RMS WHITE PAPER

1868 HAYWARD EARTHQUAKE: 145-YEAR RETROSPECTIVE

RMS Special Report

Introduction

On October 21, 1868, a major earthquake on the Hayward Fault ruptured a section of the fault from the location of present-day Fremont to just north of Oakland (Yu and Segall, 1996). Until the 1906 Great San Francisco Earthquake and Fire, the event on the Hayward Fault was known as the "Great San Francisco Earthquake" for the damage it caused to the major population center of San Francisco. Damage along the Hayward Fault was extensive, with strong shaking and liquefaction destroying unreinforced masonry buildings in Oakland, as well as structures in Hayward and San Leandro (Figure 1). Chimneys were knocked down in cities as far away as Santa Rosa, located approximately 63 miles (100 km) north of Oakland. According to the San Francisco Bulletin, "the total loss of property [in San Francisco alone] was variously stated from $300,000 to $5,000,000….a careful estimate of damages made a day or two after the disaster, placed it at about $350,000."

Figure 1: Damage to the Alameda County Courthouse in San Leandro, California, following the 1868 Hayward Earthquake (Source: National Information Service for Earthquake Engineering, EERC, University of California, Berkeley)

In 2008, to commemorate the 140th anniversary of the 1868 Hayward Earthquake, Risk Management Solutions (RMS) investigated this historic event and explored the potential impacts of a similar event occurring again. *In 2013, following the 2009 release of the latest generation of the RMS® U.S. Earthquake Model and the 2011 release of the RMS U.S. Industry Exposure Database, the analyses in this event retrospective have been updated to reflect RMS' latest view of earthquake risk.*

As scientists have illustrated that the southern section of the Hayward Fault has ruptured, on average, every 140 years for the past 700 years, the passing of the 140th anniversary in 2008 is significant, as the fault is considered "locked and loaded" for a repeat. A series of six three-dimensional ground motion simulations provided by the United States Geological Survey (USGS, 2008) for alternative earthquake scenarios along the Hayward Fault have been utilized to estimate a range of economic and insured property losses, as well as the potential impacts to the Bay Area's infrastructure and economy. Implications for the earthquake insurance industry in California are highlighted, including the vulnerability of the property at risk and current mitigation efforts throughout the San Francisco Bay Area.

The 1868 Hayward Earthquake

Occurring at approximately 8:00 a.m. local time on October 21, 1868, the Hayward Earthquake was felt throughout the entire San Francisco Bay Area, with strong shaking lasting more than 40 seconds. The most recent studies of the earthquake have placed the moment magnitude between 6.8 and 7.0, with the earthquake creating up to 6 ft (1.8 m) of horizontal offset along a 28 to 37 mile (45 to 60 km) section of the Hayward Fault (Figure 2). Historical records indicate that strong aftershocks were felt throughout the region in the weeks following the main shock.

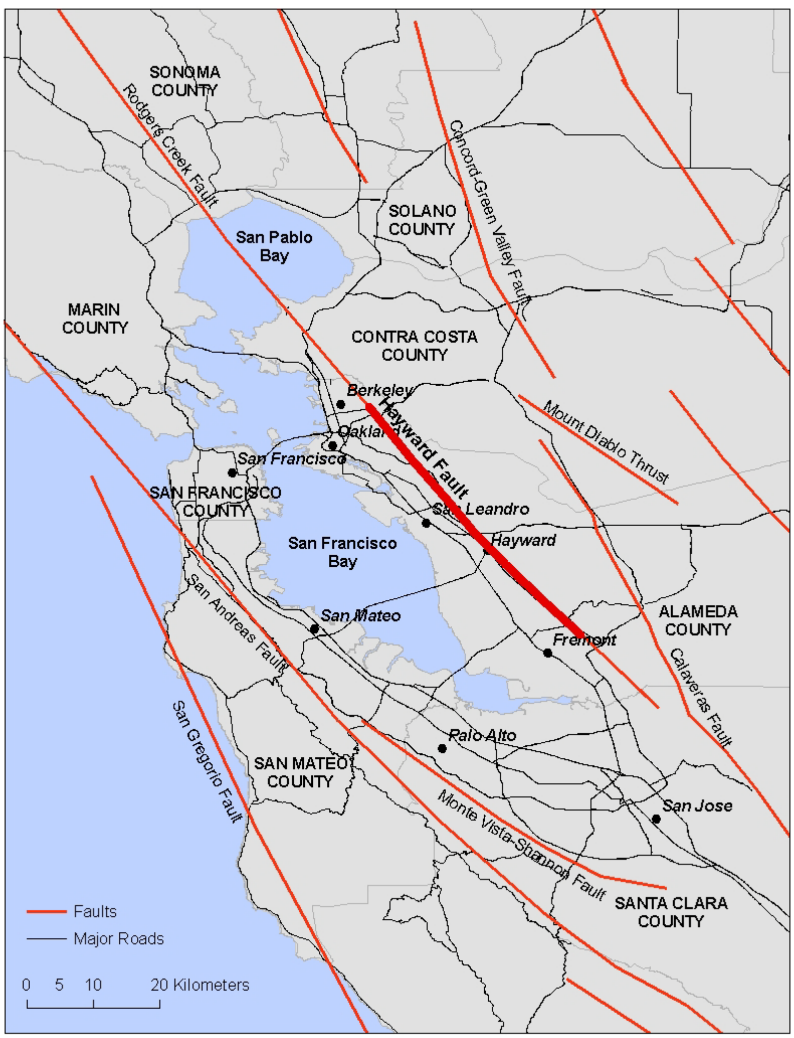

Figure 2: Map of the San Francisco Bay Area counties in 2013, highlighting the 1868 rupture on the Hayward Fault, as well as the surrounding faults

According to U.S. census records, at the time of the 1868 earthquake, the total population of the Bay Area was about 260,000, with approximately 10% of the population living along the Hayward Fault. Casualties from the earthquake totaled thirty people and most loss of life was a direct result of building collapse. The most severe damage was in small farming communities along the Hayward Fault, with nearly every building in the town of Hayward, with a population of 500 people, wrecked or severely damaged. In 2013, Hayward's population is 149,000 – almost 300 times the population of 1868.

In the city of San Francisco, the shaking and accompanying liquefaction severely damaged and destroyed unreinforced masonry buildings in the business district, and caused the ground to "open up" in many places. With approximately 150,000 individuals living in San Francisco, the city was the largest one on the U.S. West Coast at the time, and thus, the earthquake's damage to San Francisco was well-documented in the newspapers. Accounts of damage ranged widely—for example, the San Francisco Bulletin reported that "upon Russian and Telegraph Hills, the shock was not very damaging. In some houses on the latter, ornaments were not displaced from the mantel." In the Alta California, it was written that "at the junction of Market and Front Streets, the ground sank for a foot or two, and there was evidence that the tide had risen in the adjoining lot at the same time, for a pond of water collected and remained until low tide."

Damage was also chronicled in the Lawson Report (Figure 3), which was written following the 1906 Great San Francisco Earthquake and Fire (Lawson, 1908). In this report, it was written that "the portion of the city which suffered most was that part of the business district, embracing about 200 acres, built on 'made ground'; that is, the ground made by filling in the cove of Yerba Buena." The Lawson Report also chronicled damage in other locations, such as the Old Mission Church in San Jose, "which was of adobe, was shaken down, as were several other buildings at the same place."

Figure 3: Damage in downtown San Francisco as a result of the 1868 Hayward Earthquake (Source: National Information Service for Earthquake Engineering, EERC, University of California, Berkeley)

From these reports, it is clear that the vulnerability of structures constructed on bay fill or “made land” was understood, as was the importance of earthquake-resistant structures. According to one reporter for the San Jose Mercury News, it was recognized that “we need to correct our style of architecture…to work a savings of untold sums of money in the future.”

A Hayward Fault Earthquake in 2013

In 2013, the Hayward Fault transects the highly urbanized East Bay corridor of the San Francisco Bay Area. For most of its length, the Hayward Fault runs through Alameda County, transecting or adjacent to the city centers of Berkeley, Oakland, San Leandro, Hayward, and Fremont. As a result, close to 2.5 million people live on or near this fault zone, with over 7 million people in the surrounding counties of Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma. This is over 25 times the population of the region at the time of the 1868 earthquake. Within these eight counties, close to $1.9 trillion of residential and commercial properties are at risk from a major earthquake occurring along the Hayward Fault (Table 1). This property value is based on U.S. Census data, as well as the 2011 RMS® U.S. Industry Exposure Database (IED), which estimates total insured values for building, contents, and time element coverages (i.e., additional living expenses and business interruption).

