Catastrophe Modeling through Robust Simulation

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Robust Simulation – An innovative framework for robust loss assessments

Agenda

- An overview of uncertainty treatment in catastrophe modeling
- A more robust approach – Robust Simulation
- Implementation of the USGS hazard models
- Alternative vulnerability models
- Examples of loss modeling through Robust Simulation
- Some takeaways
Uncertainty in modeling catastrophe risks

- Two types of uncertainties

  - “Aleatory” – random variability (natural or modeled)
    - The odds of each outcome is known in advance
    - Commonly characterized by statistical distributions.
    - Often uncorrelated.
    - The Law of Large Numbers and Central Limit Theorem play.
    - Large quantities dramatically reduce randomness in aggregation.
    - Traditionally defined as “Risk”

  - “Epistemic” – Lack of knowledge
    - The possible outcomes are unknown in advance
    - Alternative models and parameters to be considered
    - Typically modeled with a multiple model (logic-tree) approach.
    - Systematic (correlated)
    - Large quantities often do not reduce the uncertainty in aggregation.
    - Traditionally defined as “Uncertainty”
Epistemic uncertainty in hazard modeling

The Logic Tree of UCERF3 and USGS 2014 NSHM Models

<table>
<thead>
<tr>
<th>UCERF3.3 Logic-tree Branches (for long-term model)</th>
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<tbody>
<tr>
<td><strong>Fault Models:</strong></td>
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<tr>
<td>FM3.1</td>
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<td>FM3.2</td>
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<td><strong>Deformation Models:</strong></td>
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<tr>
<td>Geologic</td>
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<tr>
<td>Awe/Block/Mod.</td>
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<td>Near/Craterian</td>
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<td>Zeng</td>
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<td><strong>Earthquake Rate Models:</strong></td>
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<td>Scaling Relationships</td>
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<td>Stress-dependent</td>
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<td>Slip Along Rupture (Dist.)</td>
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<td>Total M=5 Event Rate (yr^-1)</td>
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<td>Inversion Model</td>
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<tr>
<td><strong>Modeled r_m</strong></td>
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<tr>
<td>Off-Fault Spatial Sols PDF (aka SpatPDF)</td>
</tr>
<tr>
<td>Fault Moment Rate Fix</td>
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</tbody>
</table>

**UCERF3** - 1440 alternative rupture models

5 Ground Motion Models (GMMs)

3 branches in median of GMMs

The total number of branches: 1440 x 5 x 3 = ???

The number of alternative models: 21,600 !!!

Each represents an admissible solution
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The Robust Simulation Approach
(Taylor 2015; Lee et al., 2014, 2018)

Acknowledge model limitations and seek to reveal the uncertainty associated with imperfect knowledge
- Hazards and risks are depicted by an ensemble of solutions.
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(Taylor 2015; Lee et al., 2014, 2018)

Acknowledge model limitations and seek to reveal the uncertainty associated with imperfect knowledge

- Hazards and risks are depicted by an ensemble of solutions.
- Each solution provides a scientifically justifiable and defensible view among a variety of scientifically plausible outcomes.
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The Robust Simulation Approach
(Taylor 2015; Lee et al., 2014, 2018)

Acknowledge model limitations and seek to reveal the uncertainty associated with imperfect knowledge

- Hazards and risks are depicted by an ensemble of solutions.
- Each solution provides a scientifically justifiable and defensible view among a variety of scientifically plausible outcomes.
- Solutions preserve model transparency, integrity and traceability.
Implementing the USGS 2014 NSHM models through Robust Simulation and Comparison to the USGS Hazards

Characterizing the Epistemic Uncertainty in the USGS 2014 National Seismic Hazard Mapping Project (NSHMP)
Y. Lee, W. Graf and Z. Hu

The Bulletin of the Seismological Society of America
Vol. 108, No. 3A, pp. 1465–1480, June 2018
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San Francisco

PGA

SA at 1 sec
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Los Angeles

PGA

SA at 1 sec

Ground Motion Distribution at 475-Year Return Period

Ground Motion Distribution with Exceed. Prob. of 10% in 50 Years
Comparison of the Mean Hazard from Robust Simulation (RS) with the USGS Published Values

Spectral Accel. at 0.2 sec (SA02)

Mean from RS

Spectral Accel. at 1.0 sec (SA1)

Mean from RS

SA02 (g)

SA1 (g)

0.00 - 0.01
0.02 - 0.03
0.04 - 0.05
0.06 - 0.10
0.11 - 0.15
0.16 - 0.20
0.21 - 0.25
0.26 - 0.30
0.31 - 0.40
0.41 - 0.50
0.51 - 0.60
0.61 - 0.85
0.86 - 1.25
1.26 - 1.60
1.61 - 2.50

USGS

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Alternative Admissible Vulnerability models
Vulnerability Models

- **Empirical** models vs. **Expert** models vs. **Engineering** models

  Most Cat modelers use proprietary damage functions ("secret sauce"), but this makes them more difficult to check

- Some of the public models
  - ATC-13 [ATC 1985]
  - HAZUS [FEMA/NIBS, 1997]
  - FEMA P-58 [FEMA, 2012]
Example: A 1970, one-story Wood-Frame Residential Building in Los Angeles

- **HAZUS**
  - MBT: W1
  - Design Level: Moderate Code (MC)
  - Occupancy: RES1

- **CODA**
  - MBT: W_E
  - Period \((T_e)\) = 0.22 s
  - Base Shear Coefficient \((C_s)\) = 0.186
    (according to 1967 UBC Code)
  - R-Factor = 4.0
    (Predating plywood sheathing and hold-downs)

- **Wesson et al.**
  - Damage as a function of \(S_R03\)

- **FEMA P-58**
  - (Taken from DeBock et al, 2016)
  - MBT according to ASCE/SEI 7-10
  - Design short period spectral acceleration \(S_{DS} = 1.0\) g
  - \(C_s = 0.154\)
  - R-factor: 6.5
Comparison of the Damage Functions

*X-axis shows the distances from a site on Site Class D to a hypothetical strike-slip fault and spectral acceleration at 0.3s calculated based on the BSSA NGA West 2 GMPE (2013)
A hypothetical portfolio of 1,123 WLF buildings in Los Angeles, $200,000 replacement value each

Total TIV: $225 Million
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The Exceedance Probability (EP) Curves

Portfolio Losses

Loss (M$)

Average Return Period (Year)

ImageCat, Inc.
The Exceedance Probability (EP) Curves

Portfolio Losses

```
- Wesson
- CODA
- HAZUS

“Mean” EP

475-year
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Uncertainty in Estimated Risks

A more robust estimation of uncertainty

“A Mean” EP

Loss (M$)

Average Return Period (Year)
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Uncertainty in Estimated Risks

Loss (M$) vs. Average Return Period (Year)

“Mean” EP Curve

475-year

Loss Distribution at 457-Year Return Periods

Normalized Frequency vs. Loss (M$)
Some Takeaways

- Uncertainty in earthquake risk modeling is large.
- A single consensus “mean” may significantly understate the potential for extreme consequences.
- Professional Engineers can help select one or multiple models that best suit the analyses, based on knowledge, information and resources available.
- The ensemble of scientifically justifiable and defensible views provides a better depiction to future risks.
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Thank you!