A Ground Motion Selection and Modification Method Preserving Characteristics and Aleatory Variability of Scenario Earthquakes

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Outlines

- Introduction
  - Ground Motions Characteristics and Variability
- Ground Motion Selection and Modification Method
  - Flow Chart and Example
- Predicting the Distribution of Nonlinear Structural Response
- Conclusions

1. Introduction

- **The aleatory variability of ground motions should be carefully incorporated in the ground-motion selection model to predict the full distribution of system response under a scenario earthquake.**

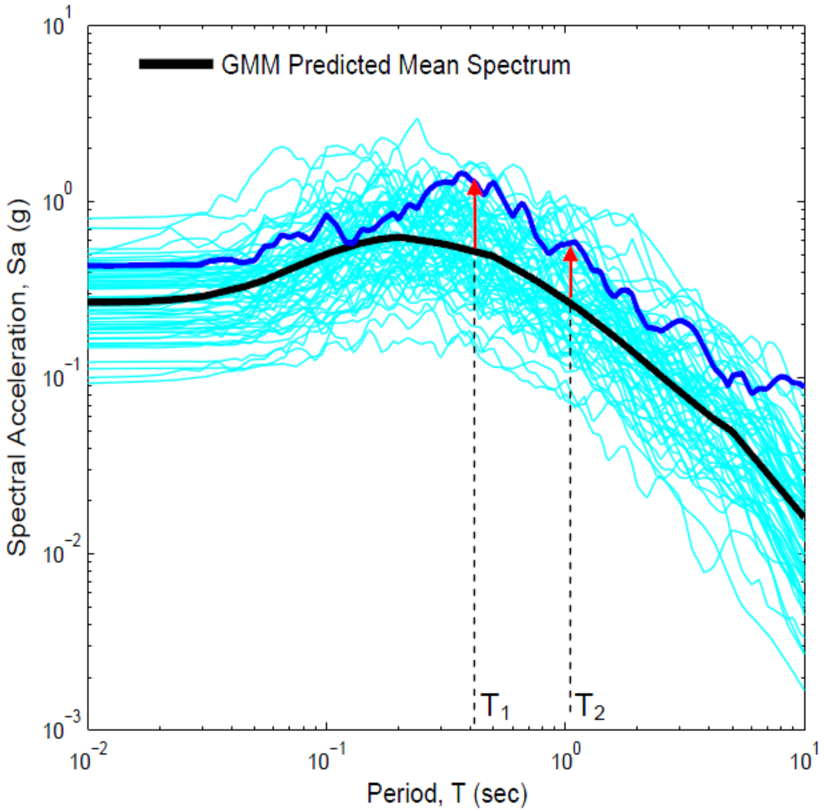
- **Current GMSM efforts are mainly focused on predicting the median response under a prescribed seismic demand.**

- **Existing methods considering ground motion variability:**

➢ ATC-58: *Guidelines for Seismic Performance Assessment of Buildings*, 50% Draft, April, 2009.

➢ Semi-automated method (Rathje & Kottke, 2008)

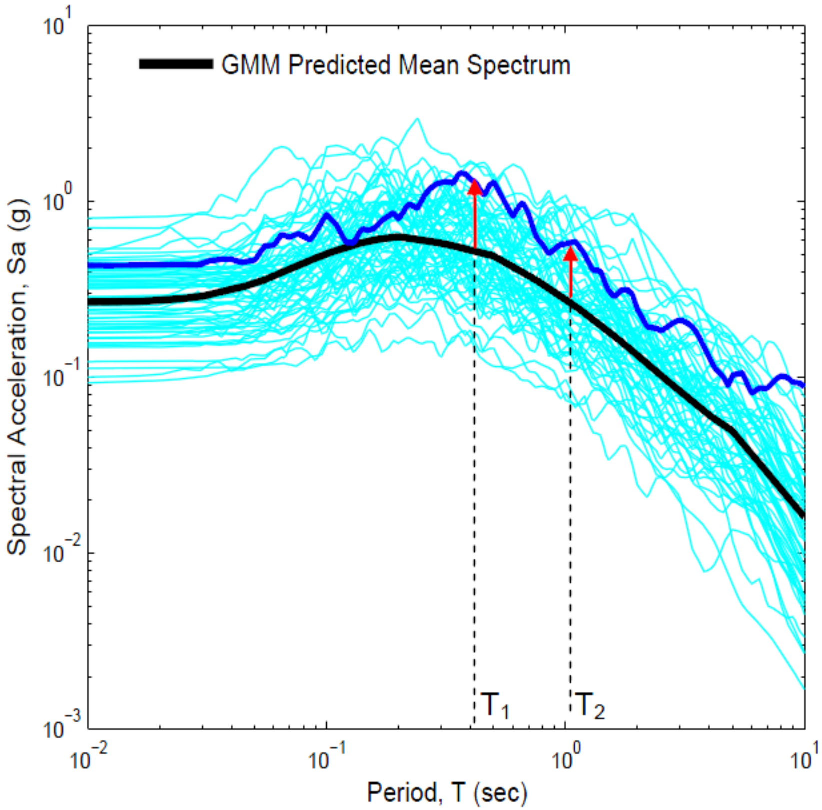
❖ Ground Motion Variability



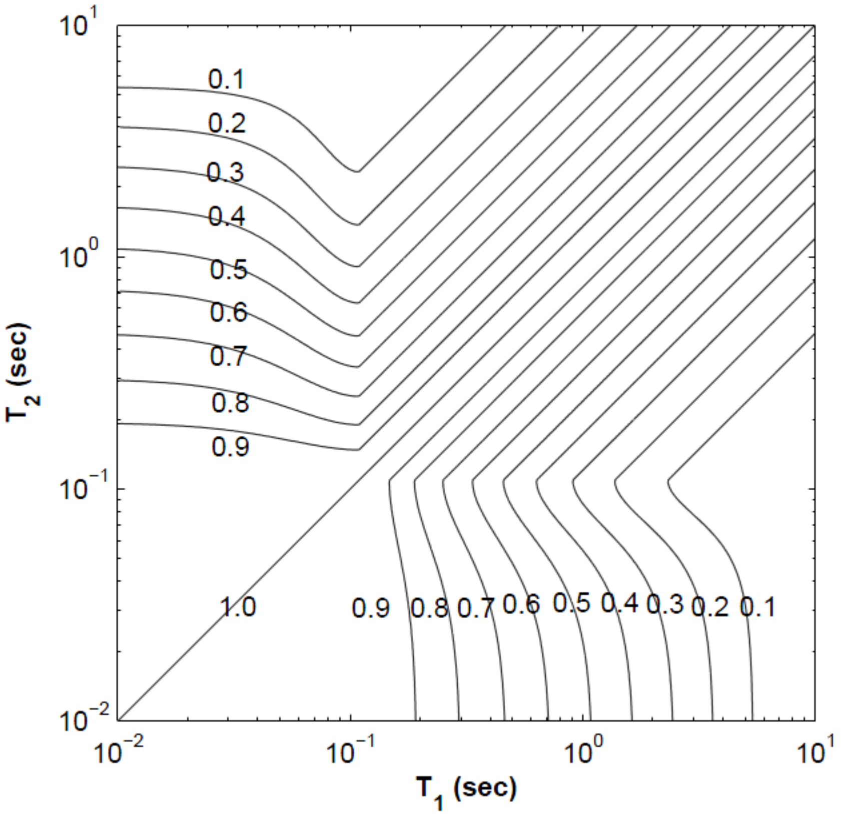
(a) Spectral acceleration distribution

- **Ground-motion attenuation models usually provide the median value and the standard deviation of log spectral acceleration of a scenario earthquake.**
- **The correlation between spectral values at different periods is an intrinsic property of ground motions. It describes correlation of the seismic demands over frequency content. It is one of the most important properties in quantifying the variability of ground motions.**

