

# Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco

## Potential Earthquake Impacts



**ATC** Applied Technology Council

Prepared for  
San Francisco Department of Building Inspection  
under the Community Action Plan for Seismic Safety (CAPSS) Project

## **Community Action Plan for Seismic Safety (CAPSS) Project**

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The Community Action Plan for Seismic Safety (CAPSS) project of the San Francisco Department of Building Inspection (DBI) was created to provide DBI and other City agencies and policymakers with a plan of action or policy road map to reduce earthquake risks in existing, privately-owned buildings that are regulated by the Department, and also to develop repair and rebuilding guidelines that will expedite recovery after an earthquake. Risk reduction activities will only be implemented and will only succeed if they make sense financially, culturally and politically, and are based on technically sound information. CAPSS engaged community leaders, earth scientists, social scientists, economists, tenants, building owners, and engineers to find out which mitigation approaches make sense in all of these ways and could, therefore, be good public policy.

The CAPSS project was carried out by the Applied Technology Council (ATC), a nonprofit organization founded to develop and promote state-of-the-art, user-friendly engineering resources and applications to mitigate the effects of natural and other hazards on the built environment. Early phases of the CAPSS project, which commenced in 2000, involved planning and conducting an initial earthquake impacts study. The final phase of work, which is described and documented in the report series, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco*, began in April of 2008 and was completed at the end of 2010.

This CAPSS Report, designated by the Applied Technology Council as the ATC-52-1 Report, focuses on estimating impacts to the City's privately owned buildings in future earthquakes; a companion *Technical Documentation* volume (ATC-52-1A Report) contains descriptions of the technical analyses that were conducted to produce the impact estimates. Several other CAPSS reports are also available in the series, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco*:

- *A Community Action Plan for Seismic Safety* (ATC-52-2 Report), which recommends policies to reduce earthquake risk in privately owned buildings of all types;
- *Earthquake Safety for Soft-Story Buildings* (ATC-52-3 Report), which describes the risk of one vulnerable building type and recommends policies to reduce that risk, and the companion *Documentation Appendices* volume (ATC-52-3A Report), which details the technical methods and data used to develop the policy recommendations and related analyses; and
- *Post-earthquake Repair and Retrofit Requirements* (ATC-52-4 Report), which recommends clarifications as to how owners should repair and strengthen their damaged buildings after an earthquake.

Many public and private organizations are working actively to improve the City's earthquake resilience. The CAPSS project participants cooperated with these organizations and considered these efforts while developing the materials in this report. Three ongoing projects outside of CAPSS but directly related to this effort are:

- *The Safety Element*. The City's Planning Department is currently revising the Safety Element of the General Plan, which lays out broad earthquake risk policies for the City.
- *The SPUR Resilient City Initiative*. San Francisco Planning and Urban Research (SPUR) published recommendations in February 2009 for how San Francisco can reduce impacts from major earthquakes. SPUR is currently developing recommendations on Emergency Response and Post-Earthquake Recovery.
- *Resilient SF*. San Francisco City government is leading a unique, internationally recognized, citywide initiative that encompasses the City's All Hazards Strategic Plan and seeks to use comprehensive advanced planning to accelerate post-disaster recovery. This work is coordinated by San Francisco's General Services Agency (GSA), the Department of Emergency Management (DEM) and Office of the Controller in collaboration with the Harvard Kennedy School of Government.

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# **ATC-52-1**

## **Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco Potential Earthquake Impacts**

Prepared for the  
DEPARTMENT OF BUILDING INSPECTION (DBI)  
CITY AND COUNTY OF SAN FRANCISCO  
under the Community Action Plan for Seismic Safety (CAPSS) Project

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## PREFACE



Most San Francisco Bay area residents know that future, devastating earthquakes will occur. Most people have a sense that some buildings (such as brick buildings) in some locations (on top of the Hayward Fault, for example) are bad places to be during the next big earthquake. However, no comprehensive study previously existed to give a clear picture of the risks from the various categories of privately owned buildings, on the people of San Francisco.

The purpose of the Community Action Plan for Seismic Safety (CAPSS) project is to recommend specific, comprehensive mitigation efforts for the privately owned buildings in San Francisco in order to reduce the impacts from future earthquakes. However, to be most effective in targeting our recommendations, we needed to first determine what building types are the most vulnerable.

This vulnerability study and report, *Potential Earthquake Impacts*, is unique. No other city in the nation has undertaken such a comprehensive and detailed analysis of the impacts of a likely natural disaster. The many impacts are explored at the neighborhood level, and include the number and types of damaged buildings, along with the implications the damage will have on affordable housing, vulnerable populations, small businesses, neighborhood's sense of place, and the City's resiliency. This report provides a realistic, state-of-the-art assessment of how the City will likely fare.

But this report is much more than an academic study. It provides a clear picture of the extent of injuries, deaths, and property damage that we can expect if we take no action. It gives policy makers a choice: is it acceptable to have hundreds of people die, thousands injured, and thousands of housing units destroyed – when those impacts are largely preventable?

This is one of several CAPSS reports. Other reports in the CAPSS series, *Here Today-Here Tomorrow: The Road to Earthquake Resilience in San Francisco*, build on the foundation of information contained in this study to formulate recommended programs and an action plan to help San Francisco become a safer, more resilient city if government takes action.

Does San Francisco have the political will to invest in its future, by retrofitting the many known vulnerable building types? We have a clear choice. The effects of future earthquakes, discussed in this report, paint a grim picture if we choose to do nothing.

Mary Lou Zoback  
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## REPORT SUMMARY



No one knows when the next large earthquake will strike San Francisco, but it is certain that a “big one” will come. When it does, the City’s people and economy, its housing and businesses, its culture and character, could suffer heavy consequences. Recovery may take many years and the new, post-earthquake San Francisco that emerges could be different in notable ways.

This report examines four possible earthquakes that could strike the City (Figure A) and estimates the amount of damage and resulting ripple effects that each could cause. It looks only at damage to privately-owned buildings and the impacts that flow from this. Damage to utilities, transportation networks, and public buildings have not been studied but are likely to add substantial consequences to those described here.

The consequences of a large earthquake would be staggering, as summarized below and described in detail in this report. However, it is important to note that San Francisco has already taken great strides to reduce its earthquake risk. If the City continues these efforts in the decades to come (and a major earthquake does not occur in the near future), the damage expected in future earthquakes will decrease. As an example, the City’s program requiring retrofit of unreinforced masonry buildings has resulted in a large decrease in the casualties expected to occur in future earthquakes. If the City pursues a program that results in retrofits of large, wood-frame soft-story buildings as recommended in the companion CAPSS report in this series (ATC-52-3 Report, *Earthquake Safety for Soft-Story Buildings*), the number of housing units that cannot be occupied or need to be demolished after an earthquake would be reduced. This report focuses on identifying the consequences of large earthquakes on the City the way it is today. Another report in the CAPSS series (ATC-52-2 Report, *A Community Action Plan for Seismic Safety*), guided by the information presented here, will examine and recommend steps the City can take to reduce these consequences.

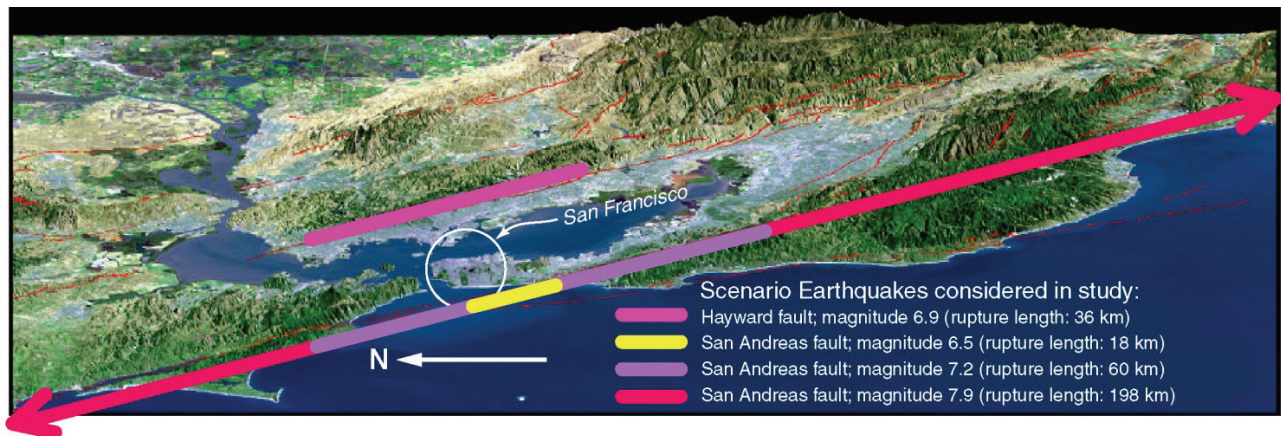


Figure A The location and length of fault ruptured in the four CAPSS scenarios.

Focusing on one possible earthquake, a magnitude 7.2 earthquake on the San Andreas fault directly offshore from San Francisco, illustrates the types of consequences the City can expect following its next large earthquake. Such an earthquake could be considered expected because enough strain to produce an event of this size has built up on the San Andreas fault since 1906. If such an event occurs, the City should expect the following impacts:

- About 27,000 buildings of the 160,000 buildings in San Francisco will not be safe to occupy after the earthquake. About 73,000 more buildings will have moderate damage but will remain usable. Most of the damaged buildings will be wood-frame soft-story buildings, which make up more than half of all buildings in the City. Other structure types, notably concrete buildings built before 1980, will also suffer heavy damage.
- About 3,600 buildings will need to be demolished and rebuilt. Many of these will be older and architecturally valuable buildings; some will be historic resources. The City will permanently lose the character and feel that these buildings contribute. It will also permanently lose any rent-controlled units in these demolished buildings, due to state law.
- Two hundred to three hundred people could be killed, and 7,000 more could have injuries requiring medical care. If the earthquake occurs during the day, older concrete commercial buildings will be responsible for the largest share of casualties. If the earthquake occurs at night, wood-frame soft-story and older concrete residential buildings will cause the most casualties. Casualties could be much higher if even one large, densely occupied building collapses.
- Earthquake shaking sparks fires (Figure B). This scenario is likely to ignite more than 70 fires simultaneously, while impeding the San Francisco Fire Department's ability to respond quickly. This means some fires will burn unchecked for hours. An estimated 2,700 additional buildings could be destroyed by fire, including 5,800 housing units. Damage from fire could be much higher or lower than these estimates, depending on weather, wind, and many other factors.
- 85,000 housing units would not be suitable for occupancy and would take months to years to be repaired or replaced. Rental and low-income housing would be the slowest to come back.
- Economic losses will be huge. The cost for owners to repair or replace their damaged buildings could be \$30 billion. Most of this damage will be uninsured. Only 6 to 7 percent of home owners in San Francisco carry earthquake insurance, although coverage is higher for commercial properties. An additional \$10 billion could be lost in damage to building contents, loss of inventory, relocation costs, income losses, and wages directly linked to this damage. Post-earthquake fires could add over \$4 billion to these losses. Secondary economic losses, stemming from reduced business and household spending, would increase economic hardships.

The next major earthquake that strikes San Francisco will change the City and its people. San Francisco is a world-class city with many special attributes that draw businesses, innovative people who want to live here, and visitors from around the world. In the long-term, San Francisco will recover and thrive, but it will be a different San Francisco. It is possible that a new, post-earthquake San Francisco will have less socio-economic diversity. The loss of many affordable housing options,



exacerbated by a limited number of housing units in the years it will take to rebuild the City, will make it difficult for some middle and low income people to remain in San Francisco. Earthquake damage will stress businesses and the jobs they provide, particularly many small and independent businesses in the City. It will change the way the City looks, with some of the most interesting and beautiful buildings and neighborhoods changed forever. Despite the damage, San Francisco will retain many of the elements that make it an economically successful and socially desirable place – physical beauty, cultural amenities, and proximity to world-class universities, to name a few.

The scenarios described in this report present what is likely to happen if San Francisco makes no changes to its preparations for earthquakes. As discussed in the companion ATC-52-2 Report, *A Community Action Plan for Seismic Safety*, much of this damage is preventable. It is up to San Franciscans to decide how much to invest in steps to reduce the consequences of future major earthquakes.



**Figure B** View looking east from California Street during post-earthquake fires in 1906. Photo credit: Courtesy of the National Information Service for Earthquake Engineering, University of California, Berkeley.



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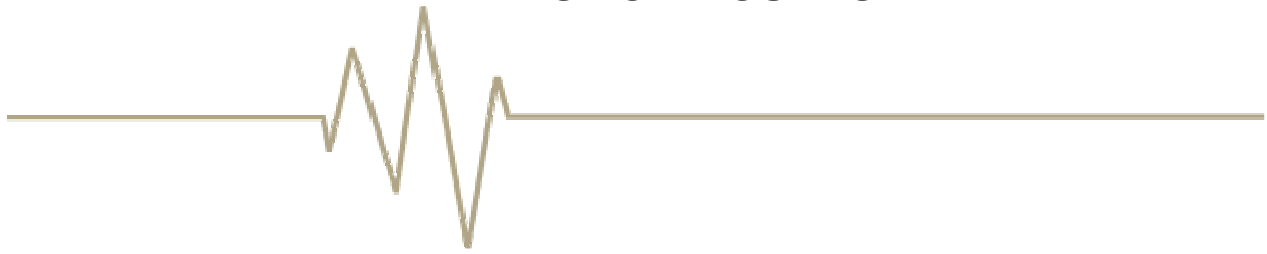


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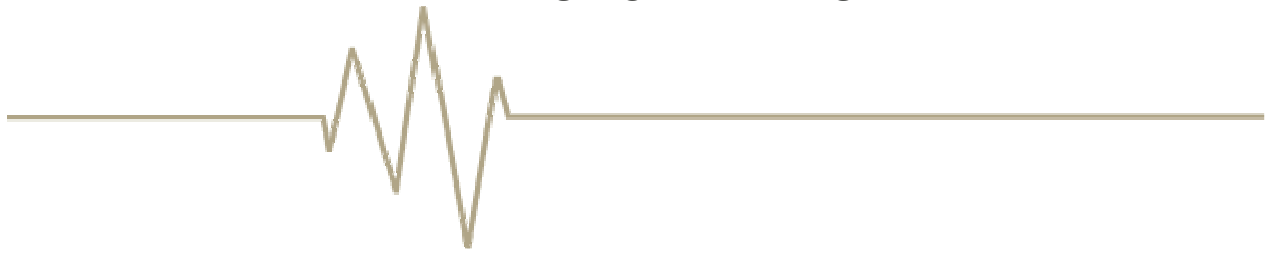
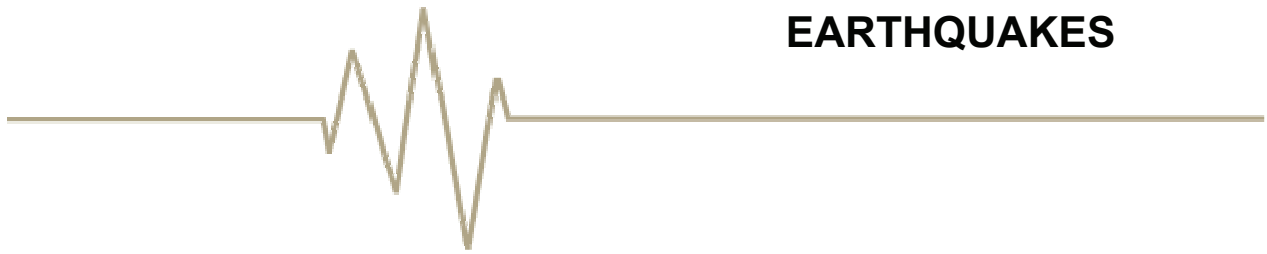


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# CHAPTER 1: FOUR POSSIBLE EARTHQUAKES



No one knows when the next large earthquake will strike San Francisco, but it is certain that large earthquakes will occur. Scientists estimate that there is a 63 percent chance that a magnitude 6.7 or larger earthquake will occur in the Bay Area within the next thirty years<sup>1</sup>. This report selects four possible earthquakes that could strike the City and estimates the amount of damage and the resulting ripple effects that each could cause. The next large earthquake to strike the City will surely be different – in size, location, and many other characteristics – than the four scenarios examined in this report. The consequences of the next large earthquake, however, are likely to be similar in nature to the consequences estimated in the following chapters. To begin, this chapter describes the four earthquake scenarios studied in this report.

Four scenarios were selected to represent a range of likely seismic events that could strike the City in coming years. The four scenario earthquakes are:

1. A magnitude 6.9<sup>2</sup> earthquake on the Hayward fault in the East Bay. Of the four earthquakes studied, this event has the highest likelihood of occurring in the next 30 years.
2. A magnitude 6.5 earthquake on the portion of the San Andreas fault closest to San Francisco.
3. A magnitude 7.2 earthquake on the peninsula segment of the San Andreas fault closest to San Francisco. This earthquake would produce a level of shaking in many areas of the City that is similar to the level of shaking that the building code requires new structures be designed to resist without major structural failure. For this reason, damage from this scenario is used as an example to explore consequences in detail in many places throughout the report.
4. A magnitude 7.9 earthquake on the San Andreas fault, which is a repeat of the 1906 earthquake. This is the largest known earthquake to have occurred in northern California on the San Andreas fault.

Any of the four earthquake scenarios examined in this study would result in very strong shaking in San Francisco<sup>3</sup>. Figure 1 shows the shaking that would be produced

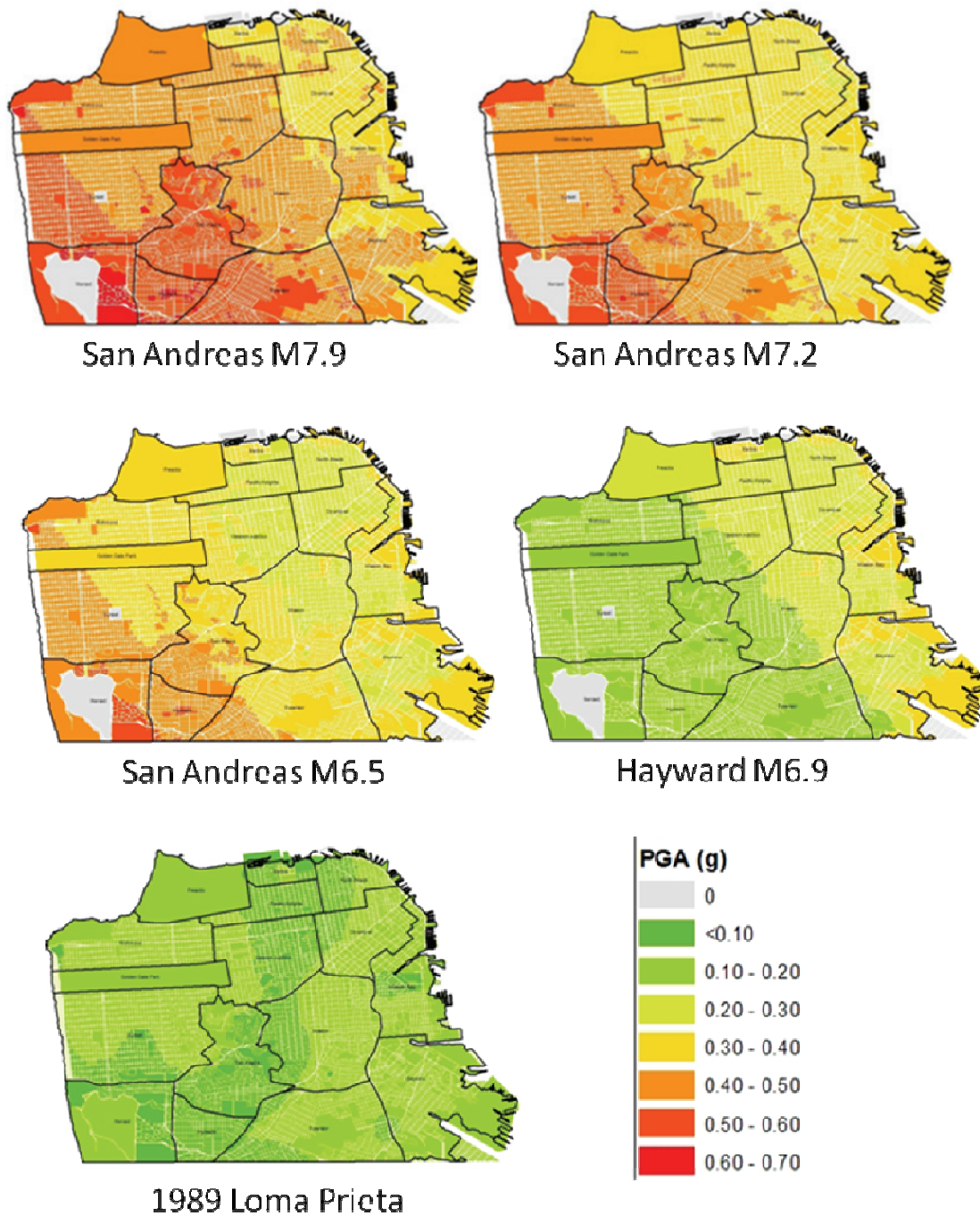
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<sup>1</sup> WGCEP, 2008.

