Advances and Trends in Earthquake Ground Motions Selection and Modification (Scaling) for Response History Analyses

PEER

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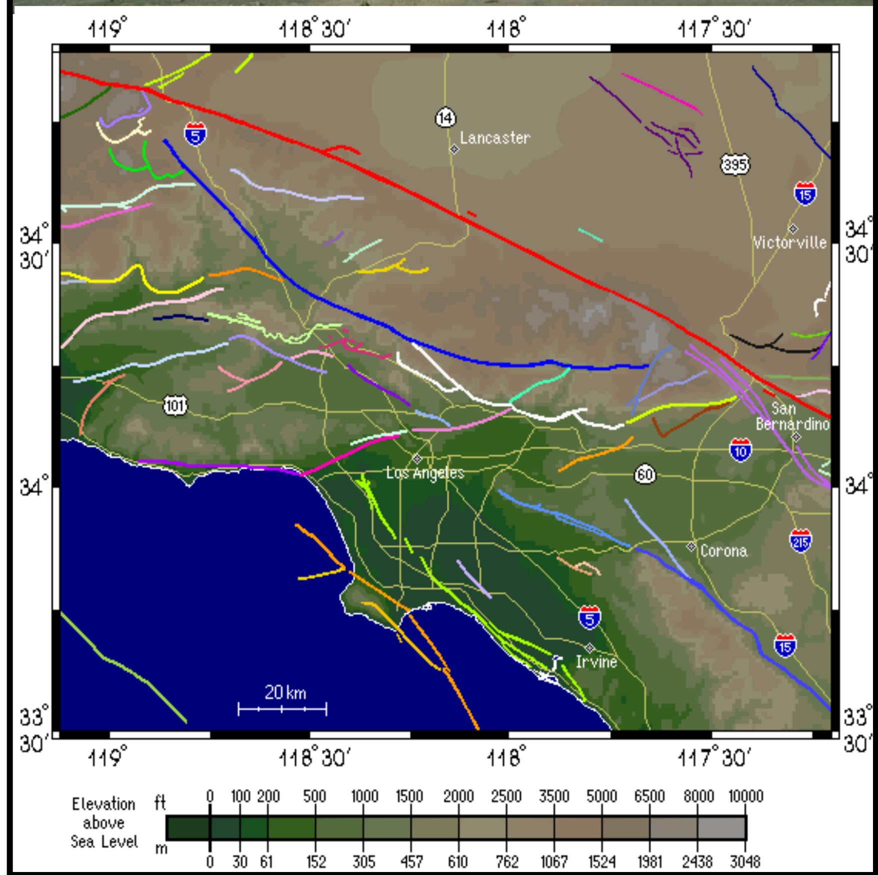
NORTHRIDGE 20
SYMPOSIUM

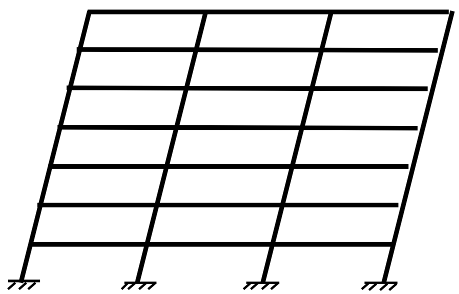
Menu du jour

- Introduction and background
- Target spectral shape
- The GMSM project and lessons learned
- Building code key features
- Where to go from here

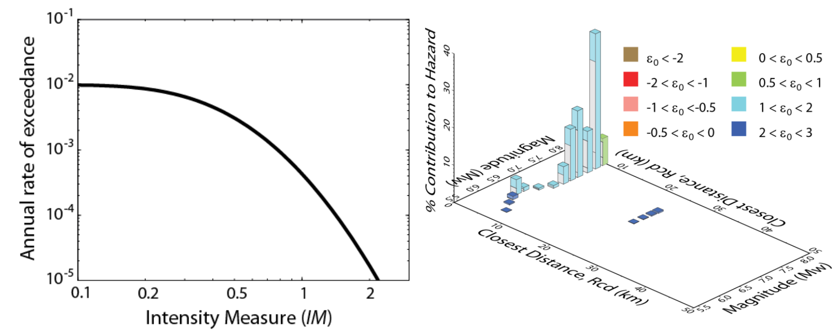


Big picture

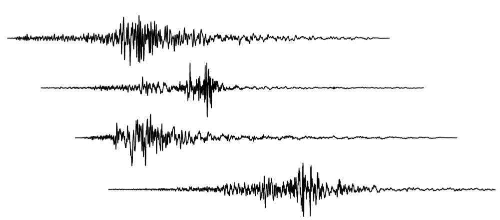
Nonlinear dynamic structural analysis



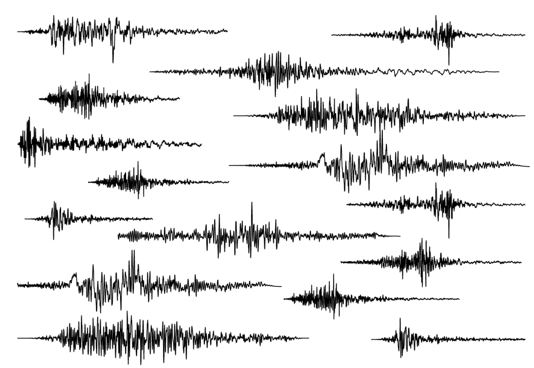
Hazard: what kind of shaking might I experience at my site?



Selected ground motions



Candidate ground motions



Source: J. Baker

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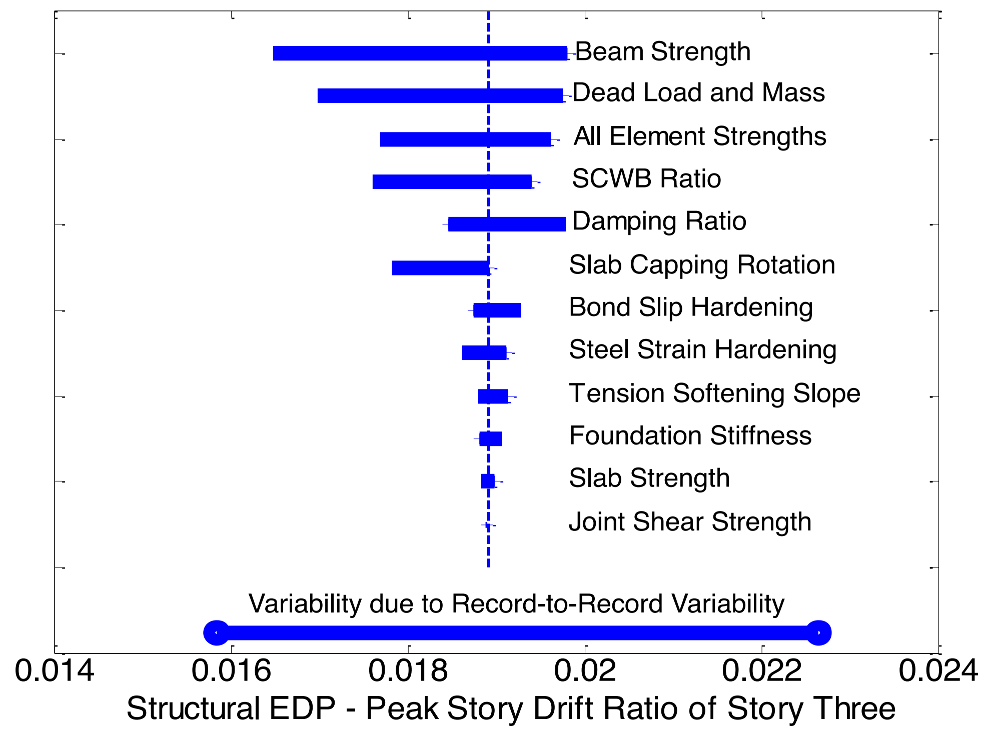
The GMSM problem

- Results of (NL)RHA are very sensitive to the suite of input ground motions.
- No consensus as to best selection process: choice quite subjective.
- Selection based on seismological principles only leads to large variability.
- Important for code applications (option) and essential for PBEE

Sources of variability (2% in 50 years)



