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

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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
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 (M5.5+) earthquake is too small; it is the related risk that can be acceptable or not.
“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.

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**
- IM: Intensity Measure
- EDP: Engineering Damage Parameter
- DM: Damage Measure
- DV: Decision Variable

**Structural analysis**
- HPC simulation

**Damage analysis**
- Performance Databases

**Loss analysis**
- Consequence Functions

- Fragility Functions

- Ground motion selection and scaling

Images: Yousef Bozorgnia
Performance Based Earthquake Engineering (PBEE)

**PEER Methodology**

- **Hazard analysis**
  - IM: Intensity Measure

- **Structural analysis**
  - EDP: Engineering Damage Parameter

- **Damage analysis**
  - DM: Damage Measure

- **Loss analysis**
  - DV: Decision Variable

- Design OK?
  - No: modify design
  - Yes: build!

**Symbols**
- D: Design
- IM: Intensity Measure
- EDP: Engineering Damage Parameter
- DM: Damage Measure
- DV: Decision Variable
Performance Based Earthquake Engineering (PBEE)

PEER Methodology

Hazard analysis

Structural analysis

Damage analysis

Loss analysis

Risk Integral:

\[ P(DV > dv) = \int \int \int P(DV | DM) \cdot P(DM | EDP) \cdot P(EDP | IM) \cdot \lambda(IM) \]

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
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

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

- \( \ln(IM) \) is normally distributed with median \( \mu \) and standard deviation \( \sigma \)

![PDF Distribution](image)
Terminology

- **Aleatory variability (randomness)**
  - Inherent randomness in a process
  - Refined with more data
  - Captured by $\sigma$

- **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 $\mu$, 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
“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

- Mean hazard, ergodic
- Mean hazard, non ergodic (region-, site-, path- specific)
From aleatory variability to epistemic uncertainty

- - Epistemic uncertainty (non ergodic)
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

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

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

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)

- Average Annual Loss (AAL) distribution
- 475-year loss distribution

Mean curve

A Robust Model Uncertainty Estimate

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
- $T_1 = 1\text{s}$

Goulet et al. 2007
Ground motions and hazard contributions

Sources of variability (2% in 50 years)

- Beam Strength
- Dead Load and Mass
- All Element Strengths
- SCWB Ratio
- Damping Ratio
- Slab Capping Rotation
- Bond Slip Hardening
- Steel Strain Hardening
- Tension Softening Slope
- Foundation Stiffness
- Slab Strength
- Joint Shear Strength

Structural EDP - Peak Story Drift Ratio of Story Three

Source: Curt Haselton
Effects of Spectral Shape ($\varepsilon$)

- Probability of Collapse
- $PSA(T_1=1.0s)$ (g)

Graph showing the effects of spectral shape on the probability of collapse.

- $\varepsilon$ Consistent with hazard
- $\varepsilon$-neutral set

(2% in 50 yrs)
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?

Thank you!