Annual Report:

Trimming the Hazard Logic Tree, Phase 1

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Abstract. This document summarizes progress on an effort to test and depict the sensitivity of societal risk estimates to branches in the UCERF hazard logic tree. The work is not yet complete. In this phase, seismic vulnerability functions have been created that relate the both building repair costs and fraction of indoor occupants killed or injured to shaking intensity, by structure type and occupancy classification. Intensity is measured using a vector measure: 5%-damped elastic spectral acceleration response at 0.3-sec and 1.0-sec periods, also conditioned on magnitude, distance, site soil classification, and tectonic regime. The casualty rate seismic vulnerability functions were created for another (USGS) project, while both mean and probabilistic seismic vulnerability functions of repair cost were created for the SCEC under the present phase of the work (SCEC 2008-2009). In work for the 2009-2010 SCEC year, a portfolio of assets exposed to seismic risk was also estimated, in work for this project and another USGS project. (The USGS work quantified indoor occupants; the SCEC work added square footage and replacement costs, by census tract, occupancy classification, and structure type.) A component of the OpenRisk software, designed for SCEC in previous work and developed in collaboration with USGS programmers, will be used to carry out the loss calculations. The sensitivity analysis, not yet begun, will employ a tornado-diagram-analysis approach developed for decision analysis and applied and extended in the last 10 years by SPA personnel and others for use in earthquake engineering loss estimation.

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1 INTRODUCTION AND OBJECTIVES

The goal of the present project is to assess the sensitivity of selected measures of societal risk to selected branches in the hazard model, in particular to the branches of the Uniform California Earthquake Rupture Forecast, either version 2 or the just-beginning UCERF 3. By "measures of societal risk" is meant expected annualized loss—either economic or human deaths and injuries—or aspects of the loss-exceedance curve for the same measures. A loss-exceedance curve here means a relationship between loss and mean exceedance frequency. The value of such a capability is that it will provide insight into the relative importance of scientific inquiry into this or that aspect of the ERF in particular or the hazard model in general.

The insight can help in two ways: first, by identifying branching points that do not matter much to important measures of risk, this "tree-trimming" capability can help to reduce computational effort expended on risk modeling. One could in principle pick a single branch and not iterate or simulate over several. A second, possibly less important and more controversial use is to identify uncertainties that warrant, because of their effect on societal risk, additional study. For example, if an uncertainty in seismic hazard can potentially be reduced by further study, this might potentially reduce uncertainty in a practical risk model, such as the loss-exceedance curve of an insurer, which in turn affects reinsurance needs and costs.

This is important: we do not wish to imply that scientific inquiry should be judged solely by its effects on uncertainty in social or economic risk. Scientific inquiry into any particular topic of the hazard model has its own internal values and drivers: curiosity of the investigators, relevance to other aspects of seismic hazard, broader relevance outside of seismology, etc. But nonscientists affected by science may wish to direct research resources to topics with a potentially important practical benefit to them, and this tree-trimming capability can potentially aid in those decisions. Others for whom computational expense can be significantly reduced by eliminating relatively immaterial branches to an uncertain hazard model may also value the capability aimed for here. To achieve this goal requires a few developments, begun here.

1. An estimated portfolio of assets exposed to shaking—building occupants, building value, etc. The "portfolio" comprises an estimate, by relatively small geographic area such as census block or census tract, of the quantity of people and building replacement cost by structure type and possibly occupancy class (if breakout of risk by occupancy class is important).
2. A computer model capable of estimating the expected annualized loss (EAL) for a portfolio of assets exposed to seismic shaking. The model must be capable of estimating EAL for single paths along the hazard logic tree.
3. A similar model capable of estimating the portfolio loss exceedance curve (LEC).
4. A set of (mean) seismic vulnerability functions for deaths and nonfatal injuries of indoor occupants in each structure type in the portfolio. A mean seismic vulnerability function here refers to a relationship between the expected number of deaths or injuries (typically as a fraction of occupants, i.e., the mean damage factor) and a scalar or vector shaking intensity, whether shaking is measured in terms of damped elastic spectral acceleration response at some index period, or instrumental intensity, or some combination of these with one or more of magnitude, distance, site class, etc.
5. A set of mean seismic vulnerability functions for the economic repair costs for each structure type in the portfolio. Again, this is a relationship between the expected value of loss—this time as a fraction of replacement cost, new—and shaking intensity.
6. For an LEC of repair costs, the repair-cost seismic vulnerability functions must be probabilistic, i.e., providing an estimate of the probability distribution of repair-cost damage factor of the asset class as a function of shaking intensity.
7. For an LEC of casualties, the casualty-rate seismic vulnerability functions must be probabilistic, i.e., providing an estimate of the probability distribution of casualty rate for each injury level and structure type, as a function of shaking intensity.
8. A methodology for quantifying sensitivity of the loss estimate to each logic-tree branch in question.

