Short Term Portfolio Risk Can Inform Hazard Models

Objectives:

- Operationalize regional-scale risk assessment in NSHM development
- Use risk to test and quantify the implications of modeling decisions
- Ensure NSHM is appropriate for short term portfolio risk applications

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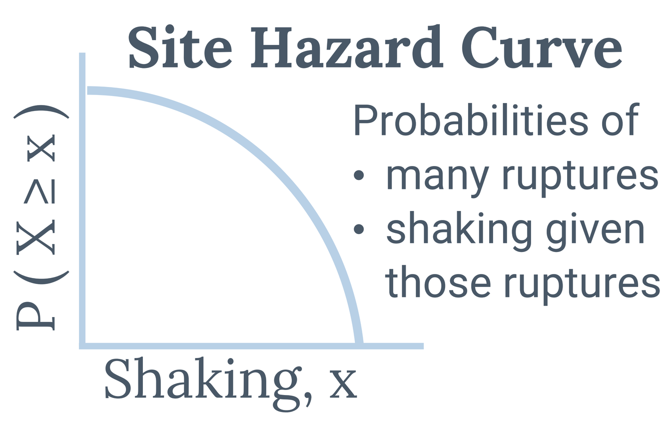
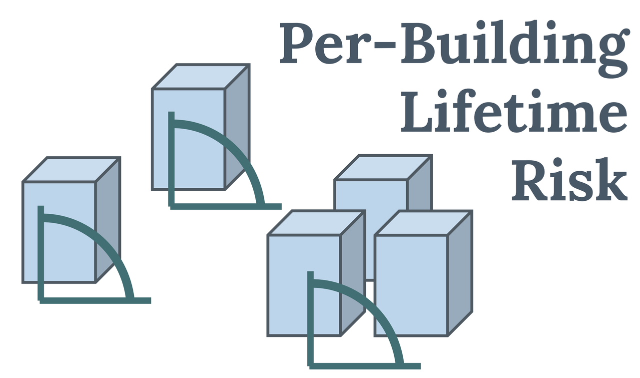
Building code committees provide end-user feedback to the National Seismic Hazard Model (NSHM)

The development of the National Seismic Hazard Model is closely coupled with the building code development process. Modeling decisions that significantly affect policy outcomes are carefully scrutinized to confirm their suitability in this use context.

The building code is applicable at the scale of a single site, considering long term risk over the life of the building. Design ground motions are based on isolated, per-building risk calculations, using the site hazard curve (the probability of exceeding increasing shaking intensities) and the building's probabilistic response to those intensities.



This accumulates one building's risk across many possible ruptures and the shaking uncertainty per rupture.



Short term portfolio risk is a missing link

While the NSHM is vetted for use in the building code context, there is no similar scrutiny with respect to short term portfolio risk assessments, as used in the insurance industry. Certain model features take on additional significance in this context, where the collective risk is covered by thousands of short term (e.g., 3 year) policies.

Short term risk is more sensitive to time dependence with respect to recent events, a feature which is under active development for the NSHM. Portfolio risk also includes a spatial dimension, whereby insurance agencies must remain solvent even when many buildings are affected by the same event. This type of spatially distributed risk is more sensitive to the NSHM's multi-fault rupture probabilities and distribution of ground motion epistemic uncertainty. As with the building code, such modeling decisions can affect policy outcomes, warranting similar levels of scrutiny.

Portfolio risk considers an individual rupture's impact across all affected buildings. This complicates the bookkeeping for accumulating risk over many rupture probabilities and their shaking uncertainties.

	long term	short term
single site	Building Code	
regional portfolio		Insurance Policies

1) multi-fault ruptures

2) spatial distribution of ground motion uncertainty

3) time-dependence

increasing significance

Policy decisions consider unlikely outcomes, not just expected ones

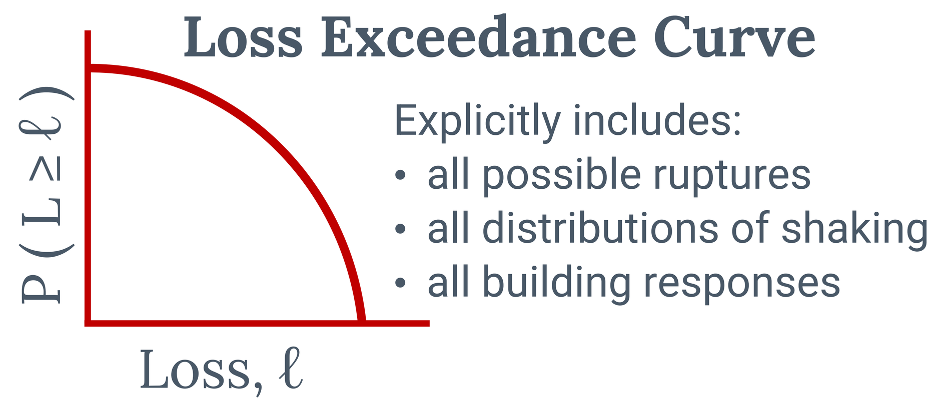
One portfolio risk metric of interest is the average annual loss, AAL. This is the long term expected loss across the whole portfolio, averaged over the long term duration. Expected value calculations are useful for collapsing many dimensions of uncertainty into a single, scalar value. The spatial dimension can be collapsed by simply summing the per-building expected losses, using each one's site hazard curve.