The residents and additional workers, who commute daily into the Bay Area, depend upon the major lifelines and transportation routes that cross over the Hayward Fault. For example, a number of major roadways—including interstates 580, 680, and 80, as well as Highway 24—traverse the fault. In addition, the bulk of the water supply for the region flows from the East through pipelines that bisect the Hayward Fault. This infrastructure, as well as electric and gas lines, will most likely be damaged and disrupted during a major earthquake event, as the horizontal movement on the strike-slip fault will be significant.

Table 1: Property and people at risk from a significant earthquake on the Hayward Fault

County	Residential Property (in $ billions)	Commercial Property (in $ billions)	Population (in thousands)*
Alameda	$210	$150	1,550
Contra Costa	$215	$70	1,075
Marin	$70	$25	255
San Francisco	$85	$160	825
San Mateo	$140	$85	735
Santa Clara	$290	$185	1,840
Solano	$60	$25	420
Sonoma	$80	$30	490
Total	**$1,150**	**$730**	**7,190**

* Based on California Department of Finance January 1, 2013 estimates

A catastrophic earthquake on the Hayward Fault would almost certainly have ripple effects throughout California and the United States. The San Francisco Bay Area has one of the highest concentrations of people and wealth in the U.S., and is recognized as a center of innovation in the country, due to the high density of venture capital firms in Silicon Valley, located along the southern part of the San Francisco Bay. Due to the importance of this metropolitan region to the U.S., an accurate assessment of earthquake risk is vital, and this assessment begins with an understanding of the expected magnitude and recurrence of a major earthquake along the Hayward Fault.

Earthquake Magnitude

Scientists believe the Hayward Fault is segmented into two parts, often referred to as the North Hayward and South Hayward fault segments. Sometimes, one part of the fault ruptures—as it did in 1868 when the southern segment of the fault broke—and, sometimes, the fault ruptures along its entire length. As the magnitude of an earthquake is generally proportional to the length of rupture along a fault, an earthquake on one segment of the fault will be smaller than one along the entire length of the Hayward Fault. Comparing the length of the segments of the fault system with similar fault systems worldwide (e.g., North Anatolian Fault in Turkey), scientists of the USGS have estimated a maximum magnitude of 6.8 for an event on the South Hayward Fault and a magnitude of 7.0 for an earthquake rupturing both the North and South Hayward fault segments.

Earthquake Recurrence

Recent studies by the USGS, in cooperation with the California Geological Survey (CGS) and the Southern California Earthquake Center (SCEC), indicate that the expected probability of a major earthquake ($M \geq 6.7$) on the Hayward and Rodgers Creek fault systems in the next 30 years is over 30% (WGCEP, 2008)[1]. This ranks as the largest probability of occurrence among the seven major fault systems in the Bay Area (denoted “Type A” faults by the USGS). This high likelihood is based in part on recent geologic studies along the Hayward Fault near Fremont, California, revealing that the South Hayward Fault has generated twelve major earthquakes in the last 1900 years, on average every 160 ± 65 years[2]. As previously noted, the last five earthquakes have been shown to occur more frequently, at an average interval of about 140 ± 60 years.

Ground Motion

The pattern and intensity of ground shaking during an earthquake depends on three key factors: the earthquake’s source; the seismic waves’ attenuation from source to site; and the site conditions. A key component of the source “factor” is the earthquake magnitude: the larger the magnitude, the greater the ground motion. Other source factors influencing ground motion include variations in slip along a fault’s rupture length, as well as the direction in which the fault ruptures.

The attenuation of seismic waves from their underground source to the surface of the Earth is itself highly dependent upon “path effects”—the geological structures the seismic waves encounter as they move through the Earth can absorb or refract seismic energy, impacting seismic attenuation. In particular, thick accumulations of soft sediment in basins can trap seismic energy and amplify it, causing a longer duration of

[1] The Rodgers Creek Fault and the Hayward Fault were treated as a single fault system in the Working Group on California Earthquake Probabilities (WGCEP) study, as the Rodgers Creek Fault is considered a continuation of the Hayward Fault north of San Pablo Bay. Therefore, while it was assumed that the Hayward and Rodgers Creek faults rupture independently most of the time, a small likelihood (~5%) was assigned to the scenario where the two faults rupture together, producing a magnitude 7.4 earthquake.

[2] This estimate includes one standard deviation of uncertainty, ranging between 95 years and 225 years.

ground shaking. The site conditions near the surface—in particular, the existence of soft (or clay) soils—can further amplify the seismic waves relative to sites with underlying rock.

Overall seismic energy decays with distance from a fault rupture, following behavior that is defined by an attenuation relationship appropriate to a particular region. While attenuation relationships are widely accepted in earthquake engineering practice, both recordings of large earthquakes and theoretical studies indicate a wide variability in these empirically-based relationships, primarily due to the above-mentioned factors.

Numerical Modeling

RMS has collaborated with a group of U.S. research seismologists in order to investigate the variation in expected losses due to different realizations of a major earthquake rupturing the Hayward Fault. Fifteen researchers from five institutions—the USGS, Lawrence Livermore National Laboratory (LLNL), University of California, Berkeley, Stanford University, and URS Corporation—collaborated on the research, with the USGS taking the lead. The work has involved applying three-dimensional numerical modeling to predict the variation in shaking intensity from a range of possible earthquakes on the Hayward Fault[3]. This type of numerical modeling begins with a detailed geometry of the fault systems in the Bay Area which are embedded in a three-dimensional seismic velocity model of the upper 20 miles (32 km) of the Earth's crust. The seismologists then simulate an earthquake by prescribing a particular pattern of slip on the fault and propagating the seismic energy released through the crustal model to produce synthetic ground motion seismograms throughout the region. In all, the researchers considered a set of 35 scenarios for ground motion calculations, which reflect variations in rupture length, hypocenter (i.e., point along the fault where the rupture initiates), and slip distribution, among other parameters.

From the suite of 35 scenarios, a set of six simulations were chosen for loss modeling. At the present time, seismologists cannot assess which, if any, of these alternate scenarios might be most likely for the next earthquake on the Hayward Fault or be most representative of the 1868 earthquake. These are simply six of an infinite possible range of realizations for a Hayward Fault earthquake.

Figures 4(a) through 4(f) illustrate the shaking intensity footprints computed from the ground motion simulations for these six Hayward Fault earthquake scenarios. Three scenarios represent magnitude 6.8 earthquakes on the southern segment of the Hayward Fault, and three represent magnitude 7.0 earthquakes rupturing the entire length of the Hayward Fault. The scenarios were selected to investigate the effects of the rupture propagation pattern or directivity, which results in a focusing of the seismic energy in the direction of rupture. This was done by keeping all fault slip parameters for the two different magnitudes identical and only varying the starting point (hypocenter) of the earthquakes. The alternate scenarios have hypocenters at the north, center, and south end of the ruptures; these are respectively denoted by the researchers as Oakland, Hayward, and Fremont for the M6.8 events and as San Pablo, Oakland, and Fremont for the M7.0 events).

The regional patterns of shaking intensity in Figures 4(a) through 4(f) are depicted by Modified Mercalli Intensities (MMIs), with the warmest colors (orange to red) representing the strongest ground shaking. A comparison of the footprints illustrates that the areas of strongest shaking for the M7.0 events (on the right) are generally more than twice the size of the areas of strongest shaking for the M6.8 events (on the left). This is consistent with the increase in the amount of energy released during a magnitude 7.0 earthquake compared to a magnitude 6.8 earthquake.

[3] http://earthquake.usgs.gov/regional/nca/simulations/hayward/

For hypocenters near the northwest end of the rupture [Figures 4(a) and 4(b)], the earthquakes focus energy primarily to the southeast. While the areas of strongest shaking for the M6.8 event beginning at Oakland [Figure 4(a)] are focused within Alameda County toward Santa Clara County, the areas of strongest shaking for the M7.0 event beginning at San Pablo Bay [Figure 4(b)] extend more than fifty miles (80 km) south of Fremont and beyond the town of Gilroy, as well as extending significantly eastward into the Central Valley.

In the scenarios with hypocenters near the center of the fault rupture—Hayward in the case of a South Hayward Fault rupture, or Oakland in the case of a full Hayward Fault rupture [Figures 4(c) and 4(d)]—the earthquakes propagate simultaneously to the northwest and southeast. For the M7.0 scenario of NW-SE propagation, similar to the M7.0 scenario shown in Figure 4(b), a southern expansion of strong shaking is observed. In addition, the buried basins east of San Jose, which trap and amplify ground motion, expand the area of strong shaking.

