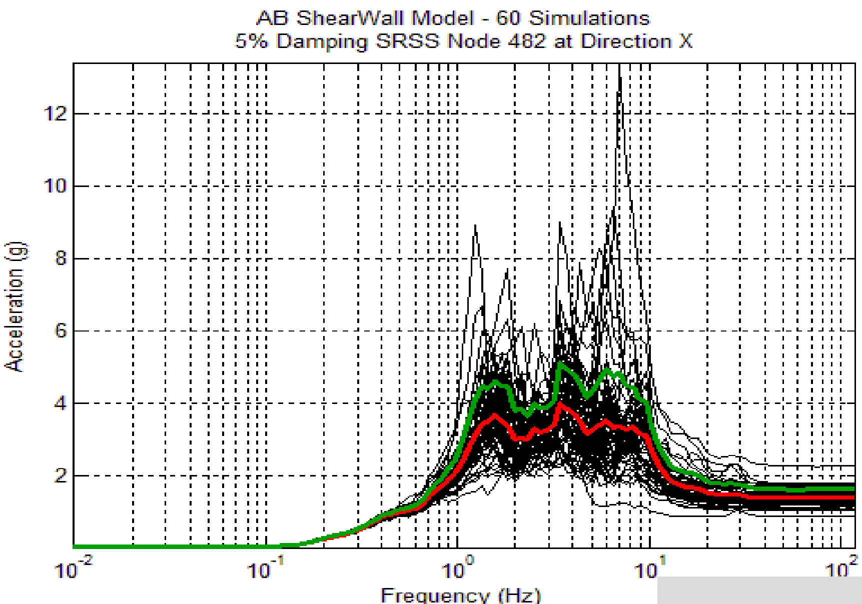
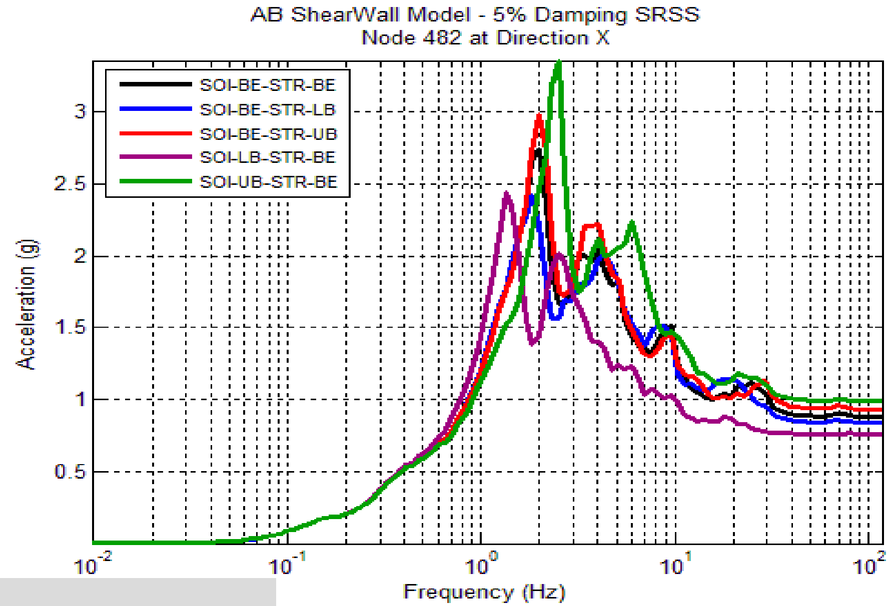
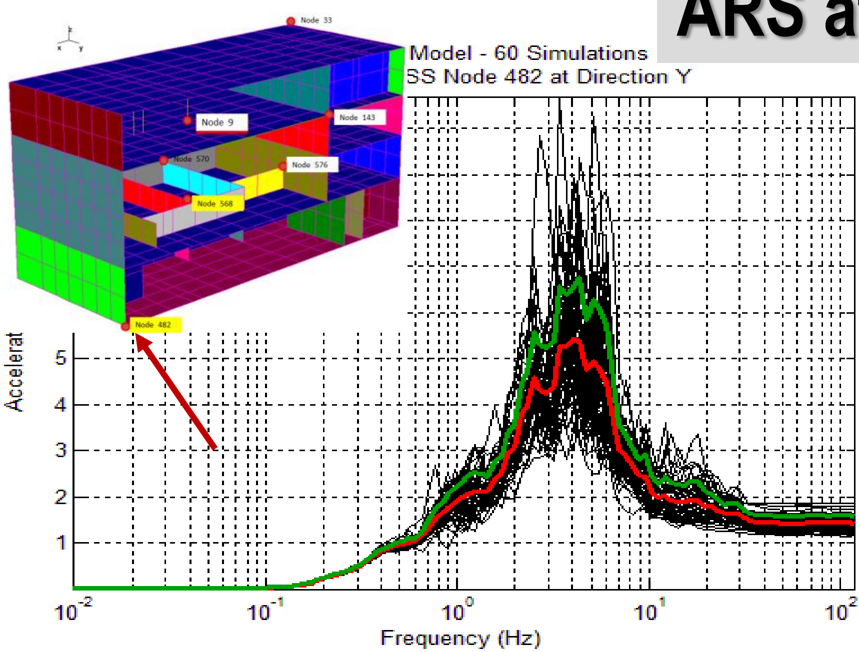
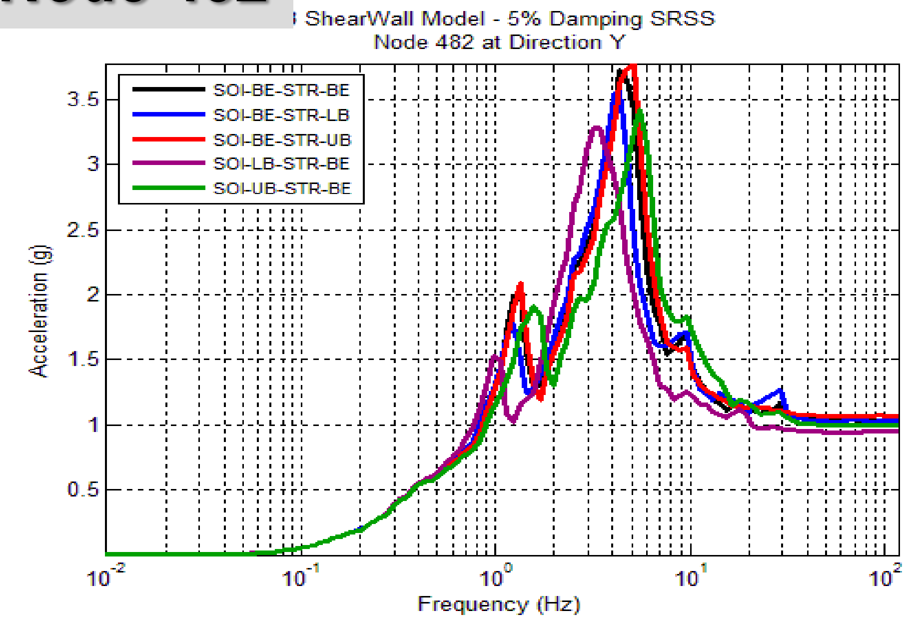
ASCE 4 PSSI-Based ARS vs. EPRI DSSI-Based ARS