$$AAL = \sum_{all\ buildings}$$

Collapsed dimensions:
- spatial loss per rupture
- probability of many ruptures
- shaking given those ruptures

However, while the AAL is the average loss per year, few if any years will experience that level of loss. If a 10-building portfolio experiences total loss every 10 years, the yearly loss is either 0 or 10 but the AAL is 1. To maintain solvency, insurance policies are based on the probability of exceeding a loss level, not the average loss. Loss exceedance curves, LEC, rank every possible loss outcome by how likely it is to be exceeded. In concept, this explicitly considers every dimension of uncertainty. Integrating over all loss levels returns the single, scalar AAL value.

$$AAL = \int_{\ell=0}^{\infty}$$



Explicitly considering all sources of variability is computationally intensive and the bookkeeping is complicated. The state-of-the-art approach is to simulate the uncertainty in ground motion by randomly sampling to produce many spatially correlated ground motion fields for each rupture. Then each building's response is sampled based on its local ground motion for each field.

The scale of the NSHM logic tree poses challenges

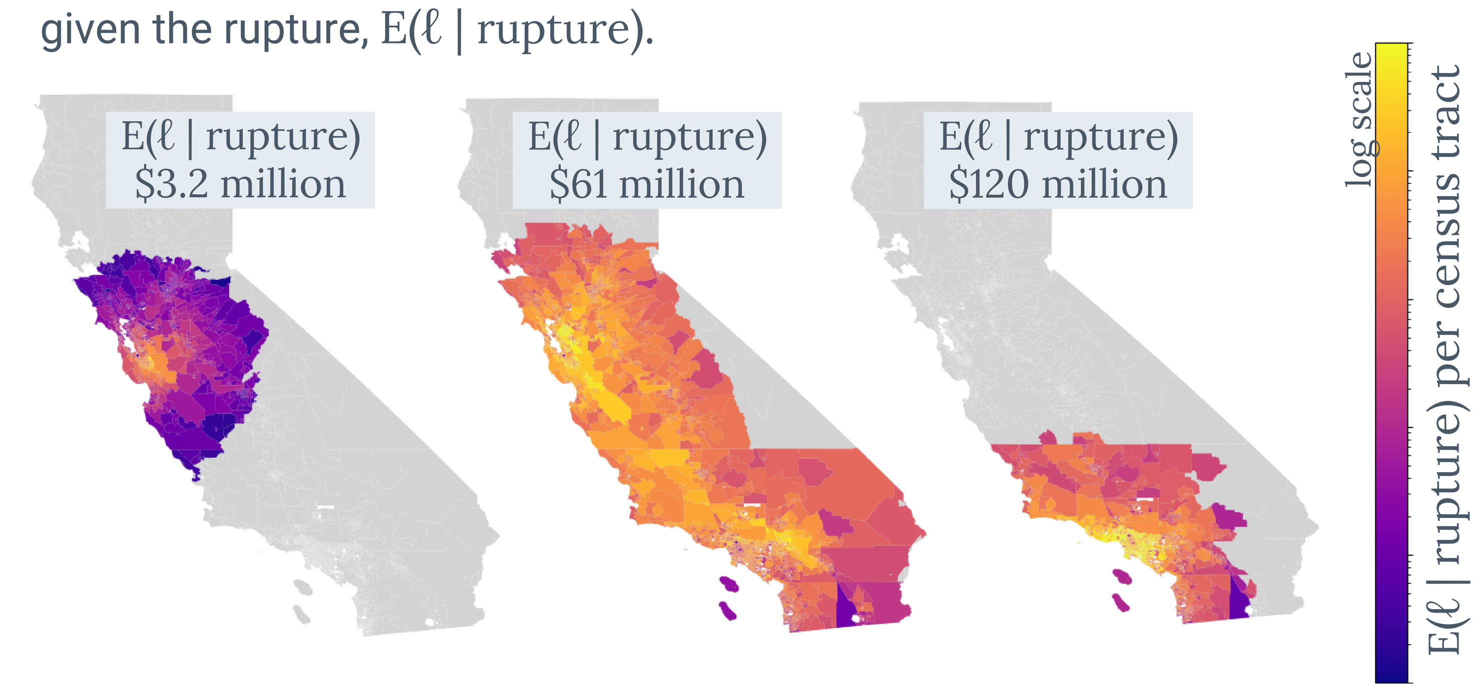
The complete LEC sampling described above is typically applied in the context of a single set of ruptures with a single ground motion model (GMM) to be applied to those ruptures. The NSHM uses a logic tree to account for uncertainties in the earthquake rupture forecast (ERF, the set of ruptures and their probabilities) and the selection of GMMs, resulting in millions of ERF+GMM combinations, each requiring its own per-rupture ground motion field and building response sampling.

