

Proposed Updates to the RIPB-based DRS Scale Factors for ASCE/SEI 92

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Session D1-B-3: Code Calibration, Design Criteria, and Seismic Hazard Basis
September 22, 2026

Outline

- Robert Kennedy framework

- Design to achieve target performance goal (TPG)

- $DRS = SF * UHRS_{TPG}$

- Closed-form risk solution (Kennedy, 2011)

- Hazard slope: A_R

- Fragility slope: β

- DRS scale factors in ASCE 43-05 and 43-19

- Function of A_R

- Empirical fitting independent of β

Performance-goal based (risk informed) approach for establishing the SSE site specific response spectrum for future nuclear power plants[☆]

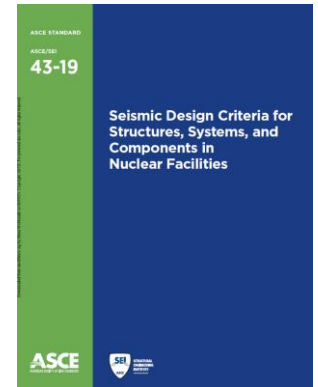
Robert P. Kennedy

RPK Structural Mechanics Consulting, 28625 Mountain Meadow Road, Escondido, CA 92026, United States

(Kennedy (2011))

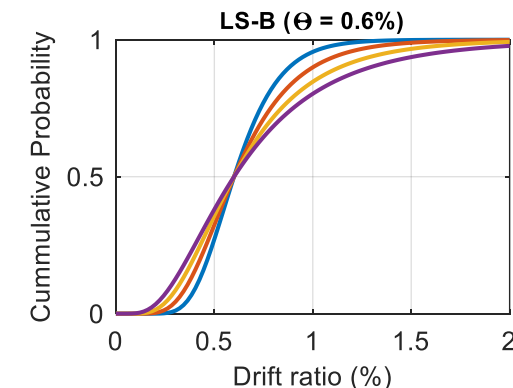
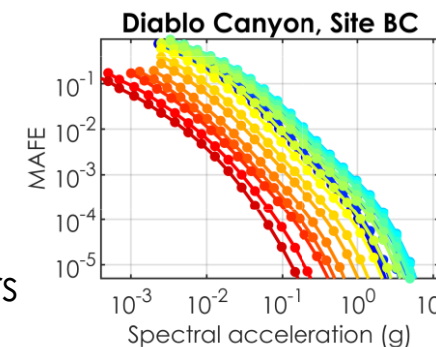
$$SF_{\text{Kennedy}, p\%} = e^{\left(\frac{1}{2} \frac{\beta^2}{\log(A_R)} - \Phi^{-1}(p) \beta \right)}$$

$$SF_{\text{ASCE 43-19}} = \max \left(\frac{1}{A_R}, \frac{0.6}{A_R^{0.2}}, 0.45 \right)$$



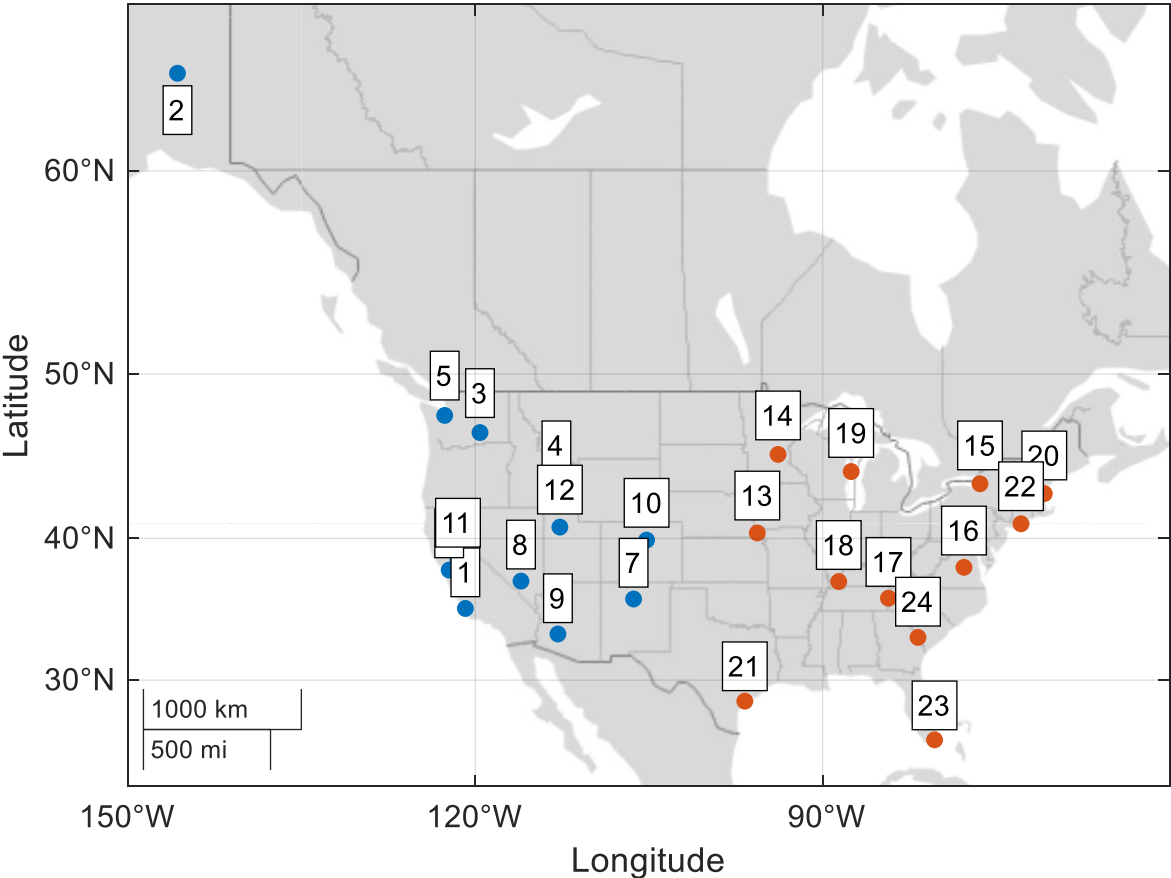
- Technical basis for RIPB framework: ASCE/SEI 92-**

- Characterize A_R across continental U.S.
- Characterize β for different structural limit states
- Risk performance of RPK solution and ASCE 43-19 scale factors
- Revised DRS scale factors proposed for ASCE/SEI 92-**



Characterize A_R across continental U.S

24 representative nuclear sites



12 Western US sites

#	Location	#	Location
1	Diablo Canyon Nuclear Station	7	Los Alamos National Lab
2	Fort Greely Nuclear Station	8	Nevada Test Site
3	Hanford Site	9	Palo Verde Nuclear Station
4	Idaho National Lab	10	Rocky Flats Plant
5	Kitsap Naval Base	11	Sacramento
6	Lawrence Berkeley Lab	12	Skull Valley Band

12 Central & Eastern US sites

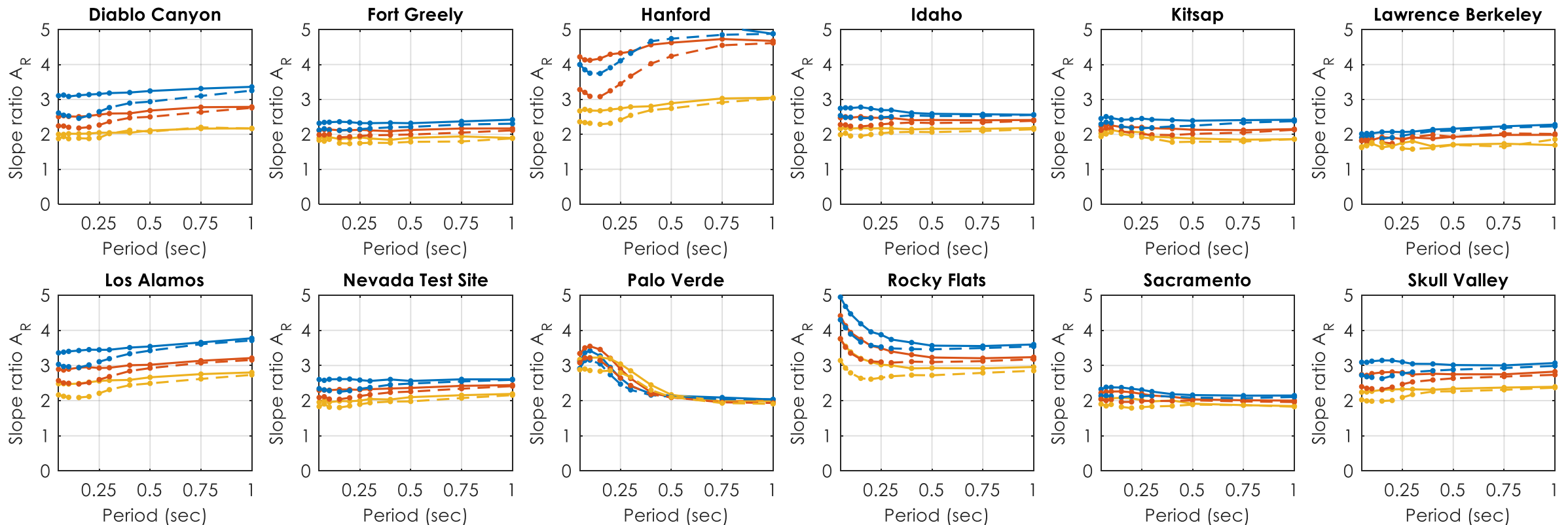
#	Location	#	Location
13	Cooper Nuclear Station	19	Point Beach Nuclear Station
14	Monticello Nuclear Station	20	Seabrook Station
15	Nine Mile Nuclear Station	21	Seadrift
16	North Anna Nuclear Station	22	Shoreham Nuclear Station
17	Oak Ridge National Laboratory	23	Turkey Point Nuclear Station
18	Paducah Nuclear Station	24	Vogtle Nuclear Station

