Exogenous Uncertainties in Earthquake Risk Modeling for Infrastructure Systems: A Demonstration Evaluation In Northern California

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Investigations Underway and Undertaken

The goal of this project is to explore the impacts of uncertainties on seismic risk and risk reduction estimates of infrastructure systems. The focus on these risk and risk reduction estimates modifies the metrics of typical concern in practically oriented geoscience projects from such fractile estimates as X% probability in Y years to such metrics as reduced average annualized losses and their variance.

In this project, *endogenous uncertainties* are those directly incorporated into the system risk simulation process. *Exogenous uncertainties* are those not so incorporated into this systems risk simulation process. (See D. Perkins, 2002, for an exploration of exogenous uncertainties with respect to probabilistic strong ground motion hazard modeling.) The more familiar aleatory and epistemic uncertainties may—depending on the application—be treated endogenously or exogenously.

For illustrating seismic risk results, we have constructed an artificial system of four berths, two at Oakland, one at San Francisco, and one at Richmond, California. Modified from previous work by the investigators (Werner et al., 2002), four deterministic berth vulnerability models are artificially constructed using state-of-the-practice procedures. An artificial and simplified set of shipping demands on these berths has also been constructed. This *baseline system model* further employs a "walkthrough" approach using the Frankel et al. (2002) earthquake source models along with Abrahamson-Silva (1997) empirical attenuation models. The walkthrough approach is a Monte Carlo simulation of earthquake occurrences that represents not only their spatial variabilities (as does, for instance, Latin hypercube pre-sampling) but also their variabilities over time. (See Taylor et al., 2001, Werner et al., 2000) To explore endogeous uncertainties, this walkthrough approach is buttressed by post-sampling variance reduction techniques that yield more efficient estimates of mean losses and their confidence limits along with various fractile estimates (e.g., 500-year losses) and their confidence limits. (see Perkins and Taylor, 2003) To explore the critical risk and decision parameter of reduced losses, a seismically less resistant berth is substituted for one of the more seismically resistant alternative in order to provide an artificial decision alternative.

The exploration of exogenous uncertainties is being undertaken on two fronts. The first relates to the distribution of losses and reduced losses relative to some specific earthquake source. The second relates to the distribution of losses and reduced losses from all seismic sources.

The first front is here guided by two main earthquake faults contributing the bulk of earthquake losses to the artificial system. This project is considering **M** 7.3 Hayward and **M** 7.8 San Andreas (San Francisco) earthquakes. Uncertainties in source processes such as slip model and nucleation point as well as site dynamic material properties such as shear-wave velocity and the strain dependence of soil shear moduli and damping factors will be modeled by randomly varying these parameters and computing resulting seismic demands on the berth structure and economic losses owing to earthquake damage to the berth. Source and site parameter distributions are empirically verified.

The goal of this first front is to incorporate the coupling of uncertainty in seismic demand to uncertainty in loss as well as to isolate those parameters within source and site soil models that have the largest impacts on the economic loss estimates. The multiple hazard result sets (ground motions and liquefaction-induced permanent ground displacement) will be input into the above-mentioned berth vulnerability model. These results will then incorporate hazard-related uncertainties into this previously deterministic vulnerability model. Then the distribution of overall losses and reduced losses from the baseline model relative to the major fault systems above will be compared with the distribution of overall losses and reduced losses from the improved model.

The second front consists of varying a number of parameters and models in order to see how these variations impact overall seismic risk and risk reduction estimates from all earthquake sources affecting the hypothetical system. Of interest are a number of parameters and models, including:

- changes in estimates of earthquake magnitudes

- incorporation of uncertainties in rates of occurrence (especially as regards the use of slip rates for rates for active fault systems)
- use of alternative empirical attenuation models (with special reference to models explicitly incorporating directivity effects)
- variations in the geographic locations of berths
- variations of estimates of shipping demands on the artificial berth system
- variations in constant dollar discount rates used to assess the present value of reduced losses

Results to Date

Results to date primarily pertain to the consideration of loss distributions relative to the overall seismicity affecting the artificial berth system. These results address first the evaluation of endogenous uncertainties (which results test the tools used) and second the evaluation of exogenous uncertainties. All such results should be regarded as being preliminary.

