ATC 52-1A

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

Potential Earthquake Impacts: Technical Documentation

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

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-52-1A Report, contains descriptions of the technical analyses that were conducted to produce the impacts presented in the companion *Potential Earthquake Impacts* volume (ATC-52-1 Report), which focuses on estimating impacts to the City's privately owned buildings in future earthquakes. 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-52-1A

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Potential Earthquake Impacts: Technical Documentation

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

Everyone knows that San Francisco faces high earthquake risk. A companion Community Action Plan for Seismic Safety CAPSS) report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco*, *Potential Earthquake Impacts,* provides specifics about how much and what types of damage the City can expect in future earthquakes, and the costs—economic, social, and cultural—of that damage to San Francisco residents. It includes estimates of the number of buildings of various types that will be damaged, the costs of that damage, the size of possible fires, the number of displaced households, and many other aspects of loss for four likely, future earthquakes.

This report presents the technical methods, sources, assumptions, and calculations behind the results in the companion *Potential Earthquake Impacts* report. The results presented here, which are based on significant technical work using scientific and engineering research, were conducted under the review of an independent, distinguished Project Engineering Panel. While the companion report is written for a broad audience, this report will mainly be of interest to readers with a technical background. It is written assuming that readers have some knowledge of structural engineering and earthquake risk analysis; however some chapters will be accessible to readers of all backgrounds who are interested in details of the work.

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 potential impacts study to formulate recommended programs and an action plan to help San Francisco become a safer, more resilient city if government takes action.

Mary Lou Zoback
Advisory Committee Co-Chair

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CHAPTER 1: INTRODUCTION

1.1 Purpose of Report

The purpose of this report is to describe the technical analyses that contributed to the information in the companion ATC-52-1 report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts,* (ATC, 2010), and to present additional data, analysis, and results that enhance the information in that report. The intended reader is expected to be familiar with the technical aspects of earthquake loss estimation.

1.2 History of CAPSS Project

In the late 1990's, Laurence Kornfield, Chief Building Inspector, Department of Building Inspections (DBI), City and County of San Francisco, conceived of the Community Action Plan for Seismic Safety (CAPSS) as a program of the Department of Building Inspection of the City and County of San Francisco. The program was to evaluate the seismic risk facing the community and to recommend feasible and practical measures to reduce the risk.

In early 2000, DBI initiated a multi-year effort to define and implement the CAPSS program as a wide-ranging program of studies and recommendations involving City staff, citizens, and experts. The program was conceived to extend over several years, and would develop a basis for policy decision-making related to earthquake risk reduction and repair of earthquake-damaged buildings by the City and County of San Francisco.

Phase I of CAPSS was carried out by the Applied Technology Council (ATC) under contract to DBI, and was an initial effort to define the tasks that should be carried out under the CAPSS project. Phase I involved preliminary evaluations of the seismic risks in the City and County and involved public meetings to obtain input on proposed approaches for reducing these risks. The Phase I findings were documented in the ATC-52 report, *Community Action Plan for Seismic Safety (CAPSS), City and County of San Francisco, Plan Description and Needed Services* (ATC-52, 2000), which was completed and submitted to the Department of Building Inspection in late 2000.

In September 2001, following a competitive bidding process, DBI awarded ATC a two-year contract to conduct Phase II of the Community Action Plan for Seismic Safety (CAPSS), City and County of San Francisco. The purpose of Phase II was to conduct a citywide earthquake vulnerability assessment, formulate guidelines for post-earthquake building repair and retrofit policies, and identify practical, achievable, and community-backed earthquake mitigation programs. This report describes the detailed analysis behind the first of these tasks: conducting a citywide earthquake vulnerability assessment.

Phase II of the CAPSS project was suspended by the City in early 2003. The project was resumed in the Spring of 2008. Phase II of the CAPSS project was completed in 2010. In February of 2009 the CAPSS project released its initial report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings* (ATC, 2009a), along with a companion report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings, Documentation Appendices* (ATC, 2009b). That report was followed in 2010 with four reports, including this technical documentation report and the companion ATC-52-1 (ATC, 2010) report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts* (see the inside front cover of this report for additional information).

1.3 Report Organization

The main body of this report consists of nine chapters and two appendices. Chapters 2 through 6 describe the methodology and approach used to calculate damage and losses resulting from ground shaking, Chapter 7 addresses the expected impacts of post-earthquake fires (fire following earthquake), and Chapters 8 and 9, respectively, address losses due to business interruption, and an in-depth analysis of the social and economic resilience of San Francisco.

