ESTIMATING THE UNCERTAINTY OF PORTFOLIO LOSSES USING NEW SHAKEMAP FOOTPRINT UNCERTAINTY MAPS

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ABSTRACT:

The uncertainty of economic or insured losses from large earthquakes can have many sources. The impact of the ground motion and loss estimation uncertainty to the portfolio loss uncertainty has been studied previously (Molas, et. al, 2006). Recently, the ground motion uncertainty corresponding to the ShakeMap ground motion maps have been estimated and published by CISN. ShakeMap ground motion estimates at or very close to recording stations have very small or zero uncertainty, while those farther away have uncertainty estimates that may exceed the standard deviations of the attenuation relationships, if the source parameters are not known. This study utilizes the spatially varying standard deviations of the ground motion estimates published with the ShakeMap.

The 1994 Northridge earthquake in Southern California in the United States is presented as a case study. Monte Carlo simulations are applied around the median ground motion estimates based on a ShakeMap footprint. The simulation accounts for the inter- and intra-event components of the variance of the predicted ground motion. The intra-event component of the variance is considered to be spatial correlated to generate correlated random fields that realistically represent the ground motion distribution between sites. The results of this study can be used to gain a probabilistic perspective of the range of possible loss values for a scenario event, which is very useful for the management of risk.

KEYWORDS: Ground motion simulation, spatial correlation, Monte Carlo simulation, loss uncertainty

1. INTRODUCTION

A large earthquake may occur near downtown Los Angeles, not unlike the recent Magnitude 5.4 event in the Greater los Angeles Area last July 29, 2008, but with a larger Magnitude. If this event occurs, civil authorities will trying to assess the extent and amplitude of damage and its impact to the local citizens and businesses immediately after the event. An event that causes significant damage also initiates urgent activity in the financial and financial community where risk managers would try to assess the situation and its impact to the financial exposure of their company. Both of these situations need an estimate of the damage and losses due to the event, including the geographic distribution and uncertainty.

This study proposes a methodology for estimating the distribution and uncertainty of large events that utilizes on information published as part of the ShakeMap products (Wald, et al., 1999). The loss and uncertainty estimates can be used for different levels aggregation from a single location to a portfolio of locations, typical of insurance companies. The methodology is a modification of the spatially correlated simulation methodology given by Molas, et al. (2005, 2006). While the previous studies assume a uniform variability of the ground motion value across the footprint, this paper uses the uncertainty estimates provided by ShakeMap for recent events and some older, but important events.

Using uniform variability of the ground motion is used when there is no information available regarding the ground motions in addition to those predicted by the attenuation relationships. An example of this is the prediction of ground motion from stochastic or scenario events, where the actual ground motion have not yet occurred. It may also be used for actual events where there are no known ground motion records.

In the case of recent historic events where a number of ground motion are recorded, the fact that the ground motion was recorded means that the uncertainty of the ground motion value at the recording site is very small relative to locations where there are no records. The uncertainty is not completely eliminated because of uncertainty in the recording process. While this case is limited to events that have uncertainty estimates published as part of the ShakeMap products published after an event, it is an important upgrade because it uses all available information to reduce the uncertainty of loss estimates. The reduction in uncertainty is certainly an important improvement in the risk manager's perspective.

2. METHODOLOGY

The uncertainty in the loss estimate of an event can have many sources. In this study, we consider the effects of the variability in the ground motion estimates and the subsequent loss estimates. Other sources of uncertainty, like the variability in the distribution of the building stock is not considered, that is, the building stock was assumed to be known (deterministic) and the type of structure is assumed to be uniform. However, the methodology can be easily applied to a portfolio of locations where the structure is known.

Figure 1 shows the schematic of the simulation process: from the simulation of the ground motion footprints to the simulation of the variability in the loss estimates. Three elements are needed to estimate the loss for any given location: 1) a hazard value, given in terms of ground motion in this paper; 2) hazard to loss ratio relationship, defined for typical structure configurations and includes uncertainty descriptions; and 3) the value of the structure at the location. The following sections discuss each element. However, a more detailed discussion can be found in Molas, et al (2006).