2 PROGRESS OF THE WORK

2.1 ESTIMATED PORTFOLIO OF ASSETS: DONE FOR 2009-2010

The work has begun somewhat out of order. In work for the USGS's PAGER project, the number of indoor occupants was estimated and tabulated by census tract, type of occupancy, and structure type. In 2009-2010 work for SCEC, the replacement cost of buildings and contents was estimated and tabulated alongside indoor occupants. The work amounted to extracting the inventory from HAZUS-MH, though it was a little more difficult than it sounds. The HAZUS-MH "inventory" is contained in a normalized database: it requires a sequence of queries of up to 15 tables to extract sufficient inventory information to compile the basic unit of the portfolio required for the present work. That is, there is no single table in the HAZUS-MH database that can answer the question: How many people are there buildings in census tract W, at time of day X, in structure type Y, and how much building square footage, building value and content value in those buildings in occupancy classification Z? To extract this inventory information required denormalizing the HAZUS-MH database, an effort documented in our 2009-2010 progress report and Porter (2009a). A sample of the database is shown in Table 1. The fields are defined in Table 2.

Table 1. Sample of California portfolio

ID	Tract	OccLabel	SsType	DesignLevel	A	Vb	Vc	PopDay	PopNight	PopCommute
349	06001400100	RES1	W1	MC	1482	249794	124905	247	1544	546
350	06001400100	RES3A	C2L	HC	2.00	184	92	0	2	1
351	06001400100	RES3A	C2L	LC	0.65	59	30	0	1	0
352	06001400100	RES3A	C2L	MC	1.94	178	90	0	2	1
353	06001400100	RES3A	C3L	MC	0.65	59	30	0	1	0

Table 2. Layout of inventory table

Field name	Data type	Description	Comment
ID	Autonumber	An index	1, 2, …
Tract	Text, 11	Census tract number	e.g., 06001400100, from hzTract.Tract
BldgSchemesId	Text, 5	Identifies scheme to distribute from occupancy to material, structure type and design level	In California, distinguishes L/M/H hazard
OccLabel	Text, 5	HAZUS-MH occupancy label	RES1, RES2, … EDU2
SsType	Text, 10	FEMA earthquake structure type	W1, W2, … or MH
DesignLevel	Text, 2	HAZUS-MH seismic design level	PC, LC, LS, MC, MS, HC, or HS
A	Double	1000 sq ft	See Porter (2009a) for deriv
ValYr	MM/DD/YYYY	Year in which dollar valuation is made	Default = 1/1/2003
Vb	Double	Building replacement cost, $1000s	See Porter (2009a) for deriv
Vc	Double	Content replacement cost, $1000s	See Porter (2009a) for deriv
PopDay	Long integer	Daytime population, people at 2 PM	See Porter (2009a) for deriv
PopNight	Long integer	Nighttime population, people at 2 AM	See Porter (2009a) for deriv
PopCommute	Long integer	Commute-time population, people at 5 PM	See Porter (2009a) for deriv

2.2 PORTFOLIO EAL CALCULATOR: DONE; NEEDS REVISION

In previous work for the US Geological Survey and SCEC, we addressed item 2 and designed OpenRisk (Porter and Scawthorn 2007, 2009), open-source software that extends USGS and SCEC's suite of open-source seismic hazard analysis software OpenSHA to calculate damage and loss. We specified a portfolio data file format, and in collaboration with USGS, SCEC, and Instrumental Software Technologies, Inc., created a portfolio import tool and a portfolio EAL calculator. The OpenRisk Portfolio EAL calculator is currently available at www.risk-agora.org and its source code is available within the OpenSHA software repository. The software currently does not include the suite of seismic vulnerability functions referred to in items 4 and 5.