The chapters describing the estimation of losses/impacts resulting from ground shaking include: a brief description of, limitations of (uncertainty), and history of the standardized loss estimation software (HAZUS®) used in the CAPSS analysis (Chapter 2); descriptions of the four earthquake scenarios considered in the analysis, the ground motion (shaking) characterization and attenuation relationships used in the analysis, and the estimation of impacts from liquefaction (Chapter 3); building inventory development (Chapter 4); building vulnerability characterization functions (fragility curves), and casualty rates (Chapter 5), and aggregation of results to estimate losses caused by ground shaking (Chapter 6).

The chapter on fire losses (Chapter 7) includes descriptions of the factors that affect fires, fire modeling, and fire loss estimation analysis and results for the scenarios considered.

Two appendices provide supplemental information pertaining to the HAZUS® analysis (Appendix A) and for the social and economic analysis (Appendix B). A list of Project Participants is also included, as is a brief overview of the Applied Technology Council.

CHAPTER 2: OVERVIEW OF CUSTOM HAZUS® ANALYSIS

2.1 The HAZUS® Software

HAZUS® (HAZards U.S.) is a geographical information system (GIS) that uses a standardized, nationally applicable natural hazard loss estimation methodology and software, developed for the Federal Emergency Management Agency (FEMA) by the National Institute of Building Sciences (NIBS). The system was developed for local, state, and federal government officials use HAZUS® for preparedness, emergency response, and mitigation planning.

The initial version of HAZUS® was released in 1997 as HAZUS®97, followed two years later by an updated and improved version of the software, that was more widely distributed and used, HAZUS®99. Two additional versions followed: HAZUS®99 Service Release 1.0 (2001) and HAZUS®99 Service Release 2.0 (2002). Final analyses conducted for the CAPSS project utilized HAZUS®99 Service Release 2.0, operating within ESRI's ArcView Software (Version 3.2).

The next generation of HAZUS®, HAZUS®MH, expanded the earthquake loss estimation capabilities to be multi-hazard and included flood and hurricane modeling capability. HAZUS®MH V1.0 was released in January of 2004, followed by the release of HAZUS®MH MR-1 (Maintenance Release 1) in January of 2005, MR-2 in May of 2006, and MR-3 in September of 2007, and MR-4 more recently.

2.2 CAPSS Use of HAZUS®99

The CAPSS project team began modeling San Francisco's earthquake risk in 2001. Between 2001 and 2003, when the project was suspended, the CAPSS team developed detailed, custom inventory and vulnerability information for San Francisco using HAZUS®99 Service Release 2.0, the latest available software at the time. The loss estimation was nearly complete when the project was suspended in 2003. Work on the loss estimation resumed in 2009. At this time, the project team determined that the extensive customization developed in the HAZUS®99 model could not easily be imported into the HAZUS®MH model. The value of the customized inventory and vulnerability models were deemed to be of significantly greater importance to producing meaningful loss estimates for the City than using the HAZUS®MH software.

2.3 Elements of Custom HAZUS® Analysis

HAZUS® uses the following inputs in its earthquake damage model:

- *Hazard*: the ground shaking that occurs at each location studied during an earthquake, including the effects of local soil conditions and liquefaction;

- *Inventory*: the buildings, people, and activities that exist in all locations studied; and
- *Vulnerability*: the likelihood of damage occurring to buildings, people, and activities when exposed to various levels of shaking.

The CAPSS analysis extensively customized all of these inputs, as described in Chapters 2 through 5 of this report.

2.4 Uncertainty of HAZUS® Loss Estimates

HAZUS®, like all earthquake loss estimation methodologies, produces results with significant uncertainties. The following text from the HAZUS®99 (FEMA/NIBS, 2002) manual discusses this issue:

> "Uncertainties are inherent in any loss estimation methodology. They arise in part from incomplete scientific knowledge concerning earthquakes and their effects upon buildings and facilities. They also result from the approximations and simplifications that are necessary for comprehensive analyses. Incomplete or inaccurate inventories of the built environment, demographics and economic parameters add to the uncertainty. These factors can result in a range of uncertainty in loss estimates produced by HAZUS®, possibly by a factor of two or more.
>
> "The methodology has been tested against the judgment of experts and, to the extent possible, against records from several past earthquakes. However, limited and incomplete data about actual earthquake damage precludes complete calibration of the methodology. Nevertheless, when used with embedded inventories and parameters, HAZUS® has provided a credible estimate of such aggregated losses as the total cost of damage and numbers of casualties. HAZUS® has done less well in estimating more detailed results, such as the number of buildings or bridges experiencing different degrees of damage. Such results depend heavily upon accurate inventories. … In the few instances where HAZUS® has been partially tested using actual inventories of structures plus correct soils maps, it has performed reasonably well.
>
> "Users should be aware of the following specific limitations:

- While HAZUS® can be used to estimate losses for an individual building, the results must be considered as average for a group of similar buildings. It is frequently noted that nominally similar buildings have experienced vastly different damage and losses during an earthquake. …
- Based on several initial studies, the losses from small magnitude earthquakes (less than magnitude 6.0) centered within an extensive urban region appear to be overestimated.
- Because of approximations in modeling of faults in California, there may be discrepancies in (ground) motions predicted within small areas immediately adjacent to faults….
- As yet, there have not been adequate tests for the following features of HAZUS®: Effects of liquefaction and landsliding; debris generation; and indirect economic losses."

CHAPTER 3: HAZARD

HAZUS®' ground motion generation capabilities were bypassed for all runs. Custom ground motion data generated by Treadwell & Rollo (consultants on the initial CAPSS Phase II efforts) in 2002 were incorporated into HAZUS®. The four earthquake scenarios analyzed are magnitudes 6.5, 7.2 and 7.9 earthquakes on the San Andreas fault, and a magnitude 6.9 event on the Hayward fault.

3.1 Selection of Scenarios

CAPSS elected to use a scenario-based approach to estimate earthquake losses. An earthquake *scenario* is an assumed earthquake that could occur, with a specific location on a selected fault, magnitude, and other characteristics. Loss estimates are conducted for this assumed earthquake. An alternative approach, not used by the CAPSS project, is referred to as a probabilistic loss estimate. A probabilistic approach analyzes a range of possible earthquakes that could affect a specific community, and then presents loss estimates in terms of the probability of various levels of damage occurring during a specific time frame. CAPSS chose to develop scenario-based loss estimates rather than a probabilistic loss estimate because they are easier for nontechnical people to understand and, therefore, provide better guidance for policy choices made by nontechnical policymakers.

CAPSS decided to produce loss estimates for four scenarios to illustrate how damage might vary in earthquakes of different sizes and locations. The following four earthquake scenarios were analyzed by the CAPSS project:

- A moment magnitude 7.9 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. It has an estimated recurrence rate of 352 years (WGCEP, 2008; Ned Field, personal communication). For comparison, the 1998 San Francisco Building Code definition of Design Basis Earthquake is one having a 10-percent probability of exceedance in 50 years, which is equivalent to a 475-year return period.
- A moment magnitude 7.2 on the Peninsula segment of the San Andreas Fault, which is the maximum postulated magnitude that could occur on the Peninsula segment (WGCEP, 1999). This earthquake would produce a level of shaking in many areas of the City that is similar to the level of shaking that the San Francisco building code requires new structures be designed to resist. For this reason, damage from this scenario is used as an example to explore consequences in detail in many sections of the companion ATC-52-1 Report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco*, *Potential Earthquake Impacts* (ATC, 2010a).

- A moment magnitude 6.5 on the Peninsula segment of the San Andreas Fault. The Working Group on California Earthquake Probabilities (WGCEP) estimates a 21-percent probability of a magnitude 6.7 or greater earthquake occurring on the San Andreas in the next 30 years.
- A magnitude 6.9 on the Hayward fault.

These four scenarios were selected by the project's geotechnical consultants, in consultation with the initial Phase II CAPSS Advisory Committee. They are based on a study of earthquake probabilities in the San Francisco Bay region conducted by the Working Group on California Earthquake Probabilities (WGCEP, 1999; WGCEP, 2008).

3.2 Estimation of Ground Motion

The ground motion for the four scenario earthquakes was estimated at the centroid of each city block in San Francisco. For a given scenario event, median estimates of the spectral acceleration for periods of 0.0 (peak ground acceleration), 0.2, and 1.0 seconds were made using three attenuation relationships. The effects of local soil amplification were also taken into account in producing these estimates. The closest distance from the site to the fault rupture was calculated. The coordinates for the faults were obtained from California Division of Mine and Geology (CDMG, 1996).

