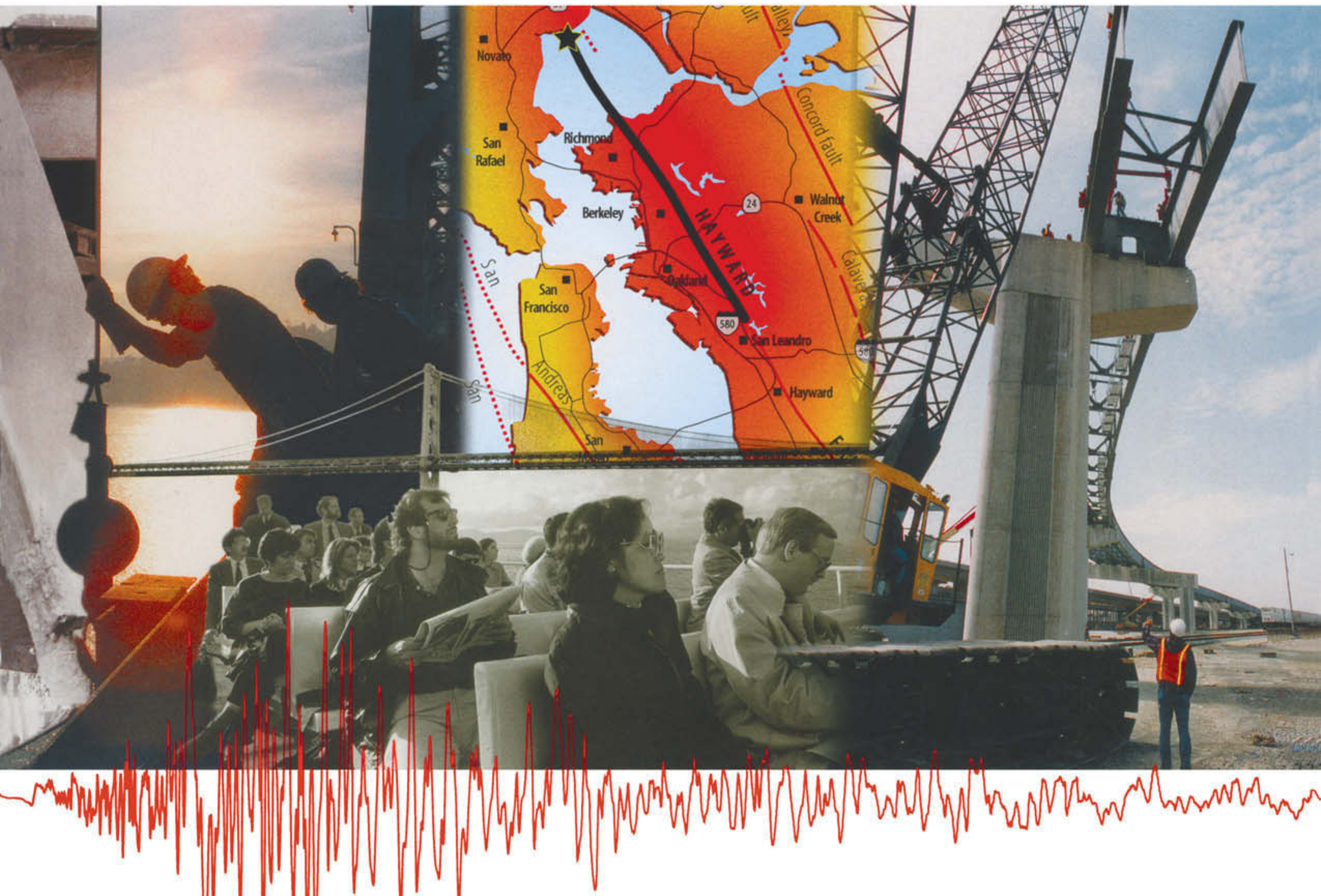
Scenario for a Magnitude 7.0 Earthquake on the Hayward Fault



Earthquake Engineering
Research Institute

Scenario for a Magnitude 7.0 Earthquake on the Hayward Fault

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The northern Hayward fault scenario earthquake has also been summarized in the EERI publication entitled *Magnitude 7.0 on the Hayward Fault: A Call to Action.* This abridged version is directed toward San Francisco Bay Area community leaders and policymakers. Single copies are available for $5 (to cover shipping and handling) from EERI at the above address.

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Preface

At the 1995 Annual Meeting of the Earthquake Engineering Research Institute, a special day-long symposium was held on the multidisciplinary challenges of a major urban earthquake, using the northern Hayward fault as an example. The Annual Meeting Planning Committee selected sixteen insightful presenters to cover all aspects of this earthquake, from the social and economic setting of the San Francisco Bay Area, through the geologic, seismologic, and earthquake engineering issues raised by such a severe earthquake in a heavily urbanized region, to the emergency response and recovery aspects that challenge the capabilities of Bay Area neighborhoods, organizations, and governments.

Several practice sessions raised interdisciplinary issues among the presenters, created a new understanding of earthquake preparedness and response interrelationships, and contributed to the insights presented during the symposium.

This account reports the substance of what was presented—the words, maps, tables, and photographs—as transcribed and edited. Though the immediacy of live presentations has been tempered, the essence of the meeting has been preserved: a compelling portrayal of a magnitude 7.0 earthquake on the Hayward fault.

This northern Hayward earthquake scenario provides an opportunity to appreciate the personal, scientific, engineering, and social issues that surround the occurrence of a major earthquake. The communities and residents of the San Francisco Bay Area know of earthquake risks, and many preparations have been made, but we all recognize that there is much more that could—and should—be done before the ground shakes again. Though this scenario has its disturbing and negative aspects, it calls for positive action.

Earthquake professionals have a unique opportunity and responsibility to encourage community leaders to take effective action to reduce earthquake risk. Understanding the significant effects and consequences of this earthquake, and by analogy other earthquakes in the United States and worldwide, is the foundation of reducing that risk.

The scenario presenters and the members and staff of EERI encourage you, the reader, to take responsibility for improving the mitigation efforts currently under way and developing new ways to reduce future losses. This scenario will serve you as a planning aid. It reveals the issues we all must face to make our region safer and to recover from the next—inevitable—earthquake.*

William U. Savage, *Chair*
Planning Committee

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Acknowledgments

The Planning Committee for the 1995 Annual Meeting of the Earthquake Engineering Research Institute selected the northern Hayward fault earthquake scenario as the topic for a symposium held on February 9, 1995. The Planning Committee chose the topics and presenters for the symposium, and convened practice sessions to coordinate the presentations. The members of the Committee were as follows:

Chair: William Savage, Pacific Gas & Electric Company
Stacy Bartoletti, Degenkolb Engineers
Ronald Hamburger, EQE International Inc.
Laurie Johnson, EQE International Inc.
Bret Lizundia, Rutherford & Chekene
Edward Matsuda, Pacific Gas & Electric Company
Marcia McLaren, Pacific Gas & Electric Company
Christopher Rojahn, Applied Technology Council
David Schwartz, U. S. Geological Survey
L. Thomas Tobin, Tobin & Associates

Lloyd Cluff, Former President of EERI, and Susan Tubbesing, EERI Executive Director, also provided helpful support and guidance in developing the symposium.

Introduction

William U. Savage, Pacific Gas and Electric Company

In the ninety years since the great San Francisco earthquake of 1906, the San Francisco Bay Area has exceeded all expectations in its growth and richness as a business, cultural, and residential mecca. In 1989, the damaging Loma Prieta earthquake brought to reality once again the threat of earthquakes to the Bay Area.

But the Loma Prieta event was only one of many potential large earthquakes identified by earth scientists as likely to occur within coming years, and it was far from being the most dangerous to life and property in the region. It occurred in a rural area of Santa Cruz County, about 60 miles south of the densely populated cities of San Francisco and Oakland.

One of the most likely sources of a magnitude 7.0 earthquake within the next few decades is the Hayward fault. Because it is located in the heart of the Bay Area, a major earthquake on the Hayward fault will be far more deadly and damaging than was the Loma Prieta earthquake in 1989. The most recent earthquakes on the Hayward fault occurred more than a century ago, long before the buildings, roadways, and utilities that serve the entire San Francisco Bay Area were built. The earthquake scenario analysis documented in this volume examines the seismic future along the Hayward fault, from ground shaking to economic recovery.

The presenters of the scenario invited the audience to use their imaginations while considering, "What if a magnitude 7.0 earthquake on the northern Hayward fault occurred right now, at 9:10 A.M. on a Thursday morning?" Suddenly, the lights in the auditorium went totally black. The terrifying noise of an earthquake began to build in the darkness—

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?

1-1 *San Francisco Bay Area map © 1996 by Rand McNally, R.L. 96-S-180.*

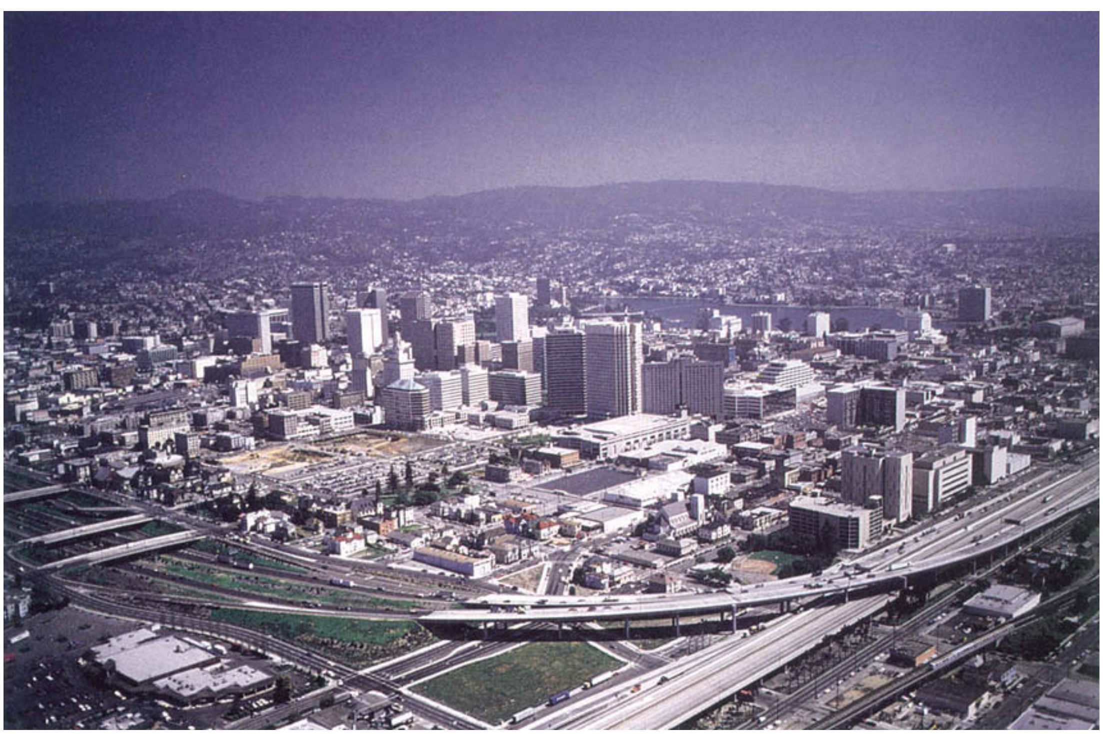
Chapter 1

Hayward Fault Socioeconomic Setting

Angelo Siracusa, Formerly Bay Area Council

Woody Allen once said, "We have the choice between despair, hopelessness, and total extinction. Let us have the wisdom to choose correctly." Someone else—I don't know who—said, "There is no problem so big, so important, you can't run away from it." These two statements reflect my own view of how the Bay Area public approaches earthquake preparedness. But that can change. And to give a compelling reason why it should, let me execute a brief sketch of the Bay Area, with special emphasis on its economic activity.

The Bay Area comprises the nine counties that touch San Francisco Bay, with 100 different municipalities and 6.5 million people (figure 1-1). This region is the fifth-largest metropolitan area in the country. If the Bay Area were a state, it would be the eighteenth-largest one. It has 2.3 million households; 2.9 million people are employed here. The Bay Area is only 15% urbanized on its 7,100 square miles. Various factors contribute to its enormous potential for growth: the holding capacity of the land; the magnetic attraction of the quality of life; and a very strong economy with its job opportunities (figure 1-2). The only serious constraint, I would say, is how the people—speaking directly and through their governments—will define the acceptable level and location of growth. And another constraint might be earthquake potential.



1-2 *Downtown Oakland before recent expansion added a new federal building on vacant land adjoining the new City Center complex.*

Unlike any other metropolitan region, the Bay Area has no central city. Though San Francisco is the heart of the region, and is perceived outside the region as the focal point, it is not in fact the seat of power. There is no natural focus in the Bay Area for regional decision making or regional planning, including disaster planning. The area is parochial and fragmented, and it is very difficult to coordinate decisions within this region.

San Francisco, with 750,000 people, has very high density and the highest assessed valuation of any location in the region. It is well served by transit, both within the city and in connections with the worker bedroom communities around the Bay. The Peninsula from San Mateo County down to Santa Clara County has about 2.25 million people. All of the development to speak of is between Interstate 280 and San Francisco Bay. I doubt that there will ever be any development along the shoreline of San Mateo or Santa Clara Counties. There's medium density all the way down until you get to San Jose, which has about 800,000 people. It's the largest city in the Bay Area, has less density, and has quite a potential for development—south. Again, the only serious constraint to growth is what public policy has to say about how much development can happen there.

The East Bay—Alameda and Contra Costa Counties—has about another 2.25 million people. The Hayward fault goes up and down the middle of that high-density area. Most of the urbanization in the Bay Area in recent years has taken place along the Interstate 680 and Interstate 580 corridors. There is enormous potential for growth there and in eastern Alameda and Contra Costa Counties.

1-3 Container ship docked at the Port of Oakland.

In the North Bay—Marin, Sonoma, Napa, and Solano Counties—there are currently about 1.25 million people. The area has less potential for growth because Sonoma and Napa Counties don't really want development except in the Santa Rosa area. The greatest potential for development is in Solano County along the Interstate 80 corridor.

We have a very sizable economy. We are the fourth-largest economy in the nation. Since World War II we have been a prodigious producer of jobs; we've always had unemployment below state and national averages. In the December 1994 figures, U.S. unemployment was 6.2%; California was 8.2%; and the Bay Area was 5.7%. By comparison, unemployment in Southern California (Los Angeles/Long Beach) was 8.0%. What we have going for us is, first of all, a diversified economy: technology, bioscience, world trade, finance, services, and tourism.

When we talk about trade, we're not just talking about the cargo tonnage handled by the shippers that use the Port of Oakland (figure 1-3). We're talking about intellectual services reflected in people who fill first-class seats and in very high value material that fills the cargo bays on the airlines that touch the far reaches of the world. We are a world-renowned center of entrepreneurship and innovation: computers, semiconductors, software, telecommunications, multimedia, biotechnology. We have top-rated, world-class universities that excel in both academics and research. They are also generators of enormous economic activity. We would not have Silicon Valley were it not for Stanford. We would not have the great bioscience concentrations were it not for the University of California (figure 1-4), both Berkeley and San Francisco, and Stanford. Though technology is concen-

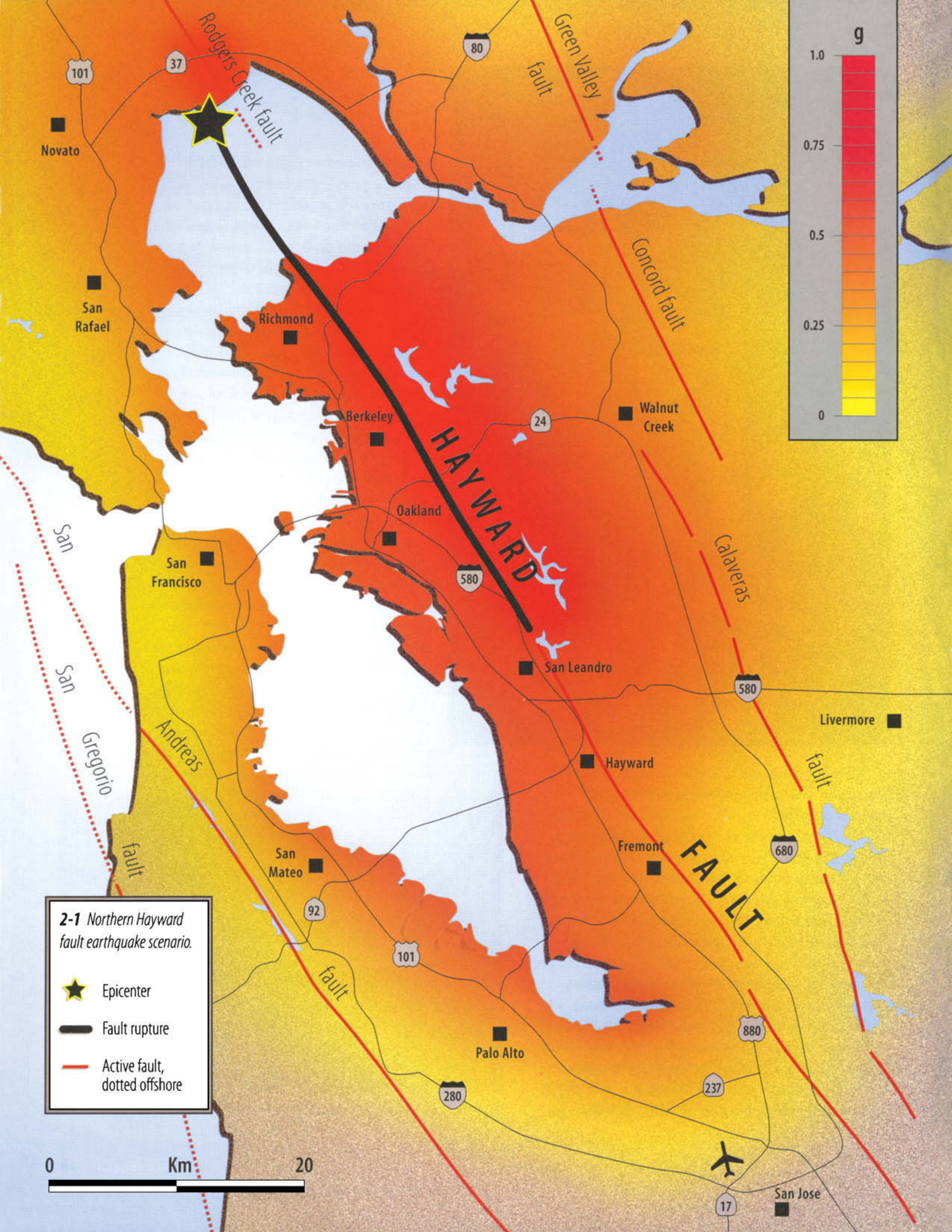
1-4 *Berkeley campus of the University of California.*

trated in Silicon Valley, biotechnology is all around the region.

We have a superior quality of life; I believe that is our greatest economic asset. The Bay Area has a gross domestic product of about $180 billion. If the Bay Area were a nation, our economy would rank among the top twenty in the world. By all standards, the Bay Area is an economic powerhouse.

I stated earlier that the Bay Area comprises nine counties, but when we look at the issue of housing affordability, we discover that the Bay Area may extend to twelve or fourteen counties. People seeking affordability are going to the Central Valley and the real South Bay to find homes, exacerbating the commute problem and the air-quality problem and hastening the loss of agricultural land. In most cases, housing follows jobs, but I think in the Bay Area jobs will follow housing. Maybe Interstate 5 will become the next I-680 corridor, with employment following the opportunity for lower-cost housing.

Mark Twain made the statement "Prosperity breeds arrogance." We've had practically fifty years of uninterrupted prosperity, and we've become very smug about our economic future. We need to use our wisdom to plan for reducing our potential economic losses in a major earthquake. All of us are asking for better information on which to base our decisions and actions and with which to plan for and survive the next magnitude 7.0 earthquake that will hit the Bay Area.



2-1 *Northern Hayward fault earthquake scenario.*

Chapter 2
Geology and Seismology of the Hayward Fault

David Schwartz, U.S. Geological Survey

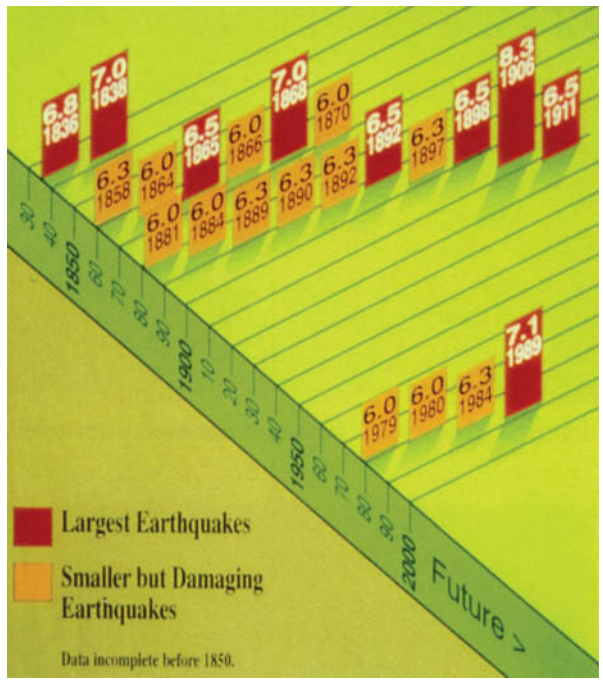
The magnitude 7.0 scenario earthquake will nucleate at the northern end of the Hayward fault in San Pablo Bay. It will rupture unilaterally to the south to Lake Chabot—50 kilometers. It will take about 22 seconds to do that. Average movement or displacement at the surface will be one meter (3 feet), but there may be up to 9 feet of surface offset in certain locations (figure 2-1).

Bay Area Seismicity

In what we informally call the tombstone diagram (see figure 2-2), the little rectangles represent past earthquakes over time. Between 1836 and 1906, there were sixteen earthquakes in the Bay Area with magnitudes exceeding 6.0. Some of those exceeded M7; the 1906 earthquake was the largest of the group. The area became quiet after the 1906 quake released all the stress in the region.

It wasn't until 1955 that there was a magnitude 5 in the Bay Area, on the Concord fault. Then in the late 1970s and early eighties we started getting magnitude 6 earthquakes on the Greenville and Calaveras faults. In 1989, we stepped up to a magnitude 7 with the Loma Prieta earthquake. Many scientists feel that we're coming out of the shadow of the 1906 event and going into another active cycle.

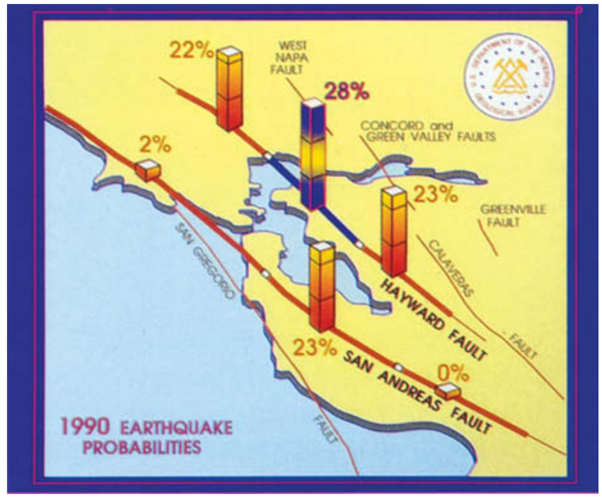
In 1990, following the Loma Prieta earthquake, the Working Group on California Earthquake Probabilities revised its estimate of probabilities for large earthquakes in the Bay Area. The group was originally convened in 1987 and issued the first California earthquake probabilities in 1988. The map in figure 2-3 represents the group's new probabilities (Working Group 1990). Depicted



2-2 *Dates and magnitudes of Bay Area earthquakes.*

are the major faults: the San Andreas, the Hayward, the Rodgers Creek, and others such as San Gregorio, Calaveras, Concord, and Green Valley. The towers represent the thirty-year earthquake probabilities for each of the fault segments. The northern Hayward fault has the highest probability of any single fault segment: 28% during the next thirty years. When you combine all the fault segments, there is a thirty-year probability for the region of 67%. As stated in the report, that is a minimum value because there are other faults that have not been included in this "seismic stew."

We're starting yet another reevaluation of Bay Area probabilities. There's no question that the new probabilities will be higher than 67%,



2-3 Map showing conclusions of the 1990 Working Group on Bay Area Earthquake Probabilities.

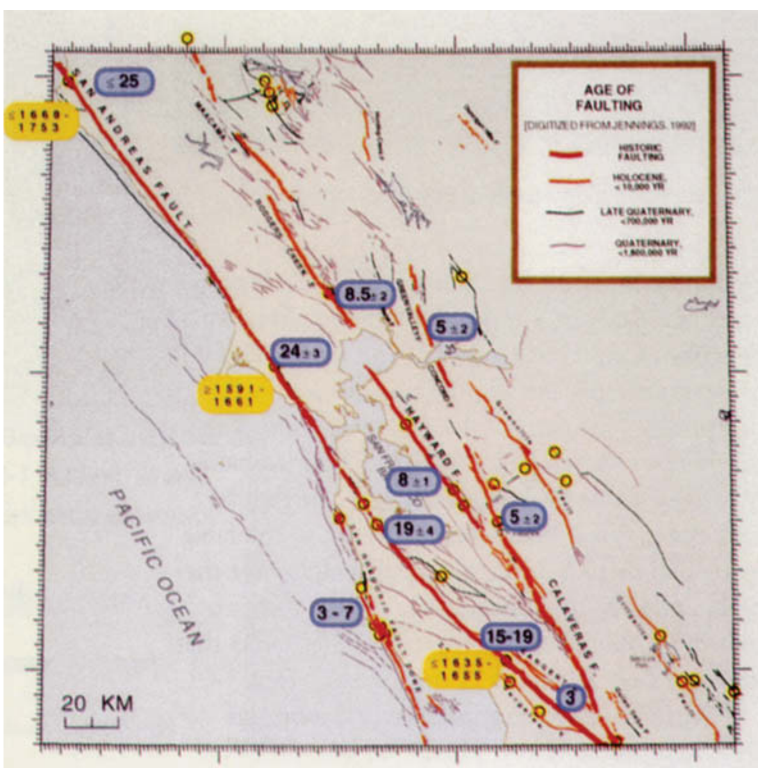
because we will include information on other faults, such as the San Gregorio, the Concord, the Calaveras, and thrust faults in the region. Whether the ultimate value is 70% or 85% or 90% over the next thirty years, we're faced with very high odds of having at least one magnitude 7 earthquake in the Bay Area. It is highly likely that the location of that event will be the northern Hayward fault.

The Hayward Fault

The black line in figure 2-4 in the San Andreas fault system is the boundary between the North American plate and the Pacific plate. These plates are moving inexorably past each other at a rate of about 2 inches (47 mm) a year. When we look in detail at the Bay Area, we can see that the San Andreas system is complex and made up of numerous individual faults. These faults accommodate about 38–40 millimeters of the total plate rate. The San Andreas fault moves at a rate of about 23 millimeters per year. The Hayward fault is moving at about 9 millimeters a year, so 25% of the slip along the plates in the Bay Area is accommodated on the Hayward fault itself. That slip rate translates to an average repeat time of around two hundred years for large earthquakes. That's true for most of the other major faults.

In the aerial view of the Hayward fault, looking from the south (figure 2-5), we see that the fault follows Highway 13, the Warren Freeway, through Oakland. The fault then runs through Berkeley, Albany, and El Cerrito and out to San Pablo Bay. Basically the fault cuts through the most densely built-up section of the entire Bay Area. In a map of seismic activity (figure 2-6) between 1969 and 1994, the Hayward fault is very well delineated by microearthquake activity (shown by yellow dots).

Figure 2-7 shows what the fault looks like in three dimensions. The earthquake activity along the fault plane extends to 12 or 13 kilometers below the surface before dying out because there's a change in the property of the rock. Below this, rock flows and is moving at about 9 millimeters a year. The microearthquake activity images or defines the trace of the fault as this planar or tabular zone. The fault is more than a

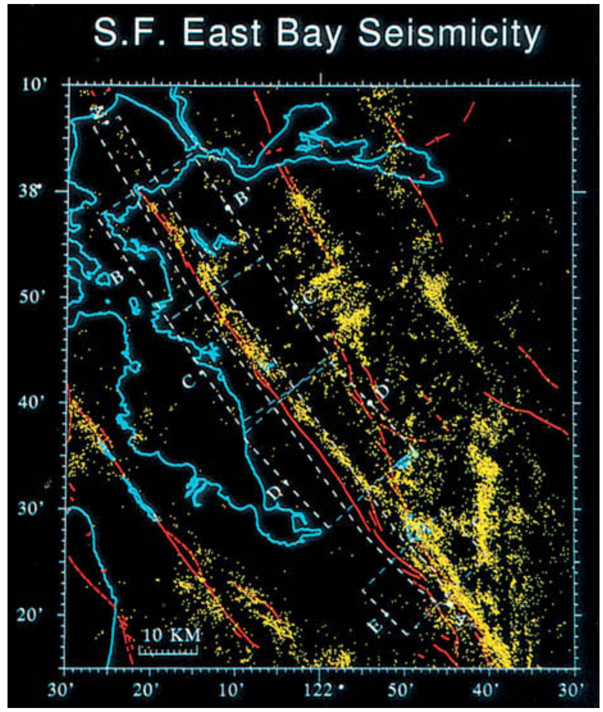


2-4 The San Andreas fault system.

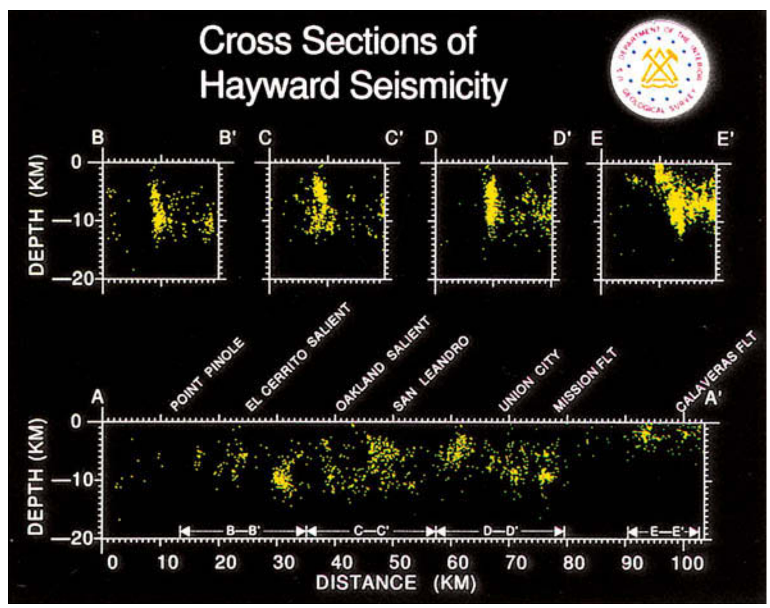
***2-5** Aerial view of the Hayward fault, looking north to San Pablo Bay.*

line on the map; it is a big three-dimensional feature going through the crust.

The Hayward fault has some unique characteristics. It's slipping both at depth and in its upper part. It's also creeping at the surface. When it crosses roads and sidewalks (figure 2-8), it breaks them. It bows out sidewalks and deforms them. These breaks have been precisely measured all along the length of the fault. It's creeping at a rate of about 5 millimeters each year on the surface. Below 12 kilometers the fault is slipping, and at the surface it's creeping. Between the creeping part and the deep-slip part (figure 2-9), there are two areas that are referred to as "locked"—locked since 1868 and locked since 1836. These are the large parts of the fault that will fail and produce the next earthquakes.

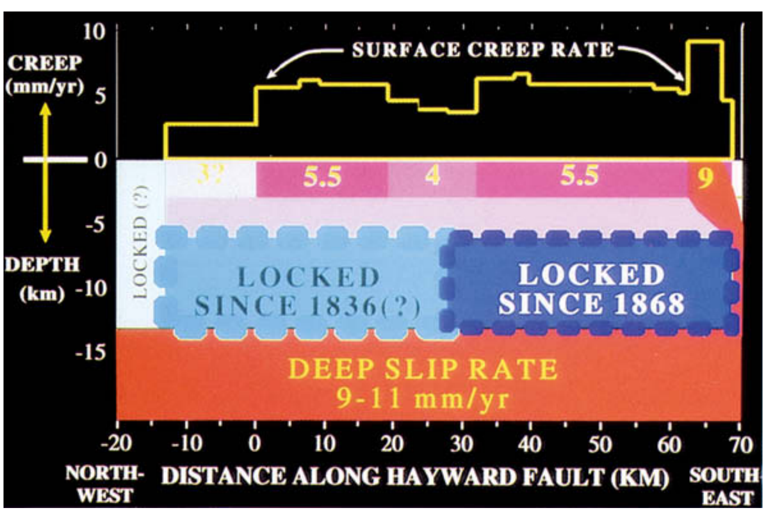


***2-6** Map of Bay Area seismicity.*



***2-7** The Hayward fault in three dimensions.*

2-8 Sidewalk offset by creep along the Hayward fault in San Pablo.



2-9 The Hayward fault between the creeping part and the deep-slip part.

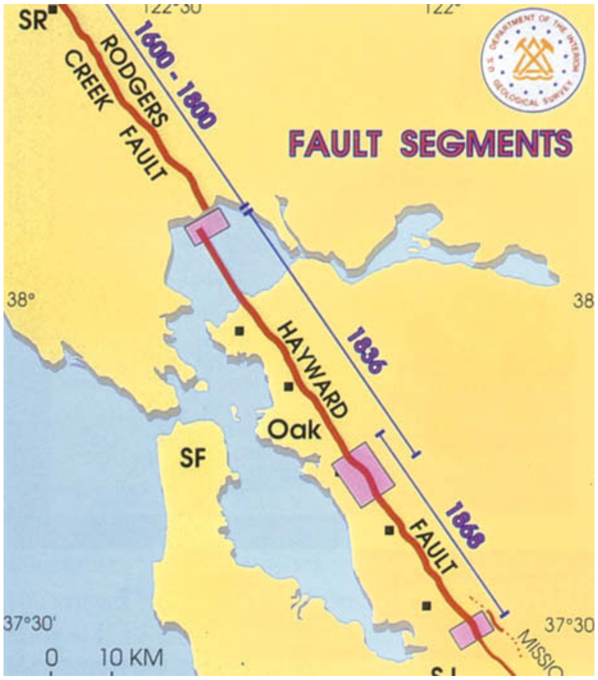
The Hayward fault is made up of two individual sections, each of which is capable of producing earthquakes. The bands or boxes in figure 2-10 represent the boundaries of the individual sections, with some uncertainty about where we think the ruptures will actually occur. The southern section, or segment, which produced a large earthquake in 1868, extends from San Leandro south to the Warm Springs area. The northern section, which extends from San Leandro north to San Pablo Bay, goes north into the Rodgers Creek fault, which is a continuation of the Hayward system. We think the northern Hayward fault had an earthquake in 1836, but there's some uncertainty.

To determine how often this fault moves, we need to dig trenches. But it's very difficult to find good locations in a highly urbanized area: the good sites have been either bulldozed or paved over. Sometimes trenches are not totally successful; they fill with water. Figure 2-11 is a working, in-progress map of what a trench in Montclair looked like before it filled with water. The arrows point to what are believed to be in-fills, old openings to the surface into which material dropped during an earthquake. The finger points to an old fissure that formed during a past earthquake that may have been in 1836.

In 1990 the Working Group estimated an average repeat time for the northern Hayward of 167 years, using the fault slip rate. If the last earthquake occurred in 1836, we've gone 159 years into that 167-year cycle. Trenching studies on the southern Hayward are very preliminary and suggest that 150 to 250 years is the average repeat time, very similar numbers to the Working Group estimate. We're very well into this earthquake time cycle.

