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# PINPOINTING THE COST OF NATURAL DISASTERS – LOCAL DEVASTATION AND GLOBAL IMPACT

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**ABSTRACT:** The 2011 Tōhoku-oki earthquake caused in excess of $200 billion in economic damages. For comparison, a single earthquake in California could cause over $600 billion in economic damages. Insurance coverage of risk has not kept up with the increasing concentration of economic assets in natural-catastrophe-prone areas, leaving a void in coverage and the potential for extended disruption and delayed economic recovery. Business interruption risks from both the Tōhoku-oki earthquake (Japan) and the Bangkok, Thailand floods of 2011 clearly demonstrate the linkage of regional events to the global economy and the systemic importance of ensuring rapid recovery.

A magnitude (M) 7.3 earthquake on the Puente Hills Fault underneath Los Angeles (LA), California is used as the basis of a case-study to examine a modeled view of the losses occurring from a large event. We identify and quantify economic impacts deriving from such an event that will impact a sector of the economy not traditionally discussed in this context. Recognition followed by quantification are key steps in mitigating long term negative impacts from earthquakes.

## 1. Introduction

### 1.1. Background

Devastating earthquakes occur suddenly, with little to no forewarning. With the affected regions from such earthquakes stretching to distances of 100 miles or more from the rupture and impacting thousands of square miles, these earthquakes have the potential to destroy more than just property. Today's concentrations of population, infrastructure and inadequate building construction have exacerbated the disastrous potential of earthquake catastrophes.

Earthquake risk management is predicated on the concept that lessons from past catastrophes can be decomposed into basic elements useful for quantifying potential future outcomes. Damage observed in historical earthquakes correlated to measured ground motions form the basis for the ability to estimate likely damage in hypothetical future events. Earthquake catastrophe risk models extend the historical record to consider events that have not happened, and grant the ability to consider changes in the risk environment such as new scientific knowledge, exposure growth, and relocation of economic resources. The rapid change in our society of the last 50 years has left us few historic earthquake catastrophe exemplars to benchmark models with as well as to identify ways in which current economies might be more vulnerable to disruption than in the past. We must therefore expand beyond just what we have seen to appropriately anticipate what can happen in the future.

The 2010 Maule (Chile) earthquake highlighted some of the fragilities to infrastructure such as ports, harbors, and elevated highway infrastructure from deep earthquakes. The 2011-2012 Christchurch (New Zealand) earthquakes highlighted the unanticipated risk in communities built on poorly consolidated flood plains; with the magnitude of the total economic impacts of having to rebuild an entire community still being developed 4 years later. The impacts of the 2011 Tōhoku-oki earthquake extended far beyond the earthquake ground shaking induced damage and challenged our ideas of being able to survive a tsunami, and a nuclear power accident exacerbated an already deadly and expansive event. These modern earthquakes, occurring on the periphery of major population centers, provide impetus for further and ongoing investigation into potential agents of damage in future events.

Modern catastrophes have demonstrated the extent to which economic impacts can be felt far beyond the immediate area affected by the event. The 2011 Tōhoku-oki earthquake disrupted automobile assembly lines throughout the world, triggered by damage to a chemical plant producing sparkly paint pigment (Canis, 2011). News reports noted that an extreme flood in Thailand (2010) disrupted the availability of computer hard-drives due to lack of access to factories in Bangkok. Superstorm Sandy (Greater New York City area, 2012) caused widespread disruption to roads and buildings, leading to speculation that unoccupied buildings, with owners unable to pay the rent, could trigger disruptions in the global bond market as cash flows were disrupted. To provide a more complete view of what could occur to our society, catastrophe risk estimation must extend beyond the direct costs of the event itself. In this paper, we quantify the risk to the home loan mortgage market from a probable earthquake scenario in Los Angeles.

## 1.2. Hazard

The 1994 M6.7 Northridge earthquake caused an estimated $20 Billion of property damage and $50 Billion of economic damage (SCEC, 2014). The event occurred on a blind-thrust fault that was unidentified at the time of the earthquake. Since the time of the Northridge earthquake much research on fault sources in California has been conducted, including research by Shaw and Shearer (1999) identifying a similar risk in the Los Angeles Basin immediately under downtown LA: The Puente Hills Fault (Figure 1).

