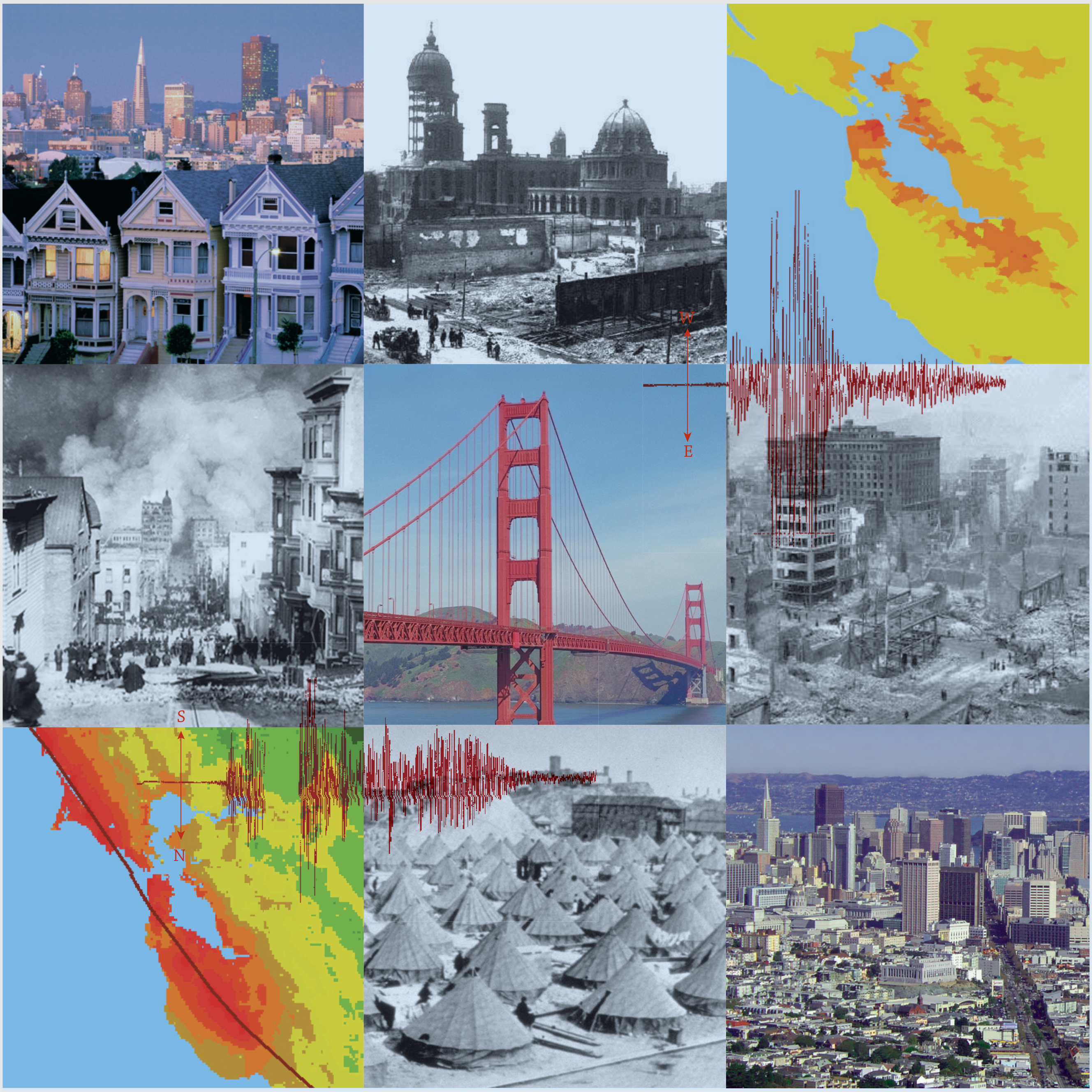
The 1906 San Francisco Earthquake and Fire: Perspectives on a Modern Super Cat



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Quotes regarding events during the 1906 San Francisco Earthquake and Fire were taken from newspaper articles published during the time and are available on the Internet from the The Virtual Museum of the City of San Francisco at www.sfmuseum.net

Image Sources

The Bancroft Library, University of California, Berkeley
California State Archives
California Governor's Office of Emergency Services
Federal Emergency Management Agency (FEMA)
The Library of Congress
National Archives and Records Administration (NARA)
National Parks Service (NPS)
San Francisco Convention and Visitors Bureau
United States Geological Survey (USGS)
The Virtual Museum of the City of San Francisco

INTRODUCTION

Over a decade ago, Risk Management Solutions (RMS) and Stanford University produced a series of studies analyzing the impact of major earthquake events in key metropolitan areas. While the science of catastrophe modeling was in its infancy, the studies proved that it was actually possible to take highly uncertain events and present a range of possible outcomes not only for insurance risk management but in the larger global context of disaster preparedness and mitigation.

Today, RMS assists clients, associates, and community leaders in understanding the potentially devastating damage, casualties, and economic consequences from catastrophic events such as earthquakes, floods, and terrorist attacks. The insurance industry in particular uses our modeling technology to quantify the impact of these events on their portfolio of risk, and in turn take steps to manage that risk.

For nearly 20 years RMS has focused our energy on using lessons learned from catastrophic events to enhance and refine existing models as well as to extend our modeling to new perils and lines of business. In 2005, Hurricane Katrina and the subsequent flooding and evacuation of New Orleans offered us some important lessons in how RMS should drive innovation in modeling the largest 'Super Cats'—catastrophes that are characterized by massive damage that gives rise to nonlinear loss amplification and correlation. These effects can increase losses to property and time element coverages, and trigger consequential hazards that are not yet captured in models today.

Our recent research and analysis of Super Cat effects has helped us gain a new perspective on the events following the 1906 San Francisco Earthquake and Fire. Like Hurricane Katrina, the 1906 catastrophe was a defining event in history and is considered by RMS to be a Super Cat, demonstrated by the extensive damage caused not by the earthquake shaking but by the subsequent fires. It was the largest California earthquake in recorded history, opening a field of active inquiry and research about earthquake risk that continues to this day. Perhaps most notably, it caused the global insurance industry to question the insurability of risk in California. The event also, in many ways, shaped the modern insurance industry's perception of natural catastrophe risk. Measured in terms of the percentage of annual premium, the 1906 catastrophe remains the largest loss ever absorbed by the global insurance industry, the repercussions of which continue to shape today's insurance market.

One hundred years later, as the anniversary of the first modern Super Cat in the United States is remembered, our hope is that this study will improve the understanding of the potential risk from events of this nature, and lead to the reduction of economic consequences and casualties in the future through increased awareness, preparedness, and risk mitigation. As leaders in our field, RMS remains committed to the continual research and implementation of improved approaches to modeling potential catastrophic losses —including the Super Cats of the future. ■

Hemant Shah

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SUMMARY

In the mid-1990s, Risk Management Solutions, together with Stanford University, conducted a series of studies to determine the potential economic and insured losses from earthquake scenarios in three major metropolitan areas: the San Francisco Bay Area, the Los Angeles Basin, and Tokyo and its surrounding prefectures. Incorporating the latest understanding of seismic sources in the urban areas, RMS centered each of these scenarios on an earthquake that would produce the largest modeled losses. For the San Francisco Bay Area, the study concluded that a repeat of the 1906 San Francisco Earthquake would cause an estimated insured loss between $75 billion and $95 billion to commercial and residential property, contents, and time element coverages (i.e. business interruption and additional living expenses). Total economic damage for the same property exposure was assessed between $150 and $200 billion. At the time, the results were an important contribution to the understanding of earthquake risk to urban communities in seismically active regions.

The 100th anniversary of the San Francisco Earthquake on April 18, 2006 provides the perfect opportunity to revisit the analyses undertaken over a decade ago. However, the consequences following Hurricane Katrina in the flooding and evacuation of the city of New Orleans shed new light and perspective on the 1906 catastrophe. The events in New Orleans during August and September 2005 have reshaped the way RMS thinks about modeling of the most extreme events known as Super Catastrophes—events in which a significant proportion of the losses are generated by a cascade of consequences resulting from the event itself. Accordingly, to understand the effects of a repeat of the 1906 Earthquake today, it is not enough to reconstruct economic and insured loss estimates based on the current approaches to catastrophe modeling but there is a need to explore the cascade of consequences from the 1906 San Francisco Earthquake.

Downtown San Francisco in 2006 (SF Convention and Visitors Bureau)

The 1906 San Francisco Earthquake, an $M_W7.9$ event, was a Super Catastrophe in which the majority of the damage was not caused by the earthquake ground shaking but by the subsequent fires. At the time, over 90% of property owners held fire insurance policies. Of the estimated $350 million of limits on damage to property and contents, $235 million was recovered from the global insurance industry. The repercussions of this event continue to reshape the California insurance market, and parallels can be made to the consequences following Hurricane Katrina. Both events caused containment failures (rampant fires in San Francisco and levee breaks in New Orleans) and widespread evacuation, the implications of which are still to be determined in New Orleans.

With dramatic increases in property and population exposures and the current insured liabilities in the San Francisco Bay Area, RMS estimates that in 2006, a $M_W7.9$ earthquake on the northern section of the San Andreas Fault would result in $260 billion of damages to residential and commercial properties. The insured portion of this exposure, in combination with workers compensation claims, would result in an insured loss between $50 and $80 billion, an amount both absolutely and proportionally reduced as compared to estimates RMS published in May 1995. The additional consequences of an event of this size include containment failures, such as fires spreading unimpeded as a result of high winds and lack of water, or inundation within a region from one or more dam failures. In the longer-term, a cascade of consequences includes the negative macroeconomic impacts due to evacuation from sections of towns or cities disabled by the earthquake or interruptions to transportation networks across the Bay Area.

As the anniversary of the first modern Super Catastrophe in the United States is remembered, RMS remains committed to learning from the past to prepare for events of the future.

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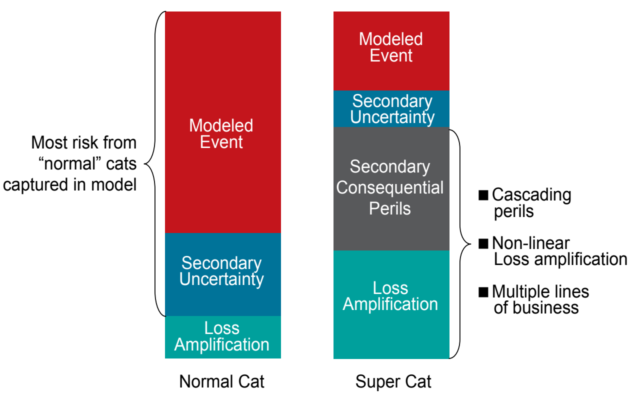
1.1 Loss Amplification

In moderate-sized catastrophes, losses are a consequence of the direct action of the hazard (e.g. the earthquake ground motion or hurricane wind speed) on the exposure. The exposure — the building or facility and its contents — is subject to damage, which takes some predefined cost to repair or replace. Damaged buildings tend to be individual and separate; the damage is discrete. Damage at a commercial or industrial facility can result in the interruption of business activities, which will further add to the losses. Where residential properties are badly damaged, people may incur additional costs if they relocate while their property is being repaired. However, this is usually the extent of economic losses. The cost is simply the sum of all the individual elements of damage and loss, and these elements are largely independent of each other.[1] This is the 'engineering model' understanding of a catastrophe, in which the total loss is the sum of the hazard multiplied by the exposure multiplied by the vulnerability at each location.

As catastrophes increase in magnitude, some of the simple assumptions of independent loss generation start to break down, as the cost of repair rises in response to external economic, behavioral, and political pressures. Delays in making repairs, due to the unavailability of builders or the difficulties of accessing the property can mean that the amount of damage itself increases. Business interruption (BI) losses can be contingent on what happens elsewhere in terms of damage to lifelines or impacts on supply and distribution chains.



Comparison of losses from a catastrophe and a Super Catastrophe, showing impacts of loss amplification

Today, within the context of insurance payments after major catastrophes, we recognize four key components of loss amplification:

- *Economic demand surge*–increases in the costs of building materials and hourly rates for labor, as demand exceeds supply
- *Repair delay inflation*–increases in the amount of damage or costs of interrupted business associated with delays in making the repairs
- *Claims inflation*–increases in the size of claims as the ability of insurance adjusters to inspect properties is impeded due to the number of claims
- *Coverage expansion*–the degree to which the terms of the original insurance contract becomes expanded to cover additional sources of loss or higher limits

For modeling purposes, RMS considers all of these factors as sources of 'loss amplification.'