The Scenario Earthquake

We have calculated the magnitude 7.0 scenario event from a number of parameters. We estimate the fault will rupture 50 kilometers, that it extends down through the crust about 12 kilometers, and that there'll be an average of about 2 meters (6 feet) of slip along the fault when it moves. Multiply

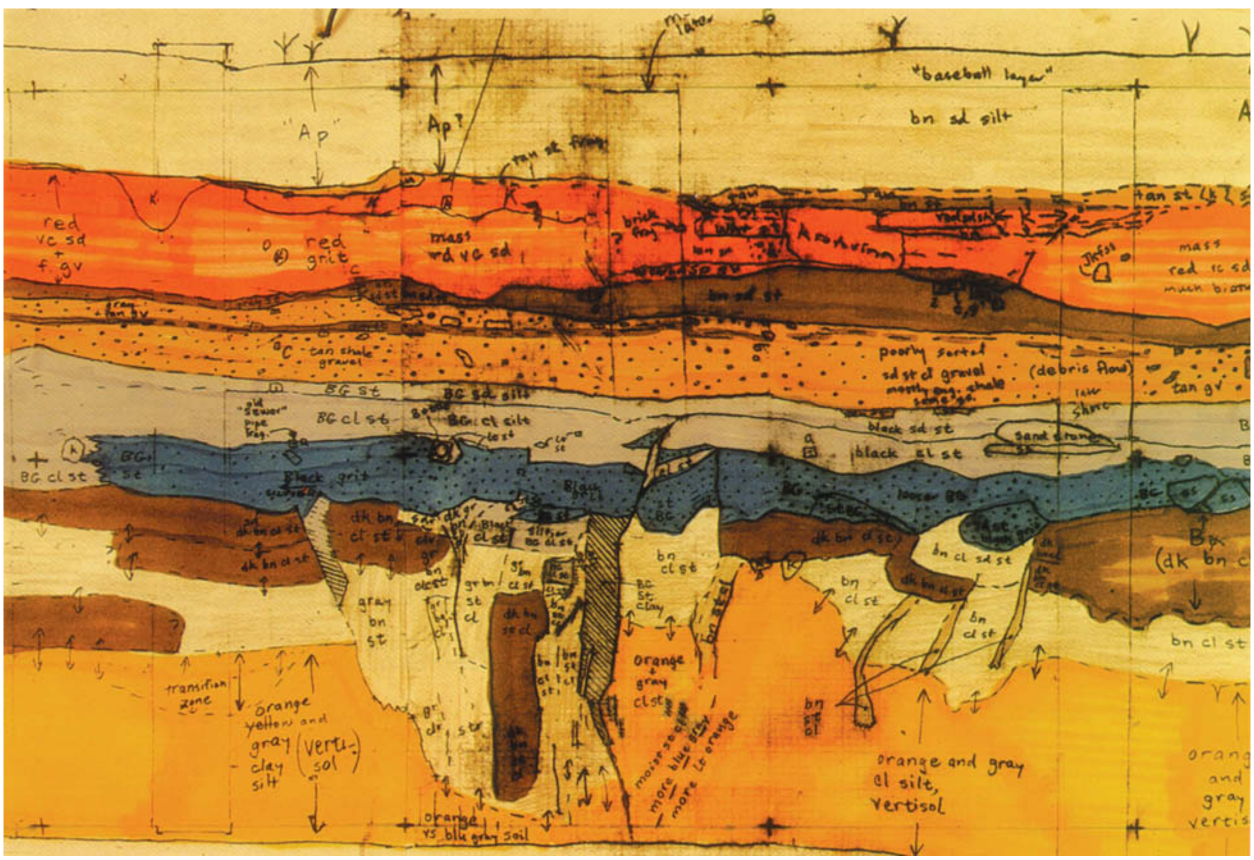


2-10 *The two individual sections of the Hayward fault.*

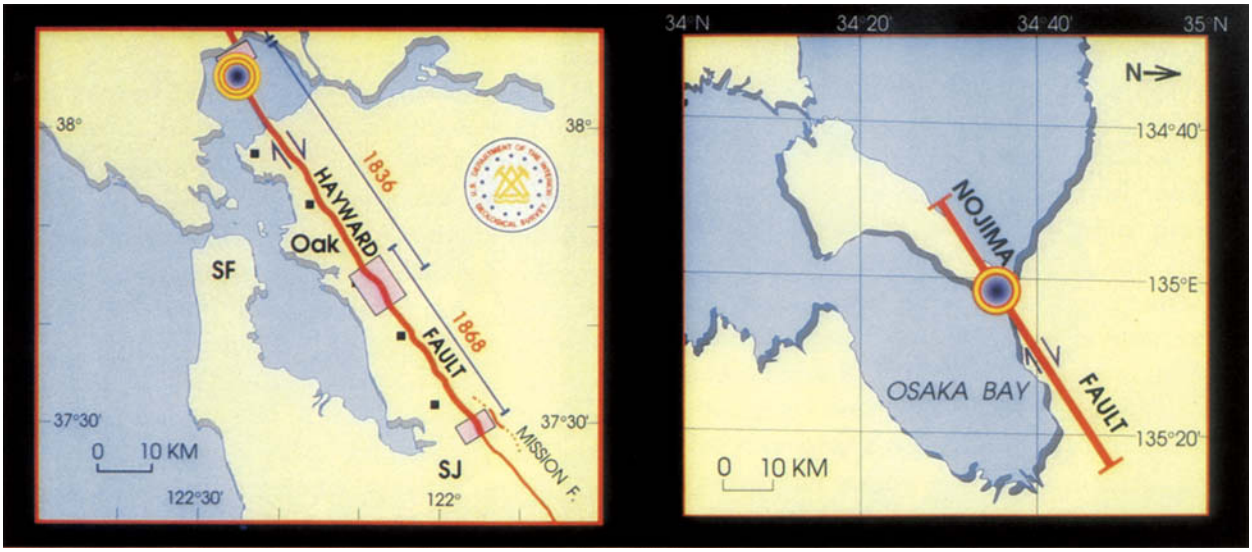
these and add in a constant to calculate what we call a moment magnitude of 7.0.

It is instructive to compare the Hayward fault movement with what happened in January 1995 on the Nojima fault in Kobe, Japan. In figure 2-12, we've equated the scales of the Kobe area and the Bay Area. The Nojima fault ruptured, the aftershocks suggest, about 50 kilometers. The circle is the epicenter; it was a bilateral rupture. In our scenario earthquake on the northern Hayward fault, we suggest that the rupture starts at the north side of San Pablo Bay and propagates south to San Leandro. We think it will be a unilateral rupture and the shaking will last about 22 seconds. That's more than two times the duration of the shaking in the 1989 Loma Prieta earthquake.

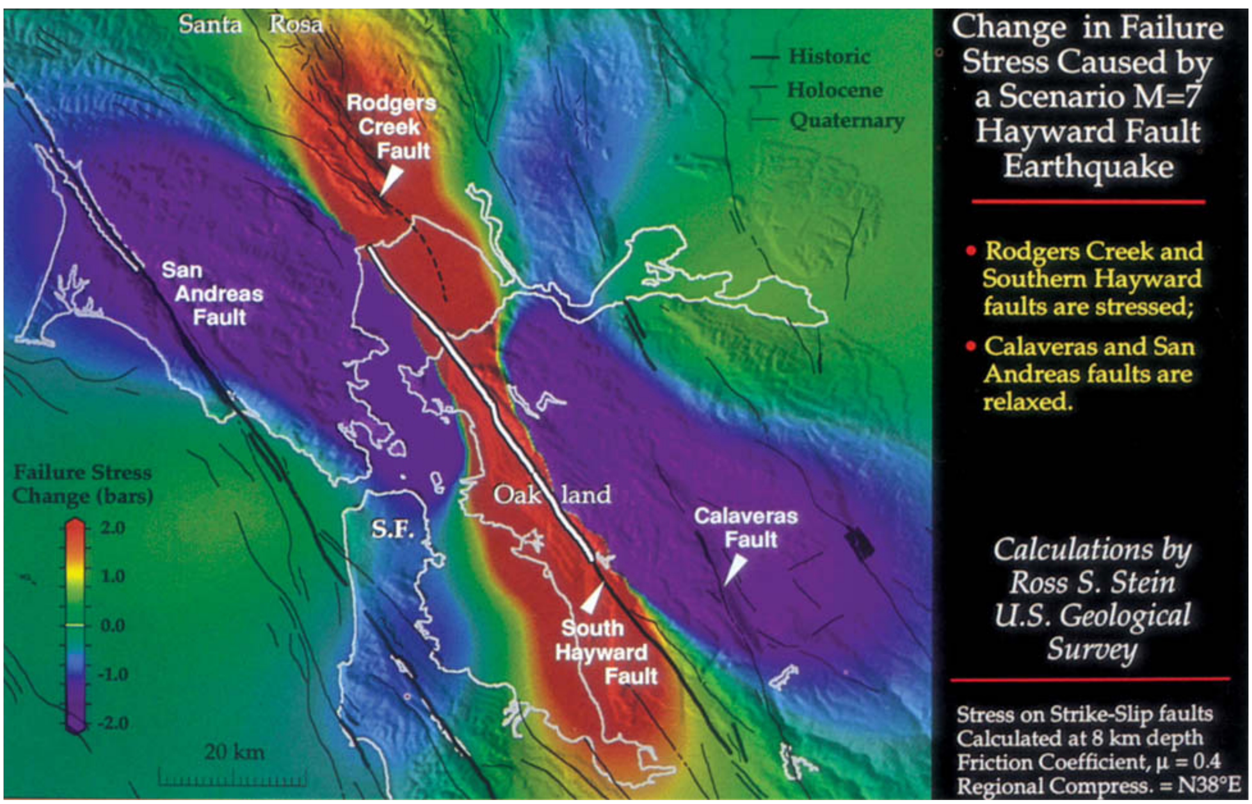
We don't have the trenching data to tell us how large the successive displacements have been on the Hayward fault, but we can look around at its neighbors and get a pretty good idea. On the



2-11 *In-progress map of a trench in Montclair before it filled with water.*



2-12 Comparison of the Nojima fault in Kobe and the Hayward fault in the Bay Area.



2-13 Effect of the scenario earthquake on other faults.

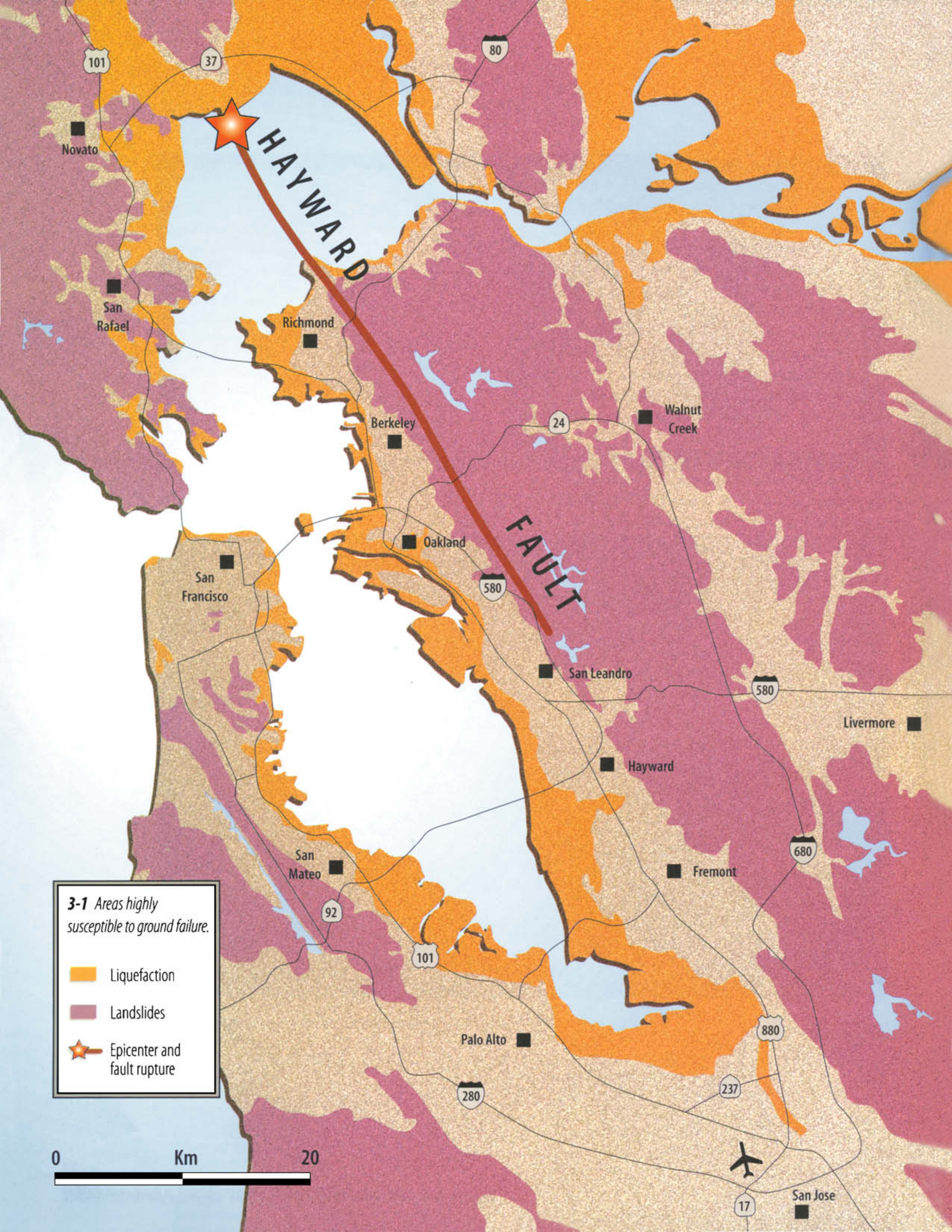
Rodgers Creek fault, which is a continuation of the Hayward, we have measured about 6 feet of slip; that's the amount expected on the Hayward fault.

We expect the average slip at depth to be about 2 meters. At the surface we expect only a meter of slip, because the fault is creeping, and that creep has the effect of reducing the surface slip. In fact, during the 1868 earthquake on the southern Hayward fault, about a meter of slip was observed. Because of local irregularities and complexities, however, we think it's possible for 3 meters (9 feet) to slip at the surface in some places.

Movement on the northern Hayward for 50 kilometers will increase stress on other faults in the region (figure 2-13). Stress on the Calaveras fault will be slightly reduced, but on the northern part of the southern Hayward and the southern part of the Rodgers Creek, the stress will be increased, perhaps anywhere from 10% to 25% of the average repeat time. So if these faults are close to (or at) failure, there is a possibility that a northern Hayward event could trigger another large-magnitude earthquake on either one.

Reference

Working Group on California Earthquake Probabilities. 1990. Probabilities of large earthquakes in the San Francisco Bay region. U.S. Geological Survey Circular 1053. U.S. Geological Survey, Menlo Park, California.


HAYWARD
FAULT
101
37
80
Novato
San
Rafael
Richmond
Berkeley
Walnut
Creek
24
Oakland
San
Francisco
580
San Leandro
580
Livermore
Hayward
680
Fremont
San
Mateo
92
101
880
Palo Alto
237
280
17
San Jose
0
Km
20
3-1 Areas highly susceptible to ground failure.
Liquefaction
Landslides
Epicenter and
fault rupture

Chapter 3

Ground Failure Phenomena

William Lettis, William Lettis & Associates

The geologic, hydrologic, and geotechnical characteristics of the Bay Area are remarkably similar to those of the Kobe area, where the recent earthquake produced extensive permanent ground deformation. We can therefore expect the scenario M7 earthquake on the northern Hayward fault to produce permanent ground deformation in the Bay Area.

The Bay margin setting is characterized by extensive areas of thick, soft soil overlain in places by hydraulically placed artificial fill and surrounded by hills underlain in many areas by weak, incompetent rocks that are susceptible to slope failure or landslides (figure 3-1). Ground failure phenomena that we expect during the earthquake can be grouped into three main categories: (1) surface fault rupture associated with the event, (2) liquefaction-induced ground failures, and (3) earthquake-induced landslides.

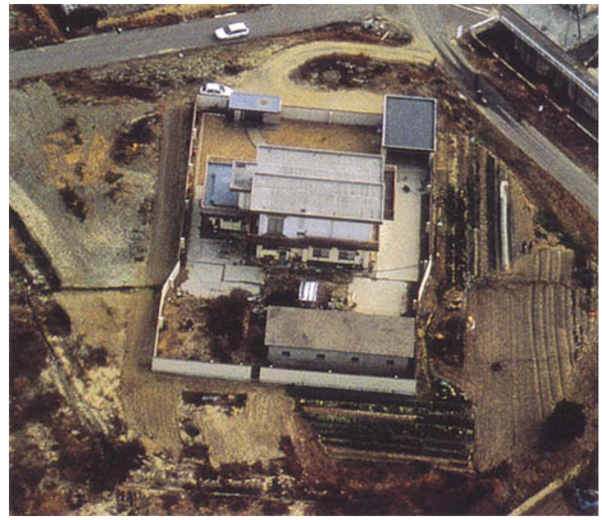
Surface Fault Rupture

We expect surface fault rupture along the northern Hayward fault for a distance of about 50 kilometers from San Pablo Bay south to near Lake Chabot in the San Leandro area. The fault rupture will extend through the Richmond area, the Berkeley hills, the eastern parts of Oakland and Hayward, and south to San Leandro. We expect surface fault rupture to average approximately 3 feet along the entire trace, with locally up to 7–10 feet of maximum ground displacement. The locations of maximum displacement are very poorly known and cannot be reliably predicted.

Ground rupture during an earthquake may occur along a single, narrow, well-defined trace or in a complex, wide zone of deformation. Figure 3-2 shows the 1906 rupture along the San Andreas fault, for example, where the ground moved horizontally between 12 and 14 feet along a relatively simply fault trace. Figure 3-3 shows surface fault rupture during the Landers earthquake, where the rupture breaks into multiple strands with secondary deformation occurring in a zone of up to several hundred feet.

3-2 *A 1906 rupture along the San Andreas fault showing a relatively simple single fault trace.*

3-3 A surface fault rupture of the 1992 Landers earthquake showing multiple rupture strands.



3-4 Effect of the 1995 Kobe earthquake rupture on a building complex showing right-lateral offset.

During the Hayward fault scenario earthquake, we expect to have relatively simple rupture along one, two, or perhaps three main traces in a very narrow zone. During the recent Kobe earthquake, roughly 3 feet of right lateral movement occurred along a single simple trace. The rupture cut through a building complex and offset it in a right-lateral sense (figure 3-4). A close-up of this rupture shows that furrows in a plowed field (figure 3-5) are offset to the right between 2 and 3 feet. This is the type of surface rupture we expect during the Hayward scenario earthquake: primarily horizontal, right-lateral slip of approximately 3 feet.

Locally, we may also have vertical separation along the fault trace, but it will be subordinate to the horizontal displacement. In the Landers earthquake (figure 3-6), fault rupture was primarily horizontal, but local vertical separation of several feet occurred along the fault trace. There may be up to 1 or 2 feet of vertical separation on the Hayward fault.

3-5 Close-up of the Kobe earthquake rupture in a plowed field showing right-lateral offset.

3-6 Landers earthquake fault rupture showing local vertical offset.

Most rupture will occur along preexisting fault traces. We can identify and map these fault traces very accurately; thus, we can identify both the expected amount and the location of potential ground rupture during the scenario earthquake. This is not the case with liquefaction and landslides, however.

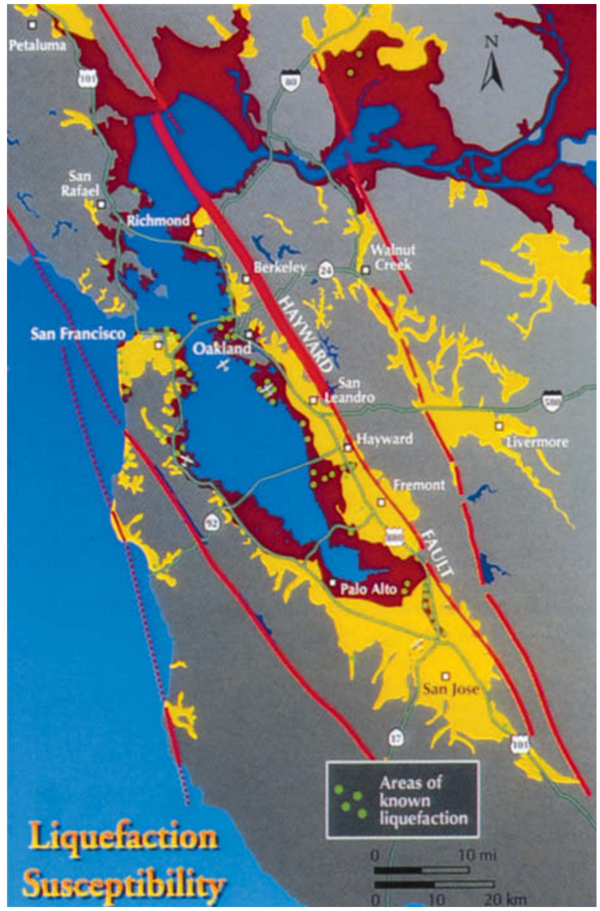
Liquefaction Susceptibility

Liquefaction does not occur randomly; it is restricted to areas with a very specific range of geologic and hydrologic characteristics. Areas with a very high susceptibility to liquefaction are underlain by soft soils, soft Bay muds along the Bay margin, and locally by hydraulically placed artificial fill. The dots on the map in figure 3-7 are areas of known liquefaction during the 1906 and 1989 earthquakes in the Bay Area. A magnitude 7.0 earthquake on the Hayward fault will produce sufficient strength and duration of ground shaking to cause liquefaction throughout the entire Bay Area in the dark areas. Roughly 90% or more of the liquefaction will occur in the dark areas.

Notice the extensive dark areas underlying the Sacramento–San Joaquin Delta. This area is underlain by highly susceptible liquefiable soils. Liquefaction and associated failure of the levees could lead to inundation of the islands, drawing saline water inland from the Bay to the Delta and leading to obvious environmental problems as well as a loss of fresh water supplies for the California Aqueduct for potentially a matter of months.

Figure 3-8 shows the Port of Oakland area. Most of the Port is built on deposits highly susceptible to liquefaction. These areas of liquefiable deposits can be very accurately mapped with the techniques and methods at our disposal.

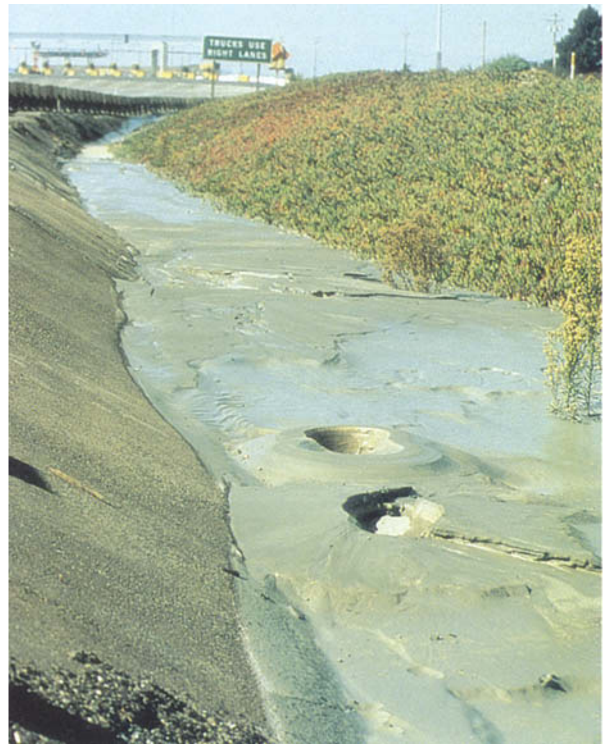
Liquefaction is essentially the transformation of a solid material with grain-to-grain contact into a liquid material, due to increased pore-water pressures during strong ground shaking. This liquid material can cause a number of different types of ground failure: lateral spreading, settlement, loss of bearing capacity, and flow slides on steeper slopes. It's a generally predictable hazard, given careful mapping.



3-7 *Areas of known liquefaction during 1906 and 1989 Bay Area earthquakes.*

3-8 *Port of Oakland areas of liquefaction susceptibility.*

3-9 *Kobe earthquake lateral spreading of 3 to 4 feet that occurred along the bay margin.*



3-10 *Sand venting at an approach to the Bay Bridge after the 1989 Loma Prieta earthquake.*

Liquefaction-induced lateral spreading is a common and highly damaging form of permanent ground deformation during earthquakes. During the recent Kobe earthquake, lateral spreading of up to 3 or 4 feet occurred along the bay margin (figure 3-9). The bay margin setting, geologic and hydrologic conditions, and size of Kobe's earthquake make it remarkably similar to the San Francisco Bay Area and this scenario earthquake on the Hayward fault. In the Bay Area we had fairly extensive liquefaction during the 1989 Loma Prieta earthquake. Figure 3-10 shows sand venting to the surface along the approach to the Bay Bridge, for example. This liquefaction and venting of sand to the earth's surface can lead to settlement. We expect much more extreme liquefaction in the Bay Area during the Hayward event than occurred during the 1989 earthquake. In the 1906 earthquake (figure 3-11), for example, up to 5 or 6 feet of settlement occurred due to liquefaction and compaction of material. About 6 feet of settlement and lateral spreading occurred on the San Francisco Peninsula and in local areas in the East Bay.

3-11 *Settlement from liquefaction and compaction of material in San Francisco following the 1906 earthquake.*

Landslides

Figure 3-12 shows areas underlain by bedrock materials that are highly susceptible to slope failure during strong ground shaking. Landslides can be grouped into two general categories: (1)

***3-12** San Francisco Bay Area showing areas underlain by bedrock materials highly susceptible to slope failure during shaking.*

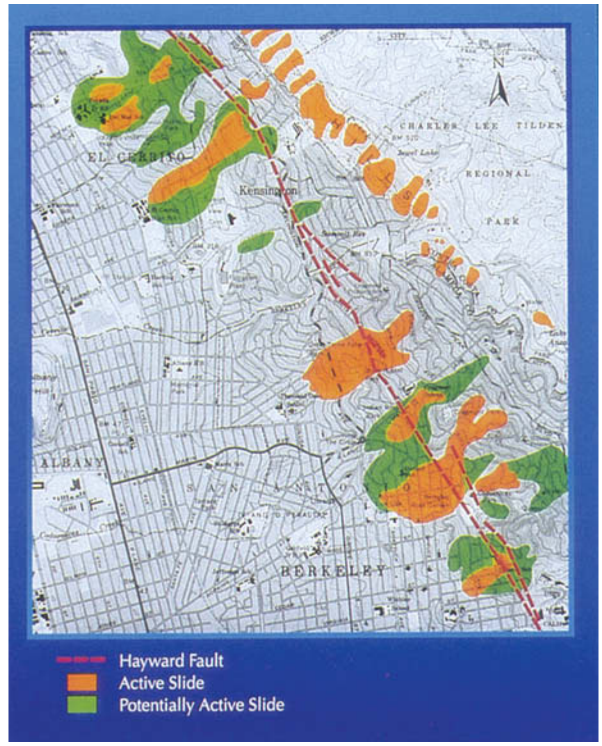
shallow, rapidly moving slides of highly disrupted material and (2) deep, slowly to rapidly moving landslides consisting of coherent blocks of material such as slumps and block slides.

We expect hundreds to thousands of disrupted material landslides, primarily in the foothills of the East Bay. Although these disrupted landslides may not be large or impressive, they are an extreme nuisance along roads and cause transportation problems (figure 3-13). Literally hundreds to thousands of rockfalls will occur in the East Bay and locally on the Marin and San Francisco Peninsulas. In the Daly City area (figure 3-14), there will be landslides along the coastal bluffs that can undermine homes built on top of the

***3-13** Disrupted landslide causing transportation problems.*

***3-14** Landslide failure along the coastal bluffs in the Daly City area.*

3-15 Landslide in the Santa Cruz Mountains reactivated by the 1989 Loma Prieta earthquake.



3-16 Map of known landslides in the Kensington area of the Berkeley hills.

bluffs, as well as fall on people enjoying the beach down below. During both the 1906 and 1989 earthquakes, people were killed by landslides along the coast.

In addition to disrupted material landslides, we are expecting on the order of several hundred deep-seated landslides during an earthquake on the Hayward fault. Figure 3-15 shows a deep-seated landslide in the Santa Cruz Mountains that was reactivated during the 1989 Loma Prieta earthquake. The landslide moved one to several feet, producing large earth fissures in the head-wall area.

Active and potentially active landslides are present throughout the eastern Bay Area. Figure 3-16 is a map of known landslides in a part of the Berkeley hills, for example. During an earthquake, there will be abrupt co-seismic movement of many, if not most, of these land-slides, potentially of one to several feet. Under wet conditions, many of these landslides may develop into catastrophic failures.

Figure 3-17 shows such a catastrophic failure in the Kobe earthquake. A deep-seated slump, or earth flow, failed catastrophically under wet conditions; it destroyed ten homes and killed thirty people. Such a failure very easily could occur in the East Bay hills if an earthquake on the Hayward fault occurs during a wet winter.

To illustrate the size of area over which severe landsliding may occur, figure 3-18 superimposes on the Hayward fault the area of extreme landsliding in the Santa Cruz Mountains during the 1989 Loma Prieta earthquake. Remember, the 1989 earthquake struck during the fall after several years of drought; an earthquake on the Hayward fault during the winter or spring will cause severe landsliding over most of the East Bay hills, almost out to Walnut Creek, and there will be local landsliding on the Marin and San Francisco Peninsulas.

As with liquefaction, landsliding is a generally predictable hazard. Although we can't precisely locate where earthquake-induced landslides will

3-17 *Catastrophic landslides during the 1995 Kobe earthquake.*

3-18 *The area of landsliding in the Santa Cruz Mountains during the 1989 Loma Prieta earthquake superimposed on a map of the Hayward fault.*

occur or how extensive they will be, we can predict in a general sense the area susceptible to slope failure and the types of landslides. These areas can be targeted for more detailed study to more accurately define the locations and probability of earthquake-induced slope failure.

Acknowledgments

I gratefully acknowledge the data and ideas contributed by several individuals for evaluating the geologic consequences of an earthquake on the northern Hayward fault. Dave Kefeer of the U.S. Geologic Survey contributed data on the distribution of landslides during the 1989 Loma Prieta earthquake and ideas on classifying landslide susceptibility in the San Francisco Bay Area. Alan Kropp of Alan Kropp and Associates, Inc., provided data on the distribution of landslides in the Berkeley hills. William Savage of Pacific Gas and Electric Company provided information on liquefaction and landslide susceptibility throughout the Bay Area and provided graphics support to make this presentation possible. Dr. Carol Prentice of the U.S. Geological Survey provided photos from the recent earthquake in Kobe, Japan.

4-1 *Water supply system.*

Chapter 4
Water and Sewer Delivery Systems

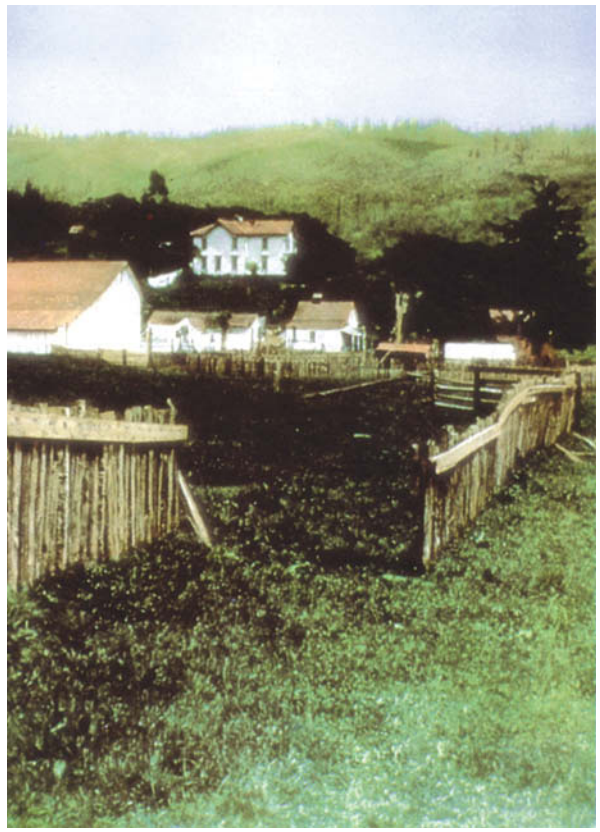
David Pratt, East Bay Municipal Utility District

The East Bay Municipal Utility District (EBMUD) serves about 1.2 million people in more than twenty cities and most of two counties. Water from Pardee Reservoir comes across the Sacramento–San Joaquin Delta into the Walnut Creek area, where the flow is split; part goes to the San Ramon area, and the rest travels toward the Caldecott Tunnel. The tunnel is an important structure; 70% of EBMUD customers are located west of the Oakland hills, and these customers depend on water that comes through the Caldecott Tunnel. There is very little redundancy in the system, and that is a problem.

Figure 4-1 shows ground failures and the EBMUD system. Liquefaction will damage some of the aqueducts in the Richmond area. Landslides up around Berkeley and down in San Leandro will damage some of the major aqueducts in those areas. Most importantly, fault offset and severe shaking are expected near the Caldecott Tunnel. A significant amount of offset could sever the tunnel, or the shaking could cause the tunnel lining to fall into the tunnel. Either could eventually cause blockage of the tunnel.

Ground Failure

A pipeline running parallel to the fence in figure 4-2 would probably rupture by fault displacement. Pipelines cross a fault in either compression or tension. With compression failure, when the fault moves, the pipe gets smashed into itself; conversely, a pipe in tension is pulled apart. In either case, a very vital aqueduct is out of service.



4-2 *Rupture by fault displacement.*

Water tanks are frequently located up on hills to take advantage of elevation. Landslides there will damage some of the tanks and possibly knock some completely out of service. Some of EBMUD's major facilities, such as the Upper San Leandro Treatment Plant, are near areas that depend on pump stations that could be damaged by a landslide.

Liquefaction will occur in areas next to the Bay. Roughly 50% of EBMUD pipe breaks will occur in liquefiable soils. Only about 20%–25%

4-3 *Liquefaction with lateral spreading.*

4-4 *Elephant's foot failure of tank.*

of EBMUD's service area has liquefiable soils, but there's a high likelihood that customers in these areas will not have water service after the earthquake.

Figure 4-3 shows liquefaction with some lateral spreading. When the soil starts moving 3 feet or so, there is a high probability that any pipe within the area will rupture and be out of service.

Ground shaking caused the tank in figure 4-4 to suffer "elephant's foot" failure. When the pipe is severed, the contents leak out through the opening. Back-and-forth shaking can also sever a connection.

Ground movement can cause aqueducts to fail. The aqueduct in figure 4-5 lost its structural steel supports; however, when the supports failed, it landed on the concrete pedestal. Luckily, it was able to stay in service.

Types of Damages and Their Impacts

Under normal conditions, EBMUD pulls water off an aqueduct and, using power from Pacific Gas and Electric Company (PG&E), pumps it up to a reservoir. Water then flows by gravity back down to customers. Typical ground failures will affect the system in various ways. If PG&E power is lost, EBMUD's ability to replenish reservoirs is lost. Pipe breaks will result from landslides, liquefaction, or ground shaking; even if a pumping plant does remain operational, there won't be a way to get water up to the reservoir (figure 4-6). If the reservoir fails, it loses its contents. If none of these kinds of damage occurs, EBMUD may still not be able to get water to residents because lines serving various homes are broken (figure 4-7).

Of six treatment plants, four would be in bypass mode if there were an M7 earthquake on the Hayward fault today. That means filters are unusable. Some chlorine injection for disinfection may be possible. The San Pablo Treatment Plant will be completely out of service, and water won't be able to get to it. There's also a good chance that the sixth plant, Upper San Leandro, will be out of service. Two-thirds of the reservoirs will be out of service, due to either total failure or partial loss of contents. About two-thirds of the pumping plants will be out of service, due to structural damage, equipment damage, or loss of PG&E power.

We expect somewhere between 3,000 and 5,500 pipe breaks. Liquefaction will cause 50% of the problems. There will also be many breaks due to ground shaking. There won't be very many breaks due to fault displacement, but when they do occur in major aqueducts (54 inches in

4-5 *Aqueduct that lost its structural steel supports.*

4-6 *Welded steel pipe, part of an aqueduct, cracked in the Northridge earthquake, 1994.*

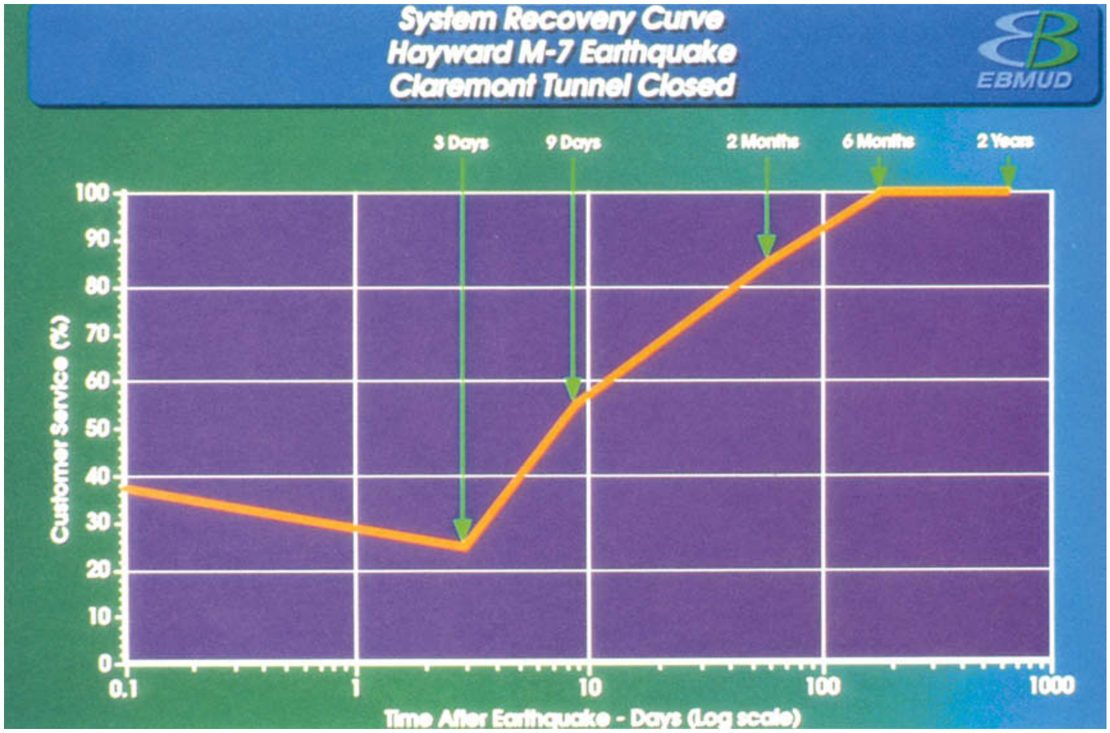
diameter and larger), our capability to deliver water will be severely limited.

