Final Technical Report

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6.	Publications:	*The Coming Bay Area Earthquake-2010 Update of Scenario for a Magnitude 7.0 Earthquake on the Hayward Fault* (See Attached)
7.	Summary:	A scenario was developed based on expected consequences of an anticipated magnitude 7.0 Hayward fault earthquake. Key decision makers (public sector, utility and transportation organizations, and financial institutions) collaborated to evaluate risks to their sectors and developed solutions and approaches to reducing this risk. This project also focused decision-maker thinking on the necessity for regional catastrophic risk planning and the priorities for implementing risk planning and the priorities for implementing risk management actions.

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THE COMING BAY AREA EARTHQUAKE

2010 Update of Scenario for a Magnitude 7.0 Earthquake on the Hayward Fault

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE
NORTHERN CALIFORNIA CHAPTER

PREFACE

The Northern California Chapter of EERI has launched a Hayward Fault Initiative. The goal of the initiative is to promote risk reduction locally by providing updated information on the consequences of a Hayward fault earthquake and actively encouraging risk reduction programs. This initiative builds on and updates information included in the 1996 EERI document Scenario for a Magnitude 7.0 Earthquake on the Hayward Fault.

This document comprises Phase 1 of the Hayward Fault Initiative. Phase 2 will create a policy agenda report for earthquake risk reduction specific to the East Bay.

This document was developed and is being published by the Earthquake Engineering Research Institute – Northern California Chapter (EERI-NC), with funds from the US Geological Survey National Earthquake Hazards Reduction Program (USGS-NEHRP grant 08HQAG0116).

The author, Janiele Maffei, Structural Engineer, was assisted by EERI-NC Past- President Keith Knudsen of URS, as well as by numerous other contributors acknowledged in each chapter. The document was edited by Sarah Nathe, University of California, Berkeley.

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INTRODUCTION

At the 1995 Annual Meeting of the Earthquake Engineering Research Institute (EERI), a day-long symposium addressed the challenges of a major urban earthquake. Sixteen presenters discussed aspects of a Hayward fault earthquake, from its seismology to its social and economic impacts on the San Francisco Bay Area. The symposium presentations were subsequently published in **Scenario for a Magnitude 7.0 Earthquake on the Hayward Fault.**

In his Introduction to that book, William U. Savage of Pacific Gas and Electric Company described a magnitude 7.0 earthquake on the Hayward fault:

> *The earthquake begins in San Pablo Bay, and we count the duration in seconds: one thousand four, one thousand five… The ground and the buildings bump and shift. One thousand eight, one thousand nine… Then, with a sickening lurch, the intensity increases. One thousand thirteen, one thousand fourteen… Again and again, thunderous blows rumble and stab. One thousand eighteen, one thousand nineteen… Slowly the movement wanes and the noise subsides. One thousand twenty-two. The future becomes the here and now.*
>
> *We have been given the answer in a few seconds to the long-asked question, When? Now we face all those other questions: Where was it? Is my family safe? Is the bridge down? My house, my business – are they damaged? How do I get home? Where do we take the injured? Where did I put that emergency plan? What do we do first? When will the phones, the lights, work again? What will we need to recover, to rebuild, to return to normal?"*

Many of the presentations at the 1995 EERI meeting included a brief description of loss reduction efforts planned or underway. Most of the presenters proposed strategies for reducing vulnerability to loss. In the final chapter, "A Call to Action," L. Thomas Tobin stressed the importance of integrating seismic safety with the other goals of the community: "we can't hide vulnerability; we must face it openly and with resolve."

INTRODUCTION

In the 15 years since Tobin made that plea, communities around the Bay have faced their earthquake vulnerabilities in varying ways; many have made great progress in loss reduction, but a troubling number have not.

In each of the following chapters, the significant points from the 1996 report are summarized and then updated information is provided. Where possible, original chapter authors were interviewed and many assisted in updating their contributions.

A similar theme emerges from each area of concern: significant progress has been made, but there remain many opportunities for more strategic loss reduction.

CHAPTER 1:
HAYWARD FAULT SOCIOECONOMIC SETTING

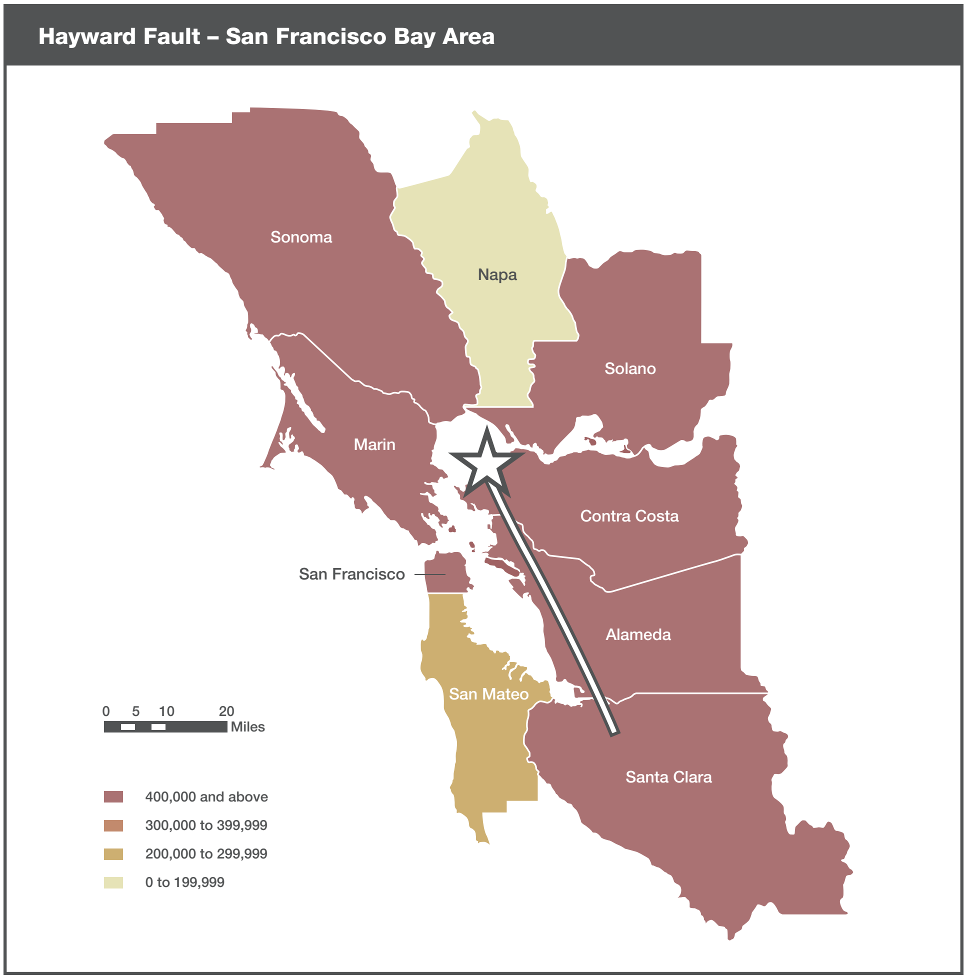
**ORIGINAL AUTHOR: ANGELO SIRACUSA,
FORMERLY OF THE BAY AREA COUNCIL**

1995 SUMMARY:

Siracusa began his chapter with the quote, "There is no problem so big, so important, you can't run away from it." He then argued compellingly for the importance of earthquake loss reduction to the economic stability of the San Francisco Bay Area.

- The Bay Area is a vibrant metropolitan region—the fifth largest in the country–comprised of nine counties.
- In 100 different Bay Area municipalities live 6.5 million people, despite the challenges of affordable housing and traffic.
- With 2.3 million households and 2.9 million employed people, it is the fourth largest economy in the country, an economy that would "rank among the top 20 in the world."
- The Port of Oakland is a center for international trade, and the intellectual services industries have touched the far corners of the world. The University of California, Berkeley and Stanford University have helped make the area a "world-renowned center of entrepreneurship and innovation."
- Unlike other metropolitan regions, and despite the caché of the City of San Francisco, the Bay Area lacks a central city, and has no regional decision-making capabilities. This hamstrings regional planning in many areas, disaster preparedness chief among them.
- Practically 50 years of uninterrupted prosperity have blinded many in the area to the potential for huge economic losses in a major earthquake.

CHAPTER 1:
HAYWARD FAULT SOCIOECONOMIC SETTING



Map of the Nine San Francisco Bay Area Counties and the Hayward fault (Source: PG&E, USGS)

Fig 1.1

2010 UPDATE

In the past 15 years the Bay Area has grown in population and economic status. In 2009, the California Department of Finance estimated the population of the nine Bay Area counties at 7.4 million people with 2.7 households (1). The Association of Bay Area Governments projected there will be 3.4 million people employed in the region in 2010 (2). The Bay Area Council Economic Institute estimated the region's economy in 2009 at $300 billion (3), noting that the area still leads the nation in knowledge-based industries.

CHAPTER 1:
HAYWARD FAULT SOCIOECONOMIC SETTING

The Bay Area Council notes that the region's challenges continue to be housing supply, transportation, and the cost of living (4). The average cost of a single-family home in the Bay Area continues to be roughly four times the national average. While growth has been focused in the more affordable counties east of the Bay, many of the jobs in the region are situated in larger metropolitan areas, taxing the region's transportation systems. In 2007 the Texas Transportation Institute ranked the San Francisco–Oakland commute 8th nationally for travel delays; the annual hours of commute have doubled since 1982 (5). The increasing population and dependence on low-occupancy travel magnify the susceptibility of the area to physical and economic losses in a major earthquake.

Container ship parked at the port of Oakland

Fig 1.2

In 1995, the San Francisco Bay region had always had unemployment below state and national averages, but things have changed. The Bay Area has been affected by a global economic crisis unparalleled since the 1929 depression. According to the U.S. Bureau of Labor Statistics, the unemployment rate in the Bay Area in August 2010 was 10.8%, below California's 12.4% but well above the national rate of 9.6% (6). The high rate in the Bay Area and California is due mostly to the impact of the subprime mortgage lending crisis on an economy that relies heavily on housing and construction industries. Simon Alejandrino of Bay Area Economics attributes the higher unemployment rate to technology and information-related industries, with hiring patterns that increase quickly during boom times and decrease dramatically during recessions (7).

The Hayward Fault runs through the University of California, Berkeley Campus

Fig 1.3

In early 2008, Silicon Valley, center of the Bay Area's high technology industry, appeared to be insulated from the financial crisis and was experiencing above-average growth. However, the 2010 Silicon Valley Index indicated steep job losses and a rise in commercial real estate vacancies (8).

Alejandrino notes that "the Bay Area economy is one of the more resilient economies in the nation" (7) However, the economic shockwaves from a major earthquake here would affect the national and global economy since the Bay Area is "a world or national leader in bioscience research, medical research, information technology, nanotechnology, number of life science companies, number of new companies created annually, Internet domains, and start-up/mid-sized/Fortune 500 technology-driven enterprises" (9, p. 5). Damage to East Bay infrastructure would also have a tremendous impact since the Port of Oakland currently handles 99% of the containerized goods moving through northern California (10).

CHAPTER 1: HAYWARD FAULT SOCIOECONOMIC SETTING

The common wisdom is that natural disasters have no long-term impacts on viable communities (11, p.178). In the United States, there are said to be sufficient resources in the rest of the country to support recovery; however, in the aftermath of Hurricane Katrina, it must be recognized that "some segments of communities are either disproportionately affected by disaster impacts or poorly integrated into the recovery networks, or (frequently) both" (11, p.182). These segments include lower-income households, which tend to be headed disproportionately by females and/or racial/ethnic minorities, who have fewer economic resources at their disposal both before and after a disaster.

Since 1995 we have known that a Hayward fault earthquake will cause severe ground shaking and serious building damage in many areas home to lower income and racial/ethnic minorities. Chapter 13 of this report details the current thinking about housing and social recovery following a big earthquake here.

In the last 15 years, national, state and local governments and organizations have taken steps to increase the region's ability to withstand a major earthquake; however, the economic recession has slowed loss reduction activities and decreased incentives once offered to the private sector. Alejandrino summed up the predicament today: "With many local jurisdictions and the state in dire fiscal straits, emergency planning becomes a secondary, and even tertiary concern" (7).

CHAPTER 1:
HAYWARD FAULT SOCIOECONOMIC SETTING

County	Residential Property (in $ billions)	Commercial Property (in $ billions)	Population (in thousands)*
ALAMEDA	$215	$150	1,575
CONTRA COSTA	$160	$95	1,075
MARIN	$55	$25	260
SAN FRANCISCO	$115	$155	855
SAN MATEO	$130	$85	755
SANTA CLARA	$315	$205	1,880
SOLANO	$50	$25	425
SONOMA	$70	$30	495
TOTAL	**$1,110**	**1,575**	**7,320**

*Economic and Insured losses estimated by RMS

Property and People at Risk. Source: 1868 Hayward Earthquake Retrospective Update, RMS

Fig 1.4

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ACKNOWLEDGMENTS

I would like to thank Simon Alejandrino, Bay Area Council Economic Institute, for providing me with information for this chapter.

CHAPTER 2: GEOLOGY AND SEISMOLOGY OF THE HAYWARD FAULT

ORIGINAL AUTHOR: DAVID SCHWARTZ,
U.S. GEOLOGICAL SURVEY

1995 SUMMARY

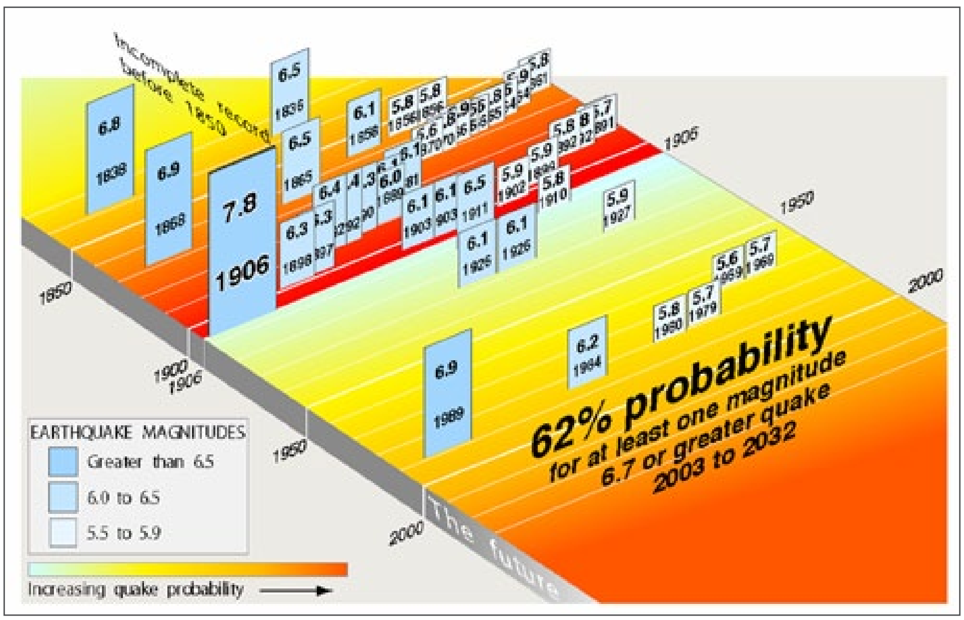
Schwartz described the expected M7.0 earthquake as beginning at the northern end of the Hayward fault in San Pablo Bay. It will rupture 50 km to the south and last for 22 seconds. Average displacement at the surface will be 1 m (about 3 feet), but there may be up to 9 feet of offset in certain locations.

Map of the San Andreas fault system in the San Francisco Bay Area

Fig 2.1

CHAPTER 2: GEOLOGY AND SEISMOLOGY OF THE HAYWARD FAULT

- In the Bay Area the San Andreas fault system, the boundary between the North American plate and Pacific plate, is made up of numerous individual subparallel faults, among them the Hayward fault.
- The rate at which these two tectonic plates slip past each other is about 47mm (2 inches) a year. The Hayward fault is moving at about 9 mm/year, comprising about 20% of the slip across all the faults in the Bay Area.
- Figure 2.2 illustrates the high seismic activity in the Bay Area prior to the 1906 earthquake; 16 earthquakes exceeding M6.0 struck between 1836 and 1906. After the 1906 quake, seismic activity dropped dramatically because the stress was reduced on the faults in the region.



The 1906 Earthquake reduced stresses in the region leading to a low level of seismic activity (source: USGS)

Fig 2.2

- The Working Group on California Earthquake Probabilities (WGCEP), estimates probabilities of earthquakes on California faults. In their 1990 report they reported the likelihood of a Hayward fault earthquake as being very high (23% in the south and 28% in the north).

- The WGCEP also estimates the approximate return period, or repeat time, for earthquakes. In 1990, it calculated the repeat time for the northern Hayward fault at 167 years, putting us "159 years into that 167-year cycle."

A photo of a trench across the fault shows what are believed to be fissure fills where old openings in the surface allowed materials to drop in during an earthquake.

Fig 2.3

CHAPTER 2: GEOLOGY AND SEISMOLOGY OF THE HAYWARD FAULT

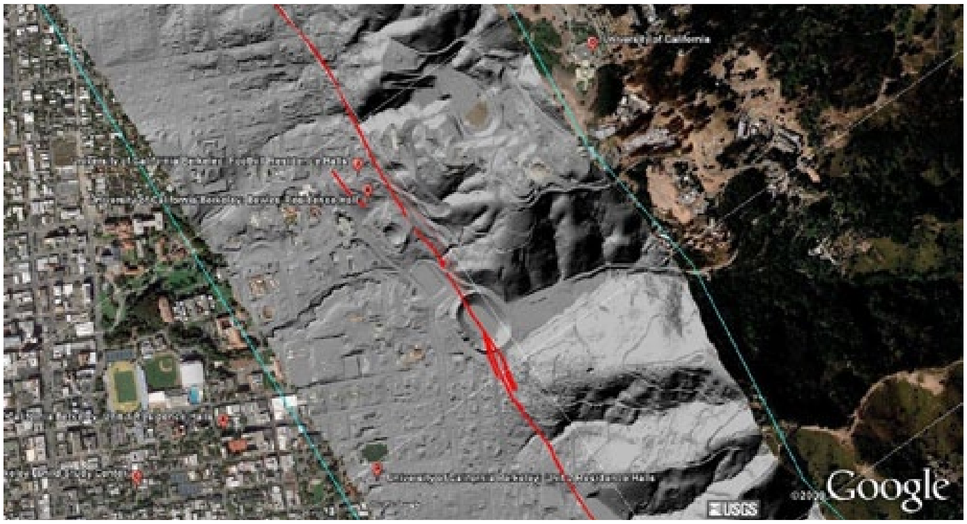


Figure 2.4 of the 1995 document traces the Hayward fault along Highway 13 through Berkeley, El Cerrito, and out to San Pablo Bay: "the most densely built-up section of the entire Bay Area."