2.1 *Ground Motion Simulation*

The use of Monte Carlo simulation to estimate the variability of losses is not uncommon. However, the use of ordinary Monte Carlo simulation to generate a realization of the ground motion footprint is not appropriate because the generated simulated ground motion values are completely independent. The physical reality is that two locations that are very close to each other would have some level of dependence. This dependence or correlation is taken into account by the use of spatial correlated random fields in the simulation of the ground motion footprints.

To generate a spatially correlated random field, it is necessary to assume a correlation function between sites. The observed ground motion from a single event from two locations that are close together will have a higher correlation than two locations that are farther apart. If the separation distance is large enough, then the ground motion observations will be almost uncorrelated. The correlation function used in this study is given by:

$$Correlation = Exp\left(-\frac{1}{R} \cdot Distance \right) \tag{2.1}$$

where R is the correlation distance in kilometers. This study uses a correlation distance, R = 10 km. for observed ground motion. The choice of correlation distance is important because the resulting uncertainties of the losses are significantly affected by the correlation distance assumption (Molas, et al, 2006). The correlation function can then be easily converted into a variance-covariance matrix for a group of points that represent the ground motion footprint. The variance-covariance matrix is important in the simulation of spatially-correlated ground motion footprints. Note that the variance-covariance matrix is independent of the uncertainty of the ground motion of each location. The standard mathematical procedure to generate correlated random variables can be found in Ripley (1987) or Johnson (1987).

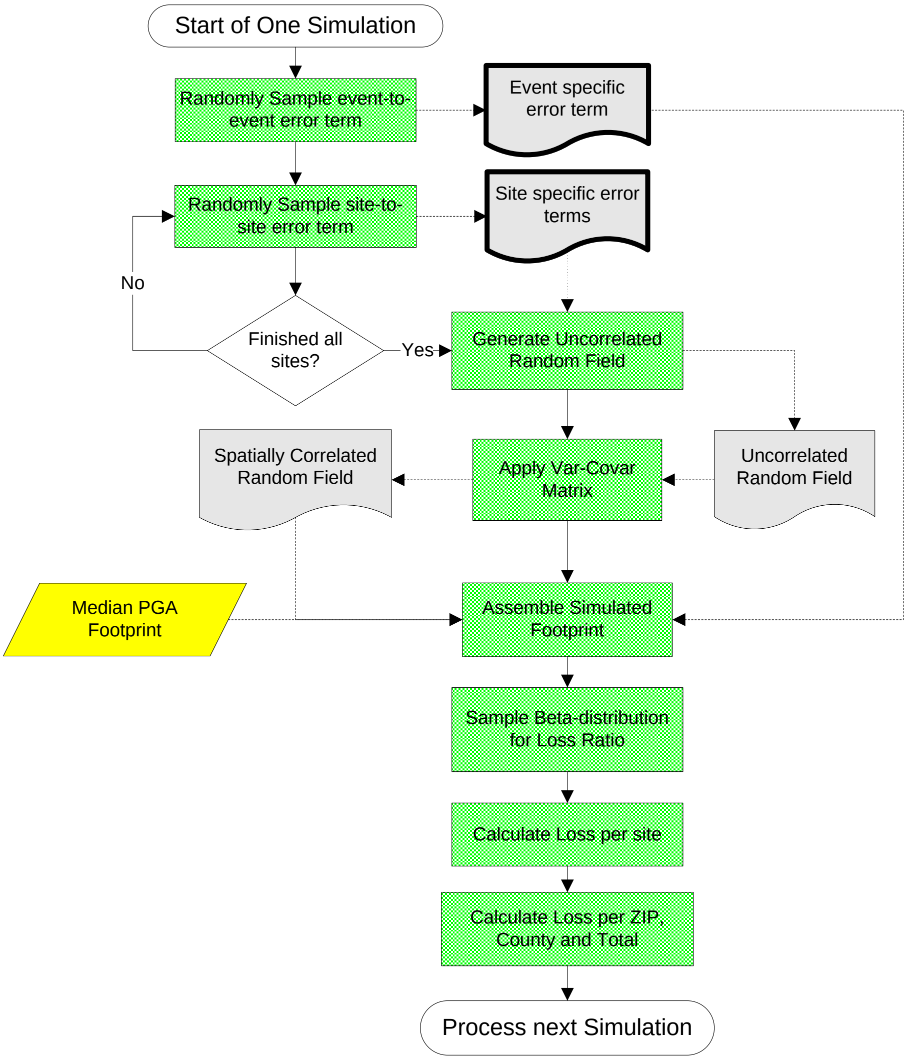

Figure 1: Procedure to generate one simulation of a stochastic PGA footprint and loss calculation

