From Seismic Hazard to Risk: Summary of Critical Issues and How SCEC Research Can Foster New Solutions

PEER

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Slide contributions from

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ImageCat, inc.

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Context: Hazard vs. Risk

Hazard

- Probability that a seismic event (and/or ground motions) will affect a given area over a certain time period.
- « There is a 10% probability that peak ground motions will exceed 1 g at USC in the next 50 years. »

Risk

- The risk combines the **hazard**, **exposure** and **vulnerability (fragility)** of human infrastructure**. Risk represents consequences** (e.g. in terms of dollars, deaths and downtime).

December 2003: **M** 6.6
California (San Simeon): very limited damage, 2 deaths
Iran (Bam): 80% of city destroyed, 31 000 deaths

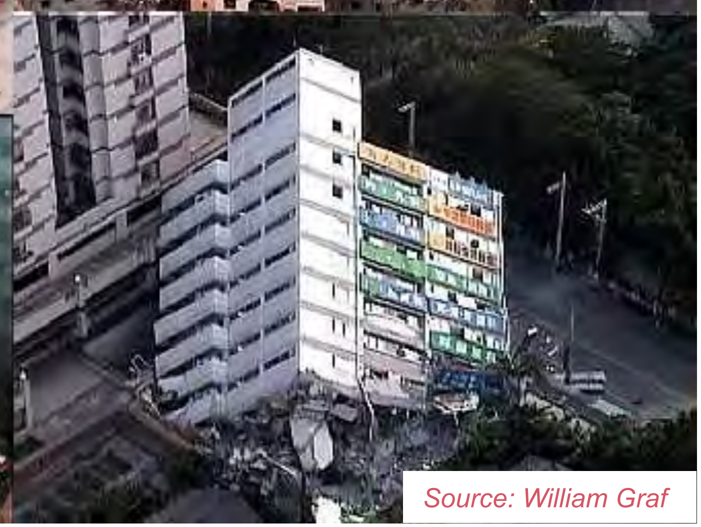
Alto Rio Building, Concepcion, M 8.8 Chile Earthquake Feb. 27, 2010
(Foundation failure)

Pictures: Walter Mooney; Source: William Graf

Slender 9-story RC shear wall building toppled in the 1995 Kobe Earthquake

Bottom picture by Charlie Kircher; Source: William Graf

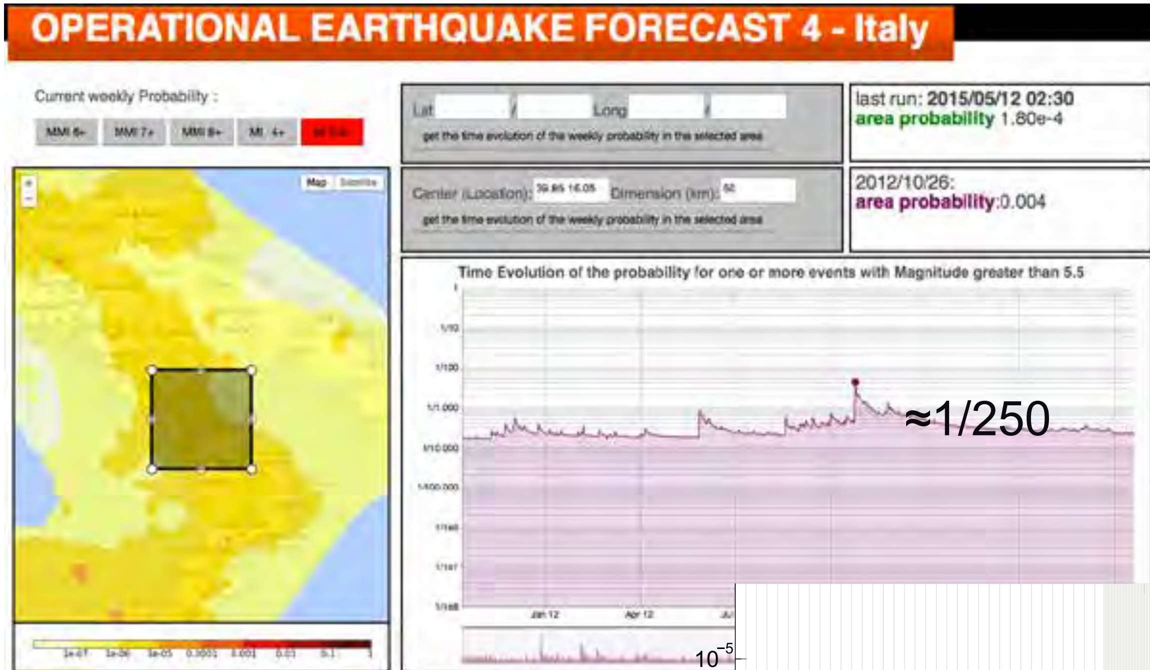
1999 Chi Chi Earthquake (M7.6) in Taiwan

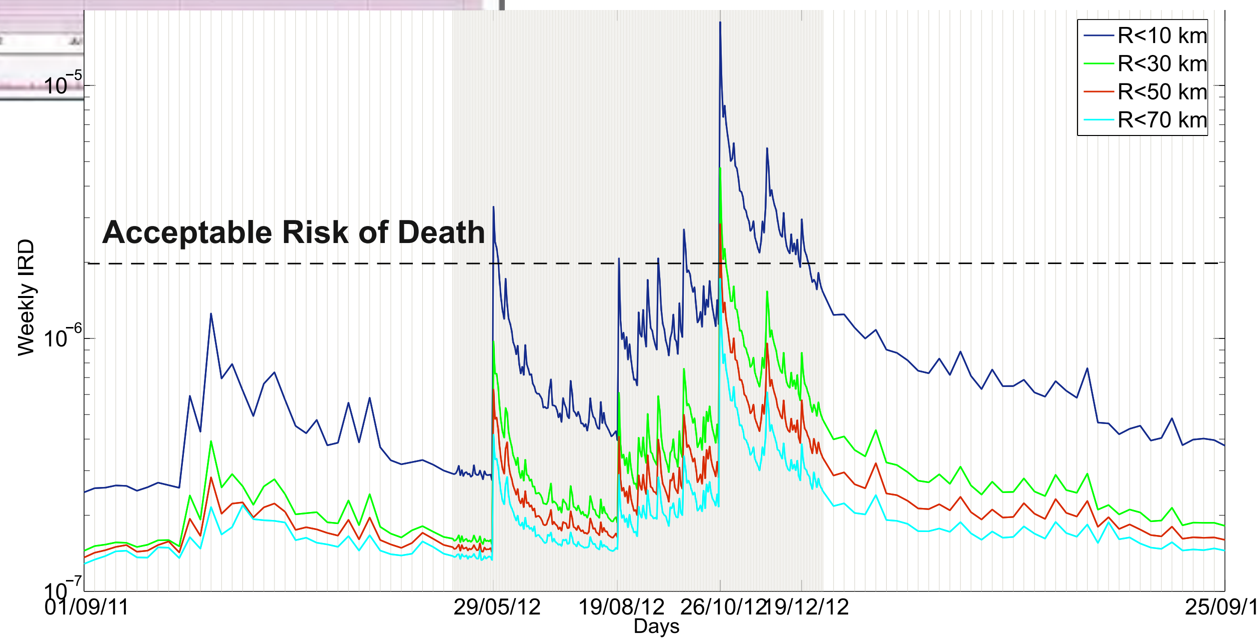


Source: William Graf




From OEF to risk *(are the earthquake probabilities too low?)*





It may be misleading asking if the probability of large (**M**5.5+) earthquake **is too small**; it is the related risk that can be **acceptable or not**

Source: Warner Marzocchi

“If a tree falls in the forest and no one is around to hear it, does it make a sound?”

A shift in paradigm for resilience

- Our contribution to a resilient society would better be served by
  - making risk-informed design decisions
  - focusing on risk-informed research priorities

Seismic Design and risk

Codes:

Set of simplified procedures for a given region and structure type. Building code performance objectives usually consist in safety and loss-of-life prevention.

Recent codes include risk-targeted design.

Picture: Air-Worldwide

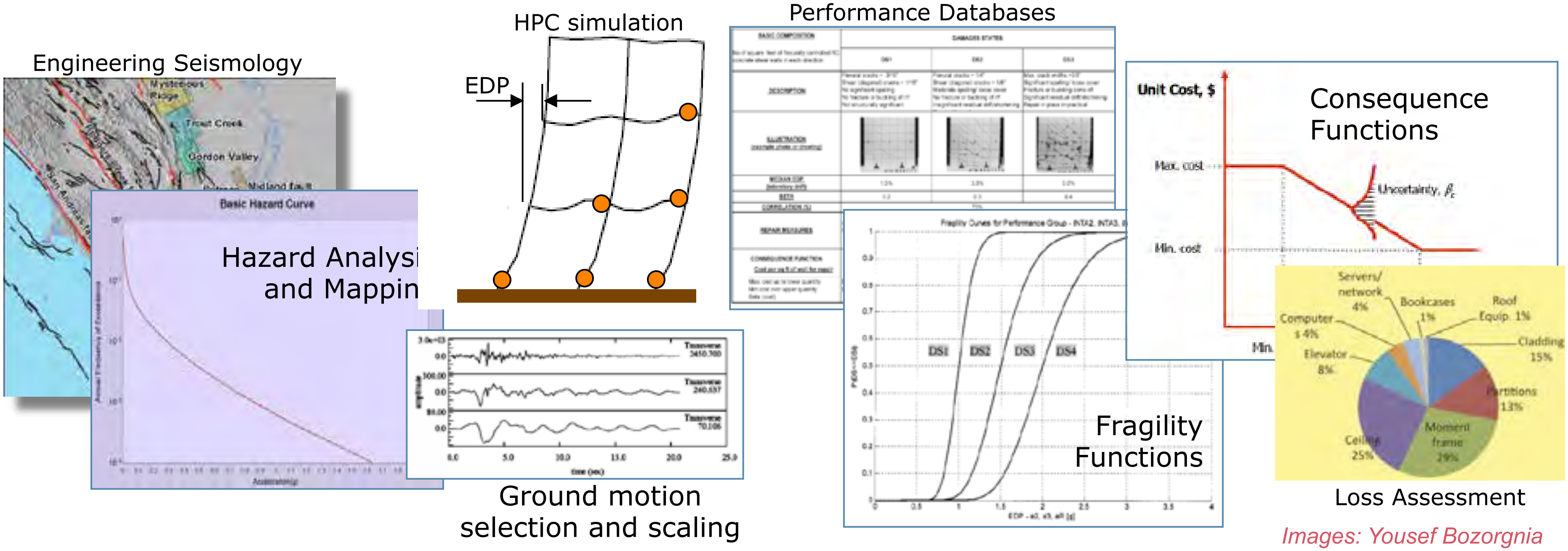
Performance-Based Earthquake Engineering (PBEE):