Hazard-curve slope factors, A_R , 12 WUS sites

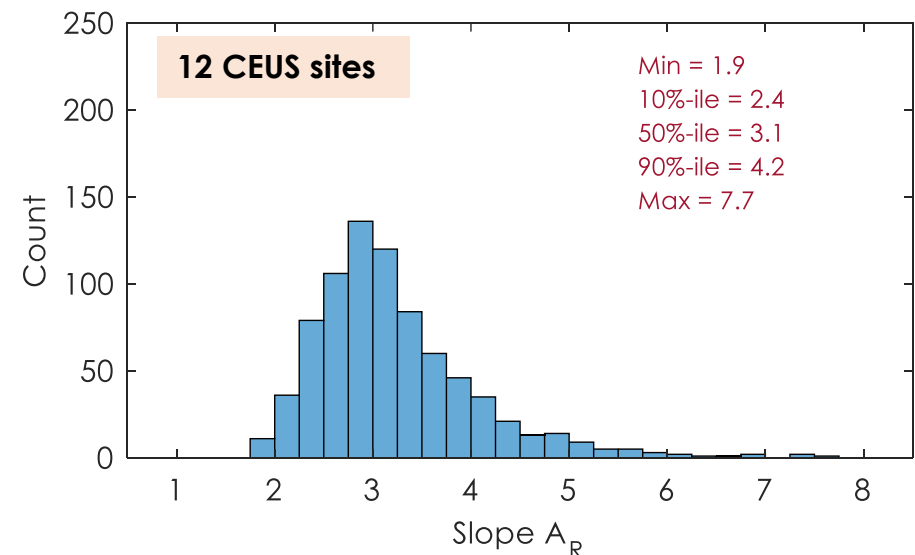
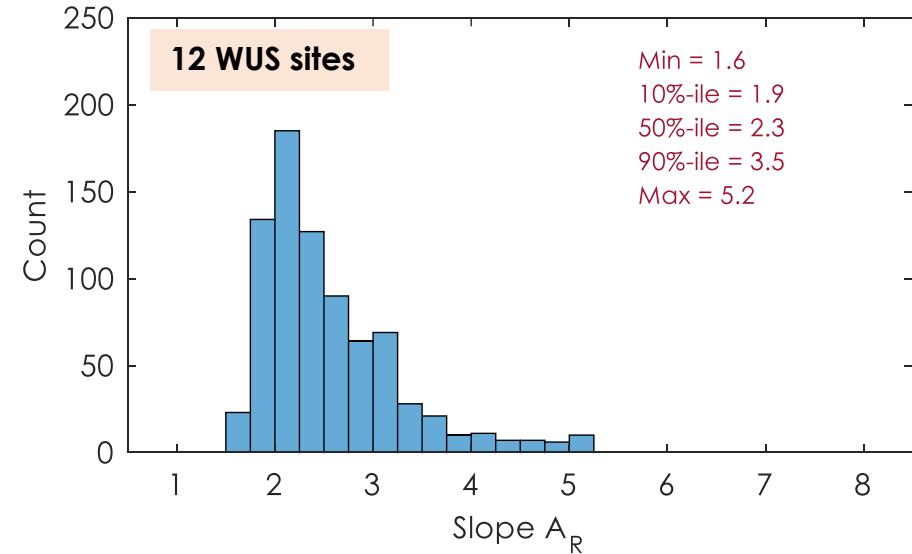
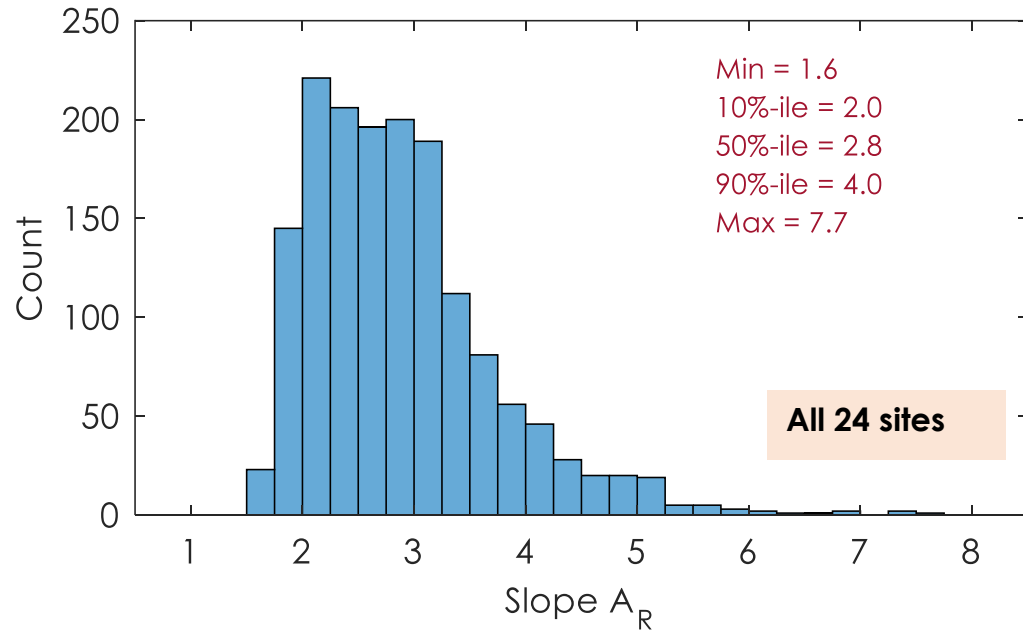
792 data points

—●— SDC3, SiteBC —●— SDC4, SiteBC —●— SDC5, SiteBC
- - -●- - - SDC3, SiteCD - - -●- - - SDC4, SiteCD - - -●- - - SDC5, SiteCD

- A_R largely constant across periods 0.05 sec (20 Hz) to 1 sec (1 Hz)
- A_R decreases as SDC increases (most cases)
- A_R slightly lower at softer soil sites



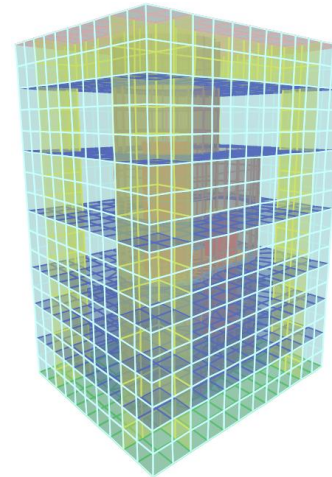
Slope factor, A_R , 24 sites: SDC-3, SDC-4, SDC-5



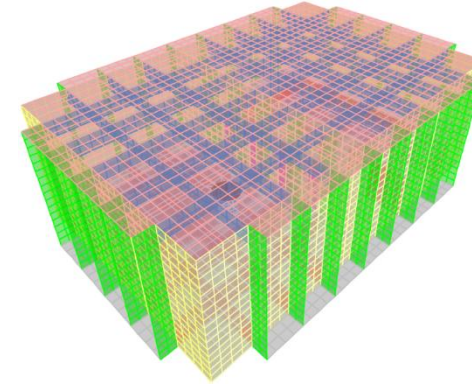
- Key takeaways
 - Ranges between 1.6 and 7.7
 - 85% between 2 and 4
 - WUS sites: left-skewed distribution, 1.75 to 2.75
 - CEUS sites: broad distribution with a longer right tail

Characterize β for structural limit states

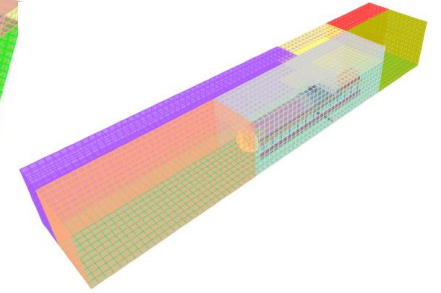
- Legacy basis for β
 - EPRI (2018) $\rightarrow$ 0.35 (conservatively low)
 - ASCE/SEI 7 $\rightarrow$ 0.6 (LS-A)
 - ASCE/SEI 43-19 $\rightarrow$ 0.3 to 0.6
- ASCE 43-19 DRS scale factors: agnostic to β
- Comprehensive technical study
 - Linear and nonlinear response-history analysis
 - Three archetype reactor building models
 - Four representative spectral shapes
 - A few thousand Monte Carlo simulations
 - Technical basis for β and limit-state performance
 - Best estimate values:
 - **0.3 (LS-D), 0.4 (LS-C and LS-B), and 0.5 (LS-A)**