Source: C. Haselton

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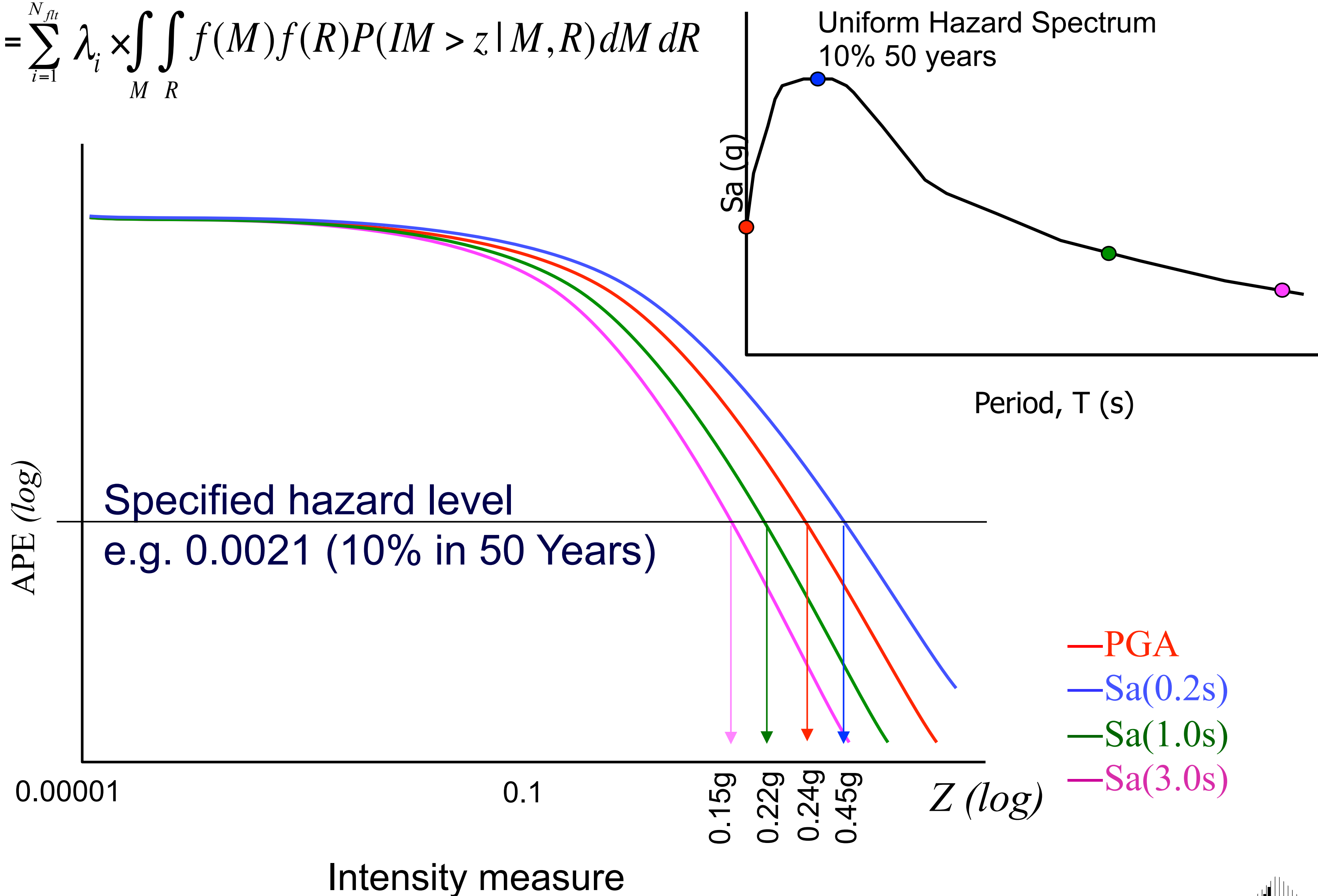
What a GMSM method consists of

- Given a scenario, the ground motion record *selection* can be based on
  - Magnitude and distance (M,R) bins only
  - M,R plus spectral acceleration or spectral displacement, etc.
  - Should be based on metric that is relevant to the structural response
- The *modification* can consist in
  - Different scaling schemes : at a single spectral period or over a period range
  - Spectral matching
- The “target” spectrum is very important

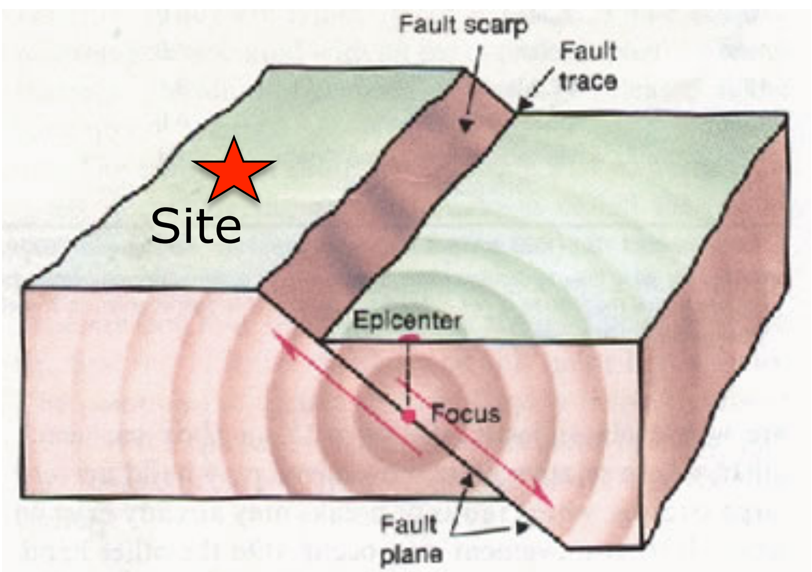
Uniform hazard spectrum (PSHA)

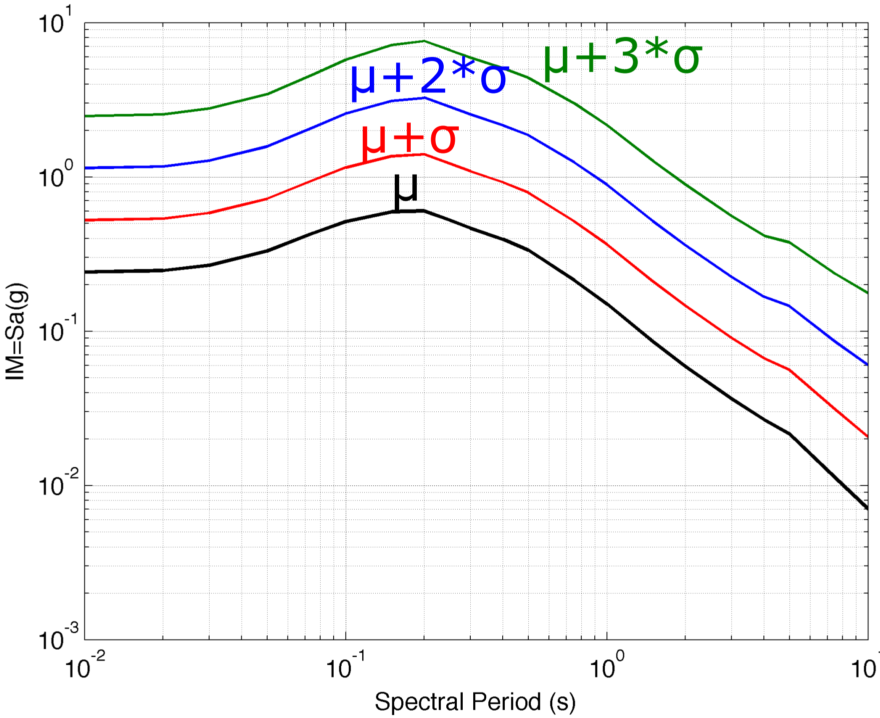
$$\upsilon(IM > z) = \sum_{i=1}^{N_{flt}} \lambda_i \times \int_M \int_R f(M) f(R) P(IM > z \mid M, R)\, dM\, dR$$



