2011 SCEC Annual Report for Project #11110:
HAZUS® Probabilistic Loss Estimates for California:
Development of a Library of County-level Risk Estimates

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The goal of this project was to build a library of county-level probabilistic loss estimates for California, using a uniform analysis platform (FEMA's HAZUS®MH MR-4) with various representations of input seismic hazard data. Probabilistic loss estimates produced by HAZUS® include building damage-related economic loss and casualties, and can be generated on an annualized basis or for specific return periods. Having such a compilation would allow an assessment of the impact on loss from the changes to the underlying seismic hazard models as they evolve.

This work would not have been possible without the generous cooperation of Ned Field and Peter Powers of the USGS, and Kevin Milner of SCEC.

Summary of HAZUS® Analyses

The current "library" of loss estimates (developed under 2010[1] and 2011 SCEC funding) includes return period losses for the 100, 250, 500, 750, 1000,1500, 2000 and 2500 year return periods, and annualized loss results for all 58 California counties, for 16 different representations of the input seismic hazard data, evaluating:

- 2002 and 2008 National Seismic Hazard Map (NSHM) data as incorporated into HAZUS® vs. Uniform California Earthquake Rupture Forecast, Version 2 (UCERF2) ground motions estimated using OpenSHA (Field et al., 2003)
- Ground motion amplification related to soil conditions explicitly considered as part of the attenuation relationship vs. using NEHRP amplification factors within HAZUS®, tested using both geology-based shear wave velocity (Vs30) data (Wills & Clahan, 2006) and shear wave velocity data derived from topographic slope (Wald & Allen, 2007)
- Use of ground motions determined using the three NGA relationships utilized in the 2008 NSHMs, equally weighted (Boore & Atkinson, 2008; Campbell & Bozorgnia, 2008; Chiou & Youngs, 2008) vs. ground motions also including the 4th NGA relationship (Abrahamson & Silva, 2008)
- Time dependency
- Grid cell size (0.1 degree vs. 0.05 degrees)

The parameters of each of the 16 HAZUS® runs are delineated in **Table 1**, along with the estimated annualized building damage, annualized total economic loss (defined in HAZUS® to include building damage, content and commercial inventory damage, and building damage-related income losses, such as lost wages and income, as well as rent and relocation costs), and annualized loss ratio (dollar loss per million dollars of exposure).

[1] SCEC Project #10056 titled "HAZUS® Probabilistic Loss Estimates for California: Comparison of 2002 and 2008 National Seismic Hazard Map Data & UCERF2 Data"

Table 1: Summary of HAZUS® Annualized Loss Results for California

Run #	Hazard Data Source	Time Dependence	Soil Data	Grid Cell Size (degrees)	Annualized Building Damage ($1,000)	Total Annualized Loss ($1,000)	Annualized Loss Ratio ("AELR"), $/million$
1	2002 USGS NSHM data (provided with HAZUS®)	Time Independent	Uniform soil conditions assumed (NEHRP D), applied within HAZUS®	0.1	2,528,932	3,919,137	1,440.20
2	2008 USGS NSHM data (provided with HAZUS®), 3 NGAs	Time Independent	No soil amplification (equivalent to NEHRP B)	0.1	1,341,385	2,057,960	756.3
3	2008 USGS NSHM data (provided with HAZUS®), 3 NGAs	Time Independent	Uniform soil conditions assumed (NEHRP D), applied within HAZUS®	0.1	1,990,703	3,092,901	1,136.60
4	2008 USGS NSHM data (provided with HAZUS®), 3 NGAs	Time Independent	Wills (2006) soils data, applied within HAZUS®	0.1	1,923,933	2,974,601	1,093.10
5	2008 USGS NSHM data (provided with HAZUS®), 3 NGAs	Time Independent	Wald & Allen (2007) vs30 soil data, applied within HAZUS®	0.1	1,958,935	3,029,674	1,113.40
6	OpenSHA NSHMP benchmark (NSHMP08 relationship, 3 NGAs)	Time Independent	No soil amplification (equivalent to NEHRP B)	0.1	1,242,348	1,909,983	701.9
7	OpenSHA UCERF2, 3 NGAs	Time Independent	No soil amplification (equivalent to NEHRP B)	0.1	1,190,705	1,830,841	672.8
8	OpenSHA UCERF2, 3 NGAs	Time Independent	Wills (2006) soil data, applied within HAZUS®	0.1	1,734,939	2,690,734	988.8
9	OpenSHA UCERF2, 3 NGAs	Time Independent	Wald & Allen (2007) vs30 soil data, applied within HAZUS®	0.1	1,767,158	2,741,233	1,007.40
10	OpenSHA UCERF2, 3 NGAs	Time Independent	Wills (2006) soil considered within OpenSHA	0.1	1,688,918	2,612,464	960.1
11	OpenSHA UCERF2, 3 NGAs	Time Independent	Wald & Allen (2007) vs30 soil considered within OpenSHA	0.1	1,764,096	2,729,798	1,003.20
12	OpenSHA UCERF2, 4 NGAs	Time Independent	Wills (2006) soil considered within OpenSHA	0.1	1,755,912	2,713,221	997.1
13	OpenSHA UCERF2, 4 NGAs	Time Independent	Wills (2006) soil considered within OpenSHA	0.05	1,795,057	2,773,325	1,019.20
14	OpenSHA UCERF2, 3 NGAs	Time Dependent	Wills (2006) soil considered within OpenSHA	0.1	1,673,666	2,589,110	951.5
15	OpenSHA UCERF2, 4 NGAs	Time Dependent	Wills (2006) soil considered within OpenSHA	0.1	1,742,194	2,692,493	989.5
16	OpenSHA UCERF2, 4 NGAs	Time Dependent	Wills (2006) soil considered within OpenSHA	0.05	1,780,073	2,750,559	1,010.80

