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THE EFFECT OF VARIATIONS IN SOURCE CHARACTERIZATION OF THE PUENTE HILLS THRUST ON PORTFOLIO LOSS ESTIMATIONS

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SUMMARY

Over the last two decades, a number of blind thrust faults have been identified within the Los Angeles region in southern California. The activity levels as well as the location and the extent of these features have been much debated within the seismological community. A newly-delineated feature, the Puente Hills Thrust, has been put forward as a major source of seismic risk in the region with potential losses to the insurance industry on the order of \$30 to \$40 billion. This study investigates the effects of source characterization on the uncertainty/variability of financial losses to a portfolio of insurance industry exposures affected by an event on the Puente Hills Thrust.

There are four parts to the financial risk assessment: the source characterization, the ground motion model, the vulnerability model and the industry exposure. The ground motion model considers the ground motion attenuation as well as the local site conditions. Site conditions are delineated through digitized surficial geology maps. The vulnerability model translates the ground motion into a damage ratio using a response spectrum approach. The industry exposure database is based on building inventory data and includes age, height, and building structure information.

The two key components of source characterization examined in this study are the source geometry (location and 3-D extent) and potential segmentation/cascade models. The impacts of these parameters on event magnitudes, variations in the exposure affected as well as exposure losses are examined. An examination of potential variations in ground motion models is also included to better delineate the relative importance of the assumptions implemented during source characterization.

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INTRODUCTION

When the next large damaging earthquake will strike the Los Angeles region cannot be predicted, but the seismological community agree that it is certain to occur. The 1994 Northridge earthquake (moment magnitude 6.7) occurred to the north of the major exposure concentrations in this region, but still resulted in more than $35 billion in economic losses and $15 billion in insured losses (Petak [1], Risk Management Solutions [2]). A large event directly under the Los Angeles metropolitan area would be devastating. The Puente Hills Thrust is a structure within the Los Angeles basin believed to be capable of producing such an event.

In the event of an earthquake, insurance companies are expected to be prepared financially to pay their clients fully for the damage to their properties. Insurance companies utilize catastrophe models to assess and to mitigate their exposure to financial risk due to such severe events. This study examines potential losses produced by a catastrophe model to an estimated, insurance-industry exposure from a significant earthquake on the Puente Hills Thrust. The objective of this study is to examine the impact on the estimated losses due to variations in the source characterization.

CATASTROPHE MODEL DESCRIPTION

Results provided in this study were calculated using a proprietary loss-estimation tool called RiskLink. It applies an event-based approach (using a set of stochastic events with corresponding physical parameters, location, and frequency of occurrence) to generate portfolio loss and to assist in risk management. The RiskLink earthquake model for the western United States is described in depth in Windeler [3] in this volume.

The RiskLink earthquake model has four principal components or modules:

1. *Stochastic Event Module*: This module contains a database of stochastic earthquake events. Each event is described by its physical parameters, location, and frequency of occurrence. For this study, the event set has been limited to eight potential source models for the Puente Hills thrust.
2. *Hazard Module*: This module determines the earthquake intensity at each property location for every stochastic earthquake event and examines ground motion relationships and adjustments for site conditions (soil amplifications and liquefaction and landslide susceptibilities). Ground motions are calculated in spectral acceleration from periods 0 to 4 seconds. The ground motion for an individual location incorporates the building's predominant period. For this study, a suite of four attenuation relationships as well as a composite relationship is modeled for each seismic source model.
3. *Vulnerability Module*: This module calculates the mean damage ratio and coefficient of variation to buildings, contents, and the resulting loss of use. For more details on the RiskLink vulnerability module refer to Rahnama [4] in this volume.
4. *Financial Analysis Module*: This module calculates losses to different financial perspectives and structures, considering the insurance and reinsurance financial structures.

THE PUENTE HILLS THRUST

The Los Angeles basin lies under the major metropolitan region of the city of Los Angeles. GPS measurements have observed shortening across this basin (Argus [5]) that may be accommodated on a number of possible structures. The exact structures that are actively accommodating this deformation are unclear, but many have been proposed. In terms of seismic risk to the region, the Puente Hills Thrust is particularly worrisome. This structure lies within the northern part of the basin, underlies downtown Los

Angeles and east to Brea, and is believed to have been partially ruptured during the 1987 Whittier Narrows (Mw 6.0) earthquake (Shaw [6], Figure 1).