1.2 Super Catastrophes

For the largest catastrophes, however, losses do not reflect merely the level of direct damage. Secondary processes triggered by the direct damage become additional sources of damage and loss. Significant landslide damage to primary access roads, for example, will exacerbate delays in emergency response, may require evacuation of the affected properties, and can lead to prolonged business interruption. Situations of this character are termed a 'cascade of consequences.' At the extreme, the cascade of consequences can become a significant factor in loss generation and can even become as large or even larger than the original initiating event—a situation known as a 'Cat following Cat.'

Events in which a cascade of consequences start to generate significant proportions of loss are termed Super Catastrophes (Super Cats). To have a cascade of consequences become a major component of loss generally requires that there are concentrations of exposure, so Super Cats are predominantly of significance in major cities.

There is no sudden transition between ordinary catastrophic and Super Cat loss. However, as the catastrophe gets larger and as the average level of damage increases across a major city, one can expect to see an increasing potential for cascades of consequences to become additional factors of loss. In the first generation of models with generalized Super Cat processes (released in 2006), RMS has included an increasing degree of Super

1 *When calculating net losses to an insurance portfolio, losses at property locations in close proximity to each other are highly spatially correlated*

Cat characteristics once an event reaches a certain threshold. These are modeled as loss amplification (in particular for business interruption), along with an increased uncertainty in the potential for spatial correlation of insured properties.

There are three key elements in assessing whether or not a catastrophe is in fact a Super Cat: the number and impact of containment failures, the degree to which urban areas are evacuated for long periods, and the negative macroeconomic consequences of the catastrophe on the areas worst affected.

1.2.1 Containment Failures

Containment failure is a general term that describes the process wherein a material moves outside of its confines and causes damage. Examples of containment failure include, but are not limited to, fire escaping out of the confines of a furnace, cooker or hearth; oil, gas, toxic materials, or chemicals leaking from tanks, tankers, or pipelines; and water breaking out of dams or through embankments protecting low-lying areas. Rioting and civil disorder can also be considered a form of containment failure. Some containment failures are local in extent, while some cover a wide area. Often, one containment failure can lead to others, and these failures can become a significant factor in driving additional sources of loss.

1.2.2 Evacuation

Where the habitability of an urban area has fallen below some threshold, the city, or some part of the city, will be evacuated. These evacuations may start off as mandatory in order to avoid some immediate consequence of the event, but will continue if people are unable to return to their houses or workplaces due to damage or contamination, or because of the absence of sanitation. Without inhabitants, neighborhoods become vulnerable to outbreaks of looting and arson. Evacuations or mass migrations particularly affect businesses. Where workers have moved away, the business may not be able to or may choose not to reopen because of a lack of customers.

Evacuation becomes an additional source of loss amplification through a variety of pathways. Initial damage can become extended as a result of failing to pursue simple actions, such as preventing leaks. Properties may also deteriorate in humid climates simply from not being occupied. Where policing has collapsed, as happened in New Orleans following Hurricane Katrina in 2005, intentional damage can become widespread. Instances of looting on business properties increase when security is absent as a result of evacuation.

1.2.3 Macroeconomic Consequences

Evacuation can lead to other systemic economic consequences or can become a symptom of them. Absence of housing may restrict the number of builders willing to take on reconstruction projects, which will then limit the speed with which repairs are undertaken. The economy is highly interdependent, so closure of some businesses may cause others to delay reopening. This is particularly the case for tourist economies, which are highly dependent on public perception since there are many other travel options. If information suggests that a tourist locale is devastated, tourists will divert to alternative destinations. This can lead to hotels and restaurants choosing to remain closed.

This downward spiral can lead to an area becoming completely depopulated. Over the past century, after suffering severe hurricane damage, a number of small U.S. coastal towns have simply become abandoned because of little incentive to rebuild at that location.

The solution to prevent or reverse a systemic economic downturn has to be a political one. A commitment to full reconstruction and rehabilitation requires strong leadership and clear political agreement among civic and business leaders. One of the principal obstacles that can threaten reconstruction is a lack of an agreed perspective on what caused the original disaster and hence what steps should be taken in the course of reconstruction to prevent or reduce the impact of any recurrence.

1.3 A Comparison of Super Catastrophes

Two catastrophes a century apart—the 1906 San Francisco Earthquake and Fire and Hurricane Katrina and the Great New Orleans Flood in 2005—highlight Super Cat behavior in the United States. Both were urban disasters affecting major coastal port cities of just under a half a million people. Although a fire following an earthquake may appear to be entirely different in character to a flood following a hurricane, in both cases the consequential peril caused far more loss (by a factor of three to four) than the original peril. In both cases, the consequential peril took more than a day to spread through the city, and in both the magnitude of the damage meant that the functions of the city basically collapsed, leading to large scale evacuations. In the weeks following each disaster, the population had declined by two thirds or more.

Analysis of the events that occurred during and after the 1906 San Francisco Earthquake and Fire provide a unique opportunity to examine the behavior of a Super Cat—not only to understand what happened 100 years ago, but to understand and model the potential effects the next time a major earthquake affects the city. ■

2 1906 SAN FRANCISCO EARTHQUAKE & FIRE

On April 18, 1906 at 5:12 am PDT, an M_W 7.9 earthquake shook the city of San Francisco and the surrounding region for approximately 45 to 60 seconds. The event ruptured 296 mi (477 km) of the northern section of the San Andreas Fault from north of Shelter Cove in Humboldt County to San Juan Bautista in San Benito County. Reports of ground shaking came from as far as 370 mi (600 km) north of San Francisco in the town of Coquilla to 390 mi (630 km) south of the city in Anaheim and as far as 340 mi (550 km) to the east in Nevada.

At the time, San Francisco was the largest city west of the Mississippi, with the fastest growing economy in the United States. Most of the building collapses and fires following the earthquake were concentrated in San Francisco (where most of the $500 million of damage occured[1]), but buildings were also damaged in an area up to 25 mi (40 km) wide and 350 mi (560 km) long. Damage was reported from as far as Eureka in the north to Paicenes in the south. The precise number of casualties in the disaster remains controversial (as many bodies were consumed in the fire), but recent re-evaluations have suggested as many as 3,000 people died. Most of these deaths were in San Francisco, which had around 450,000 residents at the time of the earthquake.

2.1 The Earthquake and Fires

All along the narrow northwest-southeast corridor parallel to the San Andreas Fault, wooden houses were torn off their foundations, masonry buildings crumbled, and brick chimneys suffered widespread collapse. San Francisco was the only city close to the fault with large numbers of more vulnerable buildings (e.g. masonry) in the zone of highest earthquake accelerations. Damage levels were much lower in Berkeley, Oakland, and Alameda on the eastern side of the San Francisco Bay. Most people were at home since the earthquake occurred early in the morning, so there were less casualties than if the earthquake had hit during the work day. Ordinary wooden houses, which comprised most of residential buildings, were far less susceptible to life-threatening collapse than some of the downtown office buildings in the city.

Sixty fires were reported in the downtown area of San Francisco following the earthquake. Some were extinguished by the San Francisco fire brigade, but others started to grow before they could be attended to, and as a result, they merged with other spreading fires. A number of causes were cited for the ignition and spread of fires, including a report from the city's mayor that blamed the fire that burned the downtown area on an arson attack at a restaurant.

Within an hour, the fire brigade found that there was no pressure in the water mains anywhere in the city. The water was fed from reservoirs to the south on the Peninsula, along the line of the San Andreas Fault, and the pipelines had been fractured at multiple places. There were also 300 breaks in the mains within the city limits. Some larger hotels, such as the Palace, had water tanks intended for the hotels' protection. The fire fighters tapped these tanks to try to extinguish nearby fires, but the fires continued to spread and the hotels were left without their own reservoirs.

San Francisco in 1905 (California State Archives)

San Francisco after the 1906 Earthquake and Fire (National Archives)

1 *When estimating this monetary loss in terms of 2006 dollars, there is no clear answer. Using the Consumer Price Index (CPI) to trend the loss, it would be $10 billion in 2006 dollars; using Gross Domestic Product (GDP) per capita as a basis, it would be closer to $60 billion.*

Earthquake shaking caused these houses on the east side of Howard and 17th streets to tear off their foundations and lean against their neighbors (National Archive)

There was only a light westerly wind on the April morning, so the fires spread relatively slowly. It took three days to suppress the fires, but in many areas they simply burned themselves out. A small number of buildings within the burned area were saved by their occupants, who laid wet carpets on the roofs and extinguished any small fires that started in the buildings. The fires eventually destroyed 490 city blocks, 2,830 acres, 30 schools, 80 churches, and a total of 28,000 properties.

2.2 Fire Containment Failure in San Francisco

San Francisco's fire chief, Dennis T. Sullivan, had spent several years preparing plans to reduce fire risk in the city. His death in the earthquake left his brigade without leadership, severely impairing their ability to successfully suppress the fires. Left without access to water, the fire brigade resorted to the only alternative available: the demolishing of buildings in the path of the fire.

As history books recall, the 1666 Great Fire of London was successfully checked in its eastward spread by the use of gunpowder explosions to create large firebreaks. However, since there was no experience in San Francisco with using explosives in fire suppression, it was left to trial-and-error. In Chinatown, it was reported that a number of individual fires were started on April 18 by John Bermingham, Jr. of California Powder Works as he attempted to create fire breaks. At the Viavi Building on the southeast corner of Green and Van Ness streets, fires started by incompetent dynamiting were said to have destroyed North Beach and threatened Fort Mason. On Kearny and Clay streets, more fires were claimed to have been caused by U.S. Army dynamiters.

By the third day of the conflagration, the supply of privately-held explosives had been exhausted, and army explosives from the Presidio were used in a final stand to prevent the fire expanding westward across Van Ness Avenue. Also by this time, the destruction of properties began to be employed more strategically, where every house that caught fire and the houses around it were dynamited. By this means, the brigade finally managed to halt the fire's progress.

2.3 Damage and Fires Outside San Francisco

Following the earthquake, fires also started in other towns with dense urban centers and high levels of damage. In downtown San Jose, three firehouses collapsed onto the fire equipment as the horses inside the stations ran terrified out into the street. A number of fires started in the downtown area, but the fire fighters managed to dig out their equipment and round up their horses, proceeding to fight the fires over the next three days. Preparations for fighting fires in San Jose were more advanced than in San Francisco, and cisterns were installed at every downtown crossroads. Using this water supply, the fire fighters managed to extinguish all of the fires. While the three-story Martin Building burned down and a number of other downtown buildings collapsed, the heart of the city was saved.

The community of Santa Rosa in Sonoma County was not so fortunate. Earthquake damage was high, and many of the masonry buildings collapsed, while wood frame structures slid off their foundations. Around 100 people died in Santa Rosa from the collapses, a casualty rate higher than in San Francisco. Fires started in about a dozen locations and completely destroyed the small downtown area. The total monetary loss from the earthquake and fire to Santa Rosa was estimated at $3 million.

The San Francisco fire brigade attempted to contain fires by dynamiting buildings (National Park Service)

The city in flames (National Archives)

In the coastal town of Fort Bragg in Mendocino County, near the San Andreas Fault, brick buildings in the downtown area were damaged and many frame houses were knocked off their foundations. The hotel and several other commercial buildings were soon on fire. However, a steamer captain managed to get water pumped from his vessel onto the burning buildings, and destruction was limited to less than two city blocks.