For a hypocenter near the southeast end of the fault near Fremont [Figures 4(e) and 4(f)], both the M6.8 and M7.0 earthquakes rupture unilaterally toward the northwest and the ground shaking is clearly focused in that direction. As a result, there is virtually no strong shaking south of Fremont and the concentrations of exposure in Oakland and northward along the San Pablo Bay would sustain the strongest ground shaking.

M6.8 earthquake along South Hayward Fault

M7.0 earthquake along full length of Hayward Fault

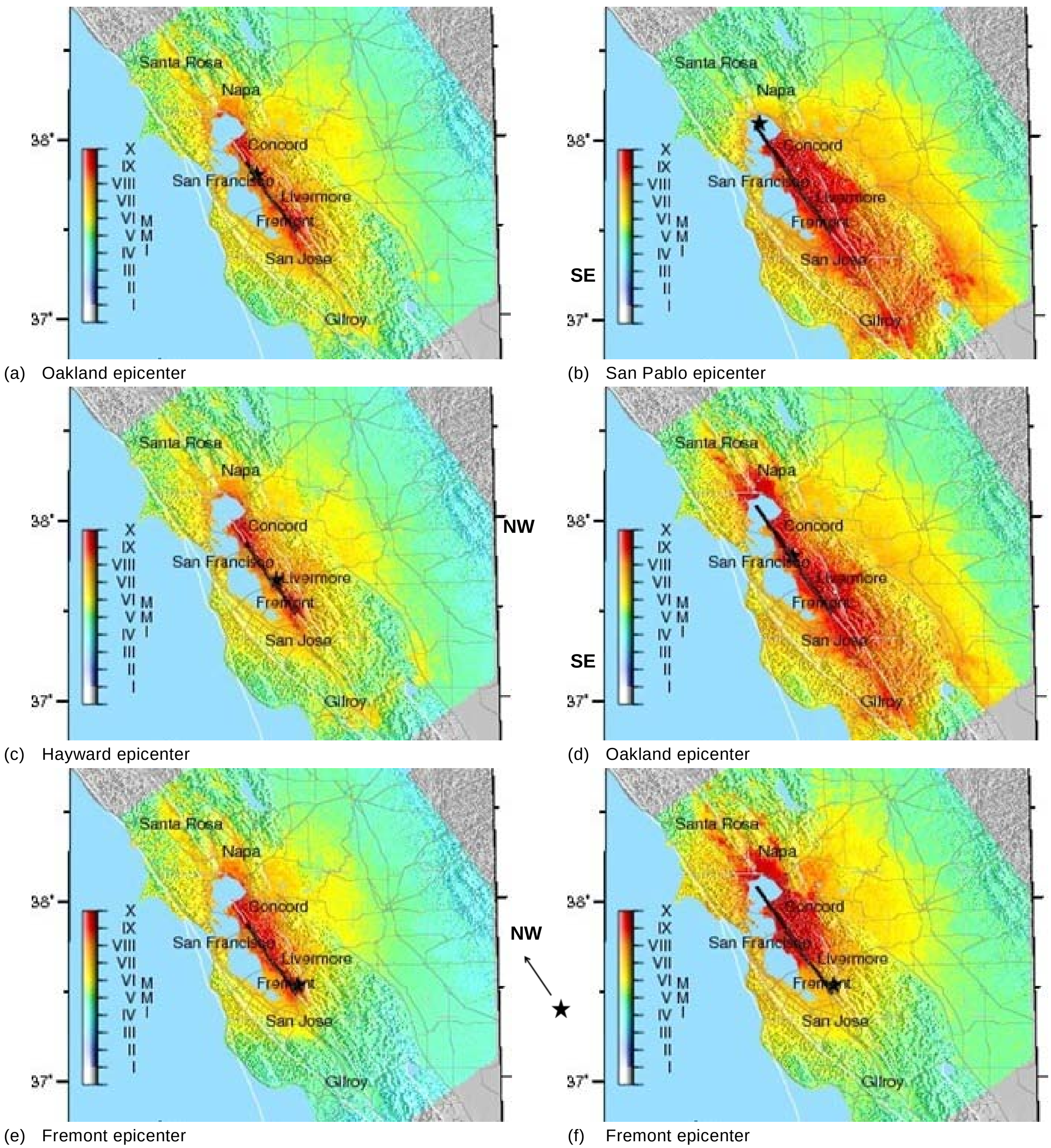

Figure 4: Three-dimensional ground motion simulations illustrating potential Modified Mercalli Intensities (MMIs) for events of M6.8 or M7.0 propagating from different hypocenters (starred locations) along the south segment or entire Hayward Fault. Arrows between the two columns indicate direction of fault rupture propagation and directivity.

Impacts of a Hayward Earthquake in 2013

In order to determine the potential property loss from a major earthquake along the Hayward Fault in 2013, the six ground motion footprints presented in the previous section were transformed into RMS footprint files and run against the 2011 RMS® Industry Exposure Database (IED) in the 2013 version of the RMS® U.S. Earthquake Model. Ground motion parameters provided by the research seismologists for the loss analysis include MMI, as shown in Figures 4(a) through 4(f), as well as peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration (Sa) at 0.3, 1.0, and 3.0 seconds. In the RMS® U.S. Earthquake Model, the spectral response methodology is implemented to determine the vulnerability of properties at risk from earthquake damage. Therefore, the spectral acceleration values at 0.3, 1.0, and 3.0 seconds are used to correlate ground motion to building performance based upon building height, construction material, and ground motion propagation. A suite of vulnerability curves has been calibrated for the predominant construction types in California (e.g., wood frame, reinforced concrete, reinforced masonry, steel frame), as well as for buildings of various heights and years of construction.

While the entire Northern California region would feel the ground motion from a M6.8 or M7.0 event on the Hayward Fault, the eight counties of Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma would sustain the majority of the damage. In addition, the strong shaking of a Hayward Fault earthquake is likely to produce both liquefaction, particularly in areas of fill along the San Francisco Bay, and isolated landslides, along the steep topography east of the fault.

Modeled Perils

A range of economic and insured losses to residential and commercial property from the six scenarios (i.e., three M6.8 earthquakes on the South Hayward Fault and three M7.0 earthquakes on the full Hayward Fault) are presented in Table 2. These loss estimates include damage due to earthquake ground shaking and fire following earthquake (FFEQ). Ground shaking losses are a direct function of the level of ground motion in the six simulations, including additional damage due to liquefaction and landslides. FFEQ losses are calculated using a simulation approach to model the behavior of fire ignition, spread, and suppression throughout the urban and suburban areas of the San Francisco Bay Area. In order to accurately estimate overall losses, burnt structures already severely damaged by the earthquake's ground shaking are not counted in the loss estimates (i.e., no double counting or "burning of rubble").

Moreover, the calculation of both economic and insured losses assumes some level of "loss amplification." For example, a shortage in materials and labor following a major earthquake on the Hayward Fault will result in higher repair costs. Delays in making repairs, due to the unavailability of builders or the difficulties in inspecting and repairing a property, can translate into increased damage. Heavy winter rains following a devastating earthquake along the Hayward Fault could greatly increase the damage to unrepaired homes open to the elements. Moreover, litigation in assessing damage and repair costs can also drive up the final costs of insurance payments. Business interruption (BI) losses can be contingent upon damage to regional lifelines or interruptions to supply and distribution chains.

All of the ways in which an insurance payment can increase in the context of a major catastrophe—beyond the loss incurred if a building had been damaged in isolation—are termed loss amplification. As given by the above examples, this includes economic demand surge (reflecting shortages of builders and materials), repair delay inflation (such as rain damage), and claims inflation (difficulties in insurer's policing claims costs). Perhaps most importantly, in a major California earthquake, there could be significant coverage expansion, reflecting the way in which the terms of an original insurance contract expand to cover additional sources of loss or higher limits. Due to the strong asymmetry in residential earthquake and fire insurance penetration (i.e., around 10% penetration of earthquake coverage versus over 90% penetration of fire coverage), homeowners may argue that a fire insurance policy should pay for some component of the damage resulting from the earthquake.

Table 2: Range of economic and insured losses to the residential and commercial lines of business from six ground motion scenarios on the Hayward Fault in 2013

Epicenter*	Economic Losses (in $ billions)			Insured Losses (in $ billions)		
	Residential	Commercial	Total	Residential	Commercial	Total
M6.8 on South Hayward Fault						
(a) Oakland	$50.0	$49.5	$99.5	$4.0	$7.5	$11.5
(c) Hayward	$47.5	$48.5	$96.0	$4.0	$7.5	$11.5
(e) Fremont	$49.5	$51.5	$101.0	$4.5	$8.0	$12.5
M7.0 on full Hayward Fault						
(b) San Pablo	$96.5	$88.5	$185.0	$8.0	$15.0	$23.0
(d) Oakland	$88.5	$84.0	$172.5	$7.5	$14.5	$22.0
(f) Fremont	$94.0	$92.5	$186.5	$9.5	$16.5	$26.0

* As noted in Figure 4

Distribution of Property Damage

Total residential and commercial property damage for the three earthquake scenarios that rupture the entire Hayward Fault ranges between approximately $170 and $190 billion. For the M6.8 scenarios, which rupture only the southern segment of the fault, the total economic loss is estimated between approximately $95 and $100 billion. Of this total damage, residential and commercial losses are fairly evenly distributed, with commercial losses comprising slightly more of the total loss.