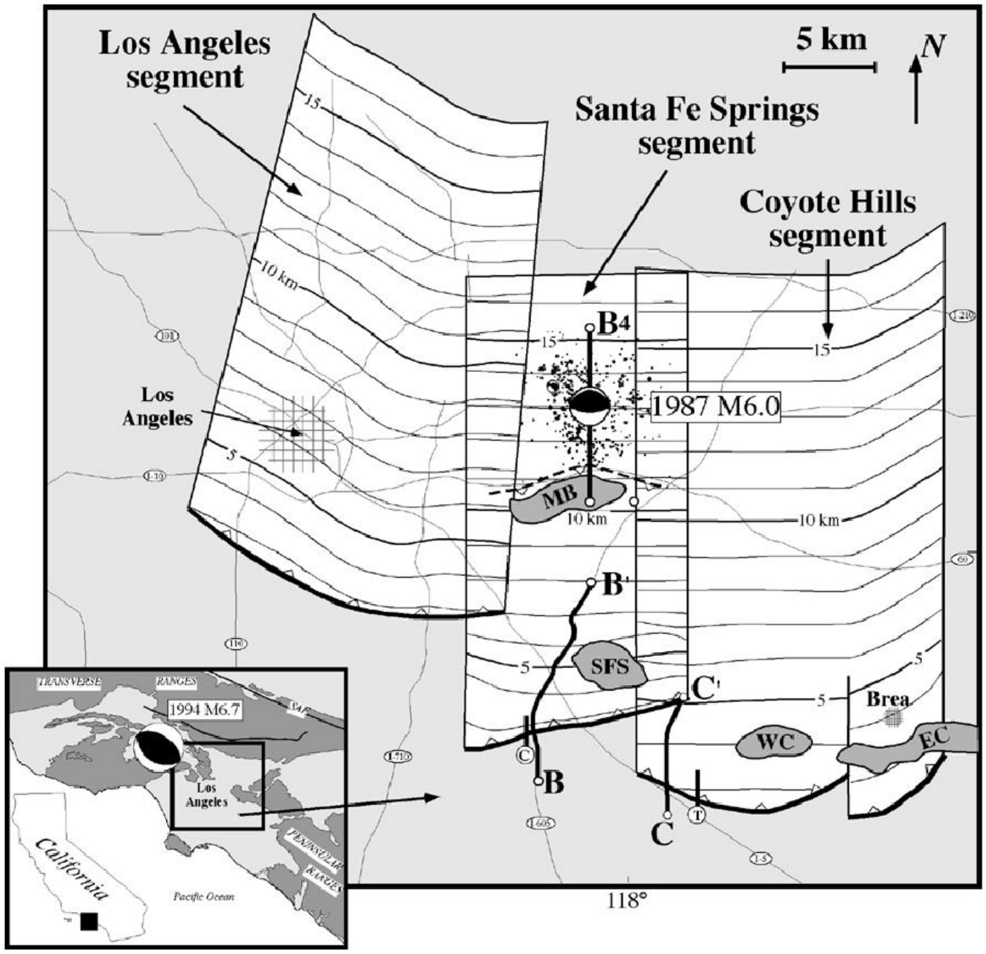

Figure 1. Structure contour map of segments of the Puente Hills Thrust showing the location of the 1987 Whittier Narrows (Mw 6) earthquake sequence (Hauksson [7]) as relocated by Shaw [6]. A0–A2 , B–B4 , and C–C2 mark the traces of seismic reflection profiles and cross sections. Traces T and C correspond to the high-resolution seismic profiles. The inset shows the location of the PHT and 1994 Northridge (Mw 6.7) earthquake. Oil fields: EC, East Coyote; WC, West Coyote; SFS, Santa Fe Springs; MB, Montebello. Major state and interstate highways are shown for reference. (From Shaw [8]).

Because the Puente Hills Thrust is a blind structure, meaning that it does not extend to the surface, it has been difficult to define in terms of location and activity. Recently, detailed locations for the Puente Hills Thrust structure were delineated by Shaw [8] using seismic reflection profiles, petroleum well data, and precisely-located seismicity. They delineated the Puente Hills Thrust as three unique structures or segments. From west to east, these structures are called the Los Angeles, Santa Fe Springs, and Coyote Hills segments. The detailed source characteristics for the Puente Hills Thrust segments are included in Table 1.