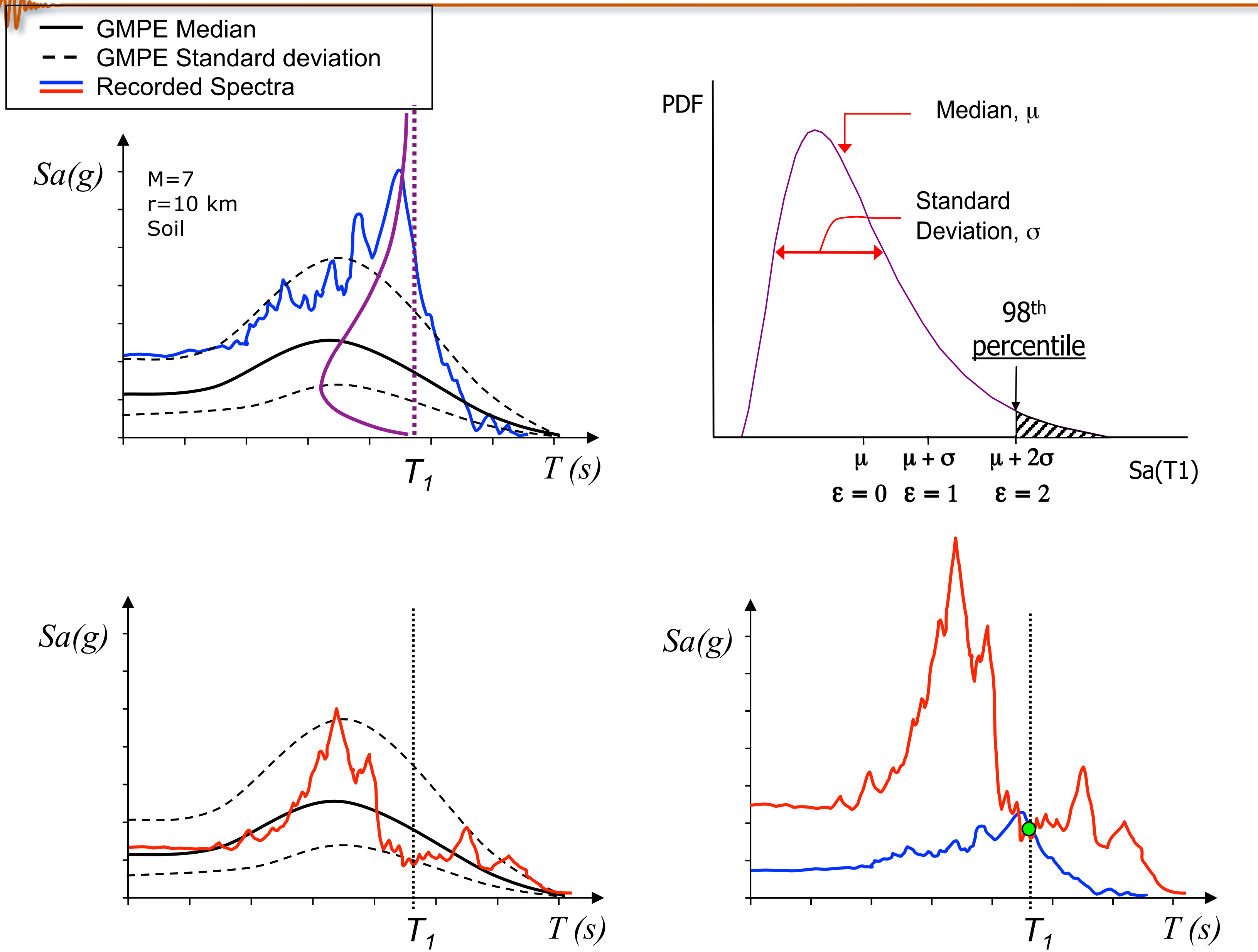
Deterministic Seismic Hazard Analysis (DSHA)

- Usually based on large plausible earthquake scenario on a near-by fault
- Use source info directly with ground motion prediction equation (specify percentile)





Epsilon and spectral shape



Conditional mean spectrum

$$\mu_{\ln Sa(T_i)|\ln Sa(T^*)} = \mu_{\ln Sa}(M,R,T_i) + \rho(T_i,T^*)\varepsilon(T^*)\sigma_{\ln Sa}(T_i)$$

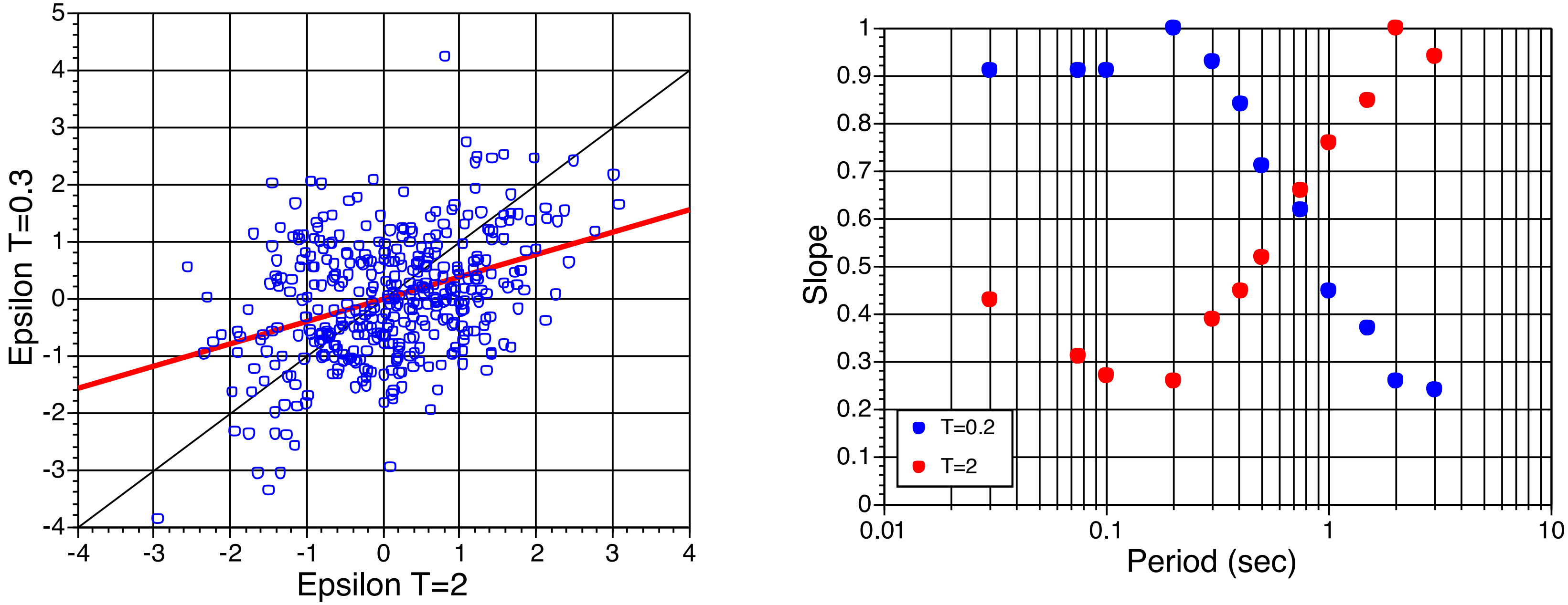


Illustration of correlation coefficients between spectral accelerations at different periods.

Source: Baker and Cornell (2007)