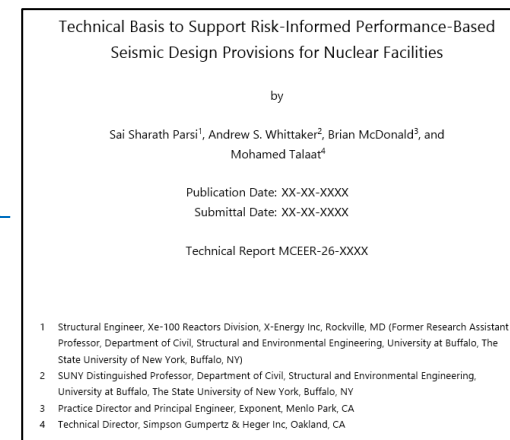
(Parsi et al., 2022)



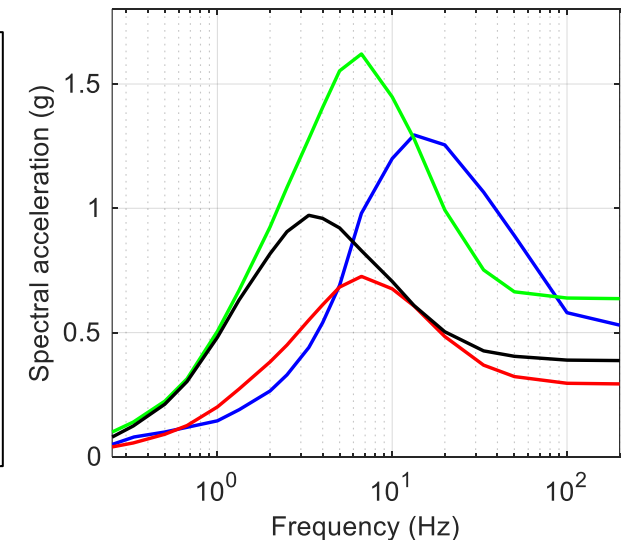
(Parsi et al., 2022)



(Parsi et al., 2024)



forthcoming technical report



DRS scale factors: ASCE 43-19 and proposed ASCE 92-**

- **ASCE 43-19 scale factors**

- Three-term expression
 - 1st term: $A_R < 1.9$
 - 2nd term : $1.9 < A_R < 4.2$
 - 3rd term: $A_R > 4.2$
- Unconservative for $\beta < 0.4$

- **Proposed scale factors**

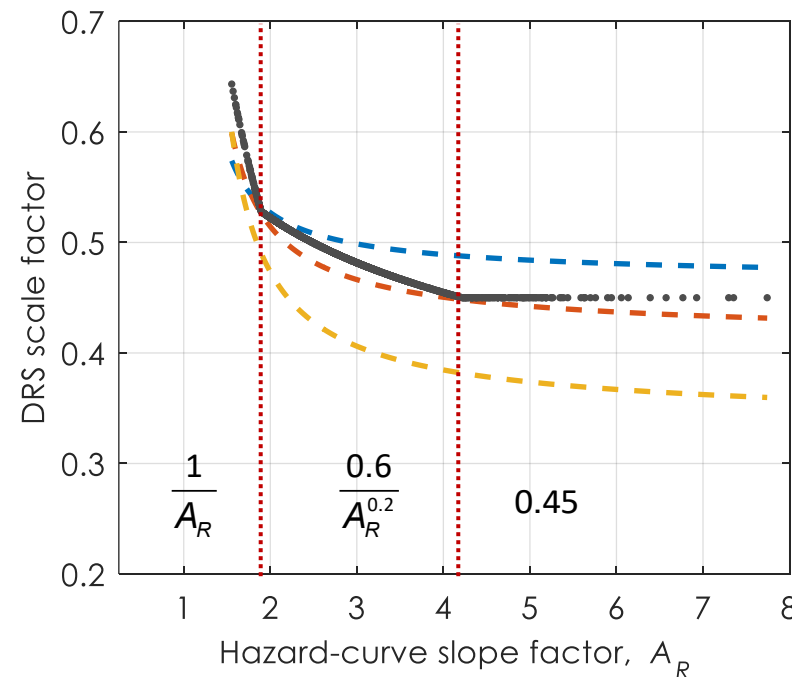
- Two-term expression
 - 1st term: $A_R < 1.9$
 - 2nd term : $A_R > 1.9$
- Conservative: $0.3 < \beta < 0.5$

↑
LS-D

↑
LS-A

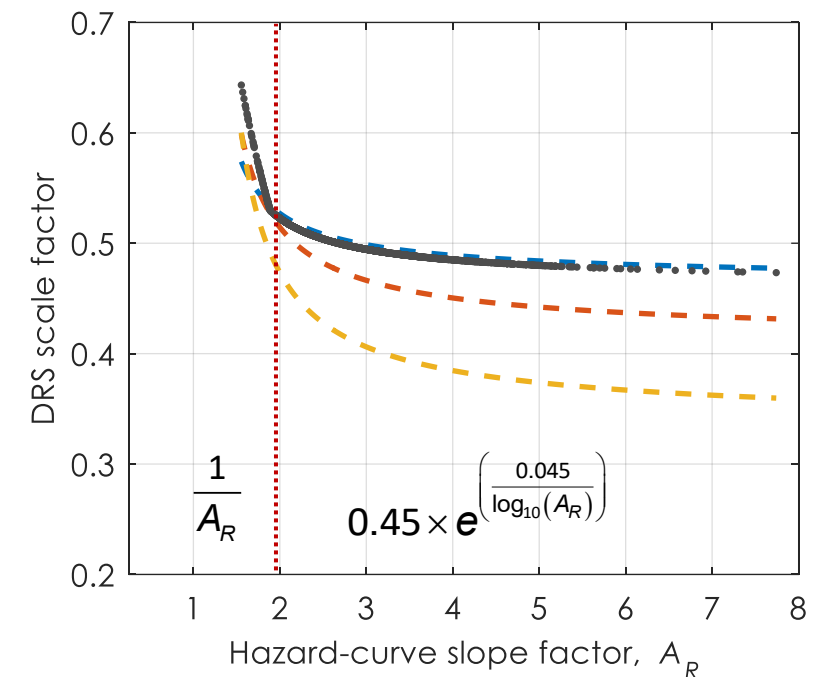
$$SF_{ASCE\ 43-19} = \max\left(\frac{1}{A_R}, \frac{0.6}{A_R^{0.2}}, 0.45\right)$$

- Kennedy solution, $\min[C_{1\%}, 2/3 \times C_{10\%}]$, $\beta = 0.3$
- Kennedy solution, $\min[C_{1\%}, 2/3 \times C_{10\%}]$, $\beta = 0.4$
- Kennedy solution, $\min[C_{1\%}, 2/3 \times C_{10\%}]$, $\beta = 0.5$
- Scale factors in ASCE 43-19



$$SF_{Proposed} = \max\left(\frac{1}{A_R}, 0.45 \times e^{\left(\frac{0.045}{\log_{10}(A_R)}\right)}\right)$$

- Kennedy solution, $\min[C_{1\%}, 2/3 \times C_{10\%}]$, $\beta = 0.3$
- Kennedy solution, $\min[C_{1\%}, 2/3 \times C_{10\%}]$, $\beta = 0.4$
- Kennedy solution, $\min[C_{1\%}, 2/3 \times C_{10\%}]$, $\beta = 0.5$
- Proposed scale factors for ASCE 92-**