"Design for the achievement of specified results rather than adherence to prescribed means." The design is usually structure- and site-specific.

Performance Based Earthquake Engineering (PBEE)

PEER PBEE Methodology

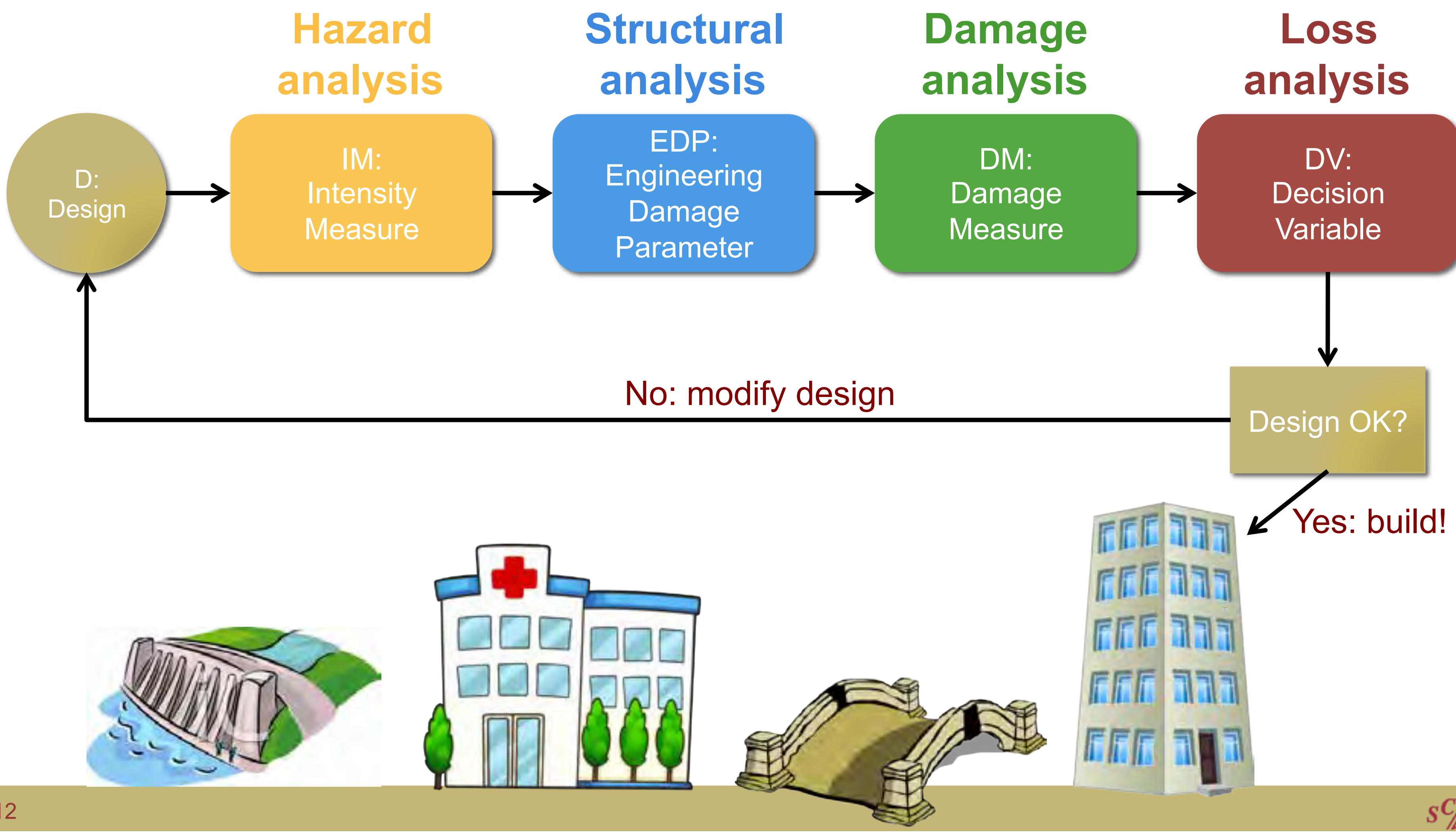
	Hazard analysis	Structural analysis	Damage analysis	Loss analysis
D: Design →	IM: Intensity Measure →	EDP: Engineering Damage Parameter →	DM: Damage Measure →	DV: Decision Variable



Images: Yousef Bozorgnia

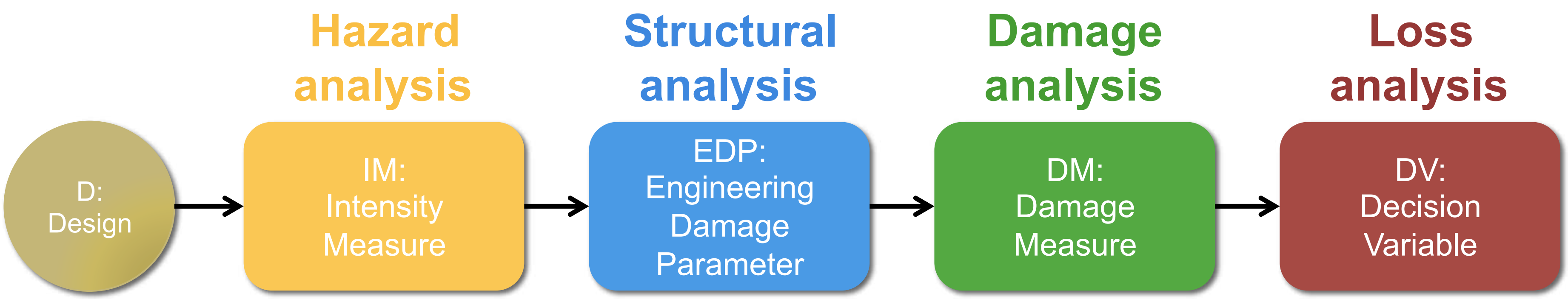
Performance Based Earthquake Engineering (PBEE)

PEER Methodology



Performance Based Earthquake Engineering (PBEE)

PEER Methodology



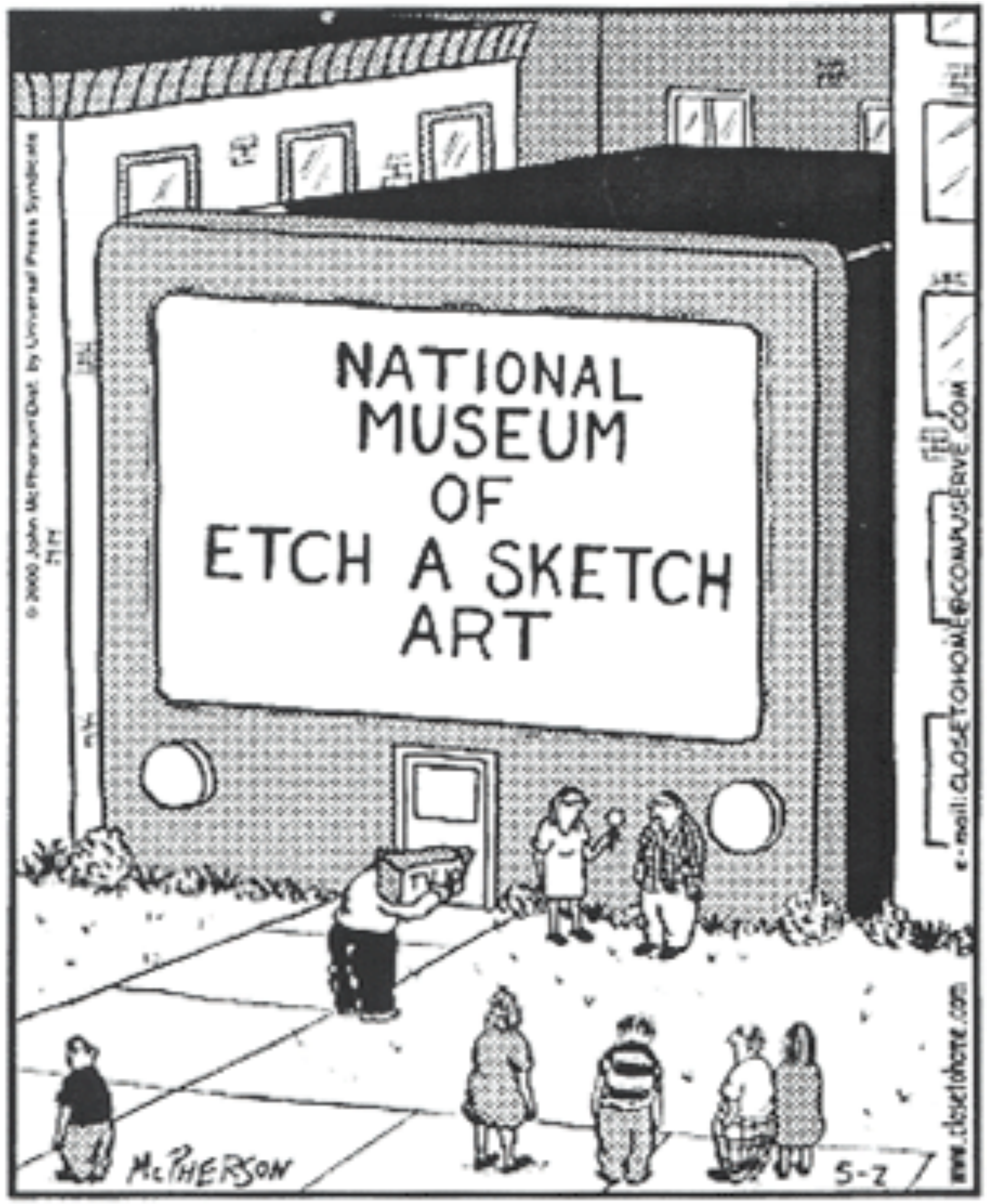
Risk Integral:

$$P(DV > dv) = \int_{im} \int_{edp} \int_{dm} P(DV \mid DM) * P(DM \mid EDP) * P(EDP \mid IM) * \lambda(IM)$$

3Ds:
- **Dollar**
- **Deaths**
- **Downtime**

Others

Non-structural damage



"Structurally, the building is fine. But sadly, the earthquake destroyed all of our art pieces."

A shift in paradigm for resilience



- One of the largest contribution to risk variability is from hazard and ground motions. Need for
  - Improved ground-motion modeling
    - Reduce uncertainty
    - Provide physics-based models (simulations)
  - Improved pool of available seismograms

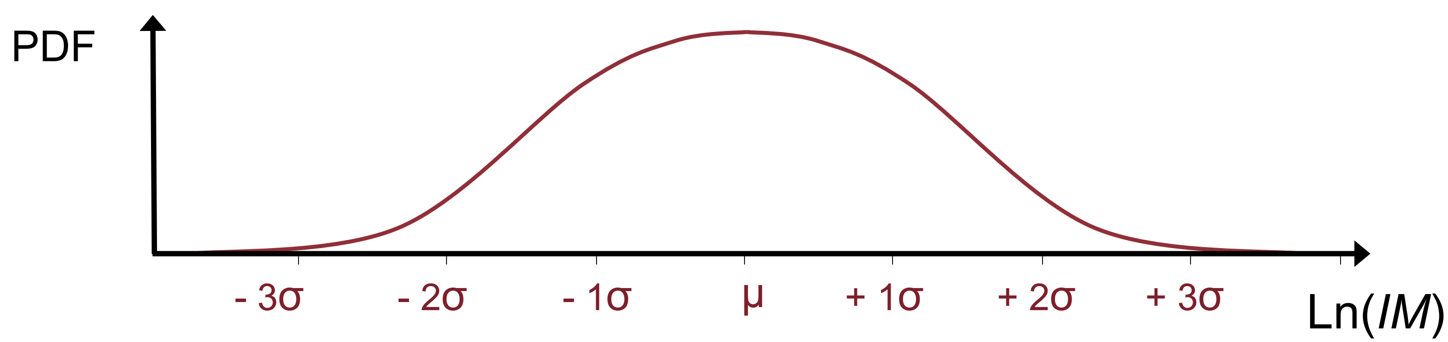
Pictures: Christine Goulet & USGS

Ground-Motion Models / Ground-Motion Prediction Equations (GMMs/GMPEs)

- Empirical regression models constrained by known physical processes
- Contain multiple sub-equations to account for different effects

$$\ln(IM) = C_0 + f(\text{Magnitude}) + f(\text{Distance}) + f(\text{Source}) + f(\text{Site}) \ldots + \text{error}$$

- ln(*IM*) is normally distributed with median μ and standard deviation σ



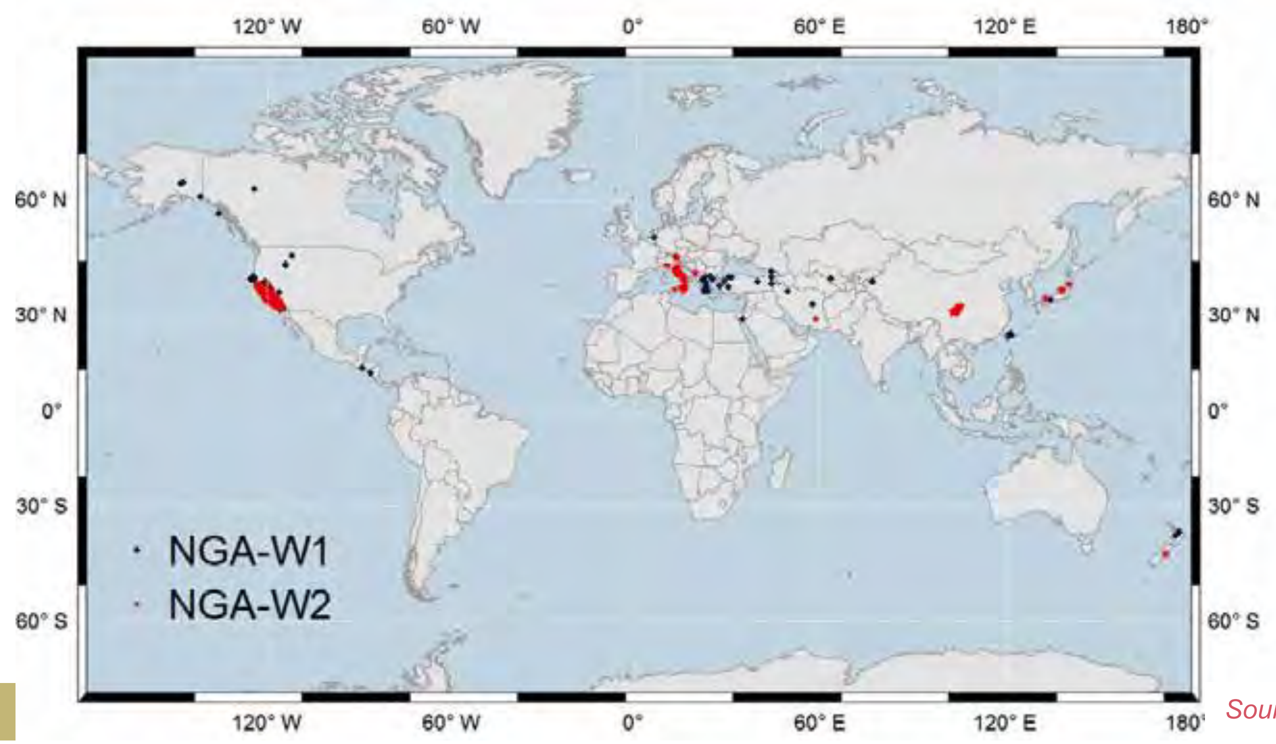
Terminology

- **Aleatory variability (randomness)**
  - Inherent randomness in a process
  - Refined with more data
  - Captured by σ
- **Epistemic uncertainty ("knowable", science-based)**
  - Many models, which is correct? Range represents the lack of knowledge...
  - Repeatable site effects, path effects, regional source effects can be considered epistemic uncertainty and *removed* from the aleatory variability
  - Penalty is that alternate models must be considered (added epistemic uncertainty)
  - Investment in data collection and targeted research can then be used to REDUCE that epistemic uncertainty
  - Captured by different μ, organized in logic trees