Observations that may be drawn as a result of these analyses include:

- Annualized loss estimates for California developed using the 2008 NSHM data provided with HAZUS® are 21% *lower* than those estimated using the equivalent 2002 NSHM data (Run 1 vs. 3).
- Annualized loss estimates for California generated using the NSHMP08 relationships coded within OpenSHA are within 8% of those generated with the NSHMP08 data provided with the HAZUS® software (Run 2 vs. 6).
- Annualized loss results generated using OpenSHA's UCERF2 formulation are within 4% of the NSHMP08 OpenSHA results (Run 6 vs. 7).
- A decrease in analysis grid cell size from 0.1 degree to 0.05 degree results in an approximately 2% *increase* in annualized loss statewide, for both time independent (Run 12 vs. 13) and time dependent (Run 15 vs. 16) ground motions.
- Initial UCERF2 analysis runs utilized ground motions estimated using the same three NGA relationships as the 2008 National Seismic Hazard Maps, equally weighted (Boore & Atkinson, 2008; Campbell & Bozorgnia, 2008; Chiou & Youngs, 2008). The inclusion of the 4^{th} NGA relationship (Abrahamson & Silva, 2008) results in a 4% *increase* in annualized loss statewide (Run 10 vs. 12).
- For California, the use of Vs30 data derived from topographic slope (Wald & Allen, 2007) within the OpenSHA ground motion computations produces losses that are 4.5% *larger* than those estimates produced using geologically defined (Wills & Clahan, 2006) soil data (Run 10 vs. 11).
- Consideration of soil amplification within the NGA attenuation relationships rather than by applying NEHRP amplification factors within HAZUS® results in losses that are, on average, about 3% *lower* when using Wills soil data (Run 8 vs. 10), but are virtually identical when using Wald & Allen vs30 data (Run 9 vs. 11).
- Statewide annualized loss estimates generated using time dependent ground motions are only about 1% lower than loss estimates generated with time independent ground motions (both with 3 NGAs; Run 10 vs. 14 and with 4 NGAs; Run 12 vs. 15). However, there is significantly more variation at the County level; time dependent losses are at least 5% less than time independent losses in Mendocino, San Benito, San Mateo, Santa Barbara and Ventura Counties, and at least 5% greater than time independent losses in Riverside, Alameda and Sonoma Counties, with the largest difference (13%) in Sonoma County. The difference between time independent and time dependent building damage estimates is presented by County in **Figure 1**. On the figure, positive percentage values indicate that the time independent losses exceed time dependent losses, and negative values mean that the time dependent losses are greater.

Based on the lessons learned in the current analyses, the following guidance is offered for future probabilistic loss assessment using HAZUS®:

1) Grid cell sizes of 0.1 degree likely provide sufficient resolution. Users should weigh the value of refinement on the order of 2% relative to the additional processing time and effort required to move to a 0.05 degree grid cell size.

2) Within California, the use of the statewide standard Wills & Clahan (2006) soil data is recommended for use in probabilistic loss assessments with HAZUS®; ground motion amplification should be addressed within the attenuation relationships (e.g., within OpenSHA), rather than by using amplification multipliers within HAZUS®. Outside of California, Wald & Allen (2007) Vs30 data are the best-available soil data resource, and should be used similarly.