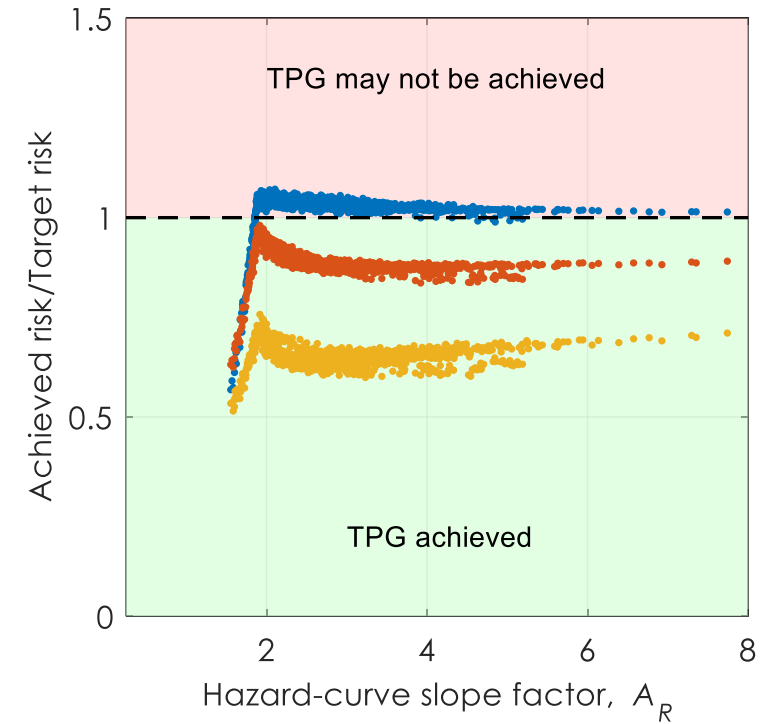
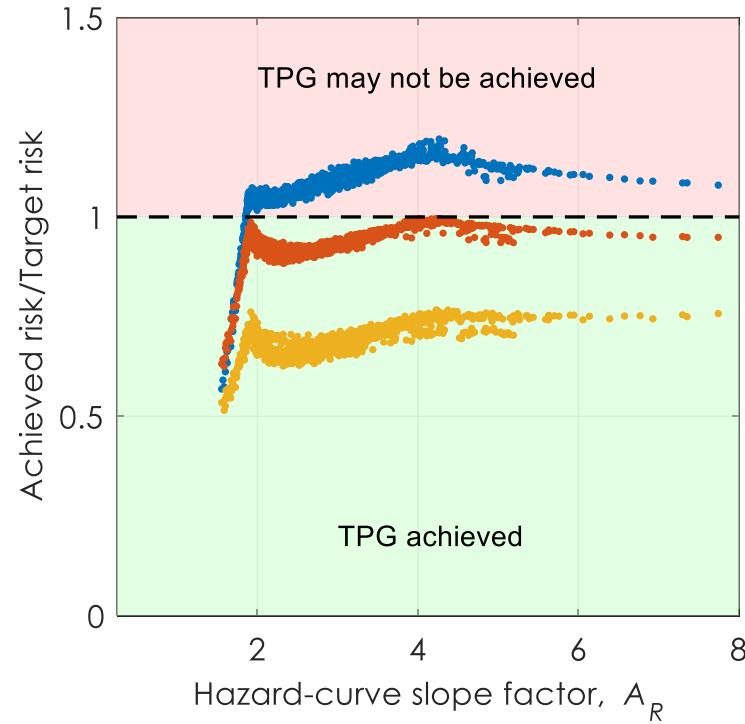
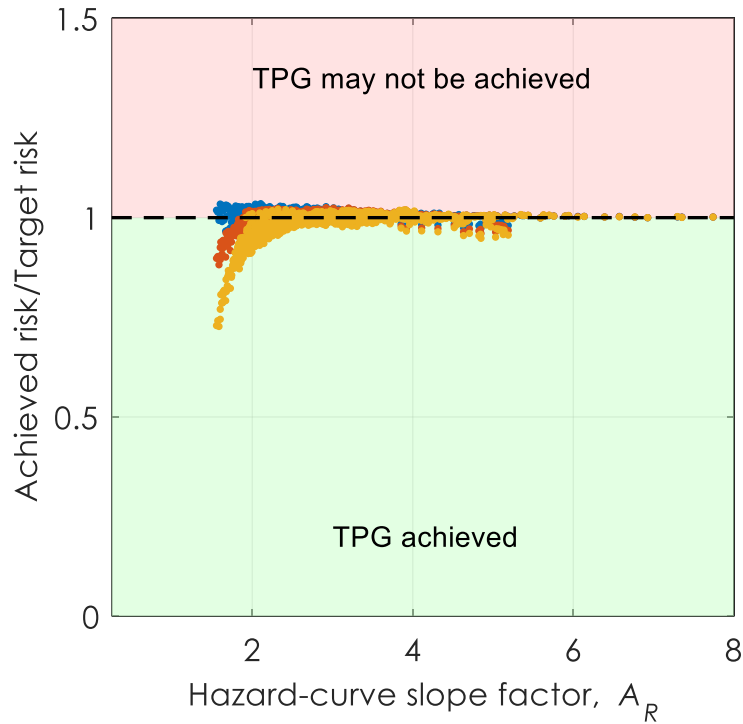
Risk-based performance: 4,752 points

- $1.6 < A_R < 7.7$
- $0.3 < \beta < 0.5$

$$SF_{\text{Kennedy}, p\%} = e^{\left(\frac{1}{2} \frac{\beta^2}{\log(A_R)} - \Phi^{-1}(p) \beta \right)}$$

$$SF_{\text{ASCE 43-19}} = \max \left(\frac{1}{A_R}, \frac{0.6}{A_R^{0.2}}, 0.45 \right)$$

$$SF_{\text{Proposed}} = \max \left(\frac{1}{A_R}, 0.45 \times e^{\left(\frac{0.045}{\log_{10}(A_R)} \right)} \right)$$

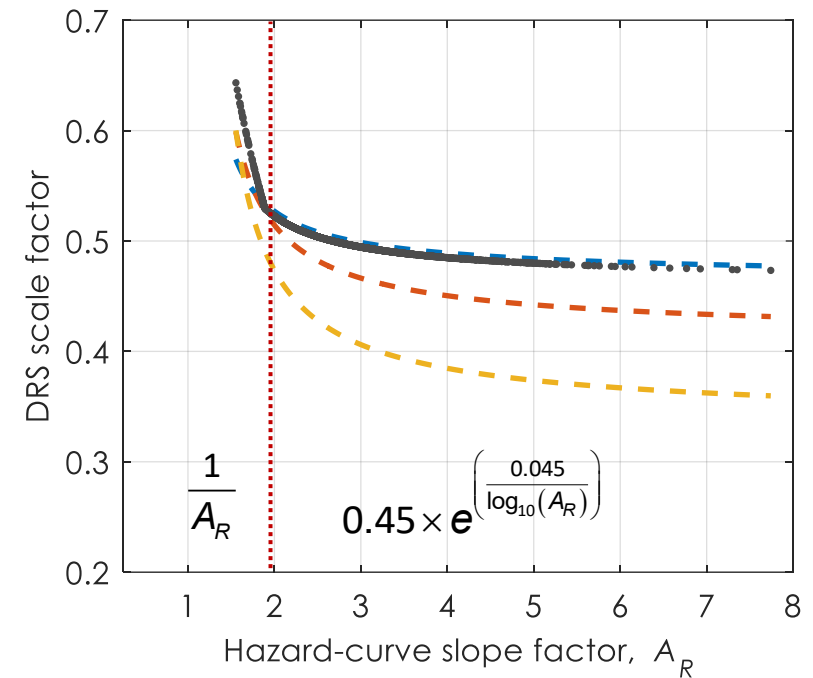
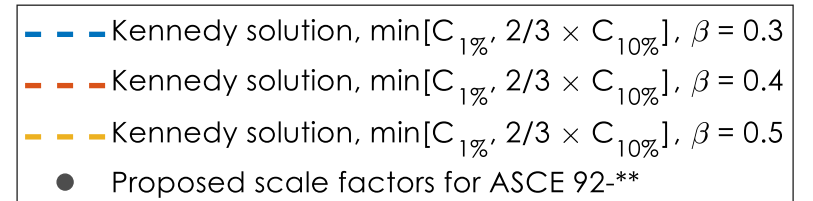


• $\beta = 0.3$ • $\beta = 0.4$ • $\beta = 0.5$

Proposed updates to forthcoming ASCE 92-**

- Simplified two-term empirical scale-factor
 - 1st term governs steeper hazard curves $A_R < 1.9$
 - Typical of WUS sites and SDC 5
 - 2nd term governs for $A_R > 1.9$
 - Covers most CEUS sites
- Better fit for low values of β
 - Reduced potential unconservative bias
- Robust technical basis
 - Benchmarked against 4,752 risk calculations
 - 24 representative nuclear sites across U.S.
 - 2 site classes (BC and CD)
 - 3 seismic design categories (SDC 3, 4, and 5)
 - 11 spectral periods (0.05 sec to 1 sec)
 - 3 values of β (0.3 to 0.5)

$$SF_{\text{Proposed}} = \max \left(\frac{1}{A_R}, 0.45 \times e^{\left(\frac{0.045}{\log_{10}(A_R)} \right)} \right)$$



Technical Basis to Support Risk-Informed Performance-Based
Seismic Design Provisions for Nuclear Facilities

by

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Mohamed Talaat⁴

Publication Date: XX-XX-XXXX

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Technical Report MCEER-26-XXXX

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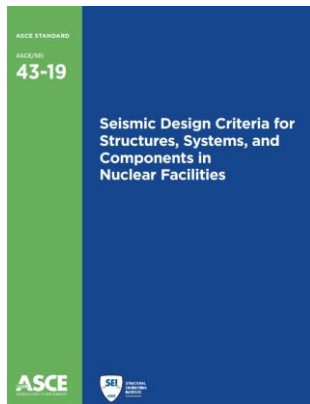
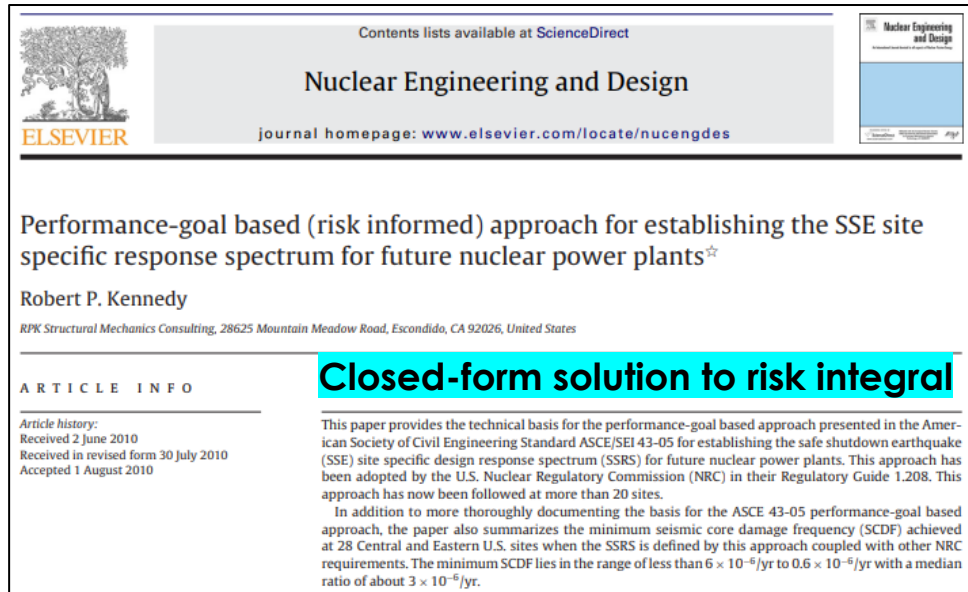
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Forthcoming MCEER technical report