Losses to the eight counties sustaining the majority of the damage are presented in Figures 5 and 6. Figure 5 illustrates losses by county for the M6.8 scenarios; Figure 6 displays county losses for the M7.0 scenarios. Several key observations can be made regarding the scenario footprints and distribution of losses. First, the losses associated with the M7.0 scenarios are close to twice the losses for the M6.8 scenarios. This is most notable for the scenarios with ruptures beginning at the northwest end of the fault—in Oakland for the South Hayward rupture and in San Pablo for the full Hayward rupture—where the losses for the M7.0 scenario are $190 billion and the M6.8 scenario losses are approximately $100 billion.

In all scenarios, Alameda County sustains the highest percentage of the total loss, ranging from 45% to 50% of the total loss. As the fault runs through the center of the western, most populous portion of the county, this result is not surprising. In addition, the five counties of Alameda, Contra Costa, San Francisco, San Mateo, and Santa Clara sustain over 95% of the total loss across all six scenarios.

However, the distribution of losses for the counties varies significantly by scenario and is largely a function of directivity, the focusing of seismic energy in the direction of rupture. This focusing of the ground shaking increases the losses to the concentrations of property exposure at the end of the fault opposite the epicenter. For example, in the case of the M7.0 scenario centered at San Pablo Bay, less than 1% of loss is in Sonoma and Solano counties, while close to 20% of the loss is concentrated in Santa Clara County along the southern San Francisco Bay. Moreover, the amplification of ground motion due to the basins east of San Jose, in conjunction with this directivity, causes losses in Santa Clara County to be a significant proportion of overall losses for the M7.0 earthquakes centered at San Pablo and Oakland. Directivity results in a wide range of losses projected for Santa Clara County—from approximately $15 billion to over $35 billion for the three M7.0 scenarios. This variation presents challenges for mitigation and emergency response planning.

Other directivity effects are seen for the northwest propagating ruptures. The scenarios with epicenters near Fremont produce the highest percentage loss in San Francisco County—between 10% and 15% of the total loss for these scenarios. Losses in Alameda County are also highest (in terms of percentage of overall total loss) for the earthquake scenarios centered in Fremont.

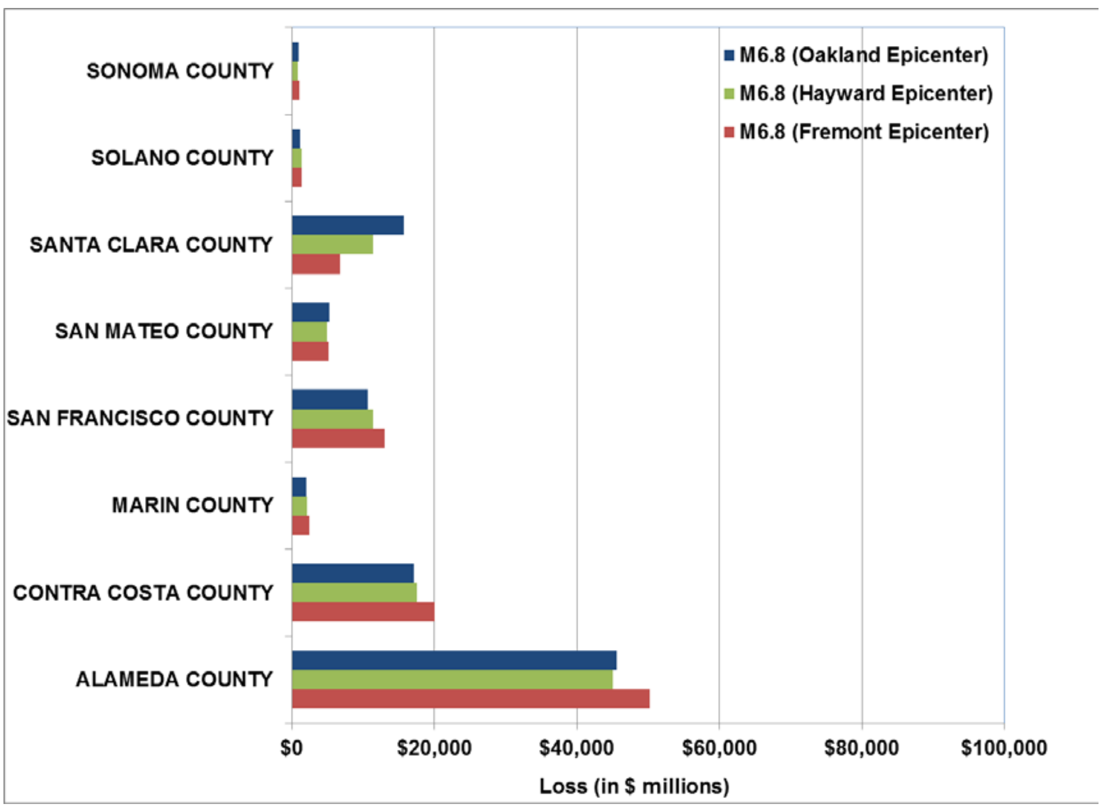

Figure 5: Economic losses by county for M6.8 earthquakes on the South Hayward Fault

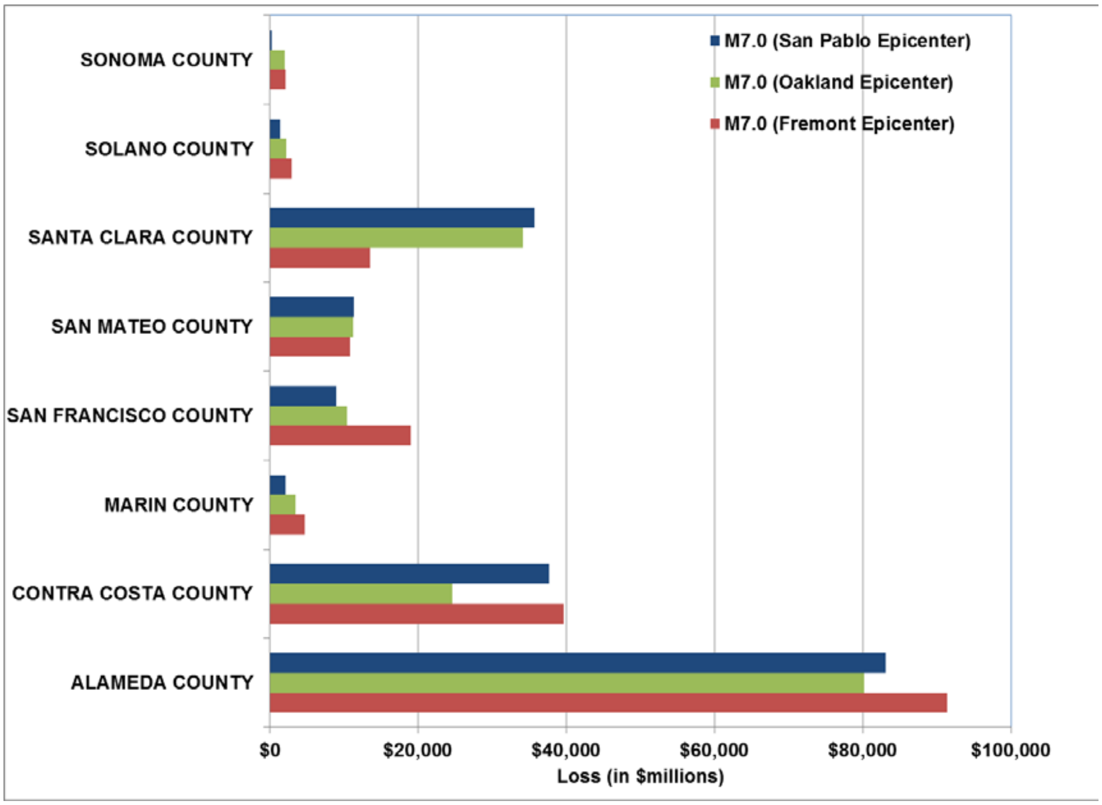

Figure 6: Economic losses by county for M7.0 earthquakes on the full Hayward Fault

Insured Losses

The insured losses from the six scenario earthquakes along the Hayward Fault are broken down by peril in Table 3 and their spatial distribution illustrated in Figures 7(a) through 7(f). These loss estimates, which range between approximately $11 and $26 billion, reflect insurance payments for residential and commercial earthquake coverage, as well as fire coverage for urban fires that will most likely break out following a major earthquake on the Hayward Fault. RMS estimates that, for all six scenarios, over 85% of the insured losses will be covered by earthquake policies with the remaining payments covered under fire policies. As previously mentioned, these estimates reflect some level of loss amplification in insurance payments—due to economic demand surge, repair delay and claims inflation, as well as coverage expansion.