2.3 PORTFOLIO LEC CALCULATOR: 10% COMPLETE

In meetings with Field and others, we have discussed the algorithm required to perform a probabilistic portfolio risk calculation, but coding and testing has not yet begun. A single-site LEC calculator has been completed in collaboration with a USGS programmer, but this tool is inappropriate to the present task. It can be used to estimate the sensitivity of loss at a single point to branches of the hazard logic tree, but not societal risk.

2.4 CASUALTY RATE VULNERABILITY FUNCTIONS: DONE, PUBLISHED

In the 2008-2009 work for USGS and SCEC, we created the (mean) seismic vulnerability functions called for in item 4. In Porter (2009b) we created and published a set of mean seismic vulnerability functions for human deaths and injuries. The work on fatalities was performed largely for USGS, but is relevant to the SCEC 2008-2009 work as well, along with the seismic vulnerability functions for nonfatal injuries. These seismic vulnerability functions essentially extract functional relationships that are implicit in the HAZUS-MH model; see especially Kircher and Whitman (1997) and NIBS and FEMA (2003). They honor all the HAZUS-MH data and methods, while avoiding the iteration required by the structural analysis component of the method, and allow for risk analysis outside of HAZUS-MH. A sample seismic vulnerability function for mean indoor fatality rate is shown in Figure 1. It shows mean fatality rate for a high-code W1 (woodframe building < 5000 square feet), western US site, NEHRP site soil classification D, medium-duration shaking (magnitude 6.5 ≤ M < 7.5), at a distance 15 km ≤ R < 30 km. See Porter (2009b) for derivation of the curve and a sample calculation at the point highlighted by an open circle in the figure.

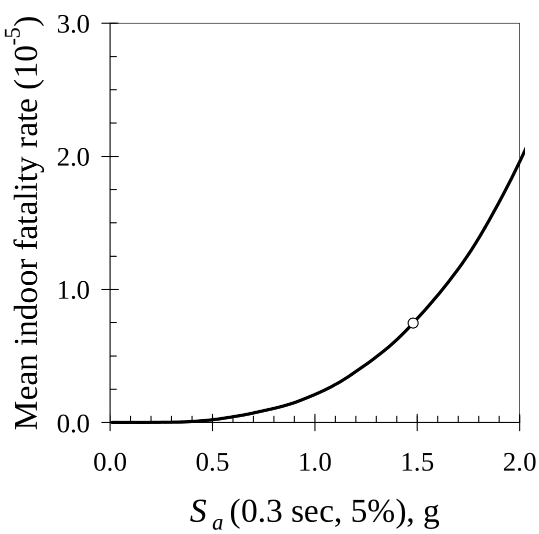

Figure 1. Sample vulnerability function

2.5 REPAIR COST VULNERABILITY FUNCTIONS: DONE, PUBLISHED

In work specifically for SCEC, we created mean seismic vulnerability functions called for in item 5: repair cost as a fraction of replacement cost (new) for each building type in the portfolio. In Porter (2009c) we created and published a set of mean seismic vulnerability functions for repair cost as a fraction of replacement cost (new) for each structure type treated by HAZUS-MH. The work has been peer reviewed and duplicated by several other engineers. A sample of the resulting seismic vulnerability functions is shown in Figure 2. It depicts the mean damage factor (repair cost divided by replacement cost, new) of a W1 building, high-code design level, single-family dwelling (RES1) occupancy, NEHRP site soil classification D, medium-duration shaking (magnitude $6.5 \leq M < 7.5$), at a distance of 15 km $\leq R < 30$ km. Dot shows results of a sample calculation in Porter (2009c).