As described in Figure 1, the simulation of the spatially-correlated ground motion footprint is essentially a simulation of a spatially-correlated random error terms that represent the inter- and intra-event variability of the ground motion. The error terms have a mean of zero and variance associated with the particular median estaimte of the ground motion. For the case where no information of the ground motion exists, the variances of all points are assumed uniform. The paper by Lin, et al (2006) tries to establish the appropriate variance for locations that are at or near a recording site, where ground motion value is presumed to be known. The current ShakeMap website includes footprints whose uncertainty maps are evaluated (Figure 2). The uncertainty map is made up of multipliers to the nominal standard deviation of the ground motion hazard value at each point (Wald, D.J., personal communications). As a multiplier, it is easily adopted into the spatially-correlated random field algorithms because each location has an independent simulation that can use the modified standard deviation directly before applying the variance-covariance matrix to produce the correlated random field. The locations in the flowchart where the multipliers are applied are indicated by thick borders in Figure 1.

A value of 1.0 in the uncertainty map signifies no modification to the ground motion standard deviation and is applied to locations that are far from the recording stations and where the finite fault is modeled. The value can become more than 1.0 if the source is defined by the epicenter and magnitude only. The multiplier becomes very small for locations that are very near the recording sites.

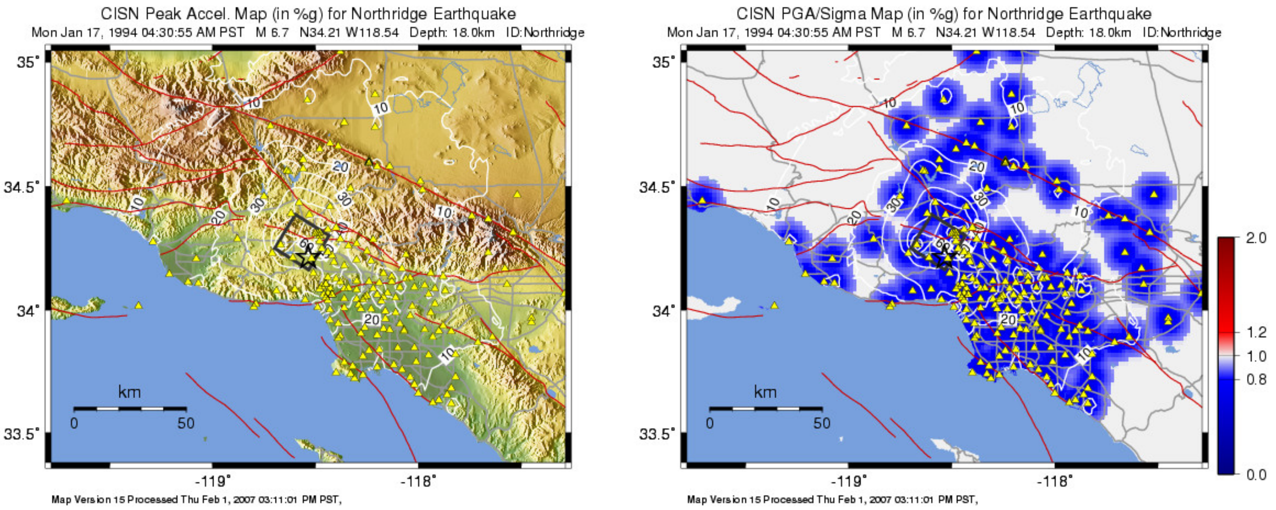

Figure 2: ShakeMap PGA and PGA uncertainty maps for the 1994 Northridge Earthquake in S. California (from the ShakeMap website)

2.2 *Loss Estimation Methodology*

The loss estimation methodology used in the previous paper (Molas, et al, 2006) is also applied here to isolate the effects of the change in the ground motion uncertainty estimates to the portfolio loss uncertainty. The exposure is assumed to be composed of typical residential buildings made with standard wood frame construction. The total value of the exposure in California is assumed to total $100 billion and distributed at 1-km grid points based on the USGS National Land Cover database, NLCD (Vogelmann, et al., 2001) at 30-m resolution and the RMS Industry Exposure database. The value of the total exposure is given for illustration purposes only and thus the loss values in the results should not be taken as actual expected loss values for the 1994 Northridge earthquake. However, the distribution of the exposure within California is representative of the actual exposure distribution.