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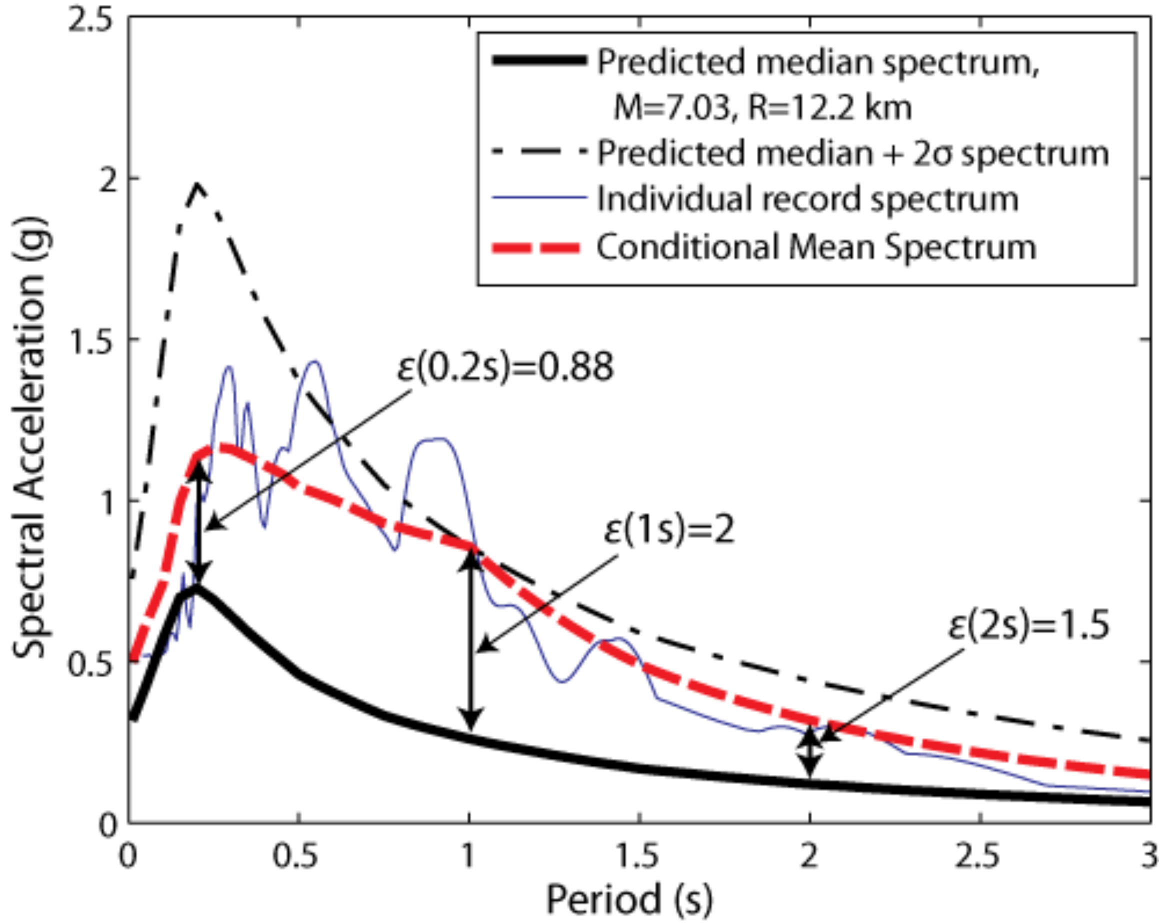
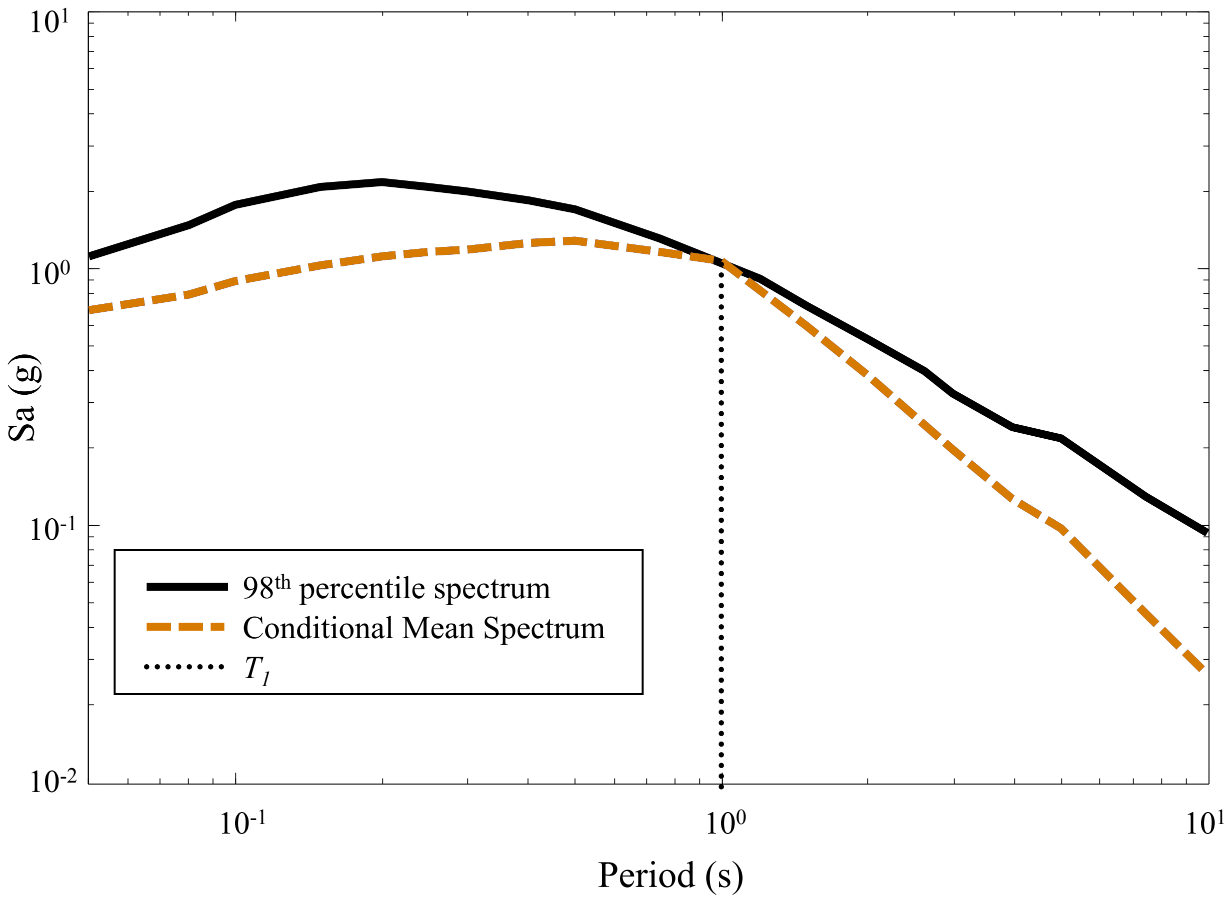
Conditional mean spectrum anchored at 1s

$$\mu_{\ln Sa(T_i)|\ln Sa(T^*)} = \mu_{\ln Sa}(M,R,T_i) + \rho(T_i,T^*)\varepsilon(T^*)\sigma_{\ln Sa}(T_i)$$



Source: J. Baker

UHS Vs. CMS


10^1
10^0
10^-1
10^-2
Sa (g)
10^-1
10^0
10^1
Period (s)
98th percentile spectrum
Conditional Mean Spectrum
T1

The GMSM problem

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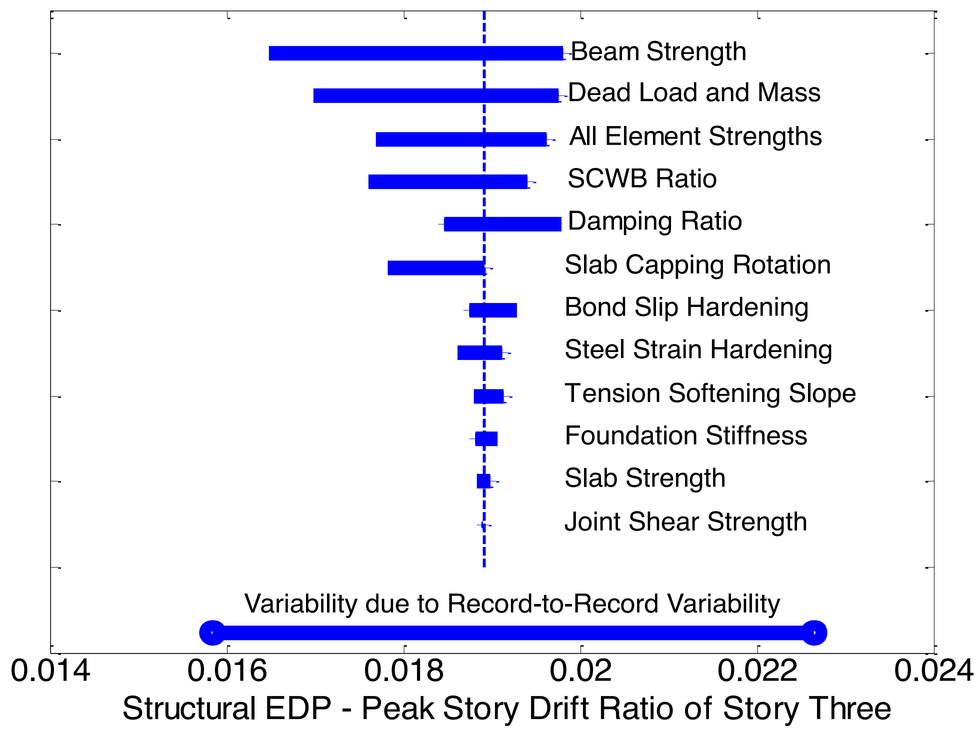
Sources of variability (2% in 50 years)



Source: C. Haselton

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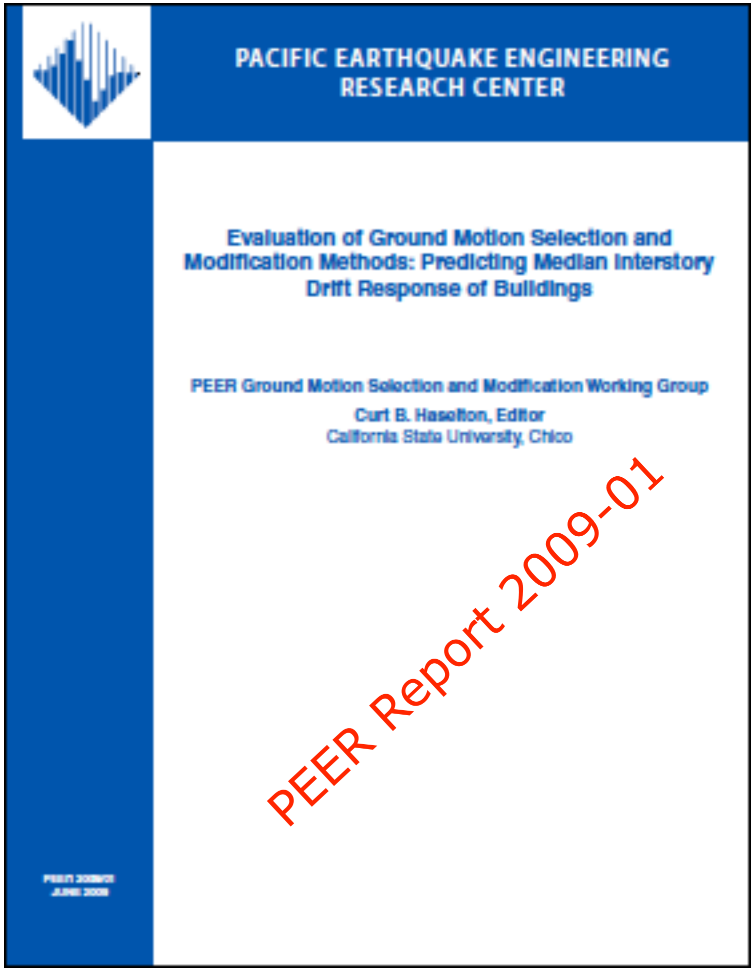
Solutions