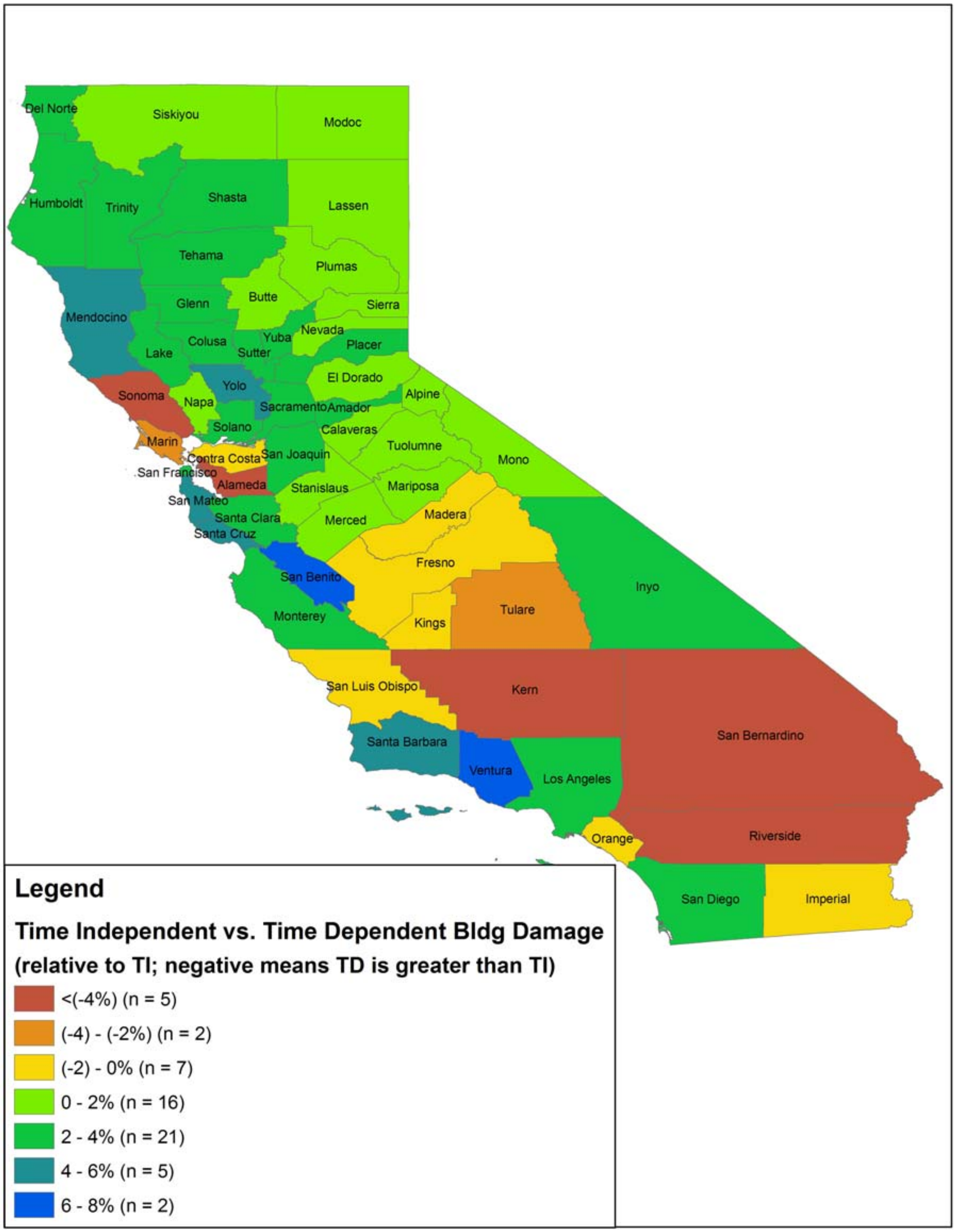

Figure 1: Difference between HAZUS® Annualized County-Level Building Damage Estimates for Time-Independent and Time-Dependent Hazard

This study's results compare reasonably well with the California Geological Survey's recently published annualized loss estimates. Their analysis utilized the USGS models developed for the 2008 National Seismic Hazard Map Update, including use of the three NGA relationships and site-specific Vs30 values based on Wills & Clahan (2006), on a 0.05 degree grid. Their estimated annualized statewide loss totals $2.8 billion (Chen et al., 2011), which is within about 7% of the closest equivalent in this study (Run 10, $2.6 billion). These numbers agree reasonable well, given that slight model implementation differences (e.g., NSHMP08 vs. UCERF2) can result in differences on the order of 4%, and differences in grid cell size (CGS 0.05 degree grid, current study 0.1 degree grid) can account for an additional 2% difference.

Future Directions

Proposed future efforts include further evaluation of loss variation related to selection of ground motion attenuation relationship (i.e., the four Next Generation Attenuation (NGA) relationships); analyses have been proposed under 2012 funding that would allow the comparison of losses generated using each NGA relationship individually, relative to the results from their weighted average, for both time dependent and time independent hazard data.

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