After the scenario earthquake, over 60% of EBMUD customers will be out of service. In figure 4-8, customer service level is shown on the vertical axis. About 62% of customers will not have water service immediately following the earthquake. It will take two or three days to get the system stabilized. Stabilization involves sending people around to valve off the broken lines so that water is not lost. And then for the next two or three days, even more service will be lost; nearly 75% of customers will not have water service as reservoirs run dry. After two or three days, crews will be able to begin their repairs and restore service to customers. It would take several months to get all customers back on line.

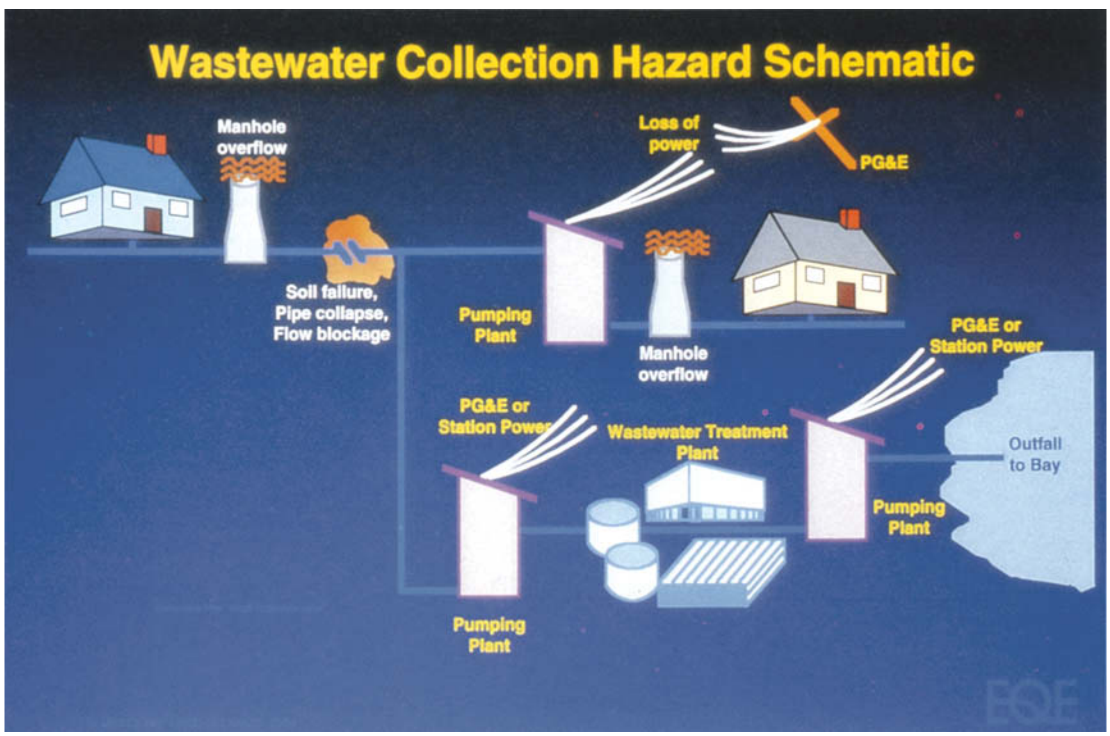
In the 1906 earthquake, most of the damage to San Francisco was caused by the lack of fire-suppression capability after the earthquake. The fires ravaged the city. That's one of EBMUD's main concerns. Upgrading tanks and fault crossings will provide at least a minimum level of fire-suppression service.

With reference to the wastewater system, the interceptors run along the Bay, where the liquefiable soils are. The interceptors will therefore suffer major damage. Figure 4-9 shows the different types of damage to the wastewater system. Power

4-7 *Flood and fire created by broken gas and water mains, Northridge earthquake.* LA TIMES PHOTO



4-8 *System recovery.*



4-9 *Different types of damage to wastewater system.*

will be lost, so the pumping plants won't work. There will be major blockages in the interceptors along the freeway as it runs next to the Bay. There will not be a way to transmit sewage to the treatment plant; the sewage will back up and start coming up through the utility holes.

Improvements to the System

There wouldn't be very good service if the earthquake happened today. But EBMUD is doing something about it. The cavalry is not exactly coming right over the hill, but it is saddling up. We have completed a two-year study and have a pretty good idea of what's wrong with the system. EBMUD has established service goals and developed a capital improvement program of approximately $189 million. The goals are to prevent loss of life, or minimize it, and to ensure public health. Fire-suppression capability is a major goal, followed by restoring customer service to hospitals, disaster centers, homeowners, and, finally, businesses. When the $189 million program is implemented, the goal is to restore service to most customers within a few weeks instead of many months. Most of the reservoirs and pumping plants will be functional. There will be less damage to our water treatment plants, and they will be back on line faster. The Caldecott Tunnel will be kept open, as will aqueducts that cross the faults or have been rerouted around landslide areas.

Acknowledgment

I thank Bob Lau, my good friend and peer, for all the hard work he did to make this presentation possible.

5-1 *Stranded truck being removed from a freeway bridge damaged in the Northridge earthquake, 1994.*
LA TIMES PHOTO

Chapter 5

Buildings and Transportation Systems Affected by Ground Failures

John Egan, Geomatrix Consultants

With the fault rupture that's been defined for the scenario earthquake, damages to structures will be extensive. Buildings are going to be affected by the rupture itself, and landsliding and liquefaction are going to affect schools, some hospitals, residential structures, and fire stations, which is going to reduce firefighting capability immediately after the earthquake. Transportation systems will also be affected by structural damage (figure 5-1).

5-2 *Bearing deformation of a footing in the Marina District of San Francisco, 1989 Loma Prieta earthquake.*

Buildings

In the Marina District in San Francisco, as well as in the Mission and South of Market areas, Alameda, and Treasure Island, we can expect liquefaction-related phenomena. Bearing-capacity failures such as that in figure 5-2 occurred in the Marina District during the Loma Prieta earthquake of 1989. This is not a very dramatic effect, but with considerably longer ground shaking and a stronger shaking, this 1 or 2 inches of bearing capacity or punching failure might well be 1 or 2 feet.

Similarly, there will be settlement-related damage, distortion of structures as seen in figure 5-3 (again in the Marina District). This particular building settled about a foot. Greater damage will follow the Hayward scenario event. There will also be lateral spreading damage. Figure 5-4 shows distortion of a building due to lateral spreading movement of 3 or 4 inches. This house happened to be sitting right astride the edge of the lateral spreading zone. With large lateral spreading movements—such as might characterize Treasure Island or both the north and south sides of Alameda—there will probably be much more severe effects on structures.

5-3 *Settlement distortion damage to a residential structure in the Marina District, 1989.*

The scenario earthquake will strike a very densely inhabited area. Figure 5-5 is an aerial view of the residential area Kensington, which is

5-4 *Damage to a residential structure astride lateral spreading zone, Marina District, 1989.*

just north of Berkeley. The fault rupture is going to rip right through that zone of houses. Figure 5-6 depicts typical damage due to fault rupture.

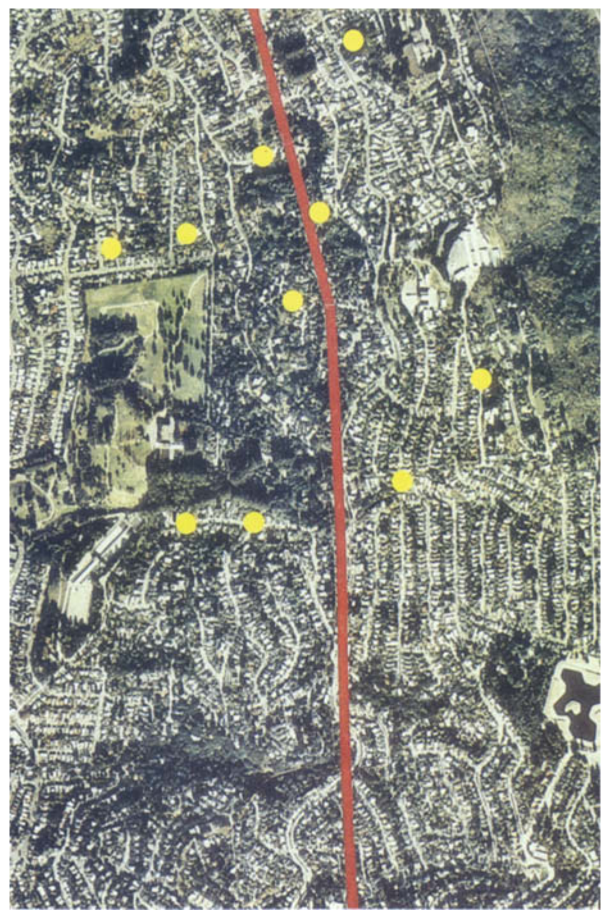
The yellow dots in figure 5-5 indicate mapped landslides that will be activated during the event. Severe landsliding is going to take out portions of roads and surface streets and cause severe damage to some of the houses that sit astride those slides. The hillside in Kensington is moving under static conditions. The blue dots on figure 5-7 indicate the locations of primary schools, middle schools, and preschools in the San Pablo, Richmond, and El Cerrito areas that sit either astride the fault or in very close proximity to it.

Buildings in downtown San Francisco, Oakland, or near the Bay margin that might be susceptible to liquefaction are typically founded on piles. We expect minimal damage to those, although some older buildings or buildings in areas where there are severe lateral spreading movements may have some damage to the pilings that support them.

Transportation

Traffic is going to have a very difficult time moving after a Hayward fault quake. BART (Bay Area Rapid Transit) is one of our main sources of transportation in the Bay Area. The Hayward fault intersects the tunnel that carries BART through the hills and feeds Orinda, Lafayette, Walnut Creek, Concord, Pleasant Hill, and the rest of Contra Costa County. Fault rupture could put that tunnel out of commission indefinitely. BART would then have to do some blasting to widen the area and replace that section of track. No one can estimate the time it would take to do that.

Another potential problem area for BART is the filled area near the Bay margin, west of the West Oakland station, between it and the Transbay Tube. That's an elevated section of track with supports on shallow footings founded in potentially liquefiable soil. Expect damage to that section due to bearing capacity failures or severe ground settlement.

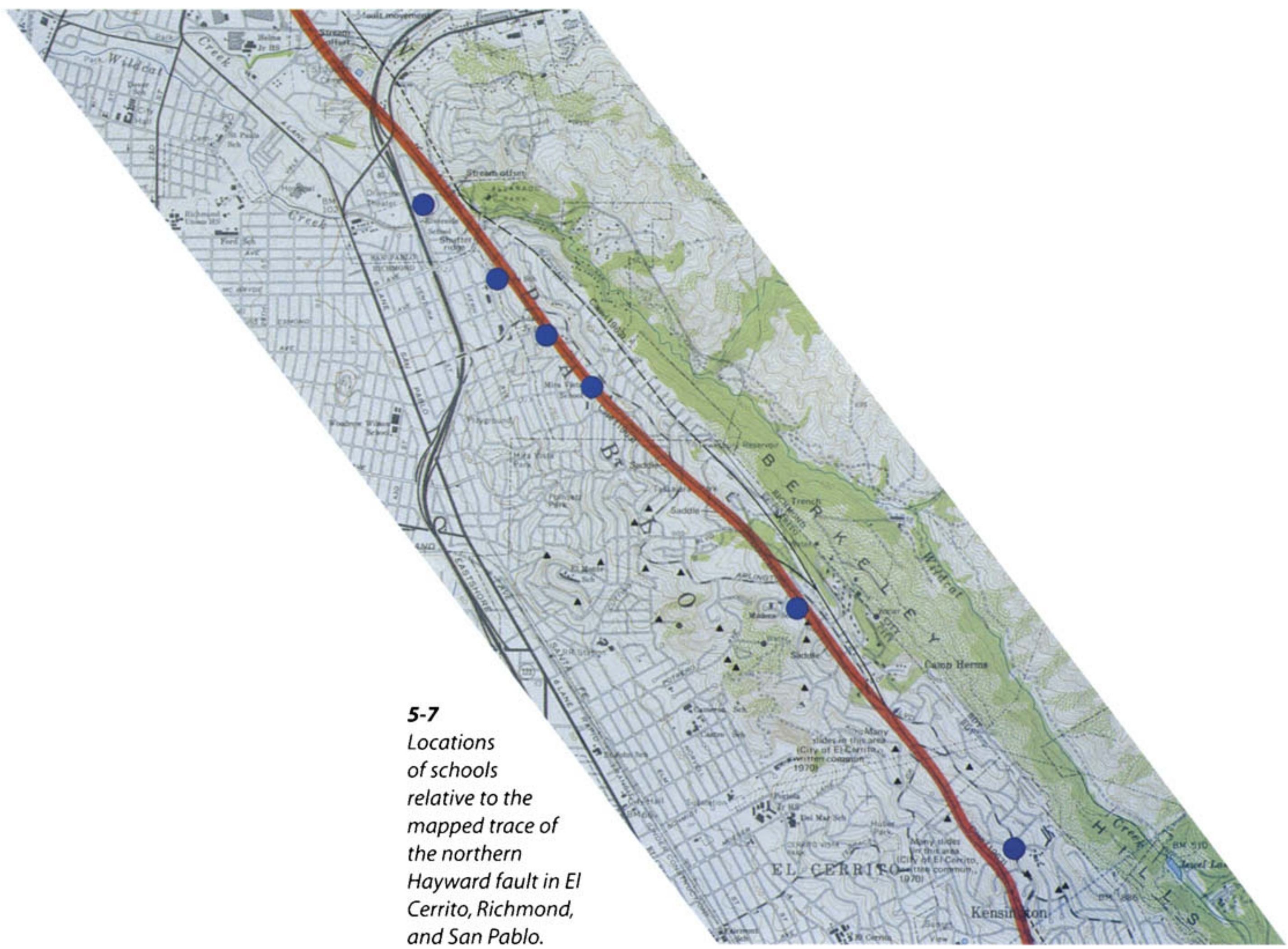


5-5 *Aerial view of Kensington illustrating a mapped trace of the Hayward fault and locations of mapped landslides.*

Figure 5-8 illustrates part of the transportation problem: The BART tunnel crosses the fault. Highway 24 intersects the fault. Highway 13 runs essentially coincident with the fault as it progresses south toward Mills College and San Leandro for its intersection with Interstate 580 to the south. Fault rupture will probably severely disrupt the road surface of Highway 13. It will shear the Highway 24 road surface and perhaps not close it but certainly severely restrict traffic flow through that area.

Interstate 80, I-880 to the south, and I-580 to the north are all going to be disrupted by liquefaction and lateral spreading effects. Farther north, I-80 is going to be disrupted by fault

5-6 *An example of structural damage caused by surface fault rupture.*



5-7 *Locations of schools relative to the mapped trace of the northern Hayward fault in El Cerrito, Richmond, and San Pablo.*

rupture effects. In the western Bay margin, on Highway 101 south of Candlestick Park, and up in Corte Madera and San Rafael, there will be lateral spreading effects and damage due to settlement. Certainly that will also be the case at the San Mateo and Dumbarton Bridges to the south.

The morning after the Loma Prieta earthquake, Caltrans crews were already repairing I-80 where it passes through Emeryville (figure 5-9). Their task wasn't terribly formidable after the 1989 earthquake, given that lateral spreading movement of only 0.1–0.2 meter disrupted the pavement. Following the Hayward fault earthquake, however, the displacements here may be on the order of ten times what was experienced in 1989. Movements of 3 to 5 feet would severely disrupt the entire width of the pavement in Emeryville, across the overpass in Berkeley, and all the other stretches of 101, 880, and 580 previously mentioned.

Airports, ports, and railroads are keys to getting into and out of the Bay Area for both individuals and emergency supplies (see figure 5-8). The Port of Oakland, Oakland Airport, San Francisco Airport (SFO), and San Jose Airport

5-8 *Areas where ground failure will cause transportation problems.*

will be affected. The railroads run out of the Bay margin—fortunately—or on land that was not within the original Bay margins. But to the north, they do cross that margin as well as the fault.

Oakland Airport in 1989 lost about 300 feet of a runway due to liquefaction-related damage and settlement effects and lateral spreading effects. The runway was out for several months while the repairs were effected. They were able to use a shortened runway. Following the Hayward earthquake, don't expect this airport to be open. The entire runway south is underlain by liquefiable materials, and severe effects are going to damage the entire extent of the runway.

In 1989 San Francisco Airport experienced 30%G. There was minimal ground-failure damage there. There may be some minor liquefaction damage during a Hayward fault event, but after a temporary closure, SFO will probably be up and running in a short time. At San Jose Airport, there won't be much of a problem.

The Port of Oakland—Outer Harbor, Seventh Street Complex, Middle Harbor, and the Inner Harbor reaches—is one of the major ports on the West Coast (figure 5-10). The quantity of goods and materials that go in and out of that port every day is staggering. In 1989, the Seventh Street Complex, which juts out into the Bay, was severely damaged by liquefaction in and under the wharf structure (figure 5-11). Lateral spreading and settlement disrupted the use of that facility for nearly two years, although a short section of it was put back into service in three months.

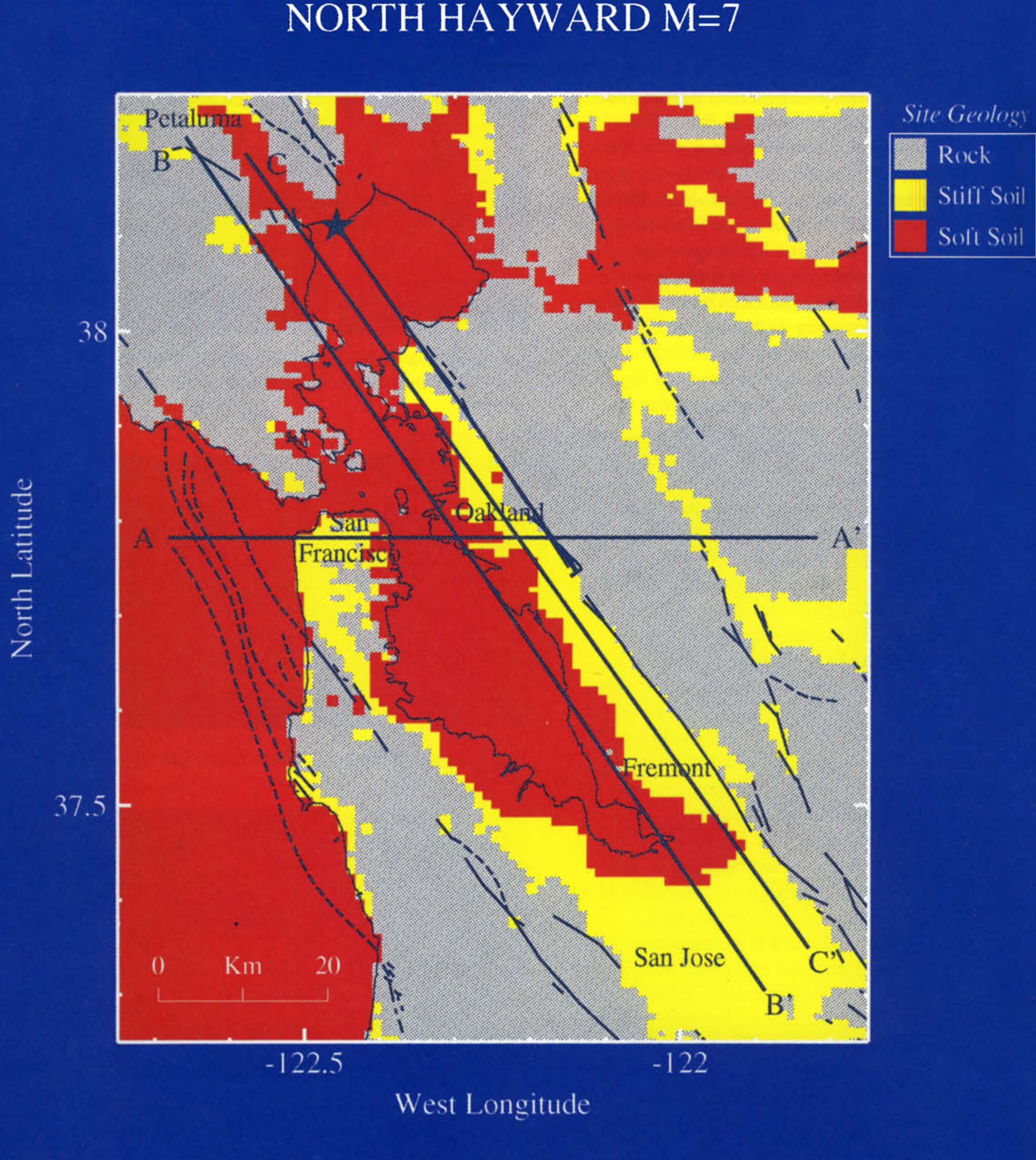
The Port of Oakland has invested in an extensive retrofit program at this facility, and the Inner Harbor facilities at Howard Terminal have been designed and built in the last fifteen years anticipating this magnitude 7 event. Facilities at Middle Harbor will probably experience significant damage, but the Outer Harbor area has mixed conditions; some areas there are underlain by thick deposits of soft Bay mud.

In general, the Port expects to function following an earthquake like this, especially at its Seventh Street and Inner Harbor terminals.

5-9 *Caltrans crews at work on repairs to Interstate 80 in Emeryville the morning after the 1989 Loma Prieta earthquake.*

5-10 *Aerial view of the Port of Oakland marine facilities.*

5-11 *Liquefaction-related damage to the Seventh Street Marine Terminal during the 1989 Loma Prieta earthquake.*



6-1 *Classification of surface geology in the San Francisco Bay region and the locations of cross sections AA', BB', and CC' for profiles in figures 6-10, 6-11, and 6-12.*

Chapter 6
Ground Motions

Paul Somerville, Woodward-Clyde

The ground motions we can expect from a magnitude 7.0 earthquake on the northern Hayward fault are described in this chapter and used in subsequent chapters to estimate the damages to different categories of structures.

Aspects of ground motion currently used by seismologists include 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 waves of energy released).

Engineers often use response spectra (the differing levels of acceleration in relation to frequency, also referred to as period) to analyze the response of individual buildings to earthquake motion. Frequencies can range from several seconds (long-period) to 0.3–0.1 second (short-period). Peak accelerations, peak velocities, and response spectra accelerations generally attenuate (lessen in intensity) with distance away from the fault rupture.

In estimating the ground motions for the northern Hayward scenario, my colleagues and I took account of two important effects. One of these is the ground-motion response of different site conditions. We used a map of different site conditions in the San Francisco Bay region, categorized into rock, stiff soil, and soft soil, prepared by the U.S. Geological Survey (figure 6-1). We used attenuation relationships by Sadigh, Egan, and Youngs (1986) for stiff soil, Idriss (1991) for soft soil, and Sadigh et al. (1993) for rock. Given the specified location of the Hayward fault rupture, I calculated the ground-motion levels for sites in the San Francisco Bay region at different distances from the fault.

The other effect we included was rupture directivity, the effect of the rupture propagation (in this case, from the epicenter at the northwest end of the fault rupture toward the southeast) on the level of ground shaking. Rupture directivity causes an increase in ground-motion levels along the fault rupture away from the epicenter and within about 10 kilometers of the fault for periods longer than 1 second. Somerville and Graves (1995) and Somerville et al. (1995) describe the procedures for modifying attenuation relationships to account for effects of rupture directivity. We also incorporated a more gradual attenuation of ground motions at all periods in directions off the ends of the fault than perpendicular to it.

The 1995 earthquake in Kobe is very relevant to the Hayward scenario because its 6.9 magnitude, strike-slip faulting mechanism, and rupture length of about 50 kilometers were practically identical to those of the scenario. Figure 6-2 compares peak accelerations and peak velocities recorded during the Kobe earthquake with attenuation relations based mainly on strong-motion data from California (Somerville 1995). The Kobe earthquake motions are similar to what we would expect in California from a magnitude 7.0 strike-slip earthquake. The peak velocities closer to the causative fault tend to be larger than one would predict; this effect may be due to the influence of rupture directivity, because the fault ruptured toward Kobe and adjacent cities, where the strong-motion recorders were located. The large long-period motions attributed to rupture directivity effects were probably responsible for much of the damage to bridges and multistory buildings during the Kobe earthquake. Because

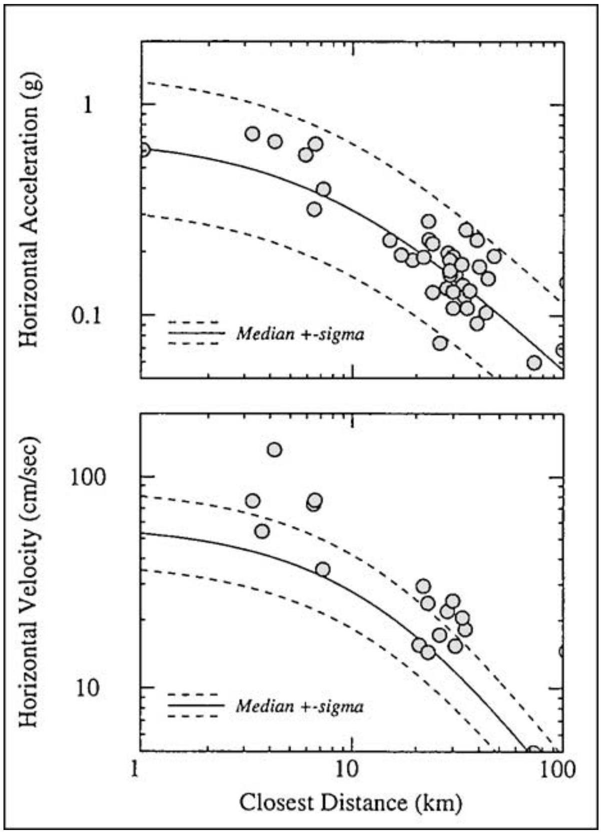


Figure 6-2 *Attenuation of recorded peak acceleration and peak velocity from the Kobe earthquake compared with empirical relations based mainly on California data.*

we can expect similar rupture directivity effects from the Hayward earthquake, it is important to understand this phenomenon.

Somerville and Graves (1993) describe how the propagation of rupture toward a site causes a large pulse of ground motion (sometimes described as "fling") in the direction perpendicular to the fault. This is illustrated schematically in figure 6-3, a snapshot of what is occurring on a vertical strike-slip fault at an instant in time. The rupture began at the hypocenter and is propagating at 80% of the shear-wave velocity. The region that is slipping at this instant is bounded by the healing front and the rupture front. All of the shear waves traveling to the left are confined to the region between the healing front and the S-wave front (the place that the first S waves, those from the hypocenter, have reached). Away from the hypocenter, all of the motion occurs in a very brief interval of time, and the constructive interference of this motion causes the large pulse of long-period motion. This is illustrated by the Lucerne

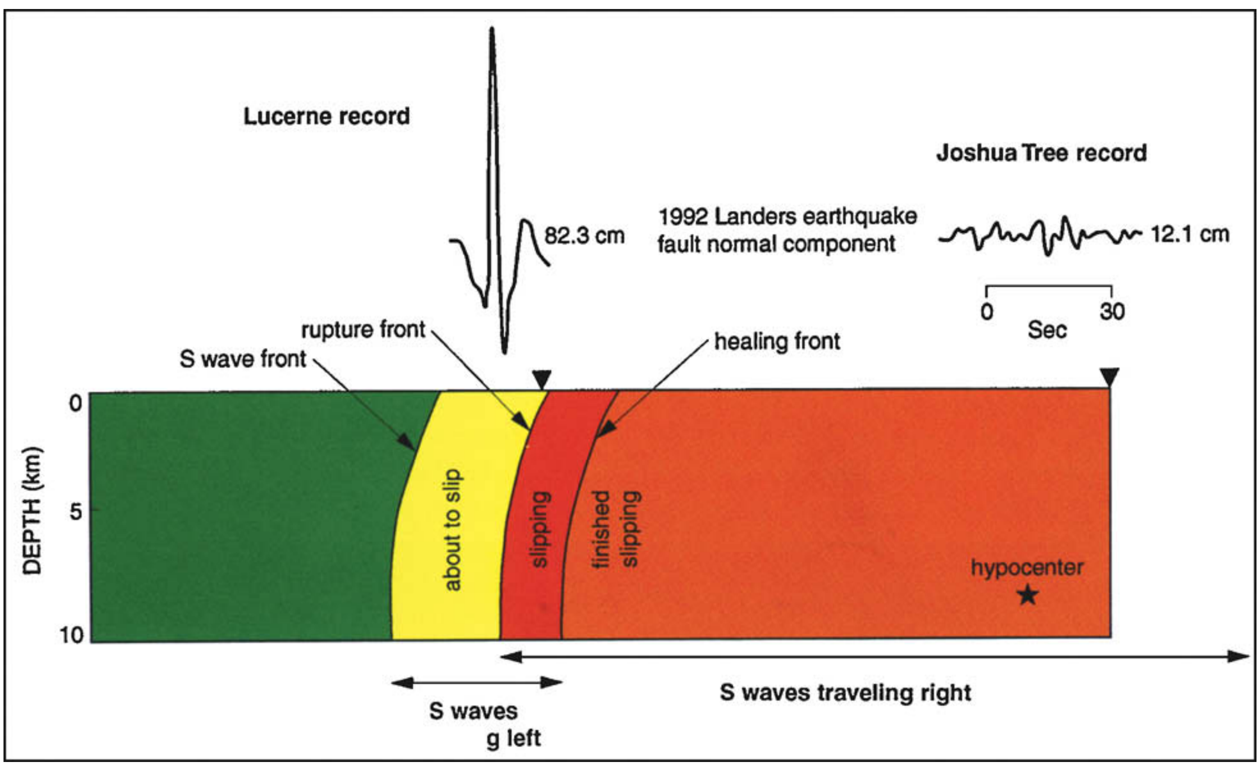


Figure 6-3 *Rupture directivity effects for a vertical strike-slip fault, 1992 Landers earthquake. The Lucerne record (left) is contrasted with the Joshua Tree record near the epicenter (right).*

record of the 1992 Landers earthquake, which had a peak displacement of 82.3 centimeters. In contrast, at sites near the epicenter, the waves from the slipping region on the fault have to travel all the way back to the epicenter, producing a long, low-amplitude record of long-period motion, illustrated by the Joshua Tree record of the Landers earthquake, which had a peak displacement of 12.1 centimeters.

The large pulse of motion is in the horizontal direction perpendicular to the fault, because earthquakes have a radiation pattern rather like that of a radio antenna. Figure 6-4 shows the epicenter and the rupture propagating toward the site. For sites located along the fault, there is a maximum in the radiation pattern for tangential motion (SH waves in the direction perpendicular to the fault), so there is a large pulse of motion perpendicular to the fault. On the other hand, the radiation pattern is a minimum for the radial component of motion (SV waves in the direction parallel to the fault). In contrast to the large pulse of motion perpendicular to the fault, the dynamic motion in the direction parallel to the fault is small, although there is buildup of a static offset along the fault in the direction parallel to the fault.

Figure 6-5 illustrates the rupture directivity effects from the Loma Prieta earthquake. The epicenter of the earthquake is near Corralitos and Branciforte Drive, where the ground-motion displacements are moderate. At the ends of the fault, however, at Lexington Dam and Hollister, the ground motions in the fault-normal direction (the direction perpendicular to the fault) are much larger because of the directivity effects resulting from this bilateral rupture. The fault-parallel motions at the ends of the fault are about the same as those near the epicenter. The large impulsive motion occurs only in the fault-normal direction.

Figure 6-1 shows the site conditions in the San Francisco Bay region categorized as rock, stiff soil, and soft soil. Figure 6-6 is a contour map of peak acceleration for the Hayward scenario earthquake. The soft Bay muds have a strong amplifying effect on the peak accelerations. These

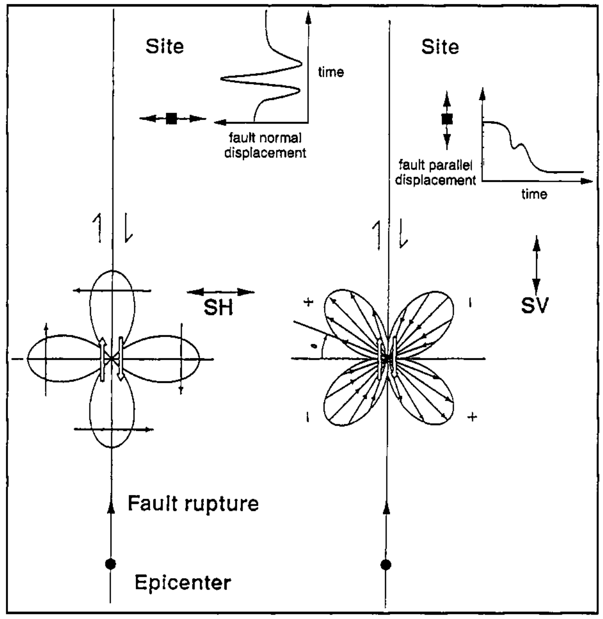


Figure 6-4 Rupture directivity effects on the radiation pattern of the fault-normal and fault-parallel motion on a strike-slip fault.

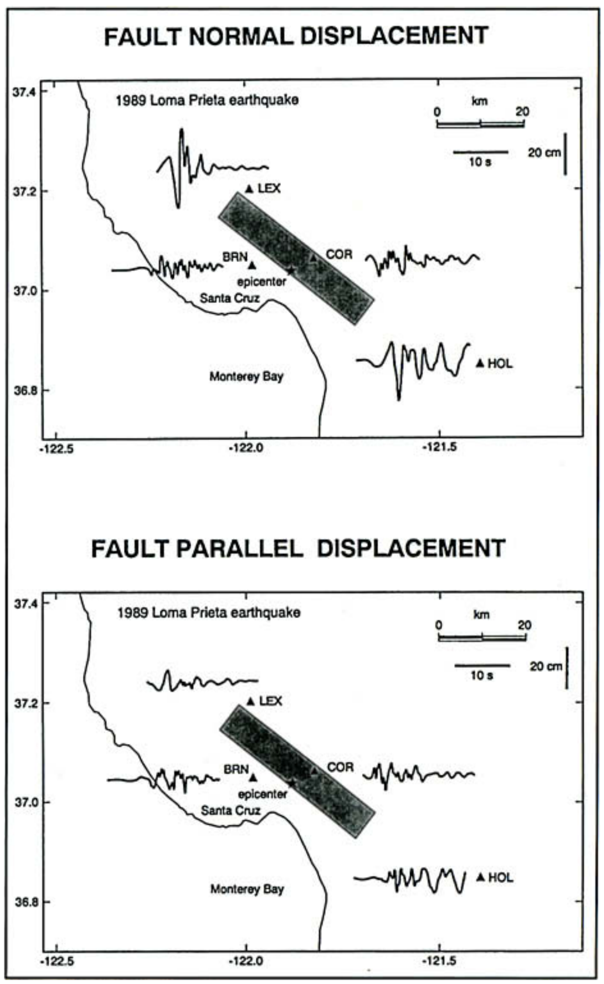


Figure 6-5 Rupture directivity effects in the displacement time histories of the 1989 Loma Prieta earthquake.

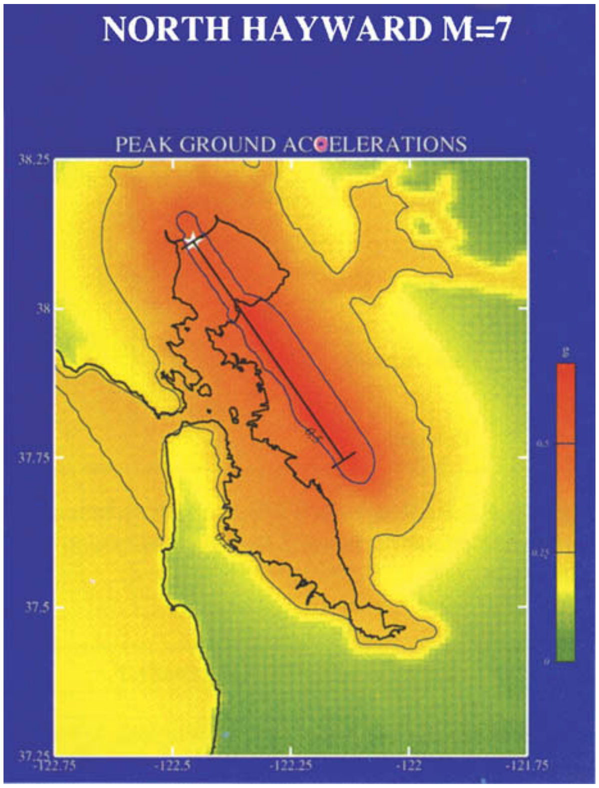


Figure 6-6 Contour map of peak accelerations from a magnitude 7.0 earthquake on the Hayward fault; the epicenter is shown by a star.