Ergodic assumption in GMM development

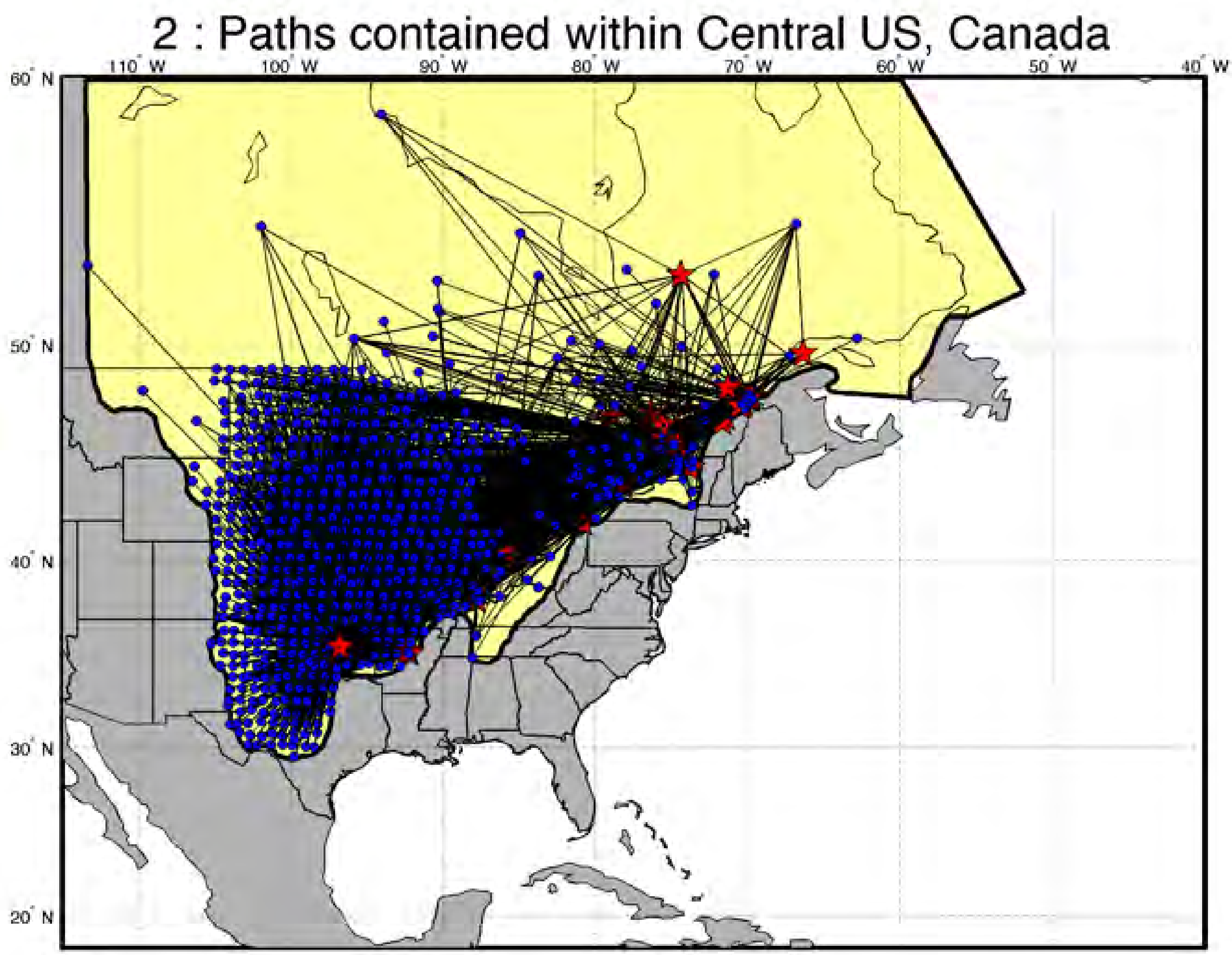
Trading space for time...

- Not enough regional data in recorded time
- Data comes from multiple regions: global models
- Potential systematic effects lumped into relatively large standard deviations



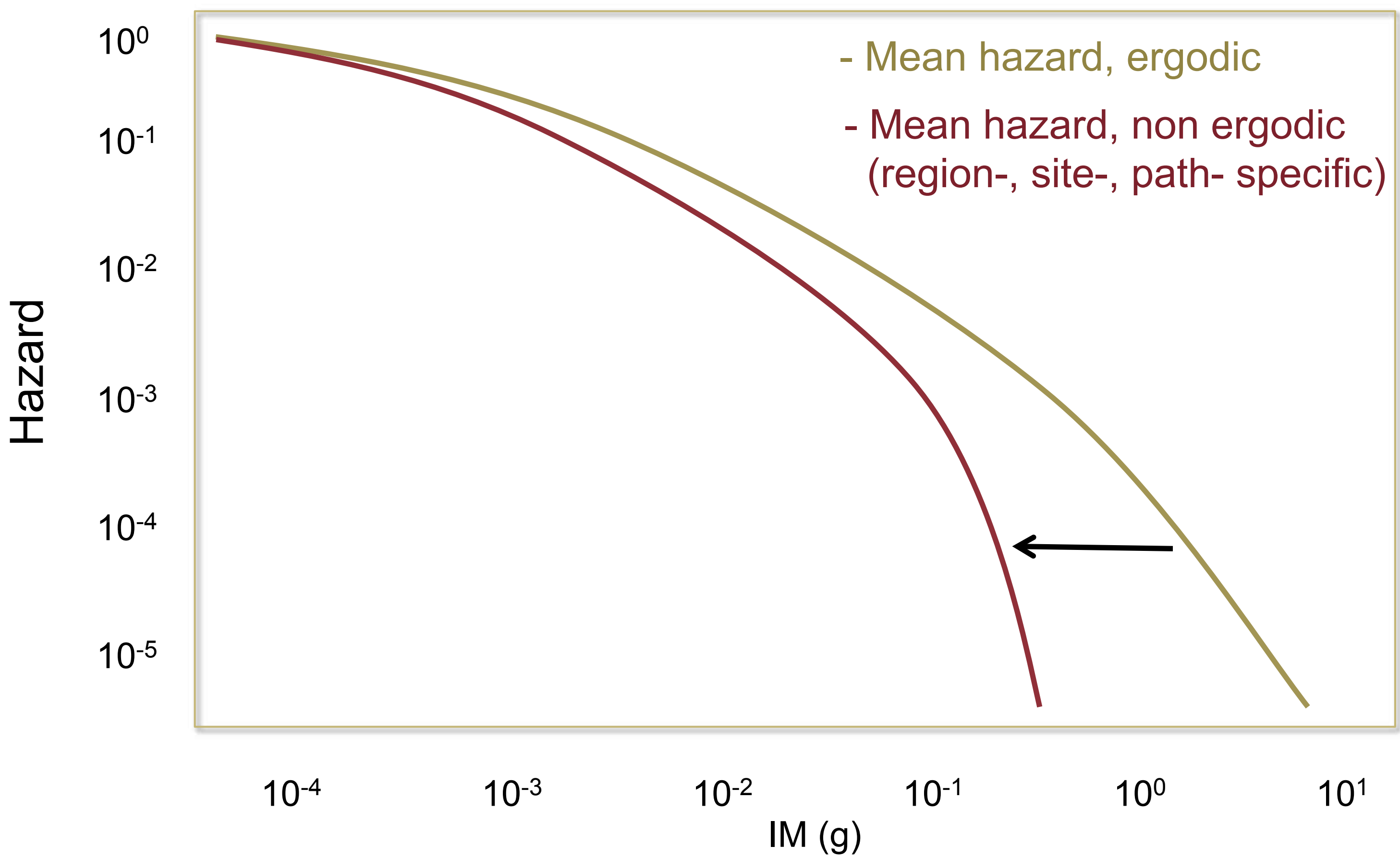
Source: Ancheta et al. 2014

“Knowable” systematic effects

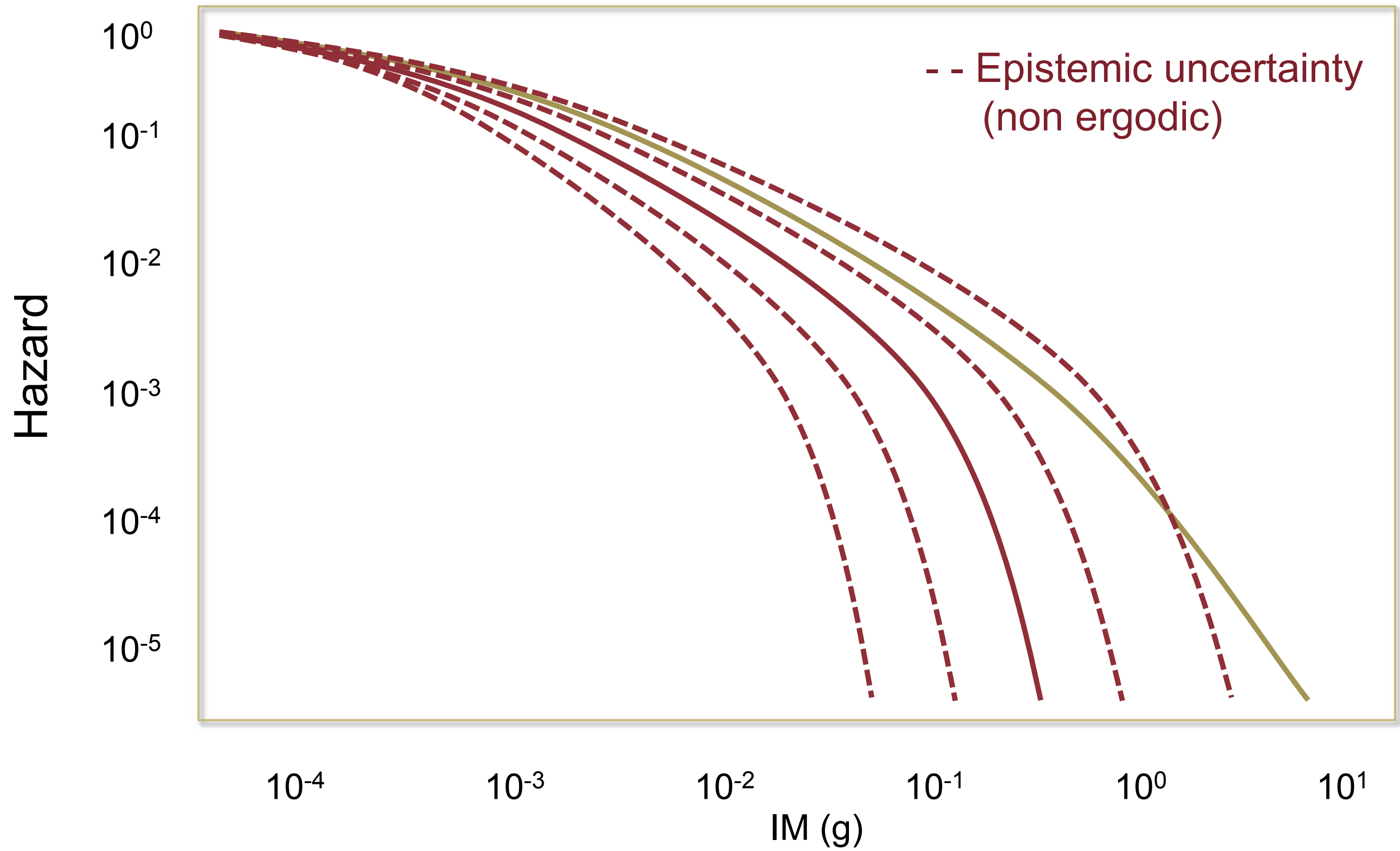


- **Source** effects (multiple events within source region)
- **Site** effects (multiple events recorded at one site)
- **Path** effects (multiple path-region sampling)

