NEAR-REAL-TIME LOSS ESTIMATION USING *HAZUS* AND *SHAKEMAP* DATA

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Introduction

This paper describes real-time damage and loss estimation using the *HAZUS* earthquake loss estimation technology and *ShakeMap* data, and provides an example comparison of predicted and observed losses for the 1994 Northridge earthquake.

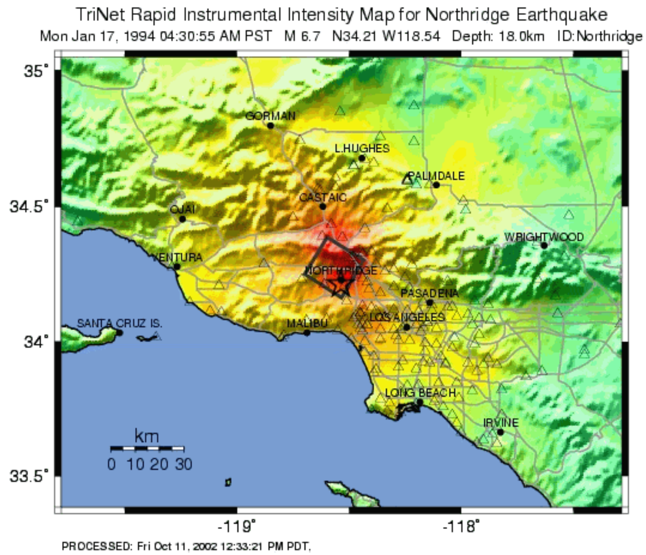
HAZUS [NIBS, 1999, Kircher et al., 1997a/1997b, Whitman et al., 1997] is the standardized earthquake loss estimation methodology developed by the National Institute of Building Sciences (NIBS) for the United States Federal Emergency Management Agency (FEMA). *HAZUS* was originally developed to assist emergency response planners to "provide *local, state and regional officials* with the tools necessary to *plan and stimulate efforts to reduce risk* from earthquakes and to *prepare for emergency response and recovery* from an earthquake."

HAZUS can also be used to make regional estimates of damage and loss following and earthquake using ground motion, *ShakeMap,* data provided by the United States Geological Survey (USGS) as part of Tri-Net in Southern California [Wald et al., 1999] or by other regional strong-motion instrumentation networks.

ShakeMaps

ShakeMaps are produced immediately following an earthquake in California (and certain other high-seismic regions of the US) and made available via the Internet. *ShakeMaps* are based on instrumental measurements of ground shaking (when instrumental records are available) and provide a more accurate and certain description of seismic demand. Since even the most extensive set of strong-motion instruments is still less than one station per census tract, on average, *ShakeMaps* have limited accuracy at the census tract, or smaller area, level. Nonetheless, they are an improvement over estimates of ground shaking based solely on predictive (magnitude-distance) equations that do not capture actual patterns and trends in the propagation of seismic waves.

Figure 1 is a *ShakeMap* of instrumental intensity for the 1994 Northridge earthquake showing, qualitatively, areas of stronger and weaker ground shaking. This map is a useful tool for rapidly identifying areas that would be expected to be hardest hit by the earthquake (e.g., areas shown in shown in orange and red), but does not provide quantitative estimates of damage and loss (in terms of economic impacts, casualties, etc.). *HAZUS* may be used to transform the qualitative information of *ShakeMaps* into quantitative estimates of damage and loss.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. *ShakeMap* of instrumental intensity of the 1994 Northridge earthquake.

Comparison of Losses – 1994 Northridge Earthquake

Figure 2 shows the large *HAZUS* study region used to estimate losses for the 1994 Northridge earthquake that includes all 1,652 census tracts of Los Angeles County, and 743 census tracts of affected areas of neighboring counties.