- Perform a high-end analysis that uses more records
- Be “smarter” about picking records and modifying them
- Capitalize on ground motion simulations

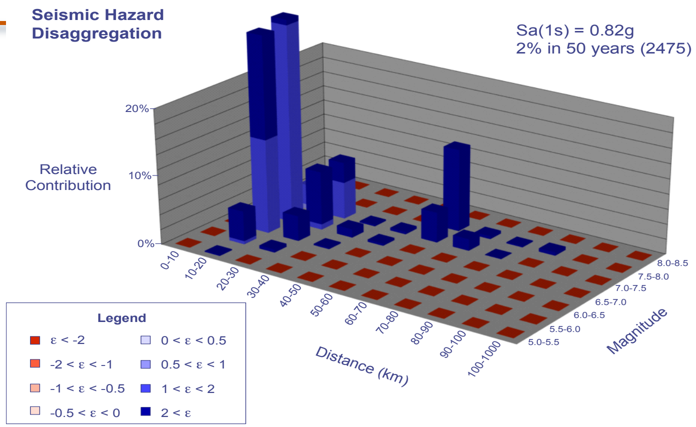
Background – GMSM results

- PEER Ground Motion Selection and Modification (GMSM) program
  - Group of people interested in effect of GMs on structural response, for research and design.
  - Mission: *"To provide guidance and tools to the engineering community on appropriate GMSM methods for nonlinear dynamic analyses."*
  - Objective: how to capture correct mean response from small number of records.

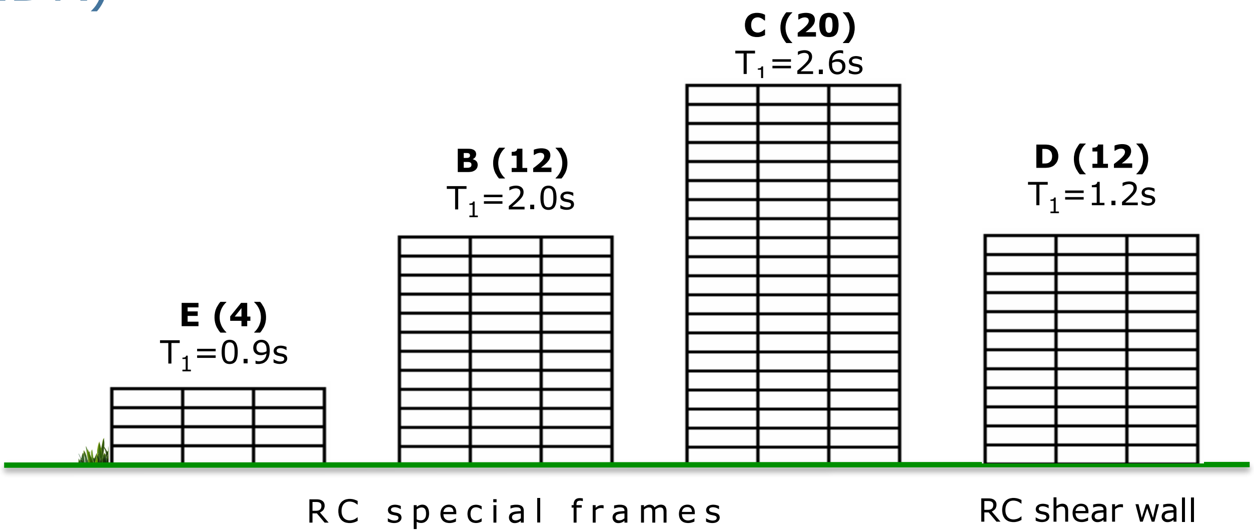


Methodology

- Select earthquake scenarios
  - M=7, r=10 km, $\mu+2\sigma = +2\varepsilon$
  - M=7.5, r=10 km, $\mu+1\sigma = +1\varepsilon$

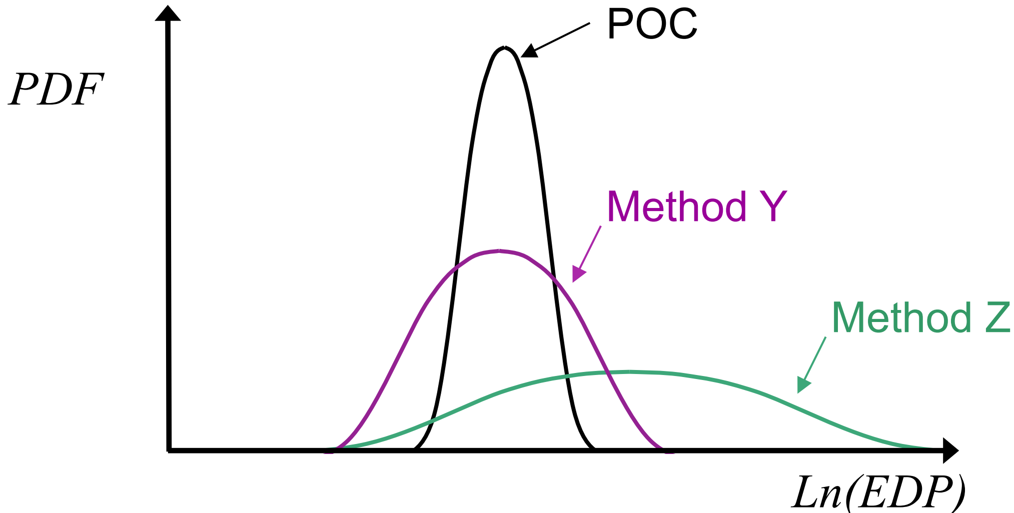


- Building models
  - Opensees models, compliant with building codes: 2003 IBC, ASCE 7-02 and ACI 318-02
  - Key demand parameter: Maximum Inter-story Drift Ratio (MIDR)



Methodology

- Compute the Point of Comparison (POC) (High end analysis)
  - Use larger set of scenario records, scaled and unscaled
  - Perform NLRHA and regress model that relates the response to the GM properties and earthquake metadata
  - Integrate over the GM properties to get a distribution of the selected EDP response
- Compare results of suites with POC
  - 14 methods (25 variants) in 5 classes. 4 sets of seven records per method.