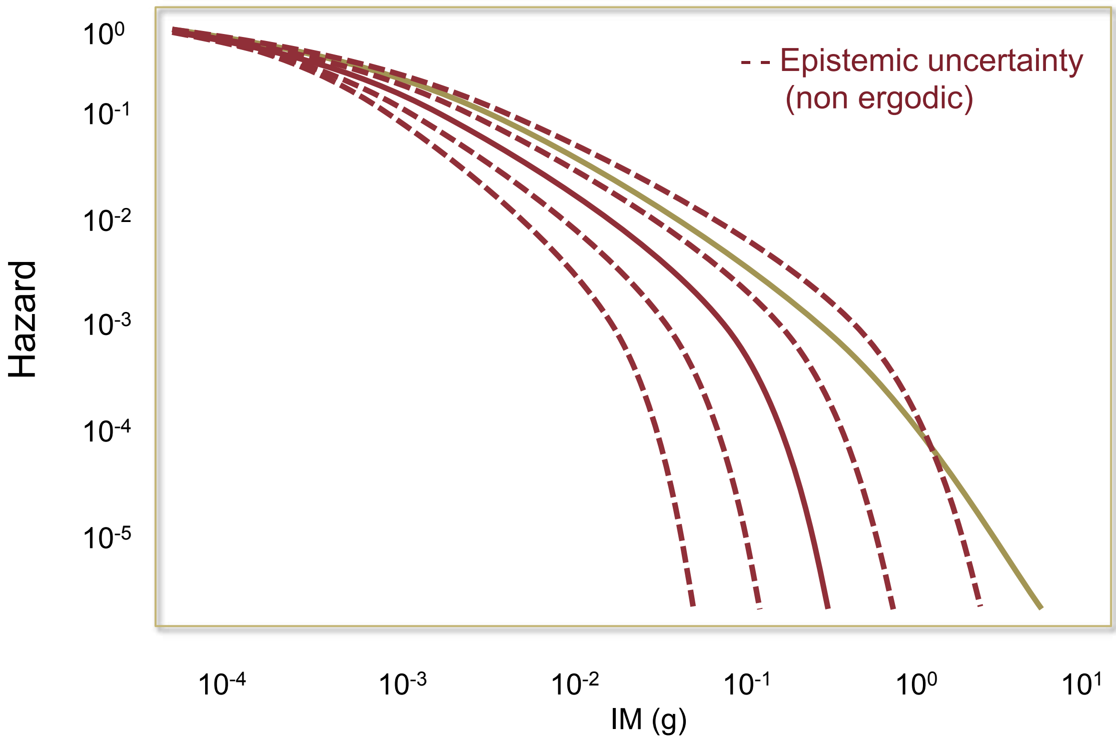
From aleatory variability to epistemic uncertainty



From aleatory variability to epistemic uncertainty



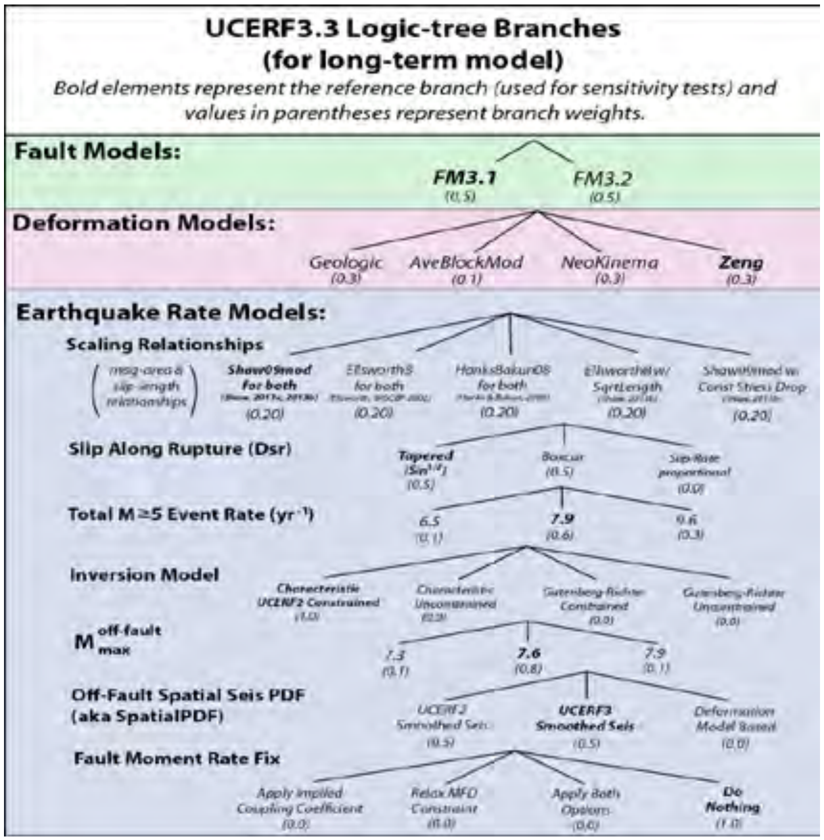
Reducing epistemic uncertainty



- Seismic experiments and data collection
- Targeted analyses of data
- Definition of appropriate GMM median

- Use data to refine (physics/ simulations based) models
- New (refined) models can be used in PSHA

Epistemic uncertainty and risk



UCERF3 Compound Fault System Solutions –
Time-dependent models: 1440 x 4 probability models

- Consideration of
  - Complete UCERF3 (time independent) model
  - Epistemic uncertainty on GMMs and aleatory variability included
  - Single fragility/loss model (with variability)

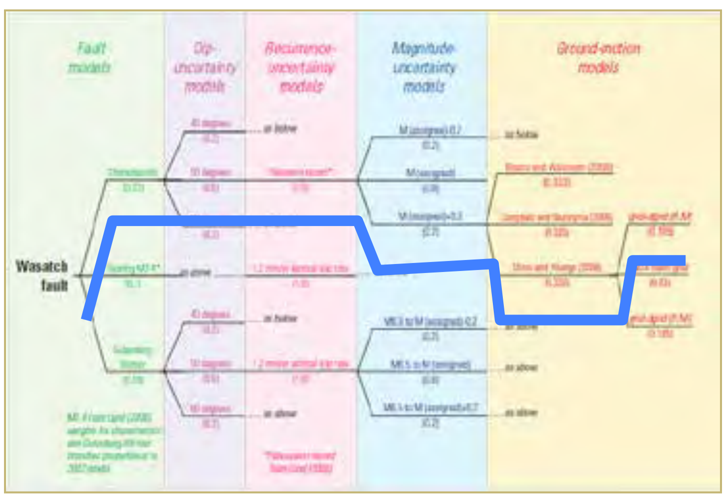
Source: Jerry Lee

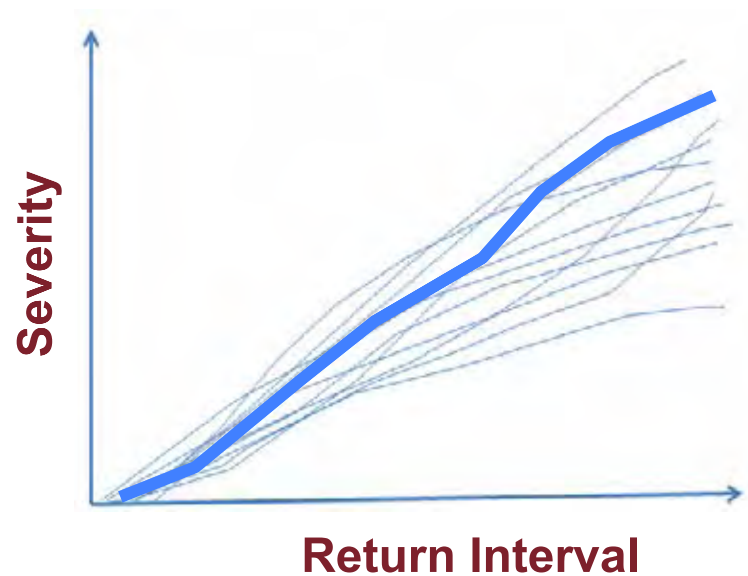
Treatment of uncertainties in risk assessment