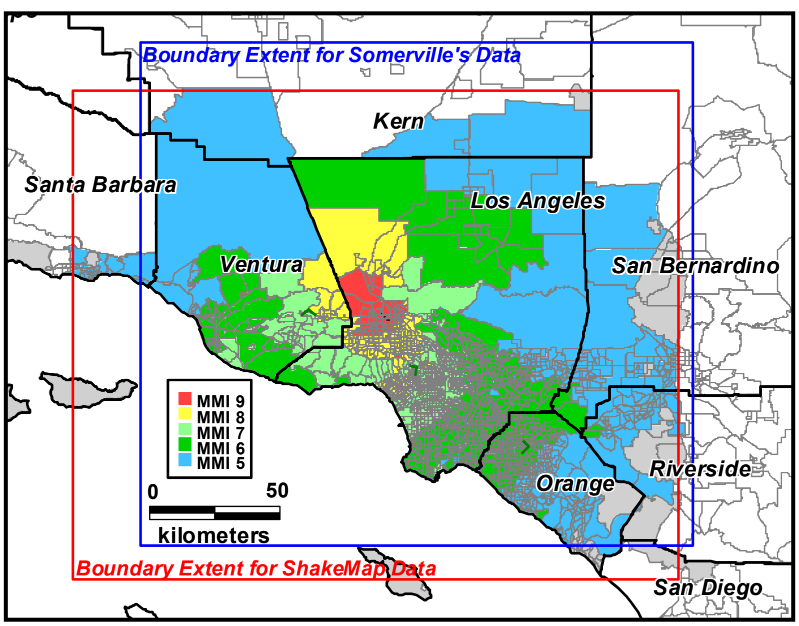


Figure 2. 1994 Northridge earthquake study region.

The total study region was subdivided into MMI study regions based on instrumental MMI of the *ShakeMap* (e.g., MMI 8 study region includes census tracts with instrumental MMI greater than or equal to 7.5 and less than 8.5). Figure 2 shows county boundaries (with bold black lines) and census tract boundaries (with gray lines) and MMI study regions (by colored areas) and the approximate extent of ground shaking data available from *ShakeMaps* and maps by Somerville.

Inventory and Population Data

With certain modifications, default building inventory and population data provided with *HAZUS* software were used in the estimation of building damage and losses in the study region. Table 1 summarizes exposure, population and other key data for the study region.

Table 1. Summary of 1994 Northridge earthquake study region data

Study Region	ShakeMap MMI	Census Tracts	Area [km2]	Exposure [x$1,000]	Exposure Fraction	Population	Households
MMI5	4.5 <= MMI < 5.5	460	12,179.9	$148,305,125	21.7%	2,854,993	952,001
MMI6	5.5 <= MMI < 6.5	989	6,099.0	$267,470,554	39.1%	5,439,665	1,747,859
MMI7	6.5 <= MMI < 7.5	537	2,150.8	$150,502,073	22.0%	2,853,539	952,798
MMI8	7.5 <= MMI < 8.5	308	1,557.2	$94,025,726	13.8%	1,513,834	602,903
MMI9	8.5 <= MMI	101	414.4	$23,467,590	3.4%	476,880	153,368
All		2,395	22,401	$683,771,068		13,138,911	4,408,929

Earthquake Ground Shaking Data

ShakeMap data includes contour maps of peak ground acceleration (PGA), peak ground velocity (PGV) and spectral response at 0.3-second and 1.0-second periods. These data are currently developed based on maximum (of the two horizontal directions of recorded) ground shaking. The predictive theory used by *HAZUS* to estimate hazard is based on the "random" direction of ground shaking (i.e., attenuation functions regressed both directions of recorded horizontal shaking as the same data set). To better match theory, 75% of maximum 0.3-second spectral response and 80% of maximum 1.0-second spectral response were used to approximate "mean" *ShakeMap* horizontal ground shaking response. These fractions are typical of the ratio of random to maximum horizontal ground shaking of empirical-based predictive theory.