3.2.1 Attenuation Relationships

Three attenuation relationships for estimating spectral accelerations were used in this study. They are:

- Abrahamson and Silva (1997),
- Campbell (1997), and
- Sadigh et al. (1997).

Each of these attenuation relationships provide estimates of spectral accelerations for rock and stiff soil conditions. Because Boore et al. (1997) is not valid for moment magnitudes greater than 7.5, this relationship was not included in this study.

The science of estimating the ground shaking that will occur during an earthquake of a specific size and location is continually evolving. The levels of ground shaking that would occur in the City during the four CAPSS scenarios were calculated in 2002 using the best methods available at that time. Since then, there have been major advances in the science of estimating ground shaking associated with scenario earthquakes and applying them to loss studies.

New attenuation relationships for seismic ground motions are now available, known as the Next Generation Attenuation (NGA) models. These models predict spectral accelerations in the short-period range that are about 10-15% less, and spectral accelerations in the one-second range that are about 25-35% less, than the models used for this study. However, NGA relationships have been developed using a form of the geometric mean of the spectral acceleration of the two components of each recorded ground motion. It has been recommended by building code writers to use ground motions proportional to the maximum value of spectral acceleration in any direction, not the geometric mean, for design of buildings. The conversion from NGA geometric-mean values to NGA maximum-spectral-acceleration-in-any-direction values results in increases in predicted ground motions that are within about 10% of pre-NGA attenuation relationships.

Studies have also been completed regarding which ground motion recording parameter is best for predicting losses in HAZUS® (Kircher, Whitman and Holmes, 2006). These studies showed that when calculating ShakeMaps for rapid estimation of potential losses using HAZUS®, maps developed using the maximum value of the two recorded directions produced losses in close agreement with observed damage, while maps developed using the mean of the two recorded directions consistently under-predicted losses by about a factor of two. These studies suggest that ground motions proposed for use in building codes (i.e., using maximum spectral acceleration in any direction) would yield predicted losses that are believed to be better calibrated with actual losses than would use of the new NGA relationships.

Considering the similarity of the ground motions used in the 2002 CAPSS estimates with those now proposed for use in building codes, the extensive effort needed to redo all the HAZUS® work with completely new ground motions, and the general uncertainties inherent in seismic loss estimation, the ground shaking estimated in 2002 has been used for the CAPSS study.

3.2.2 Amplification of Ground Shaking Due to Local Site Conditions

Amplification of ground shaking to account for local site conditions is based on the site classes and soil amplification factors proposed in the 1997 NEHRP Provisions, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, and *Commentary* (BSSC, 1997), The classification is based on the average shear wave velocity of the upper 30 meters of the local geology as shown on Table 3-1.

Table 3-1 Site Classes from the 1997 *NEHRP Provisions for Seismic Regulations for New Buildings and Other Structures*

Site Class	Site Class Description	Shear Wave Velocity (m/s)
A	Hard Rock (Eastern United States only)	At least 1,500
B	Rock	760 to 1,500
C	Very Dense Soil and Rock	360 to 760
D	Stiff Soils	180 to 360
E	Soft Soils, 10 feet or more of soft clay	less than 180

The U.S. Geological Survey (USGS) has developed a map of the San Francisco Bay Area, which delineates the site class types based on the National Earthquake Hazards Reduction Program (NEHRP) classification of Table 3-1. Figure 3-1 presents site classes for the City and County of San Francisco.

Median estimates of spectral accelerations were calculated for site classes B and D using the average of Abrahamson and Silva (1997), Campbell (1997), and Sadigh et al. (1997) attenuation relationships for rock and soil, respectively. Site class C represents an intermediate condition between rock (class B) and stiff soil (class D). Therefore, spectral accelerations for class C sites were developed using the average of rock and soil values obtained from the three proposed attenuation relationships. Because the three attenuation relationships used in this study do not provide estimates of spectral accelerations for soft soil sites (class E), spectral values for this class were estimated using a two-step approach. First, rock spectral accelerations (class B) were estimated using the attenuation relationships, and then these values were adjusted using the NEHRP soil amplification values for site class E, as presented in Table 3-2.