References

- Parsi, S. S., McDonald, B. M., Whittaker, A. S., and Talaat, M. (forthcoming). "Technical basis for risk-informed performance-based design of safety-related nuclear facilities." Technical Report MCEER-26-00XX, University at Buffalo, The State University of New York, Buffalo, NY.
- Electric Power Research Institute (EPRI). (2018). "Seismic fragility and seismic margin guidance for seismic probabilistic risk assessments." Report No. 3002012994, Palo Alto, CA.
- Kennedy, R. P. (2011). "Performance-goal based (risk informed) approach for establishing the SSE site specific response spectrum for future nuclear power plants." *Nuclear Engineering and Design*, 241 (3), 648-656.
- Parsi, S. S., Lal, K. M., Kosbab, B., Ingersoll, E., Shirvan, K., and Whittaker, A. S. (2022). "Seismic isolation: A pathway to standardized advanced nuclear reactors." *Nuclear Engineering and Design*, 387(111445).
- Parsi, S. S., Velez-Lopez, E., Stewart, W. R., Shirvan, K., and Whittaker, A. S. (2024). "Limiting the impact of the seismic load case on a horizontally configured HTGR." *Proceedings: 27th International Conference on Structural Mechanics in Reactor Technology (SMiRT 27)*, Yokohama, Japan.

Robert Kennedy RIPB framework



C1.5 ALTERNATIVE METHODS TO MEET THE INTENT OF THIS STANDARD

The DBE ground motion is defined in Equation (2-1) in terms of a design response spectrum (DRS). Structures whose elements are designed for DRS demands using design capacities derived in accordance with referenced materials standards, as modified in this standard, are expected to achieve the target performance goal listed in Table 1-1. The DRS is formulated to achieve both of the following:

1. Less than about a 1% probability of unacceptable performance for the DBE ground motion, and
2. Less than about a 10% probability of unacceptable performance for a ground motion equal to 150% of the DBE ground motion.

Linearized (log-log) hazard curve

$$\text{Hazard}(a) = K_1 \times a^{-K_H}$$

$$K_H = \frac{1}{\log(A_R)}, K_1 = \frac{\lambda}{a_\lambda^{-K_H}}, \text{ and } A_R = \frac{a_\lambda}{a_{10\lambda}}$$

Lognormal fragility function

$$\text{Fragility}(a, \mu, \beta)$$

Rigorous seismic risk equation

$$\lambda = \int_0^\infty \left(\frac{d\text{Hazard}(a)}{da} \times \text{Fragility}(a, \mu, \beta) \right) da$$

Simplified, closed-form risk equation

$$\lambda = K_1 \times (e^\mu)^{-K_H} \times e^{\frac{1}{2}(\beta \times K_H)^2}$$

$$C_p = a_\lambda e^{\left(\frac{1}{2} \beta^2 K_H + \beta \Phi_p^{-1} \right)}$$

Design and performance assessment

$$C_{1\%ile} = a_\lambda e^{\left(\frac{1}{2} \frac{\beta^2}{\log(A_R)} - 2.326\beta \right)}$$

$$C_{10\%ile} = C_{1\%ile} \times e^{1.05\beta}$$

Measure of hazard curve slope!

Measure of structural fragility slope!

$$\text{DRS} = \text{SF} \times \text{UHS}_{H_P} \quad (2-1)$$

where UHS_{H_P} is the UHS determined for the exceedance frequency H_P , and SF is the scale factor, which is defined in Equation (2-3), at each spectral frequency.

For each spectral frequency at which the UHS is defined, a slope factor, A_R , shall be determined from

$$A_R = \frac{\text{SA}_{H_P}}{\text{SA}_{H_D}} \quad (2-2)$$

where SA_{H_P} is the spectral acceleration (SA) at the exceedance frequency H_P , and SA_{H_D} is the spectral acceleration at the exceedance frequency H_D . The SF at this spectral frequency is given by

$$\text{SF} = \text{Maximum} [\text{SF}_1, \text{SF}_2, \text{SF}_3] \quad (2-3a)$$

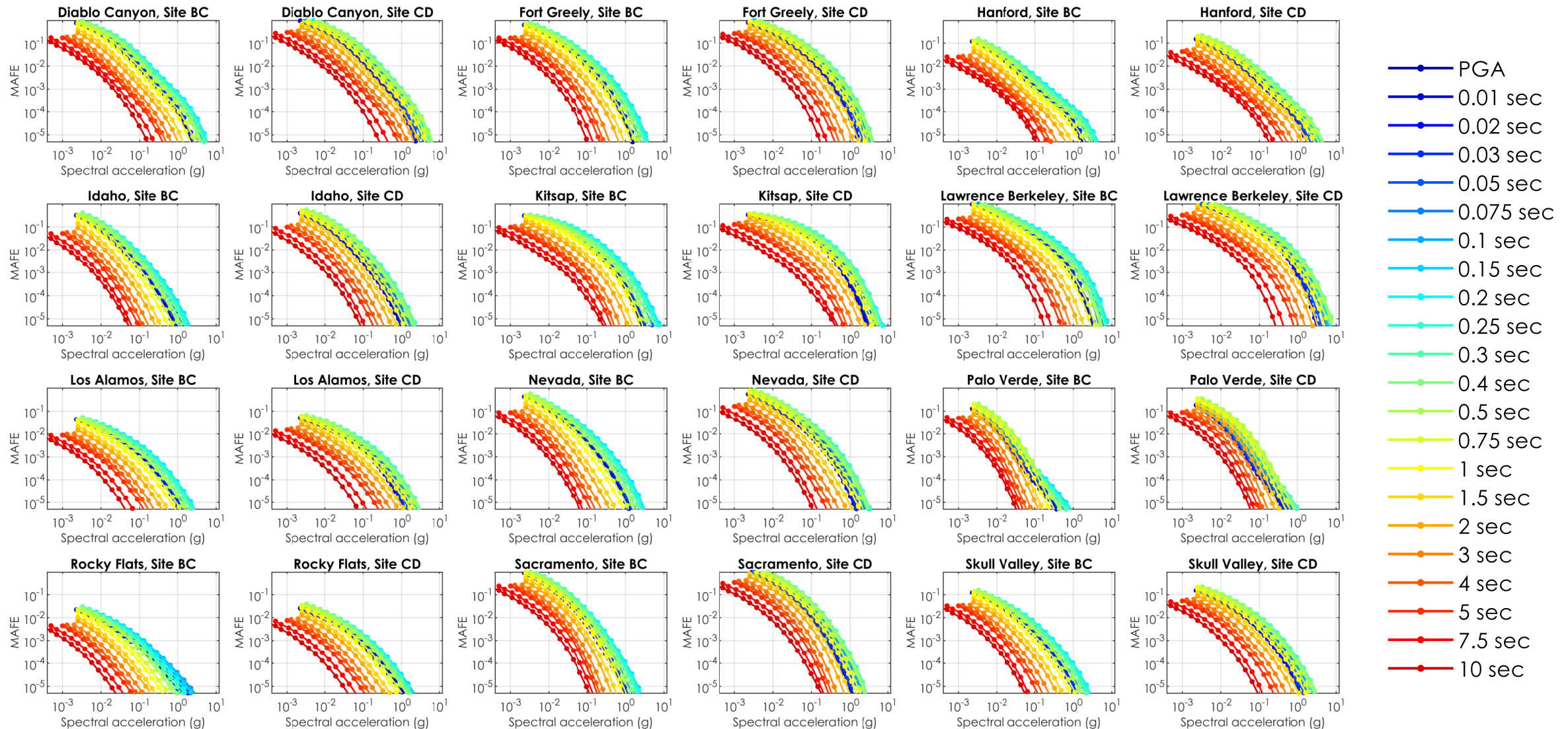
$$\text{SF}_1 = A_R^{-1.0} \quad (2-3b)$$