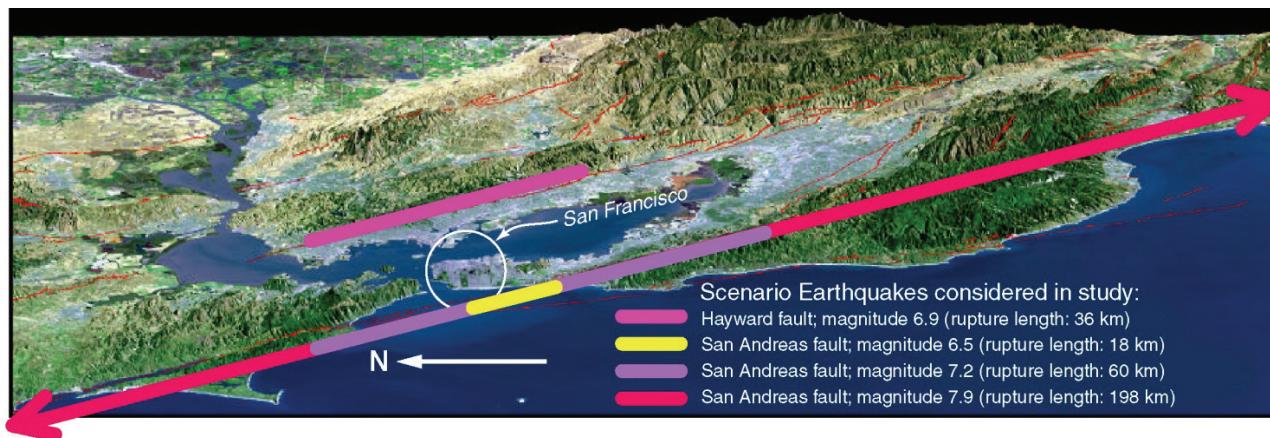
<sup>2</sup> All earthquake magnitudes in this report are moment magnitudes. Moment magnitude represents the total amount of energy released in an earthquake and is the preferred scale used by earth scientists. This is similar to Richter magnitude, which is related to the peak displacements caused by an earthquake 100 km from the epicenter.

<sup>3</sup> Information about the technical methods used to estimate this shaking, and all other results in this report, is presented in a companion volume, ATC 52-1A Report, *Potential Earthquake Impacts: Technical Documentation*.

in each of these scenarios, and compares them to the actual shaking experienced during the 1989 Loma Prieta earthquake, the last damaging earthquake experienced in San Francisco. All four of these scenarios would produce shaking throughout the City that is two to four times stronger than the shaking that struck in the Marina—the City’s hardest hit neighborhood—during Loma Prieta.



**Figure 1** The estimated shaking for the four scenario earthquakes, and the actual shaking experienced in the 1989 Loma Prieta earthquake. PGA stands for Peak Ground Acceleration, expressed as a percent of the acceleration of gravity.



**Figure 2** The location and length of fault ruptured in the four CAPSS scenarios.

Figure 2 shows the location of each of the four scenario earthquakes, in relation to San Francisco, and the size of the fault rupture in each event. Larger earthquakes break or rupture a longer length of fault.

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The chapters that follow describe what is likely to happen to San Francisco if these four scenario earthquakes occur. While the next significant earthquakes to shake the City will probably be different than those studied here, the same themes will undoubtedly emerge in the damage that follows. The City will lose housing, businesses, people, and historic character. The next chapter discusses the buildings in the City that these events would shake.





## CHAPTER 2: SAN FRANCISCO'S BUILDINGS

San Francisco has approximately 160,000 buildings, ranging from gleaming, new downtown high rises to small, single-family homes. This chapter discusses the privately-owned buildings in the City: their numbers and value, how they are used, where they are located, and variations in how they are constructed. This report only covers privately-owned buildings under the jurisdiction of the City's Department of Building Inspection.

### Dividing up the City

Earthquakes will affect different parts of the City in different ways due to each location's proximity to faults, underlying soil, and types of buildings. For this reason, some of the findings in this study are presented by district. For the purposes of this project, the City is divided into fourteen districts, shown in Figure 3<sup>4</sup>. There is still



Figure 3 Map of CAPSS district divisions.

<sup>4</sup> These districts are used by the Department of Public Works. The Presidio, Golden Gate Park and Treasure Island (not shown) were not analyzed by the project because no building inventory data were provided to the project team for these locations. Many buildings in those areas are government-owned. This study focuses only on privately-owned buildings.

considerable diversity within any of the relatively large districts used in this study. Further, the district names used by this study may represent a larger area than when those same names are used colloquially by City residents. For example, the CAPSS “Downtown” district encompasses the Financial District, Chinatown, South of Market (SOMA), the Tenderloin, and Nob Hill. Some of the different communities that make up each of the fourteen large districts addressed in this study are presented in Table 1.

**Table 1                    Communities That Make Up CAPSS District Divisions**

<b>CAPSS District Name</b>	<b>Neighborhoods Included in Each District</b>
Bayview	Bayview, Candlestick Point, Hunter’s Point, Silver Terrace
Central Waterfront	Dogpatch, Mission Bay, Potrero Hill, South Beach
Downtown	Chinatown, Civic Center, Financial District, Nob Hill, SOMA (South of Market), Tenderloin
Excelsior	Bayshore, Crocker Amazon, Excelsior, Portola, Visitacion Valley
Ingleside	Ingleside, Ingleside Heights, Ingleside Terrace, Oceanview
Marina	Marina
Merced	Lakeshore, Stonestown
Mission	Bernal Heights, Castro, Glen Park, Mission, Noe Valley
North Beach	Fisherman’s Wharf, North Beach, Russian Hill, Telegraph Hill
Pacific Heights	Cow Hollow, Pacific Heights, Presidio Heights
Richmond	Inner Richmond, Outer Richmond, Seacliff
Sunset	Golden Gate Heights, Inner Sunset, Outer Sunset, Parkside
Twin Peaks	Diamond Heights, Forest Knolls, Miraloma Park, St. Francis Wood, Sunnyside, Twin Peaks, West Portal, Westwood Park
Western Addition	Alamo Square, Cole Valley, Fillmore, Haight Ashbury, Hayes Valley, JapanTown, Laurel Heights, Western Addition

Source: Department of Public Works.

## The City’s Buildings

San Francisco contains approximately 160,000 buildings. These buildings range from small homes built over a century ago to newly-constructed high-rises. They house the many activities that take place in the City. They also contribute to San Francisco’s unique sense of place: the character, sense of history, and structure for the family and community life that makes this City what it is. Table 2 presents estimates of the number and value of buildings used for various purposes.

The density of buildings and the way they are used varies throughout the City. Many districts—the Sunset, Twin Peaks, Ingleside, and the Excelsior, to name a few—are primarily residential. Other districts have much of their building space used for commercial or other non-residential purposes, such as Downtown and the Central Waterfront. Similarly, the value of the building stock varies by district. More than a quarter of the City’s building value is concentrated in the Downtown district. This reflects the large building square footage in this dense and high-rise area. The consequences and costs of earthquake damage depend on which districts are shaken most strongly, and the types and quantity of buildings that are found there. Table 3 shows the estimated number and value of buildings by district.

**Table 2 Estimated Number and Value of Buildings Used for Various Purposes in the City**

Building Use	Estimated Number of Buildings <sup>a</sup>	Estimated Replacement Value of Buildings <sup>b</sup> (\$ Billions)
Single-family Houses	112,000	\$53
Two unit Residences	19,000	\$22
Three or more unit Residences	23,000	\$45
Other Residences <sup>c</sup>	800	\$13
Commercial Buildings	5,000	\$48
Industrial Buildings	2,100	\$7.7
Other <sup>d</sup>	700	\$2.6
Total <sup>e</sup>	160,000	\$190

a. These numbers are estimates for 2009.

b. These figures represent an estimate of the cost to replace or reconstruct a building in 2009. They do not include the value of the land the building sits on or a building's contents. Replacement values are significantly different than real estate prices or assessed valuation. Building value is based on square footage from San Francisco Assessor's Tax Roll, not the estimated number of buildings.

c. Other Residences includes hotels, motels, nursing homes, and temporary lodging.

d. Other includes religious and educational buildings listed in the Assessor's Tax Roll.

e. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.

Sources: This study, San Francisco Assessor's Tax Roll, Census data, San Francisco Planning Department, and San Francisco Department of Building Inspection.

The way each of these buildings responds to earthquake shaking depends on many things, including the materials they are constructed from, their size and shape, their engineering design, their quality of construction, and how well they have been maintained. Table 4 shows estimates of the number of buildings of various structural types that exist in San Francisco. The structural types, which reflect a building's materials and the system it uses to carry loads, are used by engineers to differentiate how buildings perform in earthquakes. These numbers are estimates only, based on engineering judgment, City databases, and field surveys<sup>5</sup>. The way that a building's use relates to its structural characteristics can be complex. Buildings used for some purposes tend to be of a predictable structural type; for example, single-family houses in San Francisco are overwhelmingly constructed out of wood. Buildings used for other purposes can be constructed in a wide range of structural types. For example,

<sup>5</sup> There have been sidewalk surveys conducted by engineers for unreinforced masonry buildings and wood-frame buildings with three or more stories and five or more residential units (these are a subset of the wood-frame buildings listed in Table 4). The number of concrete buildings built before 1980 have been estimated by a project called the Concrete Coalition (Kadysiewski, 2009) using street surveys and historical records. CAPSS conducted surveys of a small number of wood-frame buildings in all City neighborhoods to estimate the percent of such buildings with soft-stories and other conditions.

**Table 3 Estimated Number and Value of Buildings by District**

District	Estimated Number of Buildings <sup>a</sup>	Estimated Replacement Value of Buildings <sup>b</sup> (\$ Billions)
Bayview	7,600	\$5.8
Central Waterfront	3,600	\$9.9
Downtown	5,500	\$52
Excelsior	23,000	\$11
Ingleside	8,200	\$3.5
Marina	2,200	\$3.4
Merced	2,600	\$1.8
Mission	25,000	\$22
North Beach	5,500	\$13
Pacific Heights	6,000	\$10
Richmond	15,000	\$15
Sunset	33,000	\$19
Twin Peaks	13,000	\$7.4
Western Addition	12,000	\$19
Total <sup>c</sup>	160,000	\$190

a. These numbers are estimates for 2009.

b. These figures represent an estimate of the cost to replace or reconstruct a building in 2009. They do not include the value of the land the building sits on or a building's contents. Replacement values are significantly different than real estate prices or assessed valuation. Building value is based on square footage from San Francisco Assessor's Tax Roll, not the estimated number of buildings.

c. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.

Sources: This study, San Francisco Assessor's Tax Roll, Census data, San Francisco Planning Department, and San Francisco Department of Building Inspection.

this study assumes that buildings used for retail could be one of twelve different structural types, with additional variation in their seismic resistance based on the building's age, height and quality of construction.

### Seismically Vulnerable Structure Types

Some building types in the City are known to have particular weaknesses in earthquakes, which are briefly described below. In future earthquakes, it is likely that damage will be concentrated in buildings of these types.

#### *Soft-Story Buildings*

The first floor in many buildings in San Francisco is significantly weaker or more flexible than the stories above it. The weakness at the ground level usually comes from large openings in perimeter walls, due to garage doors or store windows, and/or few interior partition walls. During strong earthquake shaking, the ground level walls cannot support the stiff and heavy mass of the stories above them as they move back

**Table 4**                      **Estimated Number and Value of Buildings of Various Structural Types in the City**

Structural Type	Estimated Number of Buildings <sup>a</sup>	Estimated Replacement Value of Buildings <sup>b</sup> (\$ Billions)
Wood-frame single-family soft-story	60,000	\$29
Wood-frame two unit residential soft-story	10,000	\$12
Wood-frame three or more unit residential soft-story <sup>c</sup>	13,000	\$26
Wood-frame single-family not soft-story	52,000	\$24
Wood-frame two unit residential not soft-story	9,000	\$10
Wood-frame three or more unit residential not soft-story <sup>c</sup>	6,000	\$12
Concrete built before 1980 <sup>d</sup>	3,000	\$19
Tilt up concrete	200	\$0.8
Modern concrete <sup>e</sup>	600	\$4
Steel moment and braced frame	1,500	\$21
Unreinforced masonry, retrofitted <sup>f</sup>	1,500	\$5
Unreinforced masonry, unretrofitted <sup>g</sup>	400	\$1
Other <sup>h</sup>	4,200	\$27
Total <sup>i</sup>	160,000	\$190

- a. The numbers of buildings are estimates for 2009 based on available studies and engineering estimates.
- b. These figures represent an estimate of the cost to replace or reconstruct a building in 2009. They do not include the value of the land the building sits on or a building's contents. Replacement values are significantly different than real estate prices or assessed valuation. Building value is based on square footage from San Francisco Assessor's Tax Roll, not the estimated number of buildings.
- c. The City is currently discussing a program to require evaluation and possible retrofit of residential wood-frame buildings with 3 or more stories and 5 or more residential units. Some but not all of these buildings have a soft-story. There are an estimated 4,400 of these buildings with an estimated replacement value of \$14 billion.
- d. Concrete built before 1980 includes concrete shear wall buildings and concrete frames with masonry infill walls. The 1980 date was chosen to be consistent with the survey work of the Concrete Coalition (see footnote, next page, for a description of the Concrete Coalition).
- e. Modern concrete buildings include concrete moment frame and shear wall buildings built after 1980.
- f. This includes buildings retrofitted under the City's program.
- g. This includes buildings in the City's retrofit program that have not yet received their certificate of completion, and buildings not included in the City's retrofit program, such as buildings with fewer than five residential units.
- h. Other includes steel frame with cast in place concrete walls or masonry infill walls, reinforced masonry buildings, and non-residential wood-frame buildings.
- i. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.
- Sources: This study, Concrete Coalition, and San Francisco Department of Building Inspection.

and forth. The ground level walls could shift sideways until the building collapses, crushing the ground floor.

This type of weakness, called a soft-story, can be found in many types of buildings. It is common in single-family houses, where the dwelling space sits over a garage, and multi-family buildings, which may have parking or large and open commercial space at the ground level. Corner buildings are believed to have the highest risk, because mid-block buildings are often supported by their neighbor buildings. Soft-stories also occur in commercial buildings constructed from concrete or steel, often with retail space at the ground level and offices above. The companion CAPSS report in



this series—*Earthquake Safety for Soft-Story Buildings* (ATC-52-3 Report), released in 2009—took a detailed look at large, wood-frame soft-story buildings, such as the type shown in Figure 4. Many smaller wood-frame soft-story buildings and soft-story buildings constructed from other materials also exist throughout the City.



*Figure 4 A typical multi-family, wood-frame soft-story building in San Francisco. Soft-story buildings can also be smaller buildings, such as single-family homes, or buildings constructed from other materials, such as concrete.*

### **Concrete Buildings Built Before 1980**

Older reinforced concrete buildings can experience dramatic and deadly collapses during earthquakes (Figure 5). Such collapses are responsible for many of the casualties in earthquakes around the world. However, many older concrete buildings might remain standing but suffer a great amount of damage. Inside the columns, beams, walls and floor slabs of reinforced concrete buildings lay steel reinforcing bars. Ideally, these bars allow reinforced concrete buildings to not only carry loads from gravity, but also to withstand the side-to-side shaking caused by earthquakes. Older reinforced concrete buildings may not have enough steel inside them or may not have steel in adequate configurations to survive the level of shaking that will occur in San Francisco earthquakes.

The design and construction of Californian reinforced concrete buildings improved significantly in the mid-to-late 1970's. Engineers learned from dramatic failures of these buildings during the 1971 San Fernando earthquake in Southern California and other earthquakes. It took some years for these lessons to be reflected in building codes and new construction projects. This study assumes that all reinforced concrete buildings constructed before 1980 may have design problems. This date was chosen to be consistent with a focused earthquake hazard reduction program—the Concrete Coalition<sup>6</sup>—that is working to study this type of building.

Many older concrete-frame buildings have unreinforced masonry walls filling the space between columns and floors to form walls for the exterior, elevator shafts, and stairwells. The masonry can help these buildings to remain standing during

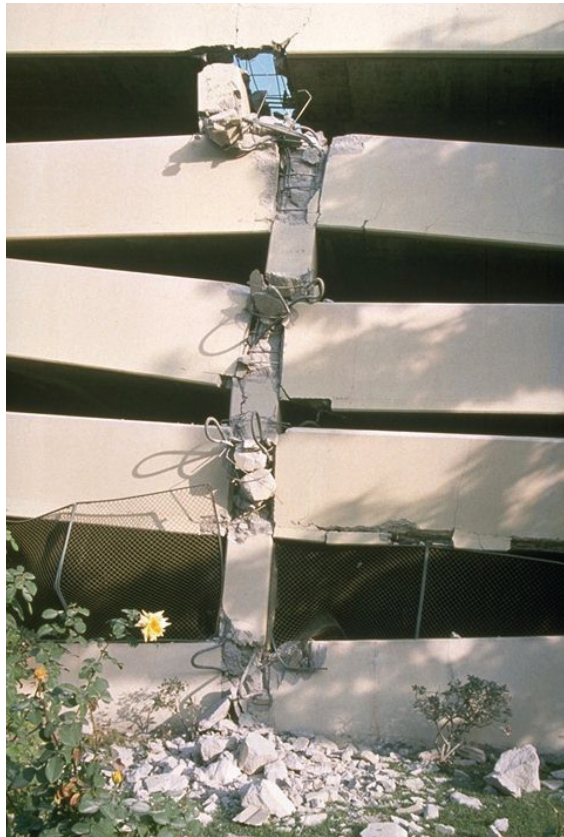
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<sup>6</sup> A program of the Earthquake Engineering Research Institute, Pacific Earthquake Engineering Research Center at the University of California, Berkeley, the Applied Technology Council, and several other partner organizations (see [www.concretecoalition.org](http://www.concretecoalition.org))



earthquakes, but the walls, being brittle, can crack and fall into or out of the building, creating significant dangers to those on sidewalks and causing damage that would be expensive and time-consuming to repair. Some of these buildings also have a soft-story at the ground level, and could collapse. It is costly and difficult to reinforce these buildings before an earthquake and to repair them when they are damaged.

There are older reinforced concrete buildings in San Francisco being used as apartment buildings, private schools, office buildings and warehouses. Thousands of people use these buildings daily. What is not known is which specific concrete buildings are most dangerous, and identifying the dangerous ones is challenging. Typically, it requires engineers with specific skills to conduct invasive and costly tests and analyze performance.



*Figure 5 Damage to a concrete-frame office parking garage in the 1994 Northridge earthquake. Photo credit: Robert K. Reitherman, Courtesy of the National Information Service for Earthquake Engineering, University of California, Berkeley.*

### *Unreinforced Masonry Bearing Wall Buildings*

Unreinforced masonry bearing wall buildings have long been recognized as one of the most dangerous types of buildings in earthquakes. These buildings are constructed with brick walls that bear the weight of the building. They typically have six or fewer stories and were built before the mid-1930's, when building codes were changed to prevent this type of construction. They perform very poorly in earthquakes. Building parapets and sections of walls can fall outward, and some buildings can collapse in even moderate shaking. This building type has been responsible for many deaths in past earthquakes.

San Francisco has been working to improve the safety of its unreinforced masonry bearing wall buildings for decades, first through an ordinance requiring parapets to be anchored, and later through an ordinance requiring most of these buildings to be retrofitted (Figure 6). As of the writing of this report, 90 percent (1,526 out of 1,699) of the buildings on the City’s list of unreinforced masonry buildings had been retrofitted or demolished, and a remaining 10 percent (173) were in process of becoming compliant with the ordinance, or were referred to the City Attorney’s Office for enforcement<sup>7</sup>. It is important to note that retrofitted unreinforced masonry buildings remain highly vulnerable to earthquakes. When exposed to strong shaking, it is likely that retrofitted buildings would cause significantly fewer casualties than those that have not been retrofitted, but many buildings could be damaged beyond repair, displacing their occupants and requiring demolition. A few hundred masonry buildings were exempted from the City’s retrofit ordinance, including buildings used only as residences with four or fewer units. It is likely that many of these remain unretrofitted.



**Figure 6**     *A retrofitted unreinforced masonry building in San Francisco. Photo credit: Courtesy of William T. Holmes.*

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<sup>7</sup> Kornfield, 2009.