Fig 2.4

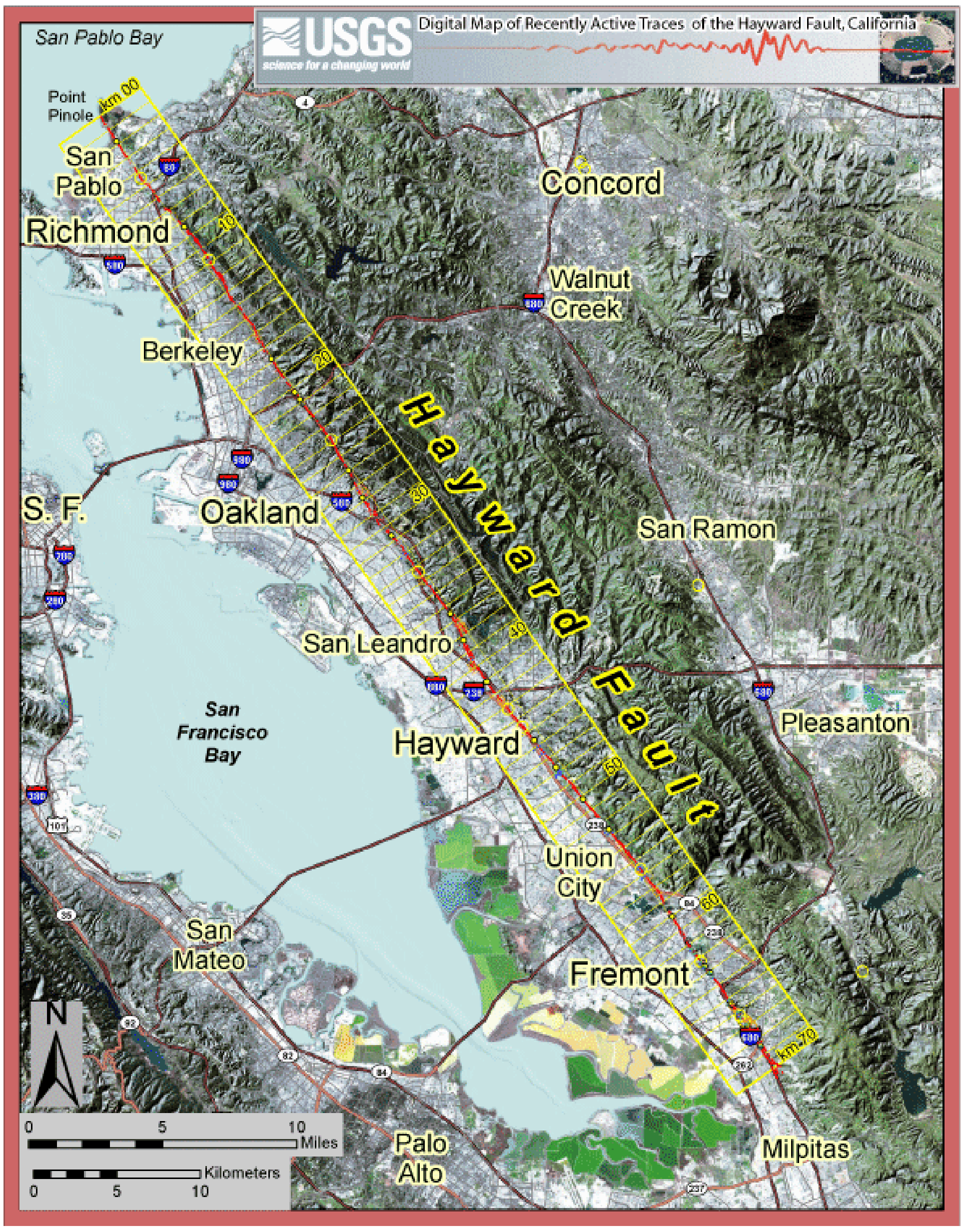
- The fault slips at depth during earthquakes and creeps at the surface between earthquakes. Between the creeping part and the deep-slip part, there are two areas that are locked. These parts of the fault will "fail and produce the next earthquakes."
- A large earthquake on the Hayward fault could also trigger a significant earthquake on the Rogers Creek or other adjacent faults.

2010 UPDATE

The paleoseismological program of Hayward fault trenching described in 1995 continues and is invaluable in detailing the history of past earthquakes. The Tule Pond site, near the Fremont BART station (Figure 2.3), has yielded a tremendous record of past earthquakes along the southern part of the Hayward fault. James Lienkaemper of the US Geological Survey and colleagues have spent several field seasons investigating the record of earthquakes preserved in the shallow layers of soil at this site and have developed an 1,800-year record of paleoearthquakes. There have been 12 earthquakes over this period and the average recurrence interval between earthquakes is about 160 years (10). This is the most detailed record of paleoearthquakes for any fault in Northern California, and this has been perhaps the most important work over the recent decade for constraining our understanding of earthquake hazards in the Bay Area.

CHAPTER 2: GEOLOGY AND SEISMOLOGY OF THE HAYWARD FAULT

Over the last couple of decades, new technologies have been developed that aid in the mapping of active faults and also in the characterization of major plate boundary fault systems. GPS, LiDAR, and InSAR provide new information to improve fault mapping, measure fault slip rates, and, together with paleoseismologic results, refine earthquake probability estimates.



Active trace of the Hayward Fault (Source: USGS)

Fig 2.5

CHAPTER 2: GEOLOGY AND SEISMOLOGY OF THE HAYWARD FAULT

GPS (global positioning system) was developed by the United States Department of Defense to provide precise locations globally for military uses. Today, GPS satellite technology is open to the broad community and earth scientists are utilizing repeated GPS measurements to monitor the strain accumulation on faults. These data help us understand the mechanics of earthquakes and the earthquake cycle. Large arrays of continuously recording GPS stations are installed in Japan and western North America and record on-going strain accumulation at rates of millimeters to centimeters per year. GPS data also record the strain accumulation on blind thrust faults that have little or no surface expression (1, p. 351).

LiDAR (light detection and ranging) is a system of pulses of laser light directed at a subject from an aircraft or from a ground based instrument. Recently, LiDAR data has been collected along many of the most active Bay Area faults, yielding high resolution three-dimensional images of the surface expression of active faults (Figure 2-4). In 2007, a LiDAR survey of the Hayward fault provided a digital elevation model, which is being used to identify geologic features such as sag ponds and push-up ridges associated with fault movement. With regular updates of the LiDAR survey, slight movements in geologic features due to creep will be apparent (2, p.21). The survey will also serve as a "pre-quake" baseline against which to map the fault offsets in great detail following the next Hayward fault earthquake.

InSAR (interferometric synthetic aperture radar) uses satellite radar data to monitor ground surface position changes. InSAR has a distinct advantage in urban areas as the technique gets great signal return from features at right-angle to the ground surface, such as buildings. Since it also works at night and on cloudy days, InSAR can be used to measure ground deformation after an earthquake and provide high resolution mapping of the fault offset and building disruption within the affected area (1, p. 354). It has been used with particular success to characterize vertical motions along faults in the San Francisco Bay Area by Roland Burgmann of the University of California at Berkeley and his colleagues.

In a 2000 paper in Science (11), Burgmann and colleagues describe how they used GPS, InSAR and seismicity data to model the movement of the Hayward fault. In part because the Hayward fault creeps (moves aseismically [or without seismicity] between large earthquakes), researchers have been unsure what part of the tectonic plate movement, and strain accumulation, happens between large earthquakes as creep and what fraction of the tectonic strain produces large earthquakes. The models developed by Burgmann and colleagues suggest that much of the tectonic strain accumulation across the northern Hayward fault is released through fault creep without producing large earthquakes and that the potential for large earthquakes on the northern Hayward fault might be less than previously thought (11). The relatively recent availability of GPS and InSAR data, and use of this data to better understand the earthquake cycle, will continue to lead to better characterization of hazards along the Hayward fault and in the Bay Area.

Post-earthquake reporting and seismic analysis have improved dramatically since the 1995 conference. At the time of the 1989 Loma Prieta earthquake, seismologists measured earthquake magnitudes by visually analyzing seismograms. They then reported these magnitudes and earthquake locations to various response agencies by the telephone. Today, most analysis is computerized and automatic. The USGS, UC Berkeley Seismological Lab (BSL), CGS and Caltech have dedicated circuits that share seismic data from instruments in the field. Preliminary earthquake locations and magnitudes are available online within 1-2 minutes of an event's occurrence; final locations and magnitudes are known in 4-6 minutes. Information about earthquakes is disseminated online, by email, and by pager.

The proliferation of instrumentation throughout California has also had a positive effect on earthquake reporting in the past 15 years. Additionally, advancements in web technology have enabled the CGS and USGS to provide Internet Quick Reports and release a shake map soon after an event. Shake maps integrate information such as soil conditions, distance from ground rupture, and length of shaking into maps of shaking intensities in order to estimate building damage. Shake maps provide emergency responders with information about heavily shaken areas very soon after an earthquake. Maps are provided whenever a new large earthquake occurs (4).

In April, 2008 a new, uniform earthquake forecast was released for the entire State of California. The new statewide analysis was a collaborative effort by the USGS, the Southern California Earthquake Center (SCEC), and CGS, with support from the California Earthquake Authority (5). This California Earthquake Rupture Forecast 2 (UCERF2) estimated a 63% probability of one or more M6.7 or greater quakes occurring in the Bay Area over the next 30 years, and a 31% probability for a quake on the Hayward-Rogers Creek fault system. While the calculated probability for a Bay Area earthquake remained about the same as earlier estimates ,the calculated likelihood of a large earthquake on the Hayward fault rose. In fact in the UCERF2 analysis the Hayward fault system had the second highest earthquake likelihood in the state (following the southern San Andreas).

Fig 2.6 (I. M6.8 a.) Oakland

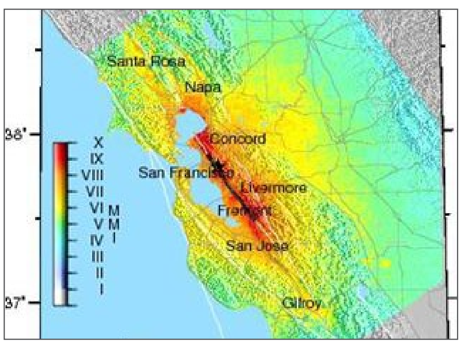


Fig 2.7 (I. M6.8 b.) Hayward

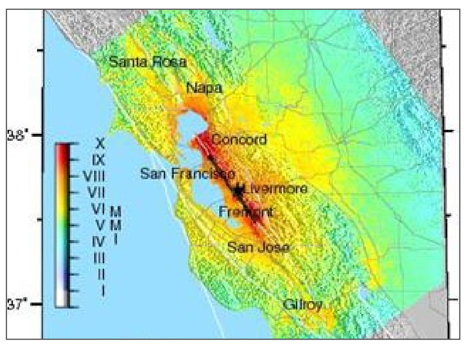


Fig 2.8 (I. M6.8 c.) Fremont

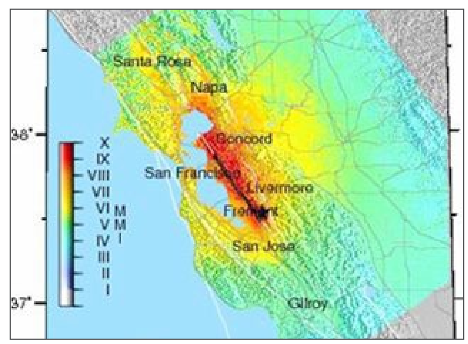


Fig 2.9 (II. M7.0 a.) San Pablo

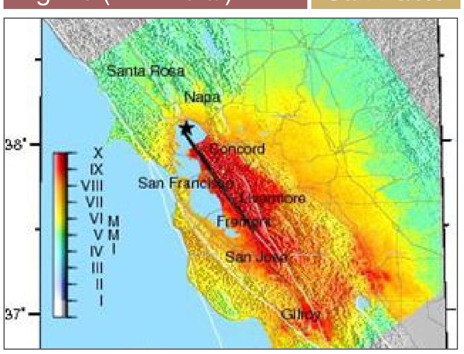


Fig 2.10 (II. M7.0 b.) Oakland

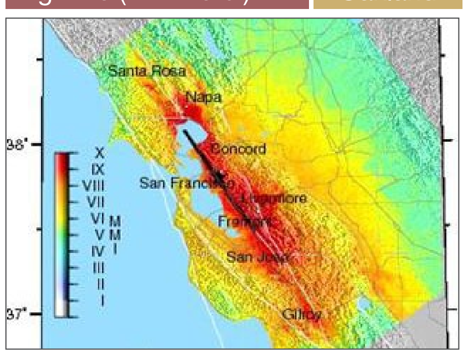
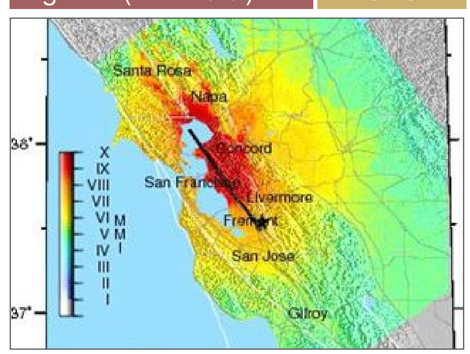


Fig 2.11 (II. M7.0 c.) Fremont



CHAPTER 2: GEOLOGY AND SEISMOLOGY OF THE HAYWARD FAULT

Leading up to the 140th anniversary of the 1868 Hayward earthquake in 2008, a group of over one dozen U.S. geophysicists developed a suite of 39 magnitude 6.6 to 7.2 scenario earthquakes involving the Hayward fault (6,7,8). Scientists from five institutions participated, including the USGS, URS Corporation, Lawrence Livermore National Laboratory (LLNL), Stanford University, and University of California, Berkeley. Earthquake features, such as magnitude (rupture length), distribution of slip, epicenter (initiation point of fault rupture), and rupture propagation speed were systematically varied across the suite of scenarios to account for the large uncertainty in the behavior of the next large earthquake on the Hayward fault. The group used ground-motion simulations that included the 3-D effects of the geologic structure and rupture propagation to characterize the shaking and its variability across the suite of scenario earthquakes. The shaking in any of the scenarios is large enough to produce liquefaction in the soft-soil sites along San Francisco Bay, as well as landslides in the East Bay hills (9).

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I would like to thank David Schwartz and Brad Aagard of the USGS, and Mary Lou Zoback of RMS for providing updated information for this chapter. I would also like to thank Keith Knudsen, URS, for his contributions to this chapter.

CHAPTER 3:
GROUND FAILURE PHENOMENA

ORIGINAL AUTHOR: WILLIAM LETTIS, WILLIAM LETTIS & ASSOCIATES

1995 SUMMARY

The surface fault rupture will extend 50 km from San Pablo Bay to near Lake Chabot in the San Leandro area. Lettis estimated an average of approximately 3 feet of surface displacement along the entire trace, with "locally 7-10 feet of maximum ground displacement."

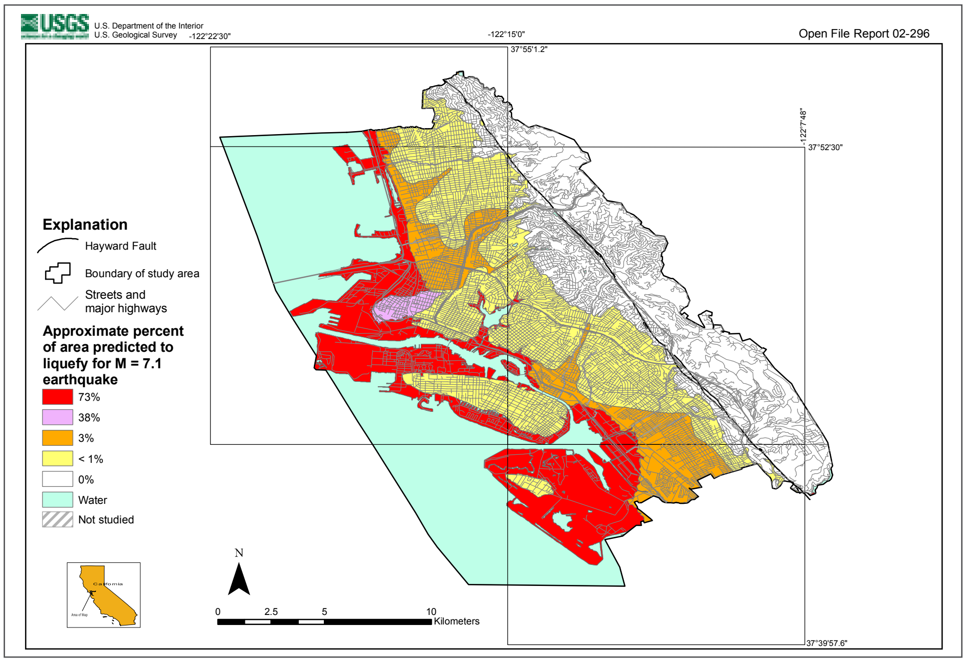
- The ground rupture may be on a narrow, well-defined trace or in a "complex, wide zone of deformation." Figure 3.1 shows the San Andreas fault after the 1906 earthquake with a "relatively simple single fault trace." However, rupture breaks during the 1991 Landers earthquake were separated into multiple strands. There may be 1-2 feet of vertical offset across the fault during the next earthquake.

Alameda County Geologic Formations Map (Source: USGS)

Fig 3.1

- In a region with numerous historical landslides, we should expect hundreds to thousands of disrupted hillsides, primarily in the foothills of the East Bay, and hundreds to thousands of rockfalls.