2.4 Crime and Disorder

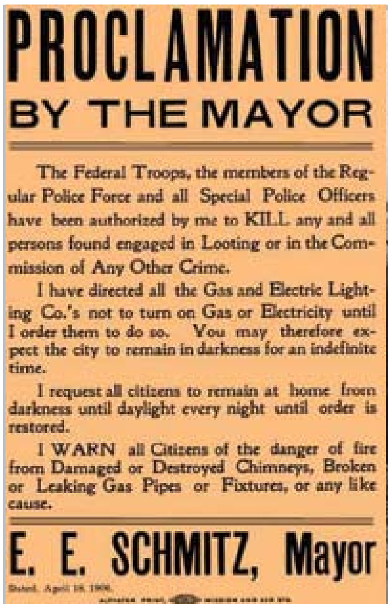
Within 90 minutes of the earthquake, San Francisco's Mayor Schmitz sent a messenger to Fort Mason on the edge of the city, requesting that the acting commander General Funston send all available troops to the Hall of Justice. The first troops arrived at 7:00 am, and by the end of the morning, there were around 1,700 troops in the city. The mayor also announced that any looters would be shot. Martial law was in place in all but name. Along Polk Street, soldiers forcibly evacuated inhabitants of the area several hours before the fire threatened the immediate vicinity, prohibiting residents from saving their valuables.

Remaining in place for 10 weeks, the soldiers maintained a tight hold on security in the city. While there were reports of looting, in many instances building owners were in fact removing inventory before the fire arrived to destroy the building and its contents. However, witnesses reported seeing soldiers steal from homes before dynamiting, and members of the California National Guard, who were assisting in keeping order within the city, were accused of looting.

2.5 Evacuation

The evacuation that followed the earthquake was a spontaneous and uncoordinated response to the progress of the growing flames. The fires were relatively slow to spread, so people were able to move ahead of the blaze. As the fire continued to spread later that afternoon, the evacuation began. People tried to escape and bring as many of their personal belongings as possible. The streets and sidewalks became impassable because of the variety of household goods left behind. Almost everyone was limited in taking what could be carried or dragged along the street in a trunk.

By the end of the second day, 60,000 refugees from San Francisco crossed the Bay on ferry boats and had arrived in Oakland. Others moved down the Peninsula into the towns of San Mateo and Redwood City. Two



PROCLAMATION

BY THE MAYOR

The Federal Troops, the members of the Regular Police Force and all Special Police Officers have been authorized by me to KILL any and all persons found engaged in Looting or in the Commission of Any Other Crime.

I have directed all the Gas and Electric Lighting Co.'s not to turn on Gas or Electricity until I order them to do so. You may therefore expect the city to remain in darkness for an indefinite time.

I request all citizens to remain at home from darkness until daylight every night until order is restored.

I WARN all Citizens of the danger of fire from Damaged or Destroyed Chimneys, Broken or Leaking Gas Pipes or Fixtures, or any like cause.

E. E. SCHMITZ, Mayor

Dated, April 18, 1906.

San Francisco's Mayor Schmitz called for an end to crime, such as this incident of a cash register being looted in the rubble of a destroyed building at the corner of 4th and Market streets, with a proclamation to kill any looters (Virtual Museum of the City of San Francisco and USGS)

Tent cities erected in the Presidio of San Francisco provided refuge for the people left homeless by the earthquake and fire (National Park Service)

weeks after the earthquake, less than 200,000 people were left in San Francisco. The homeless resided in several tent cities erected by the Army and other government agencies; these were later converted into 5,600 redwood and fir cabins to house 20,000 people. For those residents whose homes survived the fire, the city assisted in keeping the population in place by providing instructions on digging latrines in backyards and providing water in tankers parked on street corners.

2.6 Macroeconomic Consequences

The political resolve to rebuild the city was immediate. Five days after the earthquake, the Governor of California told a reporter: "The work of rebuilding San Francisco has commenced and I expect to see the great metropolis replaced on a much grander scale than ever before." In order to achieve this goal, an influx of investment money was needed. To attract this money, the risk from another earthquake was downplayed.

The real estate board met a week after the earthquake and passed a resolution that the phrase 'the great earthquake' should no longer be used; the event would be known instead as 'the great fire.' Fire was the principal hazard in American cities during the late 19th century, and this placed San Francisco squarely on a list alongside other great cities (Boston, Chicago, and Baltimore) to have experienced conflagrations. In the last decades of the 19th century, losses from fire in American cities were five times as high as in European cities, and the U.S. fire insurance industry was booming.

Categorizing the disaster as a fire rather than as a result of the earthquake meant that the reconstruction could proceed on the basis of making the city fire-proof rather than earthquake-proof. A focus on the earthquake could have significantly delayed rebuilding: there was widespread agreement on how to build fire-proof construction, while methods to construct earthquake-proof buildings were uncertain and untested.

The first temporary structures were being built within weeks of the earthquake. Eventually, new permanent buildings were constructed taller and grander than those that had been lost. Within 12 months, 60 mi (95 km) of streets made impassable by debris from the earthquake and fires were cleared. More than 200 mi (322 km) of street railways were restored. Millions of tons of debris were transported along the railway lines to be dumped as landfill into the Marina district in the northwest portion of the city. Overall, $75 million was spent in the first year on the reconstruction efforts, and by April 1907, around 435,000 people were living in the city. While 54,000 people still lived in temporary accommodations, including tents, shacks, and stables, reconstruction efforts had revived the economy.

In 1900, only 7% of the buildings in the city were constructed out of material other than wood, and most of these were in the city center and consumed by fire. By 1909, 25,000 new buildings were built to the new stringent city ordinances regarding fire risk, many of them out of reinforced concrete. A year later, the rateable value of the city's properties (60% of actual value) was $492 million, only $10 million less than in 1905. Growth in the city's population resumed, and the recovery was consolidated in 1911 when the city beat New Orleans in a competition to host the 1915 Panama Pacific International Exposition World's Fair. The fair was held on 635 acres of unconsolidated landfill rubble from the earthquake and fire, which was developed to be the 76 city blocks of San Francisco's Marina district. One disaster has the tendency to lay the foundations for the next, as the same poor soil conditions in the Marina district led to liquefaction, building damage, and fire during the 1989 Loma Prieta Earthquake.

In 1915, San Francisco hosted the Panama Pacific International Exposition World's Fair, less than 10 years after the earthquake (Library of Congress)

2.7 Loss Amplification in the 1906 Earthquake

The 1906 Earthquake was by far the largest earthquake on the northern section of the San Andreas Fault in modern times, causing approximately $235 million in insured loss at the time. The earthquake and its aftermath provide plenty of evidence of the key components of loss amplification: economic demand surge, claims inflation, and coverage expansion. The event did not result in much repair delay inflation, as properties were either completely destroyed by the fire or if only damaged by the earthquake, were outside the terms of fire insurance coverage.

2.7.1 Economic Demand Surge

Price gouging was noted throughout the evacuation of San Francisco. For example, the cost of obtaining a wagon to help transport goods from houses as people were evacuating in the path of the fire was quoted to be $100, where $5 would be the norm. In Oakland, some claimed that rents were immediately raised by as much as 500%.

In recognition of the magnitude of the disaster and the suffering of the homeless, there were many statements of good intention around resisting inflationary pressures. The Building Trades Council of Alameda met within a day of the earthquake and issued a declaration to try to curb instances of economic demand surge.

However, rampant demand surge set in during the course of the reconstruction. A year after the earthquake, there were 50,000 men engaged in rebuilding (an increase of 150% from before the earthquake) with an average builder's wage of $4 per day—a wage that was said to be higher than in any other city in the world. In 1909, wages had continued to rise; for example, masons were being paid $12 for an 8-hour work day. High prices of materials and of haulage and freight rates added expense to the task of rebuilding. However, the decision to pay regardless of cost meant that rebuilding was accomplished with remarkable energy and speed.

Clean up efforts were under way soon after the fires died (National Archives)

Construction on 4th and Market streets following the 1906 San Francisco Earthquake and Fire (California State Archives)

In the lumber town of Fort Bragg, the surge in the demand for timber from San Francisco and other areas caused an economic boom that more than offset the damage to the town from the earthquake and subsequent fire.

2.7.2 Repair Delay Inflation

Given that the large majority of claims were for completely destroyed properties, there was little opportunity for delays in making repairs to affect the overall size of the fire loss. The total number of damaged properties affected by the quake but not consumed in the fires, or even costs of their repairs, is not known, as separate earthquake insurance or any other general damage census was not available. There was at least one downpour and several rainstorms during the month after the earthquake, and therefore any earthquake-damaged properties that had survived the fire had the potential to suffer additional water damage.

2.7.3 Claims Inflation

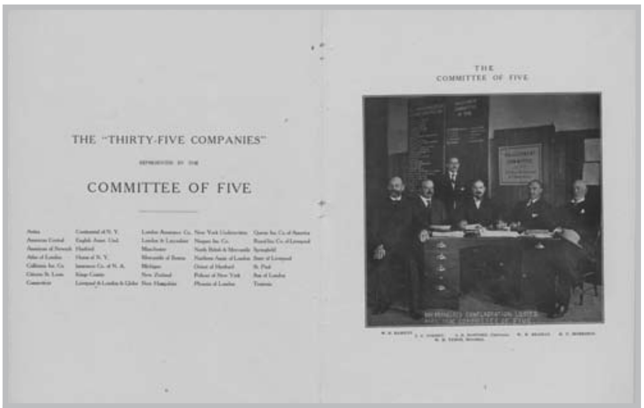
Many homeowners lost insurance documents in their burned homes, and a number of insurance companies had also lost their San Francisco offices in the fire. After some early experiences, where the contents of safes burst into flames upon being exposed to the air, companies avoided opening safes trapped in the smoldering rubble for many weeks. There was a 60-day rule for submitting claims, and therefore there were many situations where the paperwork around the policy terms was not available to either party. In the report to the "Thirty-five Companies" on the conduct of the insurance settlement procedures, the Committee of Five noted that "doubtless many claimants innocently exaggerated their statements in their haste to file them with the companies." In two instances where it had been possible to employ an accountant to investigate the insured's book of accounts, it was found that the claims had been overstated to the amount of $160,000. Given the time that had passed before the insurers became sufficiently coordinated to perform this kind of investigation, 'innocently exaggerated' claims were probably widespread. At the same time, insureds were faced by insurers initially predisposed to apply some across-the-board reduction in claims to account for the non-covered earthquake damage.

2.7.4 Coverage Expansion

There were 130 companies that provided fire insurance in San Francisco in 1906, including 50 foreign insurers. Approximately 90% of property owners held fire insurance policies—a higher percentage than today. At the time, there was much publicity surrounding major city conflagrations across the U.S., such as the fire that destroyed the center of Baltimore in 1904. Insurance policies had relatively low limits so insurers participated proportionally for higher-valued properties. Each insurer also applied its own distinct policy terms and conditions. Total premium for fire insurance in the city of San Francisco was $2.6 million for $350 million of limits (for an average rate on line of 0.75%). The domestic insurers had a surplus in excess of $100 million, while their paid-in capital was another $49 million. The surplus was around $150 million for foreign insurers.

Most fire insurance policies of the time contained a 'fallen building' clause, which is a clause in fire policies providing that if any material part of the building falls, except as a result of fire, the policy immediately ceases to cover. In calculating liabilities prior to the earthquake, it was assumed that this clause would free the insurer of any obligation to pay in the instance of fire being triggered by an earthquake.

Some of the first insurance loss adjusters to visit after the earthquake attempted to sustain the wording of the contract and deny all liability. Under political pressure, the insurers regrouped and met in New York in May 1906 to decide on a new and coordinated strategy to pay on submitted claims. The so-called 'New York



Report of the Committee of Five to the "Thirty-five Companies" on the San Francisco conflagration (The Bancroft Library, UC Berkeley)

agreement' involved a significant expansion in policy coverage, accepting that fire policies would in every case cover all losses for fire following the earthquake unless it was proved that the building was totally destroyed by the earthquake. Claimants were asked whether any earthquake damage to the property had preceded the fire. Of the first 2,000 claims submitted, not one acknowledged any damage had been caused by the earthquake before the property was consumed by fire.

However not all the insurers had agreed to this revision of the policy terms, and many were intent on reducing payments by some proportion of the damage that could be attributed to the original earthquake shaking. The political pressure was increased in June 1906 when Congressman Julius Kahn denounced dishonest fire insurance companies before the House of Representatives. Some insurers, including Fireman's Fund and Lloyd's of London, saw this as an opportunity to market their generosity in settling claims, accepting that a burned building should be paid out at the full limit. This policy served them well over the following decades.