Table 3: Breakdown of insured losses by peril from six ground motion scenarios on the Hayward Fault in 2013

Scenario	Insured Losses (in $ billions)		
	Earthquake Ground Shaking	Fire Following Earthquake	Total
M6.8 (Oakland Epicenter)	$10.5	$1.0 - $1.5	$11.5 - $12.0
M6.8 (Hayward Epicenter)	$10.0	$1.0 - $1.5	$11.0 - $11.5
M6.8 (Fremont Epicenter)	$11.0	$1.0 - $1.5	$12.0 - $12.5
M7.0 (San Pablo Epicenter)	$21.5	$1.5 - $2.0	$23.0 - $23.5
M7.0 (Oakland Epicenter)	$20.0	$1.5 - $2.0	$21.5 - $22.0
M7.0 (Fremont Epicenter)	$22.5	$2.5 - $3.5	$25.0 - $26.0

Loss amplification effects increase the insured losses by between 25% and 35% in all six scenario earthquakes. These effects are most magnified, however, for business interruption (BI) coverage following the M7.0 events rupturing the full Hayward Fault. This is primarily due to the “cascade of consequences” expected following an event of this size in the San Francisco Bay Area. Significant landslide and liquefaction damage or direct fault rupture to primary access roads, for example, will exacerbate delays in response and recovery efforts. Any dam failures can cause inundation downstream, resulting in the evacuation of buildings not damaged by the earthquake. Fires jumping between urban and wildland settings could potentially cause additional loss. All of these factors, including potential massive infrastructure failure, would lead to prolonged business interruption.

Commercial earthquake insurance (for building, contents, and direct business interruption) will cover approximately 70% of the insured ground shaking loss, with the remaining insured loss covered under residential earthquake policies. Residential earthquake coverage in California is purchased either through a member insurer of the California Earthquake Authority (CEA) or a private insurer. In 2013, the CEA is the market leader in providing earthquake insurance to homeowners. The statutory minimum (basic) coverage allows 15% deductible with low limits on personal property and loss of use ($5,000 limit on contents and $1,500 limit on additional living expenses). While the CEA-participating insurers now offer higher limits on contents and loss of use coverages (e.g., $100,000 and $25,000, respectively), approximately 90% of the homeowners policies in force (as of September 2013) have the basic coverage (CEA, 2013).

Due to the structure of insurance coverage, the penetration rate of CEA insurance coverage statewide has fallen from 33% in the mid-1990s to around 10%—the lowest level since the formation of the CEA after the 1994 Northridge Earthquake (Hemenway, 2012). CEA policies currently represent about half of the residential earthquake insurance policies written in the highly-populated San Francisco Bay Area counties; across the state of California, CEA policies represent approximately 70% of the residential earthquake policies. The balance of the residential policies, which also suffer from low penetration, is covered by the private market. Low insurance penetration combined with high policy deductibles translates into an even smaller percentage of the total residential loss being covered by insurance for a Hayward Fault earthquake. For the six scenarios along the Hayward Fault, between approximately 5% and 10% of the residential ground shaking loss will be covered by residential earthquake insurance.

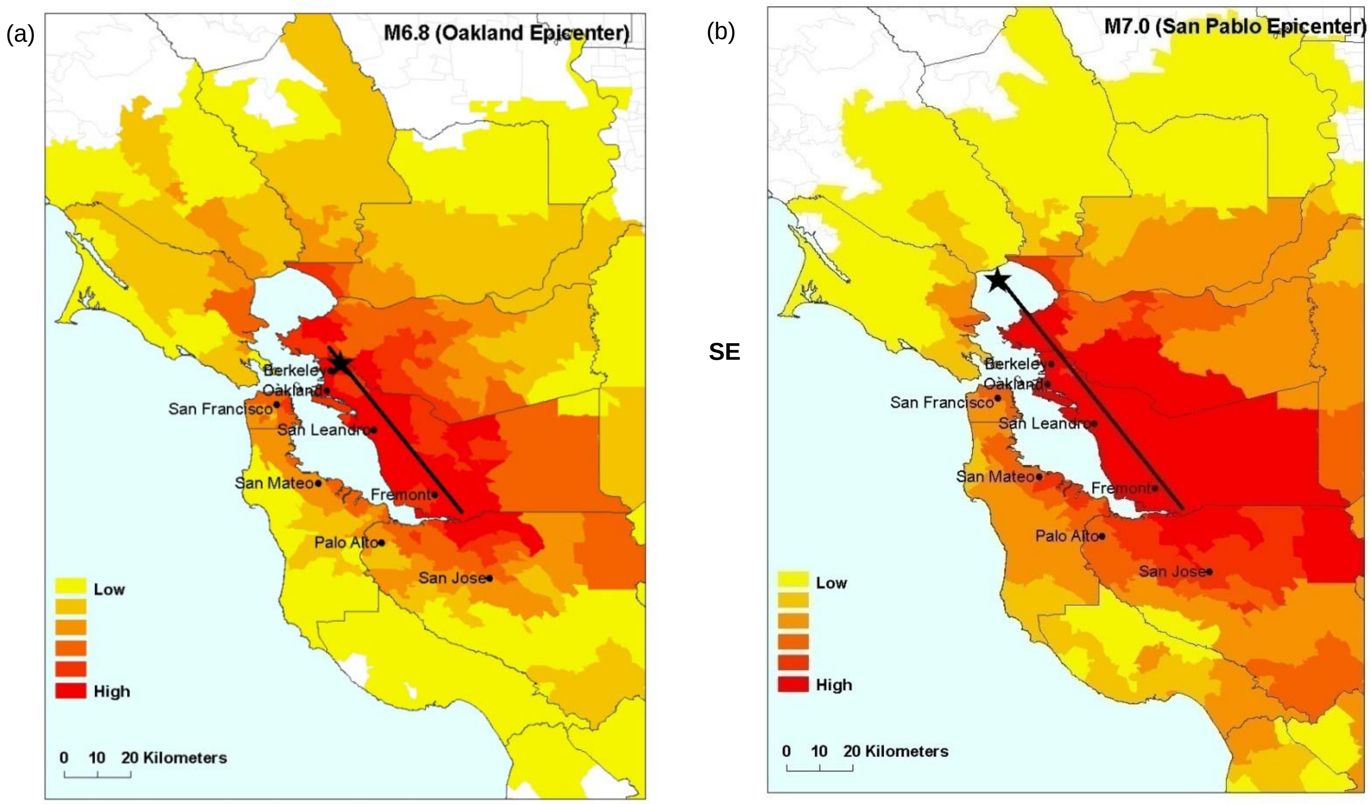

Figure 7: Maps of insured loss ratio by postal code illustrating the distribution of loss for six scenario events along the Hayward Fault: stars represent epicenter locations, arrows indicate direction of rupture propagation