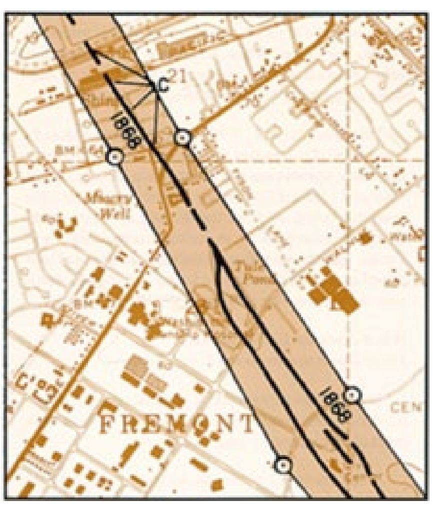
CHAPTER 3:
GROUND FAILURE PHENOMENA



USGS Liquefaction Map of Oakland/ Alameda (Source: USGS)

Fig 3.2

- The M 7.0 earthquake will have sufficient strength and associated ground shaking to cause liquefaction throughout the Bay Area. Liquefaction--the transformation of a solid material into a liquid material that leads to lateral spreading, settlement, loss of bearing capacity, and flow slides on steeper slopes--is predictable given careful mapping.



Typical Alquist Priolo Map

Fig 3.3

CHAPTER 3:
GROUND FAILURE PHENOMENA

2010 UPDATE

Future fault ruptures that extend to and deform the ground surface are most likely to occur along mapped and well located traces of known active faults (see Figure 2.4 for a map of a part of the Hayward fault). The State's Alquist Priolo Earthquake Fault Zoning act has triggered the production of maps showing zones within which studies addressing the hazard should be completed for development projects (Figure 3.3). The increasingly detailed LiDAR topographic data that is available has lead to production of more detailed and complete maps of fault locations, with Jim Lienkaemper's mapping of the Hayward fault (9) being a leading example. Although there has been some recent movement toward allowing for mitigation of surface rupture hazard for well engineered facilities, the best alternative is still simply to avoid building structures across the surface traces of active faults.

There has been a focus over recent years on trying to improve our ability to estimate the amount of surface deformation (or "offset") that is likely to occur along fault traces that rupture to the ground surface. Much of this work and research has been conducted for lifeline organizations (e.g. suppliers of water, gas, electricity, transportation, communications, fuel) so that they can better mitigate against surface fault rupture. New technologies, materials and approaches have been developed at fault crossings that make survival of pipelines and other engineered structures more likely. Additionally, probabilistic approaches have been developed to characterize the range of magnitudes of surface offset and the width of offset zones. For example, Keith Kelson and colleagues at William Lettis & Associates provided BART with retrofit design parameters for facilities that cross a number of active and potentially active faults in the East Bay. They suggested that BART plan for as much as 6.5 feet of horizontal (strike slip) fault movement and 2.0 feet of vertical fault offset at the Hayward fault crossing of BART's Berkeley Hills Tunnel.

Stemming in part from reaction to the 1989 Loma Prieta earthquake, the Seismic Hazards Mapping Act was passed in 1990. It directs the State Geologist to produce maps of zones or required investigation for landslides and liquefaction. While the law was in effect in 1995, at the time of the previous document, the associated hazard maps covering the Bay Area had not yet been developed. Currently, maps have been released covering parts or all of Alameda, San Francisco, San Mateo and Santa Clara counties (10).

Landslide inventory maps of the East Bay produced by CGS (3) and the USGS (4). indicate that a significant portion of the Berkeley and Oakland hills have landslide deposits from either actively moving or older landslides. These older landslides may get reactivated by a large Hayward fault earthquake. There are three major areas of landsliding in Berkeley--the Keith Slide, the Thousand Oaks Slide, and the Blakemont Slide—each with active subzones (11). The Hayward fault runs through all three zones. Recently, scientists at the University of California, Berkeley and Stanford University are using the latest satellite mapping techniques to investigate surface deformations in the Bay Area (1). These investigations “include exploration of deformation along the Hayward and other active fault zones, active landsliding (focusing on the Berkeley Hills), land subsidence due to groundwater level changes, and soft-sediment settling around the Bay”.

High-resolution liquefaction susceptibility maps were produced in 2000 and updated in 2006 under the auspices of the National Earthquake Hazards Reduction Program (NEHRP) (6). The maps are designed to give new and better tools to the general public as well as land-use planners, utilities and lifeline owners, and emergency response officials so they can assess their risk from earthquake damage. These “susceptibility” maps show the propensity of the area’s materials to liquefy given intense ground shaking. They have been used by other organizations, including the Association of Bay Area Governments (ABAG) (6), the California Geological Survey’s Seismic Hazard Zone Program (10), and the USGS (7) to produce other varieties of liquefaction hazard maps. The ABAG maps are earthquake scenario-based and are used very often by the general public. The CGS maps show “zones of required investigation” and are used in new development planning and permitting, and also are part of the real estate disclosure process. The USGS maps are the result of new research approaches to hazard mapping, and are available for the Oakland-Berkeley and Santa Clara Valley areas. A “zoomable” liquefaction susceptibility map for the San Francisco Bay

Area that is based on the 2000/2006 susceptibility maps is available at a USGS website (7).

While most building departments require geotechnical reports for new construction in soft soil zones, existing structures may not have been constructed to withstand the effects of liquefaction (sand boils, settlement, slope failure, lateral spreading) expected at those sites. For example, the Port of Oakland's marine and airport facilities are both located in filled areas that are highly susceptible to liquefaction. The Oakland International Airport experienced considerable damage and disruption from the 1989 Loma Prieta earthquake, even though the epicenter for this event was quite distant from the airport. The Port of Oakland's efforts to reduce seismic vulnerability are discussed in Chapter 9 of this document.

There are many urban planning and engineering approaches to protect new buildings and infrastructure from earthquake-induced ground failures. However, many older existing buildings and structures, designed in conformance to older codes, are vulnerable to the effects of fault surface rupture, landslides, and liquefaction. It is these older structures that are likely to be damaged by ground failure during the next large earthquake on the Hayward fault.

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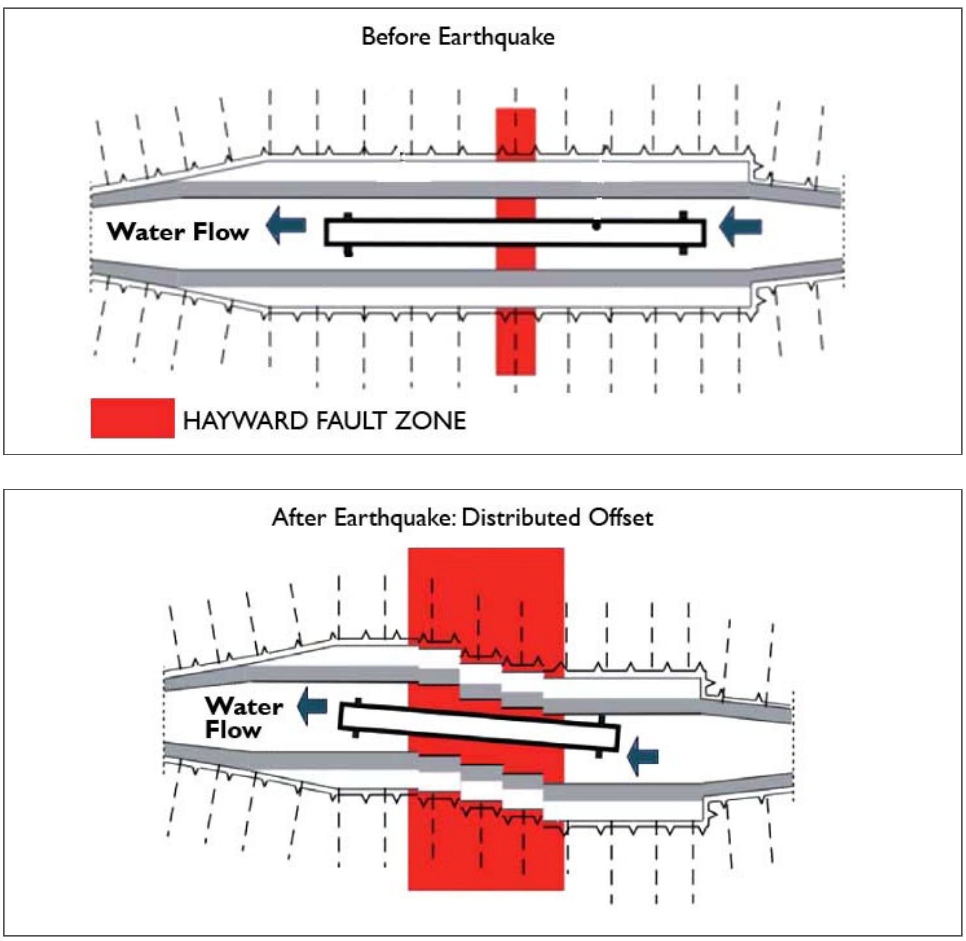
CHAPTER 4:
WATER AND SEWER DELIVERY SYSTEMS

ORIGINAL AUTHOR: DAVID PRATT, EAST BAY METROPOLITAN UTILITY DISTRICT

1995 SUMMARY

- This 1995 discussion focused on the East Bay Municipal District's system. In the mid-1990s, EBMUD served 1.2 million people in over 20 cities.
- The EBMUD water system snakes its way from Pardee Reservoir in the Sierra foothills through the Sacramento-San Joaquin delta into Walnut Creek, where it splits. To serve 70% of EBMUD's customers, the water must go through a tunnel in the Oakland Hills and cross the Hayward fault (Figure 4.1).

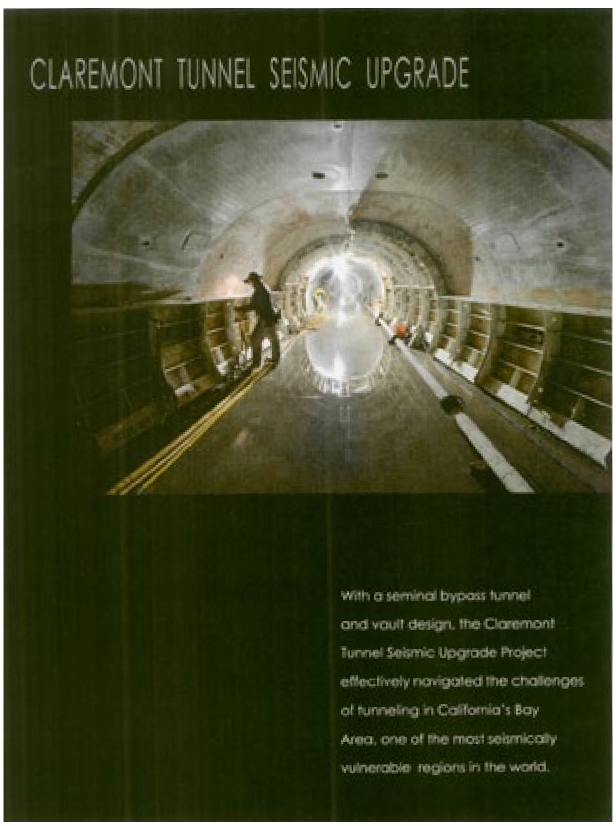


Caldecott Water Tunnel offset at Hayward Fault (Source: EBMUD)

Fig 4.1

CHAPTER 4:
WATER AND SEWER DELIVERY SYSTEMS

- In 1995 the EBMUD water system lacked redundancy and was vulnerable to ground shaking and ground failure. Ground shaking would cause tank failure and pipe connection damages. Liquefaction was anticipated to cause 50% of all pipe breaks.
- EBMUD had just begun a $189 million Seismic Improvement Program to improve its system after a two-year study had revealed that 2/3 of its customers would be without water after a 7.0 earthquake on the Hayward fault.
- The ten-year program was intended to retrofit facilities to a level necessary to guarantee enough water for fire-fighting and drinking after a M7.0 quake.



Claremont Tunnel Seismic Upgrade Project (Source: EBMUD)

Fig 4.2

CHAPTER 4: WATER AND SEWER DELIVERY SYSTEMS

2010 UPDATE

Like the 1995 volume, this update focuses on the East Bay Municipal Utility District (EBMUD) and its efforts and vulnerabilities. Other agencies have system elements that cross through the East Bay (e.g. the SFPUC's main lines, which traverse from the Sierra Nevadas to the San Francisco Peninsula, cross several active faults, including the Hayward fault), and have embarked on their own campaigns to reduce risk. EBMUD has been one of the "early-adopters" in responding to the earthquake risk and at this time is generally thought to be more resilient than some of the other water agency systems.

EBMUD's Seismic Improvement Program (SIP) began in 1995, and by the end of the fiscal year 2005, the SIP was 90% complete and had retrofitted 315 facilities; currently, the SIP program is considered "officially" complete although work remains on one last reservoir (of the 70 originally identified for upgrades). The upgrade will be complete in June 2011 The SIP was chosen by FEMA in 2007 as one of its Mitigation Best Practices Stories. FEMA estimates that EBMUD's program has avoided earthquake losses of $1.2 billion for an total investment of $200 million (1). (2).

The SIP strengthened over 70 reservoirs, upgraded 130 pumping plants, improved the Claremont tunnel, constructed a new Southern Loop pipeline, upgraded the transmission system and pipeline fault crossings, renovated building and equipment anchorage, and improved water treatment plants. Because EBMUD has been one of the leaders in seismic mitigation, it was forced to devise new and innovative engineering approaches to reduce risk and protect its system.

An important element of the SIP was the retrofit of aging potable water storage reservoirs and tanks throughout the service area. Typically placed at a modest elevation to take advantage of gravity, many of these reservoirs are vulnerable to landslides. Most of the tanks were over 40 years old, unconnected to their foundations, and without adequate shell strength to prevent damage during a major earthquake. All but one of the reservoir seismic retrofit projects has been completed as of 2010 (2).

CHAPTER 4:
WATER AND SEWER DELIVERY SYSTEMS

An 11-mile Southern Loop pipeline project provides an alternate water supply route for customers at the southern end of the EBMUD system on either side of the East Bay hills. Water distribution pipes in the system cross active earthquake faults at more than 200 locations. New technologies such as flexible joints and provisions for post-earthquake installation of flexible hoses have been used in over 100 fault-crossing locations to reduce disruption following an earthquake.

The Claremont tunnel, which crosses the Hayward fault, was constructed between 1926 and 1929 and carries up to 175 million gallons of water a day from treatment facilities in Orinda to customers to the west of the Oakland-Berkeley hills. It is a critical part of the water distribution system, but studies showed that the scenario earthquake could result in fault offset at the tunnel of on the order of 8.5 feet. Retrofitting such a long section of the tunnel in place would have created unacceptable disruptions in service, so EBMUD concluded that a bypass tunnel was the most practical and cost-effective approach. Approved in 2003, the permanent bypass tunnel was completed in the spring of 2007.

A 2004 study concluded that the soils and foundations of San Pablo Dam were susceptible to liquefaction during an earthquake. An innovative soil strengthening program was undertaken in which a cement mixture was pumped into the ground and mixed with existing soils. This allowed the dam to remain in place during remediation, thereby reducing costs and service disruption. The contract for improving the soil and constructing a larger downstream buttress for the dam was awarded in May of 2008. The $55 million project was completed in July 2010.

The SIP retrofitted five of EBMUD's six fresh water treatment plants, with the sixth one scheduled for modernization outside the program. One of the major treatment plants is within 700 feet of the Hayward fault (3).

While EBMUD manages its waste water treatment plants, sewage delivery to the plants is provided by a network of pipelines that run through and are maintained by various municipalities. Many of these pipelines cross the Hayward fault. In 1986, earth scientists and engineers cautioned that waste water pipelines from the hillside areas that cross the Hayward fault, “will be sheared and unable to carry sewage. Open trenches may be necessary to carry sewage for short distances. Alternatively, planners will have to provide for emergency housing or temporary sanitation facilities” (4, p. 7). A 2007 report concurred on the vulnerability of sewage pipes, noting that, “they are made of the most brittle materials and do not have sealed joints” (5, p. 3). However, replacement and retrofit of aging sewage systems has been spotty, and this issue remains a problem.

Treatment plants will be forced to shut down after a major earthquake if there is a loss of power. EBMUD’s treatment plant power system uses methane gas from its plant, but that will be unable to support full plant function. It may be necessary for emergency-treated raw sewage to be discharged into the Bay for up to one month following a large earthquake (4, p.7).

It has been estimated that 90% of the damage in San Francisco resulting from the 1906 earthquake was caused by fire (6). While the exact percentage has been debated, there is no doubt that the post-earthquake fire was catastrophic. Fire following earthquakes continues to pose a significant hazard in California, especially in light of California’s semi-arid climate and active and devastating annual fire season. The 1991 firestorm in the Oakland-Berkeley hills started within a mile of the Claremont tunnel and the Hayward fault. Clearly, protection of the water delivery system is an integral part of the region’s earthquake loss-reduction strategy. The important issue of fire-following-earthquake is covered in Chapter 16 of this document.