An additional set of 1994 Northridge ground motion data, previously developed from instrumental records by Somerville for the SAC Steel Project [SAC Joint Venture, 1995], were also available and used for comparison with *ShakeMap* data. Finally, the hazard module of *HAZUS* was run for a magnitude M6.9 event on the Northridge fault to produce a fourth set of ground motion data. In this case, the theory of *Project 97* (i.e., USGS project that developed seismic hazard maps for the United States) was used to develop ground motion data including site/soil effects.

Ground motion parameters of each of the four data sets were associated with the centroid of each census tract and average values of these parameters were calculated for each MMI study region to evaluate trends in the ground shaking. Figure 3 shows trends in average 0.3-second spectral response plotted as a function of average centroidal distance form fault rupture for each set of ground motion data. As expected, each set of ground motion data show the same trend of less shaking with increase in distance form fault rupture. The trend in Somerville data is similar to the trend in mean *ShakeMap* data, which is expected since both represent "random" horizontal ground shaking. However, values of Somerville data and *ShakeMap* data are typically different any given census tract.

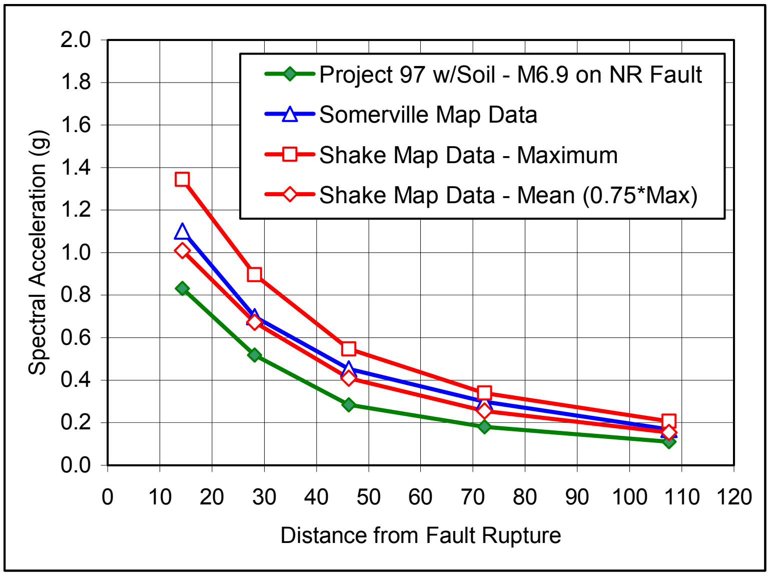


Figure 3. Trends in average values of ground shaking data for the 1994 Northridge earthquake.

Although there is considerably uncertainty in *ShakeMa*p data for any given census tract level, the value of using *ShakeMap* data is clear when such is compared with ground motion predicted by the magnitude-distance equations of *Project 97*. As shown by the trends in Figure 3, magnitude-distance equations considerably under-predict the level of ground shaking that actually occurred during the 1994 Northridge earthquake.

Observed Damage and Loss

The following types of damage and loss are used for comparison of estimated and observed earthquake consequences:

- Damage - Number of buildings with Extensive and Complete structural damage
- Social Losses:
  - Number of displaced households
  - Number of immediate fatalities (due to building-related causes)
  - Number of serious injuries (i.e., requiring immediate treatment or hospitalization)
- Economic Loss:

- Direct economic losses to residential buildings
- Direct economic losses to commercial buildings
- Direct economic losses to all buildings.

The choice of these parameters as the "metrics" for comparison of damage and loss values is influenced largely by the quality and availability (or lack thereof) of observed data.

Comprehensive data on building damage does not exist. Of the approximate 3 million buildings in the study region, only about 100,000 were surveyed as part of post-earthquake safety inspections. The results of these inspections provide "tagging" data indicating various degrees of damage, primarily to the structural system. As documented by California's Office of Emergency Services [OES, 1995], 2,657 buildings were assigned a "Red Tag" (Unsafe – extreme hazard, may collapse) and 10,505 buildings were assigned a 'Yellow Tag" (Limited Entry – dangerous condition believed to be present). Arguably, the sum of these two tagging categories, 13,162 buildings, represents buildings with Extensive or Complete structural damage.