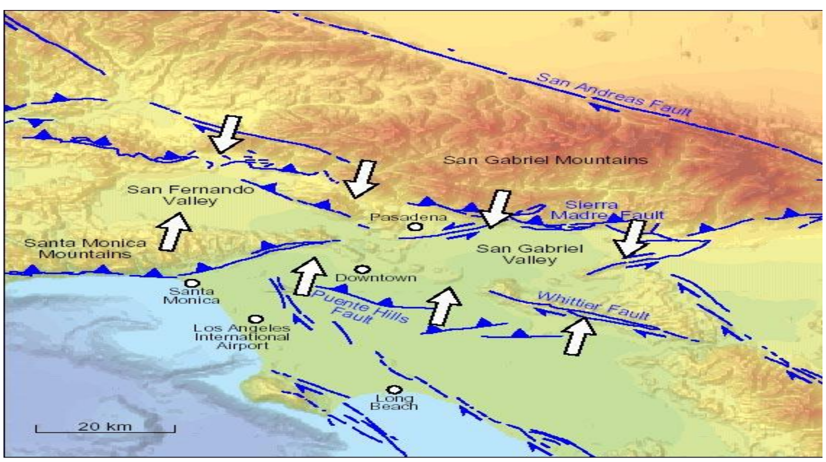


**Figure 1 – Location of the Puente Hills Fault under downtown Los Angeles (Courtesy NASA/JPL-Caltech)**

The Puente Hills fault is an active thrust fault located in Los Angeles Basin. It is comprised of three segments: Los Angeles, Santa Fe Springs, and Coyote Hills (Shaw and Shearer 1999). Historically, the Puente Hills thrust fault has experienced four major earthquakes each greater than M7 in the past 11,000 years (Dolan, et al, 2003). These major earthquakes have occurred at a rate of a few thousand years between events on this fault, but given its close proximity to one of the major economic centers of

California, the fault poses a major risk. More recently smaller earthquakes including the 1987 M5.9 Whittier Narrows and 2014 M5.1 La Habra earthquakes are suspected to have been associated with the Puente Hills fault (USGS, 2014).

Geologically, Los Angeles is located in a basin filled with softer soils. Earthquake ground motion has shown to amplify in this type of geological structure. The M8.1 1985 Michoacan earthquake was an example of how ground motions can amplify and resonate in a basin structure as was observed in Mexico City (Flores-Estrella *et al*., 2007).

In the CoreLogic US Earthquake Model, the earthquake potential on the Puente Hills fault is modeled with 60 different representations ranging in magnitude from M6.2 to M7.3 dived amongst the Los Angeles, Santa Fe Springs, and Coyote Hills segments as well as a full rupture of all three segments combined. The total modeled cumulative annual frequency of earthquakes from M6.2 to M7.3 on the Puente Hills fault is $1.4 \times 10^{-3}$.

Using the CoreLogic model to decompose the risk in southern California to look at the faults driving the risk, the Puente Hills fault illustrates a significant contribution to the risk, coming in fourth behind the Santa Monica, South San Andreas, and Sierra Madre faults (Figure 2). This demonstrates the worrisome risk that the Puente Hills fault provides to the Los Angeles Basin.