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CHAPTER 5: BUILDINGS AND TRANSPORTATION SYSTEMS AFFECTED BY GROUND FAILURES

ORIGINAL AUTHOR: JOHN EGAN, GEOMATRIX CONSULTANTS

1995 SUMMARY

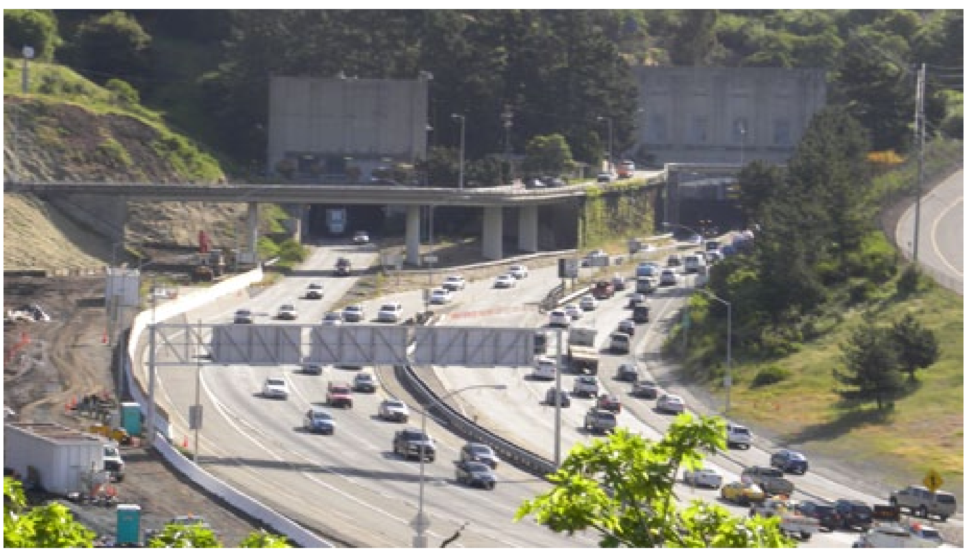
- Earthquakes cause surface fault rupture, differential settlement, lateral spreading, landslides, and liquefaction.
- In the scenario earthquake, ground motions in a densely inhabited area (Figure 5.1) will affect buildings, freeways, bridges, BART, railroads, airports, and marine structures.

Murals painted on freeway columns were redone after the seismic retrofit project was completed

Fig 5.1

CHAPTER 5: BUILDINGS AND TRANSPORTATION SYSTEMS AFFECTED BY GROUND FAILURES

- The Loma Prieta earthquake pointed up the vulnerability of many Bay Area building types to ground failure. The liquefaction in the Marina District would have been more extensive had the ground shaking been longer and stronger; bearing capacity or punching failures would have increased.
- Many landslides in the Oakland-Berkeley hills will be activated during the scenario event, putting homes, schools, and businesses at risk.
- Older pile-supported buildings subjected to lateral spreading may be damaged.
- Traffic will be disrupted, especially that on Highway 13, Highway 24, and in the Caldecott Tunnel.



Over 160,000 vehicles travel through the Caldecott tunnels, within ¼ mile of the Hayward fault, everyday

Fig 5.2

- BART intersects the Hayward fault underground near the Caldecott Tunnel; fault rupture can be expected to put the tunnel out of commission indefinitely.
- The railroads run on predominantly firm soil, except to the north where they traverse the original Bay margin with its soft soils and cross the fault.

CHAPTER 5: BUILDINGS AND TRANSPORTATION SYSTEMS AFFECTED BY GROUND FAILURES

A segment of the top deck of the Bay Bridge collapsed during the 1989 Loma Prieta earthquake

Fig 5.3

- In the 1989 quake, the Oakland Airport lost about 300 feet of runway due to liquefaction; the runway was closed for three months. In the Hayward fault scenario, the entire airport will be closed by severe runway damage. The San Francisco airport will likely be running after a short disruption, and the San Jose airport is not expected to have serious problems.
- The Port of Oakland invested in extensive retrofit for older facilities; facilities built recently were constructed to function after a magnitude 7 quake.

CHAPTER 5: BUILDINGS AND TRANSPORTATION SYSTEMS AFFECTED BY GROUND FAILURES

2010 UPDATE

In the last 15 years, the Bay Area population has grown, particularly in the eastern counties; approximately half a million more people are now employed in the area. Although these increases have stressed the region's transportation systems, most transportation agencies in the Bay Area have made significant progress towards ensuring some functionality after a Hayward fault quake.

The California Department of Transportation (Caltrans) embarked on a statewide seismic safety program following the 1971 Sylmar earthquake in Southern California, and has upgraded numerous bridges, overpasses and freeways. The replacement of the Bay Bridge eastern span is the most visible element of their seismic program; estimated to have cost $5.5 billion (1), the new bridge is expected to open in 2013.

The replacement for the East span of the Bay Bridge is being erected just North of the older, steel structure

Fig 5.4

In addition to the Bay Bridge, Caltrans completed an extensive retrofit on the Richmond-San Rafael bridge (2); at the Carquinez crossing, they retrofitted the 1958 span in 2001 and replaced the 1927 span in 2003 (3). Caltrans modified the existing span and completed a new span at the Benicia-Martinez bridge in 2007 (4).

CHAPTER 5: BUILDINGS AND TRANSPORTATION SYSTEMS AFFECTED BY GROUND FAILURES

The 1978 Antioch and 1982 Dumbarton bridges were not originally included in Caltrans seismic safety program; however, due to numerous changes in seismic design practices in recent years, comprehensive assessments of these two additional state-owned toll bridges were completed and retrofits are planned for each. The contract for retrofit of the Antioch bridge was awarded in April, 2010 and construction is expected to be completed in May, 2012 (5). The retrofit of the Dumbarton bridge is expected to cost $365 million and be complete in 2013 (6).

Since 1971, the Bay Area Rapid Transit system has grown to 360,000 daily riders. The system provided a critical backup for the damaged Bay Bridge following the 1989 earthquake. In November 2004, Bay Area voters passed Measure AA, which authorized the BART district to issue bonds for $980 million to fund earthquake safety improvements to BART facilities in Contra Costa, San Francisco and Alameda counties. With the following additional funding (in 2004 dollars), the project addressed vulnerabilities in the system headquarters, stations, trackway, elevated tracks, and the Berkeley hills and transbay tunnels:

- $134 million from California Department of Transportation Local Seismic Safety Retrofit Program
- $93 million from Regional Measure 2 (RM2)
- $11.5 million from Transportation Congestion Relief Program (TCRP)
- $3 million from FEMA Pre-Disaster Mitigation Program (7)

CHAPTER 5: BUILDINGS AND TRANSPORTATION SYSTEMS AFFECTED BY GROUND FAILURES

The West Oakland station of BART is currently being seismically retrofit

Fig 5.5

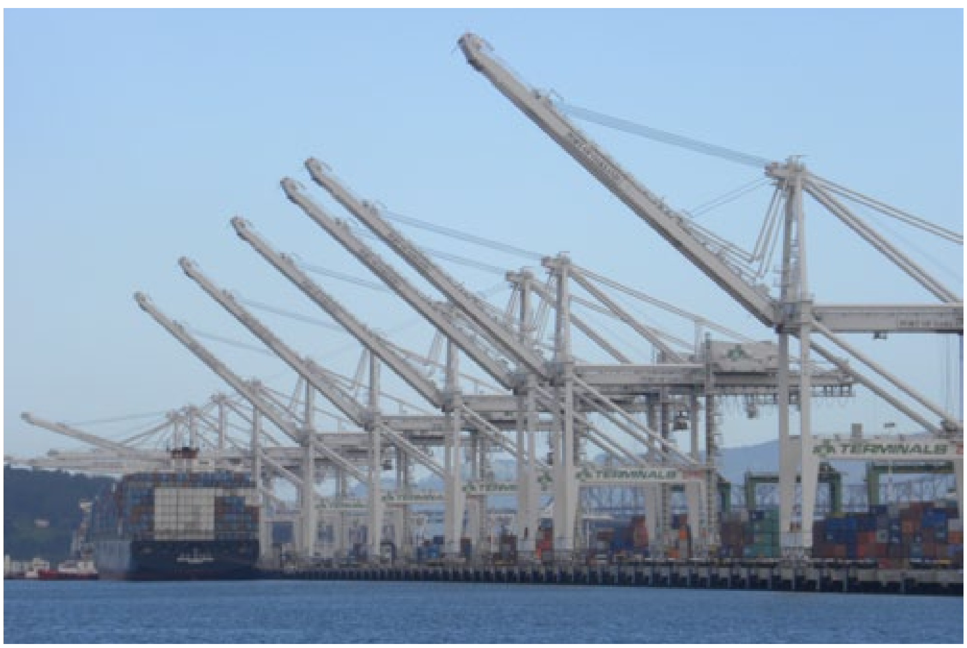
BART moved its headquarters to leased space in the Kaiser Center in downtown Oakland and the old, seismically unsafe building above the Lake Merritt station has been dismantled. Plans for retrofitting 19 out of the 34 stations in the system have been developed and four projects are under construction. BART estimates that the station retrofit work will be completed by 2014. The system has 74 miles of track, some on grade and some underground. Tracks on grade are monitored for creep and the tunnels are considered to be robust and not in need of retrofit. On the 22 miles of elevated track, 2000 columns have been strengthened with steel or poly-reinforced fiber jackets (8).

In 1991, the joints between tunnel segments were determined to be vulnerable to damage (9, p. 1201). While the joints require retrofit, they were moved from top priority to a lower priority in the 2002 system-wide Vulnerability Study after extensive analysis. Evaluation of the transbay tube indicated that backfill surrounding the tube was subject to liquefaction. To reduce this risk, work has been completed on the vibro-replacement project, and the landside vibro-replacement/ compaction demonstration program (8).

CHAPTER 5: BUILDINGS AND TRANSPORTATION SYSTEMS AFFECTED BY GROUND FAILURES

BART's Berkeley hills tunnel is located in the same area as the EBMUD and Caldecott tunnels. After careful study, BART determined that there is no practical retrofit for the tunnel due to the cost and disruption that retrofit would require. Instead, it has developed an emergency response plan to deal with disruption at this vital link in the system (10).

Oakland and San Francisco airports are constructed on non-engineered fill vulnerable to lateral spreading and liquefaction. Because it is generally accepted that upgrading airport facilities is not economically feasible, the comments made about airport disruption in 1995 are still relevant today.



Port of Oakland Maritime underwent an $11 million wharf and embankment strengthening program

Fig 5.6

The Port of Oakland is the nation's fourth busiest container port and manages 19 miles of east bay shoreline. It loads and discharges more than 95% of the containerized goods moving under the Golden Gate Bridge (11, p.20). In 2000, the Port authorized an $11 million wharf and embankment strengthening program, WESP. The program was split into three phases and involved retrofitting or rebuilding over 12,000 linear feet of pile-supported wharf structures. While many of the port facilities may still be vulnerable to liquefaction, the WESP projects have done much to reduce catastrophic damage to critical embankments and wharfs.

The Bay Area regional transportation system comprises a complex consortium of agencies serving a population of over 6.9 million people. While Bay Area transportation systems have been extensively retrofit since 1995, the Association of Bay Area Governments estimates 1081 road closures in Alameda County after a M7.0 earthquake, and over 1700 closures in the nine Bay Area counties (12). Clearly, the region will face significant transportation interruptions following the scenario quake.

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CHAPTER 6: GROUND MOTIONS

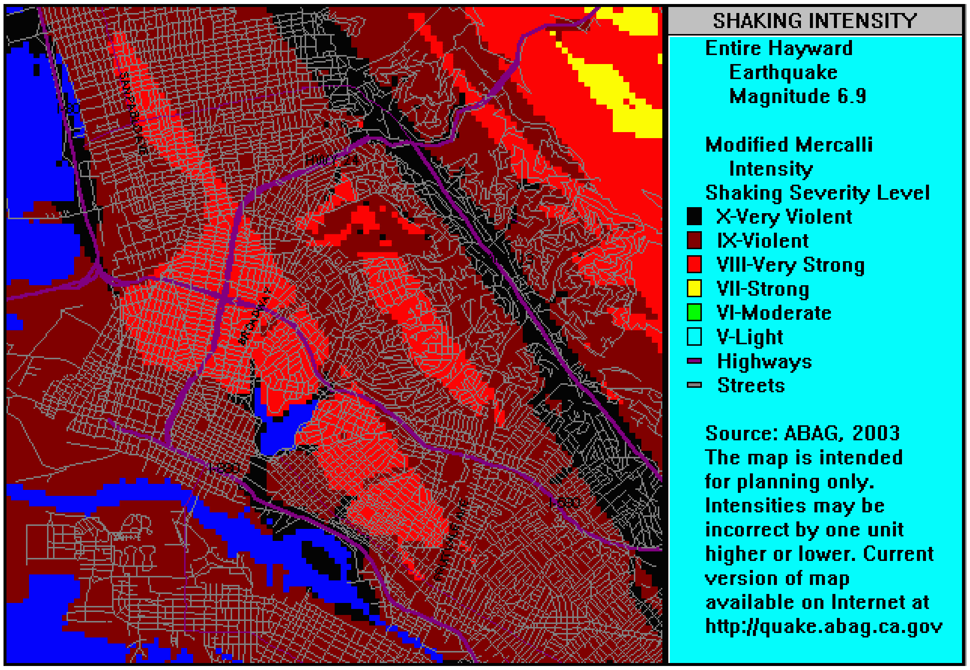
ORIGINAL AUTHOR:
PAUL SOMERVILLE, WOODWARD-CLYDE

1995 SUMMARY

The Kobe, Japan earthquake had struck about a month before the 1995 EERI meeting. Somerville suggested that the Kobe quake would yield insight into a future Hayward fault quake because “its 6.9 magnitude, strike-slip faulting mechanism, and rupture length of about 50 kilometers” are practically identical to the scenario quake. The large long-period motions attributed to rupture directivity were probably responsible for much of the damage to bridges and multistory buildings.

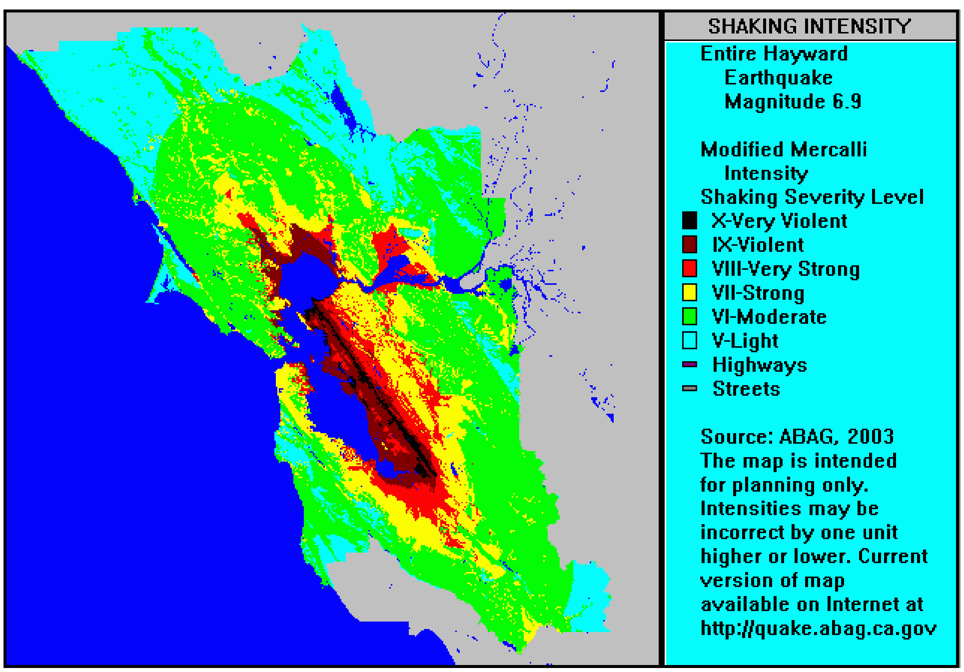
- The relevant measures of ground motion are peak velocity (how fast the ground is moving), peak acceleration (how quickly the speed of the ground is changing), and frequency (the vibration rates of the energy waves).
- Ground motion frequencies can range from several seconds (long-period) to 0.3-0.1 seconds (short period).
- Building response spectra are differing levels of acceleration in individual buildings as they respond to frequencies.
- Peak accelerations, peak velocities, and response spectra accelerations generally lessen with distance away from a fault rupture.
- A large pulse of ground motion results from rupture propagation (Somerville and Graves, 1993). The motion, called directivity, is in the direction perpendicular to the fault.
- The directivity in the scenario was estimated by using attenuation relationships of the rupture propagating from the epicenter near San Pablo Bay towards the southeast along the Hayward fault.
- Four contour maps (see Figures 6.1-6.4) illustrate the relationship between distance from the epicenter, rupture directivity, site soil conditions and the period of structures.

CHAPTER 6:
GROUND MOTIONS



ABAG Shaking intensity map showing the Oakland area just west of the Hayward fault (Source: ABAG)

Fig 6.1



ABAG Hayward fault earthquake shaking intensity map showing the entire San Francisco Bay Area (Source: ABAG)

Fig 6.2

CHAPTER 6: GROUND MOTIONS

2010 UPDATE

Observations and strong motion records from the Northridge and Kobe earthquakes have supported Somerville's hypothesis about intense, directed ground shaking near the fault ruptures. The areas affected by those earthquakes had been heavily instrumented and earth scientists were able to map the effects of soil, distance to rupture, and directivity. The California Strong Motion Instrumentation Program (CSMIP), established in 1972, had instruments in the region affected by the 1994 quake that captured important information about the variation in ground motions.

As a result of the 1994 quake, two significant changes were made to ground motion values in the 1997 Uniform Building Code: the first was a revision in soil types and amplification factors; and the second incorporated near-fault ground motions in seismic zone 4 (1). Zone 4 is the highest hazard zone and includes the nine San Francisco Bay Area counties. The near-source factors were developed by the Ground Motion-Ad-Hoc-Committee of the SEAOC Seismology Committee.

The consequence of the change is that new structures located closer to mapped faults are designed for larger lateral forces. Older structures that have not been retrofit to the higher lateral force levels remain vulnerable to the ground motions expected in the Hayward fault earthquake.

Figures 2.5-2.10 in Chapter 2 clearly illustrate the concepts of near-source and rupture directivity. The darker colors indicating stronger ground motions radiate down and out from the epicenter. Lighter colors indicating moderate ground shaking illustrate how ground motions attenuate or lessen with distance from the fault and epicenter. The maps also show how soft soil sites amplify ground shaking—note the strong shaking in the soft soil areas at the Bay margins.

Instrumentation and mapping continue to be a high priority in California. In July 2001, the California Office of Emergency Services obtained funding for the California Integrated Seismic Network (CISN), a statewide system that includes the TriNet system in Southern

California and the Northern California Seismic Network. The CISN improves our ability to create ground shaking intensity maps (2).

Improvements in hazard mapping have been incorporated in building codes to protect future construction, but the region adjacent to the Hayward fault has been in development for over 150 years, with large population surges in the early 20th century and after World War II. Most of the commercial and residential structures were built to older, less stringent building codes. These all remain vulnerable to damage in a Hayward fault earthquake.