As regards the evaluation of endogenous uncertainties, tools being tested are the Monte Carlo walkthrough method and the variance reduction techniques. These variance reduction techniques employ, among other factors, an exponential distribution as a "control" function in order to estimate years in which losses occur. These techniques can thus be less effective when the actual non-zero losses have humps, trends, or multiple modes. The use of such discontinuities in modeling seismic systems risks such as the employment of characteristic earthquakes, the use of lines or planes to represent fault rupture zones, the lack of consideration of uncertainties in berth fragility models, the use of threshold damage states in these models, and the use of upper bound repair times can all impact the resulting system loss distribution. However, to date, these problems have not arisen as regards the overall loss distributions developed. For the baseline case, the variance reduction techniques have reduced the number of simulations required in order to achieve various confidence limits by a multiplicative factor of 3.8 (and this result implies that the multiplicative factor for the non-zero loss distribution is an order-of-magnitude higher).

Also of note is that for the artificial system the San Andreas fault yields over half the overall losses from all seismic sources and the Hayward fault systems yield over 30% of the overall losses from all such sources. These results occur even though thousands of other seismic events were simulated to represent overall seismicity.

As regards exogenous uncertainties, preliminary results are available for (a) the consideration of geographic distribution within the Bay Area, (b) the consideration of percent changes to all earthquake magnitudes evaluated, (c) the consideration of changes in assumed shipping rates, (d) the consideration of alternative real discount rates, and (e) a very preliminary consideration of alternative empirical attenuation functions.

The use of three "sites" for an artificial berth system does make some difference relative to the employment of a single "site" for a regional berth system. However, there is frankly little geographic diversification in the Bay Area relative to San Francisco Bay earthquakes.

Assuming uncertainties in magnitude estimates (both upwards and downwards) makes a difference to estimates of overall losses, losses to the decision alternative, standard deviations, probabilities of some loss, and such other key statistics. However, remarkably enough, for the hypothetical system of berths being analyzed, these magnitude uncertainties appear to have little bearing on reduced losses, a key parameter is lifeline decision-making.

Changes in shipping demands appears to have a very prominent role in the performance of the overall berth system. As shipping demands increase toward full capacity, reduced losses in the hypothetical case ramp up until they reach twice the reduced losses for the baseline assumption of shipping demands at 50% capacity. That is, at what level one estimates shipping demands is a key parameter. To the extent that shipping demands are forecast to increase over time, the inclusion of this factor in longer-term planning appears to be extremely important.

The use of social discount rates can have an even greater impact. The former use of 7%, which discourages earthquake mitigation activities, yields present values of reduced losses that are less than one-half of the use of 2%, a very current estimate (written comm., A. Rose, 10/03).

To date, effects of differing ground motion attenuation models on fractile loss estimates are addressed by considering two alternative models--one by Boore et al. (1997) and another by Campbell and Borzognia (2002) . The Boore et al. (1997) models produce slightly higher losses (not much) than the baseline model. The Campbell and Borzognia (2002) models apparently yield somewhat lower loss estimates. These results are very preliminary.

Non-Technical Summary

Analyzing infrastructure seismic risks is a multi-disciplinary activity yielding the key risk and decision statistic: reduced risks through seismic improvement. This study explores some of the many uncertainties in this activity. To do so, this study constructs and evaluates an artificial regional San Francisco Bay berth system. Uncertainties are evaluated with respect to specific controlling faults, the Hayward and the San Andreas, and with respect to overall seismicity. The general approach used here maneuvers between two extreme views: that one can optimistically develop with certainty very precise risk estimates and that one can pessimistically ignore modeling details owing to all the uncertainties involved.

Reports

None to date.

Availability of Data
Contact principal investigators.

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