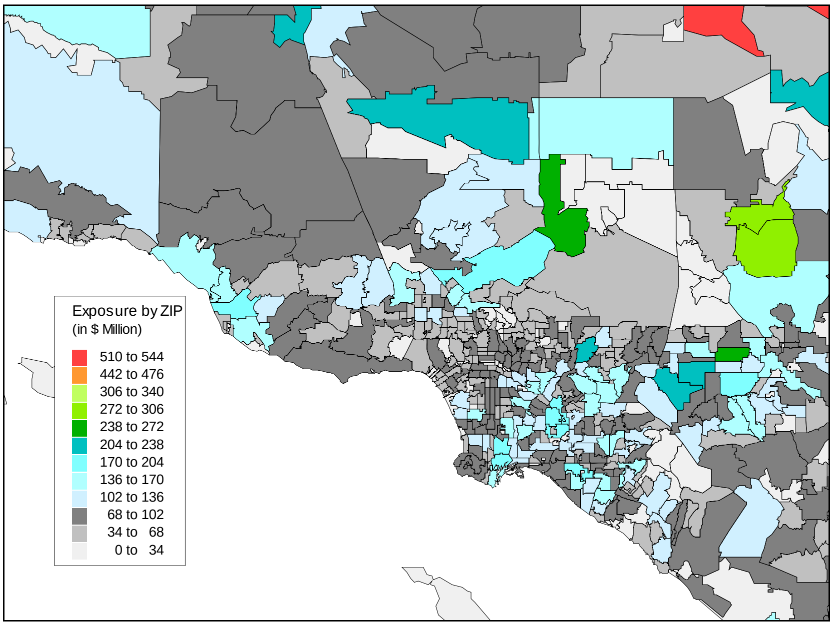

Figure 3: Map of exposure values for each postcode within the region of the 1994 Northridge Shakemap

Figure 3 shows the distribution of the study exposure in the region of the ShakeMap footprint. These are plotted at the ZIP code level. Comparing the positions of the recording stations from Figure 2, it is observed that there is a large number of recording stations around the areas of high exposures. This indicates that the loss simulations will be significantly affected by the use of smaller standard deviation values for the PGA. This is confirmed by plotting the exposure value of each grid point in the ShakeMap with respect to the closest distance of each grid point with respect to any recording station. Figure 4 shows the distribution of the exposure values for each grid point (left) and binned by distance ranges (right).

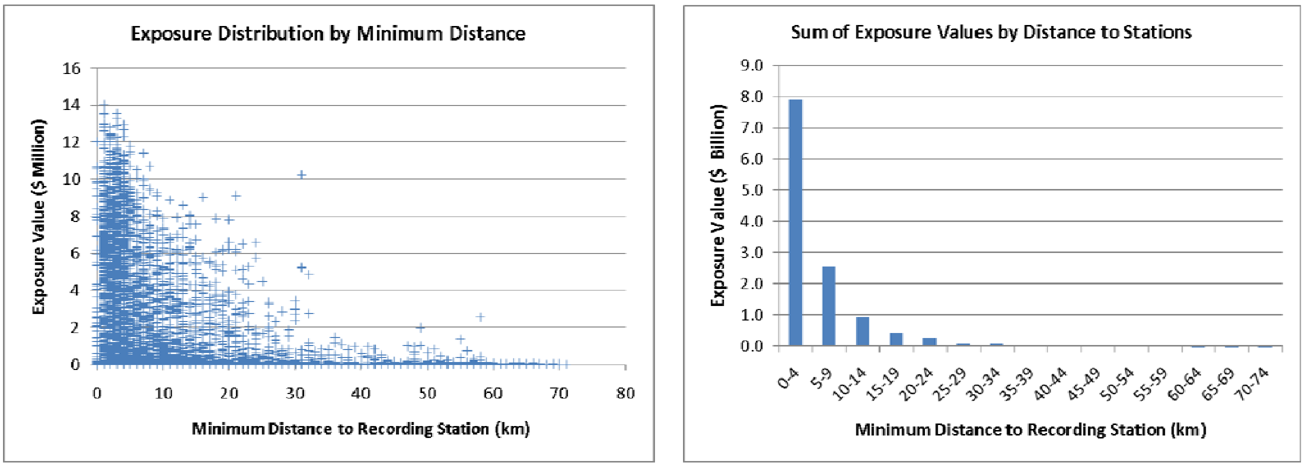

Figure 4: The plot on the left shows the distribution of the grid exposures with respect to the closest distance to a recording station. The plot on the right shows the sum of exposures with distance bins.