$$\text{SF}_2 = 0.6 A_R^{-0.2} \quad (2-3c)$$

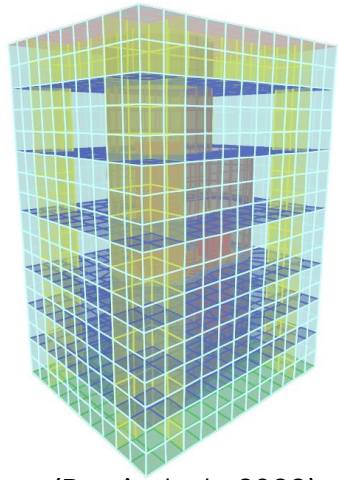
$$\text{SF}_3 = 0.45 \quad (2-3d)$$

Independent of β

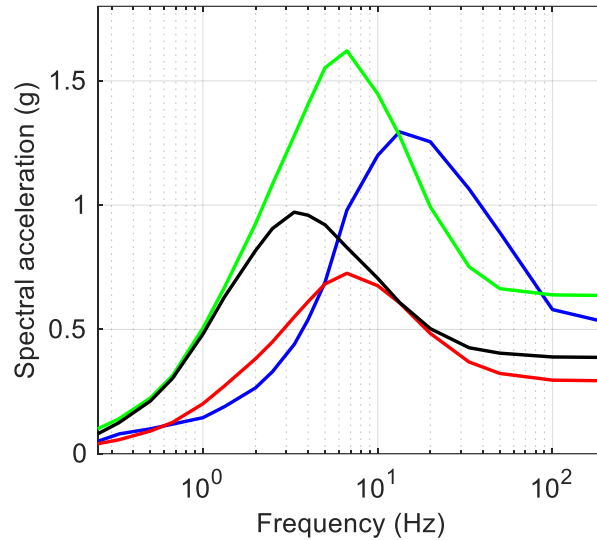
Hazard curves: 12 WUS sites (USGS 2023 toolbox)



Characterize β for structural limit states

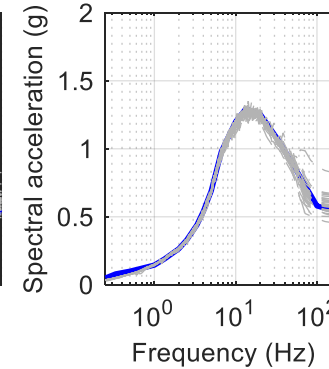
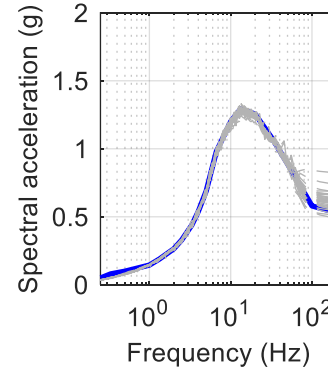


(Parsi et al., 2022)

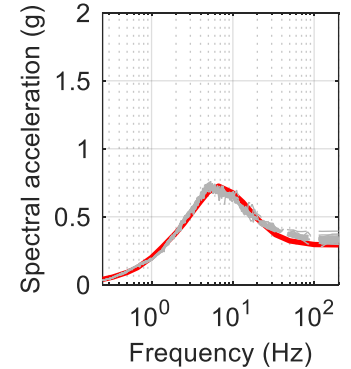
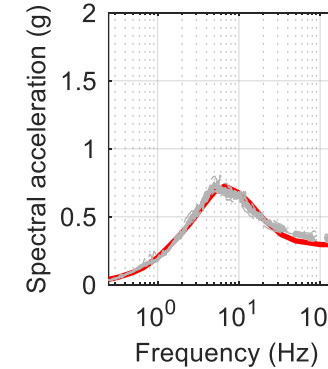


- SDC-4 DBE shaking @East Tennessee Technology Park (ETTP), site BC
- SDC-5 DBE shaking @Idaho National Laboratory (INL), site BC
- SDC-4 DBE shaking @Diablo Canyon Nuclear Station (DCNS), site BC
- SDC-4 DBE shaking @Los Alamos National Laboratory (LANL), site CD

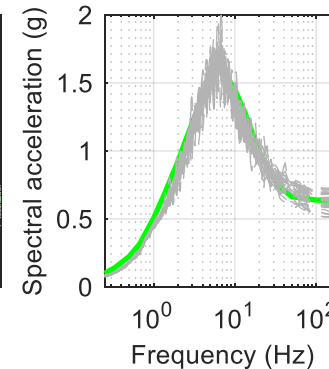
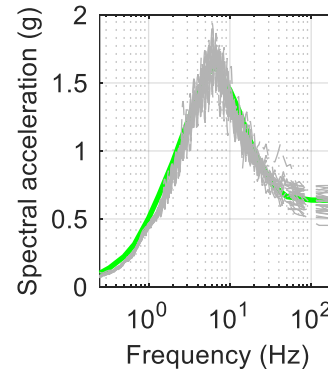
@ETTP site



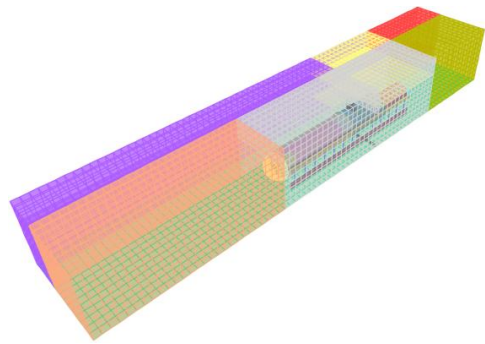
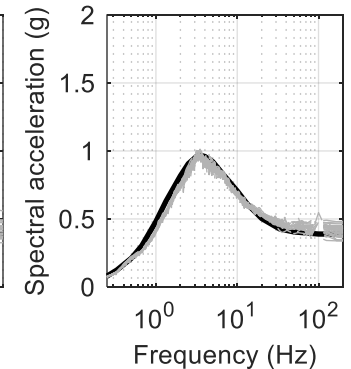
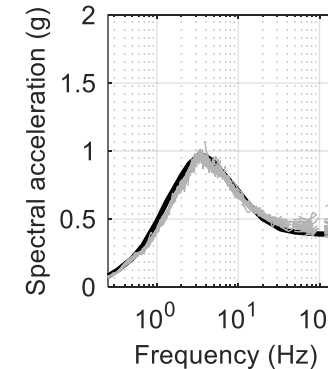
@INL site



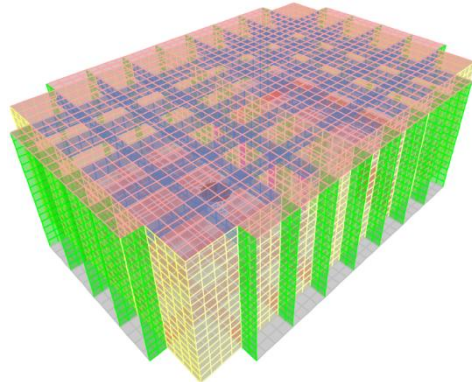
@DCNS site



@LANL site



(Parsi et al., 2024)



(Parsi et al., 2022)

Characterize β for structural limit states

Limit State D - elastic

Six variables (5 demand and 1 capacity)		β
characterized explicitly	Time series (record-to-record variability)	β_{tr}
	Horizontal directionality (max-min scaling)	$\beta_{mm} = 0.18$
	Structural damping	$\beta_d = 0.25$
	Structural frequency (stiffness)	$\beta_f = 0.30$
engineering judgement	Model fidelity	$\beta_{mf} = 0.10$
	Capacity	$\beta_c = 0.15$

Limit States C, B, and A - inelastic

Eight variables (7 demand and 1 capacity)		β
characterized explicitly	Time series (record-to-record variability)	β_{tr}
	Horizontal directionality (max-min scaling)	$\beta_{mm} = 0.18$
	Structural damping	$\beta_d = 0.25$
	Initial stiffness	$\beta_{ki} = 0.30$
	Peak strength	$\beta_{Vn} = 0.10$
engineering judgement	Hardening stiffness	$\beta_{kps} = 0.10$
	Model fidelity	$\beta_{mf} = 0.10$
	Capacity	$\beta_c = 0.15$

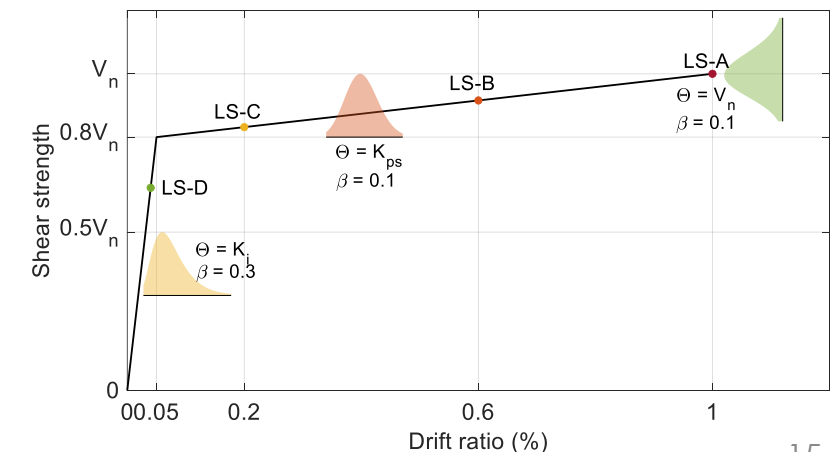
Approaches for computing β :

1. Decomposition-Based Sensitivity Analysis

- Computes the effect of each random input individually
- Uses SRSS to aggregate individual contributions
- Are input variables truly independent?