Ideal: **run all possible branches (not practical)**

Optimized: **be smarter in selecting a subset of branches**

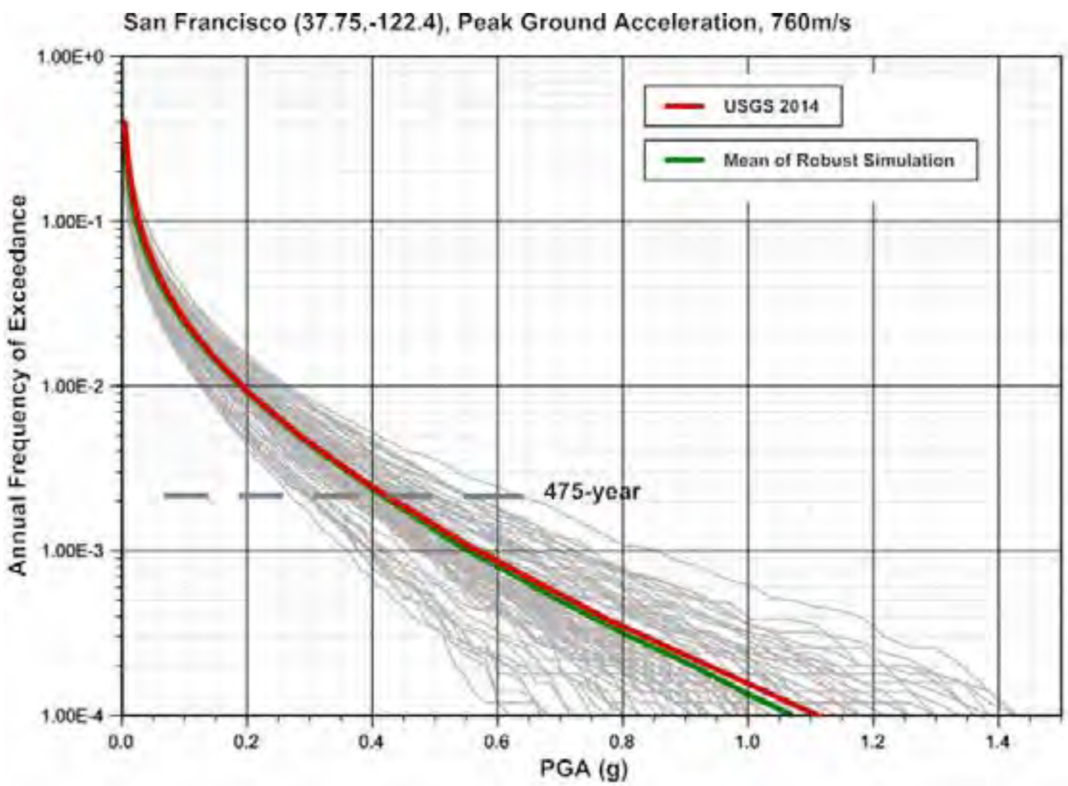
Robust Simulation Approach*: Representation of future risk through simulation of an ensemble of views that integrates valid scientific disagreement and stochastic modeling of unknown variables.*

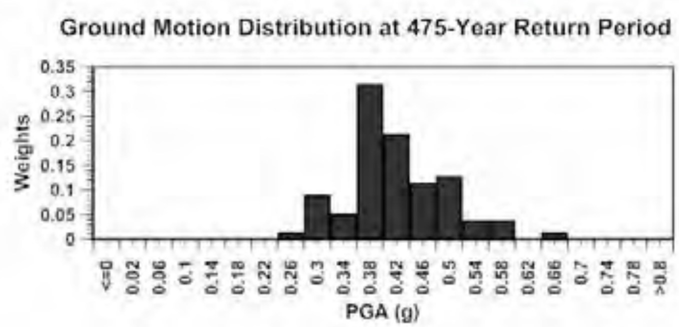




Source: Jerry Lee

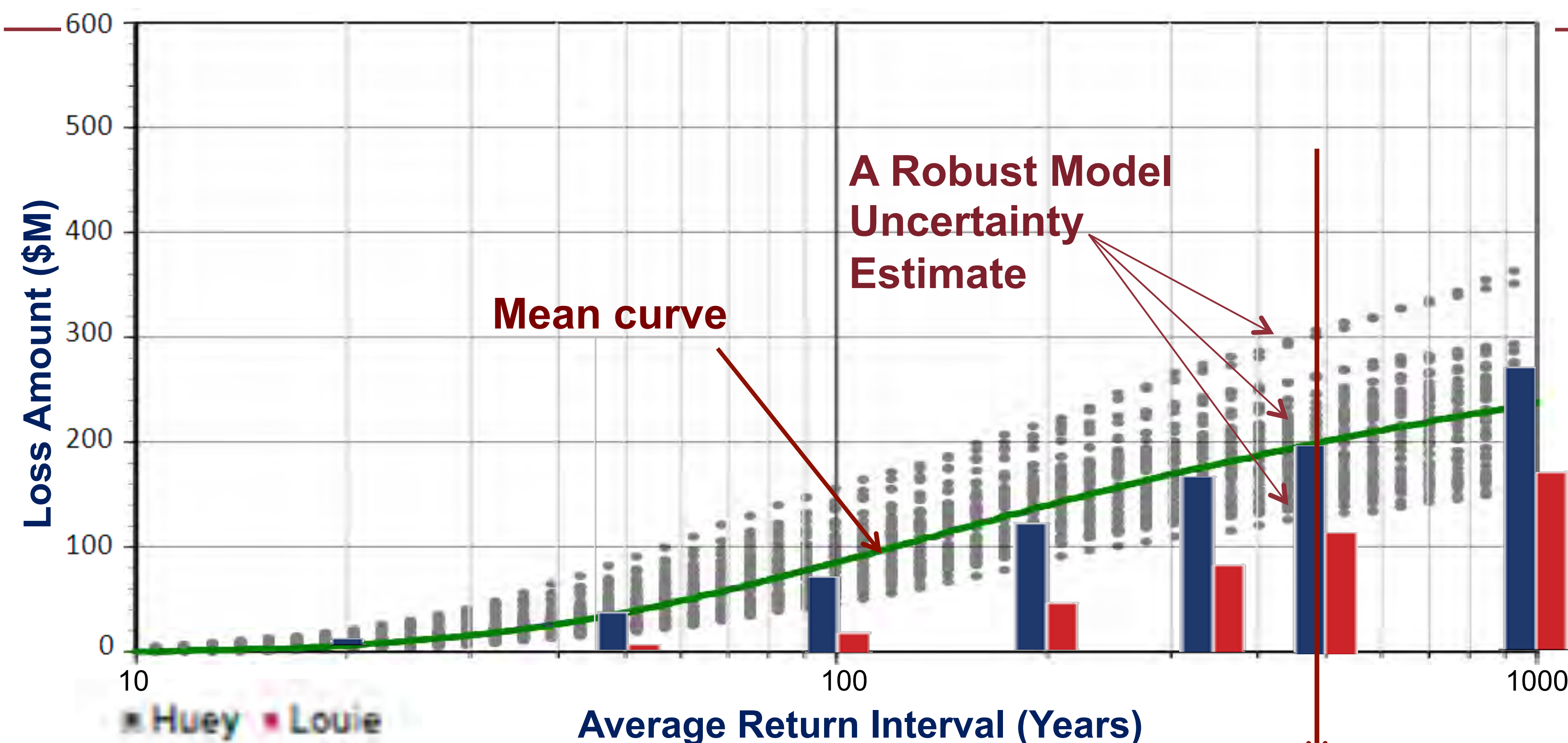
Hazard and risk, San Francisco

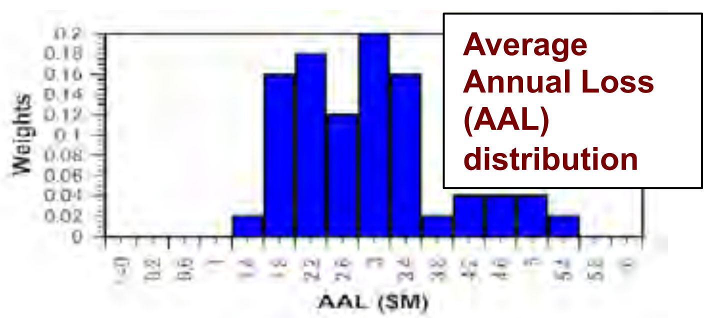


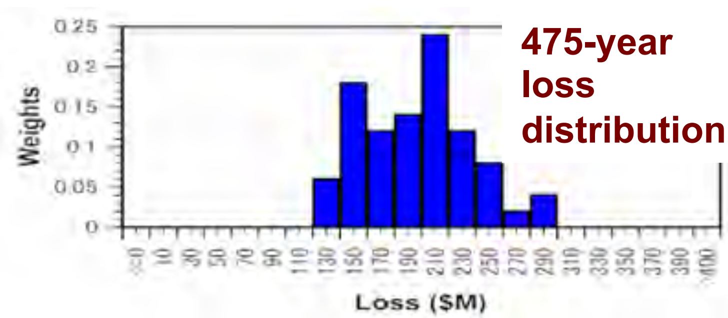


Source: Jerry Lee

Robust assessment of uncertainty (San Francisco)