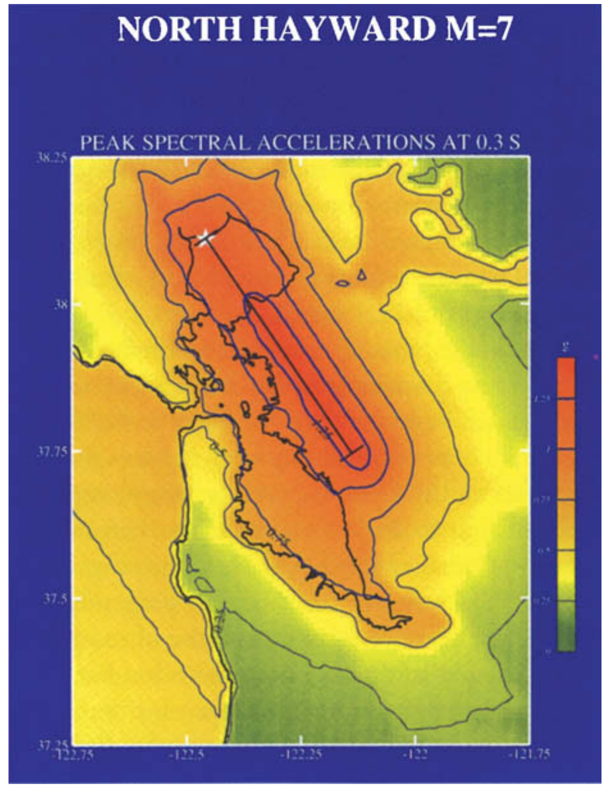


Figure 6-7 Contour map of 5% damped response spectral accelerations at 0.3 second period from a magnitude 7.0 earthquake on the Hayward fault; the epicenter is shown by a star.

are the kinds of ground motions that would affect fairly stiff structures and fairly low structures. Figure 6-7 is a contour map of spectral acceleration for a period of 0.3 second, which also would mainly affect stiff structures and low structures.

Figures 6-8 and 6-9 are contour maps of spectral acceleration for periods of 1 and 2 seconds, respectively, which would most strongly affect multistory buildings and bridges. They show that the Bay mud causes significant amplification of the long-period ground motions. For 2 seconds period motion, the contours are elongated in the direction of rupture along the fault due to the rupture directivity effect.

The next three figures show ground-motion levels along the three cross sections whose locations are shown in figure 6-1. The profile in figure 6-10 is along a line parallel to the Hayward fault that runs through downtown Oakland. The peak accelerations and spectral accelerations at 0.3 second period are not strongly affected by the site conditions, but the spectral accelerations at 1 second and 2 seconds period become much larger on Bay mud.

The profile in figure 6-11 runs along the Bay shore, which consists mostly of soft soil. The peak accelerations are about 0.4G on soft soil. At a period of 2 seconds, the spectral amplitudes increase away from the epicenter due to rupture directivity effects.

The profile in figure 6-12 runs east–west from Oakland to San Francisco, with the Hayward fault located about 45 kilometers from the western end of the profile. As expected, the peak acceleration and spectral acceleration for 0.3 second period are largest along the fault and then drop off toward the west, toward San Francisco. However, for 1 second and 2 seconds

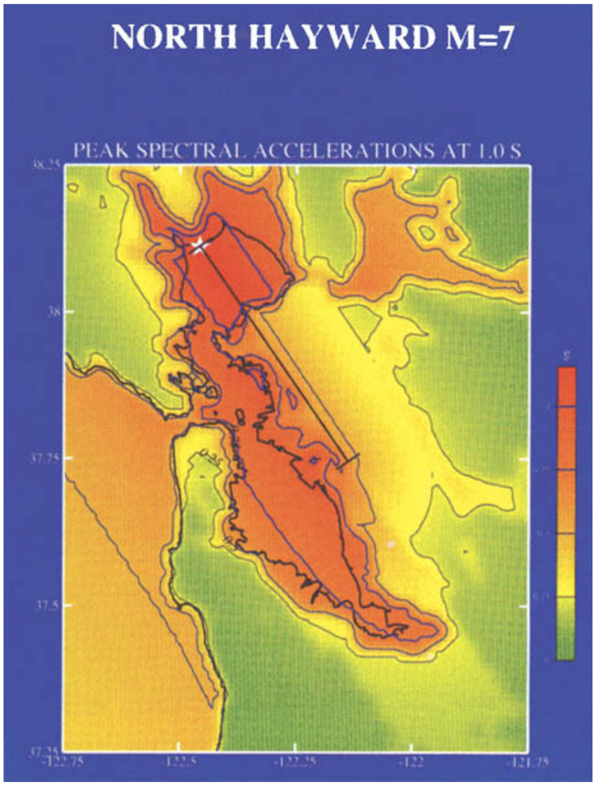


Figure 6-8 *Contour map of 5% damped response spectral accelerations at 1 second period from a magnitude 7.0 earthquake on the Hayward fault; the epicenter is shown by a star.*

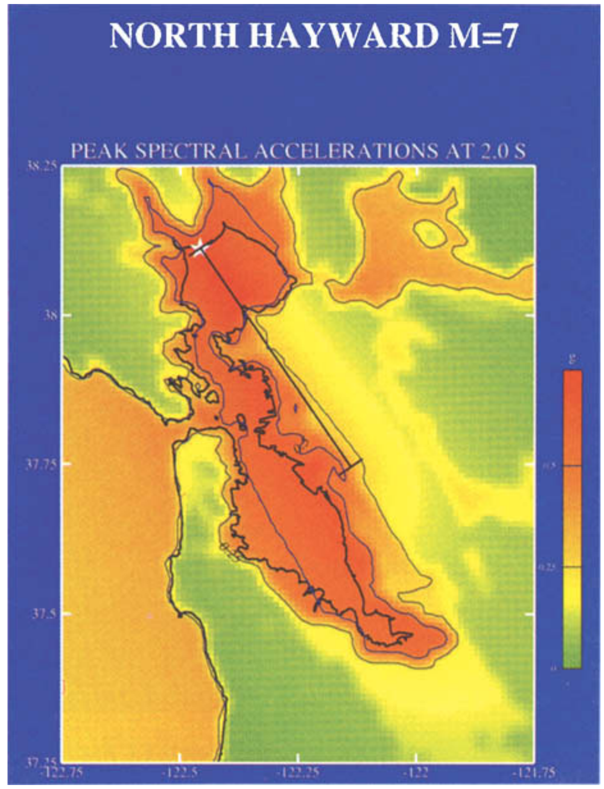


Figure 6-9 *Contour map of 5% damped response spectral accelerations at 2 seconds period from a magnitude 7.0 earthquake on the Hayward fault; the epicenter is shown by a star.*

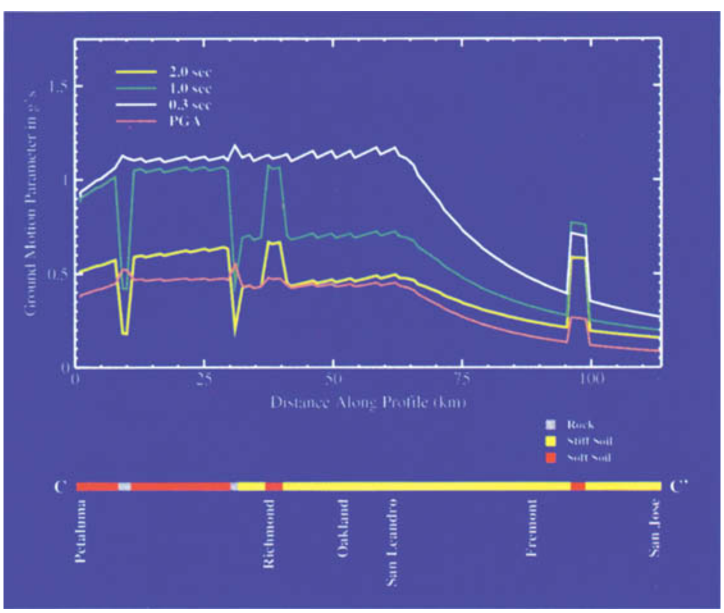


Figure 6-10 *Profile of ground motions along profile CC´ (see figure 6-1), parallel to the Hayward fault through downtown Oakland.*

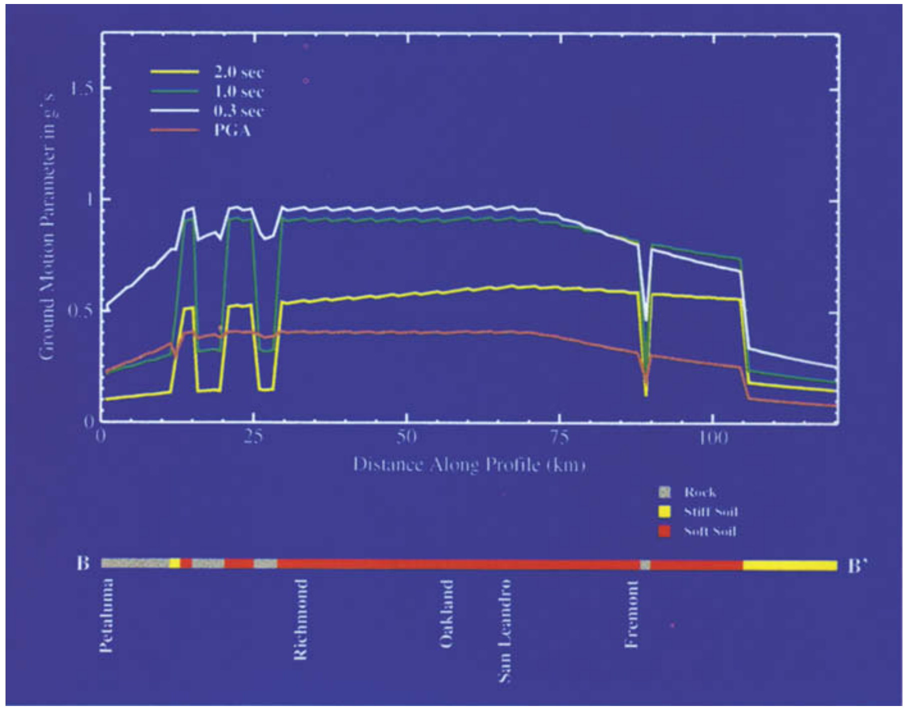


Figure 6-11 *Profile of ground motions along profile BB′ (see figure 6-1), parallel to the Hayward fault along the eastern margin of San Francisco Bay.*

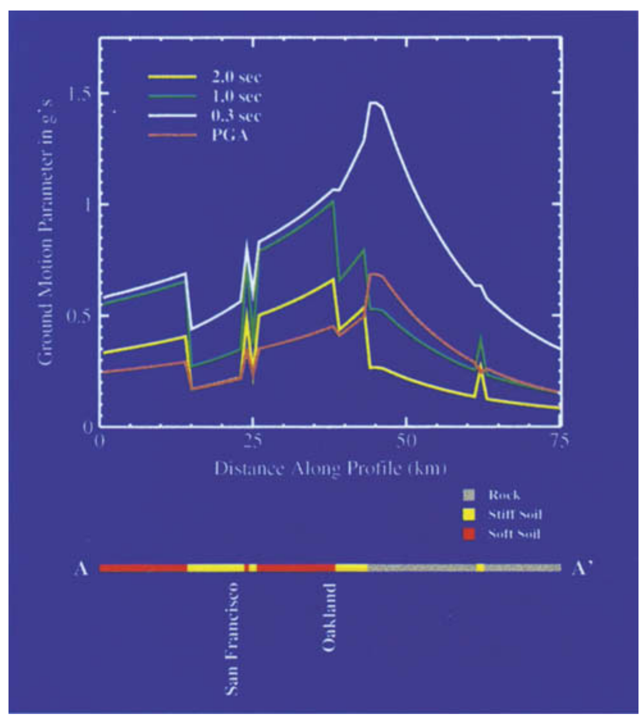


Figure 6-12 *Profile of ground motions along profile AA′ (see figure 6-1), which crosses San Francisco Bay through San Francisco and Oakland.*

period motions, the opposite occurs: the ground motions grow away from the fault as the site conditions change from rock to stiff soil to soft soil toward San Francisco Bay. The ground motions then decrease again onshore in San Francisco. This profile illustrates the very strong effect of site conditions on long-period ground motions.

We haven't yet had a strike-slip fault rupturing into a dense urban region in California, as occurred during the Kobe earthquake. However, as shown in figure 6-2, the seismological and ground-motion characteristics of the Kobe earthquake seem from a preliminary evaluation to be very comparable to what we would expect from an M7 earthquake on the Hayward fault. The damaging part of the ground motion for multistory buildings and bridges will probably be long-period ground motions caused by rupture directivity effects.

References

Campbell, K. W. 1990. Empirical prediction of near-source soil and soft-rock ground motion for the Diablo Canyon Power Plant Site, San Luis Obispo County, California. Report prepared for Lawrence Livermore National Laboratory.

Idriss, I. M. 1991. Earthquake ground motions at soft soil sites. In *Proceedings of Second International Conference on Recent Advances in Geotechnical Engineering and Soil Dynamics*, St. Louis, Missouri, March 11–15, 1991.

Sadigh, K., C.-Y. Chang, N. A. Abrahamson, S. J. Chiou, and M. S. Power. 1993. *Specification of long-period ground motions: Updated attenuation relationships for rock site conditions and adjustment factors for near-fault effects.* ATC 17-1. Redwood City, CA: Applied Technology Council.

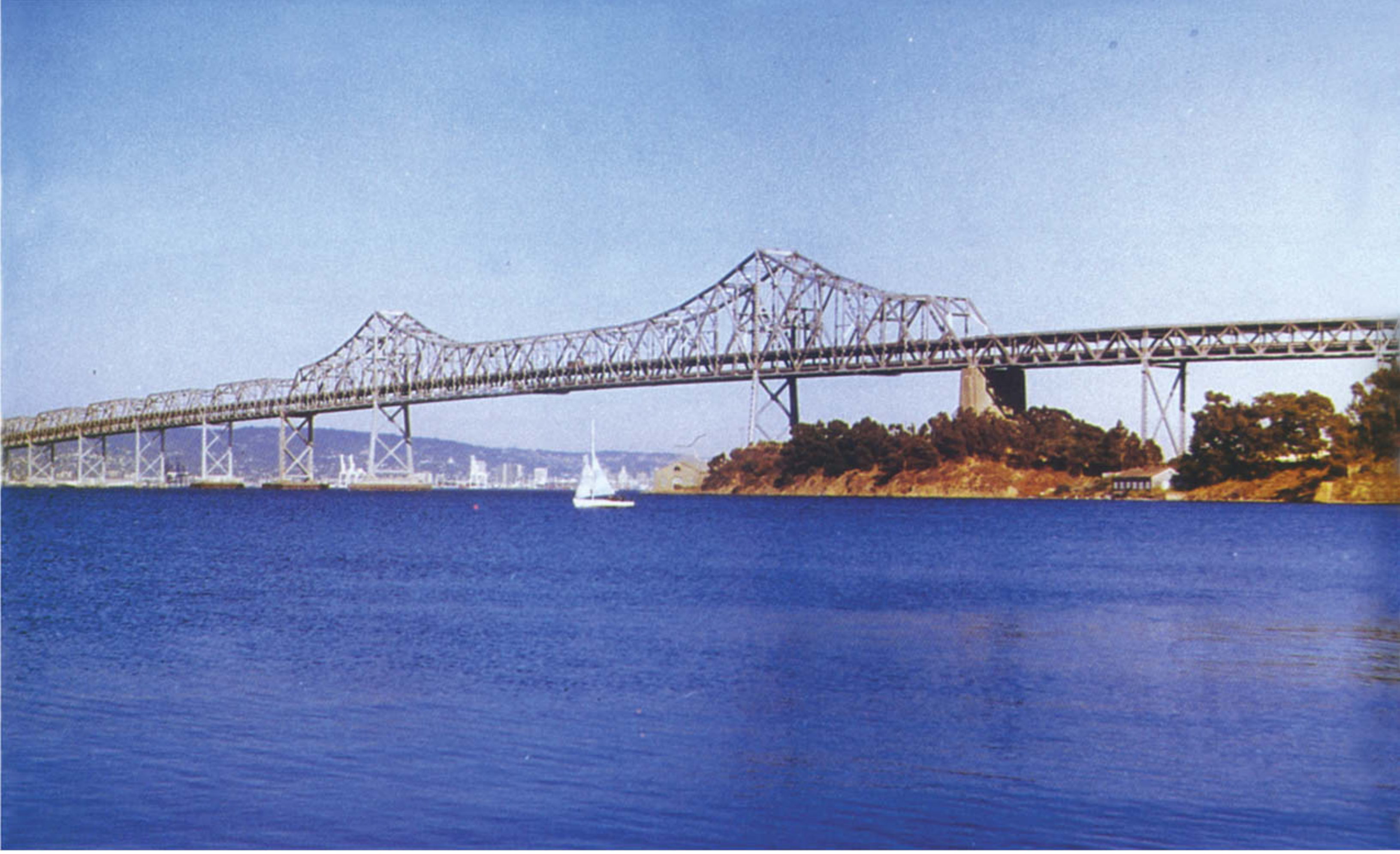
Sadigh, K., J. Egan, and R. Youngs. 1986. Specification of ground motion for seismic design of long-period structures (abstract). *Earthquake Notes* 57:13.

Somerville, Paul. 1995. Strong ground motions of the Kobe, Japan, earthquake of January 17, 1995. In *Engineering Implications of the January 17, 1995, Hyogo-ken Nanbu Earthquake.* Structural Engineers' Association of Northern California, SEAONC Spring Seminar Series, Oakland, May 18, 1995.

Somerville, P. G., and R. W. Graves. 1993. Conditions that give rise to unusually large long-period ground motions. In *The structural design of tall buildings* 2, 211–232.

Somerville, P. G., and R. W. Graves. 1995. Ground motion potential of the Los Angeles Region. In *Proceedings of the 1995 Annual Meeting of the Los Angeles Tall Buildings Structural Design Council*, May 5.

Somerville, P. G., N. F. Smith, R. W. Graves, and N. A. Abrahamson. 1995. Accounting for near-fault rupture directivity effects in the development of design ground motion. In *Proceedings of the 1995 ASME/JSME PVP Conference,* Hawaii, July 23–27.



7-1 *The San Francisco–Oakland Bay Bridge: east span (top) from Yerba Buena Island to Oakland, truss and cantilever sections; west span (bottom) from San Francisco to Yerba Buena Island, suspension section.*

Chapter 7

Transportation Systems Affected by Ground Motions

Brian Maroney, California Department of Transportation

The Hayward scenario event today would cause widespread damage, including collapses and massive disruption to the Bay Area's transportation system, that could cost billions of dollars and take many years to repair and reconstruct. Hundreds of bridge structures will experience cracking, banging, and chipping of concrete at expansion joints and/or soil settlement at the approaches to their abutments and some permanent displacement.

This scenario earthquake is very similar to Caltrans' design event for the Hayward fault, which is slightly larger than a magnitude 7.0; thus, the performance of the structures in this scenario is going to be just slightly better than it would be in our design event. Practically speaking, the differences are not significant.

I make a couple of general assumptions in my assessment of transportation system response. First, I expect older structures—structures designed, say, before 1971—to have damage. The risk posed to our community by those structures is the reason that California is currently undertaking the largest bridge seismic retrofit effort in the world. Serious damage to older bridges during past large earthquakes is not consistent, however; that is, in past earthquakes most bridges designed prior to 1971, or thought to be vulnerable, did not collapse. It seems unrealistic for anyone to predict that all older structures in the region will be out of service. On the other hand, prudence and distant observations of earthquake responses, such as those near Kobe, Japan, in 1994, cause engineers to use caution with respect to structures not designed for realistic demands from earthquake ground motions.

Second, I expect structures built or retrofitted after 1971, and particularly after 1989, to do well in this event. The engineering advances in the last five years have been tremendous. Recently retrofitted bridge structures are expected to perform well and did during the Northridge earthquake (Northridge PEQIT Report 1992). With respect to geotechnical threats to the Bay Area's collection of bridges, the most severe demands occur at locations of potential liquefaction or massive lateral spreading. Unfortunately, such areas are typically where communities need and place bridges. The approaches to many of the Bay Area's bridges are threatened by the predicted poor responses of these foundation materials. For example, the approaches to the Bay Bridge (figure 7-1) and the San Mateo–Hayward bridge are on such materials, thus defining these routes as unreliable in the event of a large earthquake regardless of what measures are taken within the structure. Figure 3-1 (chapter 3) illustrates locations around the Bay Area at high risk due to potential threateningly poor soil response to seismic ground motions.

Caltrans' performance criterion for new and retrofitted structures is "no collapse." For important structures—structures like the San Francisco–Oakland Bay Bridge—the current performance goal is that they remain essentially functional after a major event. They have not yet been retrofitted, but the designs, the evaluation, the hazard studies, and the vulnerability studies are under way. In my opinion, the earthquake performance level designed into these structures will be what the community of taxpayers and/or users is willing to fund. It has been my experience that a quality engineering team designing for "no collapse" can on occasion generate a retrofit for which the costs approach, or even exceed, the costs of replacement. I think that a retrofit for which the costs approach those of replacing the structure will be received with great resistance. The level of functionality that will finally be incorporated into the seismic retrofit design of these structures is therefore speculative at this time. The level of postearthquake serviceability designed into the retrofits will be based on maximizing cost-benefit ratios. Such evaluations will clearly be separate for each of the important bridges.

We must be careful in extrapolating from the Loma Prieta or Northridge experiences. This scenario earthquake is very different from the Northridge earthquake. Not only are the motions different and the demands on structures therefore different, but those past events did not really tax the total resources of our system. In the past, Caltrans and everyone else have been able to use the surface transportation system after earthquakes. In a Hayward event, however, many surface systems directly cross or intersect the ruptured fault segment, and they will be extensively damaged. There will be a limit on how fast highway segments can be reopened, based upon where the community wishes to place its resources. There is not going to be an infinite supply of resources, so we should prepare for making decisions about where to direct *limited* resources.

Damage Assessment and Rerouting

After the earthquake, Caltrans' Division of Structures first will do reconnaissance. History suggests that the media play a big role in this. During the first couple of hours, very valuable information comes in via television. Descriptions that go along with the images are frequently wrong, but the *images* will be useful.

Caltrans will mobilize engineers to review the structures. The first engineering teams will be the construction engineers and maintenance employees in the area. They will contact Caltrans headquarters by phone or radio. Post-EarthQuake Investigation Team (PEQIT) members from the Office of Structures Design and Structures Maintenance from Sacramento will usually arrive in the area within hours. (It is worth noting that following the Kobe event, access was extremely difficult and response times were criticized. Similar conditions could obtain, with equally slowed responses.) All engineering teams will channel information to headquarters on a variety of issues and details. These engineers will be asked to make important decisions concerning public safety and functionality of the bridges at various sites until headquarters can be involved. At the end of the first day, there may be a press conference at 5:00 P.M. We will have a fairly reliable picture of damages, and we will start organizing strategies from there.

District offices will start piecing together new routes. Segments of a route might be out, so they will use a parallel system. For example, if a segment of Interstate 580 is down, they'll use a side road to piece that together; there'll be some kind of disjointed but functioning route. If it's as simple as using an access road, that will take just a few hours. Coning takes a few hours; we did that in Northridge. Simple construction can be done in five to six hours; I saw it happen at Interstate 980 south in Oakland. But available resources are going to be fundamentally important; without enough crews, repairs can take days instead of hours.

Headquarters will be keeping track of a large number of bridges and highway segments, their damage and their functionality. A large number of decisions will be made quickly based on the information available, so it is important to use the available information to its maximum potential. Initially, damaged bridges will start to be listed on paper and boards. Information then will migrate to simple electronic spreadsheets and database software. Next, electronic mapping will be used to visualize damage. This process has been used since the 1987 Whittier earthquake. In the following few days, the understood image of the transportation system will grow in detail. This transfer of information from the field to headquarters is important to guide decisions for distributing limited resources. Better information for headquarters equates to better solutions to the challenges. Maps can be developed incorporating controlled openings, closures, and slides. These maps can take up to a week to develop and be available.

For heavy construction we will need to either bid out the work or request exemption from so doing from the governor. We will need engineers designing a complex system, putting a model together. A bridge design takes a few weeks; however, it depends on how many projects are needed. It could take a few weeks until some plans are finished, and perhaps a month before a structure is actually rebuilt. Many months are necessary for structures like those in the Interstate 14–5 interchange in Southern California. The transportation system would be incrementally improved as each piece of the reconstruction is completed to a stage of functionality and opened. Rerouting of traffic flows to improve system travel times or allow for specific construction efforts would continue throughout the reconstruction phase.

In my opinion route I-280 south is the most reliable route out of the San Francisco Peninsula in the event of an earthquake like the Hayward scenario event. I think that the most reliable route out of the East Bay at this time is I-580 east. It is worth noting that Travis Air Force Base is likely to be a important emergency staging facility following a major Hayward seismic event. In the coming years, seismic emergency routes will be identified and modified to increase reliability. These routes will mostly be segments of roadway on rock and bridges that don't cross very long structures or liquefiable regions of soil. These routes should be incorporated into emergency plans.

Damage to Bridges

Structures designed fifty years ago used design modes that were on the order of 0.05G to 0.1G lateral. Today, Caltrans designs for more than an order of magnitude higher. Older structures like the San Francisco–Oakland Bay Bridge, Richmond–San Rafael Bridge, and the Carquinez, Benicia, and San Mateo Bridges will be damaged. Bridge engineers have seen considerable damage on reinforced concrete structures, and we have good fundamental ideas about what might happen in the steel. However, we don't know what those big steel structures are going to do in this event. Nonetheless, there are indications of a significant overload. Until the retrofits of the Bay Area's large toll bridges are complete, those structures shouldn't be depended on for emergency use after an earthquake.

Large bridges as far north as the Napa River Bridge to bridges as far south as the Dumbarton Bridge would experience threatening demands: the Richmond–San Rafael Bridge on I-580, the San Mateo Bridge on Highway 92, the Dumbarton Bridge on 84, the Golden Gate Bridge on 101, the Carquinez Bridges on I-80, the Benicia-Martinez Bridge on I-680, and the Antioch Bridge on 160. Additionally, the 580–238, 92–101, and 580–980–24 interchanges will be affected.

The San Francisco–Oakland Bay Bridge is an extremely large and complicated bridge for seismic response. There are several structural system types, multiple foundation types and sizes, and varying geological and geotechnical conditions. The design of the structure is approximately sixty years old. The bridge's capacity to withstand earthquake ground motions is a fraction of those defined in this scenario. If the Hayward scenario event were to occur today, the bridge would

7-2 *The Carquinez Bridges: the westbound bridge (left) was designed in the 1920s; the eastbound, in the 1950s.*

7-3 *The Benicia-Martinez Bridge.*

develop multiple failures and have multiple span collapses. Seismic analysis of the structure supports this scenario. The bridge could be out of service for an extended period.

Of the two Carquinez Bridges (figure 7-2), the bridge carrying westbound traffic was designed in the 1920s, while the companion bridge was designed in the 1950s. Hazard studies and vulnerability studies for these bridges have been completed, and the design phase for the seismic retrofit has begun. These structures were not designed to withstand large earthquake ground motions. As was the Bay Bridge, these were designed for a fraction of the lateral load that they would experience in the Hayward scenario event. The best dynamic analyses to date show significant overloads throughout the systems, which threaten collapse.

The Benicia-Martinez, San Mateo–Hayward, and Richmond–San Rafael Bridges (figures 7-3, 7-4, and 7-5) were each designed prior to 1971. Ground-motion and structural vulnerability studies completed to date as part of the Caltrans seismic retrofit program support the necessity for seismic retrofit of these structures. Without it, all of these older structures have the potential to fail during a major seismic event. Both numerical analyses and fundamental understanding can be employed to support such conclusions; the structures simply were not designed for such large lateral loads.

The Dumbarton and Antioch Bridges (figures 7-6 and 7-7) are both special-case bridge structures that require close review. Both were designed after 1971, so the design seismic loads are not unrealistic. However, the designs do not have the

7-4 *The San Mateo–Hayward Bridge.*

7-5 *The Richmond–San Rafael Bridge.*

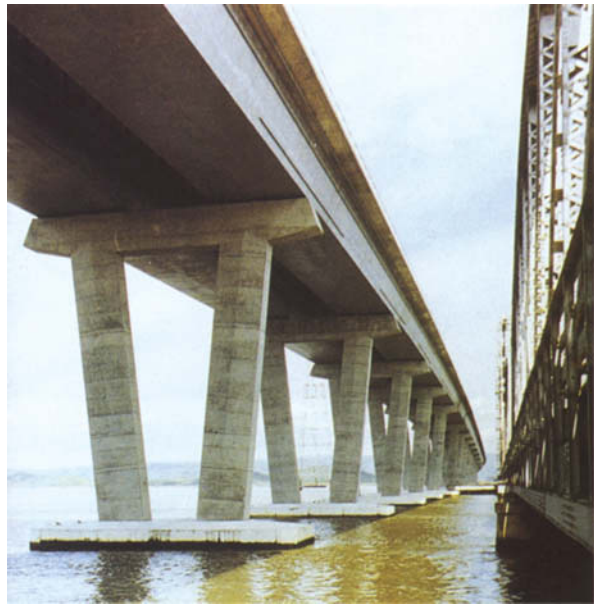
benefit of the significant research completed since then, and there are details in these structures that probably would not be used in a design today. There is some question whether the Antioch structure is as important as the other large Bay Area toll bridges. The characteristic of being a "toll" bridge has in the past suggested importance, but the average daily traffic on this segment of Highway 160 is near 1,000 vehicles per day, significantly less than that for other toll bridges discussed.

None of these toll structures has been designed to standards that the bridge industry currently believes are minimum standards to reasonably expect acceptable response to large earthquake motions.

The design of the Golden Gate Bridge (figure 7-8) is of the same vintage as that of the San Francisco–Oakland Bay Bridge. The bridge is owned and operated by the Golden Gate Bridge Authority, which is currently nearing the end of the design phase of the seismic retrofit of this beautiful structure. Special attention has been paid to maintaining its aesthetic appeal, and the GGBA is currently working to develop funding for the costs of the construction phase. Though the design of the retrofit is likely controlled by the San Andreas fault, this structure and its approaches are greatly threatened by a major Hayward event. Suspension bridges are long-period structures, which will reduce demands in many locations throughout the bridge, but the towers and the approach spans are relatively short-period systems, and they were not designed for the ground motions that are expected in the Hayward scenario event.

Damage to Interchanges

Many structures at the Interstate 580–238 interchange near Castro Valley were designed in the fifties, and some of them were designed in 1988. There will be a range of behaviors here, as was the case at the Interstate14–5 interchange in Northridge. For some of the structures, the soil in the thermo-expansion joints was not even



7-6 *The Dumbarton Bridge.*

7-7 *The Antioch Bridge.*

7-8 *The Golden Gate Bridge.*

7-9 The Highway 92–101 interchange south of San Francisco airport.

7-10 Aerial view of the Interstate 580–980–24 interchange.

disturbed; in other structures there were serious problems. This interchange is near the fault, but when there are eight or nine structures on an interchange, traffic patterns can be rerouted. When there are multiple paths to work with, a reduced-capacity system is still possible.

The 92–101 interchange (figure 7-9) is just south of San Francisco International Airport. A large number of single column bents were used in this design. Pile shafts were also used, and they were drilled and placed deep. Reasonable earthquake loads were used in designing these structures, which were most likely controlled by the San Andreas fault. The details in these structures are fairly tough, though they are not exactly representative of those used today. Given their details and location, these structures are expected to be serviceable following the Hayward scenario event.

Figure 7-10 offers an aerial view of the 580–980–24 interchange in Oakland. At this time, this interchange should not be part of any emergency planning scenario. This interchange experienced minor damage during the Loma Prieta earthquake that indicated that, in the event of a large seismic event, very serious damage would develop at this interchange full of unusual and vulnerable structural systems and details. An important item to consider at this interchange is BART. The movement of trains through the interchange would be disrupted or halted by the collapse of any one of a number of the bridges. Bulldozing or quick demolition of a downed or threatening bridge could open space for movement of trains, but in such cases considerable track repair would be required. Seismic retrofit plans for structures within this interchange are currently being developed by a team of Caltrans and private consulting engineers from multiple disciplines.

In addition to the bridges and interchanges specifically discussed, there are many small bridges, such as those shown in figures 7-11 and 7-12, that form the backbone of California's highway system. How such bridges perform as a group will have a major effect on the functioning of the transportation system as a whole. I have limited my study/evaluation to a very few bridges and structures: it should be regarded as the earliest stage of a reasonable emergency plan for a large Bay Area earthquake. I believe it would be valuable to many communities, the State of California, and the federal government to extend this study. To thoroughly evaluate the responses of the bridges and the transportation system to the scenario event would require perhaps one to three engineers working for a year. Many dynamic analyses should be carried out and a credible planning scenario developed. For such a study to produce meaningful and useful results,

7-11 *Typical single-column small highway bridge.*

7-12 *Typical double-column small highway bridge.*

time-dependent vulnerabilities of the system would have to be incorporated; that is, as bridge structures are retrofitted, the changes would have to be updated.

References

Caltrans. 1971. *Field investigation of bridge damage in the San Fernando earthquake.* PEQIT Report. Sacramento: California Department of Transportation.

Caltrans. 1989. *Loma Prieta earthquake.* PEQIT report. Sacramento: California Department of Transportation.

Caltrans. 1994. *Northridge earthquake.* PEQIT report. Sacramento: California Department of Transportation.

Caltrans. 1995a. *The performance of bridge seismic retrofits during the Northridge earthquake.* Sacramento: California Department of Transportation.

Caltrans. 1995b. *Performance of bridges during the January 17, 1995, Kobe earthquake.* Sacramento: California Department of Transportation.

Housner, G., and the Governor's Board of Inquiry on the 1989 Loma Prieta Earthquake. 1990. *Competing against time.* Sacramento: California Department of Transportation.

Housner, G., and the Seismic Advisory Board. 1994. *The continuing challenge: The Northridge earthquake of January 17, 1994.* Sacramento: California Department of Transportation.

8-1 Natural gas system.

Chapter 8

Power, Telecommunications, and Fuel Delivery Systems

Edward Matsuda, Pacific Gas & Electric Company

To visualize the impact of the Hayward scenario earthquake on the power, gas, telecommunications, and petroleum systems, it's useful to have a point of reference. Mine is the Northridge earthquake: the Hayward event's impact on telecommunications is likely to be similar; its impact on power, gas, and petroleum is likely to be more severe.

During the Northridge earthquake, there was no primary surface fault rupture. During the northern Hayward fault earthquake, we anticipate 30 miles of movement, averaging 3 feet, through some heavily developed areas. The area affected by the Hayward earthquake includes extensive zones of high liquefaction potential that are going to be shaken to high levels of acceleration. Within these areas, there are still many cast-iron and oxyacetylene-welded gas pipelines. That combination of factors did not apply in the Northridge earthquake, which affected a newer suburban area. Because the Hayward earthquake will affect older urban areas, there's likely to be more building damage and therefore more damage to both electric and gas distribution components than occurred during the Northridge earthquake. Unlike the utility buildings affected by the Northridge earthquake, many key PG&E structures are old: most were built in the early 1900s.

Gas

A number of gas facilities are close to the fault and will be strongly shaken. The above-ground gas facilities are fairly rugged, so we don't anticipate very much damage to them. Figure 8-1 shows key gas system components in the area that will experience highest peak ground accelerations. Two pipelines cross the northern Hayward fault. One is a newer modern steel pipeline, and the other has recently been retrofitted. There will no doubt be some deformation of these pipelines but probably no rupture. We have two lines that parallel the Bay margin; one of the lines is new, and the other is being retrofitted. The retrofit should be completed within 1995; however, if there were an earthquake today, there could be some leaks on that pipeline.

The Hayward fault crosses over a hundred streets, and within those streets there are gas lines. Although the majority of the gas lines are modern steel or plastic and can accommodate some movement without leaking, most will not accommodate the amount of movement we're anticipating. In the Bay margins, particularly in Alameda and West Oakland, there are still a lot of cast-iron and older oxyacetylene-welded steel pipelines in areas of high liquefaction potential. By the year 2000, these vulnerable pipelines are likely to be all gone, due to PG&E's pipeline replacement program. However, if we had an earthquake today, there would be extensive areas of pipeline damage.