## Other Vulnerable Building Types

A number of other building types and characteristics are well-documented as being vulnerable in earthquakes. These include the following:

- *Welded steel moment frame buildings.* The welds connecting columns and beams in steel moment frame buildings built before 1994 can crack in earthquake shaking, leading to a reduction in their capacity to support the building. Before this vulnerability was discovered, this construction type was thought to have excellent seismic performance and, therefore, was popular for large office buildings. The 1994 southern California Northridge earthquake revealed this weakness. A number of San Francisco's downtown high-rises are welded steel moment frames.
- *Concrete tilt-up buildings.* These buildings have precast concrete panels that are raised in place to form the building walls. If the walls are not adequately connected to each other and to the roof, they can separate when shaken by an earthquake, causing the roof to collapse on the occupants and contents of the building. This structure type is often used for industrial purposes, but may also be used for some grocery stores or other commercial purposes. There are an estimated 200 of these buildings in San Francisco.
- *Older steel buildings with masonry infill walls.* San Francisco has many steel-frame buildings from the early part of the last century with masonry walls filling the space between columns and floors to form walls for the exterior, elevator shafts, and stairwells. The steel is often encased in concrete for fireproofing purposes, making the building appear to be a concrete frame to a casual observer. The masonry walls in these buildings can crack up and fall into or out of the building, creating significant dangers to those on sidewalks and causing damage that would be expensive and time-consuming to repair. These buildings are used as residences and offices, and many have beautiful period architectural detailing.
- *Hillside buildings.* San Francisco's characteristic hills have led to many buildings that have more stories on one side than the other. For example, it is common to see buildings with one or two stories of street frontage, but three or four stories when seen from the back. Structurally, buildings with irregular heights can be especially vulnerable to earthquake shaking, particularly if the lower levels have a soft-story or other structurally deficient condition.
- *Cladding, finishes and chimneys.* Buildings of all structural types have elements that can fall off during earthquakes, particularly if their connections have deteriorated due to age or corrosion. These elements can hurt people or affect the functionality of a building. They include cladding (outside finishes of glass, brick, stone, or other materials), and decorative elements. Masonry chimneys are brittle and often lack reinforcing steel. During earthquakes they can snap at the roof or pull away from a building. Falling bricks can crash through roofs or onto the ground below.
- *Falling hazards and utility failure.* There are a variety of non-structural issues that can lead to deaths and injuries, or make buildings unusable. These include tipping of heavy furniture and equipment and falling light fixtures or objects on shelves. Falling hazards can be serious, even in buildings that are structurally sound. For example, studies following the 1999 Kocaeli earthquake near Istanbul, Turkey found that nearly half of the casualties were caused by non-

structural elements rather than damage to the building structure<sup>8</sup>. A variety of non-structural issues can also make buildings unusable, such as inoperable elevators or destruction of furniture due to water damage.

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Future earthquakes will shake all 160,000 privately-owned buildings in the City. The next chapter presents estimates of how much damage these buildings would sustain in the four scenario earthquakes.

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<sup>8</sup> Petal, 2009.

## CHAPTER 3: EARTHQUAKE DAMAGE TO BUILDINGS



This chapter presents direct estimates of damage to the City's privately-owned buildings in four possible earthquakes, with a focus on a magnitude 7.2 scenario on the San Andreas fault. In that scenario earthquake, nearly 15 percent of the City's buildings—almost 27,000 buildings—would not be fit for occupancy after the earthquake. About 3,600 of these buildings would be damaged beyond repair. It would cost \$30 billion to repair and replace damaged buildings. The type of structure that would experience the most damage, both in terms of the number of buildings damaged and the cost of damage, is soft-story wood-frame residences. This is also the most common type of structure in the City, representing slightly more than half of the 160,000 buildings. Other types of structures, such as concrete buildings built before 1980, will also fare poorly. This chapter presents losses due to shaking and ground failure. Additional losses due to fire are discussed in Chapter 4.

### **Purpose and Proper Use of These Estimates**

The damage estimates in this report are intended to guide the City in developing policies and plans that will make San Francisco safer and more resilient during and after future earthquakes. The losses and impacts described in the following pages are reasonable estimates of what could occur in future earthquakes, not accurate predictions of exactly what would happen. Estimating earthquake damage is an inherently uncertain process; if one of the exact events studied in this report should occur, damage could be double or half what is reported here. Some of the many sources of uncertainty include: selecting which scenario earthquakes to study; modeling the way seismic forces travel through the ground; modeling the impact of differing degrees of shaking on structures of various materials and configurations; and estimating exactly which structural types of buildings are in various locations throughout the City. This study looks at earthquake impacts at the citywide and district level. Analysis was not conducted for specific buildings, and this study makes no determination of how any particular building in the City will perform in future earthquakes. It is impossible to know exactly what will happen in the next large earthquake to strike San Francisco. However, the estimates presented in this report rely on internationally accepted techniques to provide reasonable estimates to help guide City decisions.

This report only examines buildings regulated by the Department of Building Inspection that are privately owned. There are many structures, buildings, and facilities in San Francisco that were not included in this study. For example, public buildings (public schools; city, state, and federal buildings; the San Francisco International Airport; and port facilities) and infrastructure (water, sewer, power, gas, transportation, bridges, piers, and tunnels), were not included in the project scope. Only private-sector building damage and repercussions on the people and economy of San Francisco traceable to this damage are addressed in this study. Therefore, the



actual total damage following any of the scenario earthquakes would likely be higher than what is presented in the report. Other City programs, such as the Resilient SF Initiative, are examining risk to public facilities.

## Direct Damage to Buildings

This study used the Hazards US (HAZUS®) methodology<sup>9</sup>, developed by the Federal Emergency Management Agency (FEMA), to estimate the amount and types of damage that could occur in four possible scenario earthquakes. The analysis using HAZUS® has been extensively customized to represent the unique buildings and conditions in San Francisco. The details of the technical analysis are described in a companion technical volume, *Potential Earthquake Impacts: Technical Documentation* (ATC 52-1A Report). To assure that the application of the HAZUS® methodology and all modifications made for San Francisco were appropriate, an extensive review of the analysis and the results was carried out by an independent CAPSS Project Engineering Panel whose members are intimately familiar with HAZUS®' capabilities and limitations.

The amount of damage that buildings in the City would experience in future earthquakes depends on many things, including the size of the earthquake that occurs, the soil that each building sits on, the proximity of buildings to the earthquake fault, and the structural characteristics and configuration of each building.

Table 5 shows the estimated cost of direct damage that could occur in four possible earthquake scenarios due to shaking and ground failure, expressed in dollar losses by building use. These figures represent the costs to repair or replace buildings damaged in the scenarios and include damage to building structures and integral non-structural elements, such as partition walls, ceilings, and fixtures. The figures combine the costs of minor repairs with the costs incurred by buildings that need to be demolished and replaced from the ground up. The following issues stand out as important findings:

- Residential buildings have the largest losses. Depending on the scenario, 60 to 70 percent of the total citywide estimated cost to repair and replace damaged buildings is due to damage to residences. This finding is not surprising since most of the City's buildings—about 95 percent of all buildings and about 70 percent of all building value—are residential.
- Single-family houses have the largest total losses in the three San Andreas fault scenarios. Many single-family homes are located in the City's western neighborhoods, closest to the San Andreas fault.
- The Hayward Fault scenario would shake the City's eastern neighborhoods more strongly than the western ones. This causes higher losses to multi-family homes and commercial buildings and lower losses to single-family homes, compared to the San Andreas fault scenarios. This difference is due to different building patterns in the City's eastern and western neighborhoods.
- Multi-family residences, including apartments, condominiums, and Tenancy-in-Common buildings, are hit hard in all scenarios. They are responsible for a disproportionate percent of the losses compared to their value. This is because many multi-family dwellings are located in vulnerable structure types, notably soft-story wood-frame buildings and concrete buildings built before 1980.

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<sup>9</sup> The study used HAZUS®99 SR2 (FEMA, 2002).



- Industrial buildings also experience heavy damage in all scenarios, particularly in the Hayward fault scenario. Again, this is due to vulnerable structure types—older concrete, concrete tilt-up, and masonry buildings—being common in buildings used for industrial purposes.

**Table 5      Estimated Cost to Repair and Replace Buildings Damaged from Shaking and Ground Failure in Four Scenario Earthquakes, by Building Use**

Building Use	Cost of Building Damage in Four Scenario Earthquakes (\$ billions) <sup>a</sup>			
	Hayward Magnitude 6.9	San Andreas Magnitude 6.5	San Andreas Magnitude 7.2	San Andreas Magnitude 7.9
Single-family Houses	\$2.3	\$6.0	\$8.8	\$13
Two unit residences	\$1.4	\$2.4	\$3.6	\$5.4
Three or more unit residences	\$4.2	\$5.2	\$7.8	\$12
Other Residences <sup>b</sup>	\$0.8	\$0.7	\$1.3	\$2.6
Commercial Buildings	\$4.5	\$4.2	\$6.6	\$11
Industrial Buildings	\$0.9	\$1.0	\$1.4	\$2.2
Other <sup>c</sup>	\$0.1	\$0.2	\$0.3	\$0.7
Total <sup>d</sup>	\$14	\$20	\$30	\$48

a. Estimates are in 2009 dollars.

b. Other Residences includes hotels, motels, nursing homes, and temporary lodging.

c. Other includes religious and educational buildings listed in San Francisco Assessor's Tax Roll.

d. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.

Another way to evaluate the damage estimates is to look at the number of buildings that will suffer various degrees of damage in an earthquake. This report expresses damage to buildings in terms of their expected functionality after an earthquake, with the following categorizations<sup>10</sup>:

- *Usable, light damage.* Buildings would experience only minor damage and residents could continue to use them. This report does not assess the likelihood of utilities—water, sewer, power—being functional, which would influence whether occupants choose to remain in these buildings.

<sup>10</sup> These functionality states were adapted from San Francisco Planning and Urban Research (SPUR, 2009), and roughly correlate with the states of Safe and Operational, Safe and Usable During Repair, Safe and Usable After Repair, Safe but Not Repairable, and Unsafe, Collapse Risk. The CAPSS state “Not Repairable” combines the SPUR states Safe but Not Repairable and Unsafe, Collapse Risk.

- *Useable, moderate damage (shelter in place).* Occupants of these buildings could continue to use them safely after a major earthquake and during its aftershocks, but there would be damage that may cause inconvenience. The use of these damaged buildings will depend in part on the City's post-earthquake inspection and posting policies and on the willingness of building owners to let tenants occupy moderately damaged buildings.
- *Repairable, cannot be occupied.* Buildings in this state would experience heavy damage and could not be occupied until repaired. Few, if any, buildings in this state would be demolished, thus, repaired rental units would remain under rent control restrictions, and neighborhood character (as defined by style of construction, building scale, and mix of uses) would be maintained.
- *Not Repairable.* These buildings would experience heavy damage and would need to be demolished after the earthquake. They could not be occupied. The City could permanently lose significant amounts of rent-controlled housing, as well as buildings that contribute to the architectural character of the City. Some of these buildings would collapse or experience partial collapse.

Table 6 shows the amount of damage that buildings used for various purposes are estimated to experience in the Magnitude 7.2 San Andreas fault scenario due to shaking and ground failure. Key points that emerge from looking at expected damage in this format include:

- About 27,000 buildings in the City would not be safe to occupy. This includes more than fifteen percent of the City's residential buildings.
- About 1,500 multi-family residential buildings would need to be demolished. When these buildings are reconstructed, the new units would not be covered by rent control due to state law. Owners may choose to rebuild their buildings with condominiums rather than as rental properties.
- Eighteen percent of commercial space—about 900 buildings—would not be safe for occupancy after the scenario earthquake. Nearly 300 of these buildings would need to be demolished and rebuilt.
- Twenty-five percent of industrial buildings—more than 500 buildings—would not be usable after the scenario earthquake. More than 200 of these would need to be demolished and rebuilt.

### **Damage by District**

The neighborhoods close to the fault, those on poor soils, and those with a prevalence of vulnerable building types would experience proportionately more damage than other neighborhoods. It is important to remember that a different scenario earthquake, such as an event on the Hayward Fault in the East Bay, would change the relative damage patterns among districts. Table 7 shows how damage to buildings would be distributed among different districts in the City for a magnitude 7.2 scenario on the San Andreas fault.

**Table 6 Estimated Damage States of Buildings Due to Shaking and Ground Failure in a Magnitude 7.2 Earthquake on the San Andreas Fault, by Building Use**

Building Occupancy	Number of Buildings in Various States of Damage <sup>a</sup>			
	Usable, Light Damage	Usable, Moderate Damage <sup>b</sup>	Repairable, Cannot be Occupied	Not Repairable <sup>c</sup>
Single-Family Houses	45,000	54,000	11,000	1,700
Two-Unit Residences	8,200	7,400	3,200	290
Three-or-More-Unit Residences <sup>d</sup>	7,200	7,500	7,200	1,100
Other Residences <sup>e</sup>	300	400	80	40
Commercial Buildings	1,600	2,400	630	290
Industrial Buildings	750	820	320	210
Other <sup>f</sup>	330	280	60	30
Total <sup>g</sup>	63,000	73,000	23,000	3,600

- Building functionality categorizations are derived from HAZUS<sup>®</sup> damage states. For more information, please see the companion technical volume, *Potential Earthquake Impacts: Technical Documentation* (ATC 52-1A Report).
- This level of damage can be referred to as “shelter in place”.
- Some of these buildings have collapsed. Others are standing but damaged beyond repair. None can be occupied.
- The City is currently discussing a program to require evaluation and possible retrofit of residential wood-frame buildings with 3 or more stories and 5 or more units. These buildings are a subset of this category. For more information about the performance of residential buildings, see chapter 6.
- Other Residences includes hotels, motels, nursing homes, and temporary lodging.
- Other includes religious and educational buildings listed in the San Francisco Assessor’s Tax Roll.
- Numbers in table have been rounded, which can make totals differ from sum of columns or rows.

### Damage by Structural Type

As discussed previously, some structure types are more vulnerable to earthquake shaking than others. Not surprisingly, these vulnerable structure types are responsible for a disproportionate share of damage to the City’s buildings. Table 8 presents expected costs of building damage in four scenario earthquakes by structural type. The following conclusions emerge when looking at damage in this format:

- Residential wood-frame soft-story buildings are responsible for the largest economic losses in all scenarios. This building type, known to be vulnerable in earthquakes, is very common in San Francisco. It has the highest total value of any structure type in the City, and because many of these buildings are small one- or two-unit residences, this type represents by far the largest number of buildings in the City.

**Table 7      Estimated Damage States of Buildings Due to Shaking and Ground Failure in a Magnitude 7.2 Earthquake on the San Andreas Fault, by District**

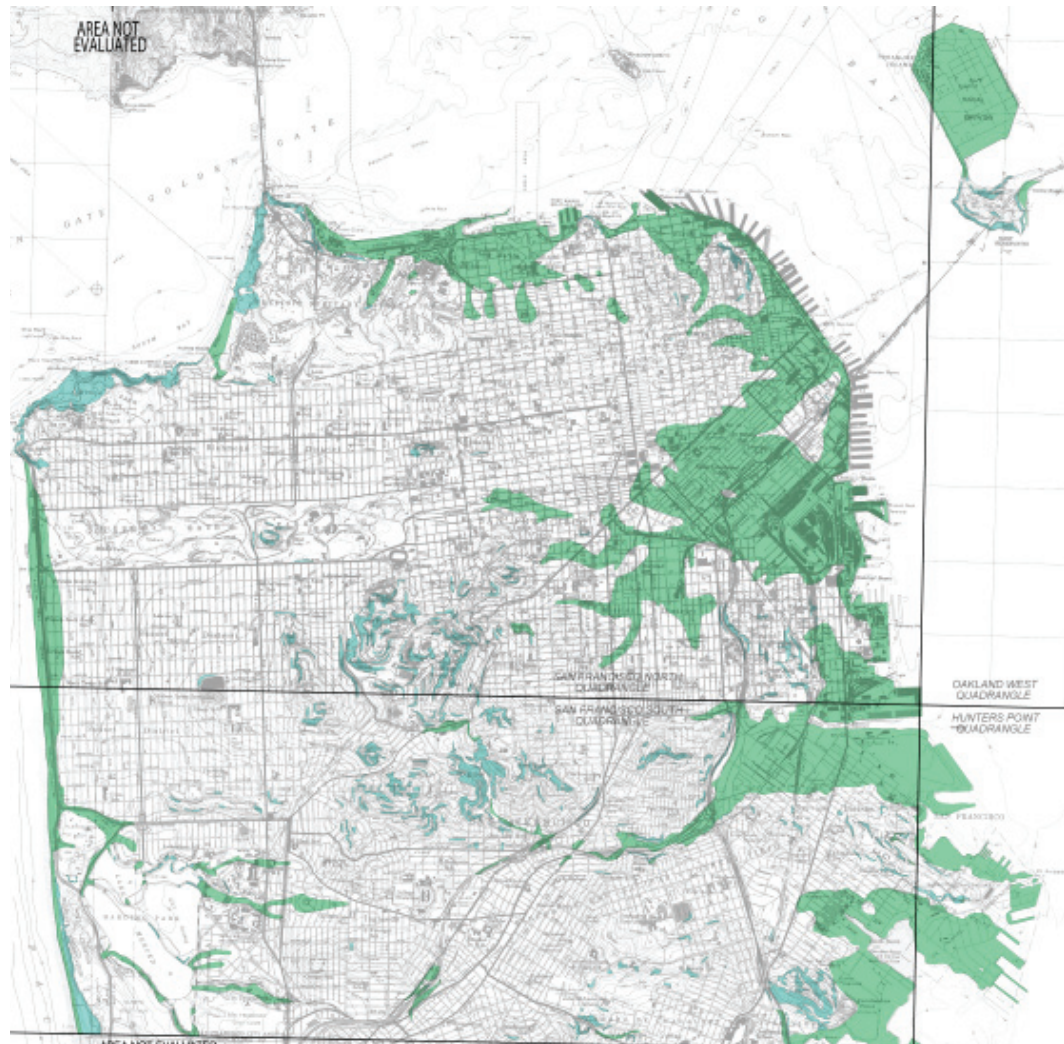
District	Number of Buildings in Various States of Damage <sup>a</sup>			
	Usable, Light Damage	Usable, Moderate Damage <sup>b</sup>	Repairable, Cannot be Occupied	Not Repairable <sup>c</sup>
Bayview	3,100	3,200	940	290
Central Waterfront	1,100	1,600	570	200
Downtown	2,000	2,600	660	190
Excelsior	9,900	11,000	2,300	340
Ingleside	3,000	4,400	830	120
Marina	700	740	600	90
Merced	840	1,400	320	60
Mission	10,000	10,000	3,800	560
North Beach	2,500	2,000	820	140
Pacific Heights	2,600	2,300	920	120
Richmond	5,400	6,400	2,700	360
Sunset	12,000	16,000	4,800	660
Twin Peaks	5,400	6,500	1,300	170
Western Addition	4,900	4,900	2,200	310
Total <sup>d</sup>	63,000	73,000	23,000	3,600

- a. Building functionality categorizations are derived from HAZUS damage states. For more information please see the companion technical volume, *Potential Earthquake Impacts: Technical Documentation* (ATC 52-1A Report).
  - b. This level of damage can be referred to as “shelter in place”.
  - c. Some of these buildings have collapsed. Others are standing but damaged beyond repair. None can be occupied.
  - d. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.
- Older concrete buildings also account for significant economic losses in every scenario, particularly when losses are viewed as a percentage of the value of each building type.
  - Wood-frame residences *without* a soft-story have relatively high economic losses, but this is due to how common these structures are rather than their vulnerability. In fact, when losses are viewed as a percentage of the value of each structure type, these buildings have the lowest percentage loss of any structure type.

### Impacts of Liquefaction

Liquefaction occurs when wet and sandy soils are shaken. It results in a loss of soil strength, and can cause buildings to move sideways or settle unevenly. As shown in Figure 7, a number of neighborhoods in San Francisco could experience liquefaction,

in particular, pockets of the Marina, Downtown, Central Waterfront, Bayview, and Mission districts. About 12 percent of the estimated dollar losses to buildings citywide can be attributed to liquefaction, and over 20 percent in some districts.