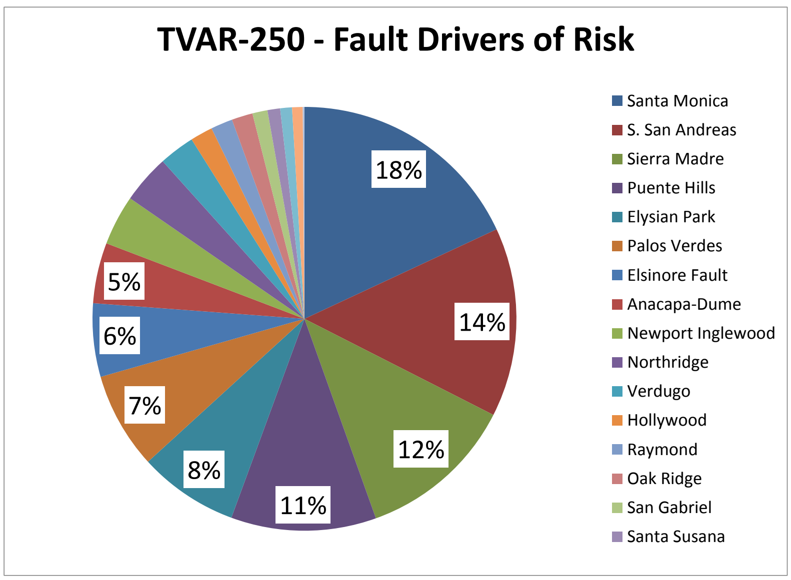


**Figure 2 – Southern California Fault Drivers of Risk for 250-year Tail Value at Risk (TVAR).**

## 1.3. The Scenario

A M7.3 earthquake on the Los Angeles segment of the Puente Hills fault has been selected as a scenario for this discussion. The Uniform California Earthquake Rupture Forecast version 3 (UCERF3) indicates that there is a 46% probability of a M7 earthquake and a 31% probability of a M7.5 earthquake in the Los Angeles region in the next 30 years (Field et al, 2013). It must be noted that this includes all fault sources in the Los Angeles region, of which the Puente Hills fault is just one. While a M7.3 earthquake on the Puente Hills fault is not the most likely scenario for the Los Angeles area, it is one of the most devastating.

As illustrated by the CoreLogic US Earthquake Model, the damage from this earthquake would extend over a very large area, impacting all of the Los Angeles Basin. The darker red colors in Figure 3 indicate the heaviest damage. This was modeled with a portfolio of uniform structure type. As such, the damage map is proportional to the levels of ground motion with higher ground motions equating to higher damage.

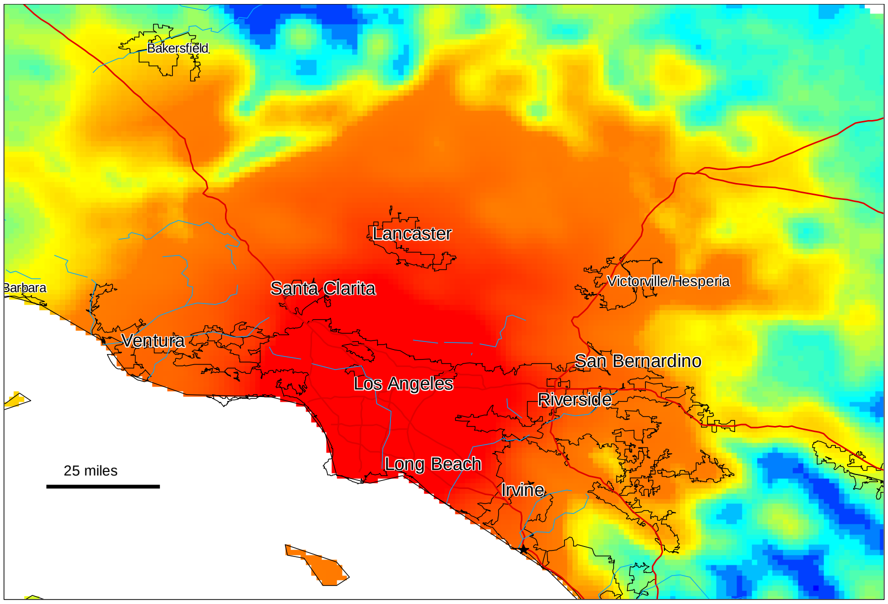


**Figure 3 – Map of Modeled Damage from a M7.3 Earthquake on the Puente Hills Fault**

## 2. The Impact of the Puente Hills Earthquake Scenario upon Property

The evaluation of the economic impacts of the scenario requires (a) the definition of the total universe of property exposed to the event (the portfolio), (b) the assignment of vulnerability to the portfolio, and (c) modeling the direct effects of the event. Modeling the follow-on components of this event include estimating indirect losses such as business interruption and additional living expenses.