To fix the pipelines at the fault crossing may take several hours to several days. During the Loma Prieta earthquake, the Marina District in San Francisco had extensive gas pipeline damage due to the combination of cast-iron pipelines and extensive liquefaction. It took about a month to restore that area. If the northern Hayward earthquake occurs in the near future, we're likely to have much more gas pipeline damage than in the

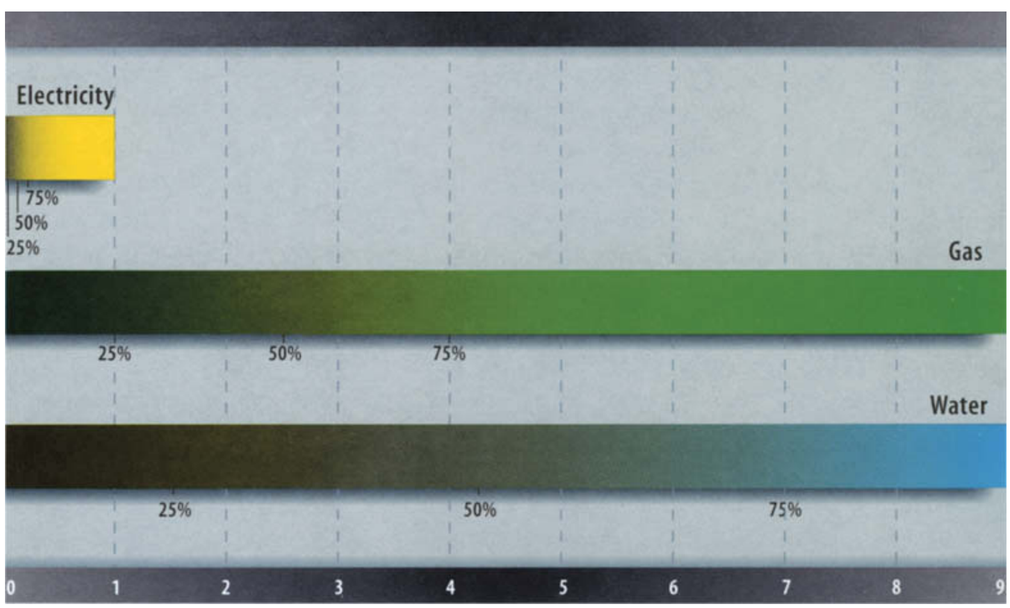
Loma Prieta earthquake. It may take up to two months to restore service in some liquefaction areas (figure 8-2).

Outside the liquefaction areas, restoration of service is influenced by the time it takes to relight customers. This is a time-consuming process because gas service people need to go into each facility to check for leaks in the gas lines and appliances. During the Northridge earthquake, there were over 150,000 gas shutoffs—130,000 customer-initiated—most of which were unnecessary. It took two to three weeks to restore service for all customers. We think there will be many more customer-initiated gas shutoffs following the northern Hayward fault earthquake, so restoration could be up to two months for some customers.

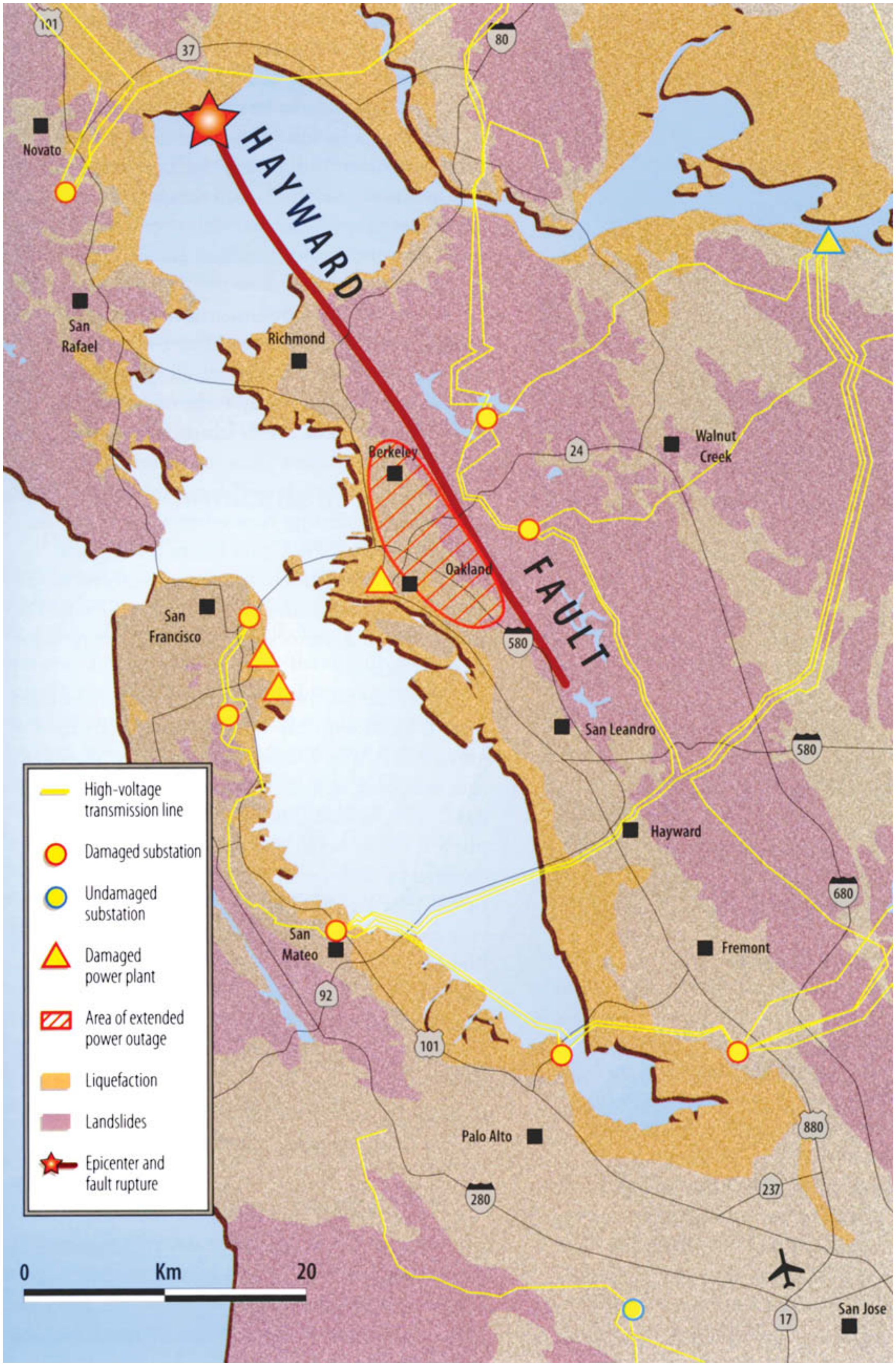
Power

Most of the power to the East Bay is routed through two transmission substations, Moraga and Sobrante. Both stations are within 3 miles of the fault and will be subjected to high acceleration levels (figure 8-3). After the Loma Prieta earthquake, a number of improvements were implemented at these substations and throughout the Bay Area. All vulnerable circuit breakers have been replaced, except two at Metcalf substation that are in noncritical positions. We've also done substation control building modifications, including both of the control buildings at Sobrante and Moraga substations. Although we have made a number of improvements, we still anticipate damage at Moraga and Sobrante. The components we are most concerned about are transformer bushings. During the Northridge earthquake, forty to fifty of these were lost due to breakage and oil leaks. At present, bushings are not available to withstand the level of shaking anticipated at Moraga and Sobrante. PG&E, other utilities, and vendors are working toward a solution to this problem.

We have some unique problems with the distribution system in the East Bay (figure 8-4). This system has two electric paths into the Oakland area. One path goes above ground to Station K and then goes underground through two 115kV cables. These cables cross the northern Hayward fault. The cables are fairly rugged, but with the amount of movement anticipated along the Hayward fault, they're likely to be damaged and inoperable. The other electric path into the Oakland area goes through Station X. This is an indoor substation. The lines go above ground into the substation building and then are



8-2
Number of weeks required for recovery of utility service.



8-3
Electric power system in the San Francisco Bay region.

8-4 *Power distribution system in the greater Oakland area.*

routed underground within the building. This building has some significant structural problems: some of its concrete walls have very little reinforcing. After an earthquake, we probably won't be able to get into the building.

The other substation control buildings in the area shown in figure 8-4 were all built in the early 1900s, with the majority built in the 1920s. We anticipate significant damage to many of these buildings. Underground cables traverse areas where liquefaction and significant lateral spreading are anticipated, and we anticipate cable damage.

We have projects in place to mitigate the damage described; however, if we had an earthquake today, both electric paths into the Oakland area are likely to be damaged and out of service for about four days. The Oakland Power Plant, which is on standby, can be brought on line in about twelve hours. Its capacity can meet the postearthquake demand in the Oakland area until other power sources into the area can be restored.

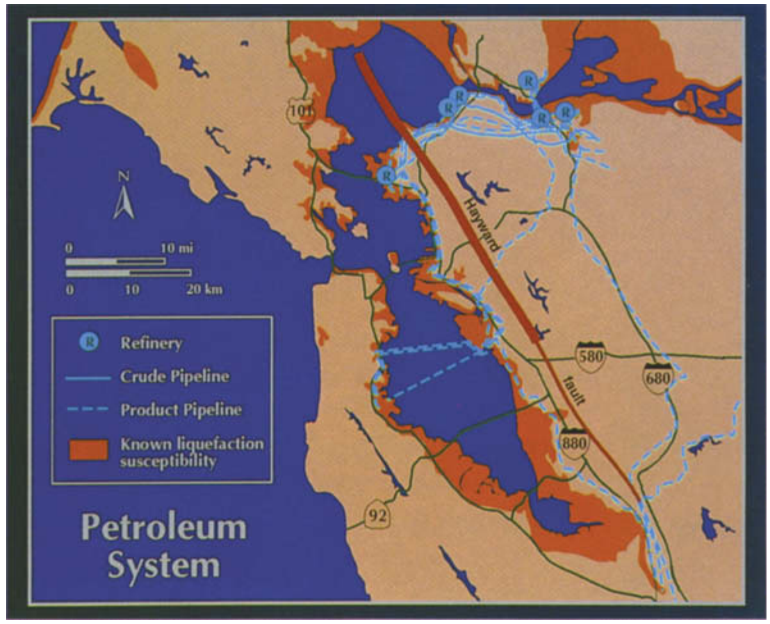
Damaged components in the transmission and distribution system need to be repaired or bypassed. However, the controlling factor in customer outages is likely to be our desire to check the area served by electric circuits for gas leaks and gas pockets prior to energizing electric circuits. This check is performed to minimize the possibility of starting fires when the circuits are energized. After the Loma Prieta earthquake, downtown San Francisco was not restored for a couple of days because we first went through the area with gas detectors to ensure that there were no gas pockets.

After the northern Hayward fault earthquake, there'll be widespread outages throughout the greater Bay Area. Outside the East Bay, the outages are going to last from several hours to several days. It is possible that some customers will be out for a little bit longer because of localized damage to their facility or to the electric system. In the East Bay, it's likely that we will not have very many customers restored within the first day; however, the majority of the customers should be restored within three days. There will be some isolated pockets in which customers may be out for as long as a week. Because there is likely to be only one source of power in the Oakland area, periodic outages of up to several hours are likely for the first four days following the earthquake.

Petroleum

There are six refineries in the area (figure 8-5) that will be strongly shaken by the northern Hayward fault earthquake. Refinery structures are fairly rugged, so we don't anticipate much impact on the public. Tanks have been known to fail in earthquakes and may fail in this earthquake; however, they're all contained within berms, or they have other provisions to mitigate the effects of spills. Petroleum lines are vulnerable where they cross the fault and where they cross liquefaction areas. A number of lines cross the fault near San Pablo Bay, and several cross liquefaction areas. If the pipelines are modern steel and provisions have been made to accommodate fault movement, they're likely to perform well. If they're older steel, there could be problems.

Another potential vulnerability is fire. After earthquakes, there have been fires at refineries. Although the refineries all have emergency plans to fight fires, they could be easily overwhelmed.



8-5 Petroleum refineries and pipelines.

Telecommunications

The telecommunication systems are going to have building and equipment damage; however, the buildings and equipment are fairly rugged and have generally performed well during past earthquakes. They've had some problems with backup systems and emergency power; however, because of the redundancy in their systems, these problems are not likely to have a significant impact on customers. The biggest problem will be the overload on phone lines due to the large number of people attempting to make calls. For the first couple of days after the northern Hayward fault earthquake, overloaded phone switches will make phoning difficult or impossible.

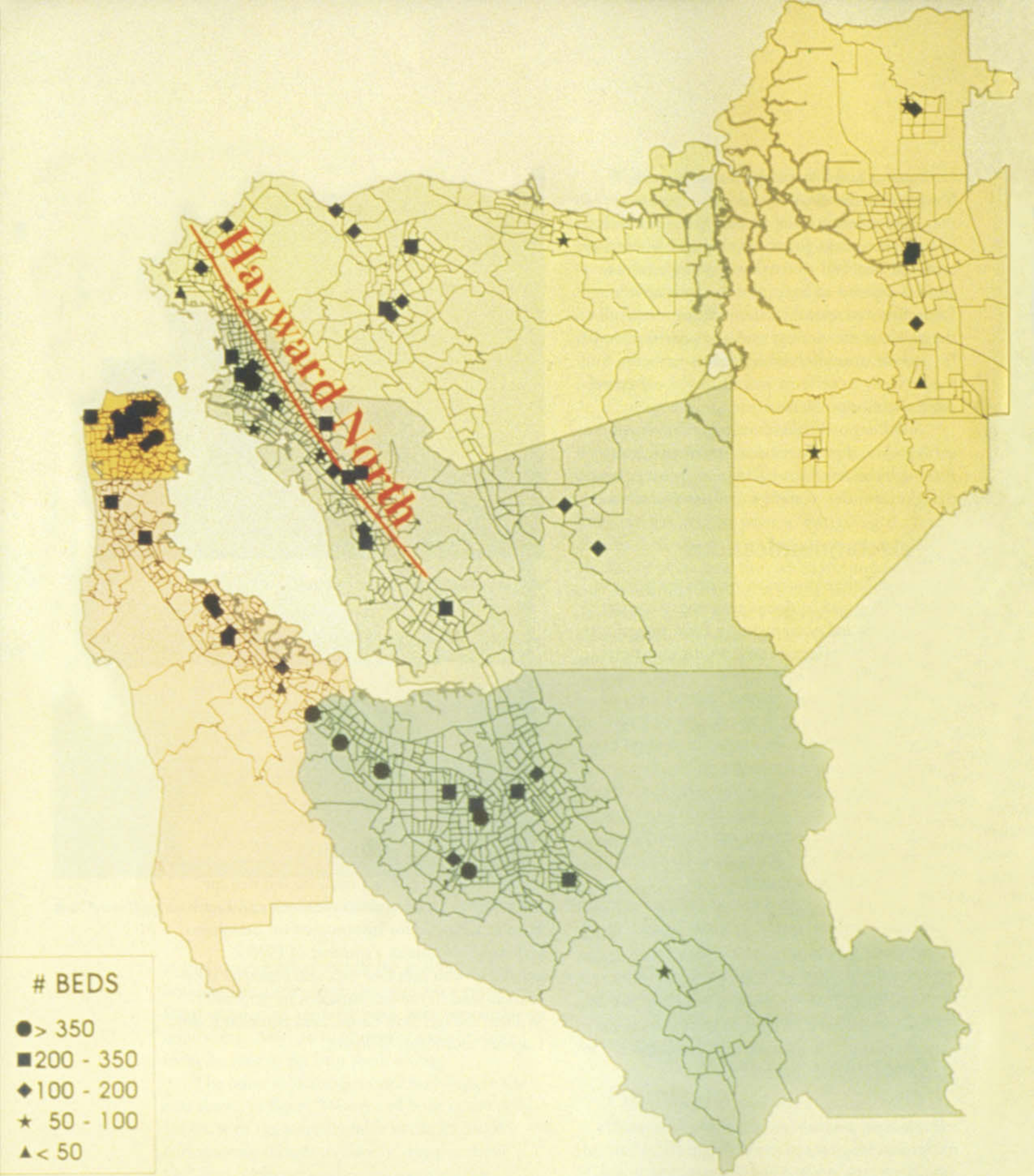
A number of people are depending on cellular phones after an earthquake, but telecommunications experts recommend against that. Cellular lines are also likely to be overloaded, and calls from a cellular telephone to a regular telephone go through the same overloaded switches.

Overview

The providers in the areas of power, gas, telecommunications, and petroleum have seismic mitigation programs in place. At PG&E we are modifying vulnerable substation equipment and replacing vulnerable gas lines. We are also modifying essential buildings and taking other mitigation steps. Our system is going to perform better today than it would have five years ago, and it's going to perform better five years from now than it would today. We know that, with time, system performance and restoration of service are going to improve, but we are concerned about whether we have enough time to implement desired mitigation steps.

Acknowledgments

I thank Larry Wong from Pacific Bell for information on telecommunications and Frank Hsiu of Chevron for information on petroleum systems. I also thank a number of PG&E personnel who supplied data and reviewed information used in the presentation, in particular, William Savage, Bob Gross, Sym Blanchard, Jim Gamble, and Keith Williams.



9-1 Spatial distribution of hospital beds in Alameda, Contra Costa, San Francisco, San Mateo, Santa Clara, and San Joaquin Counties.

Chapter 9

Critical Facilities Affected by Ground Motions

William Holmes, Rutherford & Chekene

The functioning of many critical facilities is dependent on utilities that may be out of service, but that's a systems problem dealt with in other chapters. This chapter discusses the probable state of the buildings and their contents. Included are emergency operation centers (EOCs), police stations, fire stations, and hospitals. Figure 9-1 is a map of hospital beds in the region.

Emergency Operations Centers

To assess the vulnerability in the target region, we will consider individual counties. Alameda and Contra Costa Counties are the ones surrounding the fault, Santa Clara County is at the bottom of the Bay, San Mateo and San Francisco Counties are on the Peninsula, and San Joaquin County is the county immediately to the East. Contra Costa, Alameda, and Santa Clara Counties have brand-new EOC facilities complying with the California Emergency Services Act, a California law that attempts to keep these buildings operational after an earthquake. New facilities are built to the standard set forth in that law, but there is no requirement to retrofit old buildings. There will possibly be some reduction in functionality of the San Francisco, San Mateo, and San Joaquin County EOCs, but the basic structures should be all right. The State Office of Emergency Services' regional EOC is located in a normal (not specially designed) office building in Oakland, but it has backup generators on site. The staff is also very careful about seismic protection of nonstructural elements in the office, so the office might be operable.

City halls are very important in coordinating disaster response. There are many small communities in the East Bay with their city halls in normally designed buildings. Several city halls are likely to be closed due to structural damage, problems caused by nonstructural damage, communications, or inaccessibility.

Police Stations

There really are no statistical data on how police stations have performed in past earthquakes. In the target region—the East Bay—precinct buildings are typically small and low-rise. They have a lot of walls because of security, so they're not large earthquake risks. The central administration of police operations is often in the city hall, and, as already mentioned, some city halls are vulnerable. The Oakland Police Administration building has been evaluated, and it's a known risk. It's a mid-rise building that could be severely damaged by near-field effects.

The probable performance of police facilities overall will result in some reduction in the ability to perform, due to both structural and nonstructural damage. Communications will probably be hampered to some degree. There'll be some cars trapped in parking structures and storage structures. The Oakland building probably will be red-tagged (entry prohibited) or worse, but the primary functions of police are not heavily dependent on the performance of their buildings.

Fire Stations

In the San Fernando earthquake of 1971 there were many jammed doors at fire stations and extensive nonstructural damage. In the northern San Fernando Valley, all four stations in San Fernando and Sylmar were damaged and at least temporarily shut down. In the city of Los Angeles, out of 105 total stations, there were 4 severely damaged stations and 53 with minor or equipment damage. For the Northridge earthquake in 1994 we have a little bit more data: there were thirty-five door malfunctions, some electrical problems, and some plumbing problems. However, 90% of the fire stations had green tags (entry permitted), and therefore were usable. In District 3, right near the epicenter in the San Fernando Valley, there was structural damage in 11 out of 26 stations, although it was structural damage at less than a red-tag level. In District 1, which is in central Los Angeles, 3 out of 33 stations had structural damage, and in District 2, farthest to the south, only 1 out of 28 had any structural damage.

Power failures hampered the computer dispatching system in the Northridge earthquake, and fire companies had to go to radio communications for this dispatch function. That made them far less efficient than they would normally be.

In the East Bay, there are many stations spread out over the region, most of them in older buildings because the communities themselves are older. Fire stations fall under the requirements of California's Essential Services Act, so any that have been built recently should not have a problem. Unfortunately, not many have been built recently.

Seismic evaluations have been completed in many of these communities. In Oakland, studies showed that 18 out of 29 fire stations require retrofitting. In San Jose, which is a younger community, only 6 out of 30 required retrofitting. In San Francisco, which did a very extensive study, 7 out of 55 were given very high priority for retrofitting, and 34 more were given high priority. Well over half the stations in San Francisco need retrofitting.

In Alameda and Contra Costa Counties, the primary counties of interest in this scenario, we've divided the areas into the western county, which is basically from the fault west to the Bay, and the eastern county, which is east of the fault. About a third of the stations in the western county will be red-tagged; the buildings will not be usable, and a few will lose equipment (table 9-1). There will be a large number of inoperable doors, but firefighters tell me that's not a problem; you simply chop your way out. There will be a significant nonstructural mess in all the fire stations in the western county, and certainly there will be a lot of disruption in the eastern county.

In the other counties, the shaking drops off very quickly. San Joaquin facilities, which will probably be accessible to seriously damaged counties, will be affected very little. Santa Clara County will be affected just a little, as will San Francisco and San Mateo Counties.

Hospitals

We have abundant data on the historical performance of hospitals. The 1973 Hospital Seismic Safety Act was passed after the San Fernando earthquake of 1971. Hospitals built after 1973 have a significantly greater chance of being operational after an earthquake. The statute requires them to be operational insofar as practicable.

Table 9-1 Probable Performance of Fire Stations, by County

County	*Red-Tagged*	*Equipment Lost*	*Doors Inoperable*	*Nonstructural Damage*
Alameda and Contra Costa				
West of the fault	⅓ of stations	A few	½ of stations	Significant in all
East of the fault	A few	None	⅓ of stations	Moderate in many
San Joaquin	None	None	None	Little
Santa Clara	2 or 3	None	A few	Minor common
San Francisco and San Mateo	5 or fewer	None	A few	Scattered

The hospitals built before the Hospital Seismic Safety Act are about the same quality as other structures built in their same era. Many hospital buildings were built in the 1950s and sixties, so those that are concrete are probably very vulnerable. The San Fernando Valley hospital performance in 1971 is an indicator of this and is well known. The nonstructural performance in the pre-act hospitals is slightly better than that of the general building stock because hospitals simply are put together better, and all remodels to the original buildings have had to comply with current anchorage requirements.

For post-act buildings, the structural performance has been generally good. The nonstructural performance has been marginally good. Overall, it was quite good in the Northridge earthquake of 1994, but there were several key failures, particularly in water systems, that turned out to be fatal flaws. Even in several good buildings with excellent nonstructural performance, a couple of water line breaks was all it took to shut down the building.

We have some actual statistics on the performance of buildings at twenty-three hospital sites in the Northridge earthquake (table 9-2). In pre-act buildings, there were 20 red tags, 16 yellow tags (restricted entry), and 22 green tags. In the 31 post-act buildings, there were no red tags, 1 yellow tag, and 30 green tags. In addition, 40 pre-act buildings had major nonstructural damage and 14 had minor. Only 9 post-act buildings had major nonstructural damage and 22 had minor damage. These results confirmed much of what we actually expected would happen.

For estimating the vulnerability in the scenario target region, I used a survivability study of all the hospital buildings in the state. The number of beds is used as a primary measure of the hospital's capability. A and B buildings are basically in compliance with the Hospital Seismic Safety Act and are expected to perform very well. C buildings are in between: they've been designed to a seismic code but not to a standard aimed at keeping them operational. D, E, and F buildings are poor performers and can even be considered hazardous buildings. The study was done by the number of buildings, square footage, and number of beds, so while 32% of the buildings comply with the act, only 16% of the beds are in those buildings.

Table 9-3 shows the number of beds in the different classifications statewide, for the Office of Emergency Services region that extends from Mendocino County down to Monterey County, and for Alameda and Contra Costa Counties. For the OES region the really good buildings, A and B, had 16% of the beds; the marginal buildings had 50% of the beds; and the poor buildings had about 32% of the beds. For Alameda and Contra Costa Counties, the breakdown was 20% A and B, 47% C, and 33% D,

Table 9-2 Performance of Health-Care Buildings at the 23 Hospital Sites with One or More Yellow- or Red-Tagged Buildings, Northridge Earthquake, 1994

Damage	*Pre-Act Buildings*	*Post-Act Buildings*
Structural		
Red tags	20	0
Yellow tags	16	1
Green tags	22	30
Nonstructural		
Major	40	9
Minor	14	22
Not reported	4	0

Table 9-3 Distribution of Beds by Survivability Index Classification

Area	*A, B*	*C*	*D, E, F*
Statewide	14,886 (17%)	52,459 (58%)	23,705 (26%)
OES Region 2: Mendocino to Monterey	3,690 (16%)	11,367 (50%)	7,448 (32%)
Alameda and Contra Costa Counties	1,176 (20%)	2,772 (47%)	1,915 (33%)
Used in this study	20%	50%	30%

9-2
Patients evacuated to the parking lot at Sepulveda VA Hospital, Northridge earthquake.
LA TIMES PHOTO

E, and F. For the purposes of this study, assume that 20% of the beds in all locations are in good buildings, 50% in marginal buildings, and 30% in bad buildings.

Figure 9-1 is a plot of the location of the beds; in general, the size of the dot is some indication of how many beds are in that location, and the density of dots indicates number of facilities. In Alameda County, almost all the facilities are very near the fault. In Contra Costa County, quite a few are in the eastern county. The facilities in San Joaquin County are quite distant from the event.

When we overlay the location of beds on this map with a shaking intensity map, we can estimate how many beds are subject to different levels of shaking. Hospitals can be put into three different damaged conditions for the purposes of emergency planning (table 9-4). Level 1 is essentially operational; the buildings would certainly be capable of taking in casualties. They may not have any water, but they certainly could take care of their own patients and casualties. At the intermediate level, Level 2, the buildings probably would not have to be evacuated, but they would have significant damage and probably would only be able to treat casualties in some limited way. The third category, Level 3, is for bad performers—evacuation or collapse (figure 9-2).

The percentage of buildings assumed to be in each state can be calculated as a function of shaking intensity. For example, for A and B buildings in high shaking intensity, 90% would be in Level 1 and 10% would be in Level 2. For the bad buildings, 40% at this shaking level would be collapsed or evacuated (Level 3), 30% in Level 2, and 30% in Level 1.

Table 9-4 Probable Damage Level for Various Shaking Intensities by Survivability Index Classification (Percentage of Beds)

Classification	*Level 1*	*Level 2*	*Level 3*
Shaking intensity: Light			
A, B	100%		
C	100%		
D, E, F	100%		
Shaking intensity: Moderate			
A, B	100%		
C	90%	10%	
D, E, F	80%	20%	
Shaking intensity: High			
A, B	90%	10%	
C	50%	40%	10%
D, E, F	30%	30%	40%
Shaking intensity: Very high			
A, B	60%	30%	10%
C	20%	50%	30%
D, E, F		30%	70%

Many studies count licensed beds, but there's also a category called available beds, which counts the *real* beds that are there. For example, in Alameda County there are about 4,800 licensed beds, but there are only 3,500 available. In more recently developed counties, like San Joaquin, there is a very small difference because the hospitals have not grown old and started to reduce themselves. However, in San Francisco there is a huge difference between the 5,200 licensed beds and the 3,600 available.

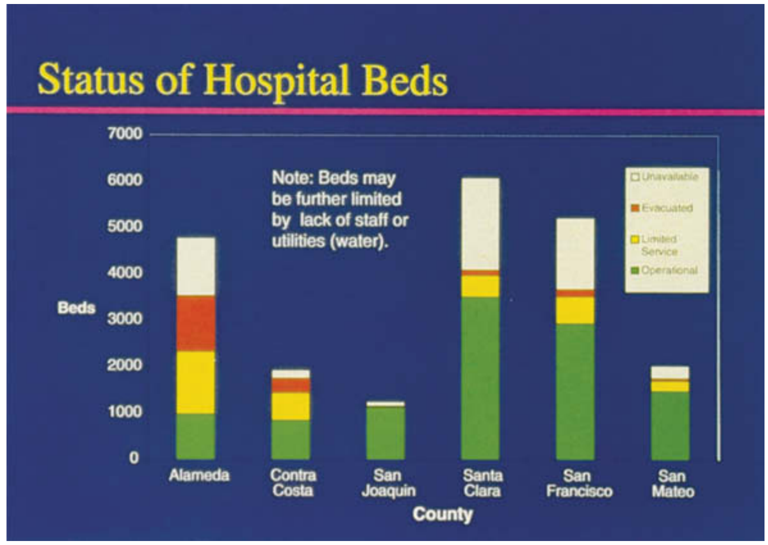
As can be seen in figure 9-3, for Alameda County, which is the hardest hit county, about a third of the hospital capacity will be evacuated (Level 3), about a third will be in limited service (Level 2), and about a third will be operational (Level 1). In Contra Costa County, about half will be operational, a third in limited service, and a small number evacuated. In San Joaquin County, far to the east, there will be almost no effect. And in Santa Clara, San Francisco, and San Mateo Counties, there will be quite a small effect.

The assumption that there might be 20,000 injuries requiring hospitalization and a total of only 10,000 beds available leads to the conclusion that local facilities will be severely strained.

Vulnerability Reduction

As already mentioned, there are several new EOCs completed. There have been some fire stations retrofitted in San Francisco. Communication has been a weakness in every earthquake, and state, county, and local agencies are really working on that. Everyone is trying to get redundancy in communications. The hospitals have something called CHORL, which is a computer-aided way to track who has beds and who has supplies so that they can exchange them. Unfortunately, right now it's based on land-line communications.

All the San Francisco fire station retrofits are funded; it'll just be a matter of time before they get the work done. All the Oakland fire station retrofits are funded. The Oakland Police main



9-3 *Status of hospitals after the scenario event, by county.*

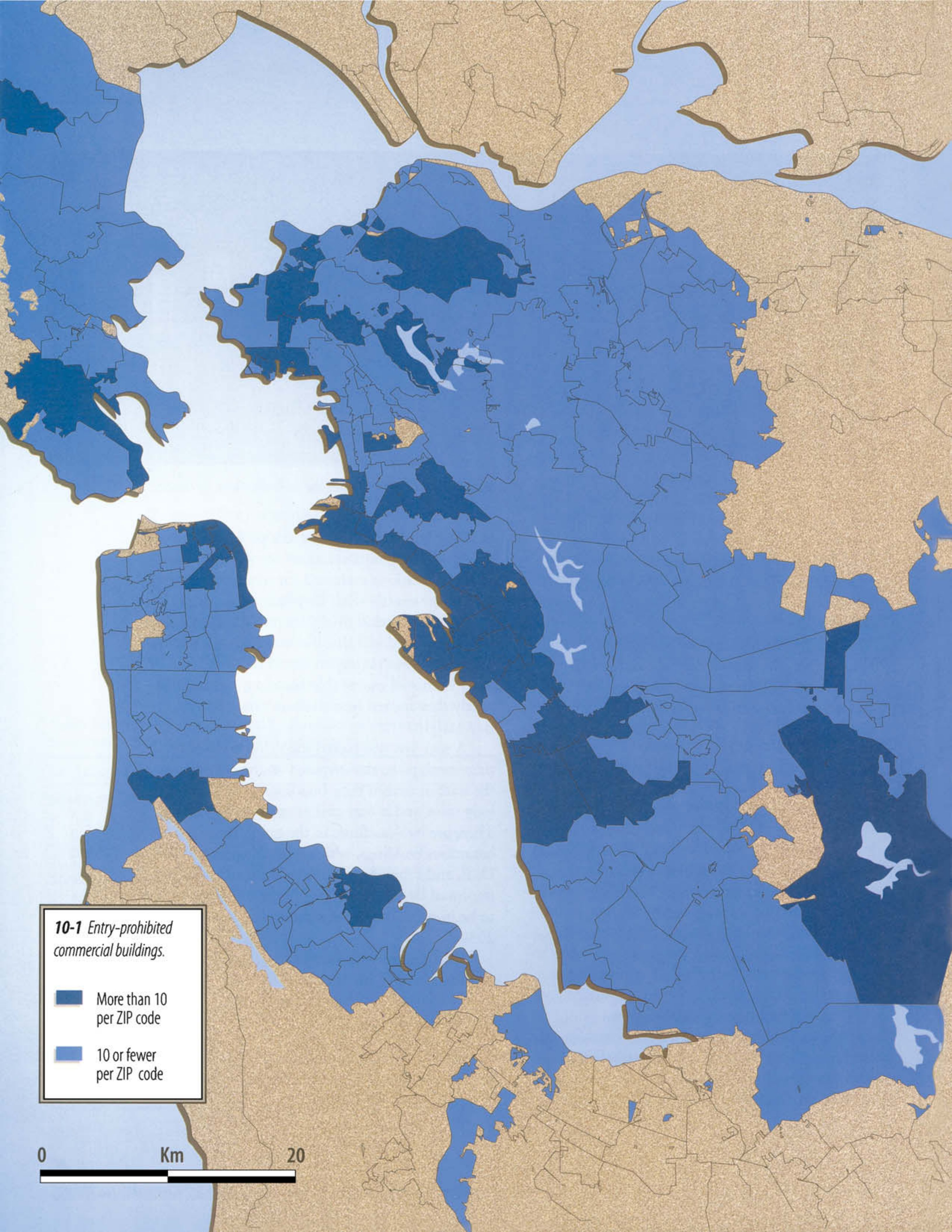
building has been identified as a problem, and they're working on a solution. San Jose has had all its fire stations evaluated for seismic strength; they know exactly what they have to do. In Berkeley, evaluation of all city buildings has been done. Hayward identified its city hall as a real problem: it was sitting on top of the fault. They've moved out of that building, but unfortunately they moved into a tilt-up down on the Bay margin.

A state law was passed following the Northridge earthquake that required all the hospitals in the state to retrofit their buildings. It will take a long time, and it may cost as much as $13 billion. There are two deadlines in the program: all the hazardous buildings, which I would characterize as D, E, and F buildings, have to be structurally improved by the year 2008; all the buildings have to be in substantial compliance with the law by 2030.

So if we can wait thirty-five years for the earthquake, we'll be fine.

Reference

Seismic Safety Commission. 1994. Governor's Executive Order report. Background report 7. Sacramento, California.



10-1 *Entry-prohibited commercial buildings.*

Chapter 10

Commercial and Residential Buildings Affected by Ground Motions

Ronald Hamburger, EQE International

This chapter takes a tour through the major cities along the length of the fault rupture, starting in San Pablo at the north, moving through El Cerrito, Richmond, Berkeley, and Oakland, and ending in San Leandro and Hayward, with a detour west to San Francisco (see figure 10-1). We will examine specific building types, and I will report on how those types have performed in recent earthquakes. I do not know what is going to happen to each building; I'm trying, rather, to show trends.

It is helpful to compare the northern Hayward earthquake with the Northridge earthquake of January 1994 because the exposures for those two events are very similar. If we look at the major damage sites in the Northridge earthquake, we see the Cal State Northridge campus. Along the Hayward fault are the UC Berkeley campus, the Cal State Hayward campus, and the Contra Costa, Mills, and Chabot College campuses. Shopping centers were a big source of damage in the Northridge earthquake; both Northridge Fashion Center and Topanga Plaza Center had major damage to the buildings and were out of service for a long time. On the northern Hayward fault, there are Hilltop Mall, El Cerrito Plaza, and Southland Shopping Center.

Business and industrial parks were heavily developed throughout the San Fernando Valley and are heavily developed in the East Bay and San Francisco area. Residences were the major source of loss in Northridge, and they will be the major source of loss in the northern Hayward earthquake. The one big difference between the northern Hayward and the Northridge earthquake is that there is more older exposure in the northern Hayward area, where most buildings were constructed between the early 1900s and the 1950s. There are few very modern buildings.

Damage Types

The tour begins up in San Pablo, at the very northern end of the fault rupture. The Hilltop Mall shopping center is located about a mile and a half from the epicenter. This is a shopping center very similar in construction to the Northridge Fashion Center (figure 10-2). There were five

10-2 *Damage to Bullock's department store in the Northridge Fashion Center, Northridge earthquake, 1994.* LA TIMES PHOTO

10-3 *Damage to wood-frame, multifamily residential buildings, Northridge earthquake.*

10-4 *Damage to downtown strip shopping mall, Northridge earthquake.*

10-5 *Damage to apartment building constructed over garage, Northridge earthquake.*

major anchor stores in the Northridge facility and a large mall connecting them. All of those stores were out of business for at least eleven months following the earthquake. Two of the major anchors, The Broadway and Sears, were reestablished in business on November 1 of 1994; the balance of the anchor stores and the mall itself were still being repaired and reconstructed and were still out of business thirteen months later. We expect similar business interruption at Hilltop Mall following the northern Hayward earthquake.

Around the Hilltop Mall area are a number of new wood-frame, multifamily residential buildings—apartments, town houses, and condominiums. A number of similar structures were affected by the Northridge earthquake. Some older structures collapsed (figure 10-3). No newer buildings collapsed; however, they did have extensive damage because neither the construction quality nor the design quality was what it should be. Many of those buildings were out of service in Northridge for more than a year. Similar buildings will remain out of service after the northern Hayward earthquake for a year or more.