*Figure 7 California Geological Survey Hazard Zones Map of San Francisco. Areas susceptible to liquefaction appear in green.*

### **Damage to Buildings with Special Uses**

The City has many privately-owned buildings that serve special purposes. These include the following:

- Facilities occupied by vulnerable people (e.g., private schools, daycare centers, assisted living facilities)
- Businesses and organizations that provide important services to people (e.g., pharmacies, medical offices, medical suppliers, dialysis centers, non-profit community service organizations, grocery stores)
- Culturally important buildings (e.g., historic and architecturally important buildings, buildings in historic neighborhoods, museums, universities)



**Table 8**      **Estimated Costs to Repair and Replace Damaged Buildings Due to Shaking and Ground Failure in Four Scenario Earthquakes, by Structure Type**

Structure Type	Cost of Building Damage in Four Scenario Earthquakes <sup>a</sup> (\$ Billions)				Estimated Replacement Value <sup>b</sup> (\$ Billions)
	Hayward Magnitude 6.9	San Andreas Magnitude 6.5	San Andreas Magnitude 7.2	San Andreas Magnitude 7.9	
Wood-frame single-family soft-story	\$2.0	\$4.4	\$6.5	\$9.3	\$29
Wood-frame two unit residential soft-story	\$1.2	\$1.9	\$2.8	\$4.1	\$12
Wood-frame three or more unit residential soft-story	\$3.5	\$4.2	\$6.1	\$9.2	\$26
Wood-frame single-family not soft-story	\$0.4	\$1.6	\$2.4	\$3.7	\$24
Wood-frame two unit residential not soft-story	\$0.3	\$0.6	\$0.8	\$1.3	\$10
Wood-frame three or more unit residential not soft-story	\$0.4	\$0.6	\$0.9	\$1.6	\$12
Concrete built before 1980 <sup>c</sup>	\$1.9	\$2.0	\$3.3	\$6.5	\$19
Tilt up concrete	\$0.1	\$0.1	\$0.1	\$0.2	\$0.8
Modern concrete <sup>d</sup>	\$0.3	\$0.3	\$0.4	\$0.6	\$4
Steel moment and braced frame	\$1.9	\$1.7	\$2.6	\$3.8	\$21
Unreinforced masonry, retrofitted <sup>e</sup>	\$0.4	\$0.4	\$0.6	\$1.0	\$5
Unreinforced masonry, unretrofitted <sup>f</sup>	\$0.1	\$0.1	\$0.1	\$0.2	\$1
Other <sup>g</sup>	\$2.0	\$2.0	\$3.2	\$6.1	\$27
Total <sup>h</sup>	\$14	\$20	\$30	\$48	\$190

a. Estimates are in 2009 dollars.

b. These figures represent an estimate of the cost to replace or reconstruct a building in 2009. They do not include the value of the land the building sits on or a building's contents. Replacement values are significantly different than real estate prices or assessed valuation. Building value is based on square footage from San Francisco Assessor's Tax Roll, not the estimated number of buildings.

c. This includes concrete shear wall buildings and concrete frames with masonry infill walls. The 1980 date was chosen to be consistent with the Concrete Coalition.

d. Modern concrete buildings include concrete moment frame and shear wall buildings built after 1980.

e. This includes buildings retrofitted under the City's retrofit program.

f. This includes buildings in the City's retrofit program that have not yet received their certificate of completion, and buildings not included in the City's retrofit program.

g. Other includes steel frame with cast-in-place concrete walls or masonry infill walls, reinforced masonry buildings, and non-residential wood-frame buildings.

h. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.

Sources: This study, San Francisco Assessor's Tax Roll, and the Concrete Coalition.



In general, the City and the Department of Building Inspection know very little about the seismic safety of privately-owned buildings that serve these functions. Many of them may be highly vulnerable to earthquake damage. No specific analyses have been conducted to assess the seismic safety of privately-owned buildings used for these purposes.

Buildings used for these special purposes are probably much like other buildings in the City. In many cases, this means they are old and built to outdated building codes. The average date of construction of buildings in the City is 1937<sup>11</sup>. Only 16 percent of the total building square footage in the City was constructed after the mid-1970's, when significant improvements in seismic safety were made in the building code. It is important to note that a building's age alone does not make it unsafe. Many older buildings were built more solidly and used better quality materials than relatively newer buildings from the 1950's and 1960's.

Buildings built to older codes, including those that may be unsafe in earthquakes, comply with City laws and can continue to be used. Only buildings that have recently changed use or undergone extensive renovations, or were covered by the City's unreinforced masonry building ordinance, have been required to undergo seismic safety upgrades.

Most people assume that school buildings are safe. For public school buildings this is generally true: the state has had stricter building regulations for public schools than other building types since the 1930's and has required retrofit of public schools built before 1933<sup>12</sup>. However, there are no such retrofit requirements for private schools. Newly constructed private schools, especially those built after the mid 1990's when enhanced private school building regulations were enacted, should perform well. However, many of San Francisco's private school buildings were constructed when building standards were much less stringent. Nearly one third of school children—more than 23,000—attend private schools in San Francisco, the highest rate in the entire state<sup>13</sup>. The City knows very little about the seismic safety of its private school buildings.

Many non-profit organizations serve critical roles aiding the City's poorest and most vulnerable residents, such as providing meals and healthcare services. Generally, these organizations operate with tight budgets and may be located in older and poorly maintained buildings, meaning their buildings could face a higher risk of damage in earthquakes than many other buildings. As discussed in Chapter 9, the elderly, poor, disabled, and non-native English speakers—many of whom rely on non-profit agencies for support—are most affected by the dislocation caused by disasters and will be in great need of support services after a large earthquake.

Historic buildings contribute to the unique character and culture of the City and provide a connection with the past. They contribute to the appeal of San Francisco to tourists from around the world. Historic buildings have vulnerabilities similar to other buildings of their era and construction type. The City has about 250 designated

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<sup>11</sup> This is the building area weighted average, calculated by this study using the San Francisco Assessor's Tax Roll.

<sup>12</sup> Some San Francisco school district buildings that are occupied by administrators, not students, have known seismic vulnerabilities.

<sup>13</sup> California Department of Education, 2009.

landmark buildings and 11 historic districts<sup>14</sup>. These numbers of officially designated buildings and areas are increasing as efforts to survey older parts of the City progress; however, it is certain that there are many more buildings that are historic resources in San Francisco. It is difficult to make any uniform statements about the seismic vulnerability of these buildings because they range considerably in construction material, size, and configuration. Some older buildings are very vulnerable to earthquake shaking; others are quite robust. An unknown number have been seismically retrofitted. What is unique about historic buildings is the impact of damage: every historic resource that is destroyed in a future earthquake is irreplaceable.

The impact of future earthquakes on privately-owned buildings that serve special functions in the City can only be understood by learning more about these specific buildings. Until a survey is conducted of these buildings, the City will not know the damage that could occur to these buildings and its consequences to the people of San Francisco.

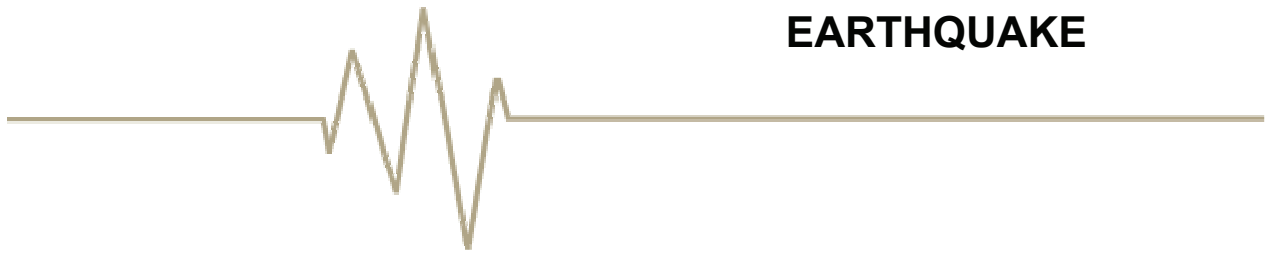
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Building damage due to earthquake shaking is only one piece of the total impact earthquakes can have on a community. The next chapter looks at another critical piece: damage due to fire sparked by the earthquake. Post-earthquake fire is a particularly relevant topic for San Francisco, given the City's experience of a devastating conflagration after the 1906 earthquake.

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<sup>14</sup> San Francisco Planning Department, 2010, designated Article 10 Landmarks and Article 10 Historic Districts.

## CHAPTER 4: FIRE FOLLOWING EARTHQUAKE



San Francisco will sustain major damage from fires following future earthquakes, in addition to the damage caused by shaking. Most earthquakes occur in parts of the world that do not have large numbers of closely spaced wooden buildings. In San Francisco, over 90 percent of buildings are constructed from wood, many of them directly touching their neighbor buildings. Earthquakes in places with this type of construction have caused the two largest peacetime urban fires in history: in 1906 in San Francisco and in 1923 in Tokyo<sup>15</sup>. San Francisco's experience in 1906 (see Figure 8), in which more than 28,000 buildings were lost, about 90 percent of them due to fire<sup>16</sup>, is well-known. The 1906 earthquake and conflagration occurred when the City had less than half the number of people and buildings existing today, and when there was very little development in the western Richmond, Sunset, and Lake Merced neighborhoods closest to the San Andreas fault. After the 1906 fire, San Francisco was rebuilt in much the same way as before, with densely packed, flammable buildings.

More modern events, such as the fires following the 1994 Northridge and 1995 Kobe earthquakes, demonstrate that fires following earthquakes remain a threat today. In both of these moderate-sized earthquakes, more than 100 fires broke out. The Northridge earthquake severely impacted area fire departments, even though it largely affected only the edge of greater Los Angeles. In Kobe, broken water mains left the fire department helpless, and fires destroyed more than 7,000 buildings<sup>17</sup>. Other recent events further demonstrate what could happen following an earthquake: the 1991 East Bay hills fire, which destroyed 3,500 buildings in only a few hours; the 1988 First Interstate Building fire in Los Angeles (the tallest building in the state at the time, requiring more than half of Los Angeles' fire departments); and the San Bruno gas explosion and fire in the Fall of 2010, which required nearly two hours for a ruptured gas line to be shut off.

Fires following earthquakes have a variety of causes, including electricity (electrical shorts, frayed wires, tipped appliances); gas leaks ignited by sparks or open flames; exothermic reactions from spilled chemicals; open flames from stoves, candles, fireplaces, and grills; and arson. In the Northridge earthquake in 1994 in Los Angeles, over half of the ignitions were due to electrical systems and about a quarter were fueled by gas<sup>18</sup>.

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<sup>15</sup> Other well-known historical fires, such as Chicago (1871) and London (1666), were not as large as the post-earthquake Tokyo and San Francisco fires.

<sup>16</sup> NOAA, 1972.

<sup>17</sup> Nagano, 1995.

<sup>18</sup> Scawthorn, et al., 1998.



**Figure 8** *Fires in San Francisco after the 1906 earthquake. Photo credit: photographer unknown, courtesy of the National Information Service for Earthquake Engineering, University of California, Berkeley.*

The San Francisco Fire Department today is a well-prepared, professional organization that trains for earthquake-caused fires. However, earthquakes simultaneously cause numerous ignitions, degrade the fire resistant features of buildings, drop water pressure due to broken water mains, overwhelm communications systems, and impede transportation routes. After the next large earthquake, there are likely to be more fires than San Francisco's fire fighters can respond to at one time. Out-of-town firefighters will not be able to help the City for many hours, and firefighters in nearby cities will be struggling with their own problems. At least some fires in San Francisco will burn out of control, and may threaten entire neighborhoods.

Following 1906, San Francisco clearly recognized the challenges of suppressing post-earthquake fires and constructed the Auxiliary Water Supply System in the City's eastern and northern neighborhoods. This system is specially designed to survive earthquake shaking and is exclusively used for fighting fires. The City has extended the reach of the Auxiliary Water Supply System with the Portable Water Supply System, which can be deployed wherever needed in the City; this was used to extinguish fires in the Marina district after the 1989 earthquake<sup>19</sup>. The combination of the drinking water system, the Auxiliary Water Supply System, the Portable Water Supply System, cisterns located throughout the City, fireboats that can pump bay

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<sup>19</sup> After Loma Prieta, both the drinking water and auxiliary water systems failed to function due to loss of pressure caused by leaks from broken pipes.

water into the auxiliary system, and other special capabilities, makes San Francisco better prepared for suppressing post-earthquake fires than any other city in the world.

This study estimates the number of fires that could occur after four scenario earthquakes and the damage those fires could cause. The analysis considered a wide range of possible situations because the scale of post-earthquake fire can vary dramatically based on conditions after the earthquake. For each earthquake scenario, multiple fire analyses were conducted, varying the number and location of ignitions, the availability of water for fire fighting, the time before professional fire fighters arrive at the scene, weather, wind speed, and many other factors that affect the scope of fire impacts. The analysis is described in detail in the companion volume, *Potential Earthquake Impacts: Technical Documentation* (ATC-52-1A Report).

Table 9 presents estimates of the number of fires requiring fire department response that could occur within hours following the four scenario earthquakes. The table presents the average number of fires estimated after running multiple analyses with varying circumstances, and many more or fewer fires could break out. For example, the average number of fires expected after the magnitude 7.2 San Andreas fault scenario is 73, but there is a 25 percent chance that there could be fewer than 52 fires and a 25 percent chance that there could be more than 89 fires. Table 9 also shows the estimated number of square feet of building floor space that post-earthquake fires could burn. Again, the size of the burned area can vary dramatically based on conditions, so the table shows how this could vary given good, average and bad conditions. For perspective, at any given time the San Francisco Fire Department has about 325 officers and firefighters on duty, and 42 engines and 19 trucks<sup>20</sup>.

Table 10 presents estimates of the square footage of building floor space that could be burned by these fires that was not already heavily damaged by earthquake shaking. The figures in this table express destruction caused by fire beyond the damage caused by shaking presented in the previous chapter. Buildings vary greatly in size; therefore, the number of buildings burned will vary significantly depending on the affected neighborhoods. Table 10 also translates the burned square footage into estimates of numbers of buildings of varying sizes.

The additional damage to San Francisco from fire would be expensive. Table 11 provides estimates of the average costs to repair or replace buildings damaged by fire that is in addition to the damage caused by shaking and ground failure. The additional increment of loss, from 12 percent (\$5.8 billion) following a magnitude 7.9 earthquake on the San Andreas fault to 22 percent (\$3.1 billion) following a magnitude 6.5 on the San Andreas fault, illustrates the economic importance of strategies to reduce fire risks.

Fire damage will add to the City's overall damage, making recovery more difficult and lengthy by increasing the number and severity of damaged buildings, lengthening the time required to repair and replace damaged buildings, displacing residents, and weakening neighborhoods. Buildings that survive the shaking can succumb to fire, including those that have been seismically retrofitted. Conflagration threatens

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<sup>20</sup> In fire service terminology, a fire engine or pumper supplements fire hydrant pressure to provide firefighting water for use by its crew, while a ladder truck, or simply truck, carries numerous ladders and other equipment and additional personnel that provide search and rescue, ventilation, and other needs.

**Table 9 Estimated Number of Fires and Size of Burned Area Following Four Scenario Earthquakes**

Scenario	Average Number of Fires <sup>a</sup>	Size of Burned Area <sup>b</sup> (Million Square Feet)		
		Good Conditions <sup>c</sup>	Average <sup>d</sup>	Bad Conditions <sup>e</sup>
Hayward Fault, Magnitude 6.9	38	3.6	6.0	11
San Andreas Fault, Magnitude 6.5	57	4.7	7.3	14
San Andreas Fault, Magnitude 7.2	73	7.7	11	19
San Andreas Fault, Magnitude 7.9	95	11	17	28

- This table shows the average estimated number of fires requiring professional response for the many analyses with varying circumstances. There would be additional small fires extinguished by residents or self-extinguished. Many more or fewer fires could occur.
- These numbers represent the size of building floor space that is burned. Some of these buildings will also have suffered damage from earthquake shaking.
- This estimate has a 75 percent chance of being exceeded. Under extremely favorable conditions, the burned area could be smaller.
- This is the average estimate for the many analyses with varying circumstances.
- This estimate has a 25 percent chance of being exceeded. Under extremely unfavorable conditions, the burned area could be larger.

**Table 10 Average Size of Previously Undamaged Area Burned, with Comparison to Buildings of Various Sizes**

Scenario	Average Size of Previously Undamaged Burned Area <sup>a</sup> (Million Square Feet)	This Square Footage Equates to...		
		Number of High Rise Buildings <sup>b</sup>	Number of Average Sized Buildings <sup>c</sup>	Number of Single-family Homes <sup>d</sup>
Hayward Fault, Magnitude 6.9	2.6	6	820	1,500
San Andreas Fault, Magnitude 6.5	6.4	14	2,000	3,500
San Andreas Fault, Magnitude 7.2	8.7	19	2,700	4,900
San Andreas Fault, Magnitude 7.9	11	24	3,500	6,100

- This is the average area for the many analyses with varying circumstances. Building square footage that experienced heavy damage from shaking has been excluded from these figures, so this table presents the amount of new destruction caused by fire. It excludes burning rubble.
- This assumes 455,000 square feet per high rise, the size of the Transamerica Pyramid in San Francisco.
- This assumes 3,200 square feet per building, the average building size in San Francisco considering all buildings of all uses.
- This assumes 1,800 square feet per single-family home.



**Table 11      Average Cost of Damage Caused by Fire Following the Scenario Earthquakes**

<b>Scenario</b>	<b>Shaking Damage (\$ Billions)<sup>a</sup></b>	<b>Average Additional Damage Due to Fire<sup>b</sup> (\$ Billions)</b>	<b>Shaking Plus Fire Damage<sup>c</sup> (\$ Billions)</b>
Hayward Fault, Magnitude 6.9	\$14	\$2.7	\$17
San Andreas Fault, Magnitude 6.5	\$20	\$3.0	\$23
San Andreas Fault, Magnitude 7.2	\$30	\$4.3	\$34
San Andreas Fault, Magnitude 7.9	\$48	\$5.8	\$54

- a. These figures include direct damage to buildings from shaking and ground failure, in 2009 dollars.
- b. These figures are averages for the many analyses with varying circumstances and do not double count shaking damage (i.e., burning rubble). Results are in 2009 dollars.
- c. In 2009 dollars. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.

residents with limited mobility, historic neighborhoods, architecturally important buildings, and the character of communities.

Fire damage is usually insured by private insurance policies. Insurance payments, if made quickly, can expedite recovery construction. However, because shaking damage is not covered by normal homeowner or fire insurance policies, fire claims after the next earthquake may be disputed<sup>21</sup>. Disputes could lead to lengthy delays in owners receiving payments to repair or rebuild their properties.

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The damage to buildings from shaking and fire can lead to deaths and injuries. The next chapter looks at how many casualties would be expected in the scenario earthquakes, and what might cause those casualties.

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<sup>21</sup> In other recent disasters insurers have disputed whether damage after hurricanes was caused by wind, which is generally covered by homeowner's policies, or flood, which is not.



## CHAPTER 5: CASUALTIES



Damaged buildings kill and injure people. Table 12 presents estimates of the number of injuries and deaths that could occur in the four scenario earthquakes studied by CAPSS. Depending on the size and time of an earthquake, deaths could range from less than 100 to nearly 1,000. These estimates are based on statistics from casualties in past earthquakes; the collapse of a single, densely packed high-rise building would dramatically increase deaths. These estimates do not include potential casualties due to major fires.

**Table 12 Estimated Injuries and Deaths in Four Scenario Earthquakes**

Earthquake Scenario	Casualties			
	Severity 1: Injuries Needing First Aid <sup>a</sup>	Severity 2: Injuries Needing Hospitalization <sup>b</sup>	Severity 3: Life Threatening Injuries <sup>c</sup>	Severity 4: Death <sup>d</sup>
Hayward Fault, Magnitude 6.9	1,500 to 2,300	330 to 510	40 to 60	70 to 120
San Andreas Fault, Magnitude 6.5	1,800 to 3,600	390 to 740	40 to 60	80 to 120
San Andreas Fault, Magnitude 7.2	3,200 to 5,600	760 to 1,300	90 to 150	170 to 300
San Andreas Fault, Magnitude 7.9	6,500 to 10,600	1,800 to 3,000	220 to 450	420 to 880

- Severity 1: Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Some examples are a sprain, a severe cut requiring stitches, a minor burn (first degree or second degree on a small part of the body), or a bump on the head without loss of consciousness. Injuries of lesser severity that could be self-treated are not estimated by HAZUS® (FEMA, 2002) software.
- Severity 2: Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status. Some examples are third degree burns or second degree burns over large parts of the body, a bump on the head that causes loss of consciousness, fractured bone, dehydration, or exposure.
- Severity 3: Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. Some examples are uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome.
- Severity 4: Instantaneously killed or mortally injured.

Sources: This study, FEMA (2002).

The deaths and injuries in the next San Francisco earthquake are likely to be on a much smaller scale than those seen in recent international earthquakes, especially those in developing countries. There are many reasons for this. One notable reason is

that San Francisco has been effectively enforcing basic building standards for generations. Fifty years ago, those standards were not as good at producing earthquake-resistant buildings as they are today, but they were far better than no standards. Today, many countries continue to have most of their buildings constructed without meeting any design or construction standards, often due to lax enforcement of their building codes. Another reason for San Francisco's low casualty estimates is that most buildings in the City are constructed from wood. Wood-frame buildings, even when they are severely damaged or collapse, are far less lethal than brick, concrete, and other heavier structure types<sup>22</sup>.

Casualty estimates vary by time of day because people are located in different places at different times of day. At night, most people are at home in wood-frame buildings. During the day, commuters significantly increase the City's population and many people are at work or school, in buildings with markedly different structural characteristics than their homes. During commute times, people are traveling from one place to another. The numbers of deaths and injuries that occur in an earthquake can vary significantly depending on circumstances. For example, the World Series baseball game during the 1989 Loma Prieta earthquake, and the consequent decline in traffic, may have prevented more people from being killed by the collapse of the Oakland Cypress Viaduct.

The estimated deaths and injuries shown in Table 12 are only those caused by damage to privately-owned buildings. This study did not estimate possible casualties from other causes, such as damage to infrastructure. In the Loma Prieta earthquake, 41 of the 63 deaths that occurred in the Bay Area were due to the collapses of portions of the Oakland Cypress Viaduct and the Bay Bridge<sup>23</sup>.