The objective to test and quantify the risk sensitivity to the hazard modeling decisions inherently requires the full logic tree. The Benchmark Earthquake Risk Model (BERM) was launched for this purpose, following initial demonstration studies for how the problem's dimensions can be collapsed in a tractable manner[1].

The Benchmark Earthquake Risk Model (BERM) handles the bookkeeping

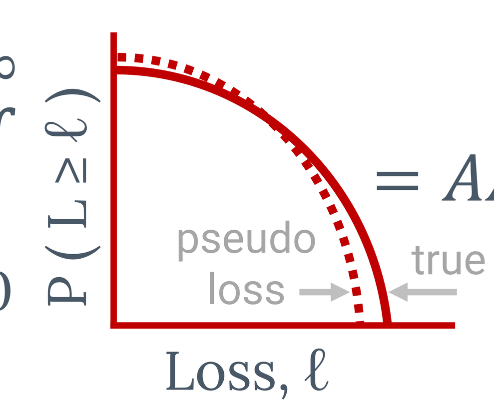
All portfolio risk calculations follow a hierarchy of operations, determining which dimensions could be collapsed and which metrics can be produced. For example, the basic AAL summation prioritizes the per-building expected loss by collapsing the ruptures and ground motion dimensions into a single hazard curve.

The BERM prioritizes the per-rupture expected loss. The ground motion dimension is collapsed into per-site conditional exceedance curves given the rupture, then the building losses are summed for the expected loss given the rupture, $E(\ell \mid rupture)$.

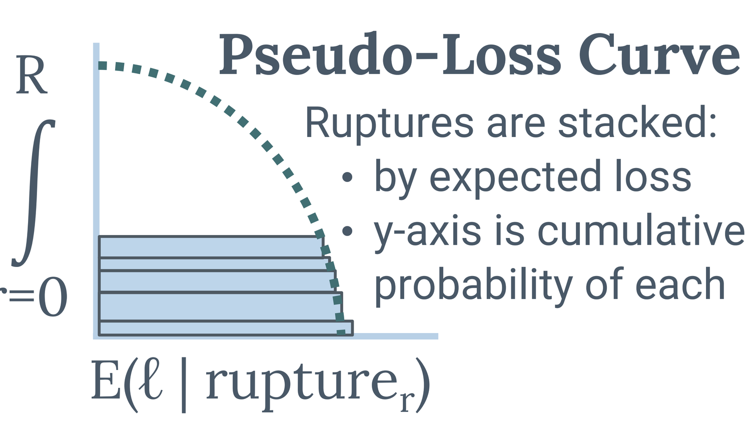


A pseudo-loss curve is created by ordering the $E(\ell \mid rupture)$ values for all ruptures and stacking their probabilities. While the area under this curve is AAL, the true LEC is wider, due to spatial uncertainty in ground motions.

$$\int_{\ell=0}^{\infty}$$



$$= AAL = \int_{r=0}^{R}$$



The missing dimension is the per-rupture ground motion field and building response sampling. This can be approximated via smaller test cases for a rupture's distribution of loss around the expected value. The result is an empirical relationship between expected loss and covariance, which can be used to approximate the LEC from the pseudo-loss curve[1].

Thus, the LEC can be approximated based on the expected losses for each rupture. Storing the expected loss for every possible rupture allows the ERF logic tree to be explored efficiently, by simply updating the per-rupture probabilities. This includes changes in the probability of **(1) multi-fault ruptures** that result in loss across wider regions. The GMM logic tree's treatment of the **(2) spatial distribution of ground motion uncertainty** can be explored via the test cases for the per-rupture loss distribution covariance models.

Finally, **(3) time-dependence** can be introduced through stochastic event sets, synthetic sequences of rupture events for a given timespan. This determines the order and timing of each rupture but the set of possible ruptures and their expected loss remains the same, already computed[2].

References

[1] Porter, K., Milner, K., and Field, E. 2025. "Trimming the UCERF3-TD Logic Tree: Model Order Reduction for an Earthquake Rupture Forecast Considering Loss Exceedance." Earthquake Spectra 41 (1): 636–53. https://doi.org/10.1177/87552930241280401.

[2] Field, E., Milner, K., and Porter, K. 2025. "Risk Implications of Poisson Assumptions and Declustering Inferred from a Fully Time-Dependent Earthquake Forecast." Earthquake Spectra 41 (3): 1977–97. https://doi.org/10.1177/87552930251340677.

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