These are three unique structures that could serve as potential sources for Northridge size events directly under the Los Angeles metropolitan area. There is also the possibility that events on these structures could be clustered in time. This means that there could be two or three events within a period of years to decades on these structures. This type of behavior has been observed on a similar en echelon blind-thrust system in central California (1981 New Idria M5.4, 1983 Coalinga M6.5 and 1985 Kettleman Hills M6.1) (Stein [9]). Because of the similar fault geometries, slip rates, and slip histories for the three segments, there is also the possibility that two or three segments could rupture together. Shaw [7] estimates the magnitude of an event that ruptured all three segments together would be approximately Mw 7.1. An event of this magnitude directly under the Los Angeles region would be the largest to directly hit this region historically and would cause extremely devastating damage levels.

Table 1. Characteristics of the Puente Hills Thrust segments as defined by Shaw [8]. Characteristic magnitudes calculated from area using Wells [10].

Segment	Area (km^2)	Mch	Repeat Time (years)	Historical Events
Los Angeles segment	370	6.6	540-1000	
Santa Fe Springs segment	260	6.5	720–1320	1987 Whittier-Narrows M6.0
Coyote Hills segment	380	6.6	400-600	
all segments combined		7.1	780–2600	

In 2002, the U.S. Geological Survey released updated versions of the National Seismic Hazard Maps (Frankel [11]). Due to the work done by Shaw [8], there was sufficient information about this structure to allow for the inclusion of the Puente Hills Thrust within the source model for the updated maps. The seismic source utilized in the national seismic hazard maps generalized the details of the three structures and assumed full rupture with a characteristic magnitude of Mw 7.1. The California source model was updated by the U.S.G.S. in conjunction with the California Geological Survey (C.G.S.) (Cao [12]).

Upon completion of the seismic source model for California, the C.G.S. undertook an analysis using the updated source model to estimate the losses due to future earthquakes in California (Rowshandel [13]). As part of that study a scenario analysis was completed for the Puente Hills Thrust. For a moment magnitude 7.1 event, the C.G.S. found estimated building damage (economic loss) as $69 billion. This was the single highest loss observed for the potential earthquake scenarios analyzed by the C.G.S. for southern California.

Figure 2 shows the earthquake planning scenario intensity map for a Puente Hills Thrust event (M7.1). It shows the intensity levels that could be observed across the Los Angeles region if this event was to occur. In the immediate area of the Puente Hills Thrust violent shaking is predicted with intensities above VIII and heavy potential damage. The entire Los Angeles metropolitan region would experience intensities of VI or higher which are capable of causing some damage to most types of structures.

SEISMIC SOURCE MODELS

For this study, eight potential source models for the Puente Hills Thrust were modeled (Figure 3, Table 2). The first three models correspond to the Puente Hills segments delineated by Shaw [8]. Because there is the possibility of two or more of the segments rupturing together, this study also examined the three possible ‘cascade’ sources: Los Angeles with Santa Fe Springs, Coyote Hills with Santa Fe Springs

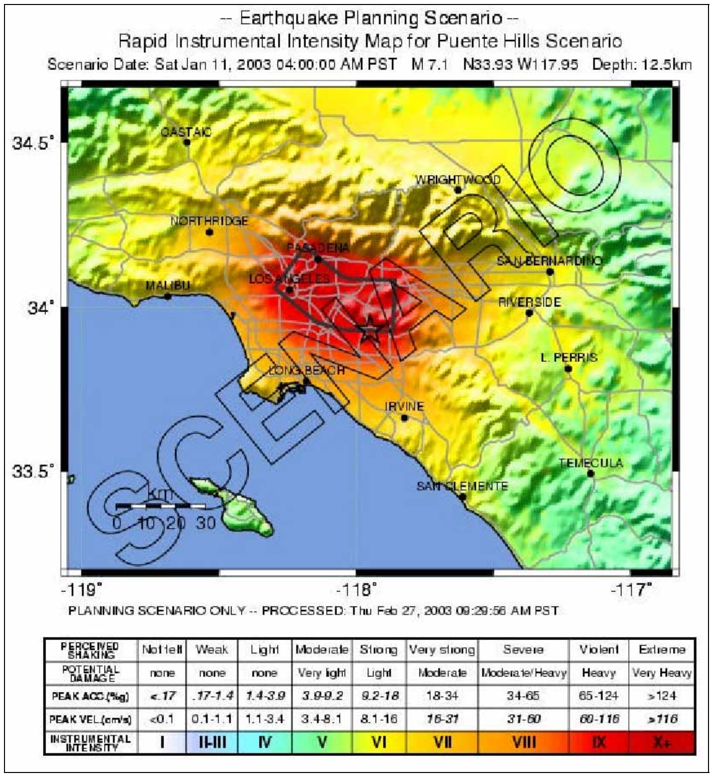

Figure 2. Earthquake planning scenario map for a Puente Hills Thrust event (M7.1) created by the C.G.S. showing the intensity levels that could be observed across the Los Angeles region if this event was to occur (from Rowshandel [12]). The source zone used for this analysis is shown as the bold box.