Losses from an event are not all immediate. In residential areas, residents who cannot continue living in a damaged building have a "loss" when they must pay for repairing the property and/or alternative accommodations. If the damaged property is a rental unit, the owner may suffer losses due to the damage that must be repaired to the building, and also due to lost rental income should the property no longer be habitable after the event. Because most properties today are financed through mortgage loans, mortgage lenders, servicers, and other financial institutions are also at risk for loss, broadening the population of those who suffer a loss from an event. The spreading of losses from an event to a broader population can produce greater resiliency to the losses because the average loss severity is much lower. But this spreading of losses may result in losses to groups that are unprepared for them, exacerbating the economic impact of the event. Developing a more complete estimate of the losses from a catastrophic event must include potential the indirect but eventual entities that must finance this risk.

### 2.1. The Los Angeles Basin – A concentration of wealth and vulnerable assets

The Los Angeles Basin is the geographic description of the physical area underneath the Los Angeles metropolitan area – one of the largest metropolitan areas in the world with a 2014 population of more than 13.2 million people (USCB, 2015). The Los Angeles Basin spans central Los Angeles and large parts of Orange County to the south. The basin is identified as the sedimentary basin bounded by the Pacific Ocean, the Santa Monica and San Gabriel Mountains to the north, the Santa Ana Mountains to the east and the Palos Verdes Mountains to the west. The sedimentary plain that has proved an accommodating location for city development also represents softer soils that that can amplify the damage potential of earthquakes (Field *et al*., 2005).

The greater Los Angeles Basin has insurable property assets exceeding $2.7 Trillion (CoreLogic, 2015). Insurable assets exposed to damage from an earthquake (exposure) is comprised of a mix of residential and commercial/industrial occupancies, with slightly more than half of the exposed values being residential structures and contents. Valuations for Additional Living Expense (ALE) and Business Interruption (BI) exposures were developed using regional statistics. The valuation was for all buildings –

public and private, in the study area. The total valuation of assets and time value exceeds $3 Trillion, exceeding the $2.2 Trillion estimate for the 2013 Gross State Product for California (US BEA, 2013).

Only a fraction of the buildings in California are insured for the damages occurring during earthquakes, with the latest California Department of Insurance report noting that in 2013, only 10% of homeowners insurance policies in the state had an accompanying earthquake insurance policy (CA DOI, 2014).

## 2.2. Estimating property damage from the Puente Hills Earthquake Scenario

Catastrophe modeling involves decomposing the risk of damage from an earthquake into discrete components that can be individually developed and validated. The four primary components of catastrophe modeling are as shown in Figure 4. For this scenario, an earthquake rupture on the Puente Hills Fault is simulated in the CoreLogic earthquake catastrophe model. The damage to properties is estimated using vulnerability functions that relate the damage to the ground motions, with different vulnerability for differing construction types and occupancies. Two loss calculations are performed: one to estimate indemnity losses and another to estimate the losses to the residential mortgage industry.

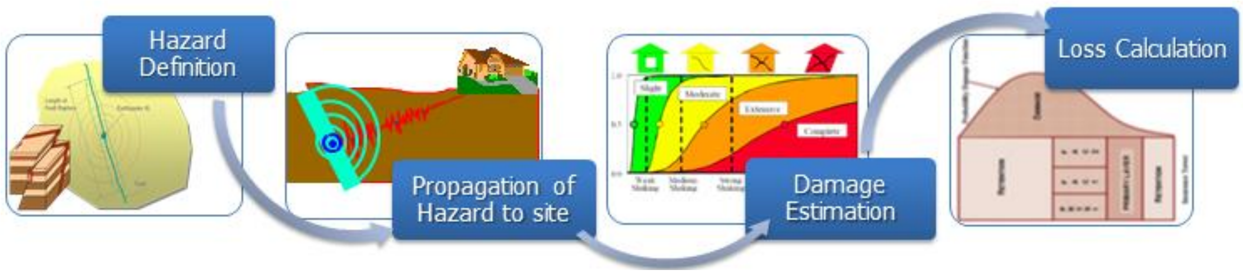


**Figure 4 – Modeling Methodology Framework**

CoreLogic estimated the damage from a M7.3 Puente Hills Earthquake Scenario using the Risk Quantification and Engineering (RQE) U.S. Earthquake Model (CoreLogic, 2014a). Propagation of the ground motions to the site is performed using ground-motion prediction equations that include earthquake magnitude, site-to-source distance, fault mechanism, local soil properties, and basin effects (Bozorgnia *et al*., 2014). Damage to property (building, contents) and monetized disruption (additional living expense for personal residences; additional time element / lost profits for commercial) is estimated using ground-motion to damage relationships (vulnerability functions) that were developed and validated using recent earthquake data, most notably the 1994 Northridge (CA) earthquake (CoreLogic, 2014a). Two different loss calculations were completed, one presuming a market mix of earthquake insurance limits and deductibles to the fraction of the populace that maintains property insurance, and the second calculation was performed using a mortgage impairment financial risk model.