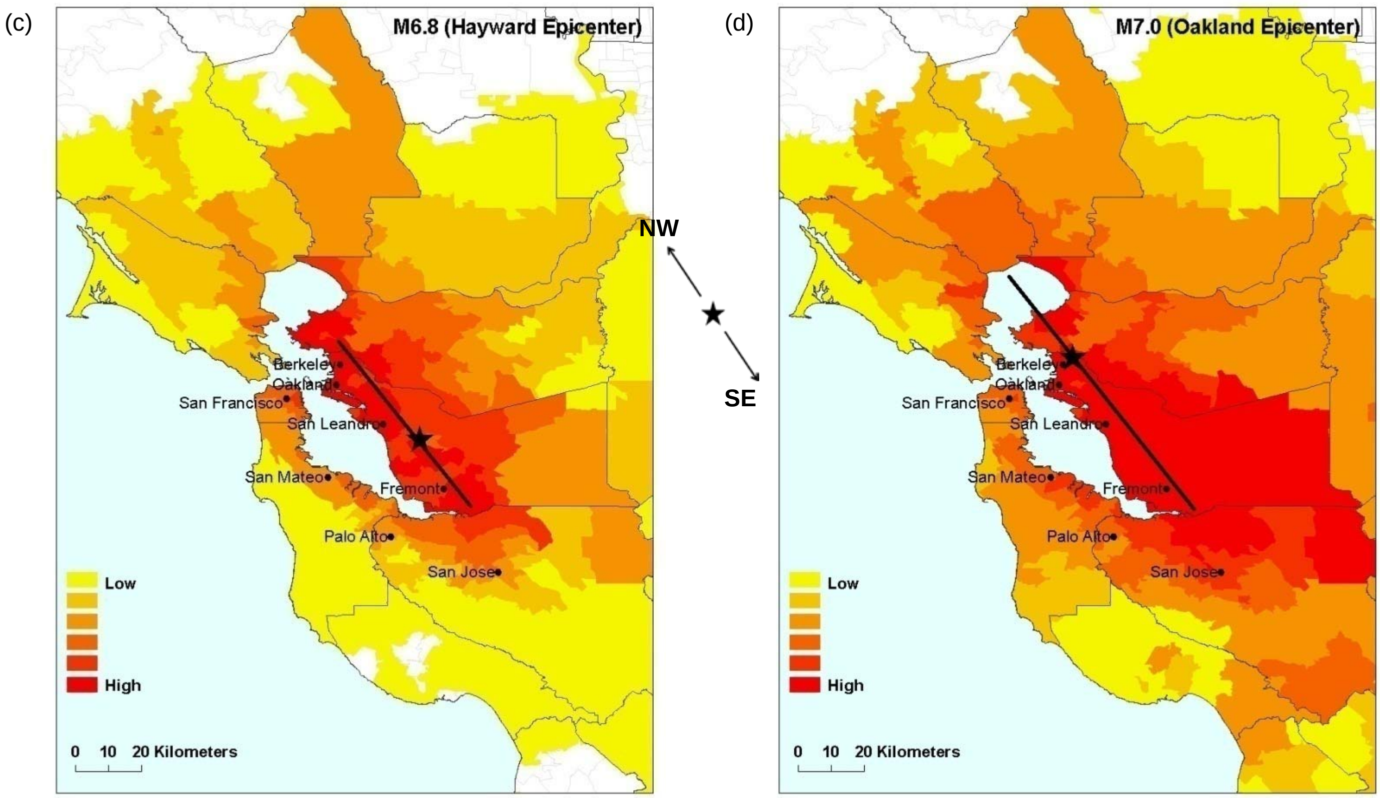

Figure 7: Maps of insured loss ratio by postal code illustrating the distribution of loss for six scenario events along the Hayward Fault: stars represent epicenter locations, arrows indicate direction of rupture propagation (continued)

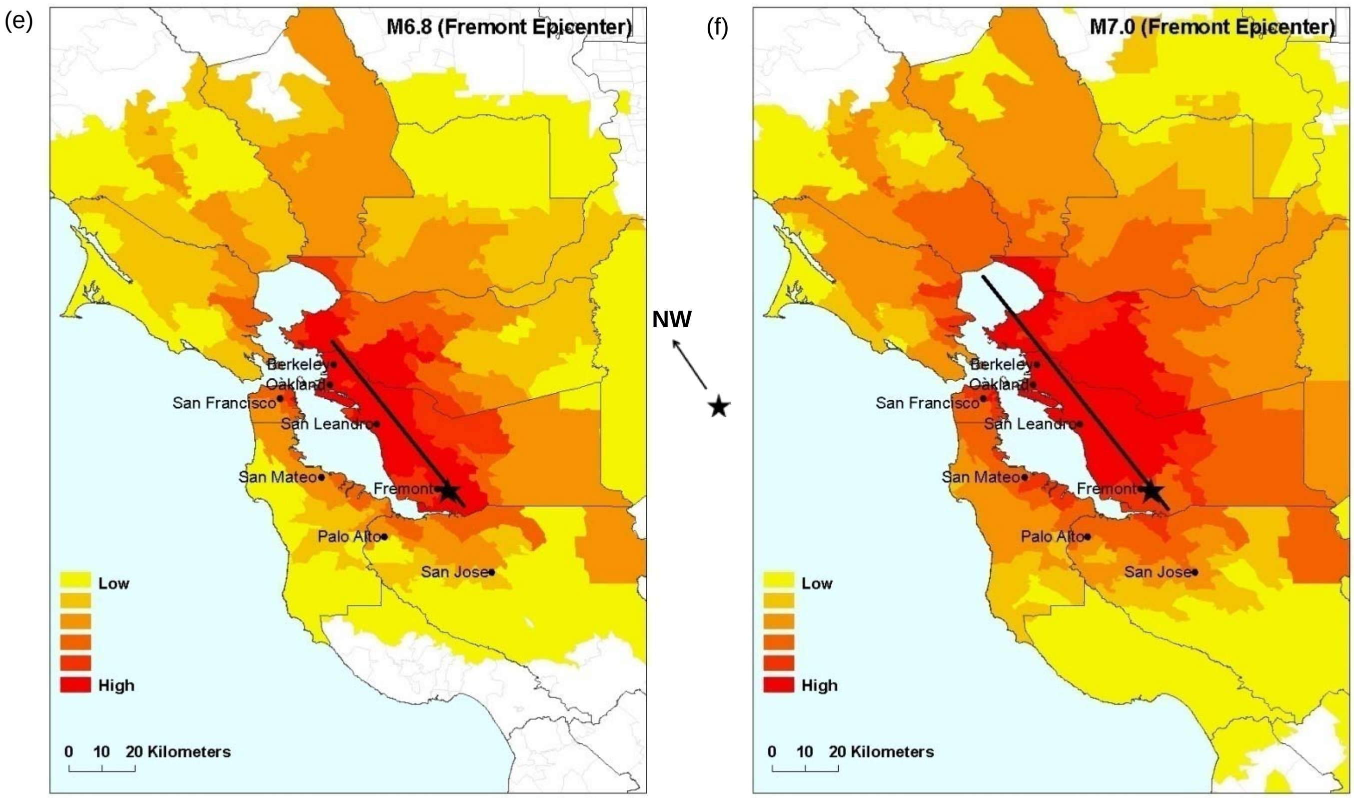

Figure 7: Maps of insured loss ratio by postal code illustrating the distribution of loss for six scenario events along the Hayward Fault: stars represent epicenter locations, arrows indicate direction of rupture propagation (continued)

Infrastructure Impacts

The unique geographic setting of the Bay Area compounds the risks posed by earthquake damage. Most of the population resides in one of two northwest-southeast corridors, the one to the west paralleling the San Andreas Fault and one to the east situated on and adjacent to the Hayward Fault. This population is serviced by an infrastructure network that is extremely susceptible to damage from a major Hayward Fault earthquake as the fault crosses nearly every east-west connection that the Bay Area depends upon for water, electric, gas, and transportation. Disruption will be a function of the horizontal and vertical displacements along the fault rupture, as well as the strong ground shaking in conjunction with liquefaction and landslides. Horizontal offsets will dominate and could average two feet (0.6 m) for a M6.8 event and 4 feet (1.2 m) for a M7.0 event on the Hayward Fault, with local displacements of 6 to 8 feet (1.8 to 2.4 m) and 7 to 10 feet (2.1 to 3 m), respectively. The design and construction of major infrastructure and lifelines that can survive such large displacements is a significant challenge.

The major infrastructure systems likely to be impacted by a major Hayward Fault earthquake include water, electric and gas power, gas refineries, and transportation networks, including roadways, bridges, airports, ports, and the Bay Area Rapid Transit (BART) (Figure 8).

Water

The majority of the San Francisco Bay Area water supply flows into the region from the Sierra Nevada Mountains by way of two major aqueduct systems. Both systems cross the Hayward Fault and other faults to the east (e.g., the Calaveras Fault). In addition, the water is transported across the San Francisco Bay to the Peninsula side of the bay in vulnerable elevated pipelines, constructed over 70 years ago. Many distribution pipelines run through liquefaction-prone fill along the margins of the bay.

The two principal water suppliers, who both have pipelines crossing the Hayward Fault, have already considered how to manage the earthquake threat. The San Francisco Public Utilities Commission (SFPUC), with 2.4 million customers, is currently upgrading and retrofitting its entire Hetch-Hetchy system. The East Bay Municipal Utilities District (EBMUD), with 1.3 million customers, underwent a system-wide upgrade and retrofit following the 1989 Loma Prieta Earthquake. Until the Hetch-Hetchy retrofit is complete by 2015, the SFPUC has estimated that, in the event of a catastrophic failure (potentially from a major earthquake on the Hayward Fault), some customers would be left without water for 10 to 30 days, and, in some instances, for as much as 60 days (CH2M HILL et al., 2000). In the event of a magnitude 7.0 earthquake on the Hayward Fault, EBMUD has projected that up to one-third of their reservoirs and two-thirds of their pumping plants would become inoperable. They also estimate that over 60% of their customers would initially be without water, and it could take as much as 60 days to restore intermittent service (EBMUD, 1994).