❖ Ground Motion Variability

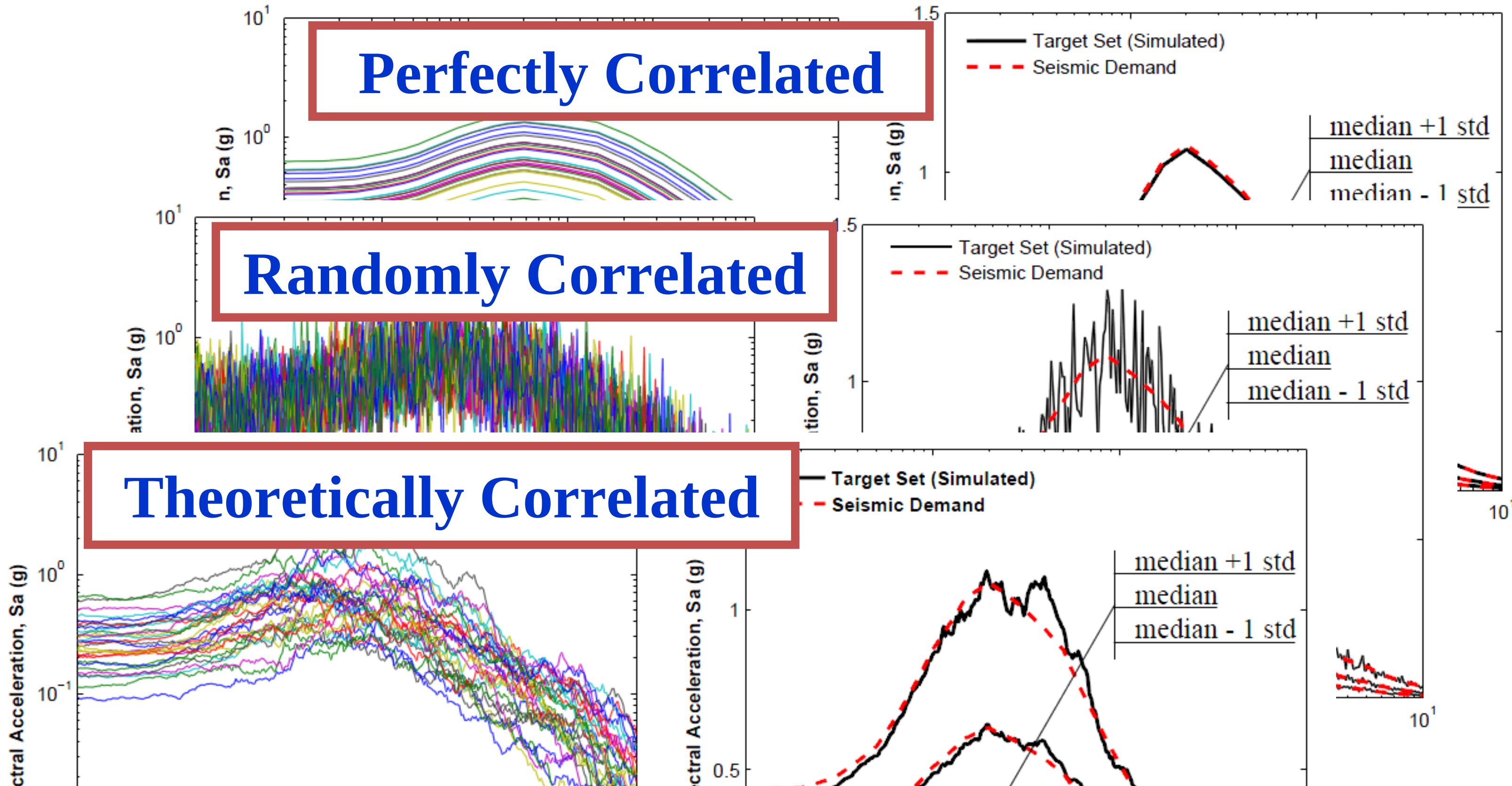


(a) Spectral acceleration distribution



(b) Correlation coefficient of spectral accelerations between periods, from Baker and Jayaram (2008).

❖ Aleatory Variability Vector (μ, σ, ρ)



The selected ground-motion set should preserve the median, the standard deviation of the spectral distribution, also the correlation structure between spectral values at different periods.