An occurrence of a M7.3 earthquake rupture on the Puente Hills Fault is estimated to cause economic losses ranging from $350 to $450 Billion (CoreLogic, 2014b). This estimate is higher than estimates from earlier published works (Field *et al.*, 2004), but these earlier estimates (which range from $100 to $150 billion) were performed between 1997 and 2005 with lower population and underlying asset models, and did not include estimates of the intangible losses from displaced persons and businesses (additional living expense and business interruption losses).

## 2.3. Losses Ceded to Private Insurance

Insurance for the damage caused by earthquake shaking is not an automatic coverage for standard fire insurance policies in California and only a small fraction of the buildings in California are indemnified for earthquake shaking. State-wide statistics demonstrate that (as of 2012), only 10.6% of residential fire policies (homeowners, renters, condominium, dwelling and mobile home insurance) include coverage for earthquake, and less than 6% of commercial policies (commercial fire, commercial Multi-peril) include coverage for earthquake (CA DOI, 2013).

Mandatory Probable Maximum Loss (PML) reporting by the state of California presents a picture of a higher tendency to purchase earthquake insurance in the areas of the highest earthquake risk (the greater Los Angeles and San Francisco Bay Areas) (CA DOI, 2012). This information has been analyzed and used to develop an estimate of the insured loss potential (the amount of money expected to be recovered from insurers as a part of the restoration effort) from an occurrence of this event.

The M7.3 Puente Hills scenario evaluated in this study is expected to cause from $75 to $125 Billion in losses to insurance companies. The uncertainty in this estimate is derived from uncertainties in ground motions, vulnerability, valuation and identification of which properties are currently covered for earthquake shaking damage. In comparison, the 1994 Northridge (California) Earthquake was a M6.7 earthquake and caused an estimated $14 Billion in insurance losses (1994 dollars).

## 2.4. Mortgage Losses

Unanticipated shocks to the economy resulting from a natural catastrophe can have the effect of dampening economic recovery resulting in increased recovery time and an increased overall impact of the disaster. The unanticipated transfer of financial losses from mortgage holders to financial institutions as a result of the natural catastrophe can negatively impact the capital available for recovery as well as the financial health of the very institutions that typically are relied upon to provide private capital investment to spur economic growth in just such a scenario.

Residential mortgage lenders in the United States typically make loans that are secured / collateralized by property being purchased with the loan. Repair of damage to that property is the responsibility of the borrower/property owner, but should the property owner be unwilling or unable to repair the property, or decide to default on the loan, or have insufficient liquidity to make mortgage payments for a time period following the disaster, the result may be financial loss to the lender. These losses then accumulate in the lending sector resulting in significant financial impacts on many participants in the mortgage lending and servicing industry. We will investigate the nature of the impacts expected from the subject Puente Hills earthquake on the mortgage lending industry and quantify these effects.

Residential home loans in California are typically "non-recourse" loans – the lender's interest is secured by liens on the property, but the borrower is not personally obligated to repay the loan. This feature places the lender at risk for realizing real losses upon borrower default, particularly in cases where the property value at time of default is less than the remaining principal balance on the loan. To a lesser degree the risk exists for full recourse loans – though the borrower is contractually obligated to fulfill any principal shortfalls upon default, this obligation may be difficult or impossible for the lender to enforce. For example, commercial mortgage loans in California are often full recourse loans, but the commercial entities may cease to exist should they suffer catastrophic losses in an earthquake.