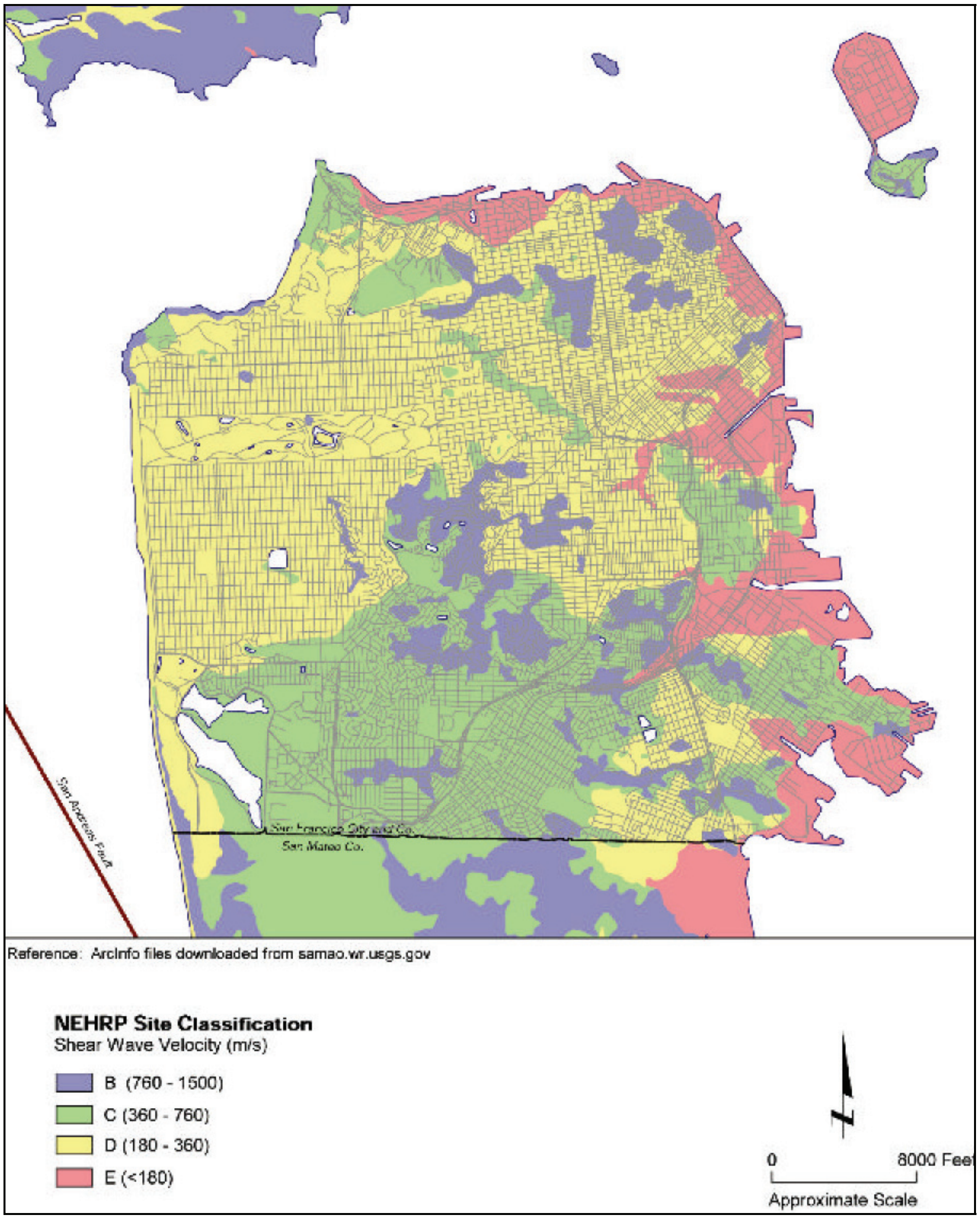

Figure 3-1 NEHRP site classes for San Francisco.

3.2.3 Liquefaction Susceptibility

HAZUS®99's capabilities to estimate liquefaction displacement and probability data from susceptibility data were bypassed. Instead, liquefaction susceptibility data were provided by Treadwell & Rollo for each city block, and were used to generate data required by HAZUS®99 to assess damage due to liquefaction, including peak ground

Table 3-2 NEHRP Soil Amplification Factors

Site Class B Spectral Acceleration	Site Class E Amplification Factor
Short Period, S_{as} (g)	
≤0.25	2.5
0.50	1.7
0.75	1.2
1.0	0.9
≥1.25	0.8*
1-Second Period, S_{a1} (g)	
≤0.1	3.5
0.2	3.2
0.3	2.8
0.4	2.4
≥0.5	2.0*

*The NEHRP Provisions do not provide site class E amplification factors when S_{as} >1 or S_{a1} >0.4. Values for these conditions were obtained from the HAZUS®99-SR1 Technical Manual.

displacements due to lateral spread and settlement, and the extent and probability of liquefaction for each city block and each scenario event. Details of the methods for estimating these quantities may be found in the HAZUS®99 Technical Manual, Chapter 4. To gauge the scope of losses due to liquefaction, the San Andreas 7.2 scenario was run both with and without liquefaction impacts.