2. Ground Motion Selection and Modification Method

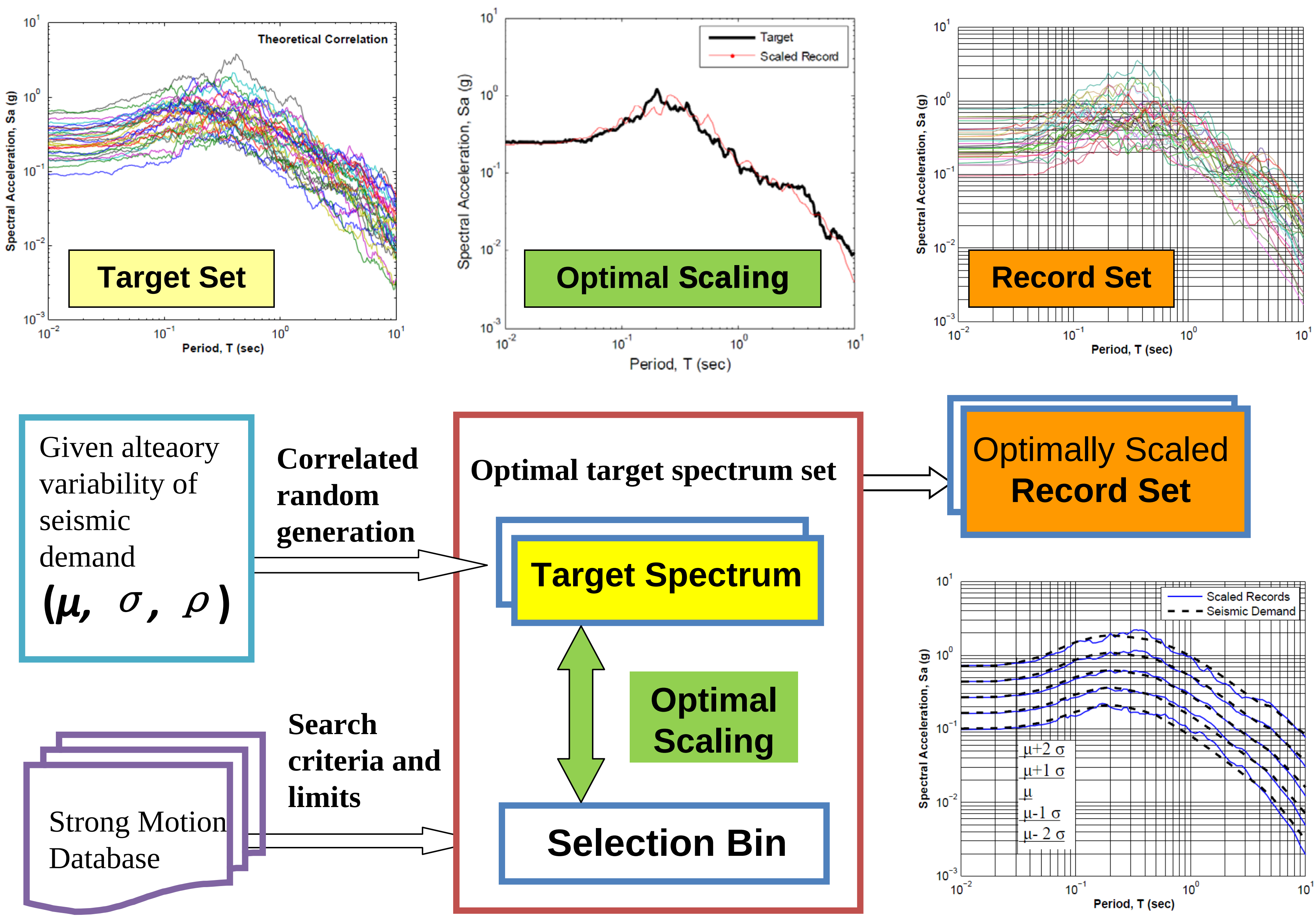
❖ Objectives

Find the optimal combination of a set of *n* records and their corresponding scale factors that preserve the aleatory variability vector (μ, σ, ρ) of a given seismic scenario.

Mathematically rigorous solution is not feasible:

- Select a set of 7 records out of 1500:
  3×10^{18} combinations (set aside the scale factors)
- Select a set of 100 records out of 1500:
  1.5×10^{158} combinations (set aside the scale factors)

➢ A Computationally Efficient Algorithm



❖ An GMSM Example

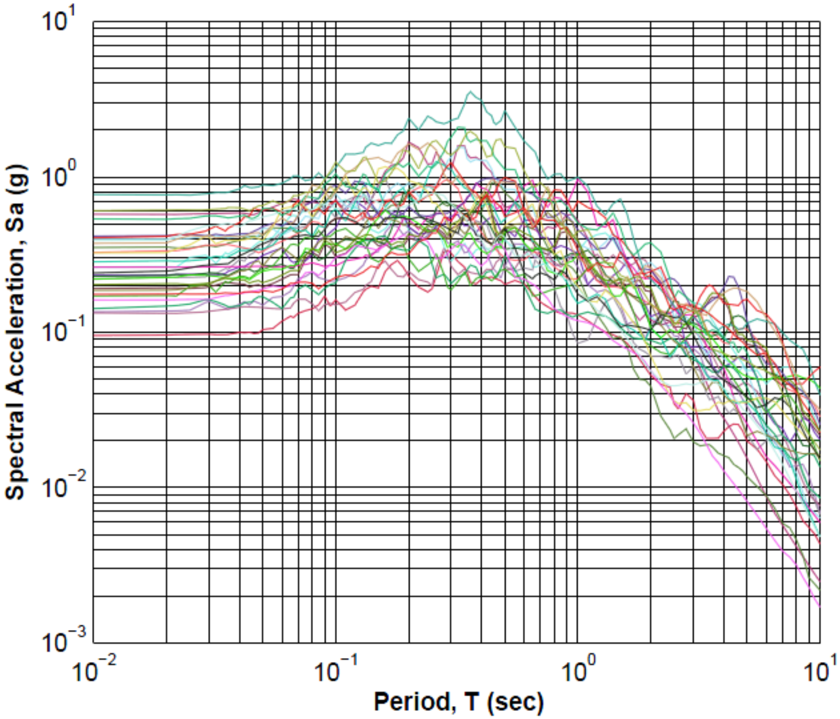
➢ Scenario earthquake

- Magnitude M_w =7, strike-slip faulting;
- Rupture distance: R_{rup} =10 km;
- Site condition: Vs_{30}=400 m/s;
- The median and standard deviation of the scenario earthquake:
  Next Generation Attenuation Model (Campbell and Bozorgnia, 2008);
- The correlation coefficients follow Baker and Jayaram (2008).

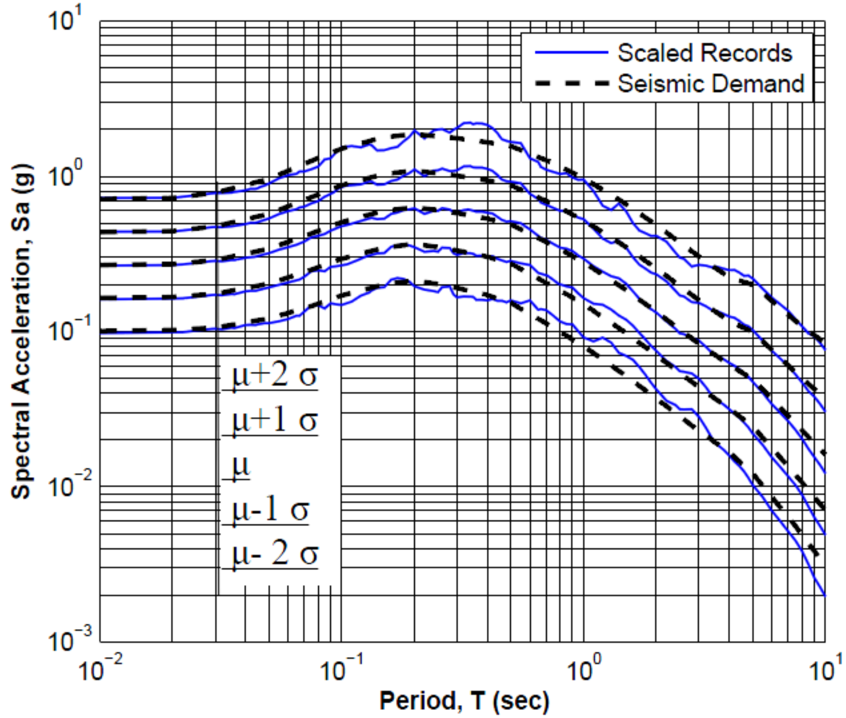
➢ Selected Records

- Magnitude bin: M_w =6-8;
- Distance bin: R_{rup} = 0-30 km;
- No restriction on the range of scale factors, the fault mechanics, the significant duration and the site condition;
- No restriction on the uniqueness of ground motion records.