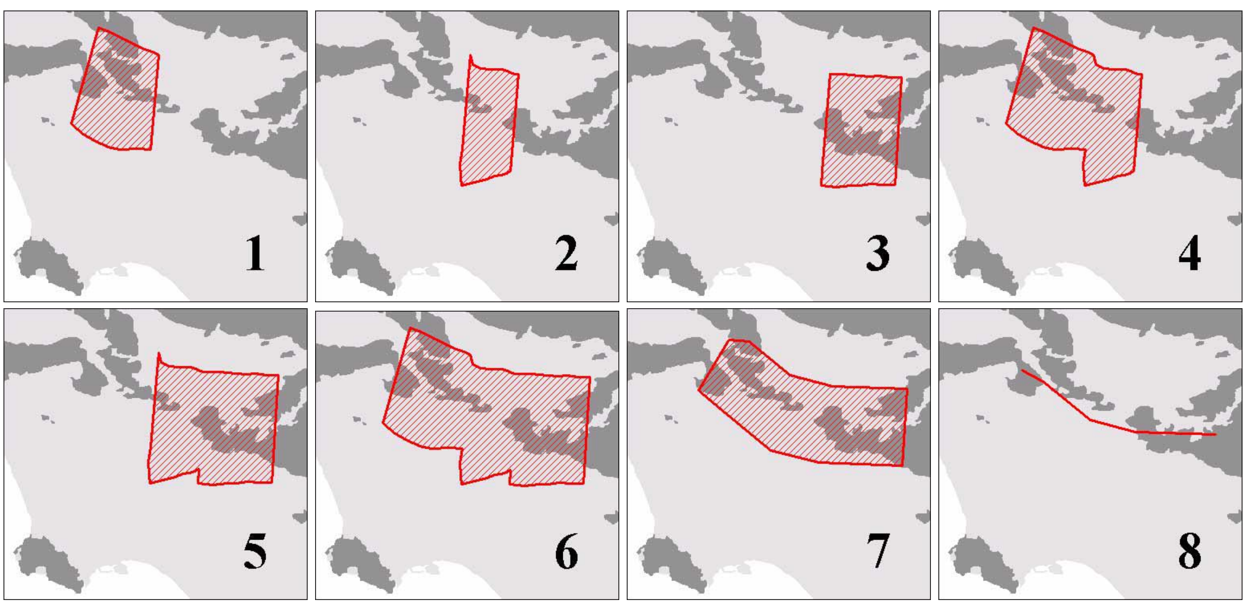

Figure 3. Maps showing locations of the 8 seismic source models used to represent the Puente Hills Thrust in this study.

Table 2. Source characterizations models used in this study. Source locations shown in Figure 3.

Model	Description	Reference	Mch	Top Depth	Bottom Depth
1	Los Angeles segment	Shaw [8]	6.6	3 km	17 km
2	Santa Fe Springs segment	Shaw [8]	6.5	3 km	17 km
3	Coyote Hills segment	Shaw [8]	6.6	3 km	17 km
4	Los Angeles and Santa Fe Springs segments combined	based on Shaw [8]	6.8	3 km	17 km
5	Santa Fe Springs and Coyote Hills segments combined	based on Shaw [8]	6.9	3 km	17 km
6	all segments combined	Shaw [8]	7.1	3 km	17 km
7	N.S.H.M.P. source	Frankel [11]	7.1	5 km	13 km
8	N.S.H.M.P. source as a line	based on model 7	7.1	8 km	-

and all three segments combined. Two additional models were also tested: the 2002 National Seismic Hazard Mapping Project (N.S.H.M.P.) source and a line source similar to the N.S.H.M.P. source. The last model was included to delineate the importance of modeling the source in three-dimensions. For each source model, a suite of magnitudes was analyzed to allow for uncertainty in the magnitude-area relationship as well as uncertainty in the area of the fault plane. For each source, the magnitude range analyzed from maximum events up to 0.3 greater than the characteristic magnitude to a minimum magnitude in the range of 6.5.