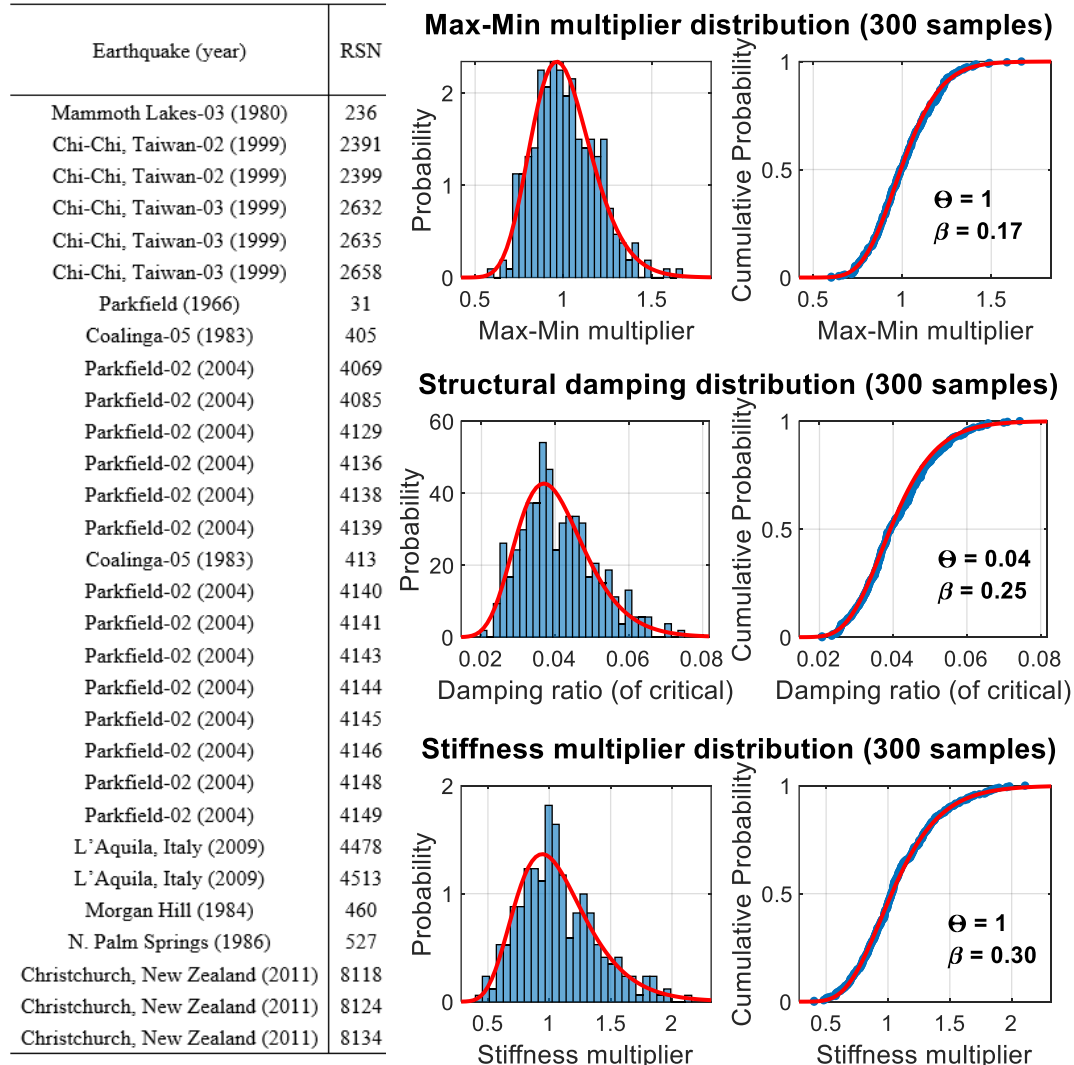
2. Monte Carlo-Based Sensitivity Analysis

- Assumes random sampling of all inputs simultaneously – 300 combinations
- Computes composite β reflecting overall sensitivity

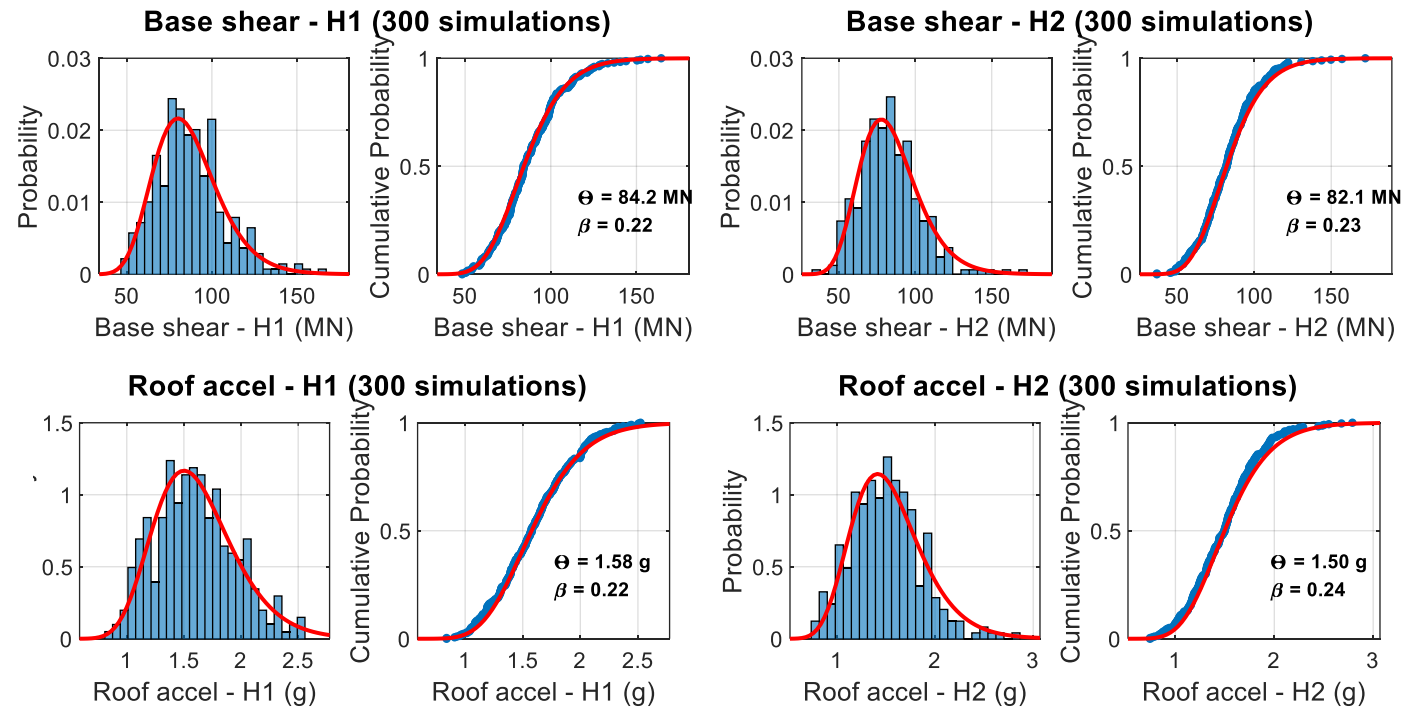


V-HTGR building @ETTP site, Limit State D

Distribution of input variables



Distribution of structural response variables



$$\text{Composite } \beta = \sqrt{\beta_{MC}^2 + \beta_{mf}^2 + \beta_c^2} = \mathbf{0.31}$$