➢ Selected and Scaled Ground Motion Set – 30 Record Set

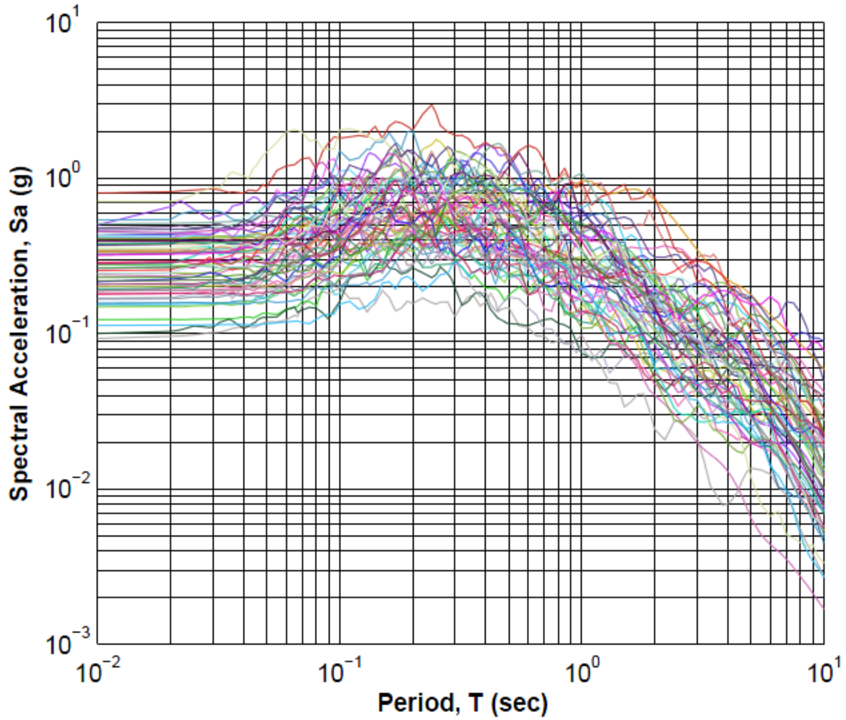


(a) The 30-record set

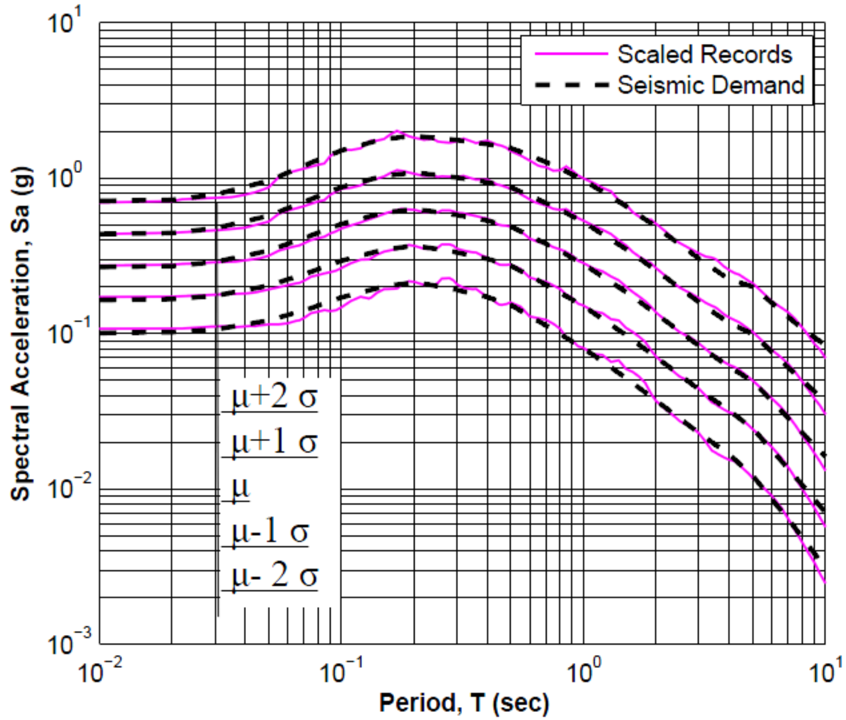


(b) The 30-record set

➢ Selected and Scaled Ground Motion Set – 60 Record Set

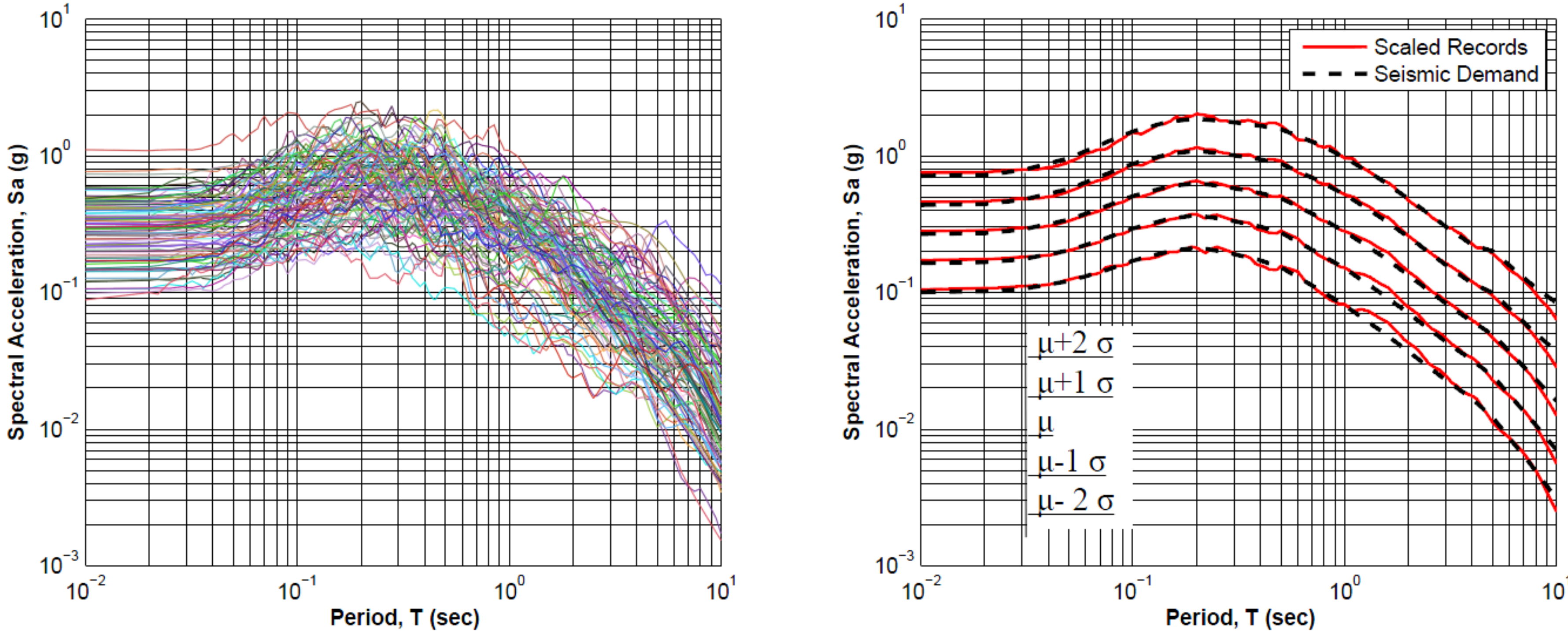


(c) The 60-record set



(d) The 60-record set

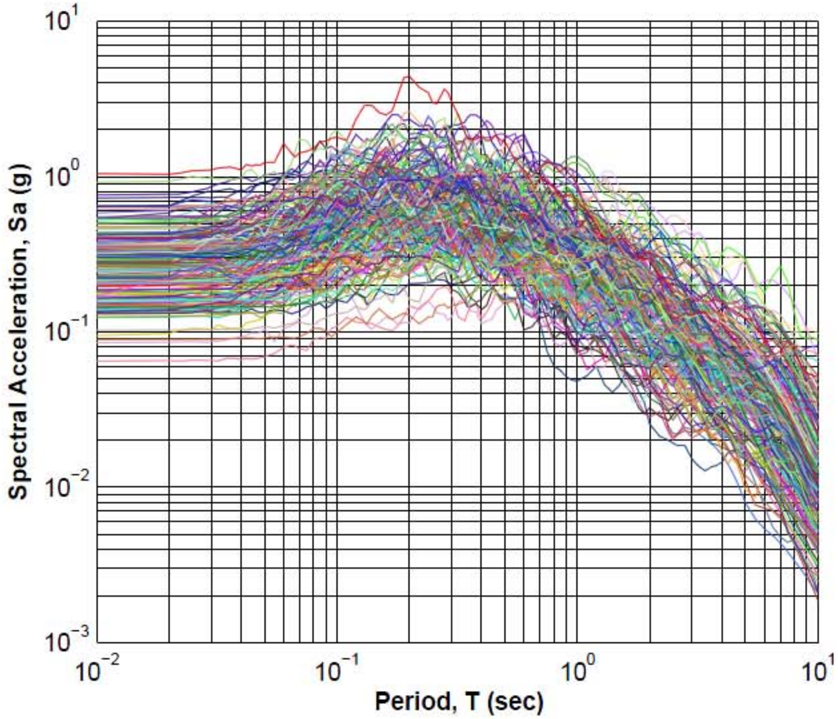
➢ Selected and Scaled Ground Motion Set – 100 Record Set