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I would like to thank Paul Somerville, URS Corporation, for providing updated information on this chapter.

CHAPTER 7: TRANSPORTATION SYSTEMS AFFECTED BY GROUND MOTIONS

ORIGINAL AUTHOR: BRIAN MARONEY, CALIFORNIA DEPARTMENT OF TRANSPORTATION

1995 SUMMARY

Because retrofitted bridges performed well during the Northridge earthquake (2), Maroney expected structures built or retrofitted after 1971, particularly after 1989, to do well in the scenario earthquake.

- Caltrans estimated that the SF-Oakland Bay Bridge, Richmond-San Rafael Bridge, Carquinez, Benicia and San Mateo Bridges would be damaged in a Hayward fault earthquake. The Golden Gate Bridge would "experience threatening demands." The Dumbarton and Antioch bridges, both designed after 1971, were at much lower risk of failure.

The Richmond-San Rafael bridge retrofit was completed in 2009

Fig 7.1

- Bridge structures are generally most vulnerable at areas of potential liquefaction or massive lateral spreading, typically found at bridge approaches.
- Caltrans' performance criterion for new and retrofitted structures is "no collapse." For important structures like the Bay Bridge, the performance goal is that they remain essentially functional after a major quake.

- The scenario earthquake is different from the Loma Prieta and Northridge earthquakes. The motions were different and those events did not really tax the total resources of the transportation system.
- Damage to freeway interchanges was also expected. Many structures at the I580-I238 interchange near Castro Valley were designed in the 1950s. The 580-980-24 interchange (Macarthur Maze) should not be part of any emergency planning scenario. Many small bridges and interchanges were at risk in the scenario event.

2010 UPDATE

Between 1986 and 1989, Caltrans had developed a bridge retrofit program divided into four phases: Phases 1 and 2, the Toll Bridge Program, and the Local Bridge Program. Phase 1 identified 1,039 state highway bridges in need of retrofit; funded by gas taxes, that phase was completed in May 2000 at a cost of $1,082 billion. Retrofit of freeway bridges typically involves strengthening columns by encasing the concrete columns in steel or, in a few instances, in advanced woven fiber casing. In many locations, bridge abutments and footings were enlarged. Where required, steel tie-down rods were anchored into the ground. Many of the retrofits included hinge seat extensions to enlarge sections that connect the bridge decks, preventing them from separating during earthquakes.

Phase 2 included retrofitting a multitude of non-toll freeway bridges throughout the state. This phase is substantially complete, at approximately 98%. The cost of phase 2 is $1.350 billion, funded by the $2 billion dollar bond (Proposition 192), which was passed in 1996 (1).

Retrofit of the toll bridges is the most difficult and costly of the four phases. Costs will be over $6 billion. When the program started following the 1989 Loma Prieta earthquake, there were nine toll bridges in California; five that required retrofitting were in the Bay Area: the San Francisco-Oakland, Richmond-San Rafael, Benicia-

Martinez, San Mateo-Hayward, and the Carquinez bridges. The replacement span for the Bay Bridge is the largest of the projects at a cost of $5.5 billion.

Originally considered "too young" to merit a seismic review, the Antioch and Dumbarton bridges were added to the Caltrans seismic retrofit program in 2008. In October, 2009, the Metropolitan Transportation Commission recommended a toll increase on seven of the toll bridges in the San Francisco Bay Area in order to fund the retrofit of the Antioch and Dumbarton bridges. The retrofit work is scheduled to begin by April 2010 and be completed in 2012 on the Antioch Bridge, and 2013 on the Dumbarton Bridge (3).

The retrofit projects are designed for the maximum credible earth movement expected at each bridge location (1). Variable soils and foundations, as well as heavy traffic volumes, make the retrofit of these bridges complex and expensive.

The last phase, the Local Bridge Program, will cost $898 million. Funding comes from gas tax revenues utilizing funds through subventions from the department's Local Assistance Program. Of these non-state owned bridges, 560 of the 1,234 have now been strengthened (1).

Caltrans has made significant progress since 1995, but the transportation system in the Bay Area is made up of countless local elements, all vulnerable to damage. Chapter 14 of this document addresses the disruption to transportation expected following the scenario earthquake.

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CHAPTER 8: POWER, TELECOMMUNICATIONS, AND FUEL DELIVERY SYSTEMS

ORIGINAL AUTHOR:
EDWARD MATSUDA, PACIFIC GAS & ELECTRIC COMPANY

1995 SUMMARY

The Hayward fault quake is expected to rupture the surface for 30 miles, with an average offset of 3 feet, through some heavily developed areas. Older urban areas are likely to see serious damage to both electricity and gas distribution.

- Little damage is expected to above-ground gas facilities as one of the two pipelines that cross the northern Hayward fault is new and the other was retrofitted.
- Cast-iron and oxyacetylene-welded steel pipelines in areas of high liquefaction potential are vulnerable to earthquake damage. It may take up to two months to restore service in areas with liquefaction.
- Experience shows that customers will shutoff their gas whether they need to or not. Gas restoration requires company personnel, and it may take two months for resumption of service to all customers after the Hayward fault earthquake.
- Most of the power routed to the East Bay goes through two transmission stations in Moraga and El Sobrante, both located within 3 miles of the fault. PG&E had replaced all vulnerable circuit breakers, but bushings would not be able to withstand the level of shaking anticipated.
- The electrical distribution system consists of two major paths: one in the Oakland area goes above ground into Station K then underground through two cables that cross the Hayward fault; the other goes above ground through Station X. Following the Hayward scenario quake, the cables are likely to be damaged and inoperable; the Oakland area could be without power for four days.

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This high voltage transmission tower doubles as a cellular antenna tower

Fig 8.1

- Fires can start when there are gas leaks near energized electrical circuits.
- Six petroleum refineries in the area will be strongly shaken. However, tank construction is fairly rugged and each tank has containment. Older steel pipelines that cross the fault may rupture and create a strong potential for fire.
- The biggest problem for telecommunications will be overload due to large numbers of customers trying to make calls.

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2010 UPDATE

The American Society of Civil Engineers (ASCE) has sponsored a Technical Council on Lifeline Earthquake Engineering (TCLEE) conference approximately every four years since 1977. During the 2009 TCLEE conference, speakers provided updates on critical Bay Area lifelines. Much of the information below is based on the TCLEE presentations.

ELECTRIC TRANSMISSION

A large earthquake on the Hayward fault will "severely test PG&E's electric transmission system" (1, p.455) although significant seismic improvements have been made to many parts of the system: new seismic design standards; strengthening of substation and control buildings; better equipment anchorage; more rugged equipment; development of an emergency response organization; and partnerships with other utilities and research organizations. PG&E has taken the "first steps" in a network performance assessment of the electric transmission system in the San Francisco Bay Area that is intended to provide valuable information on damage estimates, system vulnerabilities, and emergency response demands (1).

GAS TRANSMISSION

Since a repeat of the 1868 Hayward earthquake will affect older urban areas in Oakland and Alameda, there is likely to be significant building damage and therefore more damage to both electric and gas distribution components
(2, p. 452).

Pipeline sections installed before 1940 have been assessed as part of a long-term program of replacing aging and leak-prone segments of distribution pipelines Begun by PG&E in 1985, the Gas Pipeline Replacement Program (GPRP) has mitigated seven of eight Hayward fault pipeline crossings, and work on the final crossing is nearly complete. Out of 533 miles of gas distribution main with high seismic risk in the Bay area, 472 miles have been replaced. (2, p.451) However, in 2009 PG&E told state regulators that the second highest risk pipeline in the Bay Area is close to where the pipeline crosses the Hayward fault in Fremont. (9)

PG&E expects that fixing distribution pipelines at fault crossings may take several hours to several days following the scenario Hayward earthquake; it may take up to two months to restore service in some liquefaction areas. Emergency gas distribution shut down zones have been designed to isolate sections of the gas system following a major seismic event (2, p. 452).

Outside the immediate fault rupture zone and liquefaction areas, service restoration will involve making service calls to individual customers. After the 1989 earthquake, it took ten days to relight pilot lights turned off by customers unnecessarily.

REFINERIES

Six significant Bay Area refineries are at risk in a Hayward fault earthquake (3, p. 14). Since 1988, the State of California has required Risk Management and Prevention Program (RMPP) assessments of refineries. In June 2004, seismic studies of refineries were mandated by the California Accidental Release Prevention (CalARP) program managed through OSHA.

If strengthening is required, criteria must be developed that ensure with some confidence that the retrofitted facilities or equipment "will perform adequately when subjected to strong earthquake ground motions" (4, p. 1). If a refinery is found to be out of compliance, a timeframe for mitigation is negotiated with the county. Typically, refineries are allowed to conduct seismic retrofit projects during the "turn around period" during which they shut down for scheduled maintenance.

Marine oil terminals, usually located on soft soils, are also at risk. The Marine Oil Terminal and Maintenance (MOTEMS) state law, passed in February 2006, and regulated by the California State Lands Commission, mandates that every terminal be assessed and classified as low, medium or high seismic risk. The terminals had 30 months to comply and provide the initial assessment. The first ten "high risk" marine oil terminals turned in their initial audits to the California State Lands Commission in August 2008. The next 15 "moderate risk" terminals turned in their audits in February 2010. Audits for the remaining "low risk" terminals are due in February 2011 (5, p. 31). By 2015, it is anticipated that 30 fixed onshore marine oil terminals in California will comply with MOTEMS (5, p. 27).

TELECOMMUNICATIONS

American Lifelines Alliance ranks extreme wind as the greatest hazard to telecommunications operations (6, p. 8), followed closely by threats such as vandalism and terrorism. Since earthquakes are low-probability events, they do not rank particularly high, but telecommunications systems are very vulnerable to equipment damage during earthquakes. Additionally, telecommunications systems can fail from overloading due to increased call volume or lack of emergency power.

Cellular telephone antennas are often installed on private buildings including this church steeple in Oakland

Fig 8.2

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The value of wireless communications was first seen in the immediate aftermath of the Northridge and Kobe earthquakes (7, p. 22) and, since 1995, the technology has burgeoned. While wireless communication is also vulnerable to overload, its inherent redundancy has the potential to serve the post-disaster community. A 2005 report on telecommunications in disasters observed, “Rapidly deployable temporary cellular sites, an innovation that grew out of the Northridge experience, have been widely used to restore mobile phone service in nearly every major disaster since” (7, p. 23).

Police and fire services, hospitals, emergency service providers and many schools have access to radio communication systems for use after an emergency. Radio repeater sites may be vulnerable to earthquake damage, but systems with battery racks that are properly braced have sufficient redundancy to remain operable.

In recent disasters, when telecommunications systems failed, amateur radio volunteers coordinated disaster relief activities. The Northern Alameda County Amateur Radio Emergency Service (NALCO) is a non-profit organization that was formed in 1982 by a group of local licensed amateur radio operators. NALCO has formal agreements with the University of California and other Alameda County response agencies for support in emergency planning, drills, and emergency response (8).

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CHAPTER 9: CRITICAL FACILITIES

ORIGINAL AUTHOR:
WILLIAM HOLMES, RUTHERFORD & CHEKENE

1995 SUMMARY:

Holmes addressed the post-earthquake performance of emergency operation centers (EOCs), police stations, fire stations, and hospitals.

- The 1970 California Emergency Services Act was enacted to keep EOC facilities operating following natural disasters. While new buildings are designed to meet the requirements of the act, there was no mandate to retrofit older structures.
- The OES regional EOC was located in Oakland in an office building with backup generators on site. Nonstructural elements had been carefully braced and anchored so "the office might be operable."
- City halls are very important in coordinating disaster response, but many were situated in normally designed buildings likely to be closed due to structural damage, nonstructural damage, or inaccessibility.
- Police station precinct buildings were typically small, low-rise structures with solid walls for security, so they are not earthquake risks. However, central offices for police operations were often located in city halls and were therefore vulnerable.
- Police facilities will be damaged structurally and non-structurally sufficiently to reduce the ability to respond. Communications will be hampered to some degree, and emergency vehicles could be trapped in parking and storage structures.
- The 1971 San Fernando earthquake illustrated that fire stations are vulnerable to jammed doors and extensive nonstructural damage. Near the epicenter of the Northridge quake, 11 out of 26 stations had structural damage but at less than a red-tag level. Power failures hampered the computer dispatching system and fire companies had to use the less efficient radio communications for dispatch.

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Modern Fire Station in El Cerrito, adjacent to Hayward fault

Fig 9.1

- In the East Bay many stations are spread out over the region, most in older buildings. A 1995 study of Oakland fire stations showed that 18 out of 29 required retrofitting. About one third of the stations in the western portions of Alameda and Contra Costa counties (the area from the fault west to the bay) could be red-tagged after a major earthquake on the Hayward fault.

The Montclair fire station in Oakland sits directly on the Hayward Fault

The fairytale style structure is no longer in use

Fig 9.2

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- In 1973 the State of California passed the Hospital Seismic Safety Act. (HSSA), and hospitals built after 1973 have a greater chance of being operational after an earthquake. However, hospitals built before the act, especially 1950s and 1960s concrete structures, were very vulnerable. Hospitals constructed after 1973 performed well in the Northridge earthquake, with the exception of water systems, damage to which were serious enough to shut down entire buildings.
- In Table 9-3 from 1995, hospital buildings are placed in six categories from A to F. A and B buildings were in compliance with the Hospital Seismic Safety Act, C buildings were in partial compliance, and D, E, and F buildings were not. In Alameda and Contra Costa counties, 20% of the buildings were A and B; 47% were C; and 33% were the poor-performing D,E and F buildings.
- In Alameda County, the hardest-hit county, about 33% of the hospital capacity will be evacuated, about 33% will be in limited service, and 33% will be operational: local hospitals will be "severely strained."
- Following the Northridge earthquake, State Law SB1953 was passed to require life safety retrofits and eventual code compliance for hospitals. The first deadline for providing life-safe hospital facilities was 2008, and 2030 is the date for substantial compliance with modern building codes. Holmes concluded that, "if we can wait 35 years for the earthquake, we'll be fine."

2010 UPDATE

In the past 15 years, municipalities in the Bay Area have made some progress in reducing the vulnerability of their facilities. In 1994, the Oakland City Hall was retrofit using a base isolation system intended to provide a fully operational building following a major earthquake. The City of Oakland constructed a new EOC in downtown Oakland in 1999 and completed a $7.5 million seismic retrofit of the Police Administration building in April, 2006, using a FEMA grant. The East Oakland Police Station was also moved to a retrofitted structure.

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Following the enactment of the State of California's Unreinforced Masonry Building (UMB) act in 1986, the City of Hayward created the Hazardous Building Mitigation Task Force to inventory all seismically hazardous buildings in the city. In January of 1990 the Task Force was asked to make mitigation recommendations to the City Council (1, p. 46), and the council adopted a goal of retrofitting all vital city facilities, a project estimated at $15 million. However, voters did not approve a local bond issue in the April election (1, p. 48), so in November the council approved the Emergency Services Facilities Tax to be included in water bills. In 1998, the city offices moved out of a tilt-up building into a new base-isolated City Hall. Waste treatment plant and fire station projects were completed using state grant money made available in the 1990 Earthquake Safety and Public Building Rehabilitation Bond Act (1, p. 49).

Hayward replaced the City Hall sitting directly on the fault with this base-isolated structure several blocks away

Fig 9.3

Since 1995, the cities of San Francisco, Oakland, Berkeley, Hayward, Fremont have all completed major seismic project retrofits of their fire stations.

CHAPTER 9: CRITICAL FACILITIES

Since 1992, Berkeley voters have approved over $362 million in local taxes to seismically upgrade and improve fire resistance of public buildings. Major public facilities, schools and fire stations, along with the Civic Center Administrative Building and the Main Library have been reconstructed. The City also has a new emergency operations center, public safety building and has constructed a new multijurisdictional fire station (2).

The City of Albany seismically retrofit their City Hall, Police and Fire stations

Fig 9.4

In 2006 at the 100th anniversary of the 1096 quake, EERI jointly published a report on Managing Risk in Earthquake Country. The document reported that "the City and County of San Francisco has strengthened all fire stations and schools for earthquake and fire safety and most city administrative buildings, including the base-isolated City Hall. The City of Oakland is also in the process of seismically upgrading all fire stations and schools, and has upgraded the City Hall and main administrative building (3, p. A-11).

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An older, seismically vulnerable Cragmont Elementary school in Berkeley was replaced with this modern structure

Fig 9.5

SB1953 required hospitals to provide detailed reports about their facilities to the California Office of Statewide Health Planning and Development (OSHPD) by January 1, 2000. The original January 1, 2008 deadline for life-safe facilities was extended to January 1, 2013 because, for many hospitals, seismic retrofit of aging structures makes no economic sense (4, p. 6). By June 2009, 52 hospitals statewide had requested an extension of the 2013 deadline until 2020 so they can construct new, fully compliant buildings (5). As of summer 2010, only a handful of hospitals in the East Bay have met the 2008 deadline requirements of SB1953 (5).

A 2007 study prepared for the California Health Care Foundation (6, p. 4) analyzed the challenge to implement SB1953 using historical rates of construction and permit filings with OSHPD. The most important finding was that, "about half of the non-life-safe hospital infrastructure will not be compliant with the 2008/2013 deadlines for SB1953, and many may not be able to comply with the final 2030 deadline."

For this report, William Holmes (2010) has updated his concluding thoughts about hospitals in the Hayward fault earthquake: "At the rate we're going, we will be better, but not fine" (7).

CHAPTER 9: CRITICAL FACILITIES

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CHAPTER 10: COMMERCIAL AND RESIDENTIAL BUILDINGS AFFECTED BY GROUND MOTIONS

ORIGINAL AUTHOR:
RONALD HAMBURGER, SIMPSON GUMPERTZ & HEGER

1995 SUMMARY

Structural Engineer Hamburger travelled the Hayward fault from San Pablo Bay to Hayward for his presentation. He noted numerous buildings similar to structures damaged in the 1994 Northridge and other earthquakes. His tour began at Point Pinole Regional Shoreline.

- The construction type of the Hilltop Mall in Richmond is comparable to the Fashion Center in Northridge, a structure heavily damaged in the 1994 temblor. The typical light bungalow housing in Richmond was constructed in the World War II era, prior to modern codes. Both the housing and commercial buildings in Richmond are similar to damaged structures in the Northridge area.
- Contra Costa College sits atop an active trace of the Hayward fault.