3. RESULTS AND DISCUSSION

Two analyses were performed using the methodology described above. The difference is in the application of the standard deviation modifiers provided by the ShakeMap websites for historical events. The first case uses unity as the multiplier for all grid points. This case is used when there are no records of the ground motion for the event and the hazard variability used is the one provided by the attenuation relationships is used. Since ShakeMaps normally uses ground motion records and intensity reports, this case is not likely to be used for the ShakeMap footprints. This case is more representative of stochastic or scenario events where the Magnitude and fault geometry are often defined and the ground motion attenuation models are used.

The second case is the application of the standard deviation (sigma) modifiers from the ShakeMap website for recent and important historical events. This case is representative of loss analyses performed quickly after a significant event, and will be useful for risk managers, especially for Catastrophe risk that are covered by financial markets thru securitization contracts. This section examines the effects of using better information, in terms of recorded ground motion, in the estimation of uncertainty for event losses. In this paper, the median footprints and uncertainty modifiers given in the ShakeMap website for the 1994 Northridge Earthquake in Southern California is used.

3.1 *Portfolio Loss*

Figure 5 shows the results of the simulations, a total of 2500 realizations consisting of 100 spatially-correlated ground motion footprint simulations and 25 loss ratio simulations for each grid point and footprint. As in the previous study, it can be seen that the variation due to the uncertainty in loss calculations are not as significant as the variability in the ground motion footprint. The dispersion of the losses in the vertical axis represents the simulations on the loss ratios. This part is not affected by the use of adjusted sigma values and the plot does not indicate any significant effect. However, comparing the results based on the simulation on the ground motion footprint indicates that the overall variability of the portfolio losses is significantly lower when the ShakeMap sigmas are used. This is also indicated by the mean and standard deviation of the portfolio loss due to the application of the modified sigmas provided by the ShakeMap website (Table 1). It shows the benefit of using the modified sigma in terms of a significantly reduced overall variability in the loss estimate.

Table 1. Portfolio loss estimates in terms of mean, standard deviation, and coefficient of variation, CV, for the case of a uniform ground motion standard deviation (sigma) and the adjusted given by ShakeMap

Case	Mean Loss	Standard Deviation	Coefficient of Variation, CV
Uniform Sigma	$287,118,811	$50,003,355	0.174
ShakeMap Sigma	$268,776,618	$30,547,206	0.114