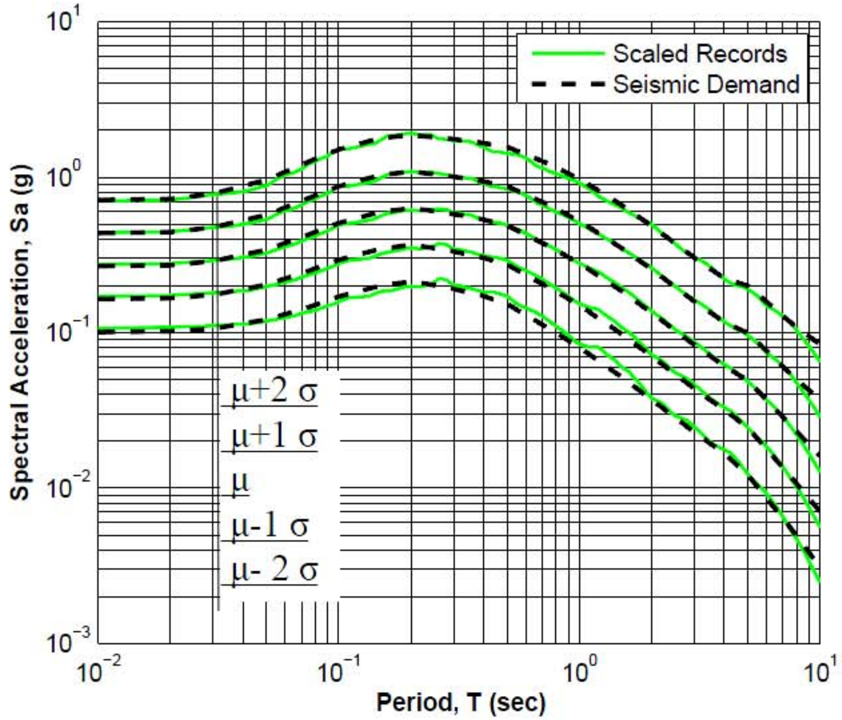
(e) The 100-record set

(f) The 100-record set

➢ Selected and Scaled Ground Motion Set – 200 Record Set



(g) The 200-record set



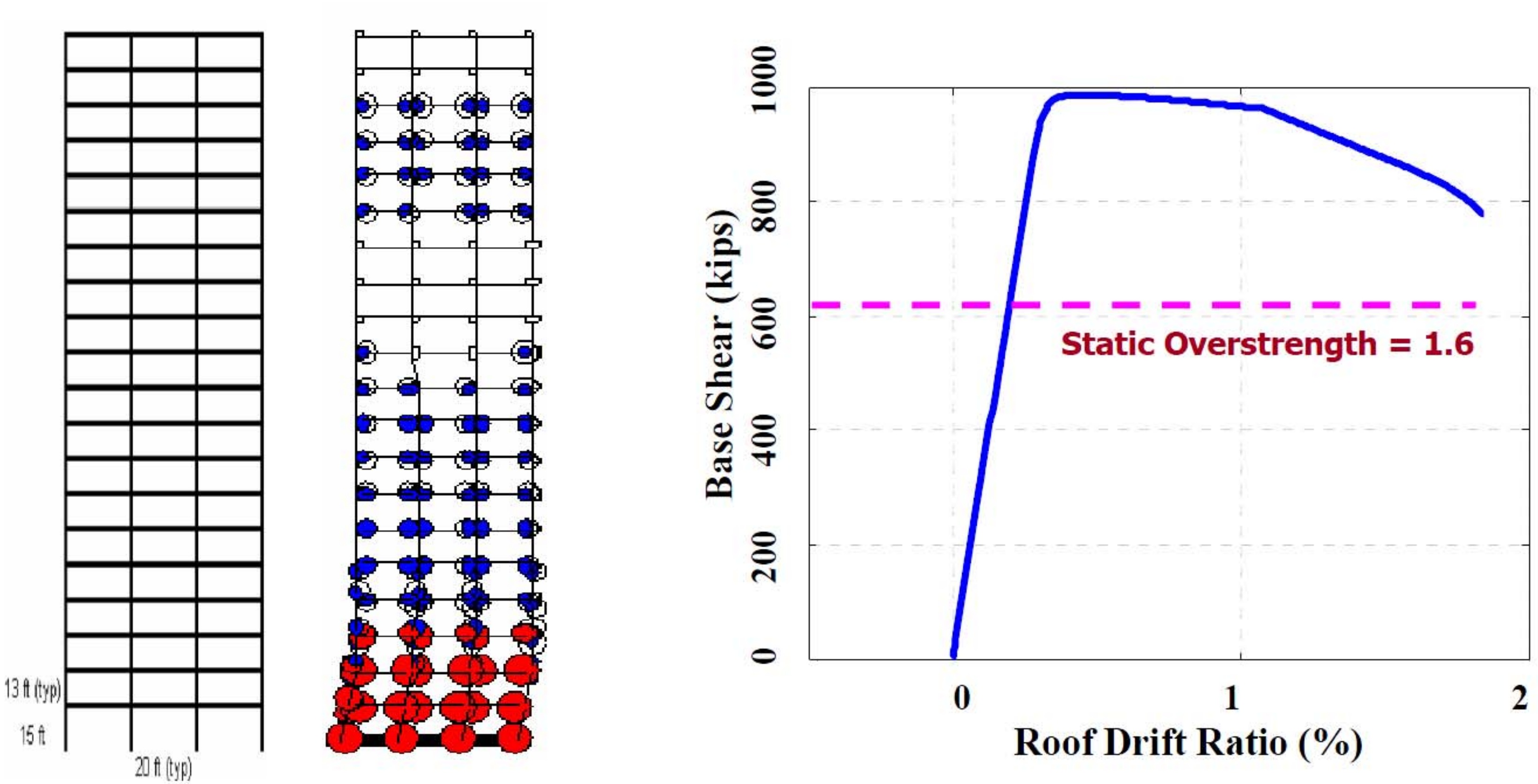
(h) The 200-record set

➢ Summary of the Ground-motion Characteristics

Ground-motion Set	**Scale Factors**	**M_w**	**R_{rup} (km)**	**$D_{5\text{-}95}$ (sec)**	**Vs_{30} (m/s)**
Scenario	—	7.0	10	14.1 §	400
30 records	**1.54**# (1.28*)	**6.9** (0.5)	**12.8** (8.3)	**18.4** (10.5)	**410** (169)
60 records	**1.75** (1.53)	**6.9** (0.5)	**14.0** (7.9)	**17.9** (10.4)	**386** (173)
100 records	**2.00** (2.56)	**6.9** (0.4)	**13.8** (8.0)	**16.1** (9.8)	**452** (257)
200 records	**1.59** (1.51)	**6.9** (0.5)	**13.3** (7.9)	**18.3** (12.1)	**426** (261)

bold data show the average value;
* data in parenthesis show the standard deviation;
§ the predicted mean value of the significant duration from Kempton and Stewart (2006).