In addition to source model characterizations, variations in ground motion models were also tested. Within the updated National Seismic Hazard Maps, the ground motion model varied by source type (Frankel [11]). For thrust sources four attenuations were equally weighted to produce a composite relationship. For this study, the composite attenuation as well as the constituent attenuations were analyzed for each source. The attenuations tested included Abrahamson [14], Boore [15], Campbell [16], and Sadigh [17]. For this study, the composite attenuation is referred to as Frankel [11].

INSURANCE INDUSTRY EXPOSURE

Two exposure data sets were analyzed for this study: one for residential and the other for commercial. These insured portfolios incorporate the penetration rate of earthquake insurance purchase, policy conditions on deductibles and limits, and coverages for structures, contents, and additional living expenses/business interruption. These were estimated from a value of public and private data sources, including insurance companies, state insurance regulators, the California Earthquake Authority, the U.S. Census, gross domestic product, Dun & Bradstreet square footage, Means construction costs, and other statistical factors. The spatial distributions of the exposure portfolios across the Los Angeles region are shown in Figure 3.

Within California, consumer demand for earthquake insurance continues to decrease as both the length of time since a major earthquake event and the cost for earthquake coverage increases. In 2002, the California Department of Insurance (DOI) reported that the percentage of homeowners with wind/fire policies that also purchase a separate earthquake policy has decreased to 17% in 2000 from around 33% in 1996. In the event of a major earthquake in the Los Angeles metropolitan area, the burden of the financial impact to be covered by the insurance industry will be significantly lower than it was at the time of the Northridge earthquake.

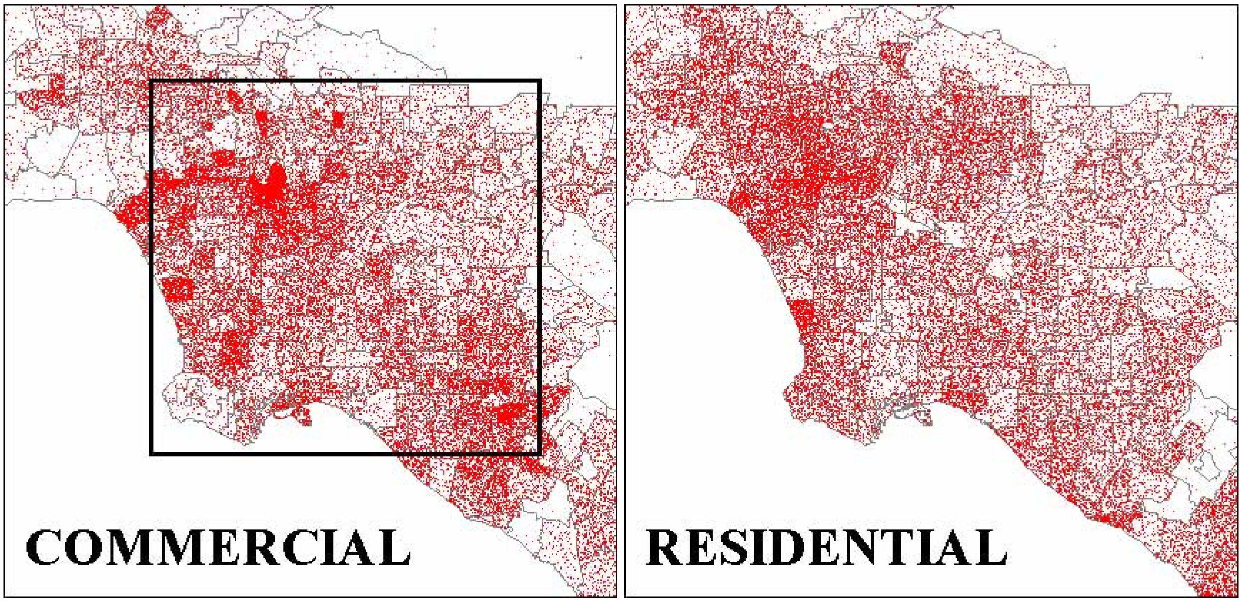

Figure 3. Dot density plots of modeled insurance industry commercial and residential exposures for the greater Los Angeles region. Box shown in commercial map corresponds to the coverage shown in the maps in Figure 3.

RESULTS

In all more than 325 combinations of seismic source model, event magnitude and ground motion were tested as potential scenarios for the Puente Hills Thrust. These were analyzed using the RMS proprietary loss-estimation tool called RiskLink. The exposure analyzed covered both the commercial and residential insured exposure for California at a ZIP code resolution. The losses levels for these analyses are plotted by event magnitude in Figure 4. The mean loss for all of the analyses was $24 billion and was calculated assuming equal weights for the source models and attenuations relations and a Gaussian distribution with a sigma value of 0.12 for magnitude uncertainty.