In all, about 100,000 claims were eventually settled, with insurers paying out 80% of the claims submitted. A number of disputed cases went to court, and in every case the insurer lost. Fifty-nine insurance companies refused to pay all or part of their claims, including six Austrian and German insurers who simply walked away from their liabilities. Twelve insurers went bankrupt. Of an estimated $350 million of limits on damage to property and contents, $235 million was recovered from the insurers (around $100 million from British insurers). Ultimately, the speed with which the majority of the claims were settled was a key factor in facilitating the rapid reconstruction of the city. ■

3 THE 1906 LEGACY FOR INSURANCE & RISK

The 1906 San Francisco Earthquake triggered changes in the global insurance industry, provisions for earthquake-resistant building design, and the overall understanding of earthquake risk in the state of California.

3.1 Insurance Policy Terms

Following the 1906 experience of significant coverage expansion, insurers attempted to tighten the language of exclusions in their contracts. In Germany, a country with little earthquake risk, state authorities were united with the fire insurance companies and reinsurers in their call to strengthen the earthquake exclusion from all fire insurance coverages. There was an attempt to influence more than 500 fire insurance companies worldwide as well as legislative bodies concerned with insurance.

One of the first opportunities to test a strengthened clause came in early 1907 in Kingston, Jamaica, when the center of the city burned down after an earthquake. The insurers sent representatives from London to deny liability under the strengthened exclusion. However in court, a witness claimed to have seen a fire break out before the earthquake, and the insurers were forced to pay out for all the properties destroyed in the fire. As in San Francisco, insurers found that in the aftermath of a catastrophe, contractual terms are not sufficient to withstand the force of popular sentiment.

When several insurance companies tried to strengthen their exclusions in California, the public reacted with fierce opposition, and the California legislature enacted the California Standard Form Fire Insurance Policy. This made it impossible to write fire insurance in the state with any earthquake exclusion. Fire following earthquake became a standard coverage in California, as it remains today.

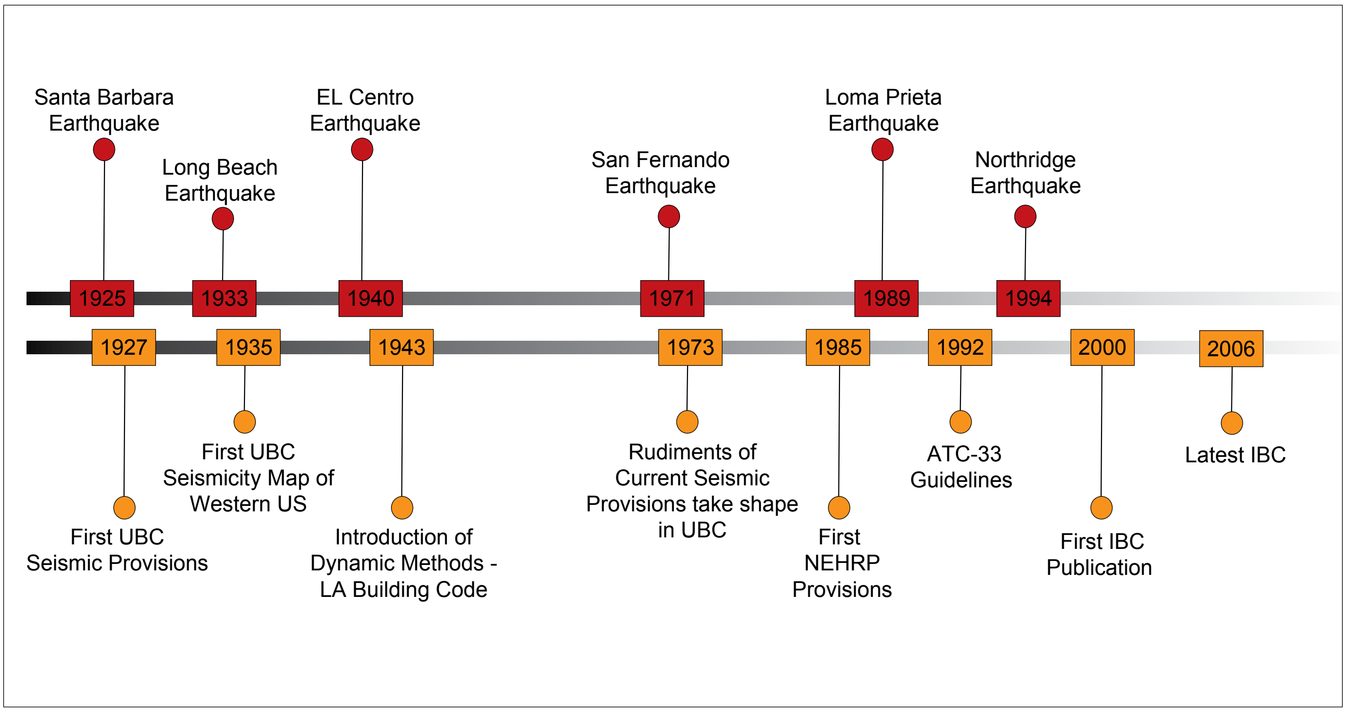
Massive destruction to residential communities prompted insurers to restrict homeowners coverage after the 1994 Northridge Earthquake (FEMA)

This policy of requiring insurance companies to include certain provisions in their standard policy structures can also be seen in more recent developments in the California residential earthquake insurance market. There was little earthquake insurance purchased by consumers in the state until the 1971 San Fernando Earthquake, after which there was significant growth. In 1985, the state passed the 'mandatory offer law' that compelled insurers who offered homeowners coverage in California to offer earthquake coverage as well. The statutory minimum coverage had an allowable deductible up to 15% with mandatory coverage for earthquake damage to a building but low allowable limits on the coverage for personal property and loss of use ($5,000 limit on contents and $1,500 limit on additional living expenses).

By the mid-1990s, one-third of homeowners had earthquake coverage. When the magnitude of the insurance losses in the 1994 Northridge Earthquake prompted insurers to try to restrict sales of homeowners coverage, the legislature decided not to repeal the 1985 law but instead establish the California Earthquake Authority (CEA), a publicly-managed, privately-financed entity. In 1996, the CEA began to offer the statutory minimum coverage and residential insurers could elect to join the CEA or opt out. At the time, roughly 70% of the California homeowners insurance market joined the CEA, and this aggregate share has changed little by the end of 2005. Expanded CEA coverage started in 1999 with lower deductible levels (10%) and higher limits on contents and loss of use coverage.

3.2 Seismic Design Provisions

Beginning in 1906, the city of San Francisco was rebuilt using well-established fire code provisions. Lessons from the 1906 earthquake only later fed into building code provisions for earthquake-resistant design. The first seismic building provisions in the United States were published as an appendix to the first edition of the Uniform Building Code (UBC) in 1927 as a reaction to the 1925 Santa Barbara Earthquake and the earlier 1906 San Francisco Earthquake. Over time, lessons learned from significant earthquakes led to the incorporation of more advanced codes for the construction of new buildings. Additionally, seismic design procedures were developed for existing buildings. For example, in 1992, the Applied Technology Council (ATC) published the first edition of the Guidelines for the Seismic Rehabilitation of Buildings (ATC-33) in part as a result of the 1989 Loma Prieta Earthquake.



Progression of seismic design provisions in building codes following significant California earthquakes since 1925 (based on Financial Management of Earthquake Risk, Earthquake Engineering Research Institute, 2000)

More recent developments in the seismic building codes in the United States stem from the establishment of the Building Seismic Safety Council (BSSC) in 1979. In 1985, six years after its establishment, the first edition of the Recommended Provisions for the Development of Seismic Regulations for New Buildings (NEHRP Provisions) was published by the BSSC. In the late 1990s, the three national model building codes—the Uniform Building Code (UBC), the National Building Code (NBC), and the Standard Building Code (SBC)—incorporated seismic risk criteria based on or similar to the NEHRP Provisions. In 2000, a common code, known as the International Building Code (IBC), was adopted for the entire U.S.

3.3 Earthquake Risk in California

The 1906 Earthquake marked a new era in awareness of California earthquake risk with the establishment of the State Earthquake Investigation Commission. The commission, led by Professor Andrew C. Lawson of the University of California, Berkeley, published a report in 1908 (commonly referred to as the Lawson Report) which was the first 'reconnaissance report' of a U.S. earthquake. The report—with photographs, detailed maps, and survey data—summarized over 20 scientists' investigations into the earthquake's damage, as well as gave new insight into the geology of Northern California and the movement of the San Andreas Fault. It served as a benchmark for later reports written following other California earthquakes over the years.

Since the 1990s, numerous studies have been published on the risk from significant earthquakes to the San Francisco Bay Area. Most recently, the U.S. Geological Survey's (USGS) report released in 2003 notes that there is a 62% probability of at least one major ($M_W \geq 6.7$) earthquake on the faults in the San Francisco Bay Area before 2032. With the intent of communicating the considerable threat of future widespread earthquake damage, the USGS works to make this information known to the general public so that individuals can prepare for the inevitable Bay Area earthquake. Along with a number of other institutions such as the Association of Bay Area Governments (ABAG) and the Earthquake Engineering Research Institute (EERI), the USGS published a guidebook "Putting Down Roots in Earthquake Country," which outlines steps for a comprehensive disaster preparedness plan, including how to create a disaster kit and identify and mitigate a building's potential weaknesses.

However, the question of how well-prepared the region truly is for an event of 1906 proportions still remains. Today, the San Francisco Bay Area is much more densely populated and heavily developed, with over 750,000 people living in San Francisco alone and 10.6 million people living in the greater Bay Area. ■

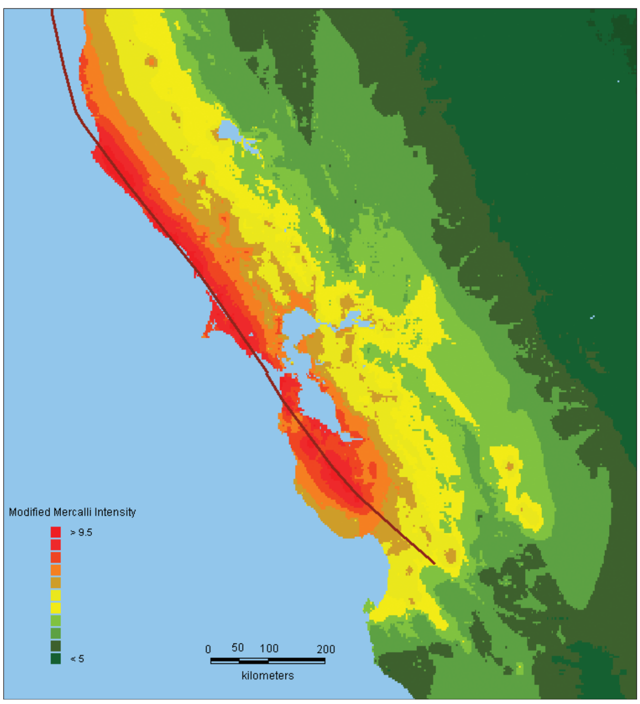
4 THE SAN FRANCISCO EARTHQUAKE IN 2006

For the 100th anniversary of the 1906 San Francisco Earthquake, RMS evaluated the potential impact of an earthquake of similar magnitude striking the San Francisco Bay Area in 2006. It should be noted that the earthquake modeled in this study, although the most potentially damaging earthquake, is not the earthquake with the highest probability of occurring. According to the USGS, the most probable $M_W \geq 6.7$ earthquake, which has a 27% probability of occurring before 2032, would rupture the Rodgers Creek and Hayward faults. The Hayward Fault is particularly concerning as property and population have grown considerably on the eastern side of the San Francisco Bay, and major lifelines (e.g. water, electricity, gas) cross the fault. And, while the next most likely location for an $M_W \geq 6.7$ event is on the San Andreas Fault, which has an occurrence probability of 21% before 2032, a repeat of the 1906 $M_W 7.9$ earthquake has only a 2% probability.

4.1 Hazard

Consistent with the historical event, this analysis assumed an $M_W 7.9$ earthquake on the northernmost section of the San Andreas Fault. While almost certainly the next big earthquake on the San Andreas Fault will produce a unique ground motion pattern, estimates of ground motion published by the USGS ShakeMap[1] format were used, as it represents an accurate estimate of the impacts of a repeat of the 1906 rupture of the San Andreas Fault.