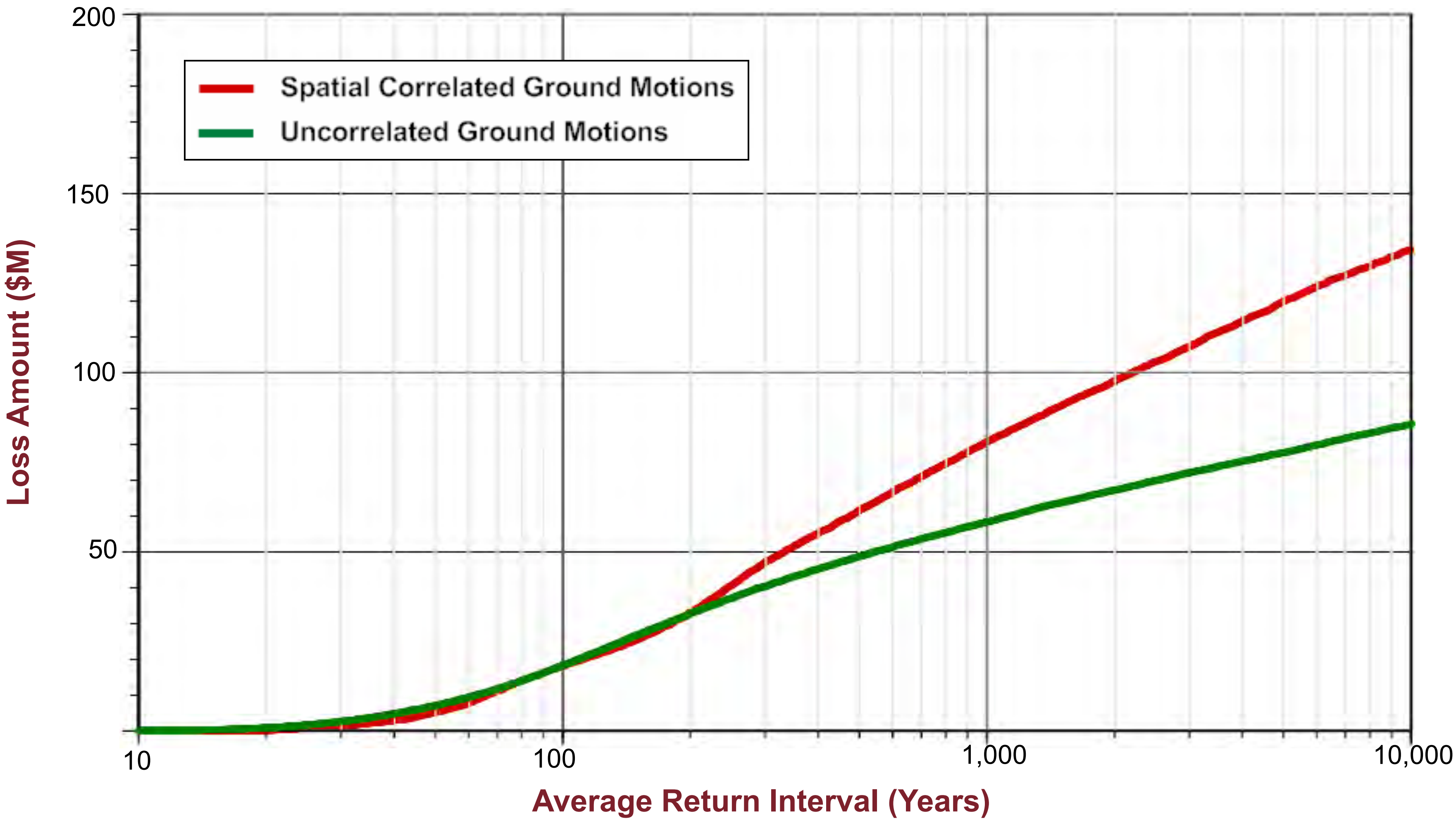






Source: Jerry Lee

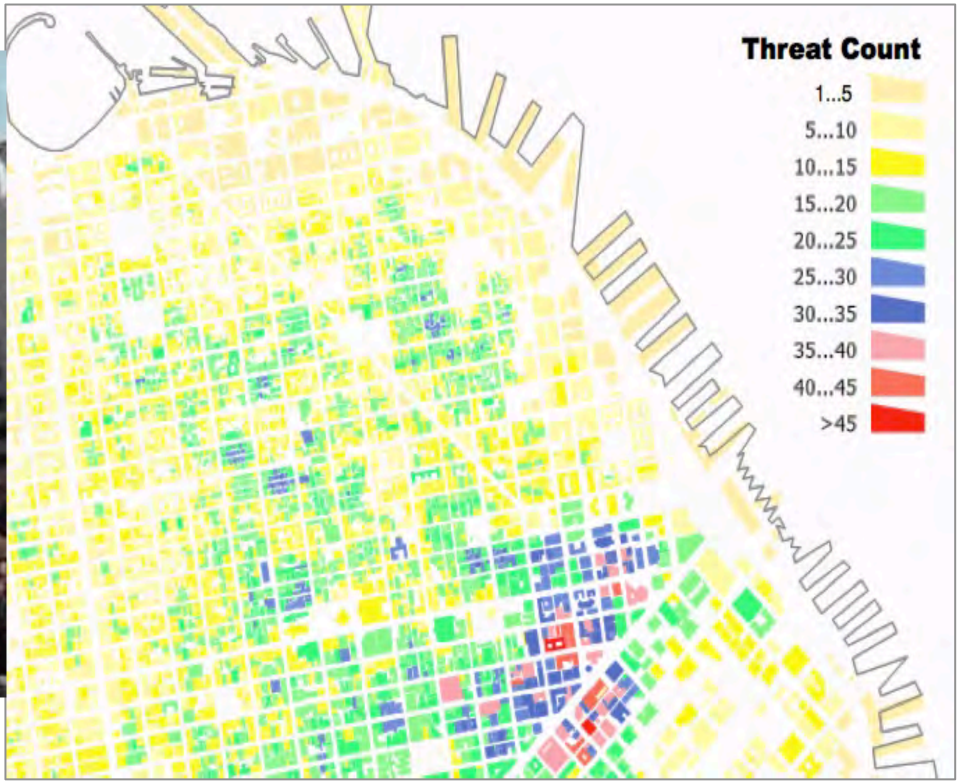
Portfolio losses and spatial correlation of ground motions (San Francisco)



Source: Jerry Lee – Figure updated 9/16/15

Tall buildings – pounding
Aggravated by spatial correlation of shaking

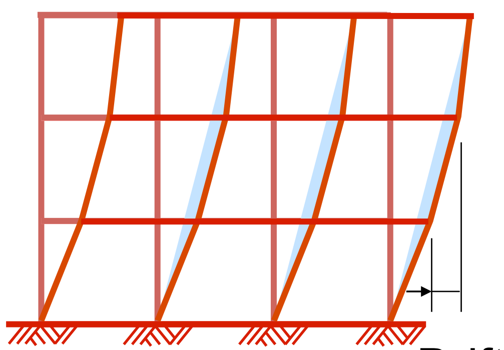
1999 Chi Chi Earthquake (M7.6) in Taiwan

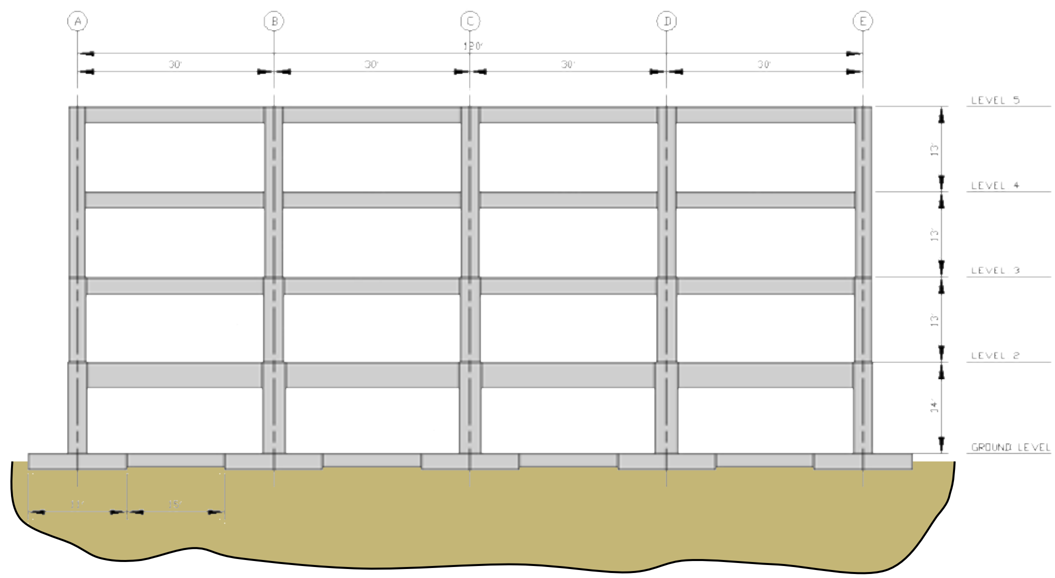


Source: William Graf

The PEER PBEE Benchmark Study

- Proof of concept of PBEE for a given hypothetical code-conforming 4-story building in SoCal
- Propagated uncertainties using first-order-second-moment (FOSM) method
- Study at seven hazard levels