Contra Costa Community College is bisected by the Hayward fault

Fig 10.1

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- Crossing Interstate 80, the fault follows Bernhard Avenue just west of Arlington Boulevard, cuts through the Mira Vista Country Club in El Cerrito, and under strip malls similar to some in Southern California still being repaired at the time.
- The fault runs south through the densely populated communities of El Cerrito, Kensington, Albany and Berkeley. Hundreds of apartment buildings are constructed over garages, and soft-stories are notoriously prone to earthquake damage.
- At the University of California in some buildings have good seismic resistance, but others do not. Famously, it bisects Memorial Stadium at the mouth of Strawberry Canyon.

Memorial stadium at UC Berkeley is currently being retrofit. Evidence of the Hayward, which runs through the stadium, can be seen in each endzone

Fig 10.2

- At the boundary with Oakland, the fault skirts the historic Claremont Hotel, crosses Highway 24 just west of the Caldecott Tunnel, then follows Highway 13 through the Montclair business district of Oakland.
- Dropping west of Highway 13 just south of Park Boulevard the fault passes the near the Mormon Temple. It lies just west of Holy Names University, crosses Interstate 580 and touches the eastern tip of Mills College.
- East of 580 the fault runs through the Oakland Zoo close to the Lake Chabot dam. In San Leandro it passes within feet of Fairmont Hospital and moves west of 580 and crosses California Route 238.
- Though Hayward is south of the scenario rupture zone, it will get some of the strongest shaking because of directivity. Downtown Hayward resembles most the heavily damaged Pacific Garden Mall area in Santa Cruz.
- In San Francisco, many of the downtown high rises are steel moment frames that may have connection failures in a Hayward fault quake. Repair costs for those failures could range from 10%-40% of their replacement cost.
- Hamburger expected the following losses: 500 red-tagged unreinforced masonry structures, most in Alameda County; 500 red-tagged tilt-up and other industrial/ light-commercial buildings; 7,000 red-tagged residential buildings throughout the Bay Area--unavailable for occupancy; $16 billion for structural damage, with $10 billion of that in residential construction.

2010 UPDATE

The US Geological Society provides an interactive map and tour of the active traces of the Hayward fault using Google Earth (1). The online map superimposes the fault on three-dimensional representations of the geographic features and major structures along the fault. East Bay business or home owners can easily find their locations and see how close they are to the fault. In many cases, the on-the-ground comparison of building structures with those damaged in the Northridge quake is possible with the use of Google Maps "street view."

The Hayward fault runs along the boundary of the Hayward campus of California State University, East Bay

Fig 10.3

Most of the commercial and residential structures observed by Hamburger in 1995 are still standing today. While other chapters of this document describe major seismic retrofit projects undertaken by state and federal agencies, this chapter focuses on commercial and residential structures that are typically privately owned. These two building categories will generate the majority of the earthquake losses in the Hayward scenario earthquake (2), and most of those losses will be uninsured.

CHAPTER 10: COMMERCIAL AND RESIDENTIAL BUILDINGS AFFECTED BY GROUND MOTIONS

The numerous garage openings at the first floor of this apartment complex in Fremont illustrate the soft-story condition

Fig 10.4

The 1986 Un-reinforced Masonry Building (UMB) Law (SB547), one of the few requiring retrofit of privately owned structures, made it mandatory for local jurisdictions to inventory their UMB stock and notify UMB building owners. The law further required each jurisdiction in California's Seismic Hazard Zone 4 to develop a mitigation program. Most, but not all, Bay Area cities responded with ordinances requiring owners to upgrade or repair the structures. Upgrade standards varied widely, but the most severe risks associated with this construction type have now been mitigated.

Unfortunately, some UMB ordinances exempt hundreds of residential buildings of four or fewer residential units. The City of San Francisco passed a $350 million bond program to make financing available for the retrofit of UMBs. Less than $8 million of the $350 million total authorized bond had been used between 1994 and 2004 (3), but in 2006, the California Seismic Safety Commission reported that the city's UMB ordinance had resulted in an 86% mitigation rate (4). In October, 2009, the most recent summary of UMBs in San Francisco listed 1,700 buildings, of which 168 buildings are not completed. Work is underway on about 50 buildings, 110 have been referred to the City Attorney for enforcement action. In a few cases, owners may simply have not yet completed the paper work needed to receive their certificate of final completion (5).

There are few state or local laws that require dangerous commercial and residential structures to be retrofitted. Buildings with significant renovations, or buildings with occupancy changes (residential to commercial, for example), are required by the building code to be seismically upgraded. However, entire categories of dangerous buildings remain vulnerable to quake damage, for example, wood frame residential structures with no sill bolting and no cripple wall bracing, certain hillside structures, nonductile concrete frames, concrete tilt-ups, and older masonry structures.

Steel frames, like this one (white columns and beam), offer strengthening to soft-story buildings

Fig 10.5

A few East Bay cities have passed ordinances to reduce losses in soft-story buildings. First and foremost, the City of Fremont enacted a mandatory soft-story and concrete tilt-up retrofit law. Hayward, Berkeley, and Alameda have laws that are voluntary now, but will eventually require retrofit of soft-story structures. Oakland and San Leandro have inventoried their soft-story buildings and have plans to introduce ordinances in the future. An Earthquake Retrofit Bond, Measure A is on the November 2, 2010 ballot for voters in San

Francisco. If approved by voters the bond authorizes San Francisco to borrow $46.15 million by issuing general obligation bonds. The bond would be used to fund soft-story seismic retrofits of multi-family residential buildings.

Many cities are also attempting to mitigate the risk to single-family residences with no sill bolting or cripple wall bracing. Berkeley offers transfer tax refunds to new homeowners who complete seismic retrofit projects. Berkeley, San Leandro and Oakland are also working with volunteers from the International Conference of Building Officials (ICBO), ABAG, and the Structural Engineers Association of Northern California (SEAONC) to adopt standard seismic retrofit plan sets for use by homeowners and builders. These plans for conventional single-family wood framed structures on relatively flat sites will eliminate the need for costly engineering studies for many projects (6).

In 2000, the City and County of San Francisco's Department of Building Inspections (DBI) initiated the Community Action Plan for Seismic Safety (CAPSS). Funded by non-general fund monies, CAPSS is intended to address seismic hazards to privately owned property in San Francisco. In their October 2009 committee report, CAPSS reported that work continues to complete and publish the 2005 report, "San Francisco's Earthquake Risk" and to formulate post-earthquake repair and retrofit requirements. CAPSS released the report – "Here Today – Here Tomorrow: Earthquake Safety for Soft-Story Buildings" in February 2009 providing recommendations specifically for soft-story buildings. (7)

Rent control militates against seismic hazard reduction in San Francisco. Although rent-controlled structures constitute some of the city's oldest and most vulnerable housing, non-mandatory strengthening is not likely to get done because only a limited amount of seismic retrofit costs are allowed to be passed along to tenants. In the current economic downturn, it is politically difficult for cities to enact unfunded mandates for seismic safety.

In their 2008 report (2), Risk Management Solutions estimated the insured and uninsured losses for residential and commercial structures in the six Hayward fault ground motion scenarios discussed in Chapter

2. For a M7.0 earthquake on the Hayward fault with the epicenter in San Pablo, losses are $186.3 billion, only $21.9 billion of which are insured. A 6.8M earthquake on the South Hayward fault with a Hayward epicenter will yield $95.0 billion in total losses.

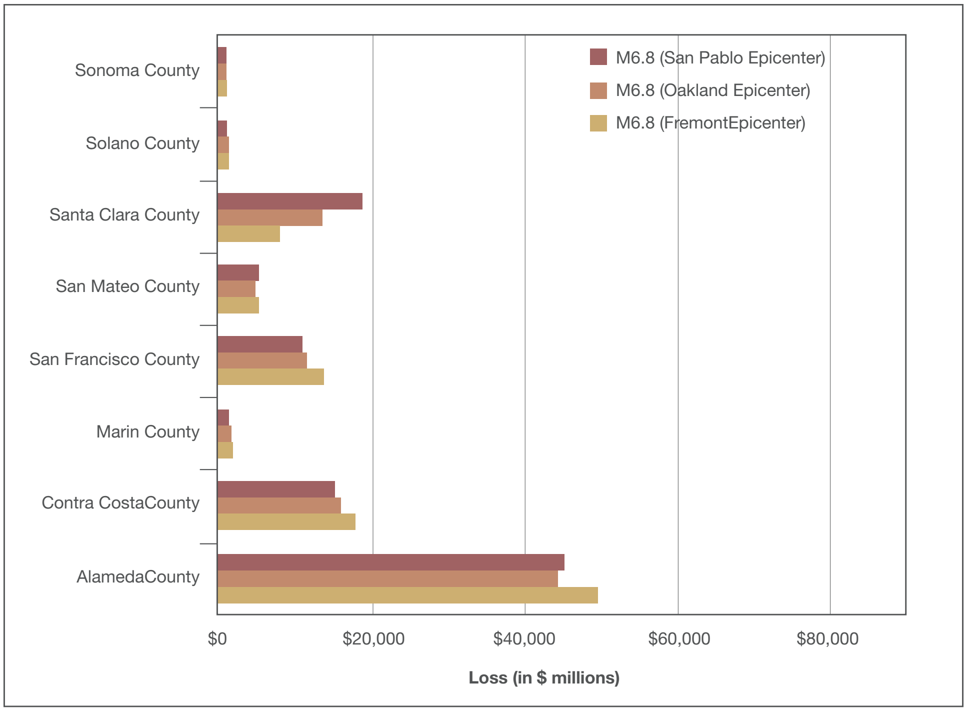
Epicenter	Economic Losses (in $ billions)			Insured Losses (in $ billions)		
	Residential	Commercial	Total	Residential	Commercial	Total
M6.8 on South Hayward Fault						
(a) Oakland	$48.3	$51.6	$99.9	$3.2	$7.6	$10.8
(c) Hayward	$45.9	$49.1	$95.0	$3.2	$7.2	$10.4
(e) Fremont	$47.1	$51.7	$98.8	$3.4	$7.8	$11.1
M7.0 on Full Hayward Fault						
(b) San Pablo	$90.4	$96.0	$186.3	$6.0	$15.9	$21.9
(d) Oakland	$84.2	$90.1	$174.3	$5.7	$15.2	$20.9
(f) Fremont	$88.6	$94.0	$182.6	$7.3	$16.1	$23.4

(Losses based on the 2009 RMS US Earthquake and Fire Following Industry Exposure Databases, vintage July 1, 2009. Modeled loss estimates generated using RiskLink v9.0, considering post-event loss amplification. All loss estimates are for property insurance coverages only, casualty estimates are in the Hayward Fault conference report and have not changed. All losses above include shake and fire following earthquake.)

Economic and Insured Losses. Source: 1868 Hayward Earthquake Retrospective Update, RMS

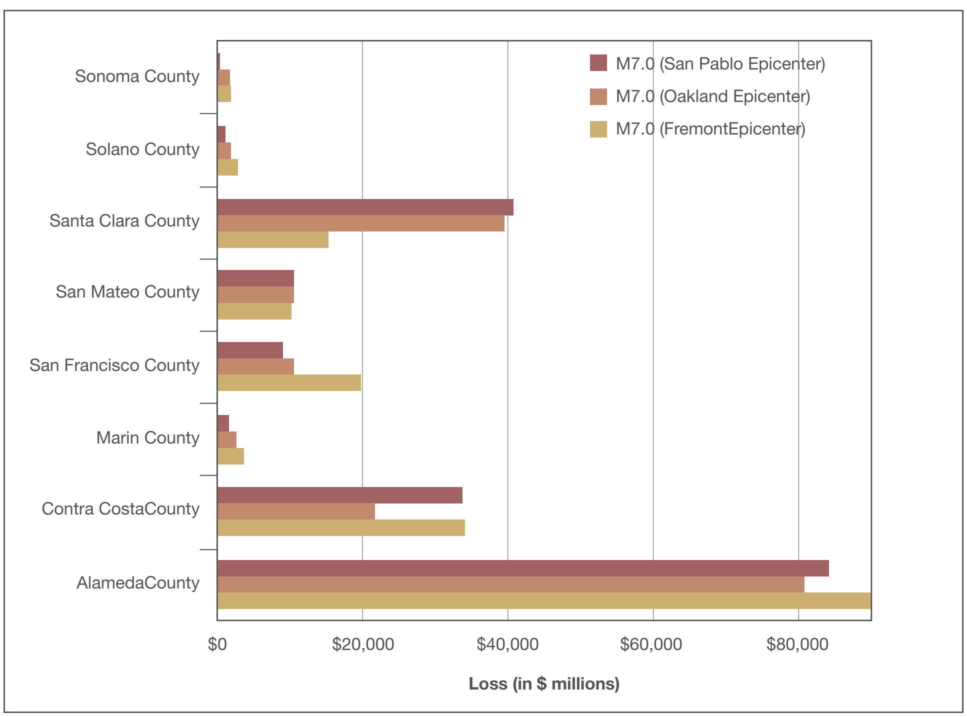
Fig 10.6

CHAPTER 10: COMMERCIAL AND RESIDENTIAL BUILDINGS AFFECTED BY GROUND MOTIONS



Economic Losses by County (M6.8) Source: 1868 Hayward Earthquake Retrospective Update, RMS

Fig 10.7



Economic Losses by County (M6.8) Source: 1868 Hayward Earthquake Retrospective Update, RMS

Fig 10.8

CHAPTER 10: COMMERCIAL AND RESIDENTIAL BUILDINGS AFFECTED BY GROUND MOTIONS

In calculating economic losses following earthquakes, the concept of loss amplification must be considered. This phenomena comprises economic demand surge (reflecting shortages of builders and materials), repair delay inflation (such as can be caused by rain), and insurance claims inflation (insurance rates rising above the rate of inflation due to fraud and the rising costs of litigation). RMS reports that in all scenarios, Alameda County sustains the "highest percentage of the total loss, ranging from 40% to 50%" (2, p. 10). The distribution of losses varies significantly and is "largely a function of directivity" (2, p.10). [See Chapter 2.]

Bold leadership is required to effect meaningful reductions in commercial and residential earthquake damage. It would appear that the next steps to seismic safety will be accomplished on a local level, one city at a time.

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I would like to thank Ronald Hamburger, Simpson Gumpertz & Heger, for providing updated information on his 1995 chapter on Commercial and Residential Buildings Affected by Ground Motions.

CHAPTER 11:
LOCAL EMERGENCY RESPONSE AND RELIEF

ORIGINAL AUTHOR:
HENRY RENTERIA, CITY OF OAKLAND OFFICE OF EMERGENCY SERVICES

1995 SUMMARY

- The City of Oakland planned to activate the EOC and field command posts using the police and fire department mobile command vehicles, and to utilize the mutual aid agreement with the Amateur Radio Emergency Services and the Radio Amateur Civil Emergency Services to provide emergency radio services at all fire stations and all schools designated as shelters.
- The Oakland Fire Department, one of two designated urban search and rescue teams for Northern California, would deal with some high-rise structural collapses, between 15,000 and 25,000 injuries, and around 4,000 casualties.
- Shelters would be open within a few hours, with capacity for approximately 10,000 people. However, if Oakland experiences the same thing Kobe did--20% of the population in shelters--95,000 Oakland residents will need shelter.
- After the earthquake, Oakland will activate a Community Assistance Center, a one-stop service center for personal help, mental health help, permits and loans, with a designated Media Reception Center. The Oakland-Alameda County Coliseum complex was designated as a staging area for equipment and supplies.
- All school district facilities were using an emergency management plan instituted in 1994.
- Some neighborhoods had organized CORE teams (Citizens of Oakland Respond to Emergencies), and Neighborhood Crime Watch.

CHAPTER 11:
LOCAL EMERGENCY RESPONSE AND RELIEF

2010 UPDATE

Significant changes in emergency planning and preparedness have taken place in the last 15 years. Most importantly, the World Trade Center disaster triggered creation of the Federal Homeland Security Department (FHS) in 2003 (1, p. 4). At that time the Federal Emergency Management Agency (FEMA) was absorbed by the new department. Since its creation, the FHS has had a significant impact on national and regional emergency planning (1, p. 6)

In 2004, FHS adopted the National Incident Management System (NIMS), pursuant to Homeland Security Presidential Directive/ HSPD-5. NIMS was created by FHS to establish standardized incident management processes, protocols, and procedures that all responders--federal, state, tribal, and local--use to coordinate and conduct response actions (2).

The Hayward fault earthquake is expected to place huge demands on emergency housing. Residents took shelter in the Houston Astrodome after Hurricane Katrina (Source: USGS)

Fig 11.1

In August 2005, Hurricane Katrina plowed into southeast Louisiana and called into question the management and response capabilities of FEMA. Worldwide coverage of New Orleans residents stranded atop their flooded homes not only drew attention to FEMA, but illustrated the harsh disparity between the rich and poor and their abilities to prepare for, and recover from a disaster. Following the disaster, Congress enacted six statutes intended to reorganize FEMA and the FHS, the most far-reaching of which was the Post-Katrina Emergency Management Reform Act of 2006. Most importantly, the act enhanced the agency's authority by directing the FEMA Administrator to undertake a broad range of activities before and after disasters strike (3).

In 2009, the State of California's Office of Emergency Services and Office of Homeland Security were reorganized, merged, and renamed California Emergency Management Agency (CalEMA). CalEMA is responsible for coordinating and monitoring the overall statewide integration of the Standardized Emergency Management System (SEMS) and the National Incident Management System (NIMS) to meet federal NIMS requirements and timeframes (4).

Local agencies and municipalities have had to adjust to the changes in emergency management as a result of changes at the state and national levels. The City of Oakland adopted the National Incident Management System (NIMS) in June, 2006, to comply with NIMS requirements in emergency planning, coordination and training. The City of Oakland general staff, first responders, supervisors, managers and directors from all city agencies continue to take training required by state and national standards set by SEMS and NIMS (5).