Liquefaction is a phenomenon where loose, saturated, cohesionless soil experiences temporary reduction in strength during cyclic loading such as that produced by earthquakes. Liquefaction can result in permanent ground displacements such as lateral spreading, settlement, and loss of bearing capacity. Knudsen et al. (2000) has addressed the liquefaction susceptibility of various types of soil deposits in the Bay Area by assigning a qualitative susceptibility rating based on general depositional environment and geologic ages of the deposit. The Knudsen et al. (2000) study assigned a relative liquefaction susceptibility rating (e.g., very low, low, moderate, high, and very high) to each soil deposit. These ratings are broad and general classifications may vary within the deposit. Mapped areas characterized as rock do not pose a liquefaction hazard.

Peak ground acceleration (PGA) values were used to evaluate liquefaction potential, using a qualitative approach. Table 3-3 presents general estimates of the threshold PGA required to trigger liquefaction for each of the liquefaction susceptibility rating levels as defined by Knudsen et al. (2000). The PGA’s that are presented in Table 3-3 are estimates only, and are provided only to indicate relative levels of shaking necessary to liquefy different geologic units. Figure 3-2 presents the liquefaction susceptibility map as developed by Knudsen et al. (2000).

Liquefaction potential for different areas within the City was evaluated by comparing the computed PGA's for each scenario earthquake to the threshold PGA. Where the computed PGA exceeded the threshold PGA, the area was designated as liquefiable.

Table 3-3 Threshold PGA Required to Trigger Liquefaction

Mapped Relative Susceptibility	Threshold PGA (g)
Very High	0.1
High	0.2
Moderate	0.3
Low	0.5
Very Low	0.6