Structures built on unconsolidated soils and artificial fills near the San Francisco Bay are likely to suffer losses due to liquefaction. Landslides could also have an impact on communities built on hillsides, where soils are very susceptible to failure. These include many of the Bay Area's prime real estate locations, including Berkeley, the Oakland Hills, Hillsborough, Woodside, Portola Valley, and parts of Marin County.



Modified Mercalli Intensity (MMI) from a repeat of the 1906 San Francisco Earthquake (based on the USGS MMI ShakeMap)

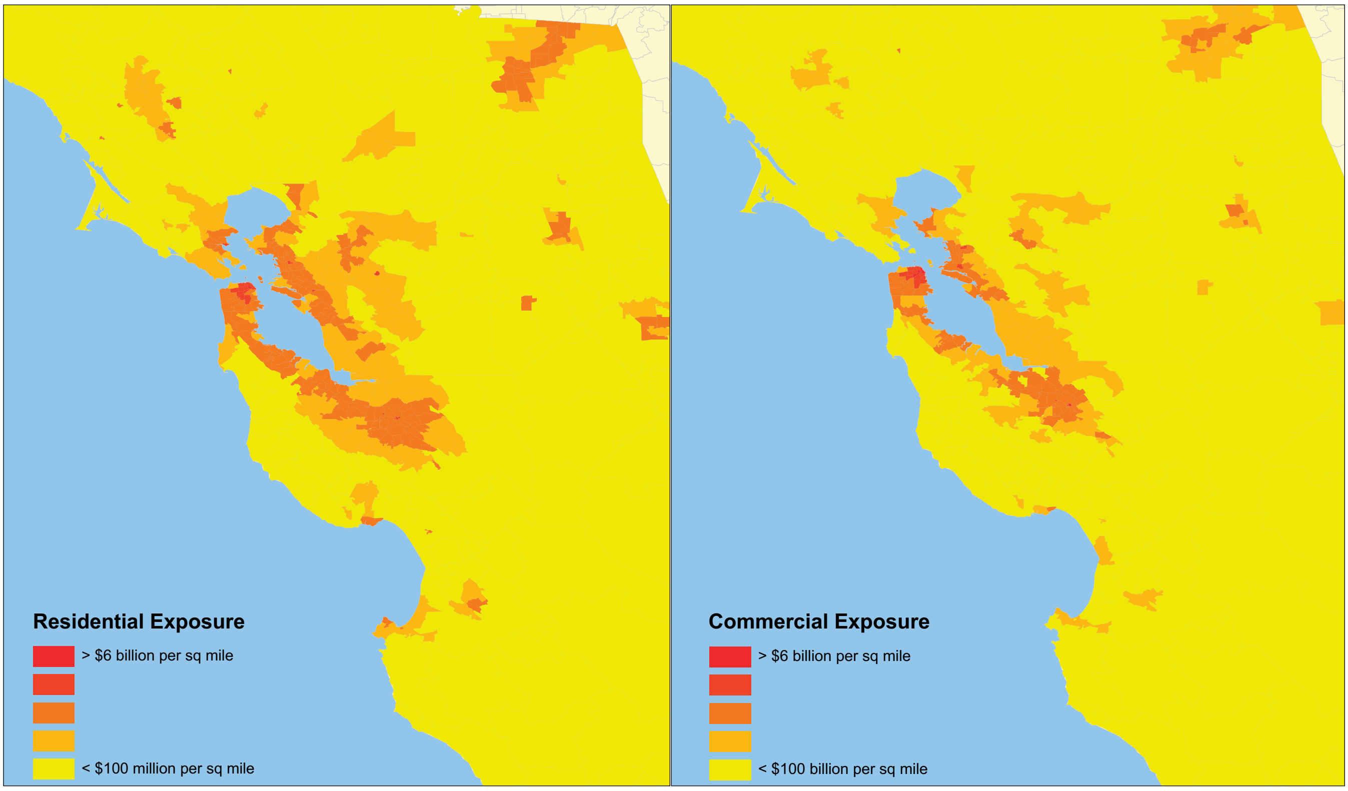
4.2 Exposure

In this scenario, strong ground shaking will affect 19 Bay Area counties.[2] The unique geographic features of the Bay Area compound the risks posed by earthquake damage. Most of the population resides in one of two north-south corridors, one to the west paralleling the San Andreas Fault and one to the east situated on the Hayward Fault. Of the 10.6 million individuals living in the 19-county Bay Area, the 1.5 million living in San Francisco and San Mateo counties are particularly vulnerable to an $M_W 7.9$ event on the San Andreas Fault. Moreover, the 4.8 million working population in the entire region is susceptible to injury while on the job and is critically dependent on four major bridges (Golden Gate, San Francisco-Oakland Bay, San Mateo-Hayward, and Dumbarton) and other transportation networks to move goods to and from the Peninsula.

RMS estimates the value of the building inventory in these counties, including structures and their contents, at over $1.2 trillion for residential properties and $750 billion for commercial and industrial properties. These inventory estimates are based on the RMS® U.S. Industry Exposure Database (IED), which captures exposure at the ZIP Code resolution for three primary insurance coverages: building/structure, contents, and time element (also known as business interruption or additional living expenses). The U.S. IED is updated to 2006 vintage and incorporates policy details (limits and deductibles) for earthquake insurance in California and coverage for fire following earthquake, which must be covered by a homeowners policy whether or not earthquake coverage is purchased.

1 *USGS ShakeMap Archive available electronically at http://earthquake.usgs.gov/eqcenter/shakemap/ (April 2006)*

2 *The 19 San Francisco Bay Area counties are Alameda, Contra Costa, Lake, Marin, Mendocino, Merced, Monterey, Napa, Sacramento, San Benito, San Francisco, San Joaquin, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Stanislaus, and Yolo*



Property exposure (building and contents) in the 19-county Bay Area, showing $1.2 trillion of residential properties at risk (left) and $750 billion of commercial and industrial properties at risk (right)

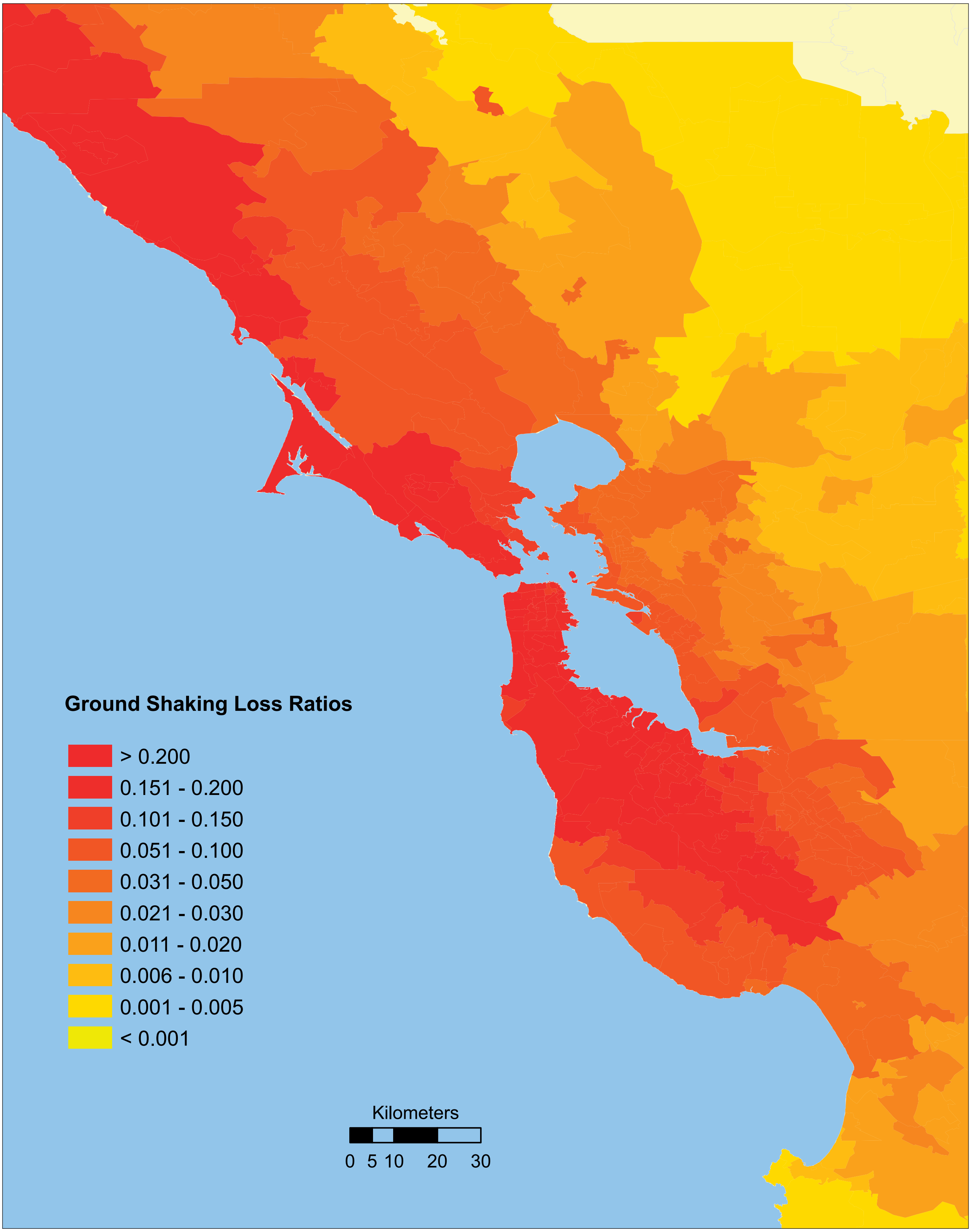
4.3 Building Vulnerability

The RMS spectral response methodology provides advanced modeling of the vulnerability of property risks. The methodology uses an objective measure of ground motion intensity (spectral acceleration) to directly correlate ground motion to building performance based upon building height, construction material, and ground motion propagation. Individual vulnerability curves are used for predominant construction types in California (e.g. wood frame, reinforced concrete, reinforced masonry, steel frame) for buildings of various heights and years of construction.