Electric and Gas Power

The region's principal power supplier, Pacific Gas & Electric (PG&E), has invested about $2.5 billion over the past twenty years to strengthen its buildings, as well as its transmission and distribution systems (EERI, 2006). However, while the major gas pipelines have been strengthened, the Hayward Fault crosses hundreds of streets underlain by gas distributions lines. Moreover, the primary power distribution in the East Bay relies on two overhead lines and two high-voltage underground cables, all of which cross the Hayward Fault. PG&E has stated that its goal would be to restore electric power to the majority of their customers within three days. Recent experience in past catastrophic hurricane events have shown that failure of critical components of transmission lines can delay power restoration by many days or weeks. PG&E has invested in seismic improvements of the Larkin Street substation in San Francisco and the Val-Dixon Substation in Vallejo (Maffei, 2009). PG&E is also proposing to retrofit the Embarcadero and Potrero subsations in San Francisco and constructing new transmission lines between them (California Public Utilities Commission, 2013). This is an essential upgrade since most of downtown San Francisco is supplied by the Embarcadero Substation. Additionally, retrofit and sustainability upgrades were completed at the Central Services Garage in San Francisco to ensure that trucks will be able to safely deploy after an event (Maffei, 2009).

Gas Refineries

The vast majority of the gasoline used in the San Francisco Bay Area is refined at six major refineries, located within 3 to 13 miles (4.8 to 20.9 km) of the Hayward Fault. In addition, nearly all of the main crude and refined product pipelines supplying the Bay Area cross the Hayward Fault and many also cross liquefaction-prone areas around San Pablo Bay. It is not known if the construction of steel pipelines included a provision to accommodate fault movement. Experience shows that older steel pipelines are likely to fracture (Matsuda, 1996).

Following a number of recent earthquakes around the world, large fires at oil refineries and tank farms have burned for days. Examples include the Tüpras Refinery in the 1999 Izmit Earthquake in Turkey and the Idemitsu Kosan Hokkaido Refinery in the 2003 Hokkaido Earthquake (Scawthorn, 2008). And although the

Bay Area refineries have emergency plans to fight fires, if water supplies are substantially disrupted, fire fighting could be severely hampered.

Roadways

Major roadways that transport goods and people into the Bay Area, including interstates 580, 680, and 80, and Highway 24, all cross the Hayward Fault. A M7.0 earthquake rupturing the full Hayward Fault would severely damage or offset all of these major freeways. In addition, many routes through the hills of the East Bay would be subject to closure due to landslides or rock falls in steep areas. Further road closures are expected along the main north-south transportation routes, interstates 880 and 101, which run along the East Bay and Peninsula side of the San Francisco Bay, respectively. Significant stretches of these two interstates are built on fill, particularly near San Francisco, Oakland and Berkeley. The Association of Bay Area Governments (ABAG) has estimated over 1,000 of the expected 1,700 road closures following a magnitude 7.0 Hayward earthquake would be in Alameda County (ABAG, 2010). Thus, in addition to damage and disruption on the major transportation routes, the surface road network will also be extensively impaired.

Bridges

The California Department of Transportation, known as Caltrans, has been performing seismic retrofits of bridges and overpasses throughout the state for the past twenty years. All of the older bridges in the San Francisco Bay Area have either been replaced or strengthened. Most recently, the eastern span of the San Francisco–Oakland Bay Bridge, which was damaged during the 1989 Loma Prieta Earthquake, was completed in 2013.

Airports and Ports

The Port of Oakland and two of the three major international airports in the San Francisco Bay Area (Oakland, and San Francisco) are built on bay fill, which is highly susceptible to liquefaction. Liquefaction often induces lateral spreading, which tears apart roads and other paved surfaces. Lateral spreading induced by liquefaction from the 1989 Loma Prieta Earthquake, with an epicenter 50 miles (80 km) away, shut down one runway at the Oakland International Airport. A Hayward Fault earthquake would be less than 5 miles (8 km) away. In addition, even if the Port of Oakland survives the strong shaking, it is likely that the roadways to and from the port will be damaged and potentially impassible, effectively shutting down the port's facilities.

Bay Area Rapid Transit (BART)

Transporting more than 350,000 commuters per day, the BART system transects the East Bay, with a main line generally parallel to and sometimes crossing the Hayward Fault. A vulnerability study conducted by BART in 2002 concluded that both the Transbay Tube, which lies on the San Francisco Bay floor, and the Berkeley Hills Tunnel, which connects the Orinda and Rockridge stations, will likely suffer significant damage in the next major Bay Area earthquake and be closed for up to two years (EERI, 2006). In 2008, BART has begun a $1.3 billion, 5-year retrofit program, which will strengthen the Transbay Tube and replace all of the support columns at elevated BART stations. In 2013, many of retrofit projects of BART stations and elevated structures have been completed along the Richmond and Concord/Pleasanton lines in the east bay with construction in progress along the Fremont line, Transbay Tube, and selected stations in San Francisco and Daly City (BART, 2013).

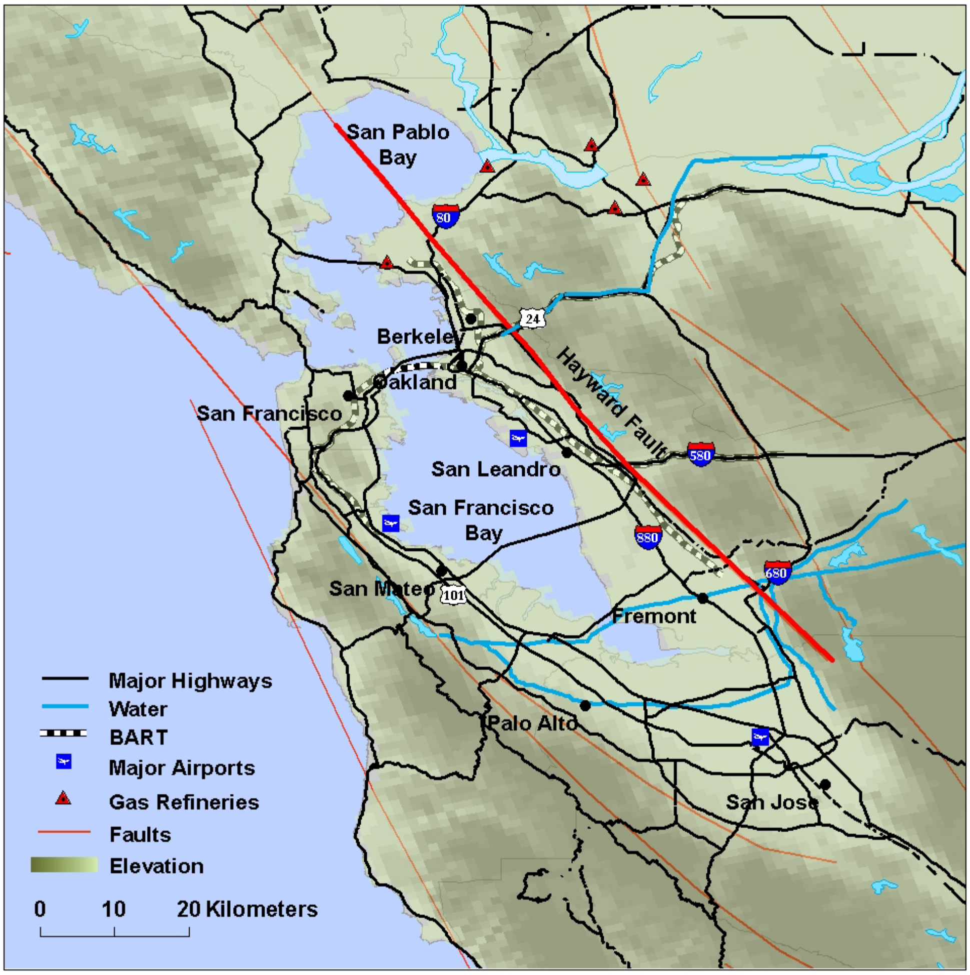

Figure 8: Map of major infrastructure crossing the Hayward Fault, including the main water distribution lines for EBMUD and SFPUC, the BART system, and major highways; the region's bridges, airports, and gas refineries are also at risk from a major earthquake on the Hayward Fault. The majority of the area's population lives along the San Francisco Bay.