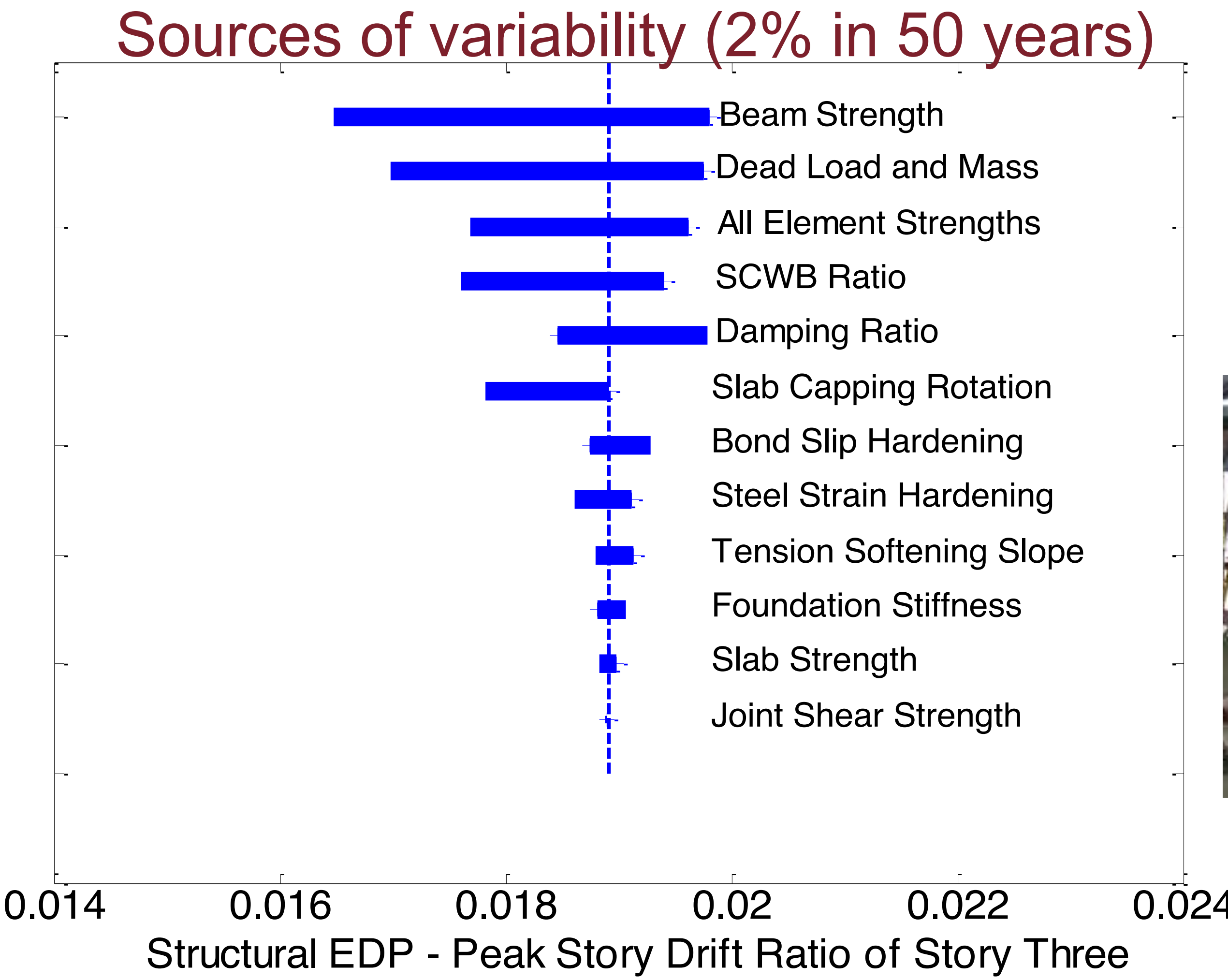


Building: RC 4 story frame building

- “Benchmark Building”: typical office building
- 4 x 6 bays
- T_1= 1s

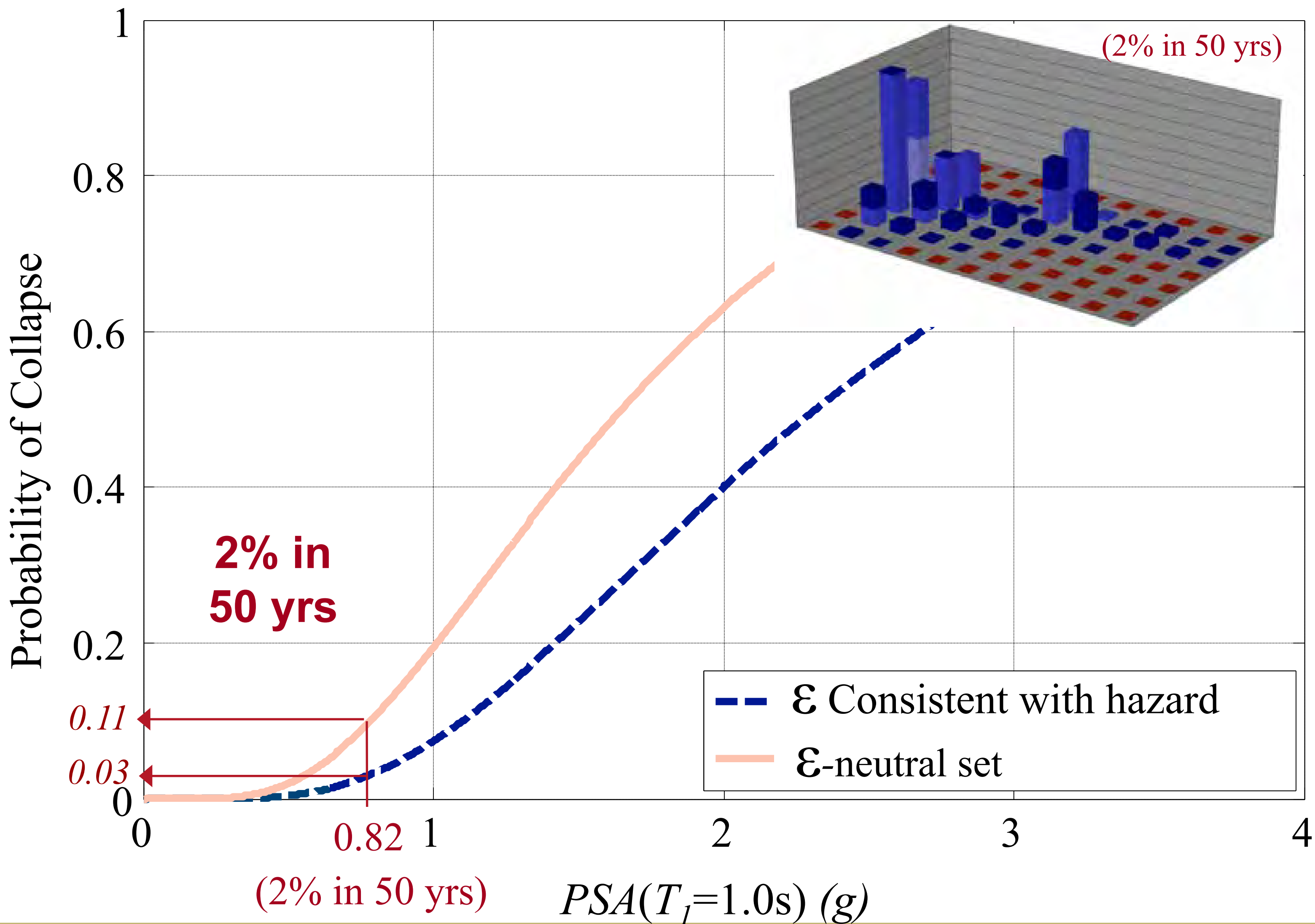
Goulet et al. 2007

Ground motions and hazard contributions



Source: Curt Haselton

Effects of Spectral Shape (ε)



Other earthquake-related natural hazards

- Landslide/rockslide
- Fault rupture (permanent static displacement)
- Liquefaction
- Tsunami

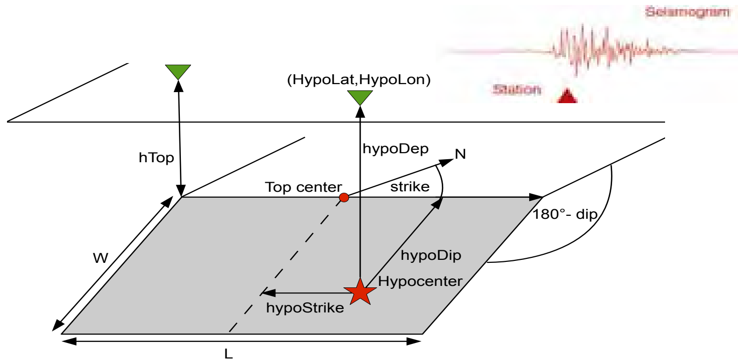
Low probability – large consequences.

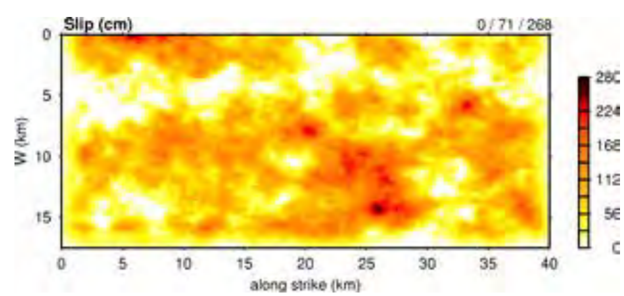
One hazard can trigger another one.

All can lead to foundation, structural or component failures (risk).

Current and future SCEC activities to consider for risk-targeted research

- Community models
- UCERF3 and faults studies
- Earthquake eng. implementation interface
- Simulation environments (earthquakes and ground motions)
  - CSEP
  - Broadband Platform
  - Dynamic verification group
  - Cybershake
  - High-F
- Other special project
  - CISM
  - SI2
  - Central California Seismic Project





Images: R. Graves and R. Archuleta

Insight into solutions from SCEC tasks?

- How can we better constrain distributions in probabilistic framework?
- How can we reduce uncertainties?