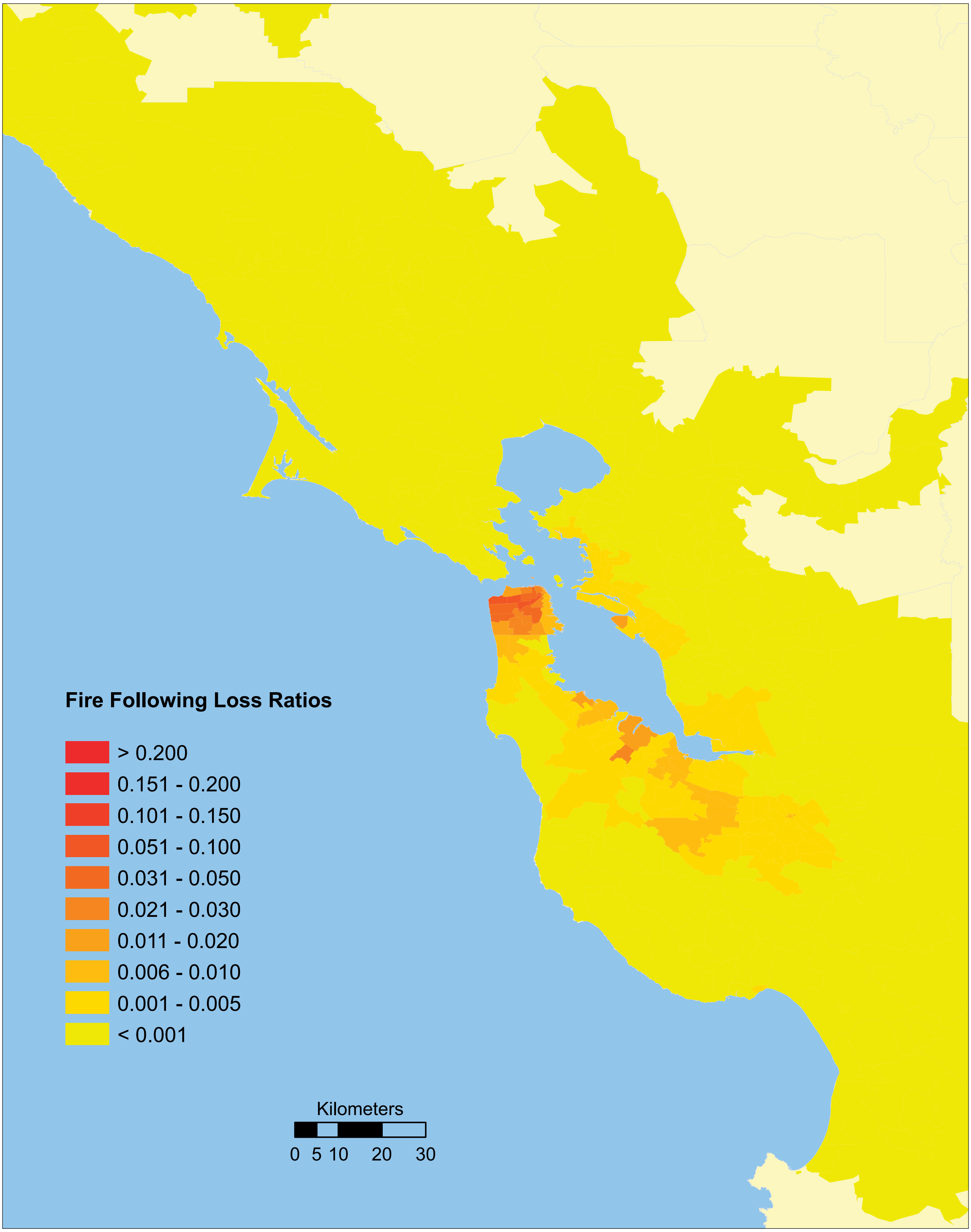
The buildings most susceptible to collapse are unreinforced masonry (URM) structures. While no longer permitted by the California building code, these are (generally) brick buildings constructed prior to the 1933 Long Beach Earthquake, at which time the construction of URM buildings ceased. A large percentage of these structures have been upgraded due to the passage of the 1986 URM Law, which required cities and counties located in Seismic Zone 4 (per the Uniform Building Code) to identify potentially dangerous URMs and adopt a plan to mitigate the hazards posed by these buildings. This legislation required that cities and counties, at a minimum: (1) survey suspected URM buildings, (2) notify owners that their buildings might constitute a hazard, and (3) report a proposed mitigation program to the California Seismic Safety Commission by January 1, 1990. Since the law does not require owners to strengthen their buildings, as of 2003 about 3,000 URMs in the San Francisco Bay Area still did not meet the minimum recommended construction standards.[3]

Buildings made of reinforced concrete, reinforced masonry, and steel frames comprise the majority of commercial and industrial construction in California. Reinforced concrete and reinforced masonry buildings are susceptible to cracking and partial or full collapse in an earthquake. Reinforced concrete parking structures, hotels, and other commercial buildings suffered extensive damage during the 1989 Loma Prieta and 1994 Northridge earthquakes. Subsequent events around the world also confirmed damage patterns to these types of structures, including damage from the Kocaeli, Turkey and Chi-Chi, Taiwan earthquakes in 1999.

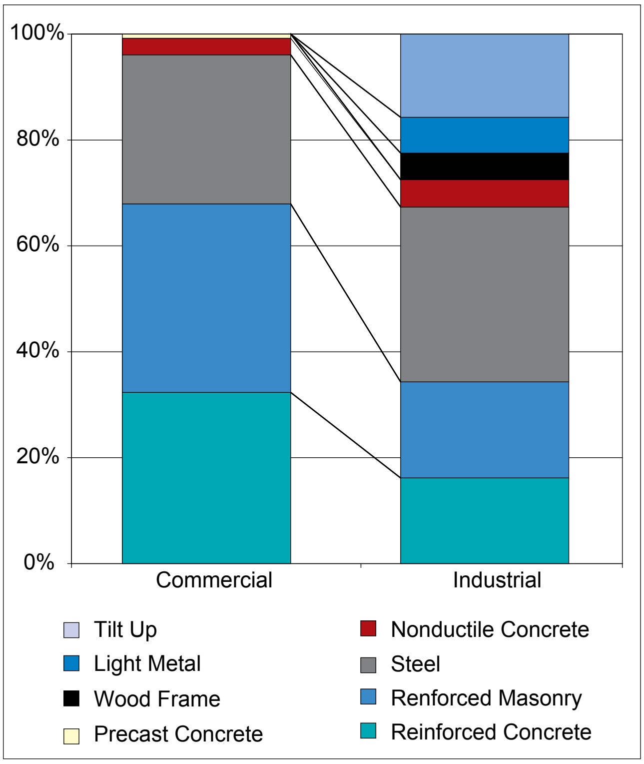
Steel frame buildings are expected to fare the best in an earthquake, although damage found in beam-to-column connections in these buildings after the 1994 Northridge Earthquake proved very costly to fix. Much of the damage was hidden and apparent only in buildings under construction or when the cladding in existing steel frame structures



Map of average residential loss ratios, defined as the ratio of the net insured loss to the total limits, for ground shaking damage from a repeat of the 1906 San Francisco Earthquake; the majority of residential buildings in California are of wood frame construction, and while wood frame structures are relatively resistant to earthquakes and are considered to be one of the safer structures during an earthquake, significant damage is expected for regions close to the fault rupture



Map of average residential loss ratios, defined as the ratio of the net insured loss to the total limits, for fire following earthquake damage from a repeat of the 1906 San Francisco Earthquake; in San Francisco, dense development of wood structures increases the vulnerability to residential fires



Mix of construction classes for commercial and industrial buildings in California

was removed. This damage pattern prompted the Federal Emergency Management Agency (FEMA) to launch the SAC Steel Project in 1994, which tested the performance of steel moment resisting frame structures from 1995 to 2000. Named with the initials of its parent organizations, the Structural Engineers Association of California (SEAOC), the Applied Technology Council (ATC) and the California Universities for Research in Earthquake Engineering (CUREE), the project culminated in the publication of a series of guidelines for seismic design and the retrofitting of these types of steel moment frame structures in 2000.

The overwhelming majority of residential buildings are wood frame structures, which are relatively resistant to earthquakes and are considered to be one of the safer structures during an earthquake. Nonetheless, significant damage to residential structures is expected, especially for the remaining pre-1940 single-family wood frame structures that have not been seismically retrofitted and the multi-family wood frame dwellings with 'tuck-under parking.' Additionally, chimneys, brick facades, and stucco walls are all susceptible to cracks and collapse, as was illustrated in all of the major recent California events (1989 Loma Prieta; 1994 Northridge; 2003 San Simeon).

Comparatively heavy damage to residential and commercial property would also occur in numerous areas of development on landfill around the San Francisco Bay. Shaking is intensified by poor soil conditions, which is why the Marina district in San Francisco suffered disproportionately large damage during the 1989 Loma Prieta Earthquake despite its distance from the fault segment that ruptured.

4.4 Contents Vulnerability

Heavy damage is also expected to contents, equipment, and inventories irrespective of any structural building damage. In the RMS approach to vulnerability modeling, contents damage assessment takes into account both ground shaking intensity and building performance. In the lower intensity events, contents damage is driven primarily by ground shaking; in higher intensity ground motion, both ground shaking and structural performance influence damage. For example, the contents within a URM structure would suffer much more damage than the contents within a wood frame structure if both sustained similar intense ground shaking. This is primarily due to the fact that the URM building has a higher probability of collapse than a wood frame building.

4.5 Fire Following Earthquake

Estimates of damage due to fire are calculated using a simulation approach to model the behavior of fire ignition, spread, and suppression throughout the region. In order to avoid double-counting losses, fire damage to structures already badly damaged by shaking is not considered (i.e. no 'burning the rubble'). Once a minimum level of ground motion is achieved, the building material (wood versus non-wood), the building occupancy (residential, commercial, or industrial), the time of day (morning ver-

Fire in the Marina district following the 1989 Loma Prieta Earthquake (USGS)

3 *Seismic Safety Commission (SSC), Status of the Unreinforced Masonry Building Law, 2003 Report to the Legislature (SSC 2003-03), Sacramento, June 2003*

sus evening), and the time of year (summer versus winter) all influence estimates of fire ignition. For example, the dry season (summer) contributes to a higher probability of significant fires following the earthquake. Fire spread is affected by such things as building density and wind velocity. More extensive fire losses would be expected if wind conditions following the event are more severe. In San Francisco, dense development of wood structures increases the vulnerability to residential fires.

The time it takes to suppress a fire is calculated using the location and number of fire-fighting units in the San Francisco Bay Area, subject to delays in discovering and reporting fires and the availability of water. In all likelihood, the vast majority of fires would be left to either burn themselves out or be suppressed by community volunteers, as the capacity of the area's fire departments to handle many concurrent fires could be hampered by the damage to water pipelines or debris in streets.

4.6 Business Interruption

Business interruption (BI) is a major component of the broader 'time element' loss. Time element is the generic term given to losses that result from interrupted operations at a location that are caused by an earthquake, for example. Time element insurance generally includes BI coverage, extra expense coverage, and additional living expenses (ALE) for the residential line of business. The BI and ALE losses calculated in this study are the direct losses, defined as lost revenues due to suspended or reduced operations at firms damaged by either ground shaking or fire, or expenses incurred by property owners for residing in a temporary location until their home can be repaired.

These loss estimates include BI due to damage to lifelines supporting the 19-county Bay Area. Any loss of functionality in lifelines can create significant ripple effects, reducing the ability of businesses, government, and households to function, regardless of whether they sustained any direct earthquake damage.

4.7 Insurance Coverage in California

4.7.1 Residential Earthquake Insurance

For residential properties in California, earthquake insurance coverage can be purchased through a member insurer of the California Earthquake Authority (CEA) or a private insurer. In 2005, the CEA insurers wrote approximately 750,000 policies. The basic CEA policy, known as the mini-policy, covers structural damages to a residential dwelling or mobile home, paying up to $5,000 to repair or replace personal possessions and $1,500 for living expenses while the home is being repaired or rebuilt. All claims are subject to a 15% deductible. Supplemental coverage is also available. Through an increased premium, a homeowner can purchase coverage with a reduced deductible (10%) and/or increased limits for contents and loss of use coverages. In 2005, close to one quarter of the 750,000 CEA-issued policies had supplemental coverage.

While the majority of residential earthquake insurance is covered by the CEA, a fairly significant private market remains. Because California law requires insurers to make an offer of earthquake coverage as an endorsement to a homeowners policy, these private insurers only sell earthquake insurance. The private insurers can therefore be more selective about the properties they cover as well as offer more comprehensive earthquake insurance policies. In comparison to the CEA mini-policy, these comprehensive policies often have lower deductibles (10%) with a single higher limit for dwelling, personal property, and additional living expenses. While this allows the homeowner a greater selection of earthquake coverage, the policies offered are usually limited to homes that specially qualify because they are well built and on stable soils.

4.7.2 Commercial Earthquake Insurance

In contrast to the residential earthquake insurance market in California, commercial earthquake insurance did not get overhauled as a result of the 1994 Northridge Earthquake. In fact, since 1994, commercial insurers have increased their commitment to the market through the use of catastrophe modeling to achieve technical risk-based returns while expanding levels of coverage to their commercial insureds. In 2006, commercial earthquake insurance in California is subject to less regulation, and the worldwide reinsurance market plays an essential role in this coverage. Aggregate volume of commercial earthquake premium is several times that on residential exposure.

4.7.3 Workers Compensation Insurance

In California, workers are offered some protection against workplace injury or fatality in the form of the heavily regulated workers compensation insurance system. Though initially designed to address employer negligence and dangerous working conditions, coverage is now required for any injury sustained while in the course of employment, even if such cause is beyond any reasonable means of prevention by the employer, such

County	Total Employees
Alameda	680,000
Contra Costa	344,000
Lake	16,000
Marin	111,000
Mendocino	34,000
Merced	67,000
Monterey	168,000
Napa	65,000
Sacramento	611,000
San Benito	16,000
San Francisco	541,000
San Joaquin	214,000
San Mateo	343,000
Santa Clara	870,000
Santa Cruz	98,000
Solano	126,000
Sonoma	189,000
Stanislaus	169,000
Yolo	92,000
Total	4,754,000

Estimated Bay Area employment by county (based on RMS® U.S.Workers Compensation Industry Exposure Database)

as for an earthquake. Under the workers compensation system, almost all employees are eligible to receive benefits, including coverage of medical costs, wage replacement (indemnity benefits), death benefits and burial allowances, vocational rehabilitation, and legal costs. Compensation is limited to the employee and does not provide coverage for injured dependents.