Proceeding south, Contra Costa College sits directly atop an active trace of the Hayward fault. These are stoutly constructed, reinforced masonry buildings, but they appear to have wood-frame roofs and panelized plywood systems. In the Northridge earthquake, there were partial collapses of some similar buildings.

Moving a few blocks to the west into the commercial district of San Pablo, we find a typical downtown strip shopping mall with a Long's Drugs, a Safeway, and similar stores. In Northridge, in a similar development, many types of damage occurred in the buildings (see figure 10-4). Most of the Northridge stores had not yet been reconstructed by 1995.

Housing damage was a big problem following the Northridge earthquake, particularly damage to apartment buildings constructed over garages (figure 10-5). When structural engineers from the Bay Area traveled to the Los Angeles area in

1994, we were surprised at the number of such buildings. But when I drove along the Hayward fault over the last few months, I was surprised at the number of buildings constructed this way in the San Francisco Bay Area. The only difference between the building construction here and in the San Fernando Valley is that Bay Area buildings tend to have garage doors. However, I don't believe that the garage doors are going to be adequate bracing to prevent collapse in a number of these buildings.

The typical housing in San Pablo was constructed prior to World War II. It's a light bungalow-type construction, typically less than 1,000 square feet. Comparison to the housing stock in the Coalinga area, and the damage there in 1983 (figure 10-6), reveals the damages we can expect in many of these houses.

The housing in Richmond is of a similar construction, except in somewhat poorer condition. In the commercial district of Richmond, and in Point Richmond, there are a number of unstrengthened, unreinforced masonry buildings. We know clearly the types of damage that are likely in these buildings; there will be a number of collapses of these types of structures (figure 10-7).

In Richmond there is a big industrial belt consisting of older, concrete warehouse-type structures, reinforced concrete tilt-up structures (figure 10-8), reinforced masonry structures, and light-steel frame structures. Here begins a continuous band that runs along the margin of the Bay, straddling the railroad tracks that run from San Pablo in the north all the way south to San Jose. Much of the construction in the North Bay, which is most heavily affected by this earthquake, is older; much of it is likely to be subject to damage. More than 400 of these structures partly collapsed in Northridge; a similar number of these buildings will collapse in the Hayward fault earthquake.

An auto parts distribution center in Richmond was damaged in the 1989 Loma Prieta earthquake, despite being located seventy miles from the epicenter. It's located three miles from the

10-6 *Small bungalow that slid off its foundation in the Coalinga earthquake, 1983.*

10-7 *Damage to unreinforced masonry commercial building, Northridge earthquake.*

10-8 *Damage to reinforced concrete tilt-up structure, Northridge earthquake.*

10-9 *Damage to The Broadway department store at Topanga Plaza, Northridge earthquake.*

10-10 *Damage to unreinforced masonry and wood-frame storefront buildings, Whittier Narrows earthquake, 1987.*

10-11 *An old wood-frame house that shifted off its foundation as a result of the failure of cripple stud walls, Loma Prieta earthquake, 1989.*

epicenter of the scenario earthquake, so it will have more damage.

El Cerrito also has a number of low-income residential units, multifamily housing, and apartments built over garages. We know how these might behave. The fault is straddled by very densely built housing, almost all of which was put up prior to World War II. In very few buildings is there adequate anchorage of the house to the foundation or any bracing of the cripple walls.

At a shopping center in the commercial district of El Cerrito, we find a department store building that was retrofitted about seven years ago. The tops of a brace-frame are visible behind that building. The retrofit of this particular building was not necessarily intended to prevent business interruption, however; the retrofit was done to the same criteria as The Broadway store at Topanga Plaza at Northridge. The Broadway was out of service for four months following the earthquake (figure 10-9).

Farther south, in Albany, the commercial district is not in very good shape. There are a number of unreinforced masonry buildings along San Pablo Avenue and also a number of older, wood-frame, open storefront structures. The damage we can expect to see in these buildings is typified by that in downtown Whittier in the wake of the 1987 Whittier Narrows earthquake (figure 10-10). Many of the unreinforced masonry buildings will partly collapse. Many of the wood-frame buildings will be unusable for a month to several months while they're straightened back up and strengthened. The Albany commercial district will be largely out of business for a number of months after the earthquake.

Berkeley is a larger town, more heavily developed, but the age of the construction is very similar to what we've seen. There are many beautiful Victorians throughout Berkeley that date to the early 1900s or earlier. Most of them have not been seismically strengthened, and after an earthquake, many of them may look like this house in Los Gatos (figure 10-11). The commercial district in Berkeley has a number of unreinforced masonry buildings. Berkeley has passed a seismic strengthening ordinance, and some of these buildings have been strengthened; however, in the Northridge earthquake it was discovered that seismic strengthening to the Uniform Code for Building Conservation is not necessarily adequate protection against strong ground motion. Because downtown Berkeley will see ground motion roughly twice as strong as that on which the Uniform Code for Building Conservation is based, a number of these buildings will partly collapse in this earthquake.

On the UC Berkeley campus there is a strange mixture of construction: concrete shear-wall buildings dating to the 1930s and forties and brand-new ductile concrete frames being constructed today. Some of the buildings on the Berkeley campus obviously have good seismic resistance, but others do not.

Some of the buildings have been seismically strengthened; others, such as the Hearst Mining Hall, have not. A seismic study has been done, and there's a plan to base-isolate it, but the construction documents have not proceeded. The building is currently quite vulnerable. Even more vulnerable is Memorial Stadium, which sits directly atop the fault. It is somewhat similar in construction to the Los Angeles Coliseum, which had severe damage despite being more than thirty miles from the epicenter of the Northridge earthquake (figure 10-12).

Back toward the Bay, in Emeryville, there is a large residential complex. The buildings appear to be nonductile concrete-frame structures with short columns; a number of shear failures in such columns were seen in Northridge (figure 10-13).

In the major metropolitan area of Oakland, there's a much larger concentration of value. Downtown Oakland is a unique mixture of very old buildings, older commercial buildings constructed of unreinforced masonry, and newer high-rise structures. One steel-frame building located on Broadway had extensive architectural damage in the 1989 Loma Prieta earthquake

10-12 *Damage to Los Angeles Coliseum, Northridge earthquake.*

10-13 *Shear failure of columns in a nonductile concrete-frame hotel structure in Van Nuys, Northridge earthquake.*

whose epicenter was about sixty miles away. We expect ground motion from the Hayward fault earthquake to be roughly three times stronger than that in 1989.

Recently, Hall and Heaton (1995) stated that a number of tall, steel-frame buildings in the near-field of an earthquake could be subject to collapse as a result of velocity pulses. The tall, flexible-steel-frame buildings in downtown Oakland along Lake Merritt are all candidates for the effect that Hall and Heaton have postulated.

Farther south, toward the end of the fault rupture, San Leandro has the same type of apartment construction that we see in each of the other cities. The municipal library for San Leandro appears to be a reinforced masonry shear-wall structure constructed in the 1960s, without any shear walls (they appear to be made out of glass). In the commercial district, there are the usual unreinforced masonry buildings. Many of them have now been retrofitted, but to the Uniform Code for Building Conservation; the ground motion expected here is stronger than that anticipated by that code.

Hayward is south of the fault rupture zone, but because of ground motion directionality and directivity, it will get some of the strongest ground shaking in this northern Hayward fault earthquake. The old Hayward City Hall was designed by the same engineer who designed the original Olive View Hospital but before the hospital and with many of the same poor details. Prior to an evaluation in 1989, it was occupied by both city and commercial offices. After the evaluation, the city moved out, but many of the commercial tenants remain in the building.

Steel moment-resisting frame buildings would be subject to the same type of ground motion seen in Santa Clarita and Newhall following the Northridge earthquake. Some buildings there took on permanent lateral deformation (figure 10-14).

Downtown Hayward resembles most the Pacific Garden Mall area in Santa Cruz. It is a nicely decorated area of old unreinforced masonry buildings, most of which have not been seismically strengthened. Figure 10-15 shows part of the Pacific Garden Mall following the Loma Prieta earthquake—much of it became a series of basements.

10-14 *Damage to two-story steel moment-resisting frame office building in Santa Clarita, Northridge earthquake.*

We must also consider San Francisco, across the Bay. Many of the larger buildings downtown are steel moment-resisting frame structures. The City of San Francisco may find it necessary, as has the City of Los Angeles, to require inspections of the connections of these buildings. After a Hayward fault quake, many of these connections are likely to be fractured. Repair costs for some of these structures will range from 10% to 40% of their replacement cost.

10-15 *Damage to Pacific Garden Mall in Santa Cruz, Loma Prieta earthquake, 1989.*

Loss Estimates

For unreinforced masonry buildings, we're estimating something on the order of 500 red-tagged buildings, most in Alameda County, with a few in Contra Costa and San Francisco Counties. For tilt-up and other industrial and light-commercial buildings, we expect something on the order of 500 red-tagged buildings, most in Alameda and Contra Costa Counties. It is no surprise that they cluster around the zone of the fault rupture.

For residential buildings, we estimate something like 7,000 red-tagged buildings, spread out throughout the greater Bay Area. This does not necessarily mean collapses, although many of these buildings may actually collapse, but it does indicate housing units that will not be available for occupancy after the earthquake.

In order to develop the structural damage estimate, we at EQE used the same proprietary software and modeling technique we used following the Northridge earthquake to develop a dollar loss estimate for the Office of Emergency Services. Although that dollar loss was not completely accurate for each individual class of building, in aggregate it was reasonably representative of the overall loss. These numbers should be looked at as representative of the overall losses that are likely.

This estimate accounts only for structural damage; it does not include loss of contents or business interruption. Double these numbers to get an idea of the total dollar loss from the earthquake. We're estimating something on the order of $16 billion for total structural damage, $10 billion of that in residential construction. There will be about $3 billion in damage to unreinforced masonry structures, and about $1.5 billion to tilt-up structures. These losses are roughly double those in the Northridge earthquake.

Acknowledgments

Dr. Charles Scawthorn and Thomas Larson, both of EQE International in San Francisco, assisted me with this chapter.

Reference

Heaton, Thomas H., John F. Hall, David J. Wald, and Marvin W. Halling. 1995. Response of high-rise and base-isolated buildings to a hypothetical Mw 7.0 blind thrust earthquake. *Science* 267:206.

__11-1__ Ships being loaded at the Port of Oakland.

Chapter 11

Local Emergency Response and Relief

Henry Renteria, City of Oakland Office of Emergency Services

Oakland is a highly industrialized city right across the Bay from San Francisco; it has a population of approximately 375,000 people. It is a major container port (figure 11-1). The Hayward fault runs right through Oakland and its neighbor cities.

At the city Emergency Operations Center, we expect to start getting major information from the field within a couple of hours of the earthquake. We have a predecessor to a major GIS system that we're setting up in the next two to three years, and through our 800 megahertz system, the helicopter that we have from our police department, and the crews from the field, we'll start getting reports of major structural damage, downtown especially (figure 11-2), and of major fires downtown or near the Port. And we will institute our Emergency Management Plan and Organization.

The City of Oakland has deviated a little from the standardized multihazard functional plan and developed departmental operations manuals. These are easier to read and carry around, and therefore, all of our departments are now equipped to handle their individual roles and responsibilities. After the earthquake, we will immediately activate our EOC. We do not have to wait for clearance from some other jurisdiction or higher authority. The decision to declare a local emergency can be made by the mayor, the city manager, the police or fire chief, or me.

We anticipate that some employees will have trouble getting in to work. If they have to check on their families, we allow for that. Once they have done so, they'll start reporting to the EOC. Currently we are using a temporary location for our EOC while we build a new $7 million facility that will house all of our departments as well as the agencies that are part of our Emergency

11-2
Downtown Oakland near Lake Merritt, building at lower right damaged in Loma Prieta earthquake, 1989.

11-3 *Apartment house in Santa Monica damaged in the Northridge earthquake, 1994.*

11-4 *Five homes in Granada Hills burned when gas mains were broken, Northridge earthquake.*

Management Organization. EOCs get crowded very quickly, and they're very noisy and very labor intensive.

We will immediately activate our amateur radio system. We have a mutual aid agreement with the Amateur Radio Emergency Services (ARES) and the Radio Amateur Civil Emergency Services (RACES) to provide emergency amateur radio support at all of our fire stations and all schools that are designated as shelters. According to the emergency plan in effect with this agreement, volunteers will be dispatched to those locations.

We will also activate our field command posts. Both the fire department and the police department have mobile command posts. These two command posts will be in areas that have been designated high-risk and in areas with high concentrations of damage and incident response. All battalion chiefs in our fire department are equipped to institute the Incident Command System (ICS). According to California's Standardized Emergency Management System, all jurisdictions must use a standardized management approach in responding to disasters; the Incident Command System is a tool that allows an organized approach to management, operations, logistics, planning, and finance. As the event grows or shrinks, ICS escalates or downsizes.

All school district facilities are under a school emergency management plan instituted in 1994. The unified school district operates independently, but it will activate its plan and evacuate schools as needed; children will be taken to designated reception centers nearby.

We will get immediate reports of damage to residential structures, like that shown in figure 11-3. Reports will address other types of structures within the Port of Oakland area and areas that are designated as landfill. We expect a number of types of collapses.

Oakland's neighborhood-based organization, Citizens of Oakland Respond to Emergencies (CORE), is a group of people trained by our fire department to respond to major emergencies.

The CORE program is a direct result of the Loma Prieta earthquake. Neighborhood groups such as the Neighborhood Crime Watch and the Home Alert programs have been taught basic skills in search and rescue, first aid, and fire suppression. These people are designated and recognized by our police and fire departments, and they serve as a support service for the first responder. They are also responsible for their area and their neighborhood. The CORE program currently has three modules; in 1995 we instituted a CORE 4 program, which is equivalent to a volunteer fire department. We anticipate that those teams will be available to help fight fires (figure 11-4).

Mutual aid will be put into effect, although in a regional disaster we don't anticipate the type of support we receive in a localized disaster. We will identify major staging areas or mobilization areas where all the various departments can get together and dispatch from there.

The Oakland Fire Department is one of two designated urban search and rescue teams for Northern California; the other one is located in Menlo Park. The teams come in very handy in a localized disaster, but in a major regional event, two teams aren't going to be able to handle all the demand. We anticipate some high-rise structural collapses. Our CORE teams will be available to assist in triage centers and in casualty collection points that we have predesignated with the Alameda County Emergency Medical Services. We're estimating between 15,000 to 25,000 injuries and upward of 4,000 casualties. Our medical facilities are clumped together, for the most part; Pill Hill, as we call it, has all of our major hospital facilities. A lot of our resources are at risk.

Shelters will be open within a few hours. People will be congregating there. Many of our neighborhoods already know where their nearest shelter is located. For the most part, we have designated twenty-five high schools and junior high schools as primary shelters, with an additional twenty private schools that are run by church organizations (figure 11-5). These

11-5 *Shelter at Hollywood High School after the Northridge earthquake.*

11-6 *One-stop center for disaster applications set up after the Northridge earthquake.*

11-7
Ferries that helped move commuters while the Bay Bridge was closed after the Loma Prieta earthquake remain in service.

facilities have been approved by the Red Cross. We have the capacity in Oakland to house approximately 10,000 people. However, if we experience the same thing Kobe did—20% of our population in shelters—95,000 Oakland residents will need shelter. We need to start looking at other facilities that could be used as shelters.

We will quickly activate our Community Assistance Center. A result of our experience in the 1991 Oakland hills fire, the Center has been open and continues to be ready to be activated in case of another disaster. This is a one-stop service center for victims to get anything they need: personal help, mental health help, permits, loans. We activated this facility within 24 hours of the fire, and we are prepared to reactivate it within 6 to 12 hours after any other event. After the fire it was also used by FEMA and the state Office of Emergency Services—there are many advantages to co-locating (figure 11-6).

The media will be everywhere. To deal with the media we will utilize the plan we instigated during the rescue effort at the Cypress Freeway. We will have designated Media Reception Centers where we will hold daily briefings and press conferences, coordinated by our designated public information officers. Our PIO plan has identified thirty individuals within the city as emergency public information officers. This is a very critical point for getting information out to the public and to the community.

We expect much of the transportation system to be down, so there will be a challenge getting resources in and out of the area. We are looking at use of the waterways and other forms of transportation (figure 11-7) to bring resources in. Currently, the city parks all its police cars under Interstate 880, the portion of the Cypress Freeway that didn't fall down. Will this structure still be standing? If so, we must move these automobiles out quickly, because they are a major part of our police force.

City Hall has recently been retrofitted and put on a base-isolation system.

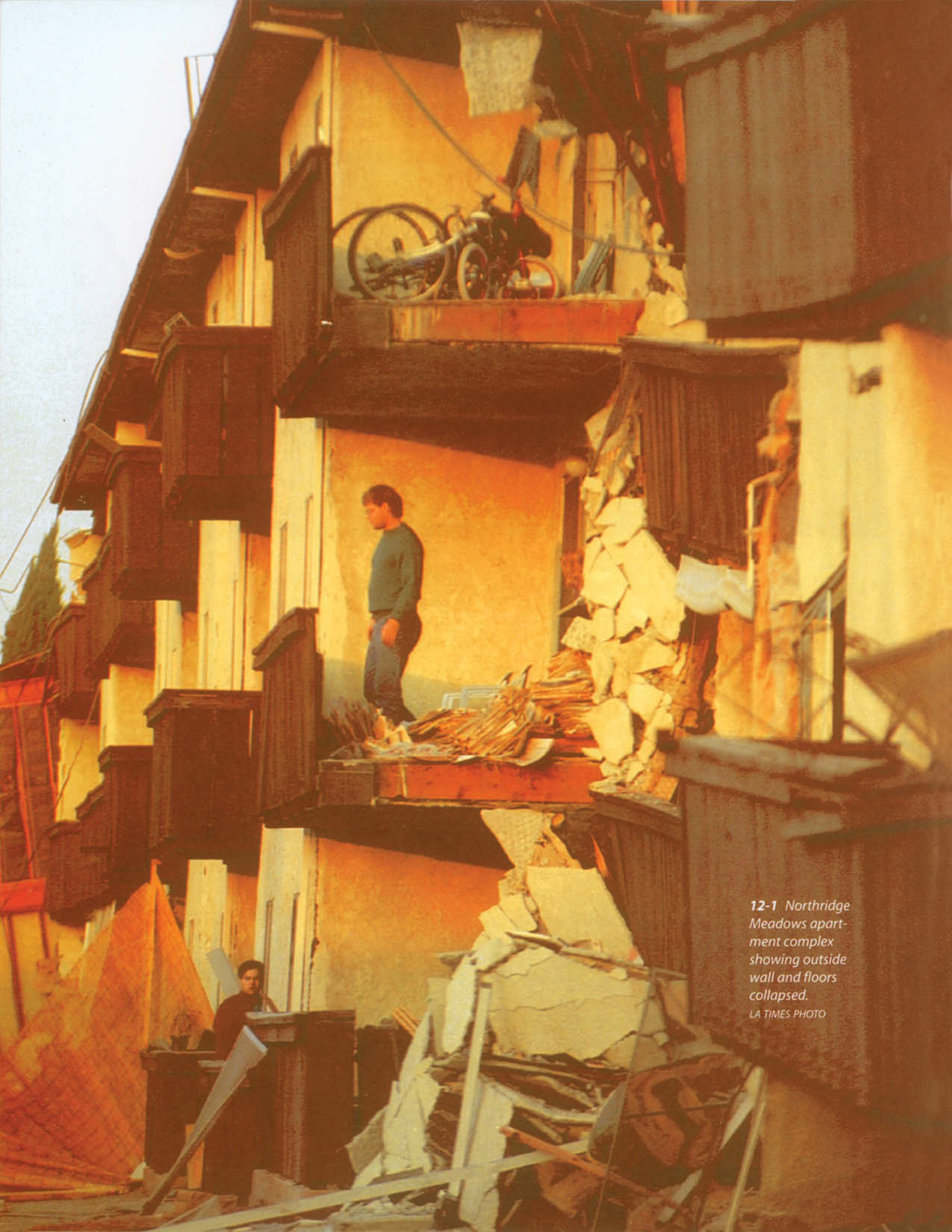
The Oakland–Alameda County Coliseum complex (figure 11-8) is already a designated staging area for equipment and supplies. After the experience in Kobe, we are also considering it as a possible shelter. It has the capacity to house a

11-8
The Oakland–Alameda County Coliseum complex with a BART train in the foreground.

large number of people, supplies, and resources, if we need to. And of course, the parking areas on each side are quite large and can land helicopters.

We will immediately start asking for federal resources and state resources. The U.S.S. *Mercy* will be docked in Oakland for another year or so; it is a 1,200-bed floating hospital. We will request the use of it as a medical facility, anticipating the loss of Pill Hill and the hospitals there. Of course, if the ship isn't in or the Navy base has closed, we have a major problem on our hands.

The airport probably will be closed, from our experience in the Loma Prieta earthquake. We will be requesting direct assistance from the Operational Area (County) with our working communication systems. Because we have a very active Emergency Managers Association in Alameda County, we will also utilize that connection, assuming that some other jurisdictions will be minimally affected.



12-1 *Northridge Meadows apartment complex showing outside wall and floors collapsed.*
LA TIMES PHOTO

Chapter 12

Regional Response

Richard K. Eisner, California Governor's Office of Emergency Services

Local governments have the primary responsibility for disaster response. While the Hayward earthquake will certainly be a regional disaster, affecting more than fifty municipalities and counties, the primary response will be undertaken by individual local governments, each reacting to their needs with their own resources. The regional and state levels are brokers of resources rather than first responders.

The California Office of Emergency Services (OES) provides assistance through its mutual aid regions, receiving requests from local governments for personnel and equipment, identifying resources from adjacent jurisdictions, other mutual aid regions, state agencies, and—if state resources are exhausted—the federal government. One of the first needs is for shelter (figure 12-1). When resources are provided to local governments, the management of the resources also transfers to the local government, consistent with "local home rule" concepts embodied in California law and tradition.

The role of the OES, Coastal Region, is that of a conduit for information and requests for assistance from local governments (figure 12-2). To do this job, it must first assess the situation within the region and advise the State Operations Center of disaster impacts and potential resource needs to support response. The region then coordinates resources from within the region, accesses resources from other mutual aid regions, requests federal resources, and supports local government response with intelligence and situation assessment.

12-2 *A chief role of California's OES is to support local governments' response to disasters such as the Oakland hills fire of 1991.*

The OES region can provide support to local governments by obtaining assistance from other local governments, assigning missions to state agencies to support local governments, providing state or local government with management support, and using the region's geographic information system (GIS) as a tool to assess the situation and project demand for state support. The region can also provide technical assistance in emergency management through Emergency Managers Mutual Aid (figure 12-3), management teams from the California Division of Forestry and Fire Protection, and qualified inspectors through the State Safety Assessment Program.

OES Response to the Scenario Earthquake

The response by OES is based on a number of assumptions: The violence and duration of

12-3 Public Works Mutual Aid team, Northridge earthquake, 1994.

ground shaking will leave many local governments severely disabled, victims of the earthquake and unable to respond. Regional, state, and federal response therefore cannot wait for requests from local governments. To shorten the built-in delay between a request for assistance and delivery of the resource to local government, the region will request resources based on projected need rather than specific requests. Resources will be staged as close to the damaged areas as possible, awaiting shipment into the disaster area.

The time line in table 12-1 shows the phasing of response and recovery for the foreseeable future. The sections that follow describe the specific actions taken and resources provided as the response proceeds through the first three days of the aftermath.

0900 Hours, February 9

When the scenario earthquake took place at 9:00 A.M., February 9, 1995, the Regional Emergency Operations Center began taking action:

- Practiced duck, cover, and hold until the shaking stopped. OES regional staff are divided between those in the field and those at the headquarters office in Oakland.
- Assessed the condition of our facilities, staff, adjacent buildings, and the surrounding area to determine the region's capacity to support response.

0900 to 1000 Hours, February 9

During the first hour after the earthquake the region initiated the following activities:

- Assessed the impact of the earthquake on the OES region staff and regional response capability.
- Established a Regional Emergency Operations Center (REOC) and began 24-hour operations.
- Established communications with the State Operations Center and requested staff support for regional operations. (Utilized satellite communications system.)
- Initiated Emergency Public Information activities to inform local governments and the public of actions to be taken to assist response. Used Emergency Digital Information System to communicate with local media.
- Established communications with Operational Areas (counties) and requested damage/situation assessment. (Used satellite communications system.)
- Prepared situation assessment for the State Operations Center and the Governor's Office.

Table 12-1 Response and Recovery Time Lines

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 +

1000 to 1200 Hours, February 9

Within three hours of the earthquake, the region initiated and/or completed the following actions:

- Declarations of emergency by the governor and the president requested and secured.
- State agencies, including the California Division of Forestry and Fire Protection and the California National Guard, placed at the Regional Emergency Operations Center (REOC).
- Liaison established between the REOC and the Fire and Law Mutual Aid Systems.
- State and federal Urban Search and Rescue teams requested (figure 12-4).
- Federal Emergency Support Functions (ESFs) dispatched to the REOC.
- NASA Ames and the California Air National Guard requested to overfly and photograph the region.
- The State Safety Assessment Plan implemented, with engineers, architects, and building inspectors requested from outside the region.
- Model of impact of the earthquake attempted by regional GIS utilizing the Early Post Earthquake Damage Assessment Tool (EPEDAT) and the FEMA/NIBS/RMS methodology. Initial isoseismals and casualty estimates provided to the REOC and State Operations Center.

1200 to 2400 Hours, February 9

By 2400 on February 9, the REOC was staffed and the following actions initiated or completed:

- REOC fully operational and federal ESFs co-located.
- Assessment of local government capability completed and state and Emergency Managers Mutual Aid personnel requested to provide staff support.
- Initial requests for assistance from local governments filled and 24- and 48-hour needs projected. Out-of-region assistance requested and being staged in Stockton and at Travis Air Force Base.
- Multiagency council established and priorities set for initial action period.
- Brokering of regional and state resources continuing.
- Interregional access planning initiated with Caltrans, California Highway Patrol, and Metropolitan Transportation Commission (MTC).
- Intraregional transportation route recovery planning initiated with Caltrans and MTC.
- Planning task forces established for housing, water, route recovery.

12-4 *Urban search and rescue team looks for survivors, Northridge.*

Critical Issues and Resources During the First 72 Hours

There are six critical needs to be addressed during the first 72 hours (figure 12-5):

1. Provision of potable water
2. Mass shelter and feeding
3. Identification and mobilization of regional staging areas and resource distribution system
4. Transportation route recovery
5. Medical response, including casualty collection and triage
6. Airport and harbor restoration

12-5 Shelters provide water and sanitation facilities, Northridge.

12-6 President Clinton talks with Caltrans workers during his visit to areas damaged by the Northridge earthquake.

State Resources

The state made the following resources available within the first 24 hours:

- California National Guard personnel, aircraft, and equipment
- Department of Forestry and Fire Protection personnel
- Fire and Law Mutual Aid
- Coroner Mutual Aid
- Public Works Mutual Aid
- Emergency Managers Mutual Aid
- State USAR Task Forces
- Safety Assessment Volunteers
- California Conservation Corps

Federal Resources

The following federal resources were requested within the first 24 hours:

- Urban Search and Rescue task forces
- Fire-suppression personnel
- Department of Defense transportation support, including fixed and rotary wing aircraft
- Helicopters, helicopters, and more helicopters
- Mass feeding and shelter resources and support from the National Guard, Army, and Navy and from the Red Cross and the Salvation Army
- Potable water supply and distribution
- Medical resources

The following federal resources were available within the first 24 hours:

- FEMA Advance Planning Team to assist in planning federal response
- FEMA Urban Search and Rescue task forces
- FEMA/DOD communication equipment and personnel
- FEMA director
- Presidential advance team (figure 12-6)

The following federal resources were available within the first 72 hours:

- DOD personnel and heavy equipment from outside California
- DOD transportation equipment and support from outside California
- DOD mass feeding and sheltering facilities
- Red Cross, Salvation Army, and private nonprofit relief operations

Other Available Resources

In addition to the resources available from the state and federal government, regional and local response and initial relief will be dependent on assistance provided by the following organizations:

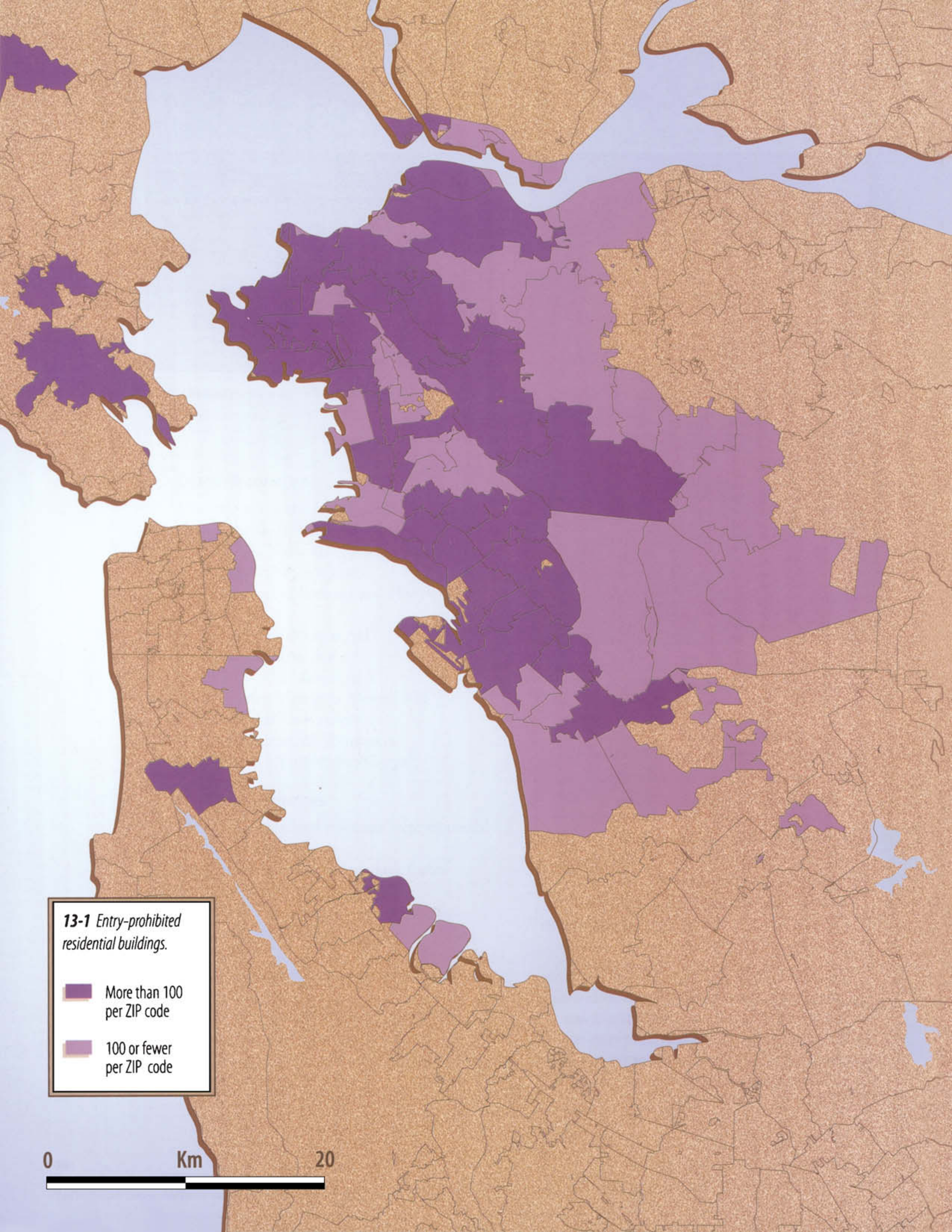
- Private nonprofit community organiza-

12-7 Volunteer engineers do safety assessments of damaged buildings, Loma Prieta earthquake, 1989.

tions providing health and welfare and other services (figure 12-7)

- Community-based organizations, particularly those serving non-English-speaking communities
- Religious organizations
- Grocery warehouses that distribute food and supplies
- Water bottlers and breweries
- CNN, ABC, CBS, NBC, and local media outlets

The Hayward fault earthquake will, no doubt, redefine our lives and careers. Those of us who live in the East Bay will be victims as a direct result of damage, as a result of disruption to transportation or utility systems, or due to the nature of our profession.



13-1 *Entry-prohibited residential buildings.*

Chapter 13

Housing and Social Recovery

Mary Comerio, University of California, Berkeley

The tragic loss of life at the Northridge Meadows apartment complex in 1994 brought home to Californians and to the nation the vulnerability of the housing stock in even moderate earthquakes. Let me be absolutely clear: in the Hayward earthquake scenario, we can expect four times the housing damage that we saw in Northridge. In chapter 10, Ron Hamburger outlined the extent of building damage throughout the Bay Area. I will focus on the housing loss figures and discuss their impact on local communities.

Housing Loss

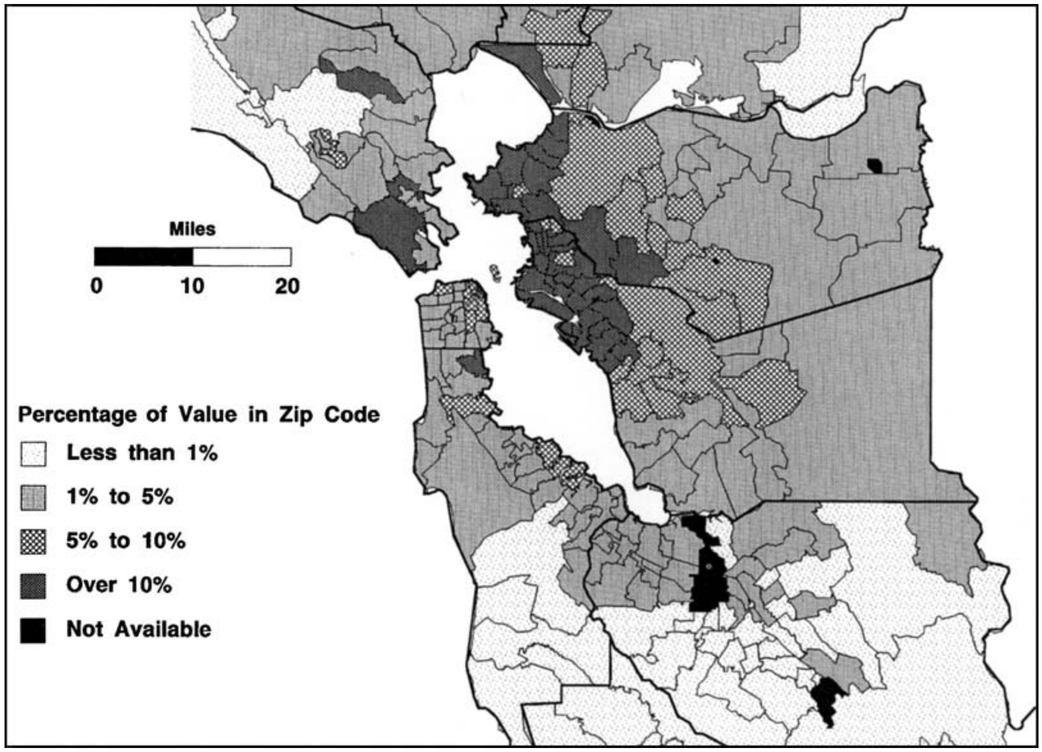
Figure 13-1 maps red-tagged wooden structures in zip codes with high concentration of damage. The map is derived from EQE HAZARD™, EQE International's computer model for estimating building and other losses in various disaster scenarios. The map shows that there is a very high impact in communities from Vallejo and Richmond down through Oakland to Hayward. In the dark-shaded areas, there are more than 100 structures red-tagged per zip code. The Association of Bay Area Governments (ABAG) has also developed estimates of uninhabitable dwelling units in future earthquakes affecting the Bay region. Their estimates of red- and yellow-tagged residential buildings tracks very well with EQE's estimates of loss to wood-frame buildings. ABAG projects there will be about 90,000 red- and yellow-tagged apartments and single-family homes, two-thirds of them in Alameda County (see table 13-1). This estimate of uninhabitable dwellings covers only the most significantly damaged; it does not represent the full extent of housing damage.

There will be $10 billion in residential structures damage. Approximately 10% of the housing stock in Alameda and Contra Costa Counties will be significantly damaged. The damage will be heaviest from the East Bay hills to the Bay, from Vallejo and Richmond through Oakland to Hayward and San Leandro. The dark-shaded areas in figure 13-2 show the zip codes where 10% to 20% of the value of residential structures is lost.

These two maps are a bit deceptive, however. The damage is not distributed evenly over this entire area; it is concentrated in pockets, depending on the soils and the construction type and quality. A similar map from the Northridge area (figure 13-3) shows very large areas of census tracts with more than 100 damaged units. However, as figure 13-4 makes clear, 60% of the vacated units were concentrated in fifteen neighborhoods in the San Fernando Valley.