Overall Infrastructure Risk

The presented analyses of lifeline disruption are largely based on assessments of the individual systems. In order to assess the true infrastructure impacts, all of the complex interdependencies of the various systems need to be taken into account. For example, a sufficient power supply is required to deliver water to areas where it is most needed (e.g., to fight fires). To generate power, an ample supply of gas must be available. Moreover, a widespread breakdown of the transportation network will hamper not only emergency response but also the delivery of goods and services critical for recovery. All of these infrastructure failures could potentially lead to major business interruption for the region. Altogether, a further amplification of disruption can be expected, where, for example, workers for the various individual systems are evacuated, or due to damage or loss of service (e.g., power or water) to their own properties, are unable to perform repairs. Further studies are needed to explore the full ramifications of prevailing consequences following such a devastating earthquake.

Implications for the Insurance Industry

Ratio of Insured to Economic Losses

The impact of a major earthquake on the Hayward Fault is beyond what has been experienced in recent California history. Figure 9 illustrates the average insured and total economic losses for the M6.8 and M7.0 earthquakes on the Hayward Fault with the two major California earthquakes in the past two decades—the 1989 Loma Prieta Earthquake and the 1994 Northridge Earthquake, as well as three U.S. hurricane events that have helped to shape the U.S. catastrophe insurance industry—Hurricane Andrew in 1992, Hurricane Katrina in 2005, and Hurricane Sandy in 2012. Total average economic losses in a M6.8 Hayward earthquake are close to $100 billion with economic losses averaging over $180 billion in a M7.0 earthquake rupturing the entire Hayward Fault. The average economic losses in the M6.8 event approach the economic losses for Hurricane Katrina ($120 billion).

The principal difference between Hurricane Katrina and a future Hayward Fault earthquake, however, involves the role of catastrophe insurance in funding reconstruction and recovery. Following Hurricane Katrina in 2005, over $60 billion in insurance payments—50% of the economic loss—were made to residents and businesses in coastal Louisiana and Mississippi, including payouts from the National Flood Insurance Program (NFIP), to help rebuild and recover. In contrast, approximately 5% to 10% of the total residential losses and approximately 15% to 20% of the commercial losses of a major Hayward Fault earthquake are expected to be reimbursed by insurance. Overall, insurance payments will cover between 10% and 15% of the total loss—and total between $11 and $26 billion.

Insurance payments, together with additional federal aid and private donations (totaling over $100 billion), have slowly reestablished New Orleans's economy despite the economic impacts of the Great Recession and the Deepwater Horizon oil spill following Hurricane Katrina (GNOCDC, 2013). The San Francisco Bay Area's economy is stronger with a far greater reach and thus is more likely to recover. However, the form of reconstruction and economic renewal is more uncertain.

The massive cost of the Hayward Fault earthquake is expected to be directly borne by the residents and businesses in the area. Homeowners unable to fund repairs will either sell or abandon their homes, depressing property prices or increasing mortgage defaults. Some businesses and many residents will choose to relocate to areas with a lower earthquake risk, such as the Sacramento Valley.

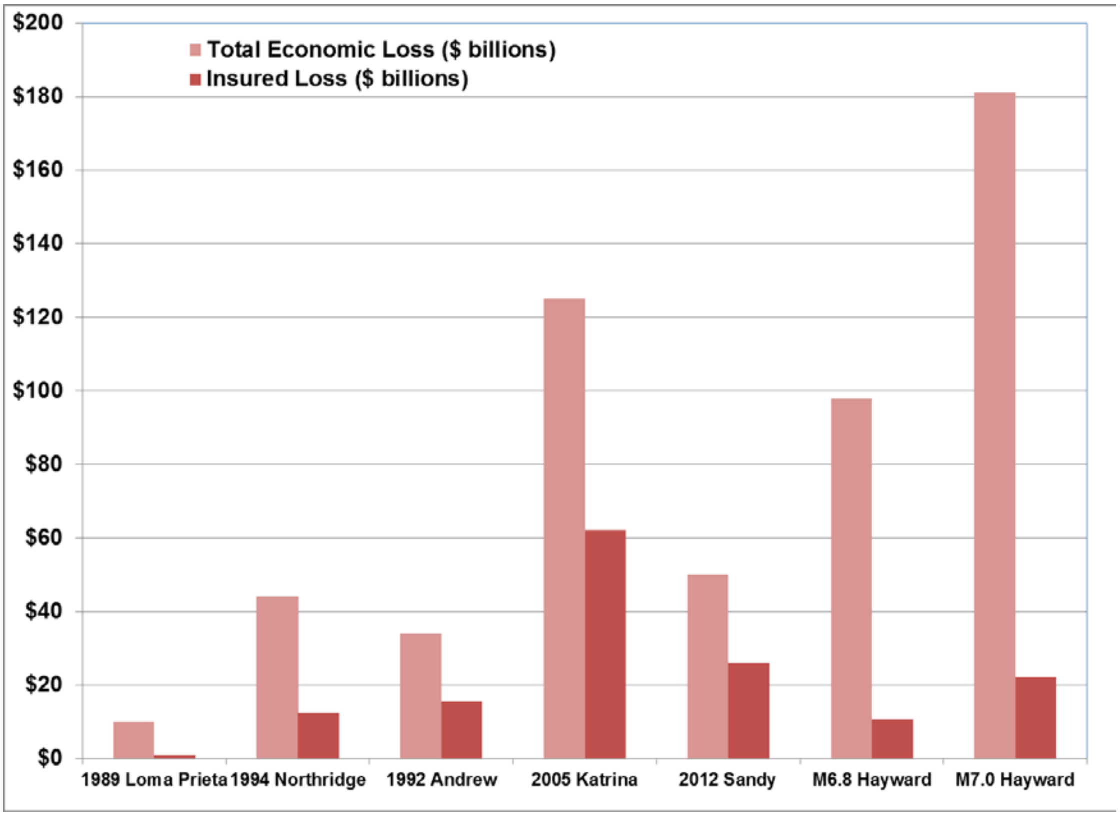

Figure 9: Comparison of insured and economic losses from recent U.S. natural disasters (at time of occurrence) to average losses from modeled scenarios on the Hayward Fault; insured losses for hurricanes Andrew, Katrina, and Sandy include National Flood Insurance Program (NFIP) policies

Role of Mitigation

A great focus on mitigating the impacts of a major Bay Area earthquake has taken place over the past twenty years. Utilities and other infrastructure operators in the region have invested (or are investing) a total of about $20 billion to reduce the impact of future earthquakes. Most of these upgrades and retrofits will be completed by 2013 or 2014. In addition, many municipalities in the Bay Area have abandoned, retrofitted, or replaced public buildings with identified seismic risk. San Francisco has been a leader, with approximate 70 public buildings strengthened, including its City Hall (ABAG, 2002).

Many seismically vulnerable private residential and commercial buildings exist throughout the San Francisco Bay Area, particularly in the urban areas of the East Bay and in San Francisco. Approximately 70% of unreinforced masonry (URM) buildings, which pose the greatest danger of collapse, have been upgraded or demolished. Several municipalities have begun to inventory or retrofit their “soft story” structures (possessing large ground floor openings, such as carports or storefront windows), which are also collapse hazards in strong ground shaking. For example, in 2007, the city of Fremont adopted a mandatory retrofit ordinance for soft story multi-unit residential apartment buildings and a voluntary retrofit ordinance for soft story multi-unit condominiums, both built prior to January 1, 1978. On September 15, 2013, the city of San Francisco passed legislation to require evaluation and retrofit for multi-unit soft-story buildings (City of San Francisco, 2013). The city of Oakland began a process to identifying and retrofit multi-unit wood framed soft story buildings within the city; however these efforts have not yet resulted in a retrofit ordinance (ABAG, 2013).

The Challenge in Managing Risk

Whether considering how insurance can facilitate reconstruction and recovery, or how risk can be reduced through mitigation techniques, the daunting challenge of keeping the subject of catastrophic earthquake risk at the center of public policy remains. The San Francisco Bay Area's particular vulnerability to future earthquakes drives a continuous need for dialogue between the public, government officials, business, and the insurance industry.

While there is much to be applauded in the work that has already been undertaken, the small role of earthquake insurance in the expected recovery from a future Bay Area earthquake is a major deficiency in preparing for such an event. To date, there has not been a clear initiative to ensure that the penetration rate of earthquake insurance in California is sustained at levels comparable to other wealthy industrialized countries. As a result, the citizens of the Bay Area remain at risk of suffering two concurrent catastrophes—the direct consequence of the earthquake itself and its economic aftermath. While possession of an insurance policy to cover earthquake damages will not be enough to ward off the systemic effects on property prices and the business economy, it could jumpstart recovery efforts throughout the region. Risk Management Solutions remains committed to facilitating dialogue among the various stakeholders and creating a culture of preparedness and resilience to better manage the earthquake risk in the San Francisco Bay Area.

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