As mentioned in Chapter 9, Oakland constructed a primary "state-of-the-art" Emergency Operations Center (EOC) in 1999 using voter-approved bond measure funds from Measure I. This involved a seismic upgrade to the old portion of the building and some new construction. In addition, the city has received Urban Area Security Initiative funding in phases for enhancements to the EOC's electronic equipment, computers, printers, plotters, software and supplies. The city has acquired and equipped an alternate EOC site and, to increase capacity for emergency response, it has acquired a CBRNE vehicle for responding to chemical, biological, radiological, nuclear events; a Fire Department communications mobile vehicle that includes amateur radio installations; satellite phones for senior management and for the

EOC; seven 500 VHF radios for Oakland Fire; 41 800 MHz radios for Oakland Police; a new generator for Fire Station 28; three conferencing telephone systems; a robot for tactical missions for Oakland Police; an upgraded GIS computer, software and enhancement to the Primary EOC; an AV System for Critical Infrastructure Assessment; and over $1 million for communications interoperability. By the end of 2010, a unified command vehicle for police and fire will be added (6).

Oakland has updated its 2002 SEMS Multi-hazard Emergency Operations Plan, based on the Incident Command System (ICS) organization's five functions: management, operations, logistics, planning/intelligence and finance/administration. Within the last two years, it has also added NIMS compliance annexes to the SEMS plan, specifically mass care and shelter plans (5, p. 2).

The city has a new Memorandum of Understanding (MOU) with the Oakland Unified School District for shelters that meet ADA accessibility. (7, p. 13). Parks and Recreation facilities that can be used as emergency shelters have been surveyed for ADA accessibility. (7, p. 15). A mass transportation/evacuation plan annex has been updated and includes integration of the federal Emergency Support Functions (ESFs) and the State of California's emergency functions (EFs). (7). Oakland also updated and rewrote the Alameda County Oil Spill Response Plan, and its CBRNE (Chemical, Biological, Radiological, Nuclear) Emergency Plan. A Pet/Animal Shelter Plan has been completed and the city is currently updating its Continuity of Operations Plan/Pandemic Plan. (6)

18,000 residents in Oakland have been trained under the City of Oakland Responds to Emergencies (CORE) program (8).

As a participant in the Association of Bay Area Governments' Regional Multi-hazard, Multi-jurisdictional Hazard Mitigation Plan, Oakland has a mitigation plan. It is one of many Alameda County jurisdictions participating: Alameda, Fremont, Hayward, Newark, Piedmont, San Leandro, and Union City. Other cities and counties in the Hayward fault area have developed individual hazard mitigation plans. As described in Chapter 12, participation in the multi-jurisdictional plan is required in order for local jurisdictions to qualify for state and federal post-disaster assistance. (9).

CHAPTER 11: LOCAL EMERGENCY RESPONSE AND RELIEF

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CHAPTER 12: REGIONAL RESPONSE

ORIGINAL AUTHOR: RICHARD K EISNER, CALIFORNIA GOVERNOR'S OFFICE OF EMERGENCY SERVICES

1995 SUMMARY

- The OES Coastal Region, located in Oakland is a conduit for information and requests for assistance from local governments.
- OES will respond based on the violence and duration of ground shaking in the earthquake. Because many local governments will be severely disabled and unable to respond, regional, state, and federal response cannot wait for requests from local governments.
- If the scenario earthquake happened at 9:00 AM, February 9, 1995, the following response times would apply:

Activity	Initiated	Completed	Duration
Emergency Response	0900, February 9	February 13	5 days
Ad hoc relief	February 9	February 12	4 days
Organized relief	February 10	Continuing	18 months
Recovery and reconstruction	February 10	Continuing	10 years +

- The regional EOC will tackle the following critical issues during the first 72 hours of the scenario quake: provision of potable water; mass shelter and feeding; identification and mobilization of regional staging areas and a resource distribution system; transportation route recovery; medical response, including casualty collection and triage; and airport and harbor restoration. Eisner closed with the observation that, "the Hayward fault earthquake will, no doubt, redefine our lives and careers."

CHAPTER 12: REGIONAL RESPONSE

2010 UPDATE

Passed in 2000, the Disaster Mitigation Act (DMA 2000) was intended to identify and assess risks from all natural disasters, including earthquakes, tsunamis, tornadoes, hurricanes, flooding, and wildfires that pose great danger to human life and to property throughout the United States (1 Sect. 101.a.1). The statute's purpose is to ensure that "critical services and facilities of communities will continue to function after a natural disaster" and that a "high priority is given to mitigation of hazards at the local level" (1, Sect. 101.a.2.C.)

Search and rescue efforts, such as these following the Loma Prieta earthquake, will be supported by local and regional teams (Source: USGS)

Fig 12.1

The DMA required state and local communities to have an approved hazard mitigation plan in place by November 2004 to be eligible for federal pre- and post-hazard mitigation grant funds. The Multi-Jurisdictional Local Hazard Mitigation Plan for the San Francisco Bay Area, introduced in the previous chapter, was created in response to the requirements of the DMA. The 2005 plan was recently updated and the 2010 version is available online (7).

In response to DMA 2000, the Coastal Region of the State of California Office of Emergency Services (CalEMA) produced the Regional

CHAPTER 12: REGIONAL RESPONSE

Emergency Coordination Plan (RECP) (5). The plan includes detailed discussions on preparedness, response, recovery, mitigation, and training for both natural and human-caused emergencies. The plan does not replace emergency response plans created by cities, counties, utilities, and transportation providers, but rather it builds on them. A list of plan participants includes San Francisco, Oakland, San Jose, CalEMA, Caltrans, CHP, FEMA, Emergency Services Offices of the nine Bay Area counties; the Water Transit Authority, MTC, ABAG, and EBMUD.

Damage from falling bricks during Loma Prieta earthquake (USGS)

Fig 12.2

CHAPTER 12: REGIONAL RESPONSE

The RECP is consistent with the Standardized Emergency Management System (SEMS) and complies with the National Incident Management System (NIMS). SEMS guidelines have been provided to the participating agencies. CalEMA has a base plan that covers roles and responsibilities, operation areas, mutual aid and other broad issues. Twelve subsidiary plans include information on fire and rescue, hazardous materials, law enforcement, logistics, care and shelter, medical and health, recovery, transportation, and communications.

Ongoing maintenance of the RECP involves evaluations, exercises, and development of subsidiary plans. Three table top meetings were conducted in the summer of 2007 focusing on the base plan. The RECP was supported by a grant from the U.S. Department of Homeland Security.

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CHAPTER 13: HOUSING AND SOCIAL RECOVERY

ORIGINAL AUTHOR:
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1995 SUMMARY:

- Following the scenario earthquake, ABAG estimates there will be 90,000 red and yellow-tagged apartments and single-family homes, two-thirds of them in Alameda County.
- At least 10% of housing stock in Alameda and Contra Costa Counties will be "significantly damaged," resulting in $10 billion in damage. The damage will be concentrated in pockets that will be determined by soil type, and construction type and quality (ABAG, 2003).
- Critical recovery issues after every major disaster are emergency sheltering, temporary housing, reconstruction time, and funding.
- In the Northridge earthquake, seven times more apartments were damaged than single-family homes (multi-family housing comprised 56% of housing in Los Angeles), with the bulk of the damage in pre-1976 structures. About 60,000 units were significantly damaged or lost, and 30,000 vacated. Bay Area housing is of the same vintage: 80%-90% is pre-1976, and 30% is pre-1940.

The soft-story, first floor of this apartment complex collapsed during the Northridge earthquake

Fig 13.1

CHAPTER 13: HOUSING AND SOCIAL RECOVERY

- In the Loma Prieta quake, approximately 11,000 housing units were lost or significantly damaged, with a concentration in the downtown areas of Santa Cruz, Watsonville, San Francisco, and Oakland. Around 60% was single-room-occupancy hotels and low-rent apartments. Though most single family homes were repaired within two years, only about half of the multifamily units had been repaired or replaced five years after the event.

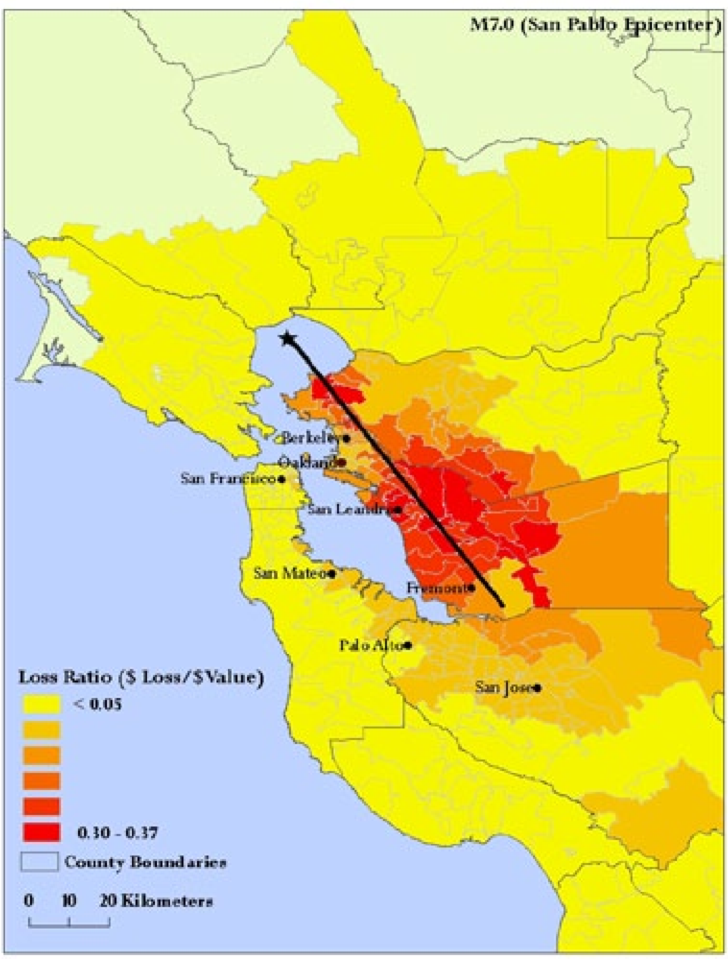
Thousands of soft-story multi-family residential buildings are vulnerable to serious earthquake damage

Fig 13.2

- In Hurricane Andrew, 20,000 of the 48,000 housing units lost were in multifamily buildings (40% of housing in South Dade County was multifamily).
- After Northridge, only 22,000 people stayed in shelters; instead 18,000 HUD Section 8 rent vouchers were issued to take advantage of Los Angeles' vacancy rate of over 8%. After Loma Prieta, Red Cross reported that 64,000 people sheltered; three emergency shelters were converted to homeless shelters due to the lack of single-room-occupancy housing.

CHAPTER 13:
HOUSING AND SOCIAL RECOVERY

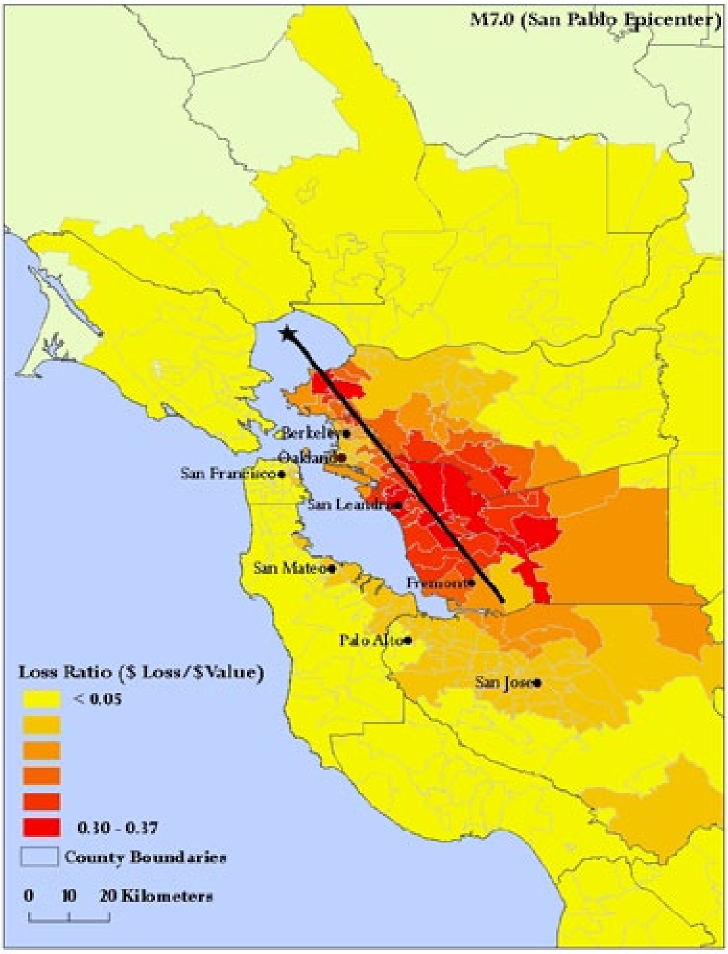
- After Hurricane Andrew, the shelter situation was dire as 100,000 people were dislocated. As many as 85,000 were in emergency shelters and many were in tent camps built by the U.S. Army.
- After the Hayward earthquake, we will need to house people in tent shelters, particularly in areas where incomes are modest and rents are relatively low.
- SBA loan programs are inadequate to meet the need for multifamily and affordable housing. Multifamily housing market economics hinder post-disaster residential recovery for most low- and moderate-income units: there is no economic incentive for an apartment owner to repair or rebuild.



Map showing economic loss ratio for commercial buildings. Note dark red areas with losses over 30% of the building value (Source: RMS)

Fig 13.3

CHAPTER 13:
HOUSING AND SOCIAL RECOVERY



Map showing economic loss ratio for residential buildings (Source: RMS)

Fig 13.4

- Comerio wrapped up by observing that, unlike the powerful City of Los Angeles, the Bay Area is politically fragmented, and therefore not an effective, unified voice in Washington. Instead of planning on federal largesse after a future earthquake, we should see to it that people who can pay, do pay for hazard mitigation and for their own insurance.

2010 UPDATE

Any contemplation of housing damage in the Hayward scenario quake reveals the prevalence of very vulnerable soft-story construction in multi-family structures. In 1999, prior to adopting the first mandatory soft-story ordinance in the East Bay, the City of Fremont conducted an inventory of soft-story, multi-family housing. Fremont identified 22 buildings containing about 1,000 units (1, p.15). At about the same time, the City of Berkeley developed a preliminary list of approximately 400 multi-story residential buildings containing almost 5,300 units in soft-story structures (1, p. 15). Shortly thereafter, San Leandro did an inventory of 350 multi-family residential, commercial/office, and mixed-use buildings containing approximately 4,000 units (1. p 16). Though many of the buildings on the lists may not be true soft-story structures, the numbers indicate a widespread problem with multi-family residential buildings. As noted in Chapter 9, Fremont, Berkeley and Alameda have adopted soft-story ordinances, but most of them do not require mandatory retrofit.

Its population of more than 394,000 makes Oakland the largest city on the Hayward fault. With assistance from ABAG and EERI, the city completed a soft-story inventory in 2008 that found 1,479 buildings containing 24,273 units met the criteria for soft story (2). Efforts by Oakland City councilmember, and mayoral hopeful, Jean Quan, to implement an Oakland soft-story ordinance have been hampered by the dire economic climate. However, her staff continues to work with ABAG, representatives from industry, and the cities of San Leandro and Berkeley to streamline residential retrofit standards (3).

“Our Housing Will Be Decimated” was the headline in the Association of Bay Area Government report estimating more than 150,000 uninhabitable housing units after the Hayward scenario earthquake (4, p. 2). ABAG estimates are based on statistical analysis of the housing damage after the 1989 Loma Prieta and the 1994 Northridge earthquakes. The estimates consider the large percentage of pre-1940, un-retrofitted homes in the Hayward fault region. Since that 2003 report, ABAG has estimated that 26,000 of 163,000 housing units in Oakland will be uninhabitable following the scenario event (2).

In addition to soft-stories, other structural conditions make residential construction, including single family homes, vulnerable to earthquake damage. Among them are wood-frame buildings that are not bolted to their foundation and those with un-braced cripple walls. These conditions become more problematic when the structures are located on hillsides. There were notable collapses of hillside stilt houses in the Northridge earthquake, one that led to a fatality. To reduce the earthquake vulnerability of single-family residences, the City of Berkeley's seismic incentive program provides an exemption from transfer taxes when new owners retrofit their structure within one year of purchase (6, p. 4).

With few state or local mandates, and little financial incentive to retrofit, thousands of residential units along the Hayward fault remain vulnerable. To make things worse, residential earthquake insurance is not widely held in the region. The California Earthquake Authority (CEA), a privately funded but publicly managed agency providing basic earthquake coverage, was created in 1996. However, in 2010, fewer than 10% of Californians had earthquake insurance (7). High premiums and large deductibles have kept most uninsured homeowners from purchasing policies. Earthquake insurance deductibles are typically 10%-15% which means the homeowner would have to pay the first $20,000 to $30,000 of damage on a home insured for $200,000 before coverage would kick in.

Comerio's plea that people should pay for their own insurance continues to go unheeded. United Policyholders, a non-profit tax-exempt organization dedicated to educating the public on insurance issues and consumer rights, cautions that, "given the recent dramatic rise in home values, protecting what may be the major financial asset in most family's portfolio is a decision worthy of appropriate consideration" (8).

A California Policy Research Center study found that Los Angeles did not suffer long-lasting losses of population or housing stock following the Northridge earthquake (5); however, houses in the damaged area were newer, located on flatter sites, and less affected by ground failure than those that will be damaged in the Hayward earthquake. The same study pointed out that residential recovery was not uniform in Los Angeles: areas with higher-than-average numbers of Hispanic, renter, low-income, and non-English speaking households were slower (5, p.8).

CHAPTER 13:
HOUSING AND SOCIAL RECOVERY

In areas along the western edge of the East Bay, the housing stock is old and predominantly multi-family, and the ethnically diverse population there typically has modest incomes and low rents. Current US Census data indicate that non-whites represent over 30% of the population in all but six of the 37 zip codes in the Hayward fault region (9). Recent disasters, most notably Hurricane Katrina, have highlighted the significantly longer recovery periods for lower-income populations.