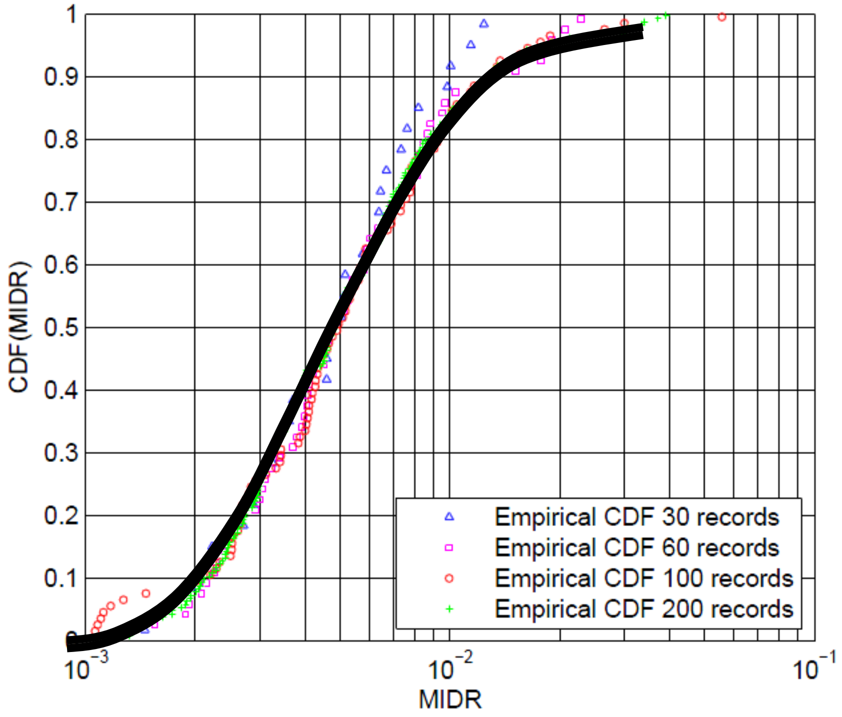
3. Predicting Distribution of Nonlinear Structural Response



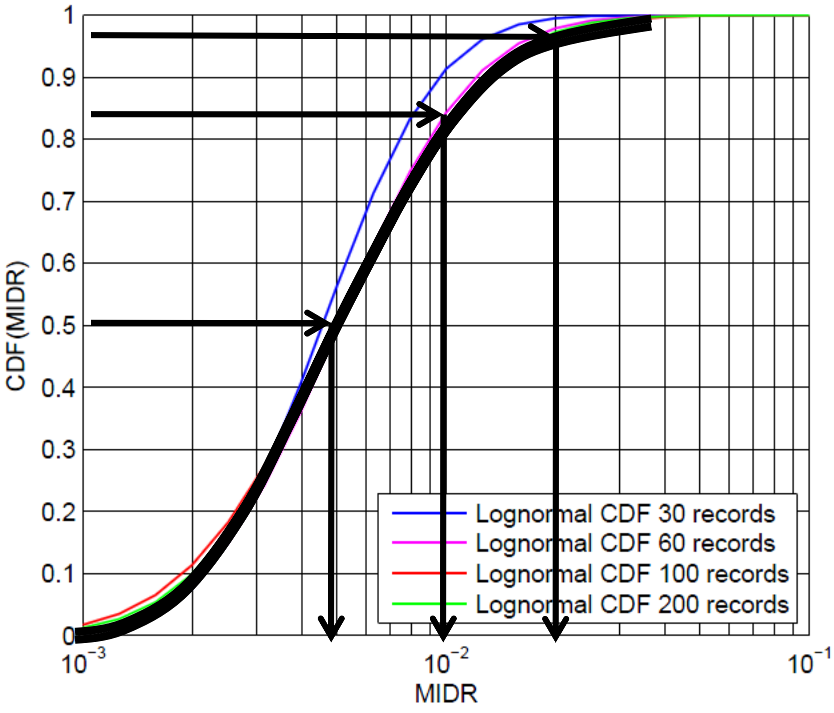
(a) FEM model (b) Deformed Model (c) Push-over Curve

The structural model: by courtesy of Dr. Haselton

➢ Cumulative Distribution of the Maximum Interstory Draft Ratio (MIDR) of All Stories



(a) Empirical CDFs



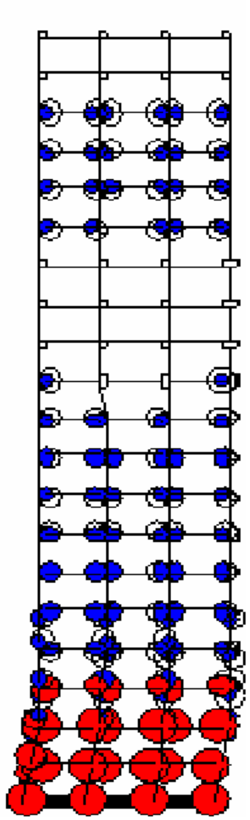
(b) Fitted lognormal CDFs

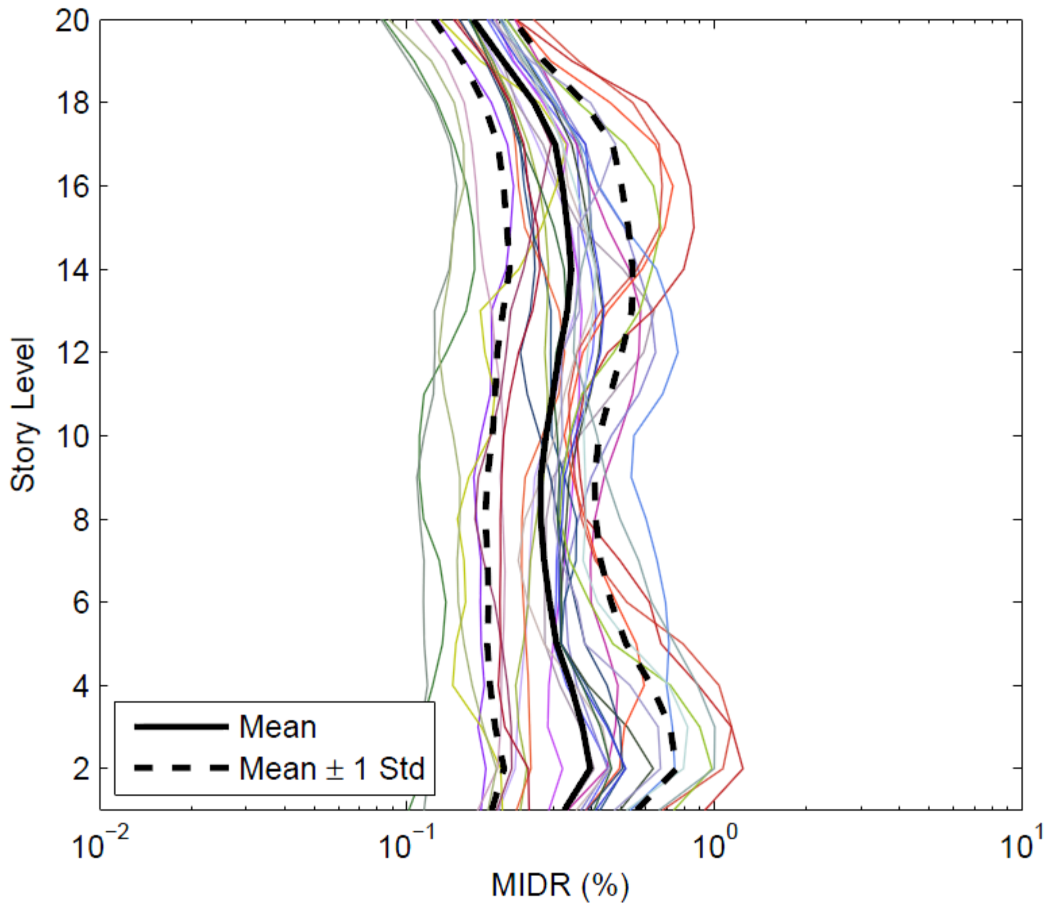
➢ Summary of the estimated lognormal MIDR distribution