Table 13-1 Estimated Uninhabitable Dwelling Units After an M7 Earthquake on the Northern Hayward Fault (ABAG 1996)

County	*Red-Tagged Homes and Apartments*	*Yellow-Tagged Apartments*
Alameda County	38,750	23,150
Contra Costa County	4,850	2,700
San Francisco County	5,950	9,350
Marin County	1,200	800
Other five counties	500	600
Total	51,250	36,600



13-2 *Residential damage as a percentage of total insured residential value.*

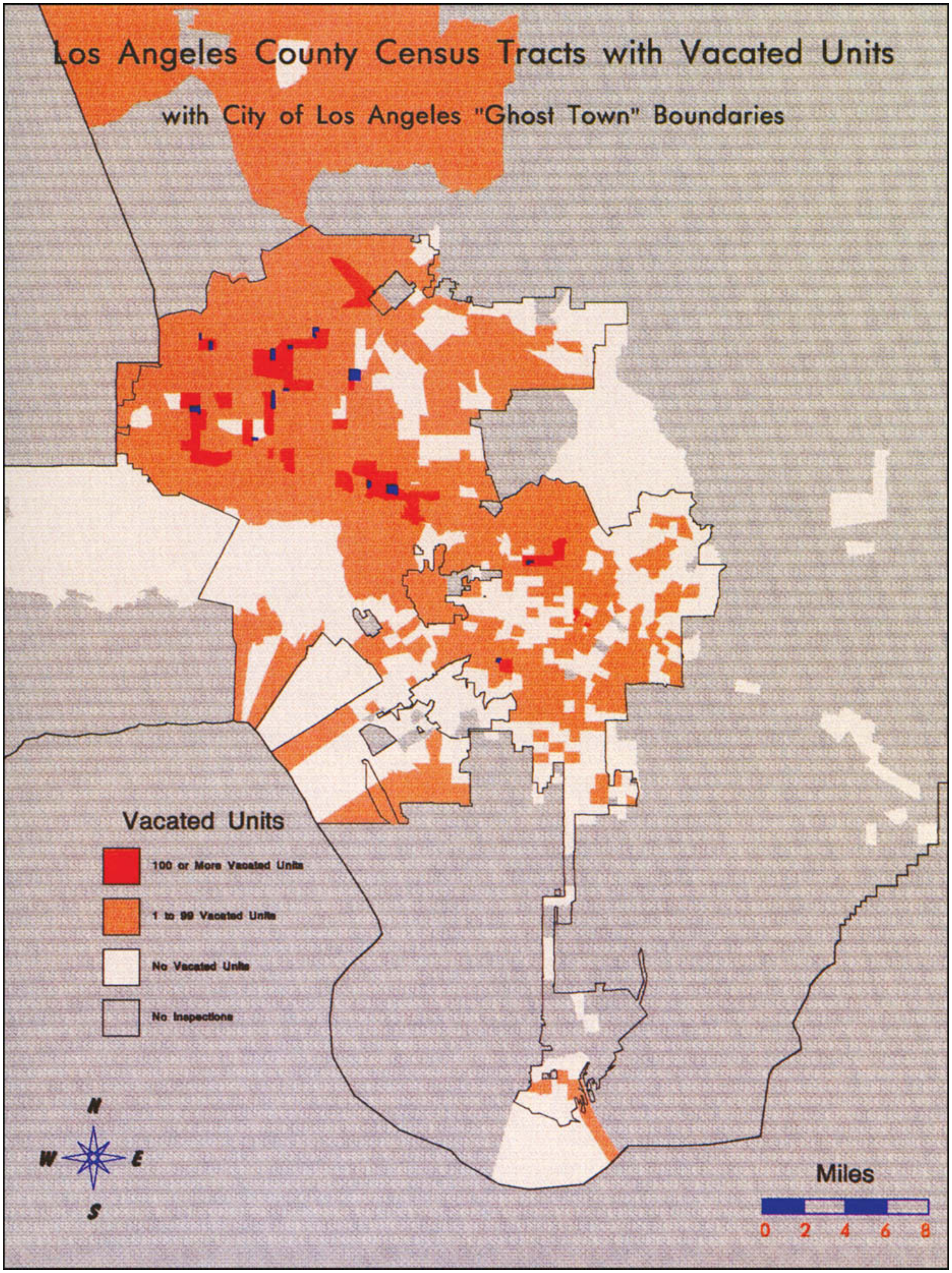
Comparisons with Other Disasters

In Northridge, seven times as many apartments as single-family homes were significantly damaged. Despite perceptions that California housing is largely single-family, 56% of the housing in Los Angeles is in multifamily structures. That same ratio is true in the Bay Area. Though densities vary from city to city, we have significant concentrations of multifamily buildings throughout the East Bay (figure 13-5). In Northridge, the buildings were overwhelmingly of two- and three-story wood-frame construction. The bulk of the damage was in pre-1976 structures, not because the code change in 1976 made newer buildings more damage-resistant, but because the damage was in direct proportion to the distribution of construction over time: 64% of the housing in the San Fernando Valley was built between 1940 and 1976, and 64% of the damage was from that era.

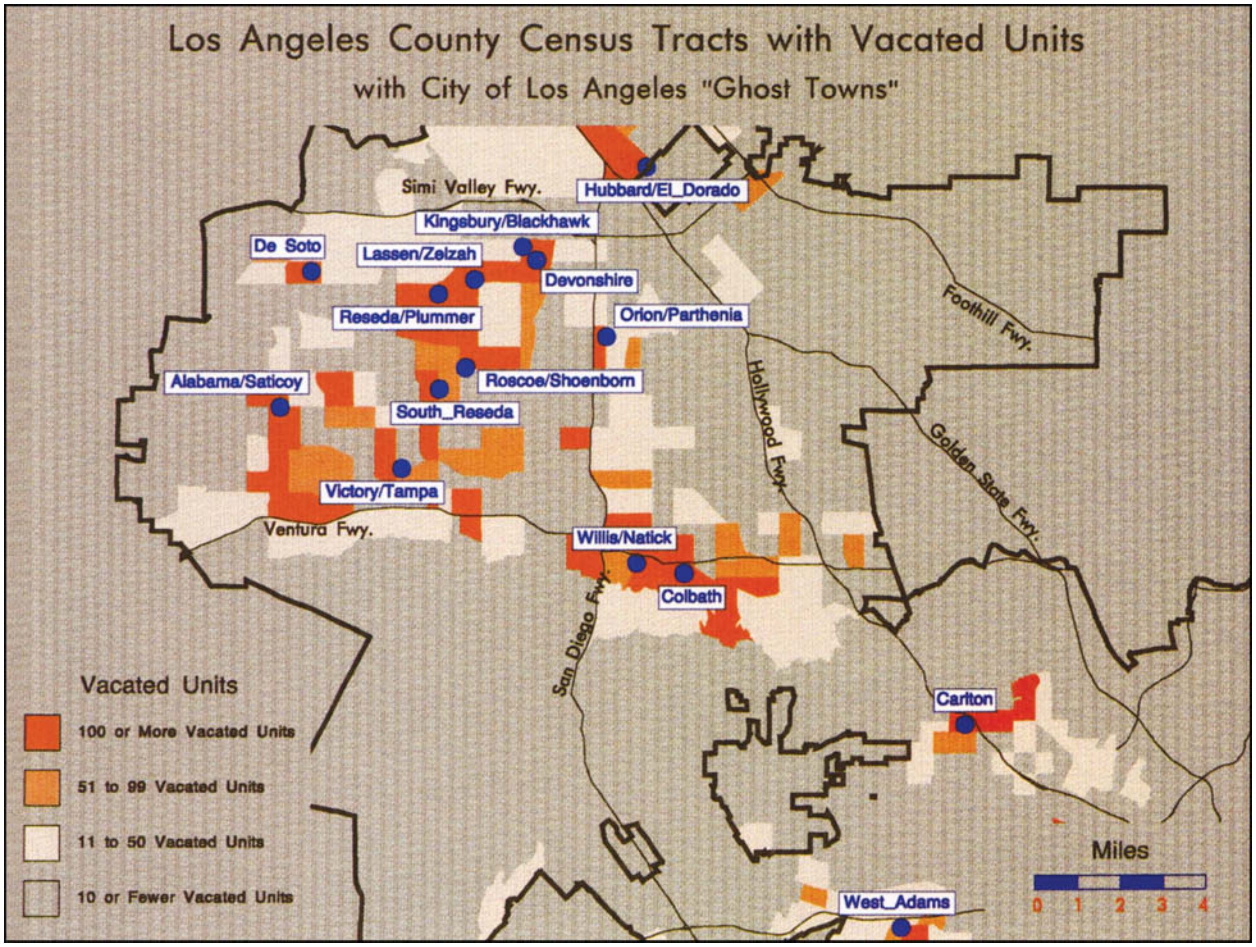
In the Bay Area, our housing is of the same vintage: 80% to 90% is pre-1976, and 30% is pre-1940. Figure 13-6 shows the median age of the housing stock in the high-damage areas.

In the Loma Prieta earthquake there were approximately 11,000 housing units lost or significantly damaged. The damage was concentrated in the downtown areas of Santa Cruz, Watsonville, San Francisco, and Oakland. Sixty percent of the housing lost was in single-room-occupancy (SRO) hotels and low-rent apartments. Though most of the damaged 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.

In Hurricane Andrew, 20,000 of the 48,000 housing units lost were in multifamily buildings. The high losses in multifamily units are not surprising, given that 40% of the housing in south Dade County was multifamily. In Northridge, 60,000 units were significantly damaged or lost; half of them, about 30,000, were vacated. Ninety



13-3 *Damage to residential units in the Northridge earthquake of 1994.*



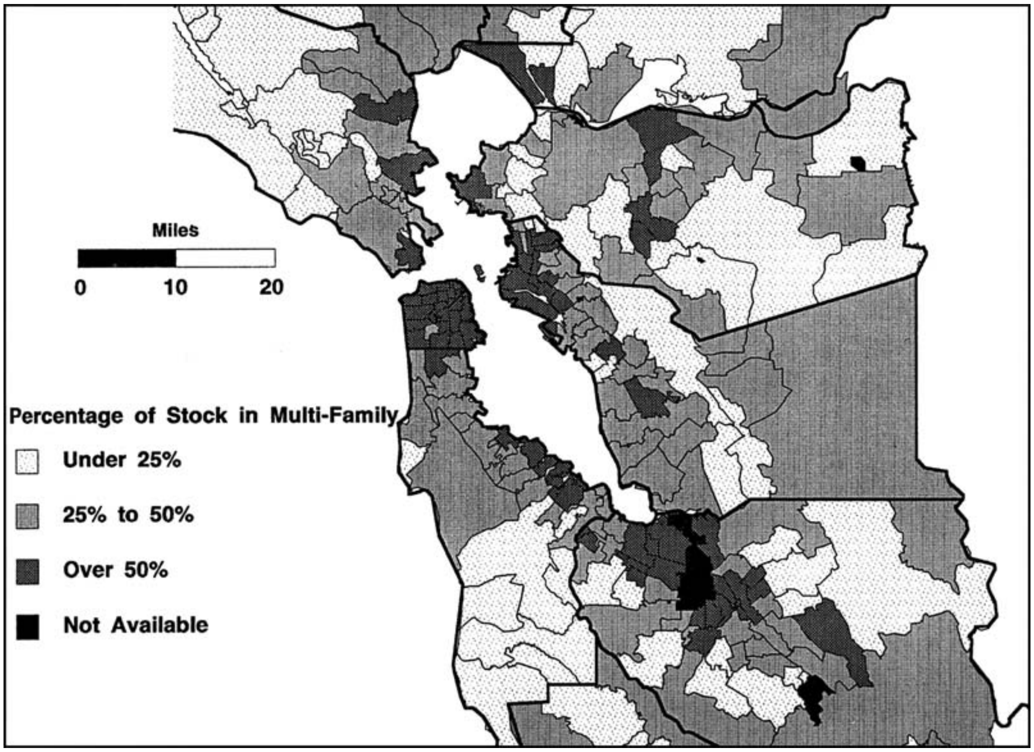
13-4 *Detail of residential damage in the Northridge earthquake.*

percent were in multifamily buildings, with the highest impact on the middle-class apartments in the San Fernando Valley. One year later, with an aggressive city loan program and a strong infusion of federal funds, about one-quarter of the multi-family stock has been financed for repair. By the end of year two, the loan money may run out, and we can expect that some portion of the damaged Northridge housing stock will go unfinanced and unrepaired, at least in the near term.

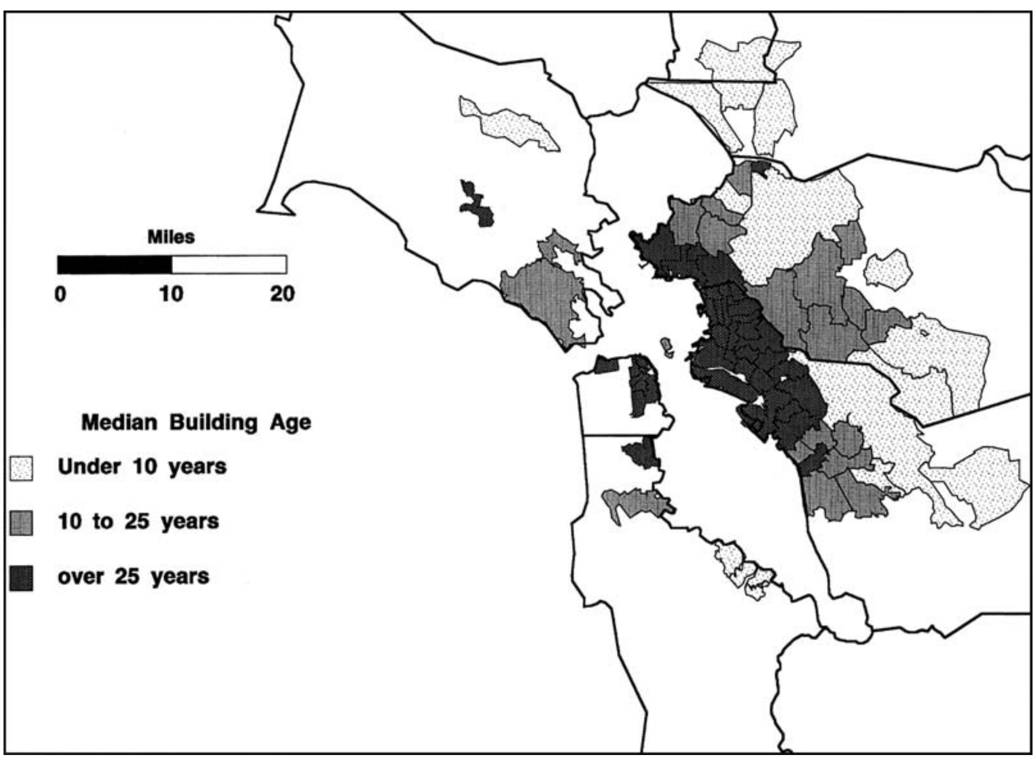
I think the ABAG projections described earlier for 90,000 uninhabitable housing units are actually low. I believe we will have yellow-tagged and even some green-tagged units that are unoccupiable, and therefore, we may see the occupants of 150,000 to 200,000 housing units looking for alternative housing in the event of a magnitude 7.0 earthquake on the Hayward fault.

Recovery Issues

In general, the housing recovery process is a combination of emergency sheltering, temporary housing, reconstruction, time, and funding. After Northridge, only 22,000 people stayed in emergency shelters. The weather was good; some people stayed outdoors, some stayed with their friends. Many found alternative housing quickly. The City of Los Angeles took an active role in matching victims who needed housing to available apartment units, and this effort was backed by an unprecedented infusion of funds



13-5 Housing stock composition (based on 1990 census data).



13-6 Median building age in high-damage areas (based on 1990 census data).

from FEMA's temporary housing program. In addition, 18,000 HUD (Housing and Urban Development) Section 8 rent vouchers were issued, and 4,000 rehousing grants were provided by the City of Los Angeles for a first month's rent. More significantly, Los Angeles had a vacancy rate of over 8%, with a 9.5% vacancy rate in the San Fernando Valley at the time of the earthquake. There were 54,000 vacant units in the San Fernando Valley before the earthquake, so after the earthquake, there was undamaged housing available to earthquake victims.

The post-Northridge sheltering situation was unique, and most families displaced by the earthquake found housing within three or four weeks. Compare that to the 1989 Loma Prieta experience, where the Red Cross reported 64,000 people sheltered. Three emergency shelters in Oakland, and two in San Francisco, were converted to homeless shelters because no alternative housing for single-room-occupancy (SRO) hotel residents was available. In Santa Cruz County the Red Cross operated emergency shelters for a record sixty-six days after the earthquake, and two months passed before FEMA (Federal Emergency Management Agency) agreed to supply temporary housing trailers in the City of Watsonville. After Hurricane Andrew, the sheltering situation was dire: 100,000 people were dislocated. There were as many as 85,000 victims in emergency shelters, and many were tent camps built by the U.S. Army when state and Red Cross efforts proved ineffective.

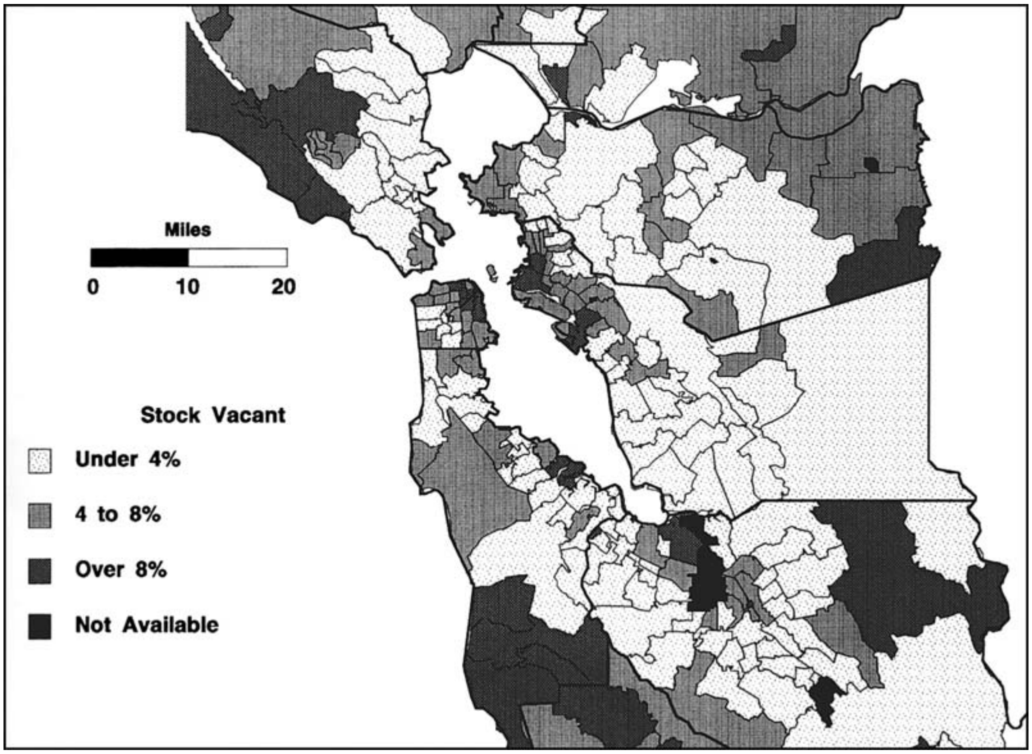
In the event of an earthquake on the Hayward fault, we will not have alternative housing for victims, and we will, in all likelihood, need to house people in tent shelters similar to those used after Hurricane Andrew. For long- and short-term sheltering issues, every aspect of our existing housing stock in the Bay Area is working against us. In the areas along the western edge of the East Bay, we have a housing stock that is old and predominantly multifamily. Vacancy rates are low. The population is ethnically diverse, incomes are modest, and rents are relatively low. Figure 13-5 and figure 13-6, referred to earlier, describe the density and age of the multifamily stock. Figure 13-7 shows vacancy rates to be extremely low throughout the Bay Area. Figure 13-8 shows median rents in the high-damage areas, where nearly twenty zip codes have average rents less than $500 per month. Figure 13-9 puts median household income at less than $40,000 in more than half of the high-impact damage area. Table 13-2 compares population and housing in the key affected counties, but figure 13-10 shows that values are much higher east of the hills and lower where expected damage is greatest.

Further, the East Bay is a very diverse area. Figure 13-11 describes the racial composition as a percentage of population in each zip code. Census data shows the population to be over 30% minority in the areas of high damage. And that figure doesn't include Hispanics, because Hispanics are counted as part of the white population in census tabulations.

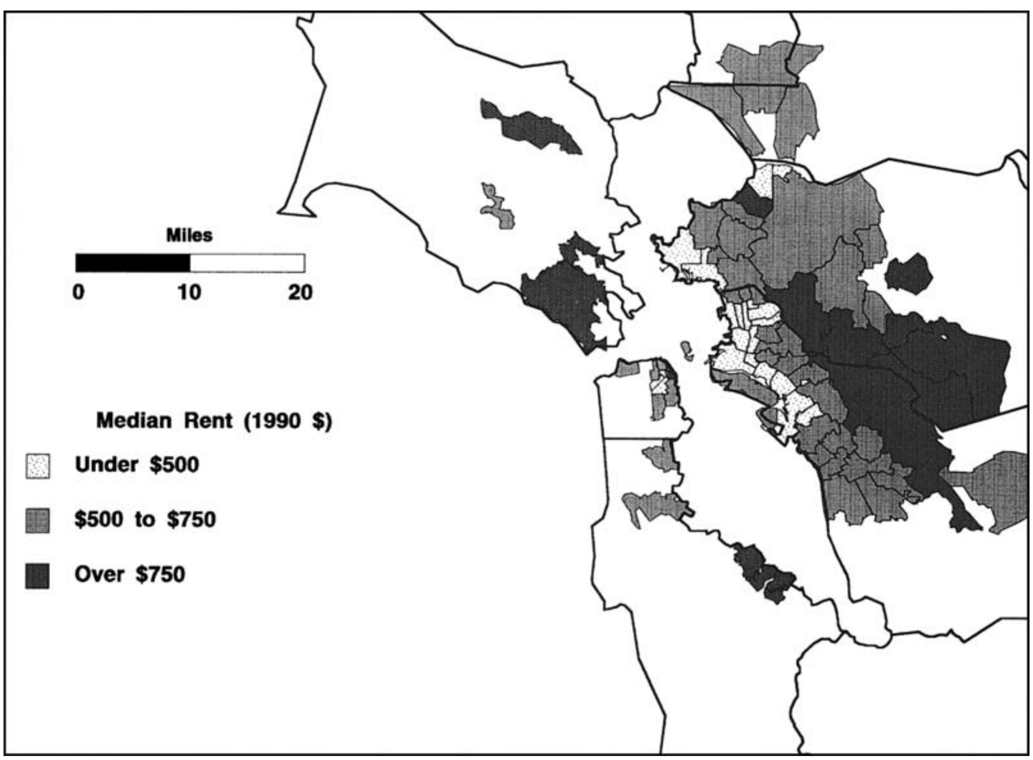
In past urban disasters, the expectation for housing recovery was five to ten years. This will likely be true in Northridge; it could be even longer in the Bay Area. In Northridge, as the first enormous effort to repair damaged housing begins to slow and Congress refuses additional disaster funds, lenders will foreclose on proper-

Table 13-2 Population and Housing in Three Bay Area Counties (1990 Census)

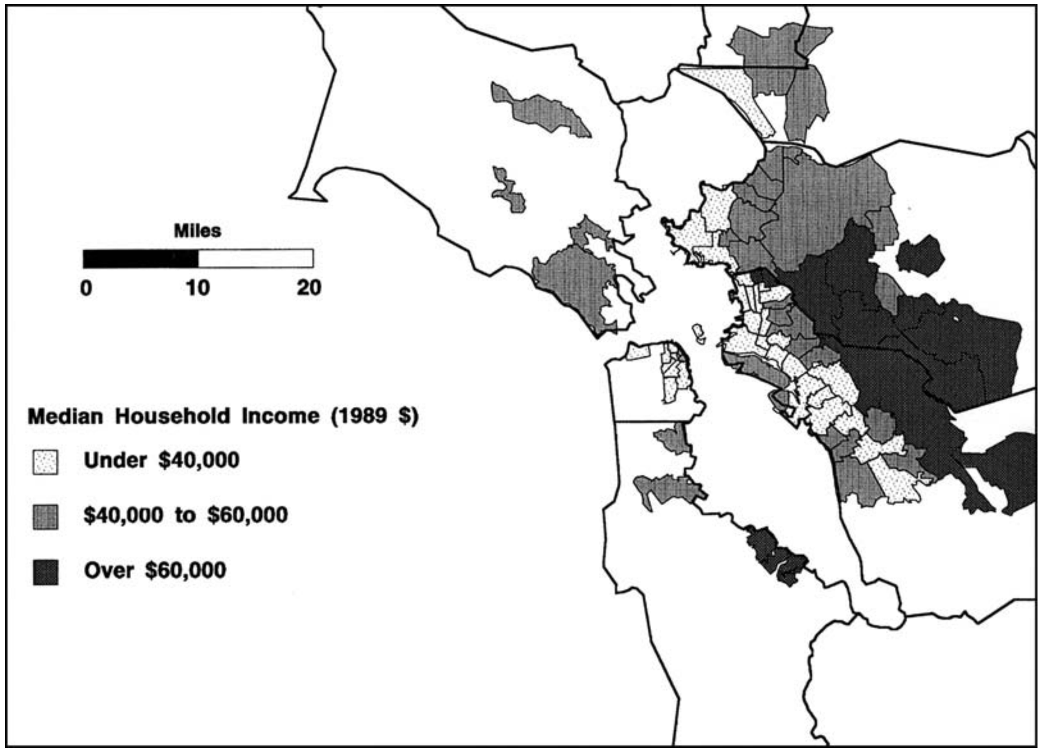
County	*Population*	*Total Housing Units*	*Median Household Income*	*Median House Value*
Alameda	1,300,000	504,000	$37,500	$227,200
Contra Costa	804,000	316,000	$45,000	$219,400
San Francisco	724,000	328,000	$33,400	$298,900



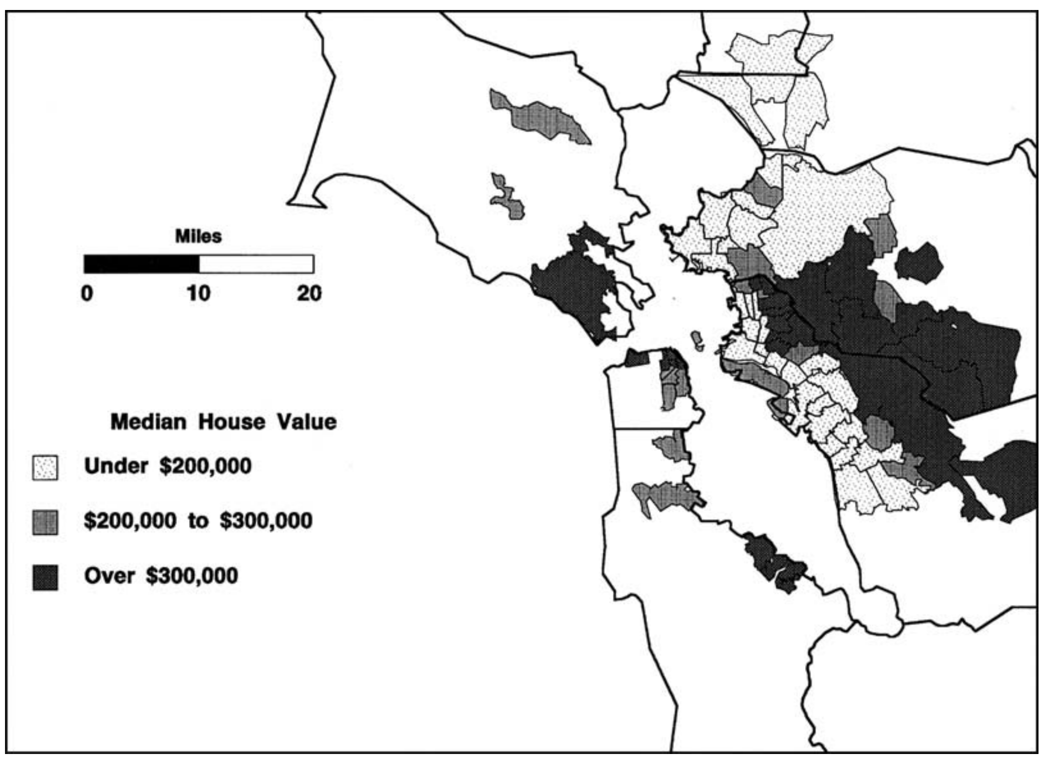
13-7 Vacancy rates in the Bay Area (based on 1990 census data).



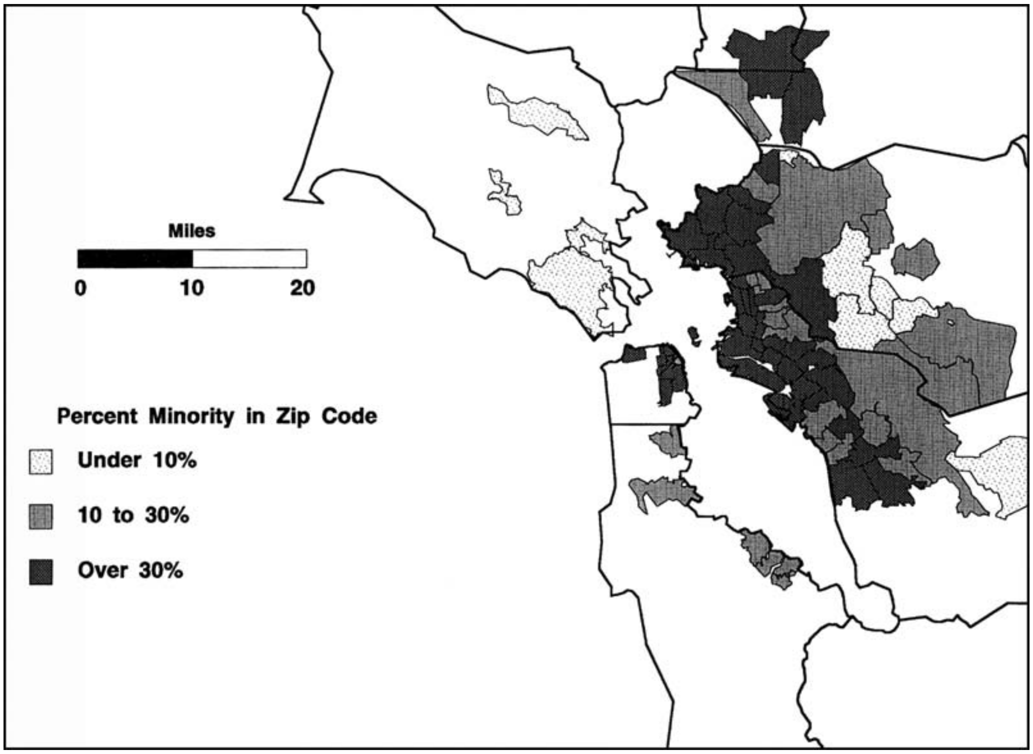
13-8 Median rents in high-damage areas (based on 1990 census data).



13-9 *Median household income in high-damage areas (based on 1990 census data).*



13-10 *Median house value in high-damage areas (based on 1990 census data).*



13-11 Racial composition as a percentage of population in zip code in high-damage areas (based on 1990 census data).

ties for which they've offered forbearance. As long as the market remains absolutely flat, we are not likely to see a full recovery in the multifamily stock in Los Angeles. Nor will we see it in the longer term here. By contrast, the single-family stock has come back in two to three years in Los Angeles and in other disasters. The reason is twofold: (1) the majority of the federal housing recovery programs are designed for homeowners, and (2) as long as property values rise even modestly, homeowners can absorb significant postdisaster rebuilding costs and still expect to make a reasonable profit on their investment, because profitability associated with home ownership stems from property appreciation.

Recent experience demonstrates that existing Small Business Administration loan programs are inadequate to meet the needs of multifamily and affordable housing, particularly low-income housing. First, the private market mechanism simply will not work. In fact, the multifamily housing market economics hinder postdisaster residential recovery for most low- and moderate-income units. There is no economic incentive for an apartment owner to repair or rebuild. Unfortunately, rental housing, unlike ownership housing, increases in value as a function of rents, not property values. Because they cannot increase rents to cover the repair costs, it is much more difficult for apartment owners to absorb the cost of disaster repairs. Second, the owners of damaged buildings are investors, not developers. They don't know how to deal with contractors, they don't know how to deal with building permits, and they certainly don't know how to deal with engineers. They are not anxious to move quickly. They are looking to get out, in the same way that their bankers, in many cases, are looking to get out.

In addition to the recovery problems posed by socioeconomic and demographic conditions in the Bay Area, there are two additional concerns unique to us. First, we are politically fragmented. We don't have the powerhouse of the City of Los Angeles to go to bat for our interests in Washington. We have nine counties and fifty cities that have to function and have to compete with one another for funds. Second, and most important, we are at the end of a long line of Californians with our hands out to agencies in Washington. It is not clear to me that the Washington purse will be there, much less open, when the earthquake happens here.

Recovery Strategies

Given the potential for significant multifamily and low-income housing loss in the event of a damaging earthquake on the Hayward fault, the probability that emergency sheltering will be needed beyond a few weeks, and perhaps for a few months or a few years, is very strong. We have neither the space nor the personnel to manage that sheltering, and we will have an extremely long and extremely difficult recovery period. We can expect ghost towns throughout the East Bay, and we cannot automatically expect that HUD financing will be available to repair them. We can expect these properties to remain vacant for years. In Los Angeles, when two- and three-block areas were damaged heavily, gangs moved in, prostitution rings moved in, and vandalism damaged the buildings further. Without the public resources to fence, monitor, and police ghost-town areas, we would have to expect even worse problems.

What should we do, besides be gloomy? First, I seriously encourage us to support—and strongly support—the initiatives of the Seismic Safety Commission to improve residential codes. Currently, we expect our codes to provide life safety. We have got to go further and set a goal that, in the next twenty years, residential structures will perform with no more than minimum damage that can be fixed in a few months after an event of this magnitude. We simply do not have the resources to repair or replace a significant number of damaged housing units.

Second, we must plan for a future that does not depend on federal largesse. Recently, some members of Congress from both parties have been calling for an end to disaster assistance in California. I think we had better pay attention to that kind of political noise. Future urban disasters will not benefit from public spending at the levels we experienced after Northridge. The nation has neither the funds nor the political will to provide disaster assistance at that level. When the City of San Francisco attempted to balance the creation of an unreinforced masonry (URM) retrofit ordinance with the preservation of affordable housing stock, the process was long and difficult. Housing activists fought with engineers over the appropriateness of a solution that limited code requirements to the minimum and provided bond money to help pay for the housing repairs. Similarly, we have to find the appropriate balance in mitigating the potential hazards in our existing housing stock in order to protect that stock against future disasters without creating a financial disaster for our citizens. And we have to do that statewide.

Third, we have to be realistic and take the politically unpopular position that the people who can pay, the middle and upper classes, should pay—for mitigation and for their own insurance. Middle-class homeowners were the primary beneficiary of federal government recovery assistance after Northridge. We have to recognize that that scenario may not be repeated, and we must plan to spread the responsibility for seismic safety so that reduced federal aid can be used to assist those who truly need it. When our roof leaks a little bit at the beginning of a rainstorm, we fix it; otherwise, we know the damage is going to be worse. We homeowners need to pay that same level of attention to the bolting of our houses and apartments and the bracing of our cripple walls and garages, because otherwise we Californians won't have anywhere else to live.

Fourth, we must get our lenders to wake up and recognize the potential losses in their portfolio and take steps to protect those assets. They need to be part of the effort to create a safer, more habitable community—before and after the earthquake. Finally, we Californians must take responsibility for mitigating hazards in our own homes, and we must expect to pay for insurance that is realistic and appropriate for our site and building condition. As citizens of an earthquake-prone region, we must not forget that it is *our* economy, *our* jobs, *our* cities, that are affected by the loss of our homes and apartments. In the Bay Area, we must begin to act now, if, after the Hayward event, we expect to have a home, and a community, to come home to.