The number of displaced households, 11,088, are well documented and traceable to Red Cross data [OES, 1997]. While the official earthquake death toll is 60, only 26 died as a result of building-related causes [Table 5-9, OES, 1995]. Other causes of deaths include trauma due to road accidents and medical-related deaths such as heart failure. The number of serious injuries requiring hospitalization, 1,044, are also well documented and traceable to Red Cross data [Table 7-1, EERI, 1995].

Total direct economic loss of $25.7 billion was paid by government and private (e.g., insurance) sources for 1994 Northridge earthquake recovery and reconstruction [Table 6-1, Comerio et al., 1996]. Of this total amount, $12.7 billion is associated with residential buildings, $4.9 billion is associated with commercial buildings and $7.2 billion is associated with transportation [Table 6-2, Comerio et al., 1996]. Assuming that all non-transportation funds are building related, total direct economic loss to buildings is about $18.5 billion (i.e., $25.7 billion - $7.1 billion). These losses represent funds actually paid (or allocated) by government agencies or insurance companies, and do not include losses that may have been incurred by homeowners and businesses who did not have insurance (or had losses that were below insurance deductibles) or who did not qualify for governmental assistance.

Results

Table 2 provides a summary comparison of key results of analyses of the total study region using ground shaking of maximum *ShakeMaps*, mean *ShakeMaps* (i.e., fraction of maximum *ShakeMap* data) and Somerville maps, respectively. In general, results of maximum and mean *ShakeMap* data provide bounding values of observed damage and loss. Casualties are the exception, immediate deaths are over-predicted (by a factor of about 2) and serious injuries are under-predicted (by about a factor of 2). With the exception of serious injuries, *ShakeMaps* based on the maximum component of horizontal ground shaking (i.e., current *ShakeMap* methods) provide reasonably accurate and modestly conservative estimates of damage and loss observed in the 1994 Northridge earthquake.

Table 2. Summary and comparison of damage and losses estimated using *ShakeMap* and Somerville ground motion data with observed damage and losses – 1994 Northridge earthquake.

HAZUS Earthquake Damage or Loss Parameter	Ground Shaking Data Set			Observed Damage or Loss
	ShakeMap		Somerville	
	Maximum	Mean		
Structural Damage (Number of Buildings)				
Extensive or Complete	14,748	5,587	7,088	13,162
Social Losses				
Displaced Households	16,602	6,782	6,646	11,088
Immediate Deaths	91	38	40	26
Hospitalized Injuries	625	285	328	1,044
Direct Economic Building Losses (Dollars in Millions)				
Residential Buildings	$14,095	$7,888	$9,984	$12,700
Commercial Buildings	$7,151	$4,445	$4,987	$4,900
All Buildings	$23,334	$13,622	$16,555	$18,500

Conclusion

HAZUS is a comprehensive GIS-based technology for estimating earthquake damage and loss. Intended primarily for use by state, regional and community governments, *HAZUS* evaluates a wide range of losses resulting from scenario earthquakes to provide a basis for decisions concerning preparedness and disaster response planning and to stimulate and assist planning for mitigation to reduce potential future losses.

While originally envisioned as a pre-event planning tool, *HAZUS Earthquake* has been enhanced to facilitate rapid post-event evaluation of damage and loss using *ShakeMap* data. These evaluations of damage and loss will assist post-earthquake response and recovery efforts by emergency services agencies. Other enhancements to the original technology include the Advanced Engineering Building Module (AEBM) [NIBS, 2002]. Expert users can input "building-specific" damage and loss functions to the AEBM and use the results to evaluate the benefits of improving building performance (e.g., through seismic rehabilitation). These two enhancements are examples of ongoing improvements to *HAZUS* to better address user needs.

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