Ground-motion set	MIDR (median)	Standard Deviation (log)	MIDR (median+1 std)	MIDR (median+2 std)
30 records	0.004566 (-9.5% *)	0.575693	0.008120 (-21%)	0.014440 (-32%)
60 records	0.005068 (0.5%)	0.676179	0.009965 (-3.6%)	0.019595 (-7.5%)
100 records	0.005012 (-0.7%)	0.761029	0.010728 (3.7%)	0.022963 (8.3 %)
200 records	**0.005045**	**0.717648**	**0.010341**	**0.021195**

* Numbers in parenthesis show the relative errors of each set *w.r.t.* the 200-record set

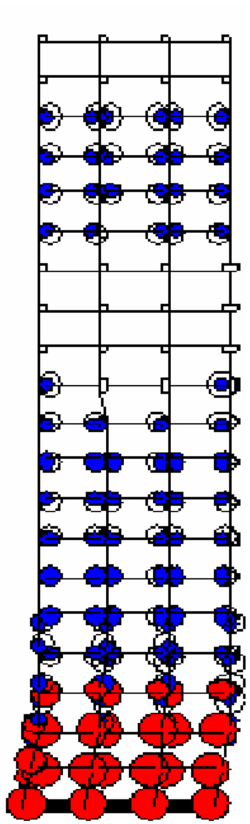
➢ Distribution of MIDRs for Each Story

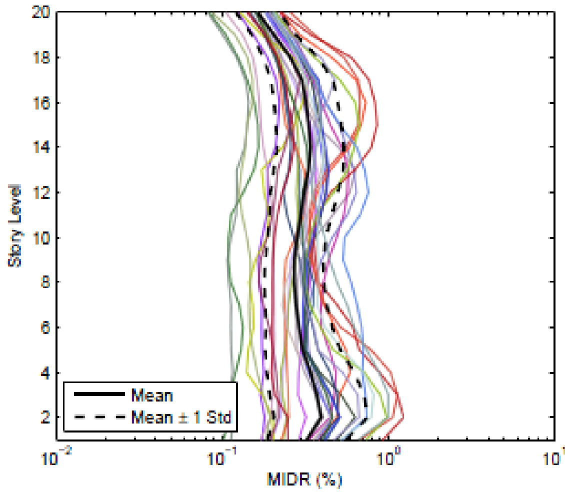




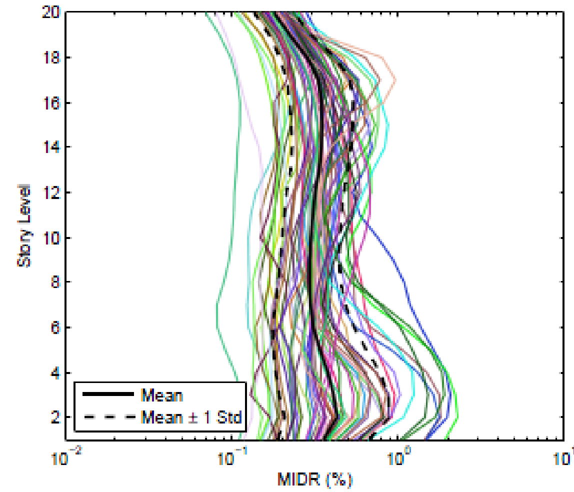
30 record set

➢ Distribution of MIDRs for Each Story

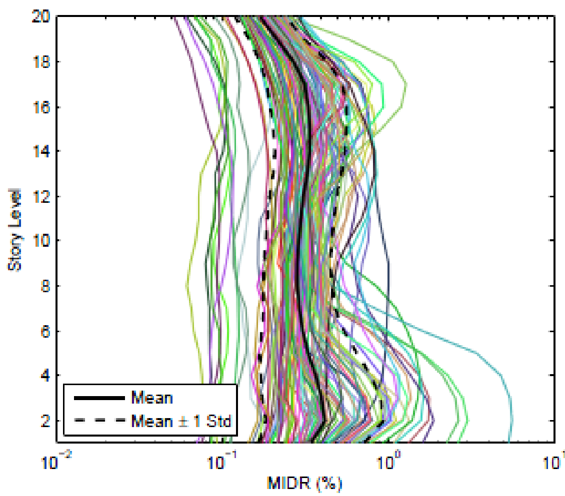




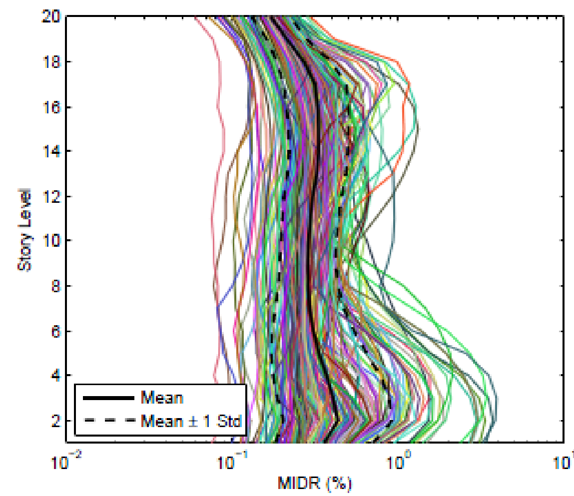
(a) 30-record set



(b) 60-record set

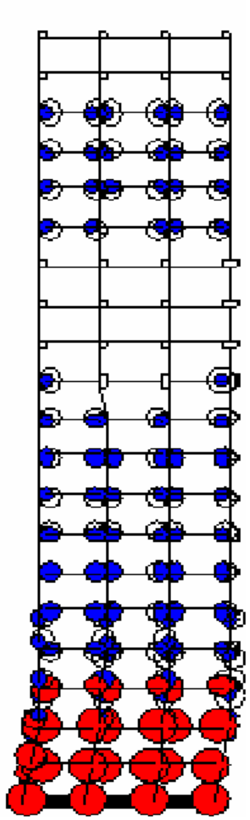


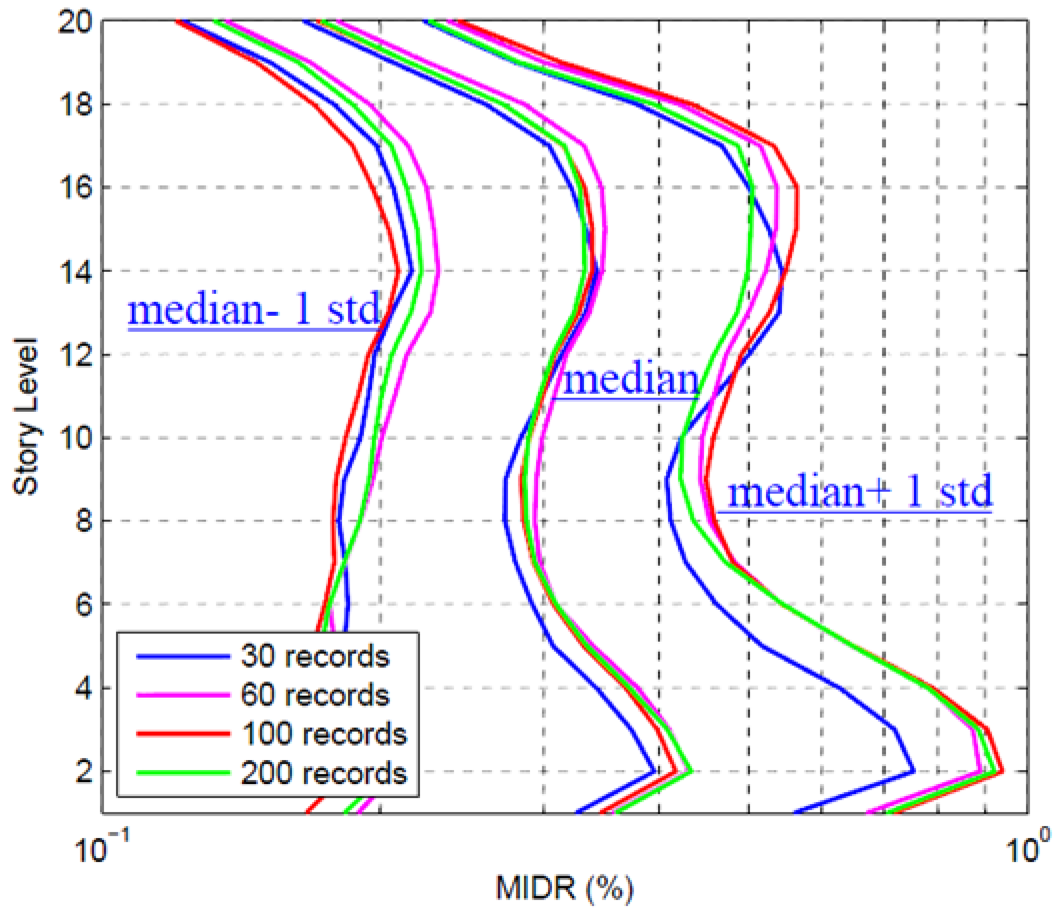
(c) 100-record set



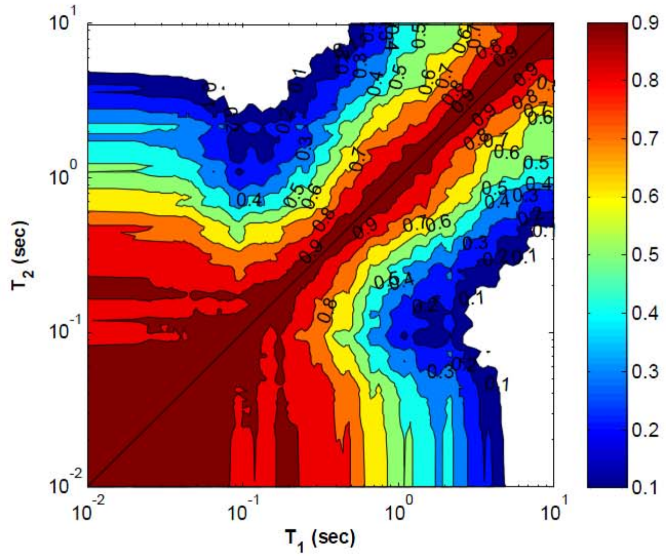
(d) 200-record set