A few structure types cause a disproportionate amount of the estimated deaths in the scenarios studied. One of the most lethal structural types is concrete buildings built before 1980. Figure 9 shows the number of deaths<sup>24</sup> caused by each structure type at three times of day in the Magnitude 7.2 San Andreas fault scenario. This figure shows that concrete buildings built before 1980 are expected to be most lethal if an earthquake occurs during the day, but residential wood-frame soft-story buildings will cause the most deaths if an earthquake occurs at night. This difference is due to the different ways these types of structures are used and when they are most densely occupied. However, the collapse of just one multi-story, older concrete residential building would add significantly to the night-time casualty estimate.

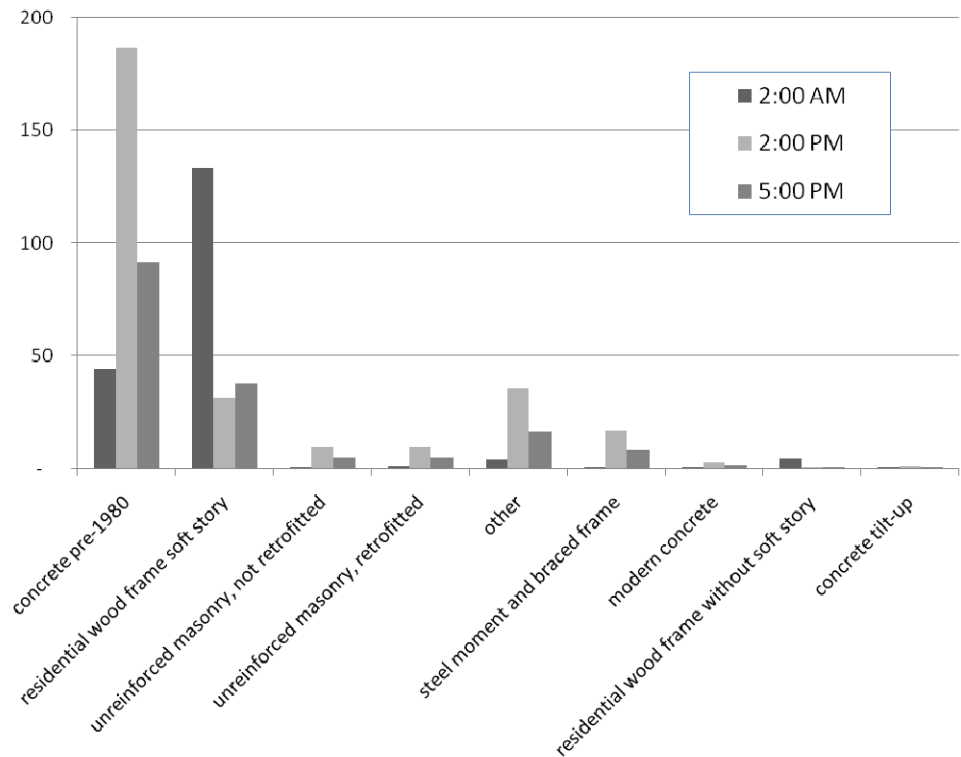
Figure 10 presents averages of the estimated casualties for the various times of day and shows the percent of estimated deaths each structure type would be responsible for in a magnitude 7.2 San Andreas fault scenario event. This shows that, on average, concrete buildings built before 1980 are likely to cause about half of the estimated deaths, and residential wood-frame soft-story buildings are estimated to cause about one-third of the estimated deaths. All other building types would be responsible for a relatively small fraction of estimated deaths.

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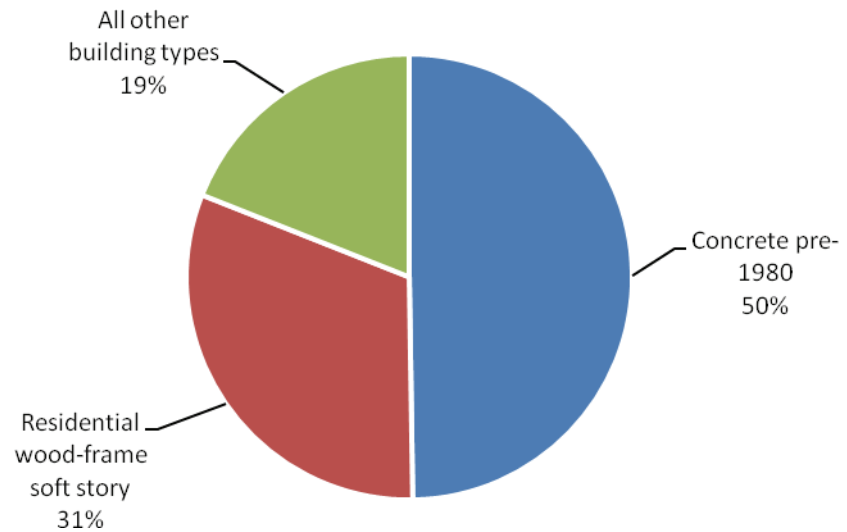
<sup>22</sup> ATC, 1985.

<sup>23</sup> EERI, 1990.

<sup>24</sup> HAZUS® severity 4 casualties.



**Figure 9** *Estimated deaths caused by each structure type for the magnitude 7.2 San Andreas fault scenario.*



**Figure 10** *Percent of HAZUS® severity 4 casualties attributable to various structural types in a magnitude 7.2 San Andreas fault scenario, averaged by time of day.*

Every death and injury the next earthquake causes will be a tragedy. However, there are also other types of losses that will have profound impacts on the entire City for years, perhaps decades, after the earthquake. The next chapter examines one of the most important of these: damage to housing.





## CHAPTER 6: IMPACTS ON HOUSING



After an earthquake, many people will not be able to stay in their homes. For some, this displacement will last only a few days. For others, it could last years. This study estimates that after a magnitude 7.2 San Andreas fault earthquake, 85,000 dwelling units will not be safe to occupy. The buildings in which these units are located will require extensive repairs and could take years before they are usable again. Financing these repairs will be challenging, particularly since only about 6 percent of San Francisco residents carry earthquake insurance<sup>25</sup>. Building owners will need to rely primarily on loans and savings to repair and reconstruct their properties. It is the long and slow rebuilding and recovery process that follows the emergency that truly shapes what the post-earthquake San Francisco will be like. The recovery of housing is a critical part of that picture. This chapter looks into damage to the City's housing and identifies issues that will affect how long it takes people to get back into their homes.

### The City's Housing

San Francisco's housing stock has unique characteristics that affect its vulnerability to earthquakes. The City's housing is old compared to other cities on the West Coast of the United States. Half of all of San Francisco's residential buildings were built before 1940, and over 80 percent were built before the mid 1970's<sup>26</sup>, when building practices improved significantly. It is a City of renters: 65 percent of San Franciscans rent instead of own their homes<sup>27</sup>, which affects building maintenance, post-earthquake repair, and how strongly residents are tied to the community. Finally, it is one of the densest large cities in the United States<sup>28</sup>. Many of its houses directly touch neighboring buildings, helping fires spread.

About 95 percent of the City's buildings are residential. These range from single-family homes to high-rise condominium and apartment towers. There are many different ways to look at the City's residential building stock. Figure 11 shows how the City's dwelling units are distributed among buildings of various sizes. The number of units in a building affects building and planning code regulations, condominium conversion, financing, and many other issues. Table 13 shows the number of residential buildings and units used for this study.

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<sup>25</sup> Marshall, 2010.

<sup>26</sup> Bay Area Economics, 2002.

<sup>27</sup> Claritas, 2009.

<sup>28</sup> Bay Area Economics, 2002.

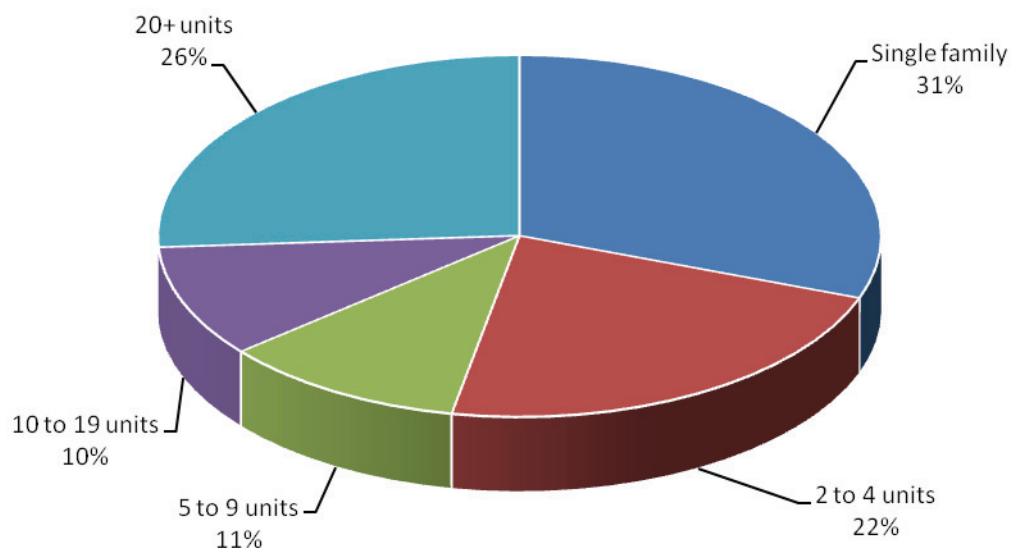


Figure 11 Percent of dwelling units in buildings of various sizes.  
Source: San Francisco Planning Department (2009)

**Table 13** Number of Residential Buildings and Dwelling Units and Building Value Used in CAPSS Analysis

Size of Building	Number of Buildings <sup>a</sup>	Number of Dwelling Units <sup>b</sup>	Value <sup>c</sup> (\$ Billions)
Single-Family houses	112,000	112,000	\$53
Two unit residences	19,000	38,000	\$22
Three or more unit residences <sup>d</sup>	23,000	180,000	\$45
Total <sup>e</sup>	150,000	330,000	\$120

a. These numbers are estimates for 2009.

b. Note that dwelling unit counts may vary from what is presented in other tables due to different source materials. The counts presented in this table represent a best effort using all available data sources to match building counts with unit counts.

c. These figures represent an estimate of the cost to replace or reconstruct a building in 2009. They do not include the value of the land the building sits on or a building's contents. Replacement values are significantly different than real estate prices or assessed valuation. Building value is based on square footage from the San Francisco Assessor's Tax Roll, not the estimated number of buildings.

d. Note that wood-frame residences with three or more stories and five or more units, discussed in the companion CAPSS report *Earthquake Safety for Soft-Story Buildings* (ATC 52-3 Report), are a subset of these buildings. That report discusses that there are an estimated 4,400 of those buildings built before May 1973, with 45,000 units, valued at about \$14 billion. Many, but not all, have a soft-story condition.

e. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.

Sources: This study, San Francisco Assessor's Tax Roll, Census data, San Francisco Planning Department, and San Francisco Department of Building Inspection.

Table 14 shows how the City’s housing is distributed throughout its districts. This table shows that certain districts have many more housing units than others. Some districts largely consist of single-family homes (e.g., Ingleside, Excelsior and Twin Peaks), while others have mostly multi-family dwellings (Downtown, Marina, and Pacific Heights).

The vast majority of residential buildings in the City are constructed from wood; nearly all one- and two-unit residences are wood frame. This study estimates that 85 percent of dwelling units in buildings with three or more dwelling units are also in wood-frame structures. The remaining 15 percent of multi-family units are spread among buildings of many structural types, old and new.

Many dwelling units are located in structure types that are known to be vulnerable to earthquakes. This study estimates that about 55 percent of single-family houses have a garage or other opening at the ground level, giving them a potential soft-story weakness. Nearly 60 percent of units in buildings with three or more units are estimated to be in wood-frame buildings with an open ground floor and potential soft-story condition. This study estimates that about 10 percent of wood-frame residential buildings have been seismically retrofitted. An additional 8 percent of units are estimated to be in other structure types with known vulnerabilities,

**Table 14      Distribution of Dwelling Units by District**

<b>District</b>	<b>Number of Dwelling Units<sup>a</sup></b>	<b>Units in Single-Family Homes (%)</b>	<b>Units in Multi-Family Dwellings<sup>b</sup> (%)</b>
Bayview	9,700	67	32
Central Waterfront	15,000	13	84
Downtown	51,000	2	98
Excelsior	25,000	82	17
Ingleside	7,700	90	9
Marina	8,400	11	89
Merced	7,100	41	59
Mission	53,000	28	72
North Beach	29,000	5	95
Pacific Heights	19,000	15	85
Richmond	29,000	30	70
Sunset	38,000	66	34
Twin Peaks	15,000	72	28
Western Addition	44,000	12	88

a. Note that dwelling unit counts may vary from what is presented in other tables due to different source materials.

b. For this table, multi-family dwellings are buildings with two or more units. Note that this table does not include mobile homes and residences classified as “other”, which means that the last two columns do not sum to 100% in all districts.

Source: This study, Claritas (2009).

including concrete buildings built before 1980, retrofitted unreinforced masonry bearing wall buildings, and older steel-frame buildings with masonry infill walls.

## Damage to Housing

Residential buildings are expected to suffer significant damage in the four scenario earthquakes studied in this report. Focusing only on one of these scenarios, the magnitude 7.2 event on the San Andreas, illustrates the scope of damage that could occur to the City’s housing. Table 15 presents estimates of the amount of damage estimated to residential buildings for the magnitude 7.2 scenario on the San Andreas. These impacts on housing only consider damage from shaking and ground failure, and do not include impacts from fire. Key things to note are:

- About 25,000 residential buildings and 85,000 residential units (out of the City’s 330,000 total dwelling units) would not be usable after the scenario earthquake. This means that about 74 percent of the City’s dwelling units would be safe to occupy after a magnitude 7.2 San Andreas earthquake, allowing residents to shelter in place.
- Most of the residential buildings that cannot be occupied will be single-family homes, but most of the dwelling units that cannot be occupied will be in multi-family buildings.
- About 3,000 residential buildings with 11,000 dwelling units will need to be demolished. Some of these will be rent-controlled apartments that will no longer be under rent control when rebuilt, due to state law.

**Table 15 Estimated Damage to City’s Housing After M7.2 San Andreas Fault Scenario From Shaking and Ground Failure**

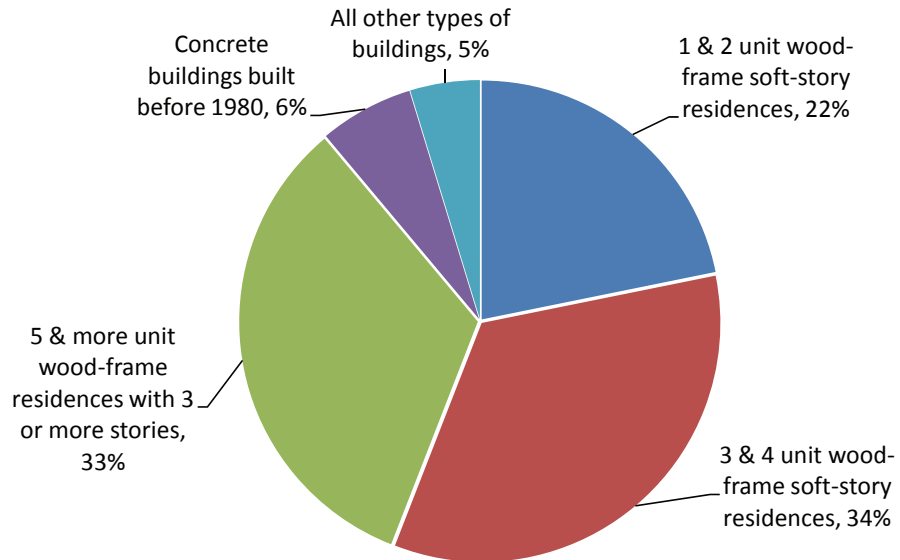
Type of Housing	Usable, Light Damage <sup>a</sup>		Usable, Moderate Damage <sup>a,b</sup>		Repairable, Cannot be Occupied <sup>a</sup>		Not Repairable <sup>a,c</sup>	
	No. of Bldgs	No. of Dwelling Units	No. of Bldgs	No. of Dwelling Units	No. of Bldgs	No. of Dwelling Units	No. of Bldgs	No. of Dwelling Units
Single-Family	45,000	45,000	54,000	54,000	11,000	11,000	1,700	1,700
Two unit residences	8,200	16,000	7,400	15,000	3,200	6,400	290	580
Three or more unit residences	7,200	57,000	7,500	59,000	7,200	56,000	1,100	8,400
Total <sup>d</sup>	60,000	120,000	69,000	130,000	22,000	74,000	3,000	11,000

a. Building functionality categorizations are derived from HAZUS® damage states. For more information, please see the companion technical volume, *Potential Earthquake Impacts: Technical Documentation* (ATC 52-1A Report). Functionality categories are defined in section 3.2.

b. This level of damage can be referred to as “shelter in place”.

c. Some of these buildings have collapsed. Others are standing but damaged beyond repair. None can be occupied.

d. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.



**Figure 12** Breakdown of the 85,000 dwelling units that cannot be occupied after the magnitude 7.2 San Andreas fault scenario, by structural type.

Again, certain structural types are responsible for a disproportionate share of the damage to housing. Figure 12 divides the dwelling units that could not be occupied after the magnitude 7.2 San Andreas fault scenario by structural type. This figure clearly shows that approximately two-thirds of all unusable dwelling units would be in multi-family, wood-frame soft-story buildings.

Fire would destroy additional homes. For the magnitude 7.2 San Andreas fault scenario, the average fire scenario would burn an estimated 8.8 million square feet of building floor space that had not already been heavily damaged by earthquake shaking. About two-thirds of all the building square footage in the City is residential buildings. Assuming that about two-thirds of the burned area is in residential buildings would suggest that an additional 5,800 housing units would be lost due to fire<sup>29</sup>.

San Francisco Planning and Urban Research (SPUR) has recommended a goal that 95 percent of residential units be available for residents to “shelter in place” after a significant earthquake, such as the magnitude 7.2 San Andreas fault scenario examined in this report<sup>30</sup>. This study estimates that, considering shaking, ground failure, and fire, about 72 percent of residential units could be used to “shelter in place” after a magnitude 7.2 San Andreas earthquake.

### Recovery of Housing

The amount of damage that the City’s housing stock sustains in future earthquakes is a critical factor in determining how well and how quickly the City rebounds and recovers. If most residents can be back in their homes quickly after an earthquake, it

<sup>29</sup> Assuming 1,000 square feet per residential unit.

<sup>30</sup> See SPUR, 2009. “Shelter in place” means buildings are structurally sound to survive aftershocks, although they may have considerable damage and utilities may not function.

would greatly speed all aspects of the City's recovery. Residents would be able to contribute to helping their neighbors and neighborhoods recover, and would remain close to their jobs, schools, businesses, and services. On the other hand, if many residences cannot be occupied for months or years after an earthquake (Figure 13), neighborhoods would have vacant buildings for extended periods, people may permanently relocate to new areas, perhaps outside the City, and the neighborhood businesses and services that depend on local customers would suffer.

Repairing and rebuilding homes damaged by an earthquake usually takes years, not months. The time for housing to get back in service is influenced by many factors and can vary a lot. Table 16 shows the length of time housing took to recover after two recent California earthquakes: Loma Prieta in 1989 and Northridge in 1994. Housing repair and reconstruction after San Francisco's next major earthquake will happen differently than occurred in either of these two events, but these data provide an interesting snapshot of the range of housing recovery times in localized events with moderate damage. When looking at the San Francisco data from Loma Prieta, it is important to note that all of the four scenarios studied by the CAPSS project would produce much stronger shaking and much more damage than occurred in the 1989 earthquake. The magnitude 7.2 San Andreas fault scenario would damage 25 times as many residences as were damaged in Loma Prieta<sup>31</sup>. San Francisco's recovery from a large earthquake could take up to ten years.

Many steps are required before a damaged building can be reoccupied. Building owners need to make decisions, hire design professionals to analyze damage and design repairs, hire construction professionals, get permits, arrange financing, and



**Figure 13** *Boarded up San Francisco residences after the 1989 Loma Prieta earthquake. Photo credit: Stephen E. Dickenson, Courtesy of the National Information Service for Earthquake Engineering, University of California, Berkeley*

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<sup>31</sup> Estimation based on tagging data reported in Comerio and Blecher, 2010.



**Table 16      Average Time Required to Repair and Rebuild Housing  
After 1989 Loma Prieta and 1994 Northridge Earthquakes**

Building Damage Level <sup>a</sup>	Loma Prieta Average Time to Reoccupy <sup>b</sup> (Months)	Northridge Average Time to Reoccupy <sup>c</sup> (Months)	San Francisco Average Time to Reoccupy After Loma Prieta <sup>d</sup> (Months)
Needed repair	11	25	7
Needed rebuilding	34	36	46

a. Only includes analysis of buildings with enough damage to be deemed unsafe to occupy.

b. Analyzed data from San Francisco, Hollister, and Watsonville.

c. Analyzed data from Los Angeles, unincorporated Los Angeles County, and Santa Monica.

d. San Francisco Loma Prieta results are based on a small dataset, and detailed timing information was not available for all damaged buildings.