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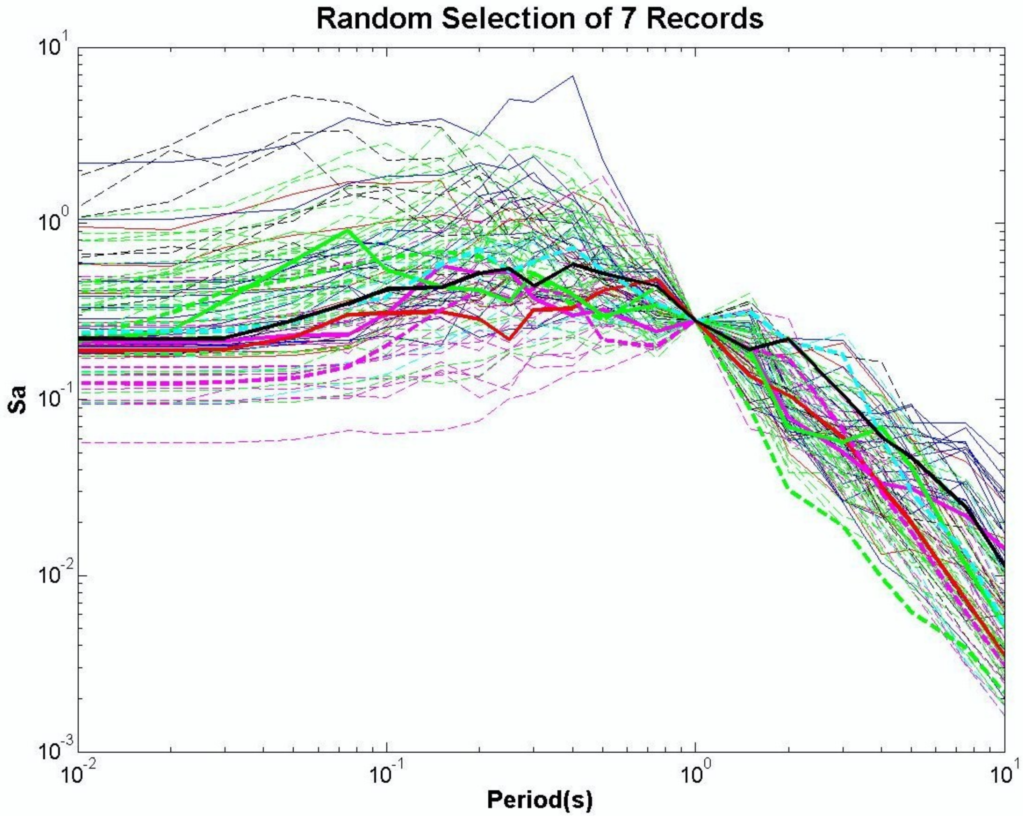
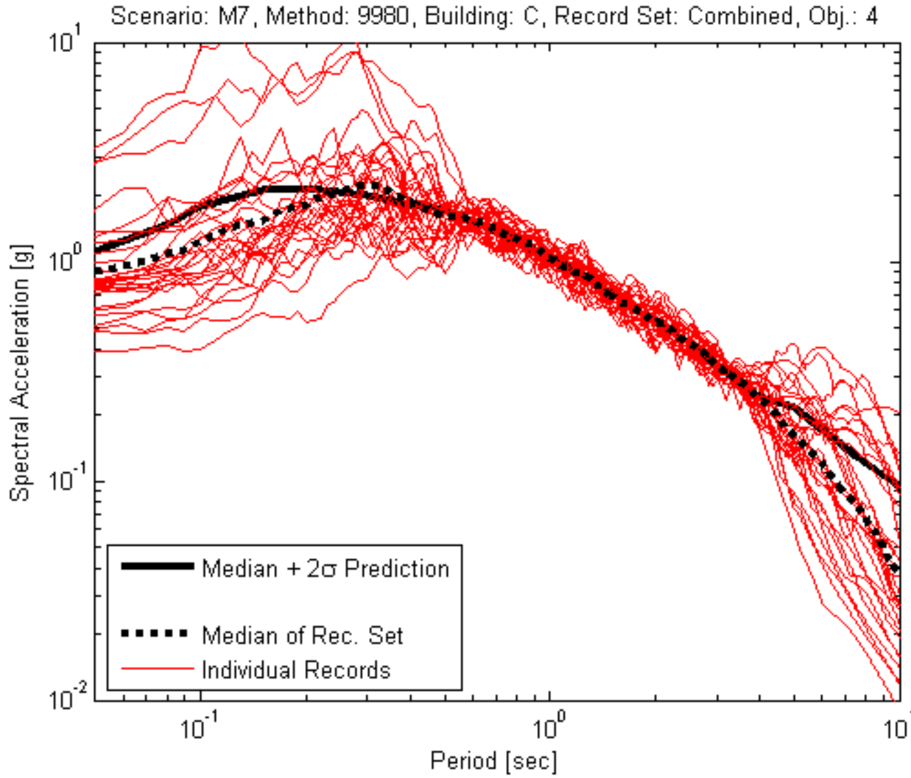
Sa(T1) Methods

- Selection: GMs consistent with given M, R
- Scaling: Match given Sa(T1)



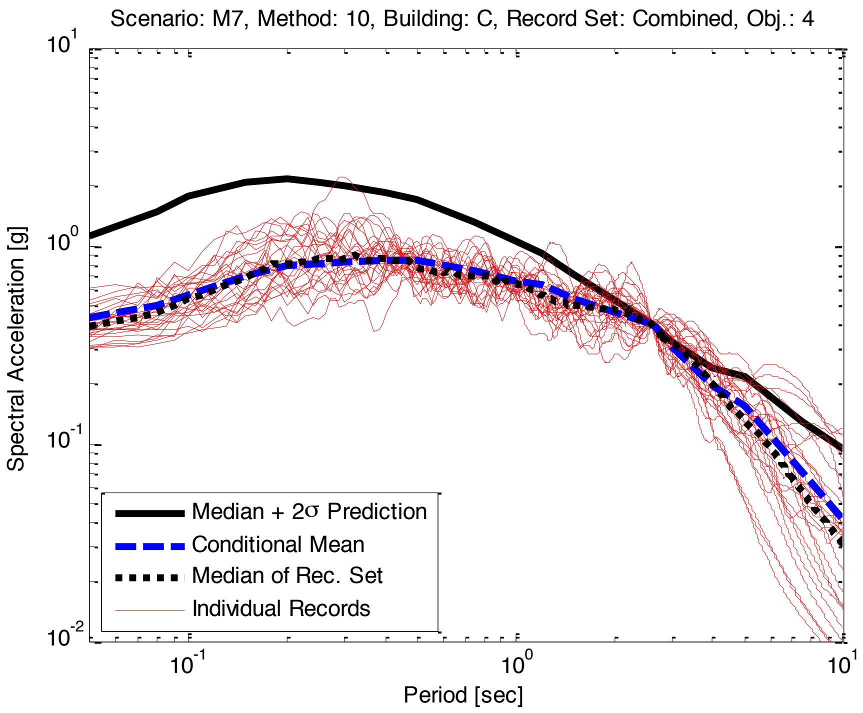
UHS Methods

- Selection: GMs with spectral shape similar to UHS, perhaps consistent with given M, R
- Scaling: "Closely match" UHS



CMS Methods

- Selection: GMs with spectral shape similar to CMS, perhaps consistent with given M, R
- Scaling: Match given Sa(T1) or "closely match" CMS



Spectral Shape Proxy Methods

- Selection: GMs consistent with given ε(T1) and M, R
- Scaling: Match given Sa(T1)