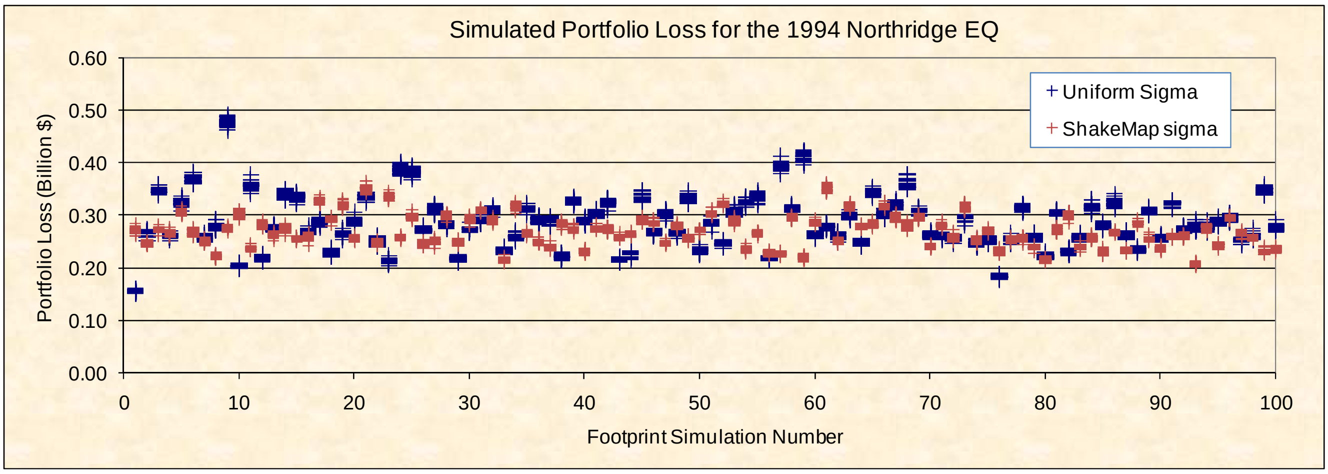

Figure 5: Distribution of portfolio loss estimates for each realization of the Monte Carlo simulation. The losses are plotted against the footprint simulation instances for the two cases.

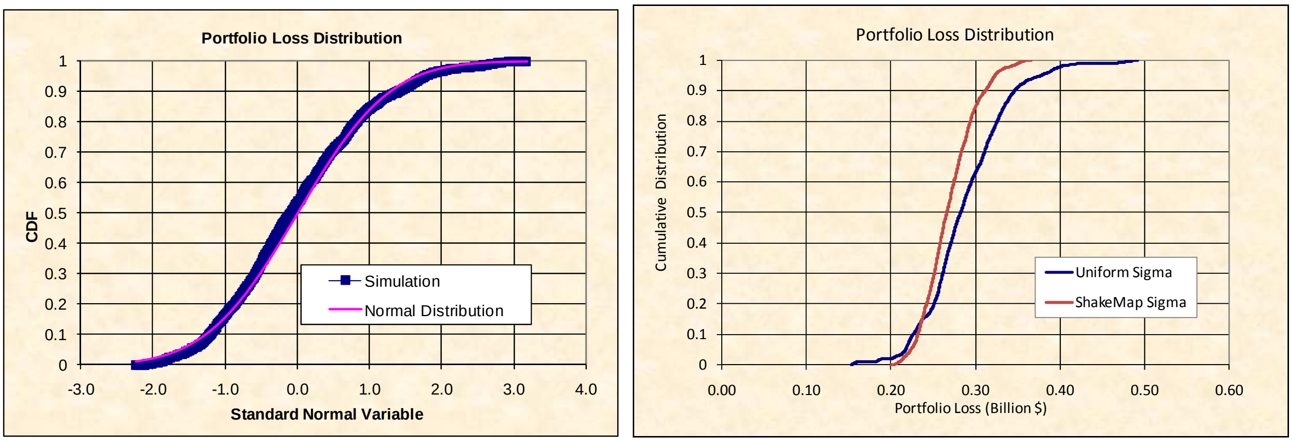

Figure 6: Comparison of the portfolio loss cumulative distribution to the normal distribution (left), and the case where a uniform sigma is used (right)

The probability distribution of the portfolio loss using the modified sigma from ShakeMap also compares well with the Normal Distribution (Figure 6.) Figure 6 also shows the comparison of the cumulative distributions between the two analysis cases. The decrease in the coefficient of variation is a significant benefit to the analysis of risk, especially when integrating the portfolio loss estimates into various risk management scenarios.

3.2 *Effect of Loss Aggregation Resolution*

The preceding section deals with the variability of the portfolio loss, but it is also interesting to look at the behavior of finer aggregation resolutions. For example, each county government will be interested in studying the loss variability within their own jurisdiction. Insurance and reinsurance companies may not have good location information for the policies that they cover, and have to rely on estimates of aggregate losses at different levels of resolution. As seen in the previous study, the loss CV increases as the size of the aggregation boundary decrease.

Table 2 shows the comparison of mean loss, standard deviation and CV for the counties affected by the ShakeMap footprint. Los Angeles County incurs the majority of the losses among the counties. Although some of the counties gets a higher mean loss by using the modified sigma from the ShakeMap, the reduction in CV is seen for all of the counties.