Source: Comerio and Blecher ( 2010).

conduct cleanup and construction activities. All of this occurs in a time when they may have other personal or professional concerns due to earthquake damage. The many factors that can influence the pace of repair and rebuilding include the following:

- *Amount of building damage.* The amount of damage influences the length of time required for buildings to recover, both from the perspective of an individual building and citywide. Intuitively, a building with more damage takes longer to repair than a building with less. If there is a lot of damage in the City, all construction work takes longer because many of the construction resources in the Bay Area would be overwhelmed. There may not be enough skilled design and construction professionals to do required work without delay. Construction materials and equipment may be in limited supply. Building owners in other Bay Area communities will also have damaged properties and will also be using local resources to make repairs to their buildings.
- *Economy at time of earthquake.* If an earthquake occurs when the City's economy is strong, rebuilding would happen more quickly than if it strikes during a weak economy. There are many reasons for this. Financing for the work would be more readily available. Building owners may also have healthier finances. Landlords would be motivated to repair buildings quickly because they know rent-paying tenants would be eager to occupy the space. During economic downturns, owners are less able and motivated to act quickly. Housing recovered more slowly after the 194 Northridge earthquake than after the 1989 Loma Prieta event, in part because there were high residential vacancy rates in Los Angeles at the time<sup>32</sup>.
- *Availability of financing.* Securing construction funds can be difficult as owners need to demonstrate the ability to repay loans and have sufficient equity to serve as collateral. Few owners would be helped by earthquake insurance, as discussed in the next bullet, which means that owners will need to rely primarily on loans and savings to finance repairs. After past disasters, lenders have sometimes been reluctant to finance repairs in heavily damaged

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<sup>32</sup> Comerio, 1998.

neighborhoods due to concerns about reduced property values. As discussed below, building ownership can also affect financing. Owners with high debt-to-equity ratios may not qualify for repair loans. Some owners will be forced to default on loans and the damaged buildings would go into a foreclosure process.

- *Insurance.* Payments from insurance companies can help finance repair and rebuilding, but they can also lead to delays. Currently, only 6 to 7 percent of San Francisco residents carry earthquake insurance<sup>33</sup>, which means that insurance payments would play a small role in financing San Francisco's reconstruction. Many more carry policies that cover fire damage. After disasters, it is common for insurance payouts to take many months. Often there are disputes about the amount of payment to be made. For example, for properties damaged by post-earthquake fire, insurance companies may want to investigate whether the structure was damaged by earthquake shaking prior to the fire and reduce payments if this is found to be the case. Those homeowners who do carry earthquake insurance may find that not all of their costs to repair or replace their building are covered due to high deductibles and limited coverage of these policies.
- *Building ownership.* Buildings with multiple owners may find it more difficult to arrange financing for repairs and reconstruction than buildings with one owner. Different owners may have varying levels of financial resources. Residential buildings with multiple owners include condominiums, co-ops, and the recently popular ownership model, tenancy-in-common (TIC). Unlike co-op ownership, in which members own shares of the corporation that owns the building, TIC residents actually co-own a parcel of real estate. This form of ownership has been popular in San Francisco in recent years because it offers would-be buyers an alternative to the City's condominium conversion regulations, and typically features a discounted sales price due to the added complication and cost of financing a TIC. The unconventional financing structure of TICs may present additional complexities in the repair process for those buildings. These buildings, however, are generally occupied by their owners, which leads to a high motivation to repair and reoccupy the property quickly after an earthquake.
- *Building use.* Multi-family housing, particularly rental housing, is repaired and replaced significantly slower than single-family housing. A year after Loma Prieta, 90 percent of the multi-family units destroyed or rendered unserviceable in the Bay Area were still out of service. Four years after the earthquake, 50 percent of these units had not been repaired or replaced<sup>34</sup>. For an owner of an apartment building, the incentive to rebuild is connected to his or her ability to enhance cash flow and to service debt. Owners have little incentive to rebuild if construction costs cannot be recovered through rents. For units serving lower-income households, access to construction financing is especially difficult.
- *Availability of construction professionals.* The Bay Area has a limited number of licensed contractors, skilled construction workers, and design

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<sup>33</sup> Marshall, 2010.

<sup>34</sup> Camerio, et al., 1994.

professionals who must serve the entire Bay Area. A shortage of skilled workers can cause delays and make construction more expensive, which could lead to additional delays for some owners. Undoubtedly, design and construction professionals from outside the region will come to help rebuild.

- *Regulatory uncertainties.* Recovery occurs quickly if regulations guiding repair and rebuilding are clear. Regulations cover issues such as repair standards, when owners can demolish their buildings, what they are allowed to rebuild, rules particular to historic resources, and many other considerations. The City building and planning codes are complicated, with many steps and requirements for obtaining permits. The sheer quantity of buildings needing repair will pose a challenge to the City in the permitting process.
- *Construction logistics.* San Francisco is a dense city. Most residences have no front yards, small back yards, and little if any access along the sides that could be used to stage construction materials. Streets and sidewalks will probably need to serve this function, but they often are narrow, steep and busy. Construction supplies and equipment may be in short supply, causing further delays.

It is inevitable that the repair and reconstruction of housing after a damaging earthquake will take time. However, many of the problems described above can be mitigated by planning and preparation.

### **Impacts on Affordable Housing**

Affordable housing is particularly slow to recover after natural disasters, as observed after Loma Prieta<sup>35</sup> and, more recently, after Hurricane Katrina<sup>36</sup>. San Francisco's affordable housing stock consists primarily of rent-controlled apartments, single room occupancy hotels (SRO's), and publicly-assisted housing. While all apartments in buildings constructed prior to June 1979 are covered by rent control, it is important to note that many of these units are currently renting at rates that would not be considered affordable to residents with the median City income, as shown in Table 17. Each time a unit is rented to a new tenant, apartment rents can be reset to market rates. This project estimates that 40 to 60 percent of rent-controlled apartments have rents that are at or close to market rates. The City has an estimated 160,000 rental units covered by rent control<sup>37</sup>, 19,000 units in SRO's<sup>38</sup>, and about 21,000 units of publicly-assisted housing<sup>39</sup>.

Building demolitions in multi-family apartments could result in permanent loss of rent controlled apartments. When multi-family properties are demolished after an

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<sup>35</sup> Comerio et al., 1994.

<sup>36</sup> Rose, et al., 2008.

<sup>37</sup> This assumes that 75 percent of rental units are covered by rent control, Bay Area Economics, 2002.

<sup>38</sup> San Francisco Planning Department, 2009.

<sup>39</sup> Mayor's Office of Housing, 2010. Assumes 6,500 units of public housing, 6,000 households subsidized through HUD section 8, and 8,900 units assisted with financing or rent through US Department of Housing and Urban Development.

**Table 17      Average Rent and Affordability in San Francisco**

Median Annual Household Income, 2009	\$70,818
Monthly income available for rent and utilities <sup>a</sup>	\$1,770
Monthly utility payment <sup>b</sup>	\$170
Affordable rent payment	\$1,600
Average rent in San Francisco, June 2009	\$2,323

a. Assumes 30 percent of gross household income spent on rent and utilities.

b. Based on San Francisco Housing Authority Utility Allowance chart.

Sources: San Francisco Housing Authority (2009), [www.realfacts.com](http://www.realfacts.com).

earthquake, the market would likely favor those properties being reconstructed as condominiums, rather than apartments. Under current conditions, buildings owners generally find that condominiums generate greater financial returns than do apartments, even in high-priced rental markets such as San Francisco. When demolished apartments are reconstructed, the new construction is not subject to the City's Condominium Conversion Lottery, and the lost rental units may therefore be replaced as ownership units. Similarly, new apartments replacing demolished rental units are not subject to the City's Rent Stabilization Ordinance, commonly known as rent control. Newly constructed buildings would also have a different look and character than the buildings they replace, contributing to a change in San Francisco's character.

Units renting at lower than market rate are often occupied by long-term residents, a significant percentage of whom are elderly. As a result, these residents will be seriously affected as they may have no alternate, affordable places to move. Often these units are older, may have deferred maintenance, and could be more susceptible to damage from an earthquake than typical multi-family residences. For example, more than 90 percent of units in SRO's are located in buildings built before 1920<sup>40</sup>, and although the structural characteristics of these buildings are not known, anecdotal evidence suggests that many are highly vulnerable to damage in earthquakes, such as concrete- and steel-frame buildings with masonry infill walls and/or soft-stories.

In the scenario earthquakes studied, it is not known what percentage of housing units lost will be apartments that are currently rented at below-market rents. What is known is that the heavy damage to the City's housing stock is likely to cause the cost of housing of all types to rise as owners invest capital to carry out repairs and tenants turnover due to loss of jobs and other disruptions. Owners will seek to pass through some costs of repairs to tenants. Vacant apartments may be in short supply, leading to price increases. Low and middle income residents displaced from their homes may no longer be able to afford to live in San Francisco.

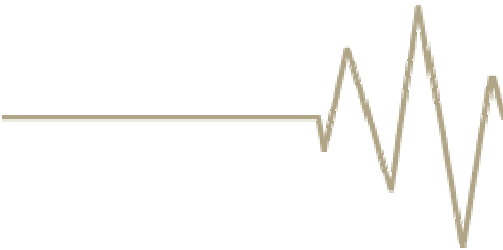
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After a large earthquake, the City's housing will be severely affected. Housing is a key part of having a functional city, but it is not the only part. People also need the City to have a functioning economy. The next chapter looks at the impact of future earthquakes on the City's businesses.

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<sup>40</sup> Analysis of date of construction of SRO's conducted by this study based on data from the San Francisco Department of Building Inspection.

## CHAPTER 7: EARTHQUAKE DAMAGE IMPACTS ON BUSINESSES, JOBS AND THE ECONOMY



San Francisco's economy depends on a complex and interdependent mix of many elements. Businesses need to be open to provide services and support the economy. Housing needs to be available to the City's workers and customers. Utility systems and transportation networks need to function. These issues are affected by building and infrastructure damage and the time needed to conduct repairs, as well as how prepared businesses are to cope following earthquakes. This chapter describes how the buildings that house businesses could be affected by future earthquakes, and the impacts that could flow from this damage. One business' loss could be another's gain, and losses experienced in San Francisco may be gains in other jurisdictions as customers or businesses relocate and the mix of residents and workers change.

This study estimates that losses to building contents and losses due to business interruption could increase direct building damage losses by 30 to 40 percent. For the magnitude 7.2 San Andreas fault scenario, this would put direct economic loss at \$40 billion. Ripple effects due to damaged businesses would add to these losses, making the economic impact of an earthquake on par with or greater than a recession. Earthquake damage could encourage some companies to relocate all or some of their employees out of San Francisco or the Bay Area. Small businesses would feel particularly heavy impacts.

### Damage to Commercial and Industrial Buildings

San Francisco's commercial and industrial buildings take many different forms. Some are modern high-rises. Others are early high-rises that went through the 1906 earthquake. Many are smaller buildings used for a variety of industrial, retail, and office functions. They have considerably more variety in their structural make-up than the City's residential buildings. Many buildings incorporate both residential and commercial functions. A common example of this is the wood-frame apartment building with ground floor retail space, often with a soft-story condition, that is highlighted in the companion CAPSS report, *Earthquake Safety for Soft-Story Buildings* (ATC 52-3 Report).

In general, San Francisco's commercial building stock is more seismically resistant than the City's housing stock. Many commercial buildings have been seismically retrofitted as a requirement of lenders or insurers or as part of a major renovation. Some older commercial buildings have been demolished and replaced with newer buildings that use modern seismic codes. Buyers, sellers, lenders, and renters of commercial properties are generally more sophisticated and better informed than their residential counterparts.

However, as presented previously in this report, commercial buildings are likely to suffer significant damage in the four scenarios studied. The estimates of direct damage to commercial and industrial buildings are:

- \$4 to \$11 billion to repair or replace damaged commercial buildings, depending on the earthquake scenario. Two-thirds of these losses occur to buildings in the Downtown district.
- \$1 to \$2 billion to repair or replace damaged industrial buildings, depending on the earthquake scenario. These losses are concentrated in the Bayview, Downtown, Central Waterfront, and Mission districts.
- More than 900 commercial buildings and 500 industrial buildings would not be occupiable after a magnitude 7.2 San Andreas fault scenario.
- Nearly 300 commercial buildings and more than 200 industrial buildings would be damaged beyond repair after a magnitude 7.2 San Andreas fault scenario. These buildings will be rebuilt differently, and could contribute to changing development patterns in some of San Francisco's neighborhoods.

Commercial buildings may get repaired more quickly than residential buildings if owners can finance repairs and are motivated to get rent-paying tenants back in place. However, the pace of rebuilding is highly dependent on market conditions at the time of the earthquake. In a time of high commercial vacancy rates, it could take years before all buildings are fully functional because owners may be loathe to reinvest immediately in repairs for buildings that may be unrented or would rent at low rates. When commercial vacancy rates are low, building owners will be motivated to conduct repairs as quickly as possible, but in the short-term, businesses could find it challenging to locate temporary space while they await repairs to their damaged buildings.

Some retail and office establishments can reopen in a new location before their original building is repaired, which means that many businesses may begin the recovery process long before their pre-earthquake location is fully functional. This might leave some building owners without tenants once repairs are complete. Some businesses will be able to use telecommuting to resume activities before their office space is usable, contingent upon functioning utilities. However, even businesses in buildings that remain functional or those that are easily repaired can be affected if their customers and employees relocate, or if the damage to nearby buildings makes the neighborhood commercially undesirable.

### **Direct Economic Losses in Addition to Building Damage**

The direct physical damage to buildings is only one component of the economic losses due to earthquakes. Many different types of economic losses flow from the building damage and loss of functionality described in previous chapters of this report. The additional types of direct losses estimated by this project include<sup>41</sup>:

- *Contents damage.* This includes furniture, computers, supplies, and equipment that is not integral with the structure. It does not include inventory (counted separately, below) or integral components such as lighting, ceilings, mechanical and electrical equipment, and other fixtures, which are included in building damage.

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<sup>41</sup> Adapted from FEMA, 2002.



- *Inventory loss.* The value of inventory varies considerably by type of business. Typically, inventory damage occurs when items fall off shelves or are damaged by water from broken pipes.
- *Relocation loss.* This includes the costs of relocating and the rental of temporary space. Relocation costs are estimated only for some uses; others, such as theatres and parking facilities, are assumed to close until repaired.
- *Output loss.* This includes income associated with business profits, gross receipts, or revenues.
- *Rental income loss.* This includes rents for residential, commercial, and industrial properties.
- *Income and wage loss.* This includes losses to wages and salaries. In some cases, wage losses can be partially recaptured by overtime work once a business resumes.

Table 18 presents estimates of the total direct economic loss resulting from the four scenarios studied. Note that these losses do not include indirect losses in businesses not sustaining direct damage, which are discussed later. Further, these losses are only those attributable to damage to privately-owned buildings, and this project did not put resources into modeling the vulnerability and economic losses associated with the City's infrastructure (roads, bridges, transit systems, water system, sewer system, electrical system, telephone system, gas system, etc.). In the four scenarios studied, the estimated direct economic losses beyond the costs of damage to buildings are about 30 to 40 percent of the costs to repair and replace damaged buildings.

**Table 18      Estimated Total Direct Economic Losses in Four Scenario Earthquakes**

Scenario	Direct Losses in Four Scenario Earthquakes <sup>a</sup> (\$ Billions)			
	Damage to Buildings	Additional Damage Due to Fire <sup>b</sup>	Additional Economic Losses	Total Losses
Hayward Fault, Magnitude 6.9	\$14	\$2.7	\$5.4	\$22
San Andreas Fault, Magnitude 6.5	\$20	\$3.0	\$6.8	\$30
San Andreas Fault, Magnitude 7.2	\$30	\$4.3	\$10	\$44
San Andreas Fault, Magnitude 7.9	\$48	\$5.8	\$15	\$69

a. Estimates are in 2009 dollars.

b. These figures do not double count shaking damage (i.e., burning rubble)

### **Ripple Effects of Business Losses**

When businesses shut down, even temporarily, the loss of revenue ripples through the local economy, creating a negative multiplier effect. These closed or suspended businesses do not support other businesses; workers do not spend their incomes on consumer goods. This analysis uses estimates of lost revenues from business

interruption, in conjunction with the IMPLAN<sup>42</sup> input-output model, to estimate the economic impacts of business interruption following a magnitude 7.2 earthquake along the San Andreas fault.

Two additional types of economic losses are estimated, described below:

- *Indirect Impacts.* This refers to the impacts of business closure or slowdown on other businesses. For example, a legal office that needs to close due to earthquake damage no longer purchases office supplies. Thus, the firm that sells those office supplies suffers economic losses due to damage to its customer, even if the office supply company suffered no damage itself.
- *Induced Impacts.* This refers to the impacts of household expenditures. When households earn income, they spend part of that income on goods and services. In the example described above, the induced impacts include the reduced expenditures of employees at the legal firm, as well as the reduced expenditures of people who work in the office supply company that depends on business from the legal firm. Only the disposable incomes from San Francisco workers are analyzed.

The business interruption losses due to a magnitude 7.2 San Andreas fault earthquake would generate a loss of approximately \$650 million in indirect activity, or business-to-business lost expenditures within the City of San Francisco. The greatest decreases in output would occur in the real estate, banking, and insurance sectors, as these sectors provide services to the broadest array and largest number of businesses.

In addition to the indirect impacts, the business interruption losses would also generate induced citywide losses (that is, lost household expenditures) of approximately \$840 million. Induced impacts represent the impacts of household expenditures of workers in the directly affected and indirectly affected firms. The greatest induced output losses would occur in the payments to housing, wholesale trade, and eating and drinking establishment sectors.

The total losses from business interruptions following an M7.2 San Andreas fault earthquake would represent approximately 2.8 percent of total citywide economic activity. As a measure of comparison, since 1960, recessions in the United States have averaged a 1.7 percent decline in economic output from peak to trough. This suggests that the economic effects of the earthquake would be on par with or greater than a recession. It is also important to note that these impacts would be over and above the damage to buildings and other losses described previously.

This analysis does not account for business interruption losses associated with fire or damage to utilities and transportation systems. These impacts can be significant. Additionally, behavioral responses to the earthquake could also affect the local economy, but that is not factored into this analysis. For example, people's fear about earthquakes could compel them to leave the region or forestall investments in the area.

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<sup>42</sup> The economic model used in this analysis, IMPLAN ("IMpact analysis for PLANning"), is a PC-based computer software package that automates the process of developing input-output models for regions within the United States. The IMPLAN model is well-respected as the industry standard for projecting economic impacts resulting from future "events." Details of this analysis are presented in the companion CAPSS volume, *Potential Earthquake Impacts: Technical Documentation* (ATC 52-1A Report).

Notwithstanding these conclusions, certain industries would conceivably recover more rapidly following the earthquake than others. The construction industry and its suppliers, for example, would likely see a boost in activity, particularly as federal assistance, state aid, and insurance payments are injected into the economy. This kind of response could mitigate some of the negative economic impacts of the earthquake. The economic benefits that come from reconstruction have not been quantified or considered in this analysis.

### The City's Economy and Jobs

Businesses in San Francisco employ approximately 570,000 people, with employment well-distributed among a range of sectors (Table 19). This diversity contributes to the City's economic resiliency as the employment base is not

**Table 19 San Francisco and Bay Area Employment by Sector<sup>a</sup>**

Industry Sector	San Francisco		Bay Area		San Francisco as Share of Bay Area (%)
	Jobs	% Total	Jobs	% Total	
Professional and technical services	130,000	22%	590,000	18%	21%
Government <sup>b</sup>	97,000	17%	450,000	13%	22%
Leisure and hospitality	79,000	14%	340,000	10%	24%
Financial activities	58,000	10%	190,000	6%	30%
Education and health services <sup>c</sup>	56,000	10%	380,000	11%	15%
Retail trade	44,000	8%	330,000	10%	13%
Other services, except public admin.	38,000	7%	160,000	5%	24%
Information	19,000	3%	110,000	3%	17%
Construction	19,000	3%	180,000	5%	11%
Wholesale trade	12,000	2%	120,000	4%	11%
Manufacturing	11,000	2%	340,000	10%	3%
Unclassified	2,000	0.4%	12,000	0.4%	18%
Natural resources and mining	290	0.1%	22,000	0.7%	1%
Utilities	( <sup>d</sup> )	( <sup>d</sup> )	5,500	0.2%	( <sup>d</sup> )
Transportation and warehousing	( <sup>d</sup> )	( <sup>d</sup> )	54,000	2%	( <sup>d</sup> )
Total <sup>e</sup>	570,000	98%	3,300,000	97%	17%

a. Includes all wage and salary employment covered by unemployment insurance.

b. Government employment includes workers in all sectors, not just public administration. It includes public school employees.

c. This does not include public school employees.

d. Indicates that data have been suppressed for confidentiality reasons. The data are suppressed when there are fewer than three establishments in the industry, or if a single employer makes up more than 80 percent of that industry's employment.

e. Numbers in table have been rounded, which can make totals differ from sum of columns or rows. Totals do not sum to 100% due to suppressed data and rounding.