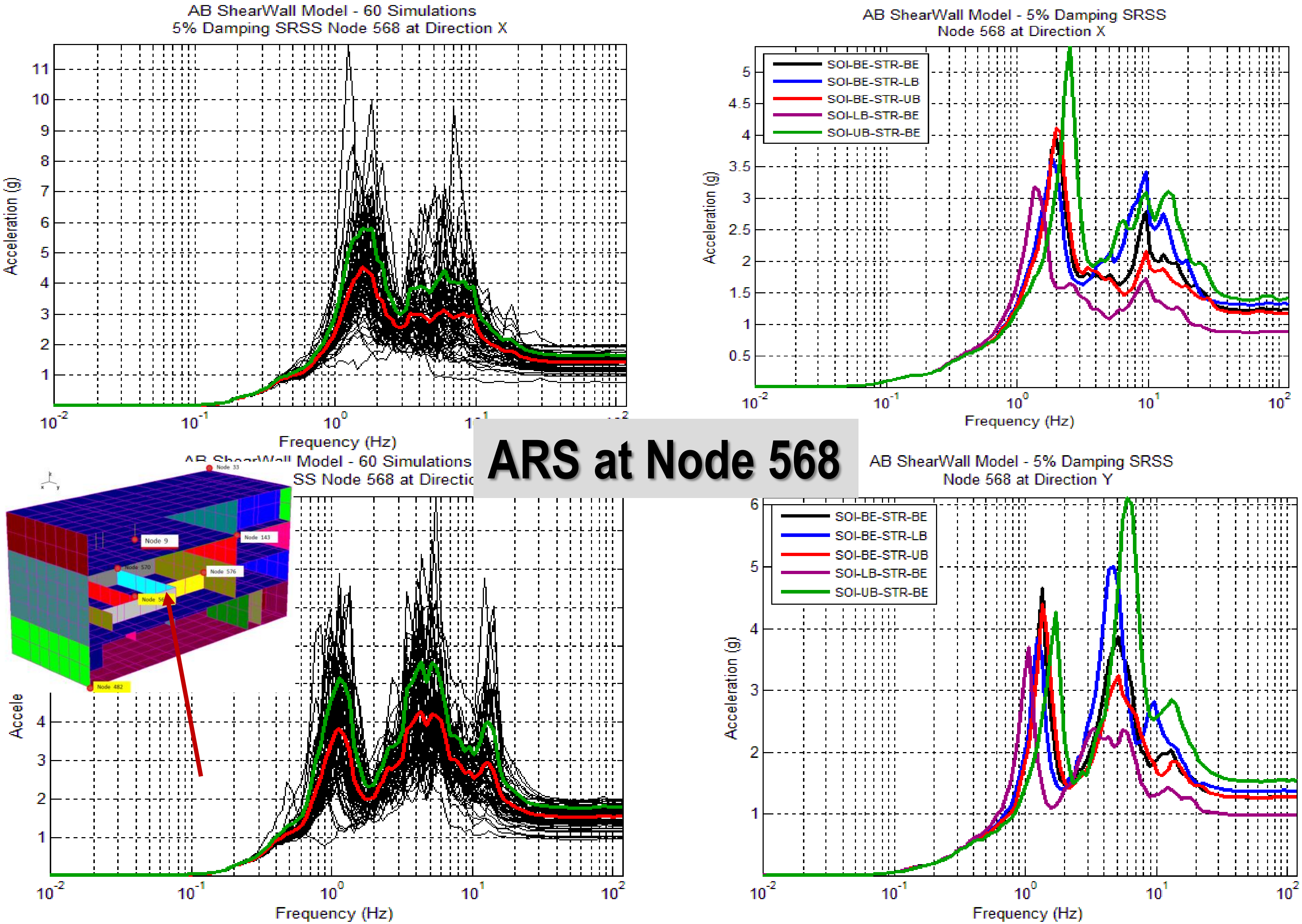


ARS at Node 482





ASCE 4 PSSI-Based ARS vs. EPRI DSSI-Based ARS



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Conclusions

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 Probabilistic SSI vs. EPRI Deterministic SSI

- 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.