Impacts to the financial sector resulting from natural catastrophe precipitated borrower defaults are not limited to lending institutions (be they private or government supported), but may also include mortgage servicing institutions who may experience significant cash flow shortfalls following a large event. The risk to financial institutions with loans collateralized by the property is contingent upon not only the physical damage suffered by the property, but also by the financial condition of the borrower in the aftermath of the event as well as by the creditworthiness of the borrower and the borrower's sense of the relativity between their equity in the property after the earthquake and the cost of repairing the property.

The loss scenario quantified here considers only the residential building damage transferred to lending institutions through the default of the homeowners. It does not consider the additional impacts on the financial sector that would result from losses to the commercial mortgage sector.

## 2.5. Mortgage Exposure Modeling

To quantify the extent of the earthquake caused damage that will result in losses realized by residential mortgage lenders a "rational homeowner" model was constructed. The model assumes that the homeowner in the immediate aftermath of the earthquake will assess whether or not the earthquake-induced damage is greater than his equity in the property; if the cost of repair is greater than the property value less the outstanding loan balance, the homeowner will decide to default on his mortgage. This model does not consider additional factors that may be important to or predictive of the homeowner's likelihood to default such as the homeowner's pre-earthquake financial health, credit history, regional

economic dislocation (the moving of jobs/industries away from the regional), and the potential for fear of additional earthquakes to motivate an exodus from the region. The model considers the losses to the mortgage lender as a function of the outstanding loan balance, the loan interest rate, and property value. The modeled losses consider the costs to the financial institution in repairing or replacing the damaged structure, lost interest payments, and recoveries from eventual sale of the repaired or rebuilt structure.
In addition to building damage modeled using the standard CoreLogic US Earthquake Model, the calculation of mortgage loss requires the estimation of additional financial parameters:

- Outstanding loan balance
- Property market value
- Loan to Value Ratio:  the outstanding loan balance divided by the property market value
- Loan interest rate
- Replacement / reconstruction cost

CoreLogic's Marshall & Swift/Boeckh (MSB™) average replacement costs per zip code were used to model the aggregate cost of repair / replacement to the houses impacted by the earthquake. The total building replacement value considered in the analysis was $950 billion. The total outstanding residential mortgage balance modeled was $917 billion, on the same order of magnitude as the total building replacement value modeled.

The earthquake exposure to the mortgage loss phenomena for the Los Angeles Basin was estimated by sampling outstanding loan balance values from regional estimates of the total outstanding residential mortgage balance by loan to value (LTV) ratio bin at the zip code level. This data was estimated using the CoreLogic TrueStandings® Servicing data set. For each bin the LTV ratio was assigned a ratio at the middle of the range. Additional studies of the sensitivity of the modeled losses to changing economic conditions were performed by sampling the LTV ratios at the top and bottom of each range. Table 1 describes the LTV ratio used to model each band for the base case as well as the two sensitivity studies. The total property market value considered in the analysis was greater than $2.0 trillion, with an aggregate LTV ratio of 45%.

**Table 1 – Modeled Loan to Value Ratio Used for Each LTV Band**

| LTV Band | Base Case | Market Values Increase | Market Values Decrease |
|---|---|---|---|
| **0% to 50%** | 25% | 15% | 50% |
| **50% to 75%** | 62.5% | 50% | 75% |
| **75% to 80%** | 77.5% | 75% | 80% |
| **80% to 85%** | 82.5% | 80% | 85% |
| **85% to 90%** | 87.5% | 85% | 90% |
| **90% to 95%** | 92.5% | 90% | 95% |
| **95% to 100%** | 97.5% | 95% | 100% |
| **> 100%** | 105% | 100% | 110% |

Figure 5 illustrates the distribution of the modeled loan balance by LTV band. 30% of the outstanding balance is associated with loans with LTV ratios of less than 50% (i.e. the homeowner has an equity share of greater than 50% of the property value), while a total of 75% of the total outstanding mortgage balance have LTV ratios less than 75%.