As expected, the larger magnitude events result in significantly higher losses. Additionally, there is more variation in the loss levels of the higher magnitude events due to the differences in the modeled ground motion attenuation relationships. The spread of potential losses ranges from $5 billion to $75 billion. The largest losses are extreme, unlikely events combining the highest ground motion models with magnitudes at the limit of what can be produced by the sources. The smallest losses are associated with the individual segment models with much lower magnitudes.

To better differentiate the impact of the source characterizations and of the ground motion models, Figure 5 shows by source model for the characteristic magnitude the expected losses by ground motion relationship. The characteristic magnitude is the magnitude of the event that would cause full rupture of the surface area (or length) of the source modeled. The composite ground motion model (Frankel [11]) uses an equal weighting of the other four ground motion models, following the 2002 National Seismic Hazard Maps. The individual fault segments (models 1, 2 and 3) defined by Shaw [8] show lower losses

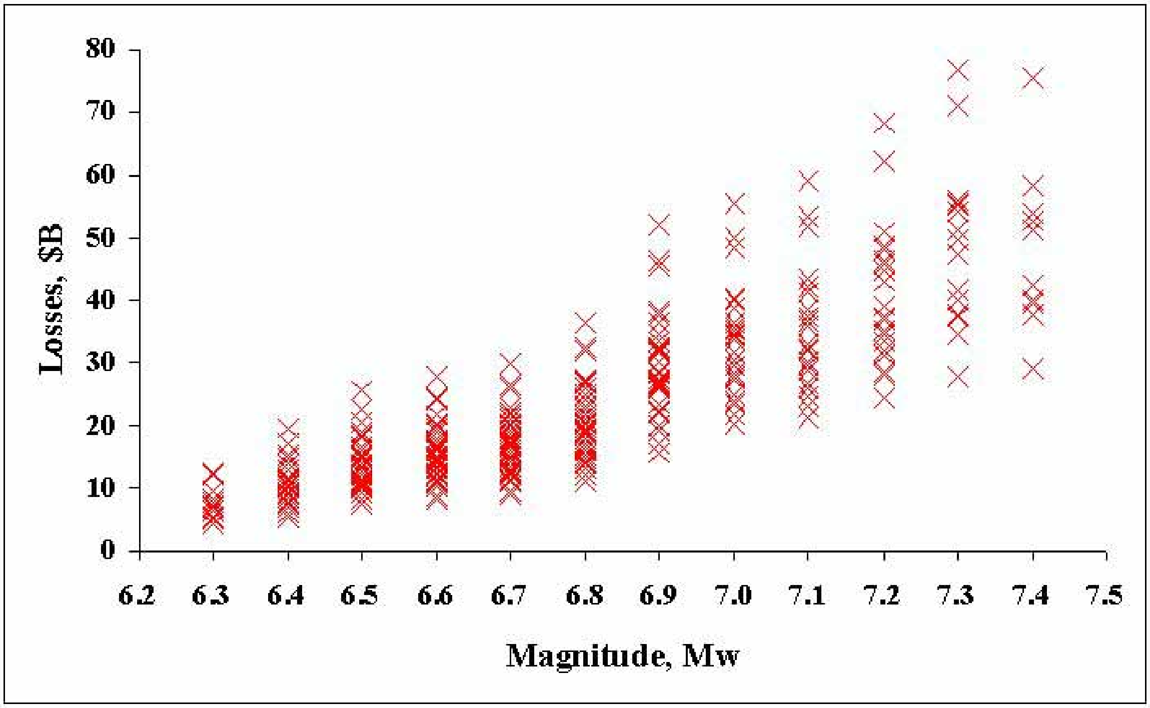

Figure 4. Magnitude versus Losses for all events modeled for this study.