The CPRC study (5, p. viii) pointed out that, after a quake, more resources are available for wealthier homeowners and in neighborhoods with a larger stock of single-family housing than in poor neighborhoods with higher concentrations of rentals and multifamily apartment buildings. Six major federal residential recovery programs were available after the Northridge quake: Small Business Administration (SBA) loans for homeowners, property loss, and business loans; Department of Housing and Urban Development (HUD) grants and loans; Federal Emergency Management Agency (FEMA) minimum home-repair grants; and FEMA individual and family grants for property losses (5, p. vii). Because repair of damage in more affluent neighborhoods with more single-family housing units was likely to be more costly, more resources were available for wealthier homeowners. Renters in poor neighborhoods got less.

While many governmental and institutional agencies in the Hayward fault region have started or completed seismic retrofit programs, most of the residential stock has changed little since 1995. Residential structures remain vulnerable to earthquake damage sufficient to displace large numbers of occupants, especially in economically disadvantaged areas.

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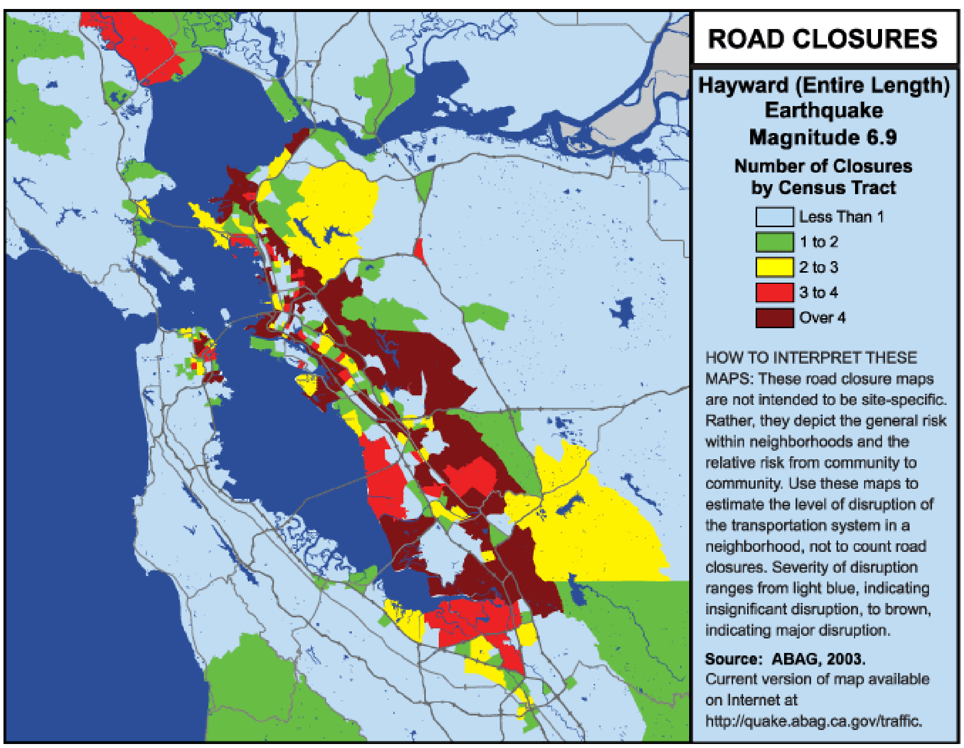
CHAPTER 14:
REGIONAL TRANSPORTATION RESPONSE

ORIGINAL AUTHOR:
JOEL MARKOWITZ, METROPOLITAN TRANSPORTATION COMMISSION

1995 SUMMARY

- The major challenge to efficient transportation response is the decentralized transportation system of the region. Communications will be inadequate to all the coordination needed among agencies.
- The following areas will be particularly problematic: a) the 24-580-980 interchange (MacArthur maze); b) BART--over 1,700 columns supporting elevated tracks have not been retrofitted, and the tracks go right through the MacArthur maze; c) the BART tunnel through the East Bay hills; d) access to the Bay Bridge and Carquinez Bridge will be closed due to their location on soft soil; e) damage on I-580 and I-880 will make access questionable and spotty.



Despite significant work on regional highways and bridges, ABAG estimates there will be over 1800 road closures after the Hayward fault earthquake

Fig 14.1

CHAPTER 14: REGIONAL TRANSPORTATION RESPONSE

- With 3 million commuters in the Bay Area on a typical weekday, close to 2 million will have some disruption and at least 800,000 will be unable to get home.
- The Metropolitan Transportation Commission, MTC, was poised to play an important role in improving post-earthquake recovery and reconstruction, in the following areas: access for first responders; access to critical facilities; evacuations; reestablishing communication; acting as a clearinghouse for damage assessment by transportation agencies; alternative transportation; and working with news media to disseminate latest information.

2010 UPDATE

Created by the state legislature in 1970, MTC is the transportation planning, coordinating and financing agency for the nine-county San Francisco Bay Area.

Since the 1989 Loma Prieta earthquake, MTC has worked with the region's transportation agencies to develop a set of interagency agreements and procedures, coordinated regional transportation emergency exercises, and initiated efforts to prepare the region's transportation agencies for the next natural disaster or major catastrophe (1). Since 1996, with MTC in the lead, regional transportation systems have addressed many of the issues described by Markowitz in 1996. Progress to improve coordination and communication includes the following:

- The Regional Emergency Coordination Plan (RECP) was developed in 2008 through collaboration among the CalEMA, Coastal Region; the cities of Oakland, San Francisco, and San Jose; and the operational area lead agencies for the ten Bay Area counties. The RECP was made possible with a grant from the Department of Homeland Security. The OES Coastal Region is responsible for the maintenance, revision, and distribution of the RECP and its subsidiary plans. MTC manages the Transportation Subsidiary Plan (2).

- Regional transit operators, Caltrans, and the CHP participate in annual emergency preparedness exercises. Exercise scenarios have included a simulated 1906 earthquake on the San Andreas fault and a Hayward fault earthquake scenario (1).

- ABAG's Local Hazard Mitigation Plan covers the same jurisdiction as that governed by MTC. Consequently, the Earthquake and Hazards Program in ABAG's Planning Department took the lead in creating the overall multi-jurisdictional Local Hazard Mitigation Plan (MJ-LHMP). The program has been involved in actively mapping hazards and identifying risks since the formation of ABAG in 1961. MTC used the ABAG hazard maps and studies to develop the RECP (3).

Chapters 5 and 7 of this document described the advancements in seismic safety made by Caltrans and BART, including the Bay Bridge east span replacement. These advancements will reduce the time required to restore services. However, the transportation systems in the San Francisco Bay Area are complex systems comprised of multiple elements. Despite the progress made with extensive seismic improvement programs, ABAG estimates that there will be over 1800 road closures in the region after the Hayward scenario event (4).

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CHAPTER 15:
ECONOMIC RECOVERY

ORIGINAL AUTHOR:
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1995 SUMMARY

- There are two kinds of losses in the aftermath of an earthquake: physical damage to structures and infrastructure; and economic losses.
- Estimated building damage from the scenario quake on the Hayward fault will be $16 billion.
- At a minimum, the scenario earthquake's effect on the economy of the Bay Area, will be about 1% of the region's product, or $1.8 billion. More likely, the total income loss will be $4 billion.

The Hayward fault runs through the vibrant commercial district of Montclair in Oakland

Fig 15.1

- The following economic losses result from earthquakes: productive capabilities of physical capital such as factories, offices, and the infrastructure are impaired; damaged or destroyed offices, factories, warehouses, roads, bridges, highway overpasses, lifelines, and telecommunications all interrupt economic processes; residential damage makes people unable to function routinely and they stop contributing to the economy or buying things; fear reduces tourism, and the hospitality industry suffers accordingly; real estate is hit hard.

- The Bay Area is home to a number of the 100 fastest-growing companies in the United States. Because the industries of Silicon Valley will determine the economic future of the Bay region and California for the next 20 years, the greatest potential economic loss to the region's economy is right there.

The Hayward fault runs through the historic commercial district of Niles near Fremont

Fig 15.2

- Damage to commercial and industrial properties will account for loss of as many as 42,000 jobs in a three-month period. A significant drop in retail sales will result in a loss of about $570 million, most of which will be in Alameda County.
- Losses in the hospitality industry could result in wage losses of $700 million for a six-month period.
- A common effect from natural disasters is the redistribution of economic activity to other regions. Following the Hayward fault quake, economic activity may shift to other nearby regions.

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Recovery following the Hayward fault earthquake will not follow the model of recovery following the 1991 Berkeley/Oakland hills fire

Fig 15.3

- Munroe closed with the observation that the real tragedy of most natural disasters is the impact on people who can least afford it—those in poor housing with low or no incomes.

2010 UPDATE

In Chapter 10 we reported that RMS has estimated $235 billion in losses to residential and commercial property after the Hayward fault event (1). Economic losses must be added to those physical losses. In a 2007 study, the authors noted that approximately "90 percent of the businesses, employees, and payrolls in Alameda County are located in the two most intense [earthquake] shaking zones on the scenario map (MMI VII and MMI VIII or higher)" (2. pp. 16-17). The two zones include more than 600,000 employees with a total quarterly wage of $8.2 billion. The risk is particularly high in health care and social assistance, educational services, manufacturing, and the retail trade sectors.

Economic losses from the Hayward fault scenario quake are expected to be much greater than the economic losses experienced by Louisiana and Mississippi after hurricane Katrina. Alameda County alone has "20 percent more businesses, 22 percent more employees, and 74 percent more in payroll earnings" than the areas affected by the hurricane (2. p. 17).

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This bucolic setting is the park at Point Pinole where the Hayward fault begins its path through the densely populated East Bay

Fig 15.4

The California Policy Research Center report discussed in Chapter 13 observes that successful long-term recovery from a disaster does not mean returning to pre-disaster conditions; real recovery, "recaptures the developmental trajectory" that was interrupted by the disaster (3, p. vii). Recovery indicators of concern include changes in population and residential units, vacancy rates, affordability of housing, retention of local residents, structural improvements, extent of retrofitting, and quality of life in areas with extensive damage.

A discussion on recovery is not relevant without consideration of mitigation strategies. A Community and Economic Impacts Briefing Book recently prepared for the San Francisco Community Action Plan for Seismic Safety (CAPSS) Program evaluated the socioeconomic impacts of a retrofit policy for soft-story wood-frame residences (4). The report included a review of the community impacts associated with Hurricane Katrina and the Loma Prieta and Northridge earthquakes. The report warned that the current recession will dampen private sector emergency preparedness: "People are far less likely to retrofit their single-family home or apartment complex when money is tight, loans are hard to access, home values remain unstable, and their employment situation appears delicate. For the same reasons, the political will to compel the private sector to take action through policy or ordinances is also weak" (5).

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Judging from the lessons of the past 15 years, the path to loss reduction and preparedness for successful recovery is long and expensive. Simon Alejandrino of the Bay Area Council Economics Institute cautions that, "earthquakes aren't timed according to the economic cycle," and he encourages earthquake professionals to continue to educate the public and be prepared for dynamic action when the economy rebounds (5).

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CHAPTER 16:
FIRE FOLLOWING EARTHQUAKE

There was no chapter on post-earthquake fire in the 1995 Hayward fault scenario. Although many of the authors mentioned fire, it was not treated as a distinct topic. In this update we have an opportunity to discuss the impacts of fire following earthquake, which is obviously important, especially in light of the recent San Bruno gas explosion.

Although most earthquake damage is caused by shaking, fire afterwards can be equally as devastating, if not more so. The shaking damage in the 1906 San Francisco earthquake was eclipsed by that from the almost uncontrollable fire, caused in part by all the water mains broken in the quake (7).

Fires generally follow all earthquakes that significantly shake a human settlement, but are usually only a serious problem in a large metropolitan area with densely spaced wood buildings (1, p. 6). The string of dense, wood-framed, residential communities bordering the Hayward fault perfectly exemplify such a high-risk area, especially since many of the neighborhoods near the fault are heavily covered in vegetation vulnerable to urban-wildland interface fires.

Studies of the post-earthquake fire hazard in other parts of California are instructive. **Fire Engineering** online magazine reported that a Fire Following Earthquake (FFE) study, undertaken as part of the 2008 Great Southern California Shake Out, postulated that more than 133,000 structures could burn to the ground in firestorms following the scenario quake, and that the fire losses could “double the damage and fatalities from the quake” (2). Charles Scawthorn, author of the FFE report, endeavored to answer the following questions:

- How will ignitions be reported after an earthquake?
- How will fire departments respond?
- How long will it take for the fires to be extinguished?
- What mutual-aid agreements are in place, and how will they be activated?
- How will damage to telecommunications, water supply, and roadway damage affect response?

- What, if any, effective mitigation actions undertaken elsewhere might be practical in Southern California?
- What are the limitations of the scenario? Is there any research that could provide a more realistic or perhaps more detailed scenario?

Modeled on a November day without Southern California's Santa Ana wind conditions, the FFE study showed that most fire departments are not sized or equipped with sufficient "surge capacity" to cope with the fires after a major earthquake. The study estimated that the scenario earthquake would result in approximately 1,600 ignitions that would require the response of a fire engine. The approximately 1,200 fires that fire fighters would not be able to adequately contain would result in conflagrations capable of destroying several city blocks in Riverside and San Bernardino counties. Of more concern, however, is that in portions of Orange County, and especially the central Los Angeles basin, dozens to hundreds of large fires are likely to merge into dozens of conflagrations, destroying tens of city blocks. There could also be one or several "super conflagrations that destroy hundreds of city blocks" (1, p. 12).

Hayward Fire Department portable water system

Fig 16.1

The San Francisco Bay Area has recent experience with conflagrations, though not earthquake-related. The 1991 Bay Area firestorm left 25 people dead, and destroyed more than 3,500 dwellings in Oakland and Berkeley. The catastrophic October 20th fire, fueled by Diablo winds, was fought by more than 400 fire companies from all around Northern California and burned uncontrolled—in the Hayward fault zone--until the wind died down (3). The September 9th natural gas pipeline explosion and resulting fire in the small community of San Bruno, south of San Francisco, destroyed 37 homes, killing seven (4). Not counting deaths or other liabilities, “property damage alone from this event is probably on the order of $50 million.” (4)

According to Scawthorn, the San Bruno explosion provides an object lesson: there was one large gas flare, perhaps 30 fire engines responded from San Bruno and nearby communities, the companies were able to bring in water from only two blocks away, and they confined the fire after 38 houses were destroyed. In an earthquake, the San Bruno Fire Department would have been on its own, with its two engines (5). The estimated insured losses itemized in Chapter 10 include fire, but should be considered to be conservative numbers. An RMS spokesperson notes that the fire following earthquake model is an urban fire spread model only—it does not account for fire expanding into a wildland interface, then jumping back into the urban environment, which is a real possibility in many parts of the Bay Area (6).

In 1992, a U.S. insurance industry-funded a study of the earthquake conflagration potential in large cities on the West Coast found “over 250 ignitions for a Hayward event, and losses of 0.5-1% of all property at risk.” (5) The RMS study in Chapter 10 estimates total property at risk in a Hayward fault earthquake at about $1.8 trillion. If we use the 1992 percentage, then fire following earthquake losses could be in the range of $8-18 billion, with a possibility of much higher losses if there are high winds or other complicating factors.

Although we clearly have indications that fire will be a major problem after a Hayward fault quake, there is no recent study of the current risk. A careful and detailed study is needed to categorize the risk and point out areas that need improvement.

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CHAPTER 17: CALL TO ACTION

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In 1995 Tom Tobin closed the EERI Annual Meeting with a call to action, urging that "earthquake risk is not so overwhelming that we can't start reducing it."

The previous 16 chapters of this document have highlighted areas in which the Bay Area has made great strides in protecting the public from the damaging effects of earthquakes. In the past 15 years, disaster resistance in the Hayward fault region has improved, particularly in the public arena. Ambitious projects have reduced seismic vulnerability in transportation, clean water storage and delivery, power delivery, telecommunications, and on university campuses. Regional and local emergency planning agencies have also advanced collaborative emergency response and worked to implement the Disaster Mitigation Act.

Improvements on a more limited scale were also made in the private sector in such areas as compliance with URM laws and initial efforts by a few municipalities to encourage mitigation in soft-story structures.

Despite these improvements, there is more to accomplish. Areas in need of immediate action are many:

- All municipalities with soft-story inventories must begin to deal with the thousands of multi-family apartment buildings with first floors that will collapse partially or completely.
- Identification and mitigation of other "at-risk" building types such as non-ductile concrete frames.
- Attention to the serious issue of fire following earthquake. This would include careful study of the problem and realistic mitigation and response plans.
- Incentives and support for the improvement of seismic safety in the K-12 school system. Public school retrofit programs continue to be voluntary and have not been implemented statewide.

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- Improvement of hospital seismic safety with the strict enforcement of SB 1953.

The Hayward fault earthquake threat is clear, as are the kinds of damages we can expect in the quake. But equally clear are the deficiencies in our preparations for recovery, particularly in the private sector. Public policymakers have long struggled to balance private interests and public needs. In the aftermath of natural disasters, that balance is always tipped when the ill-prepared private sector turns for help to the public relief system.

Where should we go in the next 15 years?

- We must continue the trajectory of our public agency mitigation of earthquake risk and find ways to increase efforts in the private sector.
- The foundation for collaborative emergency planning and response has been laid; we must maintain it regardless of shifts in threat perception and changes in government administrators.
- Earthquake professionals must continue to lead the effort to disseminate clear information about risk, damage, and mitigation strategies.
- Public policy makers and corporate decision makers should be encouraged to create programs that offer incentives to private parties for mitigation.
- Education and public policy should endeavor to link property value with risk.

Fifteen years ago, Tobin urged us to “attain an acceptable level of seismic safety by the end of this century” and encouraged earthquake professionals to be “agents of change” in the public arena, moving from the conference room to the board room, city council chambers, and to the halls of the legislature. Ten years into the new century, we have not yet reached an acceptable level of seismic safety, and it is clearly necessary for earthquake professionals to continue their advocacy. But they must take their message beyond enclosed spaces out to the stakeholders in whatever arena they can be found. Every private property owner in the Bay Area must come to understand the losses each and all of us will face, and how those impacts will harm the quality of life we enjoy in this unique part of the world.

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