Sources: This study, California Employment Development Department (2009).

dependent on one or two sectors that might be disproportionately affected by an earthquake. Diversity allows the economy to improvise, innovate, and perform resource substitution following a disaster.

In terms of the City's economic role in the Bay Area, San Francisco serves as the regional center for the finance and professional and technical services industries. While San Francisco only has 17 percent of total Bay Area employment, it contains 30 percent of the region's financial activities jobs and 21 percent of the region's professional and technical services jobs. San Francisco has evolved into a regional finance and business hub because it offers companies an internationally recognized address and lifestyle amenities, which appeal to workers in these sectors. In addition, the City's density benefits these firms, which place a high value on face-to-face interaction. San Francisco is also the regional center of the leisure and hospitality industry, containing 24 percent of Bay Area jobs in this sector. This role has evolved thanks to San Francisco's distinct urban amenities, art, culture, entertainment, retail, and dining options, which make it an international tourist destination.

Figure 14 illustrates the long-term historic trends associated with the finance and professional and technical services industries in San Francisco. The number of San Francisco jobs in the finance sector has generally declined since the early 1990's, with a spike in 2001 at the height of the "dot-com" boom. Meanwhile, the professional and technical services industry has been highly volatile, growing and shrinking in tandem with the economic cycle. The dot-com boom and bust led to a peak, followed by a sharp contraction in the early part of this decade. The industry subsequently recovered between 2004 and 2008. In comparison, the leisure and hospitality industry has shown more stability, growing gradually since 1990.

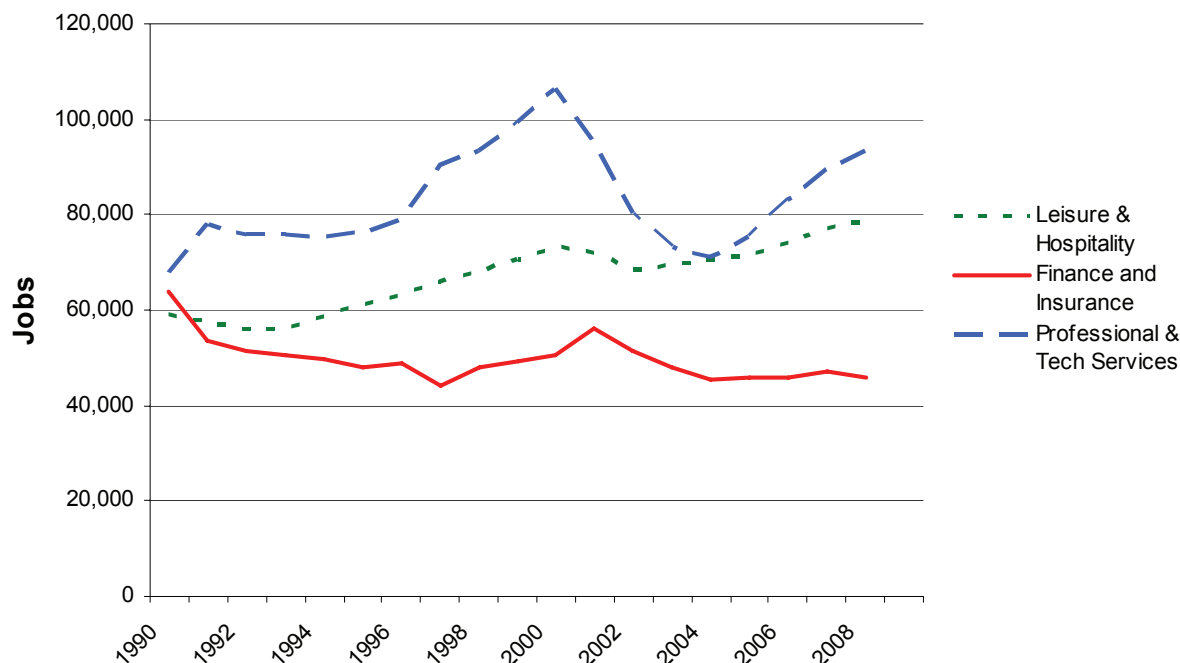
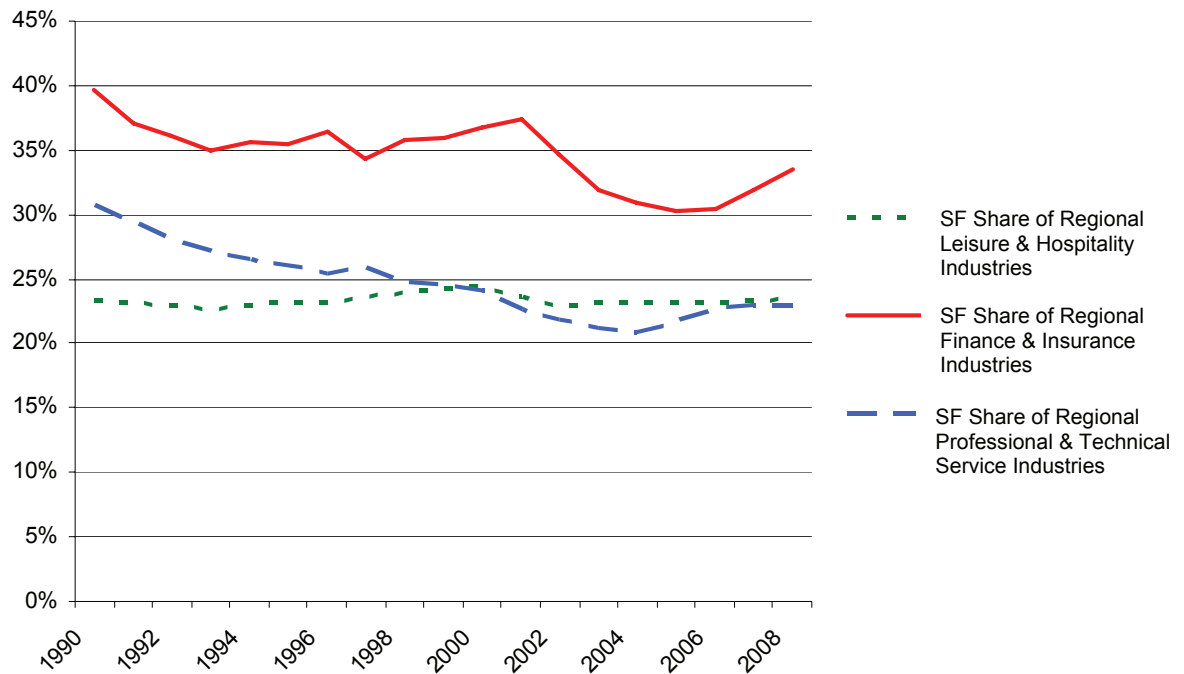


Figure 14 San Francisco jobs in key sectors, 1990-2008.  
Source: California Employment Development Department (2009).



**Figure 15** *San Francisco jobs as share of Bay Area jobs in key sectors, 1990-2008.*  
Source: *This study, California Employment Development Department (2009).*

Figure 15 presents San Francisco’s regional share of these three key industries over the last two decades. Since 1990, the City’s share of the regional jobs in the finance and professional and technical services sectors has generally declined. This trend is a result of the maturation of Silicon Valley and other parts of the Bay Area as viable locations for these industries. As information and technology firms have emerged in San Mateo, Santa Clara, and Alameda counties, finance and professional services firms that interface with these industries have followed their geographic lead.

As discussed previously, commercial space in San Francisco’s downtown—the primary location of the City’s finance and professional services sectors—would experience significant damage in the scenario earthquakes studied. In a magnitude 7.2 San Andreas fault earthquake, 21 million square feet of commercial space in the City would suffer structural damage that makes it unsafe to occupy. These damage estimates, coupled with the long-term employment trends discussed above, suggest that while the City could retain its status as a regional finance and professional services center over time, a major earthquake does have the potential to accelerate the ongoing dispersal of these industries throughout the Bay Area or even outside the Bay Area following earthquakes. This dispersal may be more pronounced if utilities are not restored rapidly, San Francisco municipal services do not respond effectively and quickly, or if commercial buildings are rendered unsafe for an extended period of time. Under these conditions, companies may opt to maintain a San Francisco presence, but shift the bulk of workers to other parts of the Bay Area. In recent years, a number of large employers have chosen to relocate much of their workforce to less expensive communities. An earthquake could encourage more companies to make this decision. San Francisco has worked hard to attract cutting edge, high-tech businesses, but these businesses are often highly mobile and could relocate easily.

In contrast with the finance and professional service sectors, San Francisco's share of the regional leisure and hospitality industry has remained steady at 23 to 24 percent of total Bay Area jobs in this sector since 1990. This stability is a positive sign of the industry's economic resilience. Certainly, post-disaster studies indicate that the City should expect a decline in visitors and contraction of the tourism industry immediately following an earthquake. A study of the 2008 earthquake in Sichuan, China found significant declines in tourism following the main shock<sup>43</sup>. Analysis of the September 1997 earthquake in Umbria, Italy showed arrival declines up to 50 percent in the city of Assisi, a major tourist destination, in the month after the earthquake, though arrivals did begin to rebound over the following year<sup>44</sup>. In addition, a 2007 analysis of the New Orleans economy following Hurricane Katrina showed a loss of 22,900 tourism jobs in the 10 months following the event<sup>45</sup>. Impacts along these lines would hurt businesses that rely heavily on tourist spending, and financially tenuous businesses may be forced to close, unable to weather the drop in revenues. Despite these impacts, however, in the long run, San Francisco would retain the unique characteristics and attractions that make it an international tourism destination.

San Francisco benefits from being part of an economically vibrant region. Jobs are spread throughout the region, with concentrations in Alameda, San Francisco, and Santa Clara counties. This geographic distribution improves the Bay Area's economic resilience by essentially disseminating the risk of an earthquake across multiple areas. In contrast, if a vast majority of jobs occurred in a single area, a severe disaster at that site would have a much more significant impact on the regional economy.

### **Small and Neighborhood Serving Businesses**

San Francisco's unique features include the many local shopping areas with small, independent businesses that serve their neighborhoods. These establishments help give each neighborhood an individual character, and contribute numerous jobs to the City's economy. Neighborhood businesses provide services, supplies, and conveniences that allow for efficient living and also serve those with language or ethnic preferences. These businesses play an important role in the City's recovery by providing essential local services to residents and contributing to the charm and community character that makes people want to stay in San Francisco. The City has emphasized the importance of these local establishments through recent laws regulating chain stores, and by developing programs such as small loans to establish local businesses.

Small businesses comprise the vast majority of local firms. Almost 89 percent of San Francisco's businesses have 10 or fewer employees, and another 6 percent have 11 to 25 employees. Altogether, firms with 25 or fewer workers contain 38 percent of the City's total jobs, as shown in Table 20.

Small businesses are more vulnerable than large firms to disruption following a natural disaster, as they are less likely to carry insurance and are rarely diversified in

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<sup>43</sup> Yang, et al., 2008.

<sup>44</sup> Mazzocchi and Montini, 2001.

<sup>45</sup> Dolfman, Wasser, and Bergman, 2007.



**Table 20 San Francisco Firms and Jobs by Number of Employees in Firm**

Number of Employees	Firms		Jobs	
	Number	% of Total	Number	% of Total
0 – 4	56,000	76%	100,000	16%
5 – 10	9,300	13%	64,000	10%
11 – 25	4,700	6%	79,000	12%
26 – 50	2,000	3%	73,000	11%
51 – 75	510	1%	32,000	5%
76 – 125	500	1%	48,000	7%
126 +	500	1%	250,000	39%
Total <sup>a</sup>	73,000	100%	660,000	100%

a. Numbers in table have been rounded, which can make totals differ from sum of columns or rows. Total may be inconsistent with other tables due to varying data sources and enumeration methodologies.

Source: Dun and Bradstreet (2008).

terms of products and services. They also often lack the resources to address equipment and inventory damage and interruptions in utility service and transportation networks. Damage to other nearby businesses and residences may also reduce customer traffic, further compounding the economic hardship. In addition, locally-owned businesses face greater difficulty in recovering from disasters compared to their chain competitors, whose operations and profits are not dependent on a single store.

Small retailers appear to be the most vulnerable to major earthquakes. Following the southern California Northridge earthquake, businesses reported that for some time after the earthquake, residents changed their spending patterns, disrupting operations. The highest job loss resulting from the Northridge earthquake was in the retail industry (24 percent of total losses). Some small businesses failed as a result of the Northridge earthquake, as long as two years after the event<sup>46</sup>.

A study of the 2001 Nisqually earthquake in the State of Washington also highlighted the vulnerability of small retailers<sup>47</sup>. Of the 13 industries surveyed, retail businesses reported higher rates of both direct physical losses (buildings and equipment) and reduced revenue as a result of lost inventory. This was attributed to the fact that retailers have a higher portion of their assets invested in inventory than most businesses.

### **Worker Access to Jobs**

Following an earthquake, workers' ability to get to their jobs is a key component of a community's recovery. Returning to work allows workers to receive a paycheck,

<sup>46</sup> Petak and Elahi, 2000.

<sup>47</sup> Meszaros and Fiegenger, 2002.

provides residents and businesses access to necessary goods and services, and generally restarts the local economic engine.

Table 21 shows commute patterns in San Francisco, as reported by the 2000 Census<sup>48</sup>. Approximately 77 percent of San Francisco's employed residents work in the City, suggesting that the majority of San Francisco residents will be able to reach their jobs following an earthquake. However, 45 percent of San Francisco jobs are held by people who live outside the City. To the extent transportation systems are damaged and inoperable after an earthquake, this could have a significant short- and mid-term impact on the local economy, and could slow recovery. Job access also depends on workers having access to support systems, such as day care and elder care.

Communications technology offers some workers the ability to telecommute, assuming utilities and workplace systems remain operational. Looking at San Francisco's major industries, the financial activities and professional services sectors could operate more effectively though telecommuting than sectors that require

**Table 21 San Francisco Commute Patterns**

Where San Francisco Residents Work	Number	%	Where San Francisco Workers Live	Number	%
San Francisco	320,000	77%	San Francisco	320,000	55%
Oakland	8,900	2%	Oakland	30,000	5%
South San Francisco	8,800	2%	Daly City	25,000	4%
Redwood City	5,200	1%	Berkeley	9,800	2%
San Mateo	4,600	1%	South San Francisco	8,500	1%
Palo Alto	3,700	0.9%	Pacifica	7,125	1%
Burlingame	3,600	0.9%	Richmond	6,900	1%
San Jose	3,400	0.8%	Alameda	6,900	1%
Berkeley	3,200	0.8%	San Mateo	5,800	1%
Other Bay Area <sup>a</sup>	43,000	10%	Other Bay Area <sup>a</sup>	130,000	23%
Other places in CA	11,000	3%	Other places in CA	28,000	5%
Out-of-state <sup>b</sup>	1,600	0.4%	Out of state <sup>b</sup>	4,000	0.7%
Total <sup>c</sup>	420,000	100%	Total <sup>c</sup>	590,000	100%
San Francisco residents Out-commuting	95,000	23%	San Francisco workers In-commuting	270,000	45%

- Other Bay Area includes other areas in Alameda, Contra Costa, Marin, Napa, San Mateo, Santa Clara, Solano, and Sonoma counties that are not specifically listed.
- Out-of-State includes Census Designated Places (CDP's) that cannot be broken down into localities.
- Figures may not match other tables due to different source materials.

Sources: U.S. Census (2000), Census Transportation Planning Package (CTPP).

<sup>48</sup> Latest available data.

employees to be present for direct contact with customers or physical activities. Workers in the government, leisure and hospitality, education, and health services industries would be less able to function remotely.

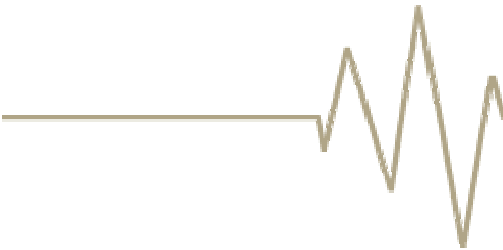
Damaged areas benefit economically from increased employment in the construction trades and an influx of workers and government and private recovery funds from outside the area. Recovery will require trained workers and contractors from outside the region. Temporary workers, insurance adjusters, and state and federal recovery workers will need nearby housing and transportation. Some of these people may relocate permanently, but most will send much of the money they earn to homes outside of San Francisco and may purchase and transport some construction supplies, furnishings, and other materials from outside the region.

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City government plays a big role in getting damaged privately-owned buildings repaired or replaced quickly, making the community function again. However, damage to privately-owned buildings also affects how well the City government functions. The next chapter looks at how the damage estimated in this report might affect the City government.



## CHAPTER 8: IMPACTS ON CITY GOVERNMENT



San Francisco will need strong leaders and capable city institutions to help the City respond to, rebuild after, and recover from future earthquakes. A large earthquake will affect the ability of the City government to function effectively, just as it affects housing, businesses, and other elements of the City. This report focuses only on damage to privately-owned buildings, which means that facilities owned by the City are not addressed<sup>49</sup>. Damage to private buildings, however, will significantly impact City government.

After an earthquake, the City will see a decline in key revenue sources. This decline will occur at a time when many residents are most in need of assistance from the City, and the City's costs to provide social services and help reconstruction would dramatically rise. San Francisco City government receives revenues from a variety of sources, including taxes on property, sales, payroll, hotels, and parking. Table 22 shows the major sources of City revenue for the fiscal year ending in June 2009. The income from a number of these sources could go down after a damaging earthquake.

**Table 22 Sources of Revenue for San Francisco General Fund in Fiscal Year 2008/2009**

Revenue Source	Amount (\$ Millions)	Percent of Total
Property taxes	\$1,000	37%
Intergovernmental	\$650	24%
Business taxes	\$390	14%
Hotel room tax	\$160	6%
Charges for services	\$140	5%
Other local taxes	\$130	5%
Sales and use tax	\$100	4%
Utility users tax	\$90	3%
Licenses, permits and franchises	\$25	0.9%
Rents and concessions	\$19	0.7%
Other	\$11	0.4%
Interest and investment income	\$9.2	0.3%
Fines, forfeitures and penalties	\$5.6	0.2%
TOTAL	\$2,700	100%

Source: San Francisco Controller's Office ( 2009).

<sup>49</sup> In recent years, San Francisco has invested significant resources into improving the seismic safety of key City buildings and infrastructure, particularly facilities needed for emergency response, but known vulnerabilities remain.

Property tax revenues are generated from taxes levied on the assessed value of buildings and land. After an earthquake, the assessed value for land may remain unchanged for most properties. However, if a building was significantly damaged, the property owner could file an appeal seeking a reduction in property taxes due to the decline in the value of the building from this damage. Once reconstruction was complete, the property would be reassessed, but there would be a short-term loss in property taxes. Some people may default on tax payments. This study does not estimate how quickly property tax revenues might recover in the City, and property tax revenue restoration will depend on factors such as the number and type of buildings that are repaired and reconstructed, the speed of the City's reconstruction effort, and how quickly and on what basis properties will be re-assessed once they are rebuilt.

Similarly, other sources of City revenue can be expected to decline in the short and medium term after an earthquake. Many retail establishments would be forced to close due to earthquake and fire damage to the building. While some of these establishments could be relocated or could re-open once their buildings are repaired, there will likely be both short- and long-term losses in retail sales tax. Impacts on businesses could result in reductions in payroll taxes. It is likely that the City will see fewer visitors for some years after a large earthquake, resulting in lower revenues from hotel taxes. Parking revenues would decrease. Other revenue sources could be affected, as well.

The City will receive some funds from the federal government. The Stafford Act provides funds, with some limitations, for the repair of state and local government and certain non-profit facilities on a matching basis, and for other emergency response expenses. However, these funds are likely to cover only a fraction of the City's increased expenses due to an earthquake. Very little federal funding is available for owners suffering losses to the privately-owned buildings studied in this report.

It is important to note that during the current economic downturn, both the state and the City had to lay off and/or furlough workers to reduce their budgets. Reduced staffing or financial capacity may affect their ability to respond to an emergency such as a significant earthquake. While municipal and State finances will eventually recover in tandem with the economic cycle, the current fiscal concerns would lead to a slower recovery if damaging earthquakes occurred during this period.

The City's pace of recovery depends on how quickly buildings—homes, offices, stores, etc.—get repaired or rebuilt and back in service. The speed with which this happens is directly linked to the ability of City departments—Building Inspection, Planning, and others—to review plans and issue permits for the many thousands of buildings that will need work. After a magnitude 7.2 earthquake on the San Andreas, it is reasonable to assume that up to two-thirds of all buildings in the City will require permits for repair or demolition and reconstruction work, although some building owners with moderately-damaged buildings will choose to do the work without permits or cover up damage rather than repair it. The City will need to rely on an interim permit process to allow work to proceed quickly, but with adequate oversight and inspection.