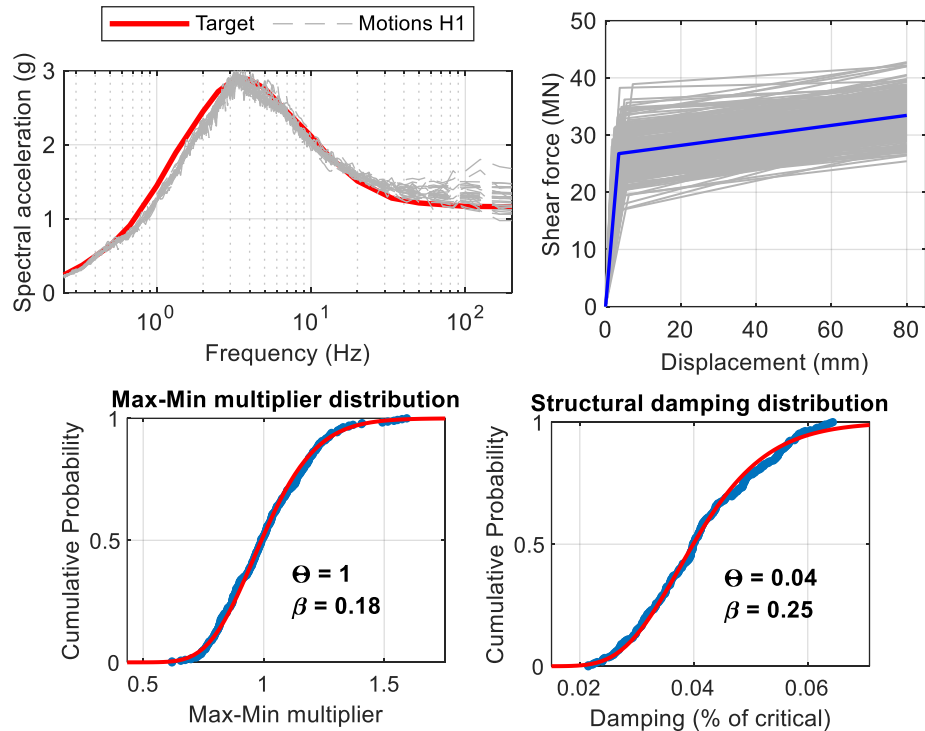
$\downarrow$
0.23

$\downarrow$
0.1

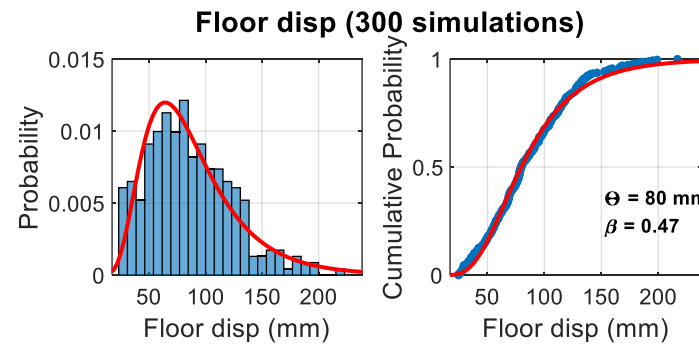
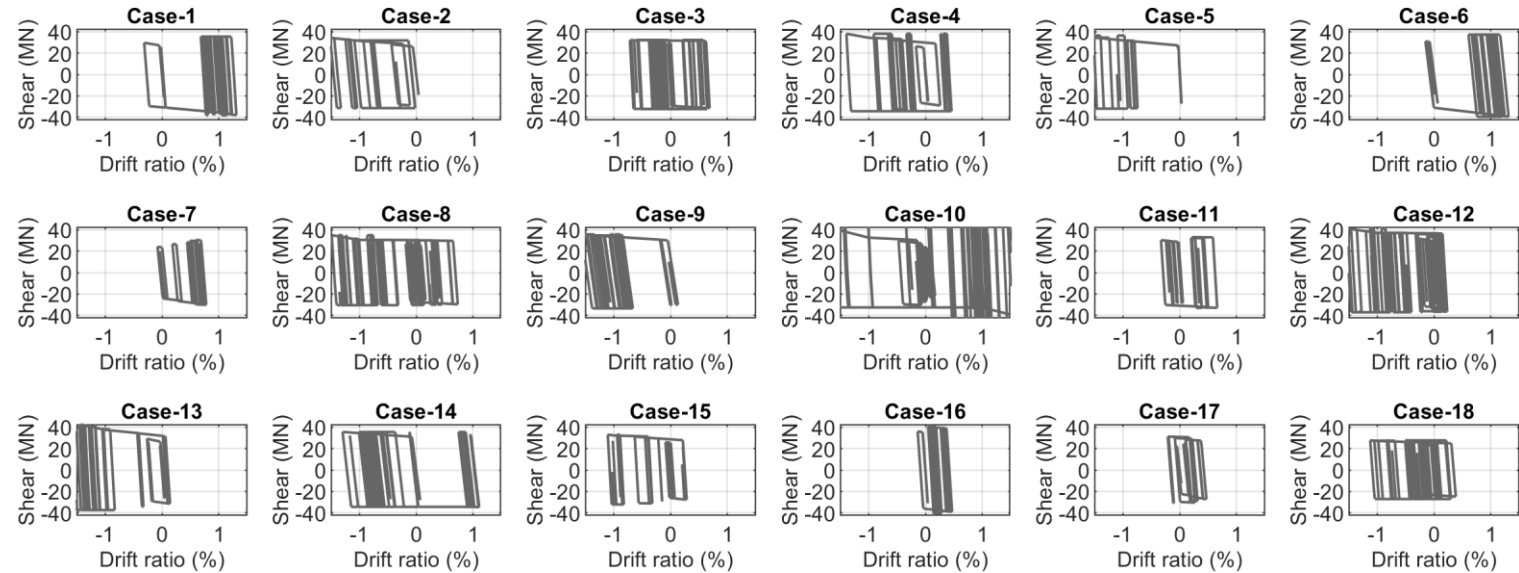
$\downarrow$
0.15

V-HTGR building @LANL site, Limit State A

Distribution of input variables



Force-displacement responses, 18 of 300 simulations



	Median	β
'base_shear (MN)'	34	0.11
'floor_disp (mm)'	80	0.47
'roof_disp (mm)'	101	0.36
'floor_accel (g)'	1.55	0.18
'roof_accel (g)'	2.73	0.15

1% drift ratio

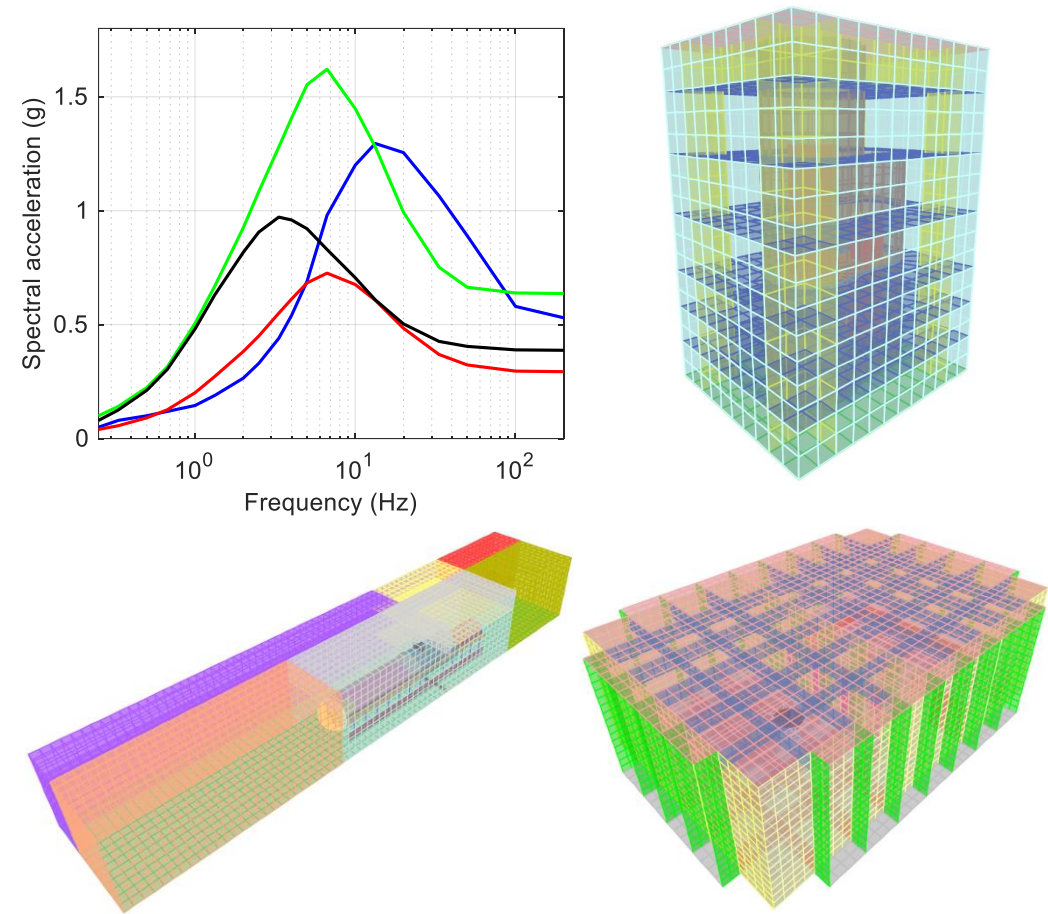
$$\text{Composite } \beta = \sqrt{\beta_{MC}^2 + \beta_{mf}^2 + \beta_c^2} = 0.5$$

0.47 0.1 0.15

β for LS-A = 0.5

Dispersions in structural fragility functions

- SDC-4 DBE shaking @East Tennessee Technology Park (ETTP), site BC
- SDC-5 DBE shaking @Idaho National Laboratory (INL), site BC
- SDC-4 DBE shaking @Diablo Canyon Nuclear Station (DCNS), site BC
- SDC-4 DBE shaking @Los Alamos National Laboratory (LANL), site CD



Characterization of Composite β		
Combinations	LS-D	LS-A
V-HTGR building @ETTP site – 300 simulations	0.31	0.44
V-HTGR building @INL site – 300 simulations	0.31	0.47
V-HTGR building @DCNS site – 300 simulations	0.32	0.48
V-HTGR building @LANL site – 300 simulations	0.30	0.50

β for LS-A = 0.5
 β for LS-B = ..
 β for LS-C = ..
 β for LS-D = 0.3

} 0.4