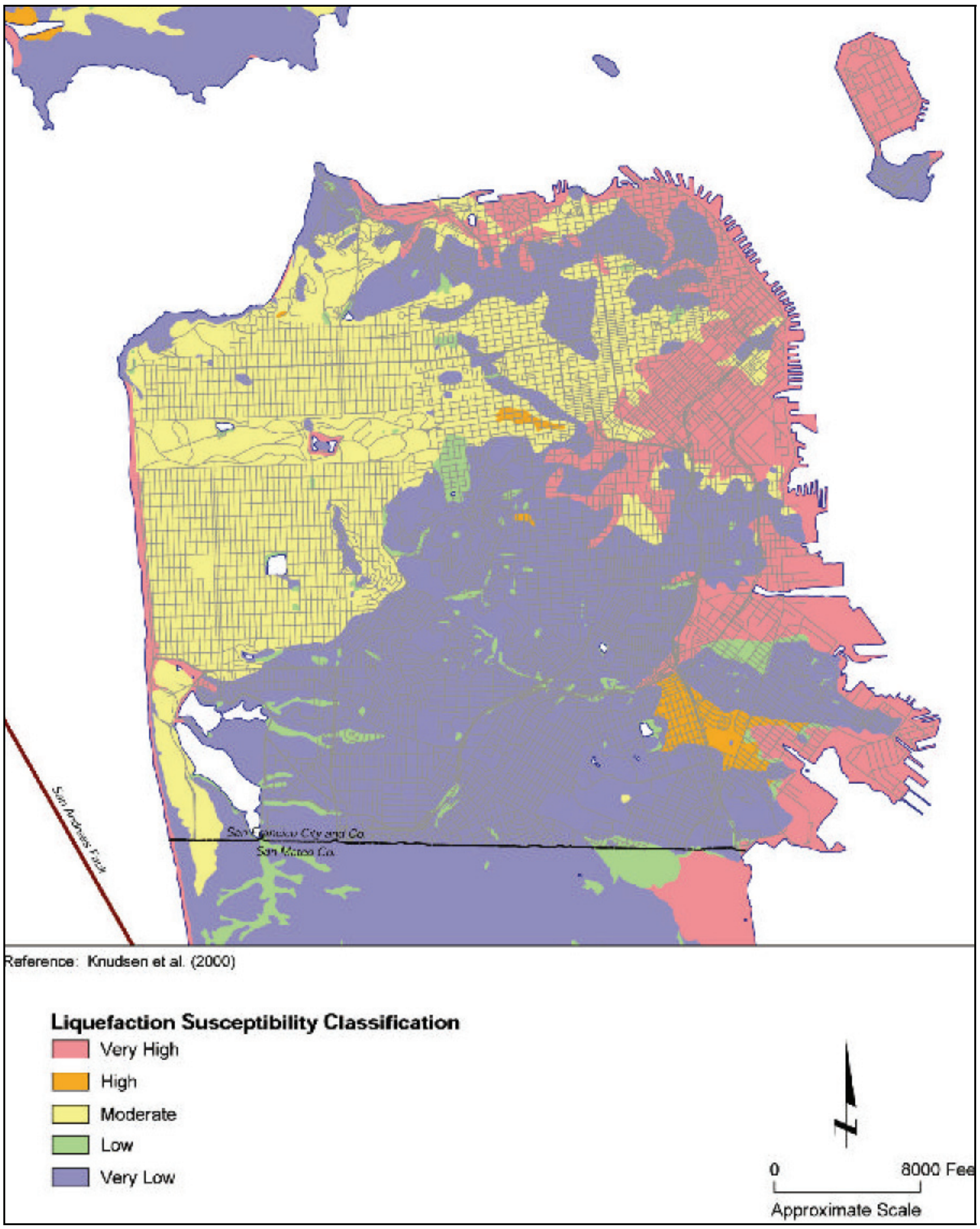

Figure 3-2 Liquefaction susceptibility classifications.

Considering the significant variations in subsurface conditions and lack of detailed knowledge about specific sites, this approach was intended to provide a qualitative evaluation of liquefaction susceptibility. Therefore, some judgment was needed in designating certain areas of the City as liquefiable for a particular earthquake scenario.

3.3 Input of Ground Motion into HAZUS® Model

For each scenario, Treadwell & Rollo provided city block level estimates of PGA, S_a at 0.2 seconds, S_a at 1.0 seconds, and distance to fault. These data were used to derive additional required parameters as described below, and were then reformatted into the required HAZUS®99 Potential Earth Science Hazard (PESH) data files:

- Spectral acceleration at 0.3 seconds ($S_a(0.3)$) was calculated from $S_a(0.2)$ by dividing by 1.1, as described in the HAZUS®99 Technical Manual Chapter 4.
- Spectral displacements at 0.3 and 1.0 seconds were calculated from spectral accelerations as outlined in the HAZUS®99 Manual, Chapter 4, equation 4-3: $S_D = 9.8 \times S_a \times T^2$, where T = period in seconds, S_D is in inches, S_a is in g.
- Peak Ground Velocity (PGV) was inferred from 1.0-second spectral acceleration as outlined in the HAZUS®99 Technical Manual, equation 4-5: $PGV = [(386.4/2\pi) \times S_a(1.0)] / 1.65$. Spectral velocities were similarly estimated (e.g., $S_v(0.3) = (386.4/2\pi) \times S_a(0.3)$) although without the factor of 1.65 in the denominator, which is the amplification factor required to convert from peak spectral response to PGV.

CHAPTER 4: INVENTORY

The HAZUS® model uses the term “inventory” to refer to data about the built and socio-economic environment: building types, and numbers of people that exist in the City, as well as building uses and their location. The CAPSS project team developed a customized inventory of the City’s buildings at the city block level based on Tax Assessor’s data and available studies. The CAPSS project team also developed customized socio-economic data.

4.1 Inventory of Buildings

This section describes the custom city block-level building inventory developed by the CAPSS project team, including how building data for various occupancy categories were assigned to each city block, and how occupancy categories were mapped to structural types.

4.1.1 Overview of HAZUS® Building Inventory Database Structure

To facilitate loss estimation to the built environment, the HAZUS® software is provided with default data representing the building stock throughout the United States. These data are aggregated to the census tract level in HAZUS®99, and may be considered proxy data, as they were developed from nationally available census data (for residential buildings) and from data purchased from Dun & Bradstreet (for non-residential buildings). Inventory data in HAZUS®99 is classified into 28 specific occupancy classes, as listed in Table 4-1 (after FEMA/NIBS, 2002).