Insured losses for workers compensation claims have risen sharply over the past decade due in part to medical inflation as well as regulatory changes that have expanded coverage and benefit levels. Insurance rates have also risen sharply over this same time period. Employers are required to purchase workers compensation insurance or self-insure, forcing them to choose between paying large premiums or accepting the risk themselves. Insurance may be obtained through private insurance companies licensed to offer workers compensation insurance in California or by the state operated non-profit State Compensation Insurance Fund, which has become the largest workers compensation insurer in the world.

Benefit levels depend on the nature of the injury and can become quite expensive. Because injuries may range from minor to permanent total disability or even death, the range of possible financial consequences is very large. Lost wages, or indemnity benefits, are regulated by the state, which enforces caps on weekly and/or cumulative benefits. But an individual who sustains a very severe or permanent disability may still receive benefits for multiple months or even decades. Medical benefits, on the other hand, are not regulated and are covered in full. Permanent injuries or disabilities can require expensive medical procedures and even a lifetime of treatment. Individual claims could potentially exceed $10 million.

RMS has estimated average nominal costs for individual claims. Although significant variability exists, the estimated average cost for a permanent total disability claim is $1.8 million and $400,000 for a death claim. These estimates are considerably greater than several years ago, reflecting medical cost inflation and regulatory changes. From an insurer's point of view, these are the most expensive injury outcomes and are the primary drivers of total workers compensation losses in a major catastrophe such as an earthquake.

4.8 Losses Not Included

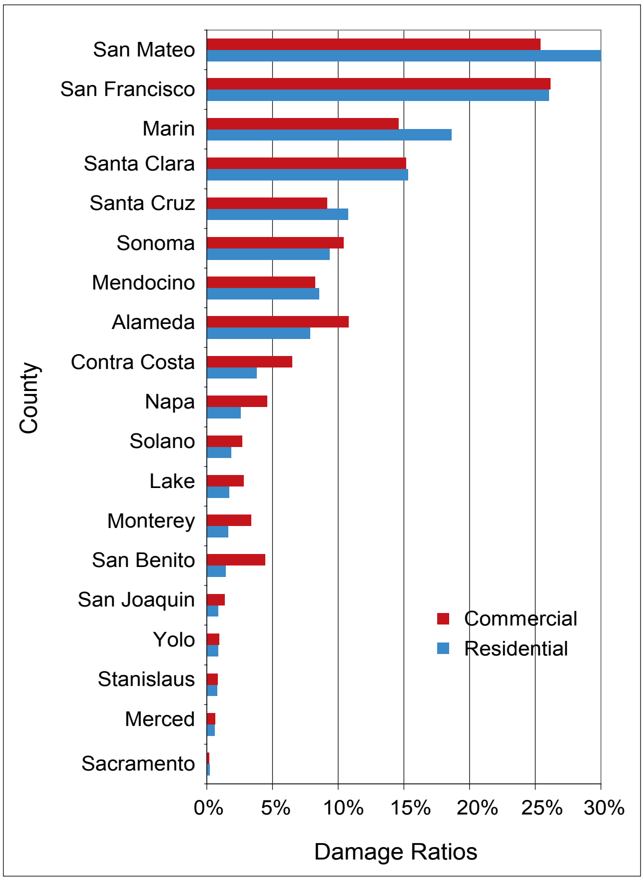
The property losses estimated in this study include residential and commercial property and contents losses as well as time element damages (i.e. direct business interruption or additional living expenses). No losses were explicitly calculated from flooding associated with dam burst or pipeline and tank failure or the release of toxic materials.

More broadly, neither indirect nor induced business losses are calculated as part of this analysis. Indirect BI loss occurs when the covered risk relies on another facility for revenue generation. The loss can be either greater or less than direct losses for a given network of locations, depending on the interaction of the network components. Induced BI loss refers to a reduction in revenue due to a depression in the economy stemming from the occurrence of an event. Estimation of indirect and induced BI losses is quite complex and involves many factors beyond hazard and loss severity.

4.9 Economic Loss Estimates

In an RMS study completed in 1995, it was concluded that a repeat of the 1906 San Francisco Earthquake and Fire would cause an insured property loss (including business interruption) between $75 and $95 billion for the residential and commercial lines of business. Total economic damage was assessed between $150 and $200 billion for the same exposure.

In the new 2006 scenario outlined above, ground shaking would occur in all 19 Bay Area counties, with the highest ground motions in the vicinity of the rupture zone of the San Andreas Fault, affecting Marin, San Francisco, San Mateo, and Santa Clara counties most severely. Total economic damages are estimated at approximately $260 billion, with $150 billion in residential damage to structures, contents, and costs for additional living expenses and $110 billion in commercial damage to buildings,



Estimated mean damage ratios, defined as the ratio of the expected monetary damage to total exposed value, to the commercial and residential lines of business in the 19-county Bay Area, showing the largest damage in San Mateo and San Francisco counties

contents, and costs of direct business interruption. The majority of the damage is caused by ground shaking loss, with a small percentage of economic damage attributable to fire following the earthquake (<5%).

In comparison to the 1995 RMS report, the 2006 economic loss estimate of $260 billion is in line with the increase in property exposure over this time, which went from under $1 trillion ($500 billion for residential properties and $350 billion for commercial and industrial properties) to close to $2 trillion ($1.2 trillion for residential properties and $750 billion for commercial and industrial properties).

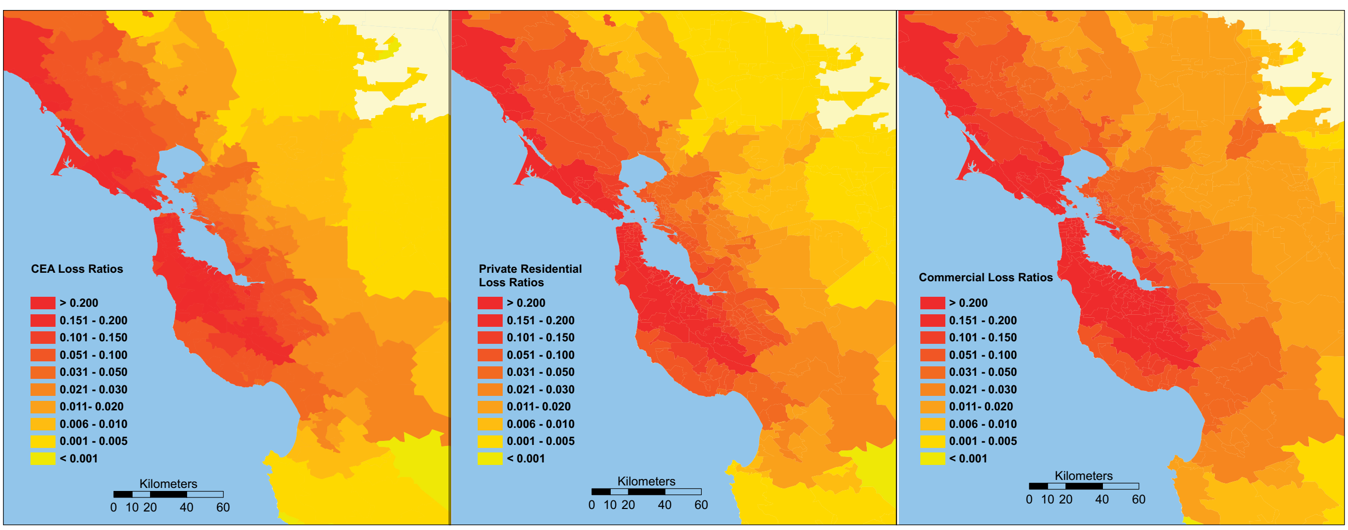
4.10 Insured Loss Estimates

4.10.1 Ground Shaking Losses

Insured losses from earthquake ground shaking alone are estimated to be $40 billion for residential and commercial building, contents, and time element coverages (direct business interruption and additional living expenses). While some damage would occur in all 19 Bay Area counties, the four counties of San Francisco, San Mateo, Santa Clara, and Marin would sustain over 85% of the total insured loss.

The total estimated insured loss to the CEA and the private companies selling residential earthquake insurance is around $13 billion. Of this total, the major loss component (over 90%) is from building damage, as there are rather severe limitations on contents and loss of use coverage.

In contrast, the estimated insured loss to the commercial line of business (for building, contents, and direct business interruption) is approximately $27 billion. Unlike the 1994 Northridge Earthquake, where approximately one-third of the $13 billion insured loss was to the commercial lines and two-thirds of the loss was borne by the residential insurance market, the significant majority of these losses would now be to commercial rather than personal lines. Moreover, a larger share of the primary losses would be



Average loss ratios, defined as the ratio of the net insured loss to the total limits, for ground shaking damage from a repeat of the 1906 San Francisco Earthquake to the California Earthquake Authority (left), the private residential insurance market (middle), and the commercial insurance market (right) borne by the global reinsurance market, as the losses would be more diversified across a broader range of commercial earthquake insurers and global reinsurance markets, given the improved attention to risk management within individual companies.

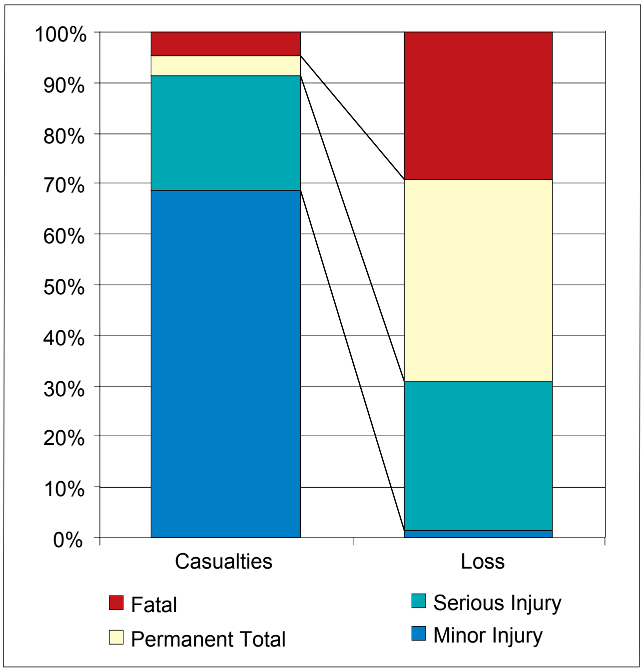
4.10.2 Fire Following Earthquake Losses

As shown in the 1906 San Francisco Earthquake and Fire, fires in the aftermath of an earthquake can often pose just as much threat to property damage as the earthquake itself. However, because a three-day conflagration in San Francisco of 1906 is unlikely to recur, estimates of fire insurance losses to the commercial and personal lines of business are less than insured loss estimates due to the earthquake ground shaking. For the personal lines, residential fire insurance covers all fire losses that are caused by or follow an earthquake, regardless of whether a homeowner has earthquake coverage. Therefore, insured losses due to fire following earthquake for the residential coverages is expected to be around $4 billion—adding an additional 30% on the insured loss estimate for ground shaking alone. In contrast, commercial fire insurance will add less than 10% ($2 billion) to the ground shaking loss for commercial lines payouts.

In contrast to the 1906 San Francisco Earthquake, where the majority of the losses were caused by fire, less than 15% of the estimated total insured property losses are expected to stem from fire. Nonetheless, fire will be significant, causing close to three times the $1.7 billion insured loss experienced in the 1991 Oakland Hills Fire. Additionally, San Francisco County is most at risk, accounting for close to 60% of the region's residential insured losses for fire following earthquake.