Acknowledgments

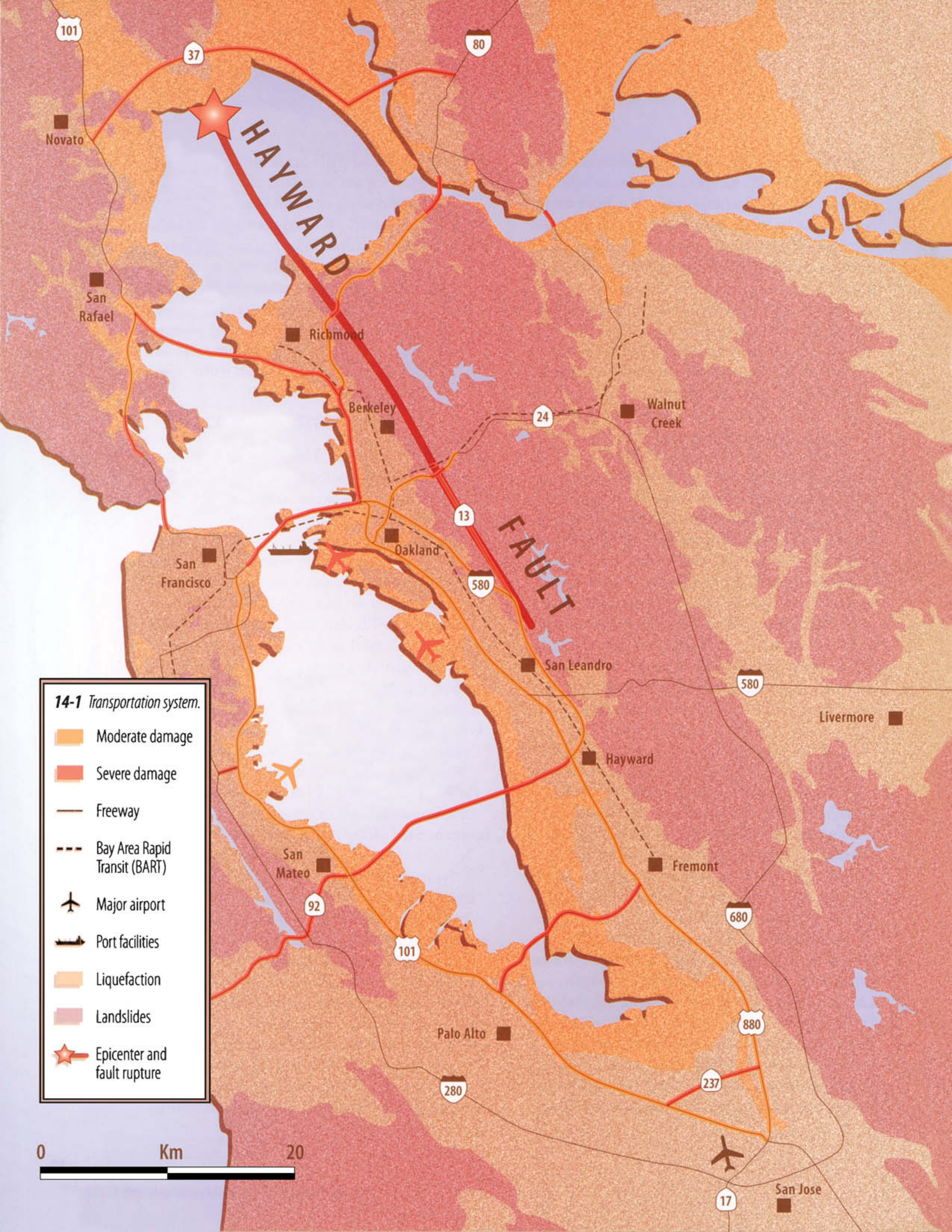
Ron Hamburger of EQE International and Jeanne Perkins of the Association of Bay Area Governments (ABAG) provided the estimates of wood-frame housing losses. Dr. Michael Smith-Heimer of the Low-Income Housing Fund created the GIS maps that demonstrate the relationship between housing loss and demographic characteristics of the affected population. Greg Rabinowitz of Hamilton Rabinowitz Alschuler created the GIS maps of the Northridge damage as part of the *Northridge Housing Losses* report listed in References. I appreciate their input and assistance.

References

Perkins, Jeanne B., B. Chuaqui, J. Harrald, and D. Jeong, 1996. *Shaken Awake! Estimates of uninhabitable dwelling units and Peak Shelter Populations in Future Earthquakes Affecting the San Francisco Bay Area.* Association of Bay Area Governments Publication #P96002EQK, April 1996. Oakland, CA: ABAG.

Comerio, M. C., J. Landis, and Y. Rofe. 1994. Post disaster residential rebuilding. Working Paper #608. Institute of Urban and Regional Development, University of California, Berkeley, February.

Comerio, M. C. 1995. *Northridge housing losses: A Study for the California Governor's Office of Emergency Services.* Berkeley: Center for Environmental Design Research, University of California.



14-1 *Transportation system.*

Chapter 14

Regional Transportation Response

Joel Markowitz, Metropolitan Transportation Commission

Here in the Bay Area, we have all manner of public transportation. We have some redundancy in some major corridors, but not much. The problem is that the area is topographically constrained; this isn't the Los Angeles basin: we don't have an extensive grid of parallel freeways or parallel local arterials that can handle freeway volumes, and we certainly don't have many spare bridges. We also have built out many of our roadways to their physical limits. Much of the new freeway construction includes sound walls that absolutely constrain our ability to pave over another lane. In some of the areas near Northridge widening could be done after the earthquake, but not here.

Management of the system is decentralized, even fragmented. On the plus side, that means there are a lot of resources and abundant leadership among many agencies that have different locations for equipment and supplies. For example, there isn't one big central public bus garage that's going to fall down and destroy our transit capabilities. We have many of these all around the region, and many are going to survive and be a resource to help out. An earthquake today, February 9, 1995, is awfully bad timing, however, because we have many of those facility retrofits under way or in design but certainly not yet done. On the minus side, it is difficult for decentralized transportation management to react quickly and get control of the situation. Control is complicated by the large number of agencies that must coordinate their efforts.

Impacts on the System

Looking north from the distribution structure at the east end of the Bay Bridge through Emeryville to Berkeley, Interstate 80 is right on the Bay margin; you can't get much more marginal than that (figure 14-1). Approaching the Bay Bridge itself, you see again how vulnerable this area is; it sustained damage in the Loma Prieta earthquake and certainly will be more seriously damaged in the Hayward earthquake. And ever since Loma Prieta and the loss of the Cypress structure, the 24–580–980 interchange (the MacArthur Maze) is the absolute hub of road transportation in the East Bay, and even the central Bay Area. In the absence of the Cypress structure, all freeway traffic, both north-south and east-west, must go through the Maze. It's absolutely critical for the recovery effort, but you can expect that it is not going to survive completely intact.

Where BART enters the Berkeley Hills tunnel, on the Berkeley side, it goes right across the fault and is going to have some severe problems. We know it has only about a foot of movement allowance on either side of the trackways, and a 3- to 5-foot offset is going to interrupt train service dramatically.

There will be local street damage; it won't be terribly severe in the flatlands, but the hills are going to be severely disrupted in many cases, making either evacuation or access quite difficult. And we are very uncertain about how much time it will take for repair.

The immediate roles of the transportation system are many: (1) access for first responders—you have to clear the rubble out of the way before you can get to people; (2) access to critical facilities; and (3) evacuations. Evacuations will involve the injured, certainly, but also others at risk for various reasons. People with no power or water have to be moved, as do people near a very bad fire that's near a toxic chemical plant. People who are displaced also have to be moved around.

Stranded commuters will want to return to their homes. The movement of emergency supplies, equipment, and personnel is going to be the responsibility of a variety of agencies trying to make use of the same scarce transportation resources.

Constraints on Response

We know what problems we'll have. First, inadequate communications. We won't know exactly what's down; we will get conflicting reports. Getting correct information is going to be difficult, especially in the early hours. We may know the status of one route but not available alternative routes. It will take time to put that together. Field personnel will be using their best judgment to decide whether something should be open or closed, evacuated, rerouted, or stopped. All the agencies have procedures for making those decisions, but they will be highly fragmented, especially in the early hours. Local resources will be overwhelmed. The streets you will want to use, if you can't use the freeways, will themselves be blocked by rubble, downed power lines, ruptured water and gas lines.

Figure 14-1 is a reflection of what I have concluded in preparing this study. The major bridges crossing the Carquinez Straits and San Francisco Bay will be closed immediately for service—not necessarily because somebody went out there with a stop sign, but because the approaches in the Bay margins will make them inaccessible. Maybe the structures themselves also will be damaged. We have to assume we won't be able to get "there" from "here" almost anywhere. San Francisco will be isolated except to the south. Route 37 across the top of San Pablo Bay is on Bay fill, as is Highway 237 at the bottom of the Bay, and both are therefore vulnerable.

Beyond Castro Valley through Livermore, Interstate 580 may be accessible, but it is in the fault zone, so we're not sure. Both I-580 and I-880 are going to be questionable and spotty; there will be damage, but we don't know how much. We hope it will be relatively easy to repair. Likewise, we hope that Highway 101 will be accessible, but it, too, is on vulnerable Bay fill. This pattern of failures effectively cuts off the Bay Area from most of the major routes of access. How to house stranded folks is going to be a bigger question than perhaps we thought earlier.

There are about 3 million commuters in the Bay Area on a typical weekday. We expect to be able to get commuters home in San Francisco, West Bay, South Bay, North Bay, and inland areas (table 14-1). Some areas will be questionable, and some will depend on the bridges. Close to 2 million people will probably have

Table 14-1 Effects of Disruption on Intercounty Commuters (Based on 1990 Census)

To:	*San Francisco*	*West/South Bay*	*North Bay*	*East Bay (West)*	*East Bay (Inland)*	*Total*
From:						
San Francisco	292,900 G*	40,400 Y*	6,000 R*	19,500 R	5,500 R	364,300
West/South Bay	86,600 Y	968,600 G	2,400 R	35,300 Y	6,700 Y	1,099,600
North Bay	52,900 R	9,700 R	380,800 G	27,200 R	18,900 R	489,500
East Bay (West)	74,300 R	73,000 Y	9,100 R	428,300 R	42,100 R	626,800
East Bay (Inland)	34,200 R	19,900 Y	5,900 R	60,900 R	235,200 G	356,100
Total	540,900	1,111,600	404,200	571,200	308,400	2,936,300

*G (green) = minimal disruption; Y (yellow) = delays; R (red) = major disruption.

minimal disruption; there will be some way for them to get home. This does presume that certain structures and key points like Candlestick Causeway out of San Francisco aren't totally down and it's possible to get to I-280 as an alternative. But at least 800,000 people will have to be transported back to where they want to be (table 14-2).

Regional Coordination

The Metropolitan Transportation Commission, the regional nine-county planning, coordinating, and financing agency, is responsible for coordinating among transportation systems. Our first step will be to reestablish communications, as best we can, with our partner agencies. We do have a new experimental electronic bulletin board system; we hope to have power and telecommunications back fairly soon. In the first few hours, however, we don't expect to be able to do much except get hold of people to plan the next steps.

Damage assessment for the public transportation and highway systems will be done by the original agencies that have responsibility; we will get their information as soon as they know. We have helped public transit agencies put together mutual aid agreements, and we will try, along with the Caltrans office, to provide a clearinghouse for transportation-related information. We are in a building that we expect will do well. It is built to the highest standards at the time the building was designed in the early 1980s. The new Caltrans building is also built to a relatively high standard.

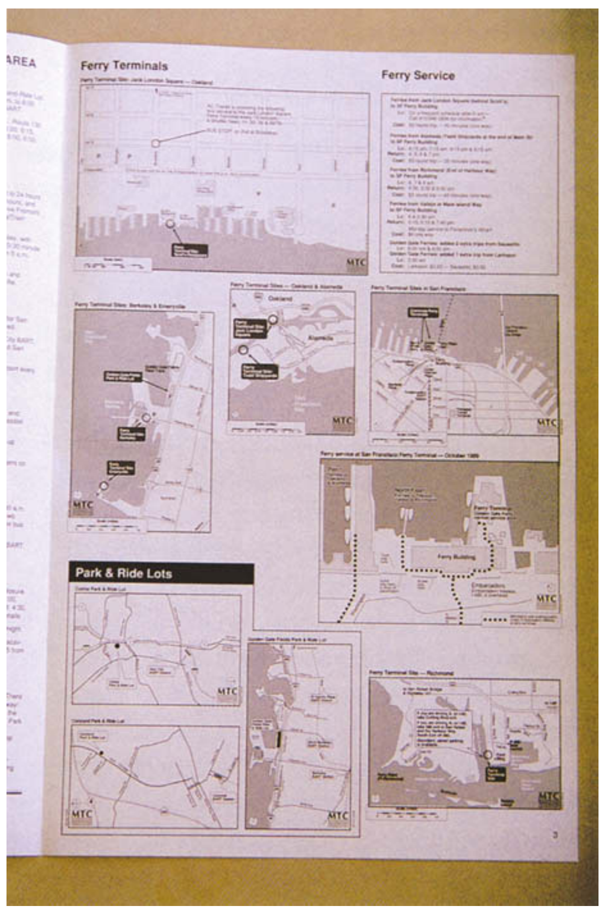
Alternative transportation saved the day in the Loma Prieta and Northridge earthquakes (figure 14-2). The major challenge is to get out good public information (figure 14-3). We have almost fifty freeway service patrol trucks out on the major freeways now, during the peak periods in the morning and afternoon, equipped with automatic satellite vehicle-location and radio. They are additional eyes and ears that can help Caltrans, the California Highway Patrol, and us.

Table 14-2 Commuters Affected by Damage to Transportation Systems (Based on 1990 Census)

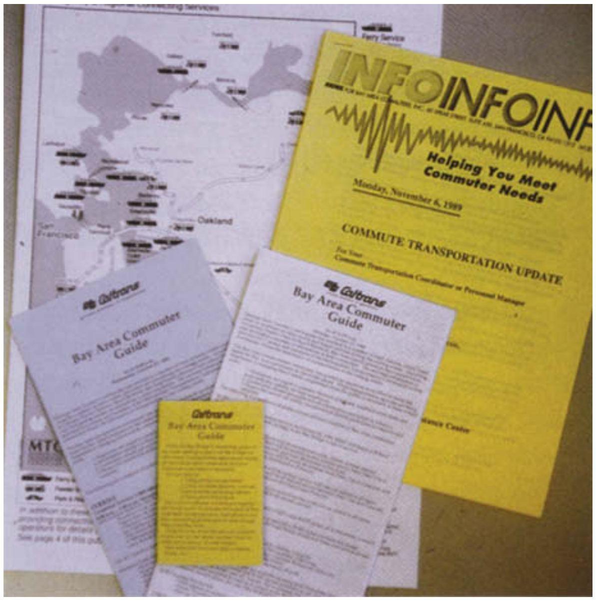
Minimal disruption	1,877,500	64%
Delays, circuitous routes	261,900	9%
Major disruptions, closures	796,900	27%
Total	2,936,300	100%

We will be working with all major news media to disseminate the latest information on the best alternative routes and on services, including buses, ferries, trains, and park-and-ride lots (figure 14-4).

We now have triple the number of ferry docking locations we had in 1989. But still they are not really able to handle a great volume. We



14-2 Close-up of a special tabloid on new transportation systems produced by MTC, Loma Prieta earthquake, 1989.



__14-3__ Public information on alternative transportation services, Loma Prieta earthquake.

__14-4__ Press conference announcing services in place for the return to the "normal" commute after the Loma Prieta earthquake.

have ferry fleets in the Bay that can help us overcome the problems of route closures, but keep in mind that Golden Gate Transit has only four ferry boats. We have the local, mostly tourist, cruise lines—the Red and White fleet and the Blue and Gold fleet—with fairly small boats. It sounds attractive to move thousands of people by ferry, but this region just isn't set up for it.

BART really came through in Loma Prieta (figure 14-5). It began overnight to go to full 24-hour service; it began handling the number of people in just the Bay Bridge corridor that it handled in its entire system before the earthquake. But we're not so sure BART is going to be unscathed by the Hayward fault earthquake. The Berkeley Hills tunnel may very well be out of service for an extended period.

Certainly we hope BART will again survive well, but the BART system has about 1,700 columns supporting elevated tracks that have not been retrofitted. We think they will behave fairly well. The rails themselves are continuously welded steel; that helps hold things together. We don't believe there's going to be a massive collapse, but with 1,700 columns, you must expect some problem somewhere in the system.

At BART's MacArthur Station, the BART tracks go right through the middle of the MacArthur Maze. You can count six structures crossing over the BART tracks. This isn't just any old BART track; this is the center of the system—where the east-west and north-south routes come together and provide the distribution. If there is damage to any freeway structure, even minor spalling, debris will fall onto the trackway, and the trains will be unable to move. Keeping the Maze open for BART may be problematic.

Recovery and Reconstruction

Administration and finance are critical. Loma Prieta was probably one of the first times that FEMA had to deal with the question of transit operating expenses and how one justifies them—on a FEMA form designed for structural damage. Restoration will mean something different from normal, just as it did after Loma Prieta. Now, "normal" is no Embarcadero Freeway, no on-ramps to San Francisco central freeways, and no Cypress structure. There is a much more crowded, circuitous, and, in some cases, dangerous merging movement to be done to go north

14-5 *Announcements of transit route and schedule changes after the Loma Prieta earthquake.*

and south between I-80 and I-880. "Normal" will change again. There will be a new baseline, but we don't know what it will be. People will have to adjust, as they have before.

Demolitions, repairs, and rebuilding will go on certainly for months, possibly years. And it's not just a matter of producing the right structural design. Recall in 1989 that the big issue with the Embarcadero Freeway and the Cypress Freeway was the response by the community: "Should we? And if so, what and where?" Discussions involving environmental lawsuits, affirmative action issues, and funding issues go on and on. We have to be prepared for those kinds of delays and decision making. It may be terribly frustrating for a lot of people, and that may even change the nature of the response.

15-1 *Damage in a commercial district along Hollywood Boulevard, Northridge earthquake, 1994.*
LA TIMES PHOTO

Chapter 15

Economic Recovery

Tapan Munroe, Pacific Gas & Electric Company

There are two kinds of losses in the aftermath of an earthquake. One is physical damage to commercial and residential buildings, roads, bridges, and other structures. The estimated building damage to the San Francisco Bay Area from an M7.2 earthquake would be around $16 billion. The other is economic loss, the topic of this chapter.

A valid assessment of economic loss must avoid overestimation and double-counting and have a solid conceptual basis. One dimension of the methodology is assessment of income loss or output loss; a parallel analysis is that of job loss.

Basis for Analysis of Economic Losses

Economic losses result from natural disasters because the productive capabilities of physical capital such as factories, offices, and the infrastructure are impaired (figure 15-1). The interruptions caused by damaged or destroyed offices, factories, warehouses, roads, bridges, highway overpasses and lifelines such as power and gas lines, water pipelines, and telecommunications all have a major impact on the economy. Residential damage also has an important economic impact, because if people cannot function in the normal way, it is very difficult for them to contribute to the economy (figure 15-2).

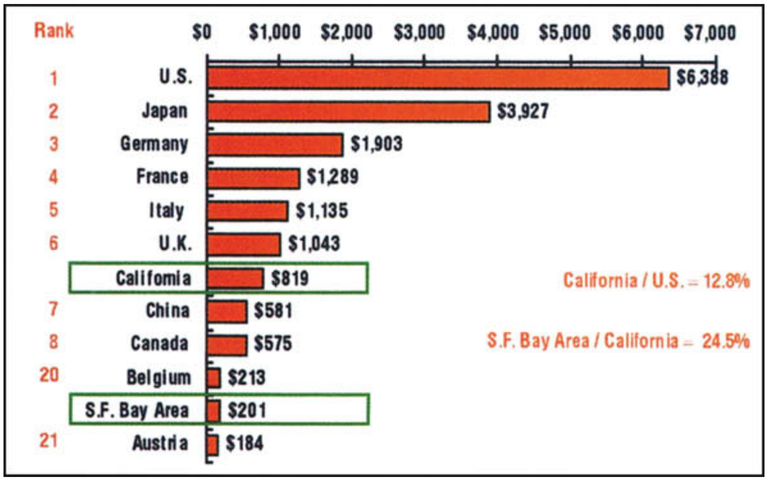
Another kind of economic loss is what I call the "economics of fear." This loss goes beyond the implications of the structural damage. The economics of fear can affect tourism and the hospitality industry—a very significant part of the Bay region's economy. In addition, retail trade, business services, and real estate also suffer from people's fear of recurrence of an earthquake and their heightened sense of risk.

Economic Effects of the Scenario Earthquake

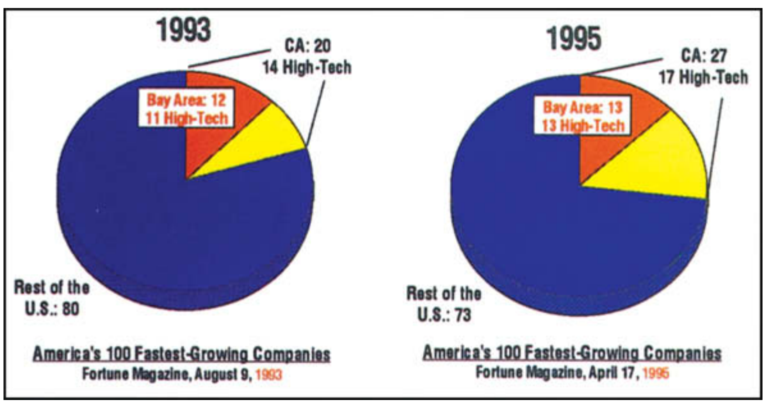
Ranked by gross domestic product, California would be the seventh-largest economy in the world if it were a nation, and the San Francisco Bay Area would be the twenty-first-largest economy—the same size as Belgium or Austria (figure 15-3). The minimum economic loss from a Hayward fault earthquake is about 1% of the region's product: about $1.8 billion. The more likely figure is really $4 billion; this figure is basically income loss in the region. That amount is significantly higher than the economic loss from the Loma Prieta earthquake. Our estimate for Loma Prieta was about $0.8 billion in a previous study.

The San Francisco Bay Area is home to a number of the 100 fastest-growing companies in

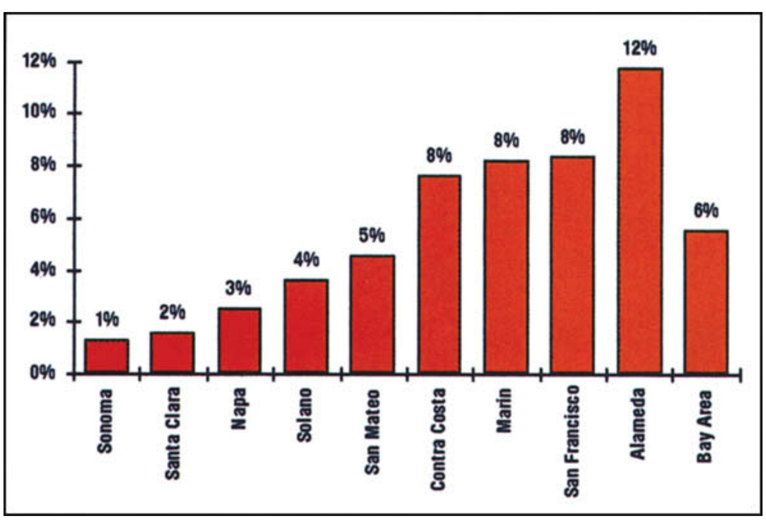
15-2 *Temporary housing on a baseball field eight months after the 1995 earthquake in Kobe.*



15-3 *Gross domestic product in U.S. dollars (1993).*



15-4 *California and Bay Area share of the nation's 100 fastest-growing companies (1993 and 1995).*



15-5 *Damage to commercial buildings in Bay Area counties as a percentage of value.*

the United States. For example, in 1993 about 12% of nation's 100 fastest-growing companies were in these nine counties, and that share increased to 13% in 1995 (figure 15-4). In light of the high concentration of fast-growing companies in the Bay Area region, the potential loss to the state economy is high for such an earthquake. The industries of Silicon Valley to a large extent will determine the economic future of the Bay region and California for the next twenty years. The potential impact of disruption would be significant, not only in terms of the region's competitiveness, but also in terms of exports; Silicon Valley is a major exporting sector in California. I am very concerned about the impact of the event on the high-tech industries of Santa Clara and Alameda Counties. The greatest potential economic loss to the region's economy is right here.

On examining the damage to commercial buildings by county (figure 15-5), it is not surprising that maximum damage is in Alameda County, which straddles the Hayward fault, followed by San Francisco and Marin Counties. Of course, Contra Costa County also has a significant economy. I have made a fairly straightforward analysis here, basing economic disruption or economic impact on damage to structures.

When we look at retail sales for a three-month period, we see a total loss of about $570 million. The highest losses are certainly in Alameda, San Francisco, and Contra Costa Counties (figure 15-6).

A backbone of the Bay region's economy is the hospitality-tourism industry. Most of the region's hospitality and convention business is concentrated in the San Francisco area, with spillover into the East Bay and the South Bay and up north into the wine country.

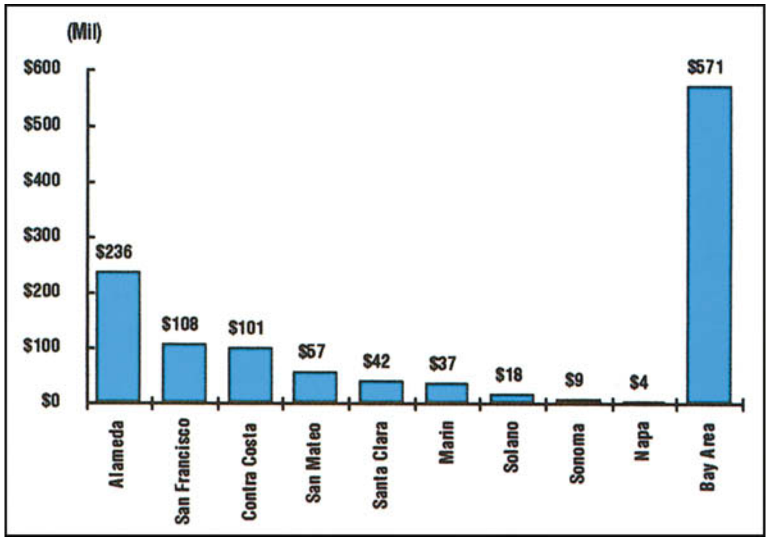
We see potentially large economic losses in San Francisco: a total of 65,000 jobs for a six-month period (figure 15-7). This loss is sizable. In addition, wage losses are likely to be $700 million for a six-month period following the disaster (figure 15-8).

Loss of tax revenue to San Francisco alone from the disruption of the hospitality industry would be very significant (figure 15-9). The City's fiscal situation is, at best, precarious, and taxes would have to be imposed to make up this deficit. The fiscal impact could be very significant for many cities in the Bay region.

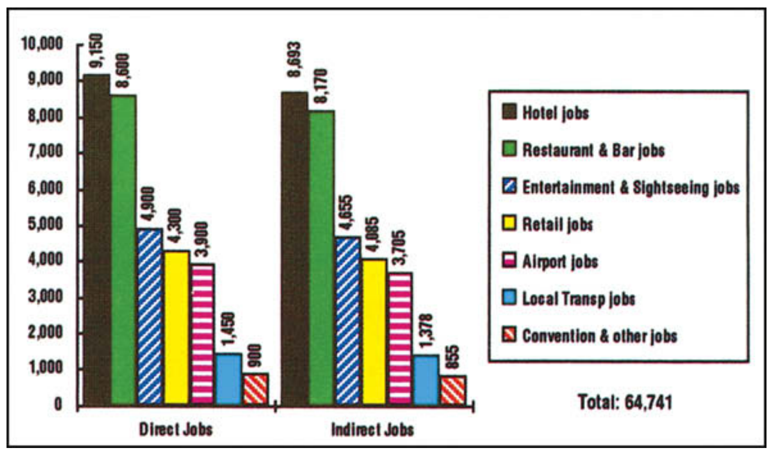
The disruption to commercial and industrial properties may account for the loss of as many as 42,000 jobs for a three-month period after the earthquake (figure 15-10). The lion's share of the job loss will be in Alameda, San Francisco, Contra Costa, and San Mateo Counties. Total wage losses in the Bay Area, just from commercial and industrial building disruption, are about $1.3 billion (figure 15-11). Add to this $700 million in wage losses that will result when tourists stay away from the region following the disaster. Thus, wage losses alone would amount to nearly $2 billion. Therefore, my estimate of about 2% of the gross regional product, which would be about $4 billion, is in the ballpark, especially if economic losses stemming from the disruption to the region's infrastructure are added to the $2 billion estimate.

One of the effects in the aftermath of earthquakes and other natural disasters in California has been a significant redistribution of economic activity. For example, after the Loma Prieta earthquake, a notable amount of discretionary economic activity disappeared from San Francisco because a number of buyers of services or goods go from the East Bay into the City. There was a shift of economic activity from San Francisco to the East Bay, which certainly had a very positive impact on the East Bay subregion. I expect significant intraregional movement of people and therefore economic activity as a result of the disaster.

One of the real tragedies of all natural disasters is the impact on people who can least afford it. Disasters have great effects on people who have poor housing and low income. These are the areas that we have left out of this presentation because of time constraints—the distributional effects, the

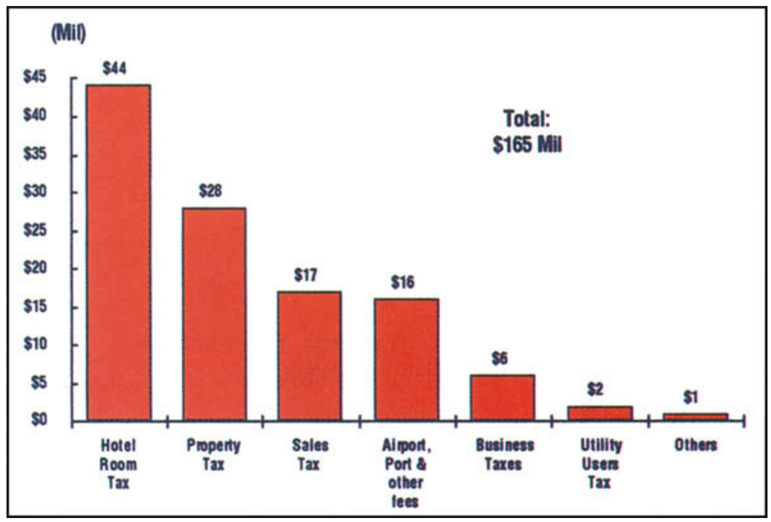


15-6 *Retail sales losses in the Bay Area, assuming damaged stores are closed for three months.*

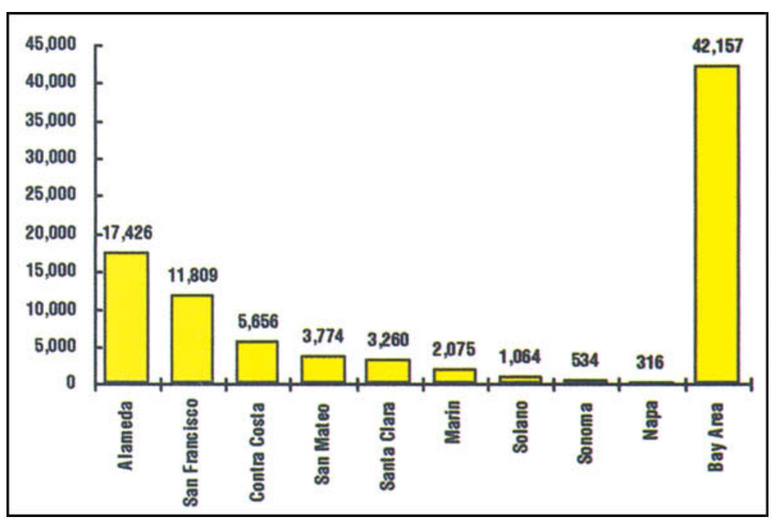


15-7 *Loss of tourist industry jobs in San Francisco, assuming damaged hotels are closed for six months.*

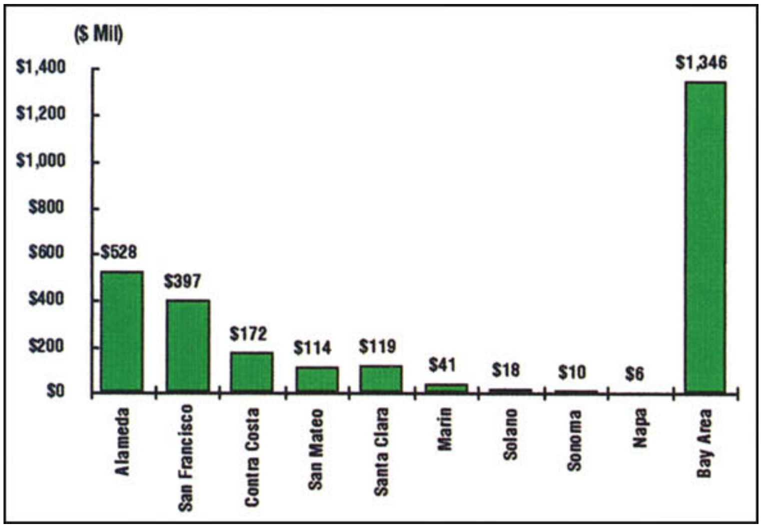
15-8 *Example of damage in the historic Pacific Garden Mall area in Santa Cruz, a tourist destination with many small businesses, Loma Prieta earthquake, 1989.*



15-9 *Loss of tourism-related tax revenue in San Francisco, assuming six month closure of damaged buildings.*



15-10 *Job losses in the Bay Area, assuming damaged commercial buildings are closed for three months.*



15-11 *Wage losses in the Bay Area, assuming damaged commercial buildings are closed for three months.*

demographic effects, and the regional redistribution of economic activity.

It is also risky to conclude, as is often done in similar analyses, that at the end of nine months—because of all the state and federal funds and insurance monies coming into this disaster-stricken area—the losses and gains will even out, or in other words, that it is a "wash." That kind of simplistic macroanalysis can result in bad public policy because it does not provide a real assessment of the losses to various sectors of the economy and to the various subregions of an area. It also has been suggested that a "disaster" can be a good thing for a region if there is net benefit over time because of the inflow of funds. This indeed is a somewhat perverse conclusion—and not a proper basis for public policy.

Acknowledgments

Thanks are due Lloyd Cluff for his many suggestions in the conceptual phase of this study. Research and graphics for this report were provided by Xiang Jie Luo.

16-1 *Installation of diagonal bracing at University Hall in Berkeley.*

Chapter 16

A Call to Action

L. Thomas Tobin, Tobin & Associates

For the most part, we're fortunate that our contributors were candid, complete, and well prepared. We should thank the agencies they represent for admitting to their vulnerability. Candid assessments are absolutely necessary if we are to manage earthquake risk. Other organizations need to be more candid about the vulnerability of their systems, however; until they are, they will not gain political support to reduce their vulnerability, and the public will not have the information needed to plan intelligently.

We can't hide vulnerability; we must face it openly and with resolve. The Hayward fault scenario gives us such a powerful message that I fear it may overwhelm some people, but the earthquake risk is not so overwhelming that we can't start reducing it. This scenario gives a good picture of the scope and complexity of the earthquake threat and the challenge before us. The picture is a policy guide, not a specific work program: for example, there are many other active faults in this state and other cities and communities at risk. Let's not be so narrow that we focus our efforts solely on the East Bay.

We must begin by moving from today's conference room to the board room, to the city council chambers, and to the halls of the legislature. We have the opportunity in California to change public policy, but that will not happen unless we are the agents of that change.

There are multiple issues and problems to be faced. First, we have to face the vulnerability of our existing buildings and infrastructure, as expensive, difficult, and controversial as that is. We must also face the inadequacies in our emergency response capability, especially our inability to deal with fire following an earthquake. As knowledgeable professionals, we must influence cities and building owners to move ahead with the retrofit of hazardous structures (figures 16-1, 16-2). Technical disagreements need to be resolved, and more information obtained. If we fight over what we don't know and fail to move ahead with what we do know, we will abandon the trust we committed to carry out when we began our careers. None of this will be done easily or cheaply, however.

To affect public policy, and effect change, we must respect the principles governing our nation. We are a free society and our leaders must balance the protection of public health, safety, and welfare with private property rights. Government cannot take people's private property in the name of earthquake safety. At the same time, the government does not have the resources, even if it had the will, to purchase private properties at risk. The government's interest in safety must be furthered through incentives and information. We must provide political support and good information to create these safety programs, but

16-2 *Homeowner taking preventive measures.*

the government's programs must be carried out within the context of a free society.

In the private sector, risk and value must be combined. A building in California that will fail in an earthquake is not worth as much as a building that will resist the same event with little damage. It's time to recognize the value of these differences. We must build on this value to encourage risk reduction.

As earthquake professionals, we must help those who own buildings manage their risk. A failure can jeopardize their investment and create liability that exceeds the value of their assets. We should help them protect their investment by understanding risk and what they can do about it. Owners should compare the cost of retrofitting against losses, liability, and the cost of disruption. The public needs our help.

We should integrate seismic safety with the other goals in each of our communities. Goals to protect historical resources and provide affordable housing can be advanced through seismic safety efforts. Virtually every government action, whether it's building new hospital facilities or protecting cultural resources, should consider earthquake risk. Each of us must work to make this happen. That's how we will get to where we're trying to go.

As earthquake professionals, we must participate in the public policy arena. We can't wait for the federal government or the State of California or the Seismic Safety Commission to do it for us. Each of us must influence our city council, our school district, and our hospital district. As responsible citizens, each of us must take care of ourselves, our families, and our businesses. We must seize opportunity. We bear responsibility.

I'd like to close with a quote from *Turning Loss to Gain*, the Seismic Safety Commission's Northridge report: "In the end it will be the role of people, expressed through personal acts, to mitigate earthquake risks, as well as their support for earthquake programs, that will determine whether California attains an acceptable level of seismic safety by the end of this century."

Reference

Seismic Safety Commission. 1995. *Northridge earthquake: Turning loss to gain*. Report 95-01. Sacramento, CA: SSC.

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