➢ Distribution of MIDRs for Each Story

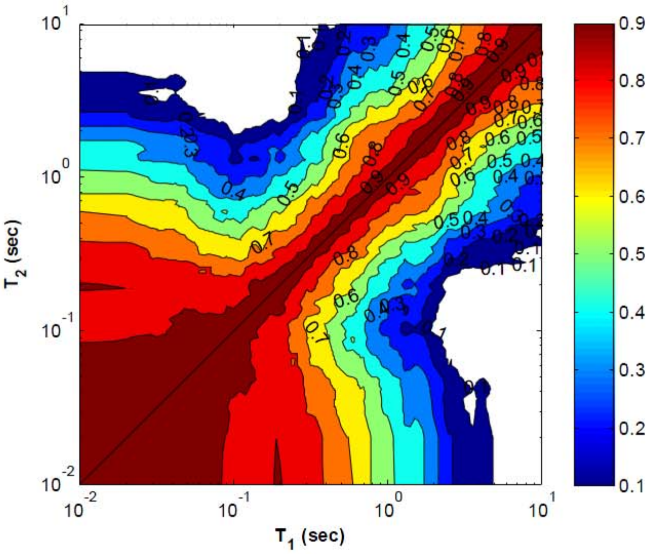




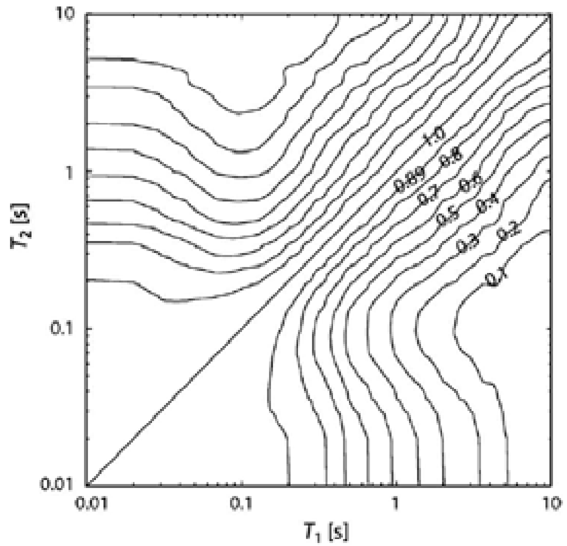
➢ Correlation Structure of Selected Record Sets



100-record set



200-record set



Chiou-Youngs empirical data

4. Conclusions

• The resulted ground motions set can preserve the statistical distribution (mean, standard deviations) and correlations of response spectra, and other characteristics of the recordings such as earthquake magnitude, distance, and site characteristics etc.

• The numerical analyses of a 20-story RC frame structure demonstrated excellent capacity of the proposed method in the study of full distribution of nonlinear responses. Studies are underway to apply the GMSM method to other nonlinear systems.

• Extension to conditional mean spectrum is straightforward and has been successful.

• The proposed method is computationally efficient.

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Thank you!