		Mean Loss ($ Millions) Due to Ground Shaking	Mean Loss ($ Millions) Due to Fire Following Earthquake
Residential	CEA	$6,000	$4,000
	Private	$7,000	
Commercial		$27,000	$2,000
Total		**$40,000**	**$6,000**

Summary of insured property losses (building, contents, and time element coverage) due to ground shaking and fire following earthquake from a repeat of the 1906 San Francisco Earthquake



Workers compensation losses by casualty type (minor injury, serious injury, permanent disability, or fatality) from a repeat of the 1906 San Francisco Earthquake

4.10.3 Workers Compensation Losses

Earthquakes in California are of particular concern to workers compensation insurers because they represent not only a credible risk, but they cannot be predicted or prevented and have the ability to produce large numbers of claims as part of a single occurrence. The majority of severe injuries is likely to result from a small number of building collapses or significantly damaged areas of a city. Ordinarily, there is little correlation between individual workers compensation insurance claims, but an earthquake could easily change that by affecting large numbers of employees all at once. An insurer covering a single employer with several hundred employees could find itself in financial danger if many of those employees are badly injured.

Minimizing this risk, however, is the fact that workers compensation is a limited coverage and applies only when employees are working. Thus, an event like the 1994 Northridge Earthquake, which occurred at 4:31 am, poses considerably less risk because the majority of employees work a standard 8-hour shift during the week. The fact that most working adults work 40 hours out of a total 168-hour week suggests that they are exposed to random catastrophic events such as earthquakes only about 25% of the time.

However, policy makers and insurers tend to take a worst-case perspective and focus on scenarios that would stress infrastructure and response systems, and/or financial resources. Earthquake loss estimates thus generally focus on large events that occur during periods of peak employment, most commonly at 2:00 pm on a weekday afternoon. A repeat of the 1906 San Francisco Earthquake during business hours could produce large numbers of casualties to the Bay Area workforce and also produce significant claims for workers compensation insurers. Estimates of workers compensation losses from this event range from $2 to $5 billion.

4.11 Summary

Several implications of this analysis merit highlighting, including the magnitude of the loss, the major loss components, the impact of fires following the earthquake, and insured loss amplification. First, the insured loss is close to four times greater than the worst insured losses experienced to date in California (1994 Northridge Earthquake) with total commercial and residential property losses from the earthquake and fire following over $45 billion. The 1989 Loma Prieta Earthquake caused approximately $1.1 billion in insured losses.

Second, the largest component of insured loss is commercial property damage. Commercial earthquake insurers in California have sustained coverage over the past 10 years or so, in contrast to the shrinking take-up rates in the residential earthquake insurance market over the same time period.

Third, in contrast to the 1906 San Francisco Earthquake, less than 15% of the estimated total insured property losses are expected to stem from fire. For example, if policy conditions hold (i.e. there is no coverage expansion in this event), it is expected that insurance payments for residential earthquake coverage will exceed the payments made for fires following the earthquake on homeowners policies.

Finally, insured losses would most certainly amplify following this Super Cat due to economic demand surge, repair delay, and claims inflation, as well as coverage expansion. As in 1906, the political fallout from a major California earthquake will lead to major pressure for insurers to be generous in expanding the terms of coverage of their fire policies.

	Mean Loss ($ Millions) Due to Ground Shaking and Fire Following Earthquake With Loss Amplification
Residential	$23,000
Commercial	$41,000
Total	**$64,000**

Summary of insured property losses (building, contents, and time element coverage) with loss amplification for a repeat of the 1906 San Francisco Earthquake

If coverage expansion was the principal experience for the insurance industry after 1906 event, it can also be expected to be an important factor in the next major earthquake loss in California. The significant asymmetry that exists between the low take-up rate (less than 14%) and punitive contract terms (15% deductible) of the CEA residential earthquake insurance policy as compared with the widespread take-up and relatively low deductible of fire insurance provides fertile ground to shift claims for losses into the fire policy.

As happened in 1906, some homeowners might conclude that faced with an earthquake damaged building, they would be better off if their property was then consumed by fire. However, more generally one can expect arguments (e.g. rain or water damage following earthquake, structural failure due to defective builder or architect) to justify why the fire policy (or a professional liability coverage) should pay for the loss. The rise in earthquake sprinkler leakage claims to commercial properties that followed the 1994 Northridge Earthquake was principally driven by the fact that the deductible was much lower in the terms of the fire coverage under which these losses were then paid.

Based on the modeling of the various loss amplification affects across the different lines of coverage, RMS estimates the total insured property losses could increase by approximately 40%, with the highest increases seen in the building coverage (most affected by economic demand surge) and the business interruption coverage (most affected by evacuations, disruption, and infrastructure damage). Overall, the insured portion of loss, in combination with workers compensation claims, could reach as high as $80 billion. Compared to the 1995 RMS estimate of the ratio of insured loss to economic loss (close to 50%) for a repeat of the 1906 San Francisco Earthquake and Fire, even this figure represents a lower proportion of the total economic loss. ■

5 MODELING SUPER CATASTROPHES

Modeling losses from Super Catastrophes requires a novel systems-based approach to capture the various ways in which losses can become exacerbated. There is no longer a single deterministic outcome of the event, but a range of possible outcomes, modulated by factors such as the time of day or weather conditions, or by stochastic processes themselves (e.g. whether a flood wall holds or fails). While the overall loss outcome increases, it also becomes more uncertain. However this uncertainty itself is also likely to be more spatially correlated than was typical of losses from the overall earthquake or hurricane. If a dam breaks or an oil storage facility leaks, then it may cause significant increases in the level of losses to properties in the area.

Certain aspects of the fires following the 1906 San Francisco Earthquake and other historical earthquakes provide examples of the range of possible outcomes if an event of similar magnitude were to occur in 2006. Additionally, some speculation can be made about other possible Cat following Cat events in the San Francisco Bay Area.

5.1 The Non-Deterministic Impact of Fire

In San Francisco in 1906, if fire fighting had been undertaken strategically with the explosives available, the fires could probably have been brought under control within a day. Alternatively, if the fires had broken out under anything other than calm weather conditions, it is likely that the whole city would have been consumed. Under windy conditions, there would have been a much greater risk of significant life loss during the evacuation, not only among those trapped in buildings but also those fleeing through the streets. The fire did not appear to present a significant hazard: by mid-morning after the 1906 Earthquake, any refugees from buildings damaged or burning south of Market Street were congregated in Union Square and only moved on after the buildings on three sides of the square were ablaze. Luckily, 1906 was still the early days of the oil economy, and apart from tanks on one pier, there were no major oil and gas tanks in the affected area.

Contrast this situation to that following the 1923 Great Kanto Earthquake in Tokyo, when a typhoon passing to the north of Tokyo brought high winds to the city. There were hundreds of individual fire ignitions as gas ranges tumbled in the wooden houses. With the winds and broken water mains, the fires spread so fast that the firefighters could not suppress the fire. In an attempt to escape the fire storm, refugees carrying clothes, bedrolls, and furniture took refuge in the moated Military Clothing complex in Honjo, where 40,000 died when the complex caught fire. The great pond in Asakusa Park in the heart of Tokyo was filled with bodies of the people escaping the fire. In all, the total number of houses that were burned was 14 times the number consumed in San Francisco in 1906. Moreover, the disaster was exacerbated by the explosion of all the municipal gas tanks, causing many more casualties. Oil from great storage tanks in Tokyo and Yokohama flowed into the sea, and the surface of the water caught fire, killing thousands who had fled in boats.

Destruction of Tokyo due to the quickly spreading fires following the 1923 Great Kanto Earthquake (USGS)

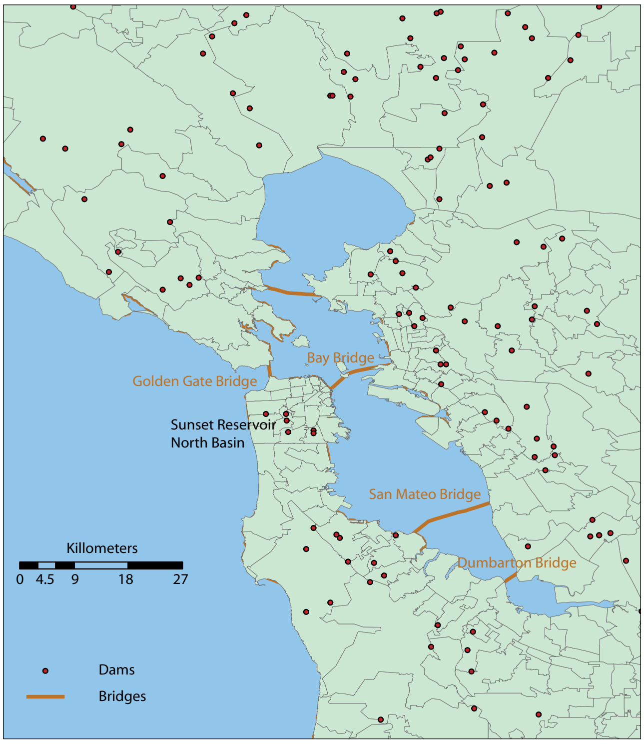
Other more recent examples of the probabilistic impact of fires include the 1995 Kobe and the 1989 Loma Prieta earthquakes. Following the 1989 Earthquake, one whole block on the edge of the badly-damaged Marina district in San Francisco burned down, but the calm wind conditions stopped the fire from spreading. The fire was extinguished with the assistance of water pumped in the area from the San Francisco Bay. In contrast, while there was no wind when fires broke out in Kobe, Japan after the earthquake, nearly 150 separate fires destroyed over 6,500 mostly wooden buildings over an area of 0.24 mi^2 (0.6 km^2). More than 50% of the fires occurred three hours or more after the quake hit, due to restored electrical supplies or the use of open fires for heating and cooking. As in San Francisco in 1906, the Kobe water supply was compromised by a large number of breaks in the distribution system, while many of the 975 underground cisterns situated throughout the city were either blocked by debris or damaged.

5.2 Other Cascades of Consequences

There are no specific examples of a cascade of consequences with respect to bridges and dams in 1906. The bridges had yet to be built, and while some dams were damaged, none completely failed. In 2006, damage to these lifelines and other essential facilities could have severe macroeconomic consequences to the Bay Area. For example, if one or more of the major bridges in the region becomes inoperable, a major conduit in or between San Francisco, the Peninsula, Marin County, and/or the East Bay would be lost, and significant disruption would follow. In the short-term, fire fighters or other responders to the event would have problems reaching damaged areas for rescue or fire suppression. In the long-term, if the bridge remained inoperable for an extended period of time, the economy of the entire Bay Area would be impacted.

The commercial enterprises of Silicon Valley would be hampered by the inability of the workforce to reach their workplaces in a reasonable time, as was seen following the 1989 Loma Prieta Earthquake, when a section of the San Francisco-Oakland Bay Bridge collapsed. The inability to transport cargo across the bay and around the region could cause suppliers to seek goods elsewhere. Moreover, if the ports of San Francisco and Oakland, which are particularly susceptible to liquefaction damage, are impacted, economic activity could move to ports in southern California or the Pacific Northwest.

The dams and reservoirs in the Bay Area provide another example of a potential cascade of consequences to the region. While the risk of dam failure is generally regarded as low, there are a number of aging dam structures in the region as well as significant property



Major dams and bridges in the San Francisco Bay Area are possible sources for a cascade of consequences following an earthquake

exposure in possible inundation areas. For example, a large portion of the Hetch Hetchy water system, which provides water to 2.4 million people in San Francisco, Santa Clara, Alameda, and San Mateo counties, is more than three-quarters of a century old. The Sunset Reservoir North Basin, a reservoir dam which is a part of the Hetch Hetchy water system, is located on a hill in the heart of the city's residential Sunset District.

5.3 The Future of Catastrophe Modeling

The 1906 San Francisco Earthquake and Fire triggered a dramatic change for the insurance industry, not only in California but for the pricing and managing of catastrophe risk across the developed world. While the largest insured losses before this time were due to fires, the event showed how large fire losses could be triggered by a geophysical hazard. The earthquake initiated the modern scientific understanding of natural catastrophes and risk management practices. In essence, the foundation of catastrophe loss modeling was established with this event.

When exploring the consequences of the 1906 San Francisco Earthquake and Fire, we can see echoes of the lessons that are currently expanding the sphere of catastrophe loss modeling in the aftermath of Hurricane Katrina. The larger the event, the greater the potential for complex and interdependent outcomes that can lead to Super Cat effects. RMS is committed to learning the lessons of these events and expanding the domain of catastrophe loss modeling. ■

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