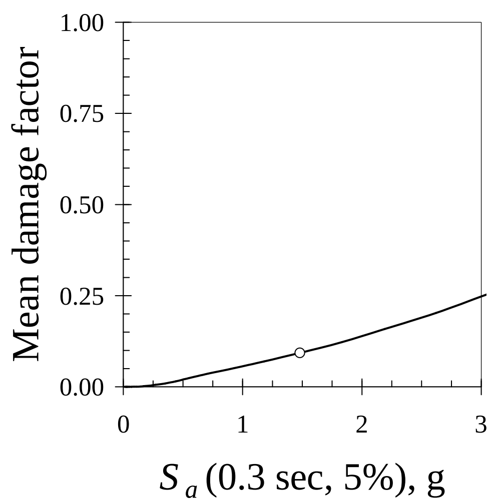

Figure 2. Sample repair-cost seismic vulnerability function

2.6 PROBABILISTIC REPAIR-COST VULNERABILITY: DONE, IN PRESS

This work amounts to evaluating a standard deviation or coefficient of variation of repair cost for each structure type at each of many intensity levels. Together with the (mean) repair-cost seismic vulnerability functions discussed above, and an assumption of the conditional probability distribution of repair cost conditioned on structure type and intensity. The work is documented in a manuscript that has been accepted for publication in *Earthquake Spectra*, and which will be included in our 2009-2010 progress report (Porter ND). Sample results are illustrated in Figure 3, which shows that coefficient of variation of repair-cost damage factor tends to decrease with increasing mean damage factor, while the standard deviation tends to increase with mean damage factor.

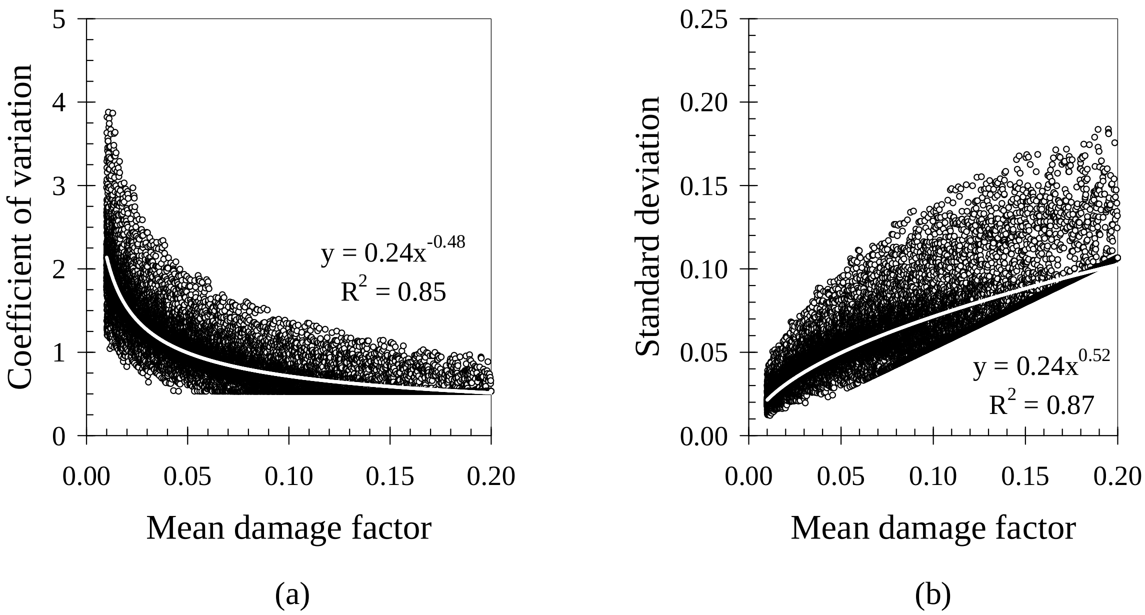

Figure 3. Trends in damage-factor uncertainty versus mean damage factor

2.7 PROBABILISTIC CASUALTY-RATE VULNERABILITY: NOT BEGUN

This work amounts to evaluating a standard deviation or coefficient of variation of casualty rate for each injury severity level and each structure type at each of many intensity levels. Together with the (mean) casualty-rate seismic vulnerability functions discussed above, and an assumption of the conditional probability distribution of casualty rate conditioned on structure type and intensity. The work has not yet begun.