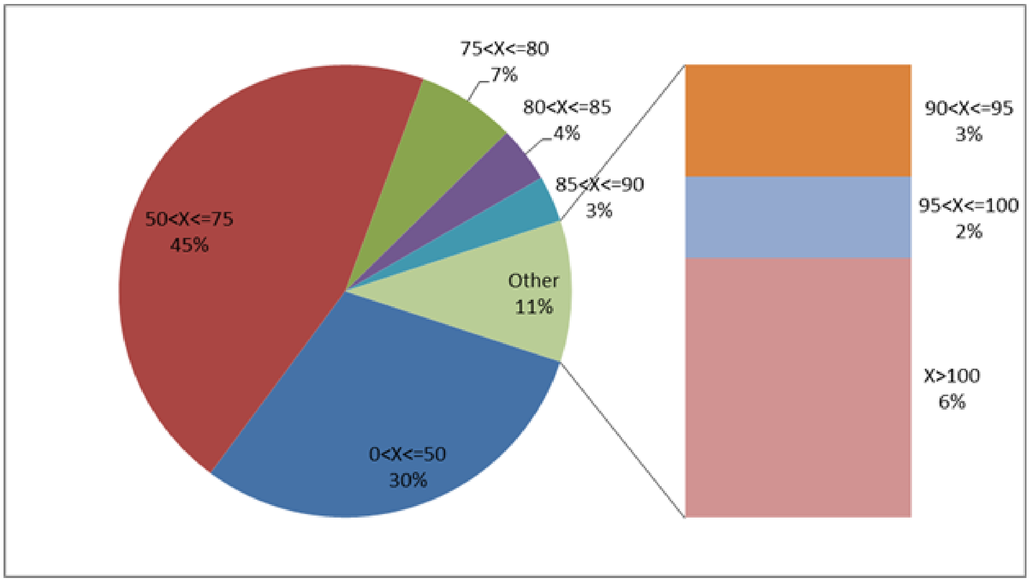


**Figure 5 – Distribution of Modeled Outstanding Loan Balance by LTV Band**

## 2.6. Mortgage Impairment Loss Modeling

The loss to the mortgage lending industry modeled in this study was estimated in two stages:

1) There is no loss to the lender if the cost of repairing damage to the property is less than the owner's equity in the property, or if the damage is low (there is still the potential for default in the case of low earthquake damage, but for the purpose of the study this is not considered to be the result of the earthquake)
2) The loss to the lender is equal to the loan balance added to the cost of repairing/rebuilding the housing minus the recoveries that the lender will recognize when selling the property. Losses also include lost interest payments before the property is sold.

## 2.7. Losses borne by the Mortgage Lending Industry

The mortgage loss study provided an estimate of $51 billion of loss to residential mortgage lenders from the M7.3 Puente Hills event for the base-case market scenario. Assuming market values rise as described in the upper bound market value case, the estimated losses to mortgage lenders drops significantly to $39 billion, the result of both the increase in the owner's equity in their house and the increased recoveries from the eventual sale of the house by the bank. Conversely, should market values fall as described in Table 1 as the lower bound case, the impact to mortgage lenders on aggregate rises to $68 billion. It must be noted that these losses do not consider potential for exacerbating conditions such as: a localized depression in market values caused by concentrations of buildings damaged resulting in the decreased desirability of damaged neighborhoods, the decrease in values resulting from an increase in houses being sold on the market, or decrease in demand for housing resulting from flight from the region by residents no longer willing to live in an earthquake-prone area.

Figure 6 illustrates the geographic distribution of the estimated mortgage losses by zipcode in the Los Angeles Basin. The distribution illustrates that the phenomena is complex – the contributions to mortgage lender losses are a function of the hazard (ground shaking) which varies non-monotonically through the region, but also that the spatial variation in property values as well as loan-to-value ratios has a significant impact on the probability of default even without the impact of a catastrophic earthquake.