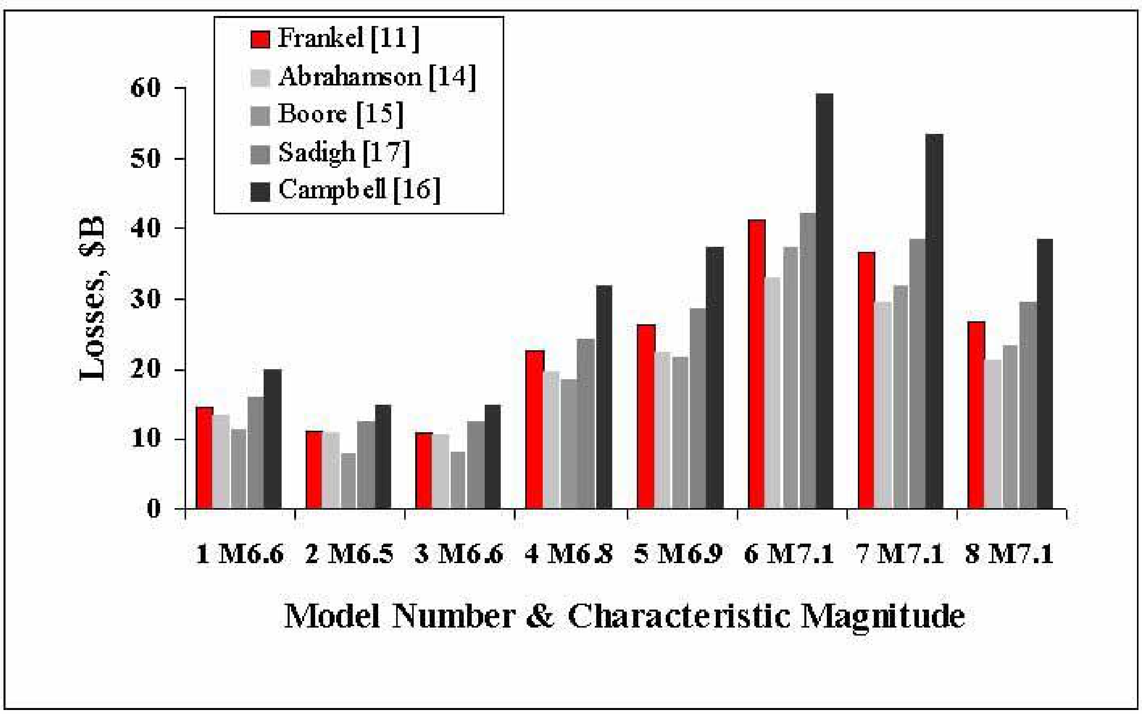

Figure 5. Variation in losses ($B) for the characteristic magnitude event by source model for each ground motion attenuation relationship.