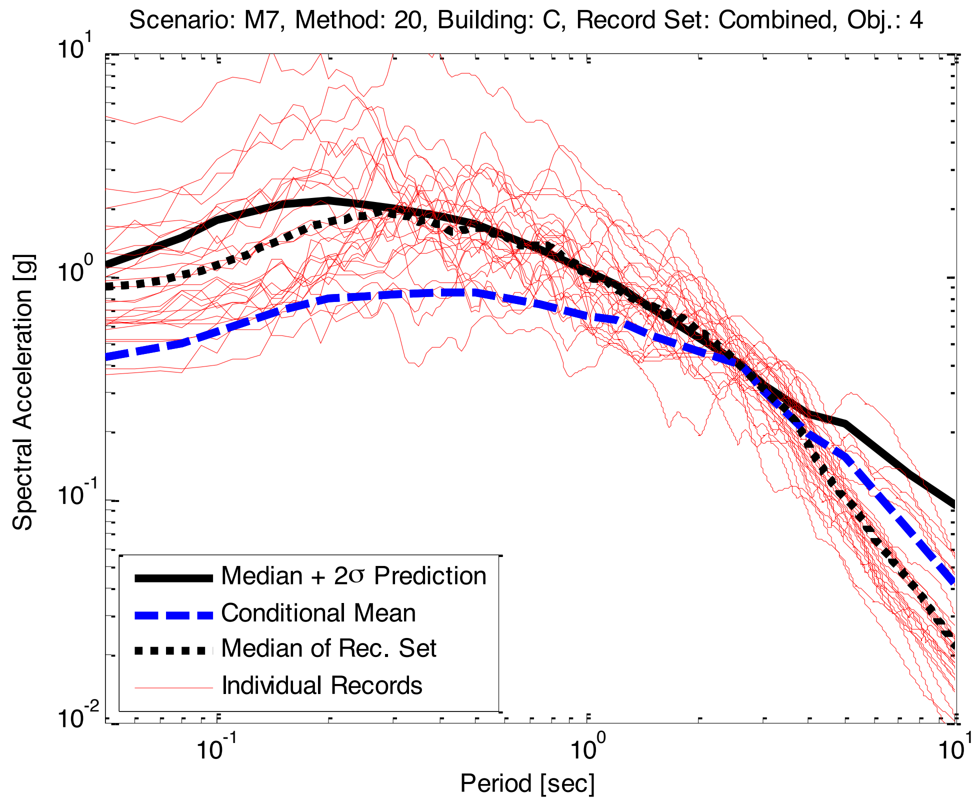
e.g., for …

ε(T1) = 1-3

M = 6.7-7.3

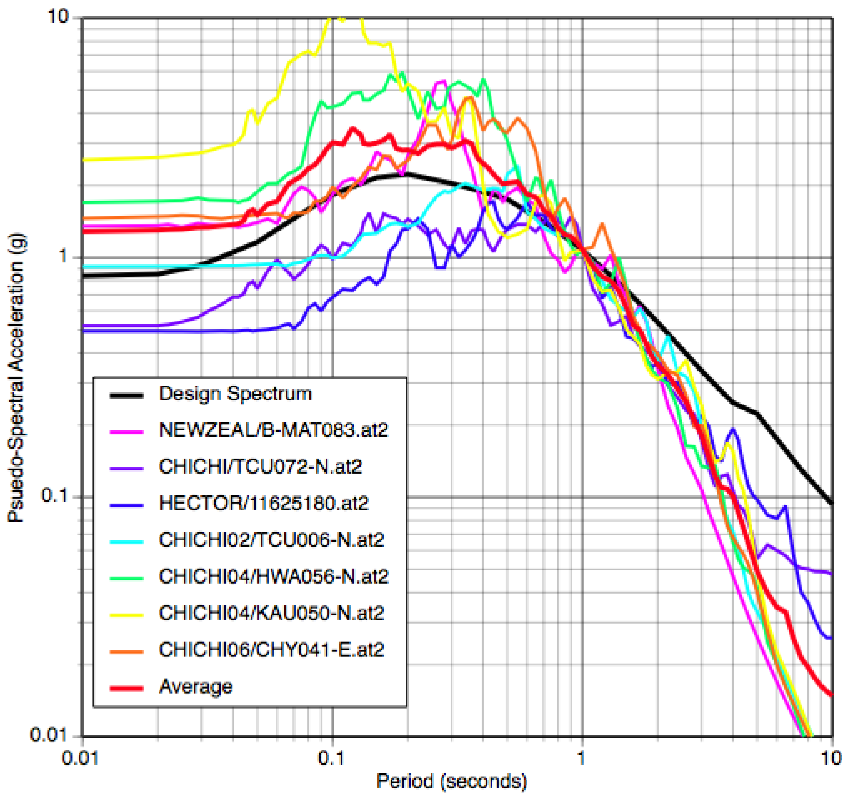
R = 0-42km

S = 215-560m/s



Inelastic Methods

- Selection: GMs with expected Sdi(T1,R)/Sde(T1) consistent with that and DurUNI, PGV, Sa(2T1) for given Sa(T1), M, R
- Scaling: Match given Sa(T1)



Summary of Results by Method Class

Method Class	Building A, M7	Building B, M7	Building C, M7	Building D, M7	Building C, M7.5	Median
UHS	Syst. Bias, large dispersion					1.26
Sa(T1)	Syst. Bias, large dispersion					1.36
CMS	No Bias, dispersion depends on specifics					1.01
Proxy (i.e. ε)	No Bias, moderate dispersion					1.05
Inelastic	~No Bias, dispersion depends on specifics					1.19

Conclusions

- Selection should be consistent with hazard
  - Must consider proper “global” disaggregation (loosely consider site effects, M, R)
- Selection and modification should be based on GM parameter that is relevant to structural response
  - For 1st mode-dominated structures, the spectral shape is important
  - Not considering the spectral shape can lead to overly conservative predictions (not a goal of PBEE)
  - Matching to CMS or at one period using epsilon gives better predictions, so do inelastic methods
  - Single records *should not* be matched to a UHS for a wide bandwidth (envelope of multiple events); use multiple CMS instead

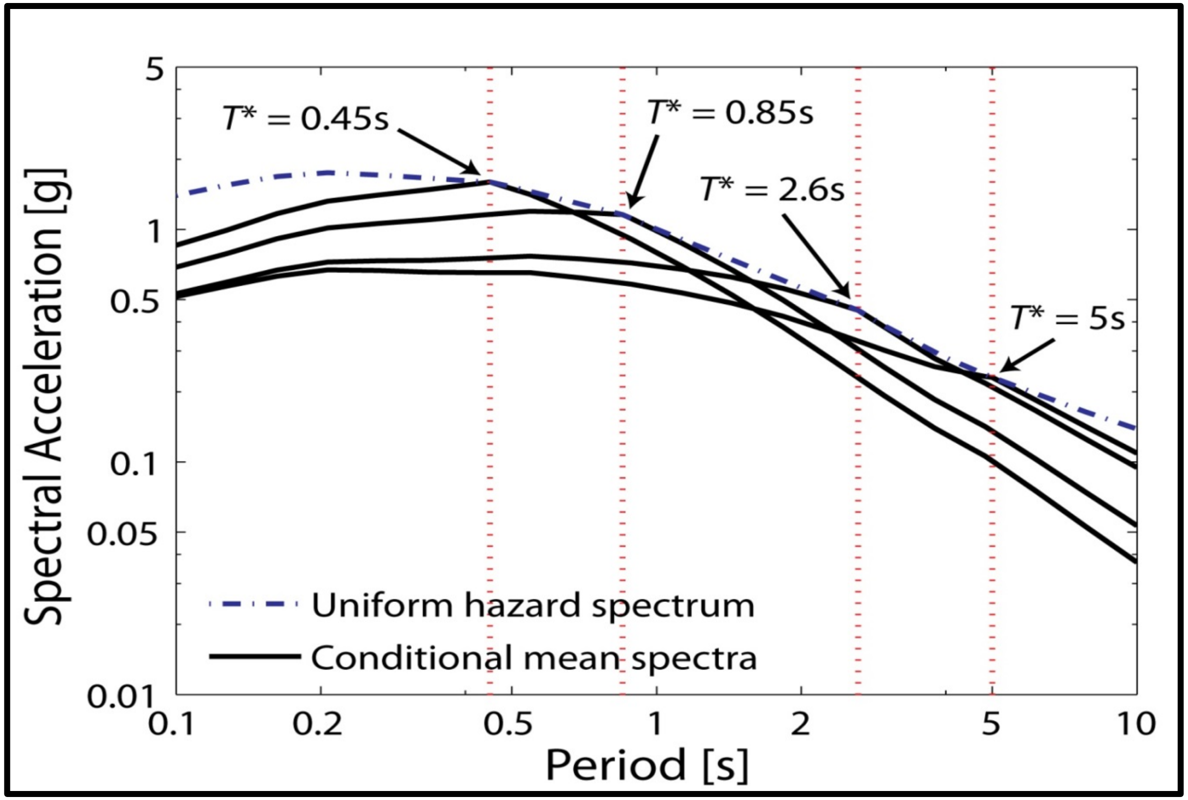
Nonlinear Response-History Analysis Chapter 16 Proposed for ASCE 7-16

- Ground motion level: MCE_R
- Number of ground motions: 11 motions
- Selection of motions:
  - Same general language.
  - Added: "*The ground motion spectral shapes shall also be comparable to the target response spectrum....*"
- Scaling of motions: Scale the maximum direction Sa to the target spectrum (which is maximum direction).
- Period range: $0.2T_1$ to $2.0T_1$
- Spectral matching: Each comp. must meet target.

Source: C. Haselton, BSSC Issue Team 4

Nonlinear Response-History Analysis Chapter 16 Proposed for ASCE 7-16

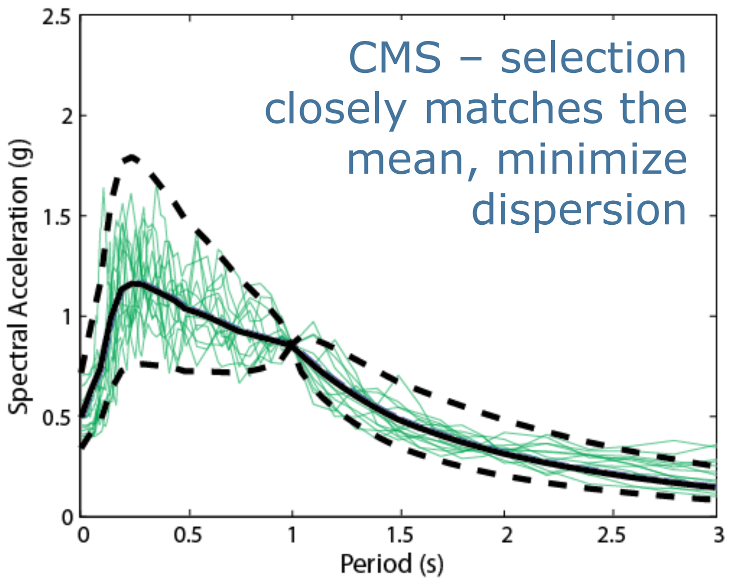
- Target spectrum:
- Method 1: Typical MCER spectrum.
- Method 2: Multiple "scenario" spectra (≥ 2 scenarios).