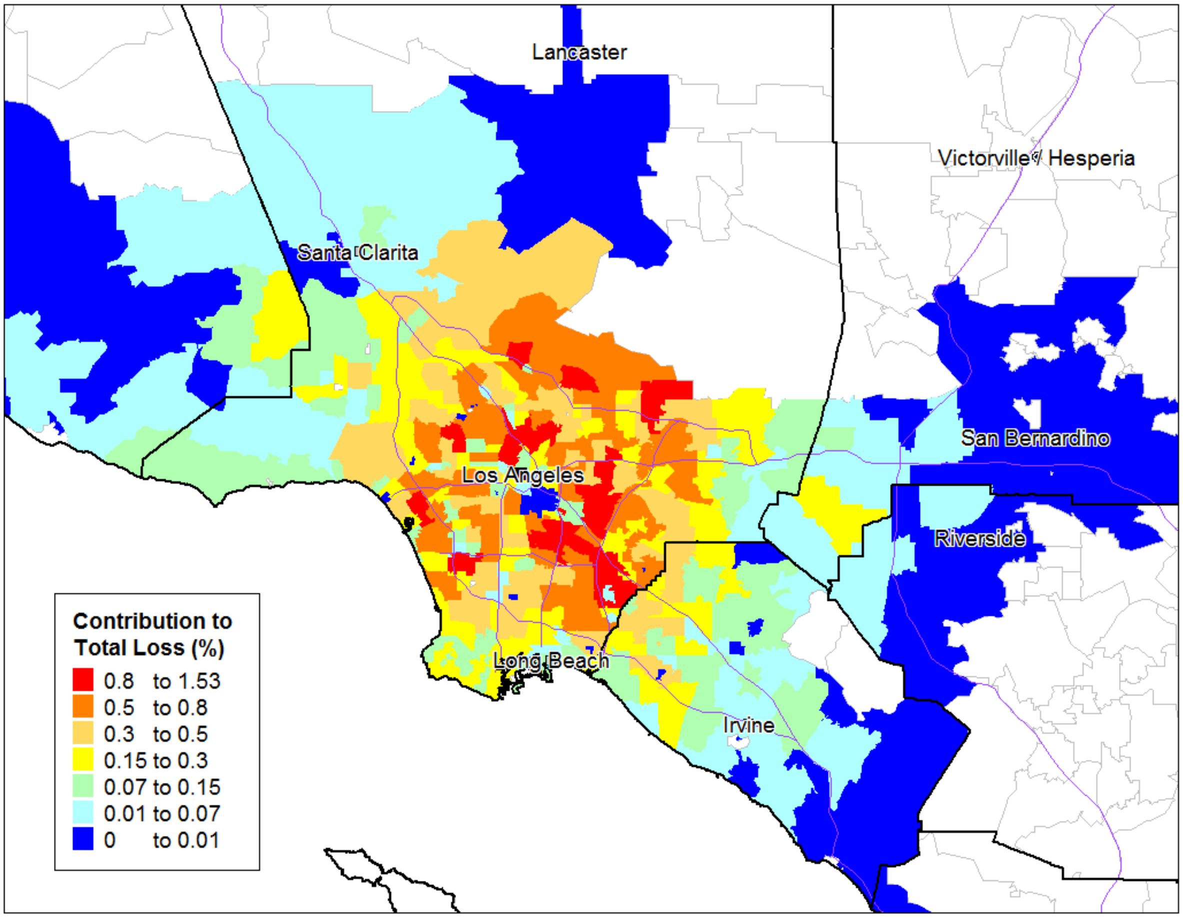


**Figure 6 – Geographic Distribution of Mortgage Lender Losses in Puente Hills Event**

## 3. Improving resiliency: New Tools available

Resiliency is defined as rebounding from the disaster and being stronger than before the disaster. This can be doing by anticipating what can happen and then developing plans that include both responding and strengthening.

It's just a matter of time before the Los Angeles Basin is struck by a damaging earthquake – whether it be a M7.3 earthquake on the Puente Hills Fault hypothesized in this paper or a large magnitude event on one of the other faults in the region. The seismological, engineering, and catastrophe risk management communities are well aware of the risk and continue to develop strategies to help prepare for such an event. Translating the risk of damage from earthquakes to purely financial terms, society is left with 3 alternatives to pay for the loss: Expenses before the event, either through insurance premiums or investments in the strengthening of properties, expenses immediately after the event, comprised of using savings to pay repair costs, and payment in arrears, leveraging loans and other lending facilities.

Minimizing the disruption and costs of devastating catastrophe requires the accurate assessment of the costs of the damage and ensuing economic disruption. In this paper, we have introduced the measurement of secondary losses to mortgage issuers, a real risk that is only a small portion of the spectrum of identifiable losses to industry and, eventually, the regional economy. The identification of more of these risks, and their quantification in an open and critical forum, can help society better measure the cost of catastrophes. And quantifying the cost is the first step in developing a more successful plan.

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