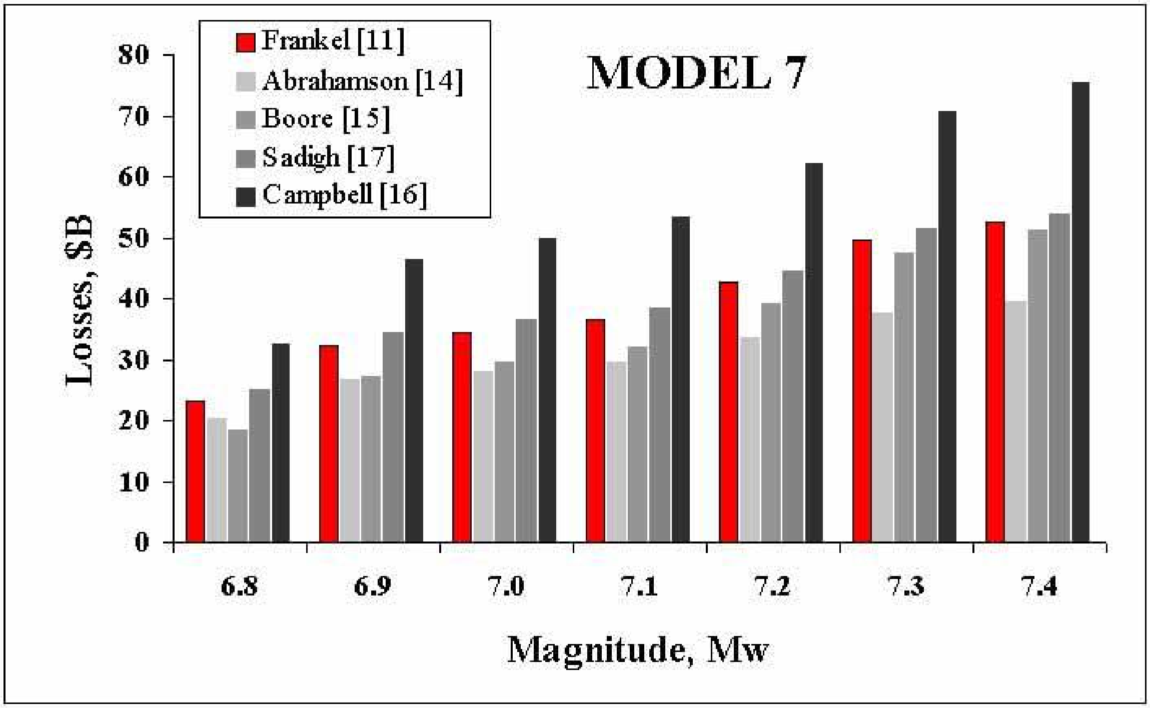

Figure 6. For Model 7 Losses by magnitude for each ground motion model.

than the sources with more extensive ruptures and resultant larger magnitudes. Of the individual segment models, the M6.6 Los Angeles segment (model 1) event shows the highest losses. This is due to the exposure concentration in the downtown Los Angeles that is directly above this source. The two-segment cascade models (4 and 5) show higher losses than the segments, with the highest losses are observed in the eastern model due to the slightly larger characteristic magnitude.

In Figure 5, it is clear that the full rupture models have the highest loss events. Model 6 represents the full rupture of the three segments of Shaw [8] combined and shows the highest losses. Since the characteristic magnitude is the same for all three of these models, the difference in losses is driven by the differences in the exposure that is impacted by the events. Model 6 extends to slightly shallower depths and further out under the Los Angeles basin. Model 7 is consistent with the C.G.S. planning scenario analysis and shows slightly lower losses than model 6. Model 8 as expected shows lower losses than the other two. Since model 8 is characterized with a line instead of a plane, the exposure in close proximity to the source is lower. Note that model 8 was included to illustrate that blind thrust sources need to be modeled in three-dimensions to fully characterize their impact.

Figure 6 shows the losses for model 7 for a range of magnitudes and shows the variation in losses to these magnitudes for each of the ground motion models. This is the source used in the 2002 National Seismic Hazard Maps. Small variations in magnitude have a large impact. This shows that the choice of characteristic magnitude is critical as well as the choice of magnitude for scenario analyses. Also note that as the magnitude extends beyond 7.1, the losses step up more dramatically with each magnitude unit due to an increase in slope of the damage relationship.

In Figure 5 and Figure 6, the highest losses are observed for the Campbell [16] attenuation across all sources and magnitudes. The losses associated with Abrahamson [14] and Boore [15] are the lowest, with a crossover in the magnitude 6.9 to 7.0 range causing Boore [15] to be higher for the larger magnitude events. The results of the Sadigh [17] ground motion model are very similar to those derived for the composite curve Frankel [11].

DISCUSSION

The California Geological Survey estimated that a Puente Hill Thrust scenario with a moment magnitude of 7.1 would result in building damages (economic losses) of $69 billion (Rowshandel [13]). This study examined the insured losses expected from a suite of Puente Hills Thrust source models. The event most similar to the C.G.S. event within this study is model 6 at magnitude 7.1 with the Frankel [11] ground motion model. For this source, this study found an insured loss of $41 billion. The difference between these values is the difference in the economic exposure and the insured exposure. In other words, the amount of loss that would need to be carried by home and business owners as well as local and national government agencies. The ratio of this study's insured loss to the C.G.S. economic loss is higher than expected given the low penetration rate of insurance for residential properties. This may indicate that the economic losses are higher than estimated, but more likely due to the assumptions regarding exposed value. The Rowshandel [13] study used exposure based on 1990 census data, whereas this study used 2003 exposure values. This indicates that total economic losses for a Puente Hills Thrust event in today's values may be much greater than $69 billion.

CONCLUSIONS

This study has shown that for the Puente Hills Thrust that event losses are tied to the exposure concentrations in the source region, the determination of characteristic magnitude and the choice of ground motion model. Due to the large variation in losses due to the many parameters that must be defined for the Puente Hills Thrust, it is important to use a logic tree approach to weigh the various parameters to produce a scenario result that is representative of the potential losses. Better still a suite of results should be presented.

The full rupture of the Shaw [8] segments together results in higher losses than the source model used in the 2002 National Seismic Hazard Maps. Given the observations in this study it would seem more appropriate to include a closer representation of the Puente Hills Thrust in the next version of the hazard maps. It would seem best to include the three individual segments as well as allowing for the three potential multiple segment ruptures. Since this structure lies in a zone of such high exposure concentration it requires a full detailed treatment to best characterize the risk that it poses.

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