In addition to financial impacts, a large earthquake will reduce the City's ability to focus on other important policy goals. Programs on homelessness, health, environment, and other issues important to San Francisco's people will likely suffer



setbacks or delays. Possible environmental impacts of an earthquake can be used to illustrate this. Currently, the City has nearly met its goal of diverting 75 percent of its waste stream from landfills by 2010. A magnitude 7.2 San Andreas fault scenario earthquake is estimated to result in 6.8 million tons of debris from damaged buildings. Although much of this debris may be recyclable, it is probable that the need to clear debris quickly so rebuilding can start will mean that a large share of it is sent to landfills. A magnitude 7.2 earthquake would produce waste equating to nearly 14 years of trash generation<sup>50</sup>. Rebuilding damaged buildings will require resources, as well, in the form of newly harvested lumber and other construction materials. Newly constructed buildings will probably be very energy efficient, complying with San Francisco's stringent green building requirements. However, specialists estimate that 15 to 20 percent of a building's energy consumption during its lifespan occurs during the extraction, processing, and assembling of raw materials into the finished building<sup>51</sup>. This means that, typically, saving an existing building is more energy efficient than constructing a very energy efficient new building. A final example of an environmental impact from an earthquake could be the release of hazardous materials. There were numerous hazardous materials releases in San Francisco due to the moderate shaking in Loma Prieta, including spills of chemicals, paints, pesticides, and mercury<sup>52</sup>. A larger earthquake could cause much more significant releases that harm the people, land, water, flora, and fauna of the City and region.

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Future earthquakes will damage the City's buildings and affect its housing supply, businesses, and government functions. Can San Francisco rebound from this damage? The next chapter puts all of the pieces together to examine how San Francisco's people would recover from future damaging earthquakes.

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<sup>50</sup> Calculation based on figures from 2007 and 2008, from SF Environment website (sfenvironment.org) and Upton, 2009.

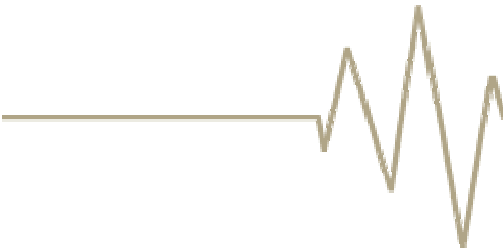
<sup>51</sup> Hays and Cocke, 2009.

<sup>52</sup> Perkins and Wyatt, 1994.



## CHAPTER 9: THE RESILIENCE OF SAN FRANCISCO AND ITS PEOPLE

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The analysis presented in this report makes it clear that future large earthquakes would damage thousands of San Francisco’s buildings and have significant repercussions on the activities that occur inside them. This chapter looks at what this damage means for San Francisco. How will the people of San Francisco cope? Will the City be able to rebound and thrive after such an event? This analysis suggests that, yes, in the long-term, the City will continue to thrive after a large earthquake. San Francisco is a strong and robust City situated in a strong and robust region. It will, however, take time for the City to recover, and not all of the City’s residents will recover to the same degree. After a large earthquake, the City will change. Some people will lose their assets, with ramifications on their lifestyle, such as the inability to afford college or loss of homeownership. Others will thrive and help shape the new City.

### **Factors that Affect San Francisco’s Long-Term Recovery**

Many issues contribute to what San Francisco will be like after it recovers from future damaging earthquakes. Some key components of this—housing and business activity—were explored in previous chapters. Another important factor is the ability of San Francisco’s people and organizations, governmental and non-governmental, to adapt to changing conditions after a disaster and mobilize resources to address problems. San Francisco has a large number of highly-educated and innovative residents. These characteristics are often paired with post-disaster resilience. The City also has a large number of residents with modest and fixed incomes, first generation immigrants, and people with disabilities—people who may have a limited ability to respond and adapt to the demands imposed on them by an earthquake. This section of the report discusses a few factors that influence whether businesses and people will want and be able to remain in San Francisco after an earthquake.

#### *Quality of Life*

San Francisco is a vibrant city—economically, culturally, and socially—largely because many people find it an attractive place to be. Urban theorists have postulated that economic development in a post-industrial economy requires a strong “Creative Class” of workers<sup>53</sup>. The Creative Class includes scientists, academics, designers, artists, and others whose economic function is to create new ideas, technology and creative content; they are the drivers of today’s information economy. Analysts emphasize that quality-of-life factors such as the arts, recreational opportunities, educational institutions, cultural diversity, and attractive urban environments play a crucial role in attracting, cultivating, and maintaining a Creative Class.

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<sup>53</sup> Florida, 2002.

San Francisco and the Bay Area benefit from a rich array of quality-of-life features that have helped it become an international center for the Creative Class. These include outdoor amenities (e.g., The Golden Gate National Recreation Area; City, regional and state parks; the Lake Tahoe Basin), a world-class food and wine culture, a strong network of cultural and arts organizations, a wide range of housing types, and cultural diversity. These characteristics enrich the life of all San Francisco residents. The Bay Area would largely retain these amenities in the event of an earthquake, keeping it a location of choice for many.

### *Educational Institutions*

The San Francisco Bay Area is home to a strong network of public and private educational institutions. Historically, these institutions have played a vital role in establishing the region as a global hub of economic activity and technological development. They act as economic engines and draw employers by creating a highly-educated populace, spawning businesses, and conducting groundbreaking research.

The region's world-class research universities include the University of California campuses in San Francisco and Berkeley, and Stanford University. In addition, the California State University system has campuses in San Francisco and elsewhere in the Bay Area. There are dozens of smaller private institutions in San Francisco such as the Academy of Art, the University of San Francisco, the San Francisco Art Institute, and many others located throughout the region.

Universities will suffer significant damage in a large Bay Area earthquake that could affect their ability to educate students and conduct research. This study has not evaluated the vulnerability of these critical institutions. The University of California and Stanford University have invested heavily in upgrading their buildings and developing plans to prepare for future earthquakes, and other institutions may have made similar investments. The recently constructed University of California San Francisco (UCSF) Mission Bay complex meets modern seismically resistant construction standards. However, these institutions rely on the private sector, and on local businesses and suppliers, for housing and neighborhood support. After a major earthquake, these institutions will continue to attract and produce intellectual and monetary capital, contributing to San Francisco's economy and community. However, it may take time before these "economic engines" restart after an earthquake.

### *Household Incomes*

San Francisco's resilience is affected by the resilience of the region. The Bay Area's strong economy has supported a relatively affluent region. In 2009, the regional median household income was \$76,900<sup>54</sup>, 28 percent higher than the statewide figure, and 50 percent higher than the national figure. With these higher incomes comes greater social resilience, as households are able to withstand temporary downturns in the economy following an earthquake and may be able to draw upon sufficient financial resources to repair physical damage to their homes. Many San Francisco residents may be able to afford to repair or rebuild their homes, replace their possessions, and rent temporary space while construction is underway.

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<sup>54</sup> The Bay Area region is defined as the counties of Alameda, Contra Costa, Solano, Sonoma, Napa, Marin, San Francisco, San Mateo, and Santa Clara.

However, many San Francisco residents have limited or fixed incomes that would not easily accommodate the expenses associated with disruption after an earthquake. Lower-income households will have more difficulty weathering a loss in employment following a disaster, and are less able to rebuild damaged property, particularly with high construction costs in the Bay Area. Moreover, lower-income households are more likely to be renters than homeowners. As discussed previously, rental properties are rebuilt at a slower rate than owner-occupied properties. Demolished rental units may be replaced by condominiums that are unlikely to be affordable to the previous occupants. An earthquake could lead to increased gentrification in San Francisco: households with ample resources could afford to pick up the pieces and stay, and households with fewer resources may need to move somewhere less expensive, perhaps permanently.

### *Cost-of-Living*

The region's overall affluence has led to a relatively high cost-of-living in the Bay Area. As of September 2009, San Francisco's median home price was \$675,000, compared to the statewide median home price of \$251,000. Looking at the Consumer Price Index (CPI) shows that, on average, between 1975 and 2008, inflation rose faster in the Bay Area than the nation 57 percent of the time, or 20 out of 35 years. The CPI measures the change in prices on a general basket of consumer goods over time, and serves as an indicator of the cost-of-living. Higher rates of inflation suggest that the cost-of-living in the Bay Area increases faster than the nation as a whole, depending on the rate of annual wage increases relative to prices.

As another measure of the cost-of-living, Sperling's BestPlaces.net web site uses data from the Council for Community and Economic Research to compare the cost of living between US cities. According to Sperling, the cost of living in San Francisco is 87 percent higher than the national average – mostly because of housing costs.

This high cost-of-living may prove a negative factor for San Francisco's recovery following an earthquake. For example, higher construction costs may slow the rebuilding process. Again, the City's high housing costs may also compel households to leave San Francisco altogether if their residences are severely damaged.

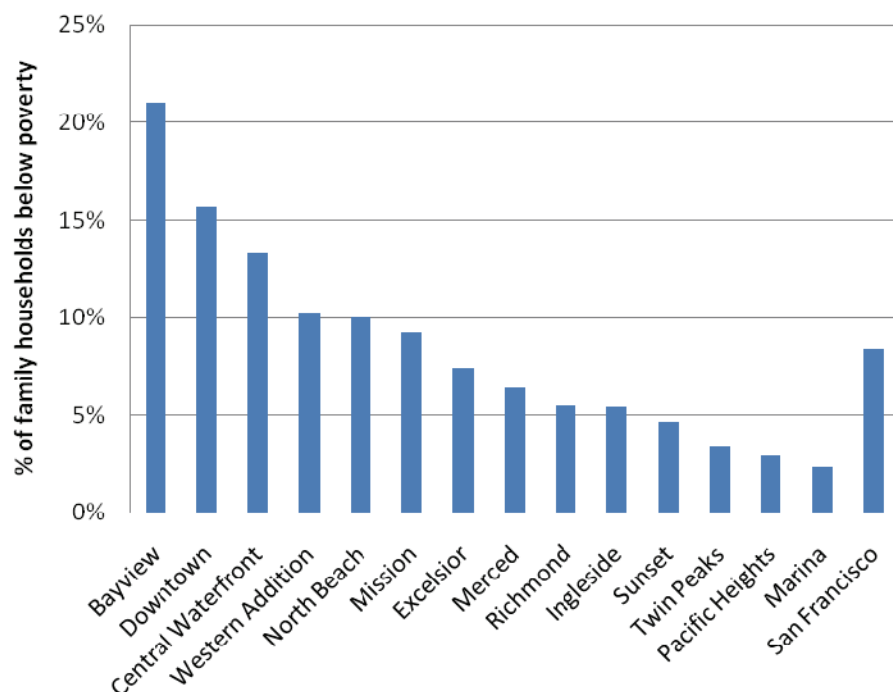
### **Resilience of San Francisco's Neighborhoods**

Although San Francisco is a generally affluent city, not all residents are affluent and some neighborhoods are less disaster resilient than others due to their socioeconomic characteristics. Displacement after an earthquake is most difficult for those City residents who are elderly, disabled, or poor. These residents often have limited resources to rebound when they lose their home and possessions, even temporarily. It can be a hardship for them to be separated from services and community members they rely on. Nearly eight percent of residents (over 60,000 people) are physically disabled<sup>55</sup>. These people could be significantly impacted if they need to vacate their homes. Even elderly and disabled residents who can remain in their homes could suffer severe consequences after an earthquake if utilities, such as electricity, gas, water, and sewer, do not function, or if neighborhood services, such as pharmacies and grocery stores, are not open.

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<sup>55</sup> Claritas, 2009.

The percentage of households living below the federal poverty threshold serves as one indicator of a neighborhood's socioeconomic resiliency<sup>56</sup>. As shown in Figure 16, approximately eight percent of San Francisco households live below the poverty threshold<sup>57</sup>. In comparison, Bayview, Downtown, Central Waterfront, Western Addition, and North Beach, all have at least 10 percent of households below the federal poverty threshold.



**Figure 16** *Percent of households living below federal poverty threshold in 2009 by district (only includes family households).*  
Source: Claritas (2009).

Homeownership is another factor that affects how quickly recovery occurs. As noted earlier, homes occupied by their owners tend to be rebuilt at a faster rate than multi-family rental housing following an earthquake. Table 23 presents homeownership rates and housing types by district in San Francisco. As shown, nearly two-thirds of residents in the City are renters. Homeownership rates are lowest in Downtown, North Beach, and the Western Addition, all districts with a heavy concentration of multi-family housing. Conversely, the Sunset, Excelsior, Twin Peaks, and Ingleside have relatively high homeownership rates and a greater incidence of single-family homes.

<sup>56</sup> The federal poverty threshold was originally developed in 1963-1964 by the Social Security Administration based on the U.S. Department of Agriculture's economy food plan, and is updated each year by the Census Bureau. Although it presents methodological problems, particularly in a high cost region such as the Bay Area, it remains the official federal definition of "poverty" and serves as a useful benchmark for comparing neighborhood profiles for this study. The 2009/2010 poverty threshold for a four person household is \$22,050 (USDHHS, 2009).

<sup>57</sup> Only includes family households.

**Table 23 San Francisco Unit Types and Homeownership Rates**

District	Unit Type		Unit Occupancy	
	Single-Family (%)	Multi-Family (%)	Owner Occupied (%)	Renter Occupied (%)
Downtown	2	98	8	92
North Beach	5	95	19	81
Western Addition	12	88	21	79
Marina	11	89	21	79
Pacific Heights	14	85	28	72
Merced	41	59	28	72
Mission	28	72	33	67
Central Waterfront	13	84	35	65
Richmond	30	70	36	64
Bayview	67	32	52	48
Sunset	66	34	56	44
Excelsior	82	17	68	32
Twin Peaks	72	28	68	32
Ingleside	90	9	74	26
Citywide	31%	69%	35%	65%

Sources: This study; Claritas (2009).

Socio-economic resilience varies significantly by district. In general, districts with higher-income households, greater homeownership rates, and more single-family homes will likely recover and rebuild faster than lower-income areas with more renters and multi-family units. Table 24 provides a perspective on how these factors compare across districts, based on the data presented above. The analysis assigns a “resilience score” to each district according to its poverty rates, homeownership rate, and the percent of units in multi-family buildings. Neighborhoods with greater rates of poverty, renters, and multi-family housing receive lower resilience scores. The findings suggest that the City’s most socio-economically resilient districts include Ingleside, the Excelsior, and the Sunset. Its least socio-economically resilient districts include Downtown, North Beach, and the Western Addition.

The next major earthquake that strikes San Francisco will change the City and its people. San Francisco is a world-class city with many special attributes that draw businesses, innovative people who want to live here, and visitors from around the world. In the long-term, San Francisco will recover and thrive, but it will be a different San Francisco. It is likely that the new, post-earthquake San Francisco will have less socio-economic diversity. The destruction of many affordable housing options, exacerbated by a reduced number of housing units available in the years it will take to rebuild the City, will make it difficult for middle- and low-income residents to remain in San Francisco. Earthquake damage will stress businesses and the jobs they provide, particularly the many small and independent businesses in the



**Table 24      Socio-Economic Resilience Index, San Francisco Districts**

District	Poverty <sup>a</sup>	Home Ownership <sup>b</sup>	Multi-Family Housing <sup>c</sup>	Average Resilience Score
Ingleside	3	3	3	3.00
Excelsior	2	3	3	2.67
Sunset	3	3	2	2.67
Twin Peaks	3	3	2	2.67
Bayview	1	3	2	2.00
Merced	2	2	2	2.00
Mission	2	2	2	2.00
Pacific Heights	3	2	1	2.00
Richmond	2	2	2	2.00
Marina	3	1	1	1.67
Central Waterfront	1	2	1	1.33
Downtown	1	1	1	1.00
North Beach	1	1	1	1.00
Western Addition	1	1	1	1.00

- a. Poverty rate, 2009      Resilience score  
0-5%      3  
6%-10%      2  
>10%      1
- b. Homeownership rate, 2009      Resilience score  
>50%      3  
26%-50%      2  
0%-25%      1
- c. % multi-family, 2009      Resilience score  
0-25%      3  
26%-75%      2  
>75%      1

Sources: This study, Claritas (2009).

City. It will change the way the City looks, with some of the most interesting and beautiful buildings and neighborhoods changed forever. Despite the damage, San Francisco will retain many of the elements that make it an economically successful and socially desirable place – physical beauty, cultural amenities, and proximity to world-class universities, to name a few.

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The scenarios described in this report present what is likely to happen if San Francisco makes no changes to its preparations for earthquakes. Much of this damage may be preventable. It is up to San Franciscans to decide how much to invest in steps to reduce the consequences of the next major earthquake. As discussed in the companion ATC-52-2 Report, *A Community Action Plan for Seismic Safety*, there are many steps the City can take to reduce damage and become more resilient.

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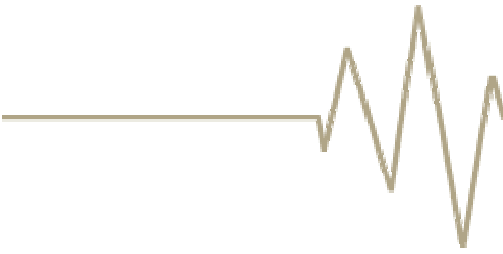
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# APPLIED TECHNOLOGY COUNCIL: AN OVERVIEW



The Applied Technology Council (ATC) is a nonprofit corporation founded to protect life and property through the advancement of science and engineering technology. With a focus on seismic engineering, and a growing involvement in wind and coastal engineering, ATC's mission is to develop state-of-the-art, user-friendly resources and engineering applications to mitigate the effects of natural and other hazards on the built environment.

ATC fulfills a unique role in funded information transfer by developing nonproprietary consensus opinions on structural engineering issues. ATC also identifies and encourages needed research and disseminates its technological developments through guidelines and manuals, seminars, workshops, forums, and electronic media, including its web site ([www.ATCouncil.org](http://www.ATCouncil.org)) and other emerging technologies.

## Key Publications

Since its inception in the early 1970s, the Applied Technology Council has developed numerous, highly respected, award-winning, technical reports that have dramatically influenced structural engineering practice. Of the more than 100 major publications offered by ATC and its Joint Venture partners, the following have had exceptional influence on earthquake engineering practice:

**ATC-3-06**, *Tentative Provisions for the Development of Seismic Regulations for Buildings*, funded by the National Science Foundation (NSF) and the National Bureau of Standards and completed in 1978, provides the technical basis for seismic provisions in the current *International Building Code* and other model U. S. seismic codes.

**ATC-14**, *Evaluating the Seismic Resistance of Existing Buildings*, funded by NSF and completed in 1987, provides the technical basis for the current American Society of Civil Engineers (ASCE) Standard 31, *Seismic Evaluation of Existing Buildings* (the national standard for seismic evaluation of buildings).

**ATC-20**, *Procedures for Postearthquake Safety Evaluation of Buildings*, funded by the California Office of Emergency Services and the California Office of Statewide Health Planning and Development, is the *de facto* national standard for determining if buildings can be safely occupied after damaging earthquakes. The document has been used to evaluate tens of thousands of buildings since its introduction two weeks before the 1989 Loma Prieta earthquake in Northern California.

**ATC-40**, *Seismic Evaluation and Retrofit of Concrete Buildings*, funded by the California Seismic Safety Commission and completed in 1996, won the Western States Seismic Policy Council's "Overall Excellence and New Technology Award" in 1997.

**FEMA 273**, *NEHRP Guidelines for the Seismic Rehabilitation of Existing Buildings*, funded by the Federal Emergency Management Agency (FEMA) and completed in 1997 under the ATC-33 Project, provides the technical basis for the current American Society of Civil Engineers (ASCE) Standard 41, *Seismic Rehabilitation of Existing Buildings* (the national standard for seismic rehabilitation of buildings).

**FEMA 306**, *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings*, *Basic Procedures Manual*, **FEMA 307**, *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings*, *Technical Resources*, and **FEMA 308**, *The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings*, funded by FEMA and completed in 1998 under the ATC-43 Project, provide nationally applicable consensus guidelines for the evaluation and repair of concrete and masonry wall buildings damaged by earthquakes.

**FEMA 352**, *Recommended Post-earthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings*, funded by FEMA and developed by the SAC Joint Venture, a partnership of the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering, provides nationally applicable consensus guidelines for the evaluation and repair of welded steel moment frame buildings damaged by earthquakes.

**FEMA P646**, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis*, funded by FEMA and completed in 2008 under the ATC-64 Project, provides state-of-the-art guidance for designing, locating and sizing structures to resist the effects of tsunamis and thereby provide safe evacuation refuge in affected coastal areas.

## Organization

With offices in California, Delaware, and Virginia, ATC's corporate personnel include an executive director, senior-level project managers and administrators, and technical and administrative support staff. The organization is guided by a distinguished Board of Directors comprised of representatives appointed by the American Society of Civil Engineers, the National Council of Structural Engineers Associations, the Structural Engineers Association of California, the Structural Engineers Association of New York, the Western Council of Structural Engineers Associations, and four at-large representatives.

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Funding for ATC projects is obtained through government agencies and from the private sector in the form of tax-deductible contributions.