Table 2. County level loss estimates in terms of mean loss, standard deviation, and CV

	Uniform Sigma			ShakeMap Sigma		
County Name	**Mean Loss**	**Std. Dev**	**CV**	**Mean Loss**	**Std. Dev**	**CV**
LOS ANGELES	233.6	47.5	0.203	211.6	28.6	0.135
VENTURA	21.5	7.3	0.341	22.8	4.4	0.193
ORANGE	20.3	5.7	0.280	20.7	5.0	0.242
SAN BERNARDINO	7.3	2.7	0.375	8.6	2.5	0.286
RIVERSIDE	2.7	1.5	0.539	3.0	1.3	0.414
KERN	1.0	0.2	0.234	1.2	0.2	0.188
SANTA BARBARA	0.6	0.4	0.584	0.7	0.4	0.510
SAN DIEGO	0.1	0.1	1.103	0.2	0.2	0.985
SAN LUIS OBISPO	0.02	0.01	0.730	0.03	0.02	0.584

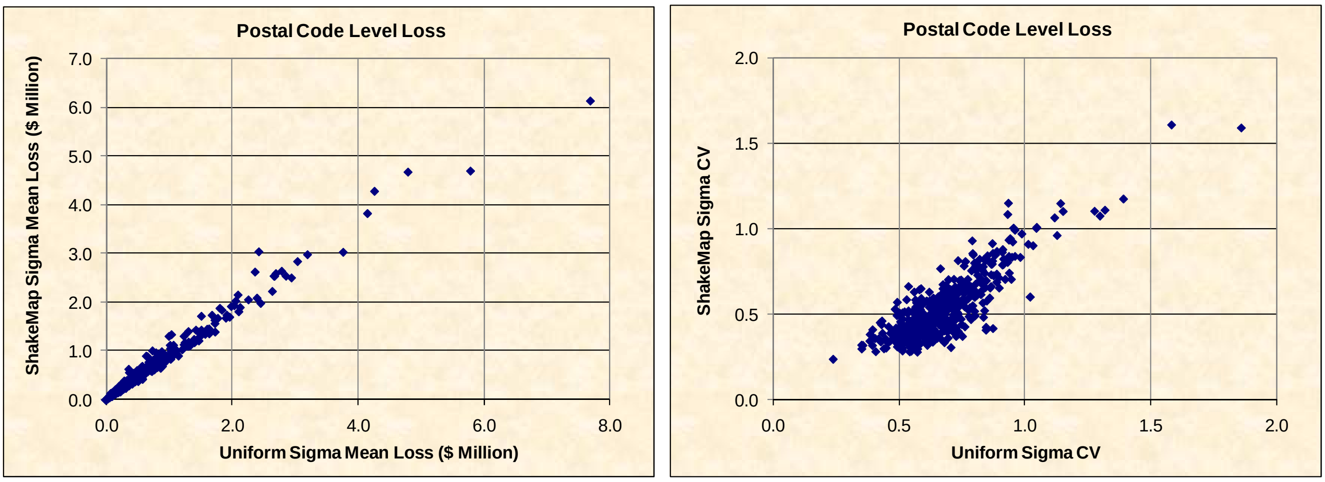

Figure 7: Comparison of the mean loss and CV for the ZIPs affected by the 1994 Northridge earthquake

The ShakeMap PGA sigma multipliers used in this study (Figure 2) are never more than 1.0 and significantly lower for grid points that are close to the recording stations. Some of the ZIPs affected by the ShakeMap footprint are far enough from recording stations that the no reductions in the sigma are calculated. For these ZIPs, the CV calculations are mostly affected by the random nature of the simulations. Figure 7 shows the comparison of the mean loss and CV for each of the ZIPs affected by the ShakeMap for the 1994 Northridge earthquake. The mean loss tends to be only slightly affected by the use of the ShakeMap sigmas. However, as the loss increases (in the case of the Northridge earthquake, the locations which are close to recording stations), there is a slight tendency for the mean loss to decrease. This behavior, however, is expected to be different for different situations of where the recording sites are located relative to the exposure concentration and strong ground shaking.

4. CONCLUSIONS

The ShakeMap Uncertainty maps are very valuable in estimating the variability of losses due to earthquakes. By making use of available information provided by recording stations, the ground motion uncertainty is greatly reduced for locations that are close to them. This reduction in hazard uncertainty in turn significantly reduces the uncertainty in the portfolio loss estimates that are important for risk management after a significant event. The amount of reduction in loss estimates are shown in terms of the loss coefficient of variations (CV).

The methodology presented in a previous study is easily modified to take advantage of available information, in terms of the reduction of the ground motion standard deviation. Since the CISN ShakeMaps are usually available for significant earthquakes worldwide, the procedures outlined in this paper are useful for quickly estimating the uncertainty of portfolio loss estimates.

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