2.8 SENSITIVITY METHODOLOGY: DONE, PUBLISHED

We will use tornado-diagram analysis to assess the sensitivity of societal loss to branches in the hazard logic tree. The method appears to have been developed for use in decision analysis. Described in Howard (1988), it is a method to test and depict the sensitivity of a scalar function to uncertainty in its arguments. In brief, one evaluates the function with all its arguments set to their expected value, except for one, which is set first to a lower bound, the function evaluated, and then the argument is set to its upper bound and the function evaluated again. The difference between the two results is a measure of the sensitivity of the function to the varied argument, and referred to as the swing of the function with respect to that argument. The process is repeated for all the other arguments, which are then sorted in order of decreasing swing. (The parameters already tested are set to their expected value in all the subsequent tests; i.e., only one parameter is varied at a time.) The results are plotted in a horizontal bar chart where the argument with the greatest swing is the topmost item on the y-axis of the bar chart, the argument with the second-largest swing beneath that, etc. Beside each argument is a bar: a thin rectangle with its left and right edges spanning from between the two values of the function at the two bounds. The x-axis depicts the value of the function. Since the arguments are arranged in from top down in order of decreasing swing, the resulting chart resembles a tornado in profile. The methodology has been applied to earthquake engineering problems, e.g., in Porter et al. (2002) or MMC (2005), the latter of which shows how to select the lower and upper bounds and combine the results to estimate the first several moments of the probability distribution of the function, using a method presented in Ching et al. (2003, 2008). Figure 4 shows a sample tornado diagram, from Porter et al. (2002). It depicts the sensitivity of building repair cost for a particular building to major uncertain variables in a performance-based earthquake engineering analysis. It shows that, for the particular building under consideration, building repair cost is most sensitive to the capacity of the individual building components to resist damage. This variable is estimated to be more important than the uncertainty in the maximum shaking intensity that the building is expected to experience in 50 years (denoted by Sa in the figure).

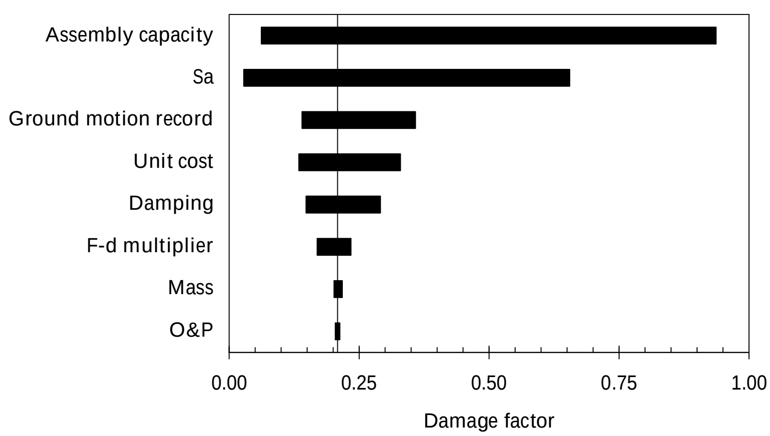

Figure 4. Sample tornado diagram

3 CONCLUSIONS

Tornado-diagram analysis (Howard 1988) will be used to test and depict the sensitivity of societal risk measures to branches in the hazard logic tree. The risk measures can be the expected annualized loss (EAL) in terms of human deaths or injuries, points on the loss exceedance curve (LEC) for human deaths or injuries such as the value with 2% exceedance probability in 50 years, or similar EAL or LEC measures of building repair cost. Tornado diagrams have been used in earthquake engineering before, such as to quantify the sensitivity of building repair cost to major uncertain variables in a performance-based earthquake engineering analysis (Porter et al. 2002) or to quantify the first several moments in the probability distribution of societal benefits resulting from FEMA's multihazard risk mitigation efforts between 1993 and 2003 (MMC 2005). The latter uses a quadrature method presented by Ching et al. (2003, 2008).

To carry out the analysis will require an extension of the OpenRisk software (Porter and Scawthorn 2007, 2009) begun for SCEC and USGS in collaboration with Field and others. A portfolio EAL calculator is currently capable of estimating sensitivity of portfolio EAL to branches in the logic tree, but it needs to be modified to accept new seismic vulnerability functions. We are discussing those modifications with Field, with the expectation that a USGS or SCEC programmer will perform the modifications. We have begun the design of a portfolio LEC calculator.

The analysis will also require mean and probabilistic seismic vulnerability functions of casualties and building repair costs. These have been completed and have either been published (Porter 2009b, c) or accepted for publication (Porter ND), with the exception of probabilistic seismic vulnerability functions for casualties, which have not yet begun development.

Finally the analysis requires an estimated portfolio of assets exposed to seismic risk: number of building occupants by time of day, building square footage, building replacement cost, and contents replacement cost, by geographic area (e.g., census tract), occupancy classification (e.g., single-family dwelling), and structure type (e.g., small woodframe dwelling, pre-code construction). This inventory work has been completed for California, and is also available for the rest of the United States (Porter 2009a).

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