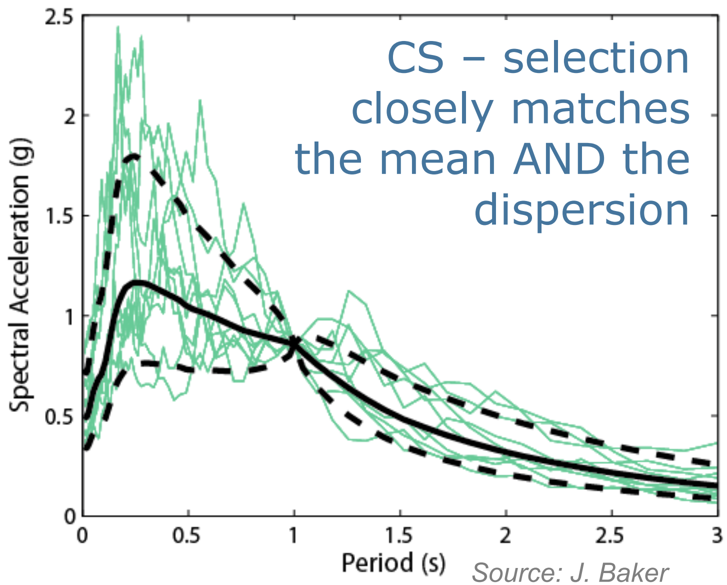


Source: C. Haselton, BSSC Issue Team 4

Where to go from here

- Continue with high-end approaches to constrain better “smart-selection” methods
  - Consider other systems (dams, levees, bridges, etc.)
  - Consider other GM metrics (structure-specific) such as duration, CAV, etc.
  - Formally evaluate spectral matching
  - Consider other objectives: quantify mean and range of response (dispersion, sigma)





Source: J. Baker

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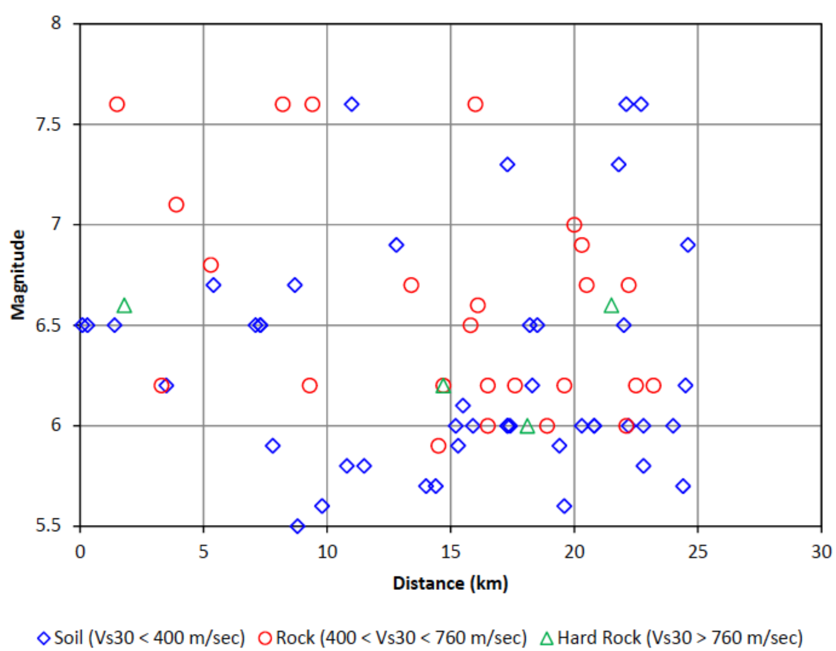
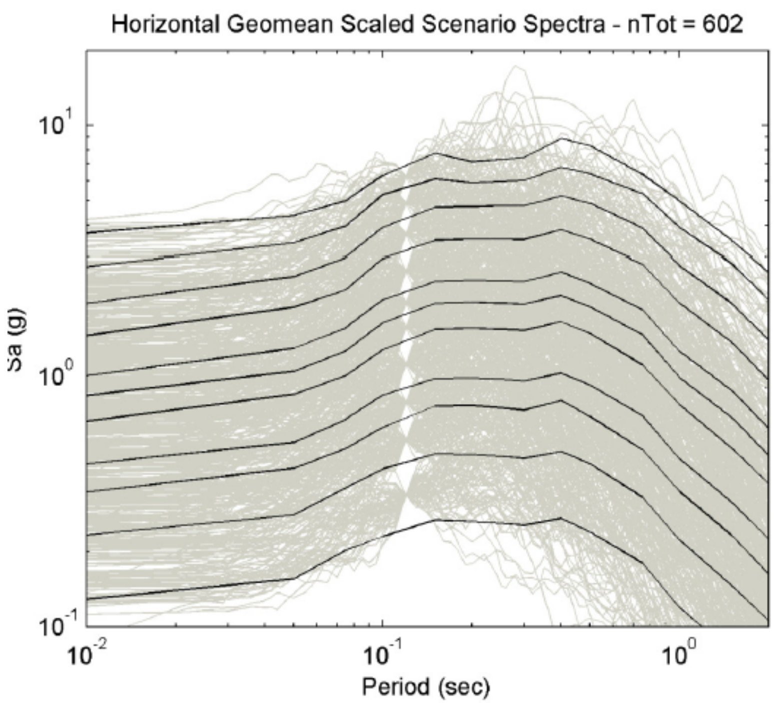
Where to go from here

- Example of on-going high-end work (AlAtik)
  - Select events that represent point on hazard curves.
  - Allowing scaling, and considering the range (conditional spectra), combine records to create large suites at various ground motion levels as the basis for comparison. The scaled records span the hazard curve.

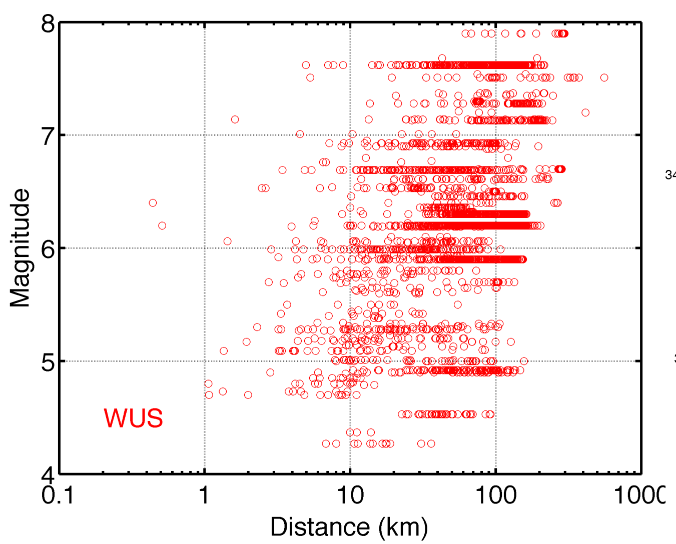




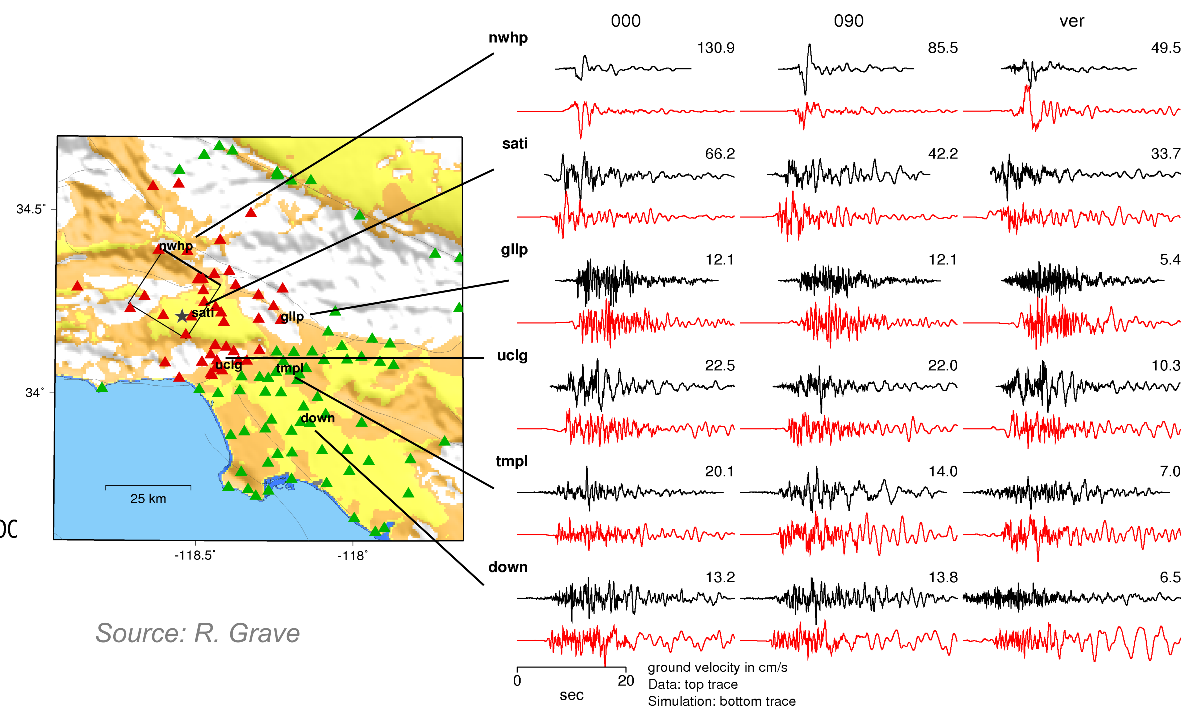
Source: L. AlAtik

Where to go from here

- Improve simulation methodologies so we can generate the “correct” records that are needed, both for high-end and simplified analyses.



Validation example: Northridge 1994



Source: R. Grave

Thank you!

- Special thanx to:
- Northridge20 and Curt Haselton
- GMSM Program participants
- Jack Baker
- Linda AlAtik and Norm Abrahamson