Building inventories within HAZUS®99 are represented by a number of related tables, storing various inventory parameters by census tract and either occupancy or building type, including building square footage, building count, building exposure values (replacement costs), and building repair costs for each potential damage state. Additional tables provide “mapping scheme” relationships: the percent distribution of square footage among various structural or model building types for each specific occupancy class. HAZUS®99’s model building types are listed in Table 4-2 (after FEMA/NIBS, 2002).

Additional detail on the “general building stock” database structure within HAZUS®99 may be found in the HAZUS®99 Technical Manual (FEMA/NIBS, 2002), as well as in guideline documents developed for the California Office of Emergency Services intended to help users develop improved databases for use with HAZUS®99 (ABS Consulting & ImageCat Inc., 2004).

Table 4-1 HAZUS®99 Occupancy Classes

HAZUS®99 General Occupancy Class	HAZUS®99 Specific Occupancy Class	Description
RESIDENTIAL	RES1	Single Family Dwelling
	RES2	Mobile Home
	RES3*	Multi-Family Dwellings (Apartments/Condos)
	RES4	Temporary Lodging (Hotel/Motel)
	RES5	Institutional Dormitories (Group Housing/Jails)
	RES6	Nursing Homes
COMMERCIAL	COM1	Retail Trade (Stores)
	COM2	Wholesale Trade (Warehouses)
	COM3	Personal/Repair Services (Service Station/Shop)
	COM4	Professional/Technical Services (Offices)
	COM5	Banks
	COM6	Hospitals
	COM7	Medical Offices/Clinics
	COM8	Entertainment & Recreation (Restaurants/Bars)
	COM9	Theaters
	COM10	Parking (Garages)
INDUSTRIAL	IND1	Heavy Industrial
	IND2	Light Industrial
	IND3	Food/Drugs/Chemicals
	IND4	Metals/Mineral Processing
	IND5	High Technology
	IND6	Construction (Offices)
AGRICULTURE	AGR1	Agriculture
RELIGION	REL1	Church/Non-Profit
GOVERNMENT	GOV1	Government General Services (Office)
	GOV2	Government Emergency Response (Police/Fire/EOC)
EDUCATION	EDU1	Grade Schools
	EDU2	Colleges/Universities

* Note – subsequent versions of HAZUS® (HAZUS®MH) include 6 subcategories of RES3, as follows:

- RES3A: duplex
- RES3B: 3-4 units
- RES3C: 5 – 9 units
- RES3D: 10 – 19 units
- RES3E: 20 – 49 units
- RES3F: 50+ units

Table 4-2 HAZUS®99 Model Building Types

HAZUS®99 Model Building Type	Description
W1	Wood, light frame (≤ 5,000 square feet)
W2	Wood, commercial and industrial (>5,000 square feet)
S1L, S1M, S1H	Steel moment frame (low-, mid- and high-rise)
S2L, S2M, S2H	Steel braced frame (low-, mid- and high-rise)
S3	Steel light frame
S4L, S4M, S4H	Steel frame with cast-in-place concrete shear walls (low-, mid- and high-rise)
S5L, S5M, S5H	Steel frame with unreinforced masonry infill walls (low-, mid- and high-rise)
C1L, C1M, C1H	Concrete moment frame (low-, mid- and high-rise)
C2L, C2M, C2H	Concrete shear walls (low-, mid- and high-rise)
C3L, C3M, C3H	Concrete frame with unreinforced masonry infill walls (low-, mid- and high-rise)
PC1	Pre-cast concrete tilt-up walls
PC2L, PC2M, PC2H	Pre-cast concrete frames with concrete shear walls (low-, mid- and high-rise)
RM1L, RM1M	Reinforced masonry bearing walls with wood or metal deck diaphragms (low- and mid-rise)
RM2L, RM2M, RM2H	Reinforced masonry bearing walls with pre-cast concrete diaphragms (low-, mid- and high-rise)
URML, URMM	Unreinforced masonry bearing walls (low- and mid-rise)
MH	Mobile homes

4.1.2 City Tax Assessor's Data Used by CAPSS

The primary database used to construct replacement building inventory tables for use in HAZUS®99 was provided by the San Francisco Planning Department in late 2001. The database contained the Planning Department's updated version of the Tax Assessor's database. Data fields are listed and described in Table 4-3.

The database included 160,339 parcel records, with a total of 524,804,945 building square feet. The data fields most relevant for developing replacement HAZUS®99 inventory databases to be constructed at the city block level (instead of at the census tract level) include: ASSRUSE (Assessor's Use Code), BLDG_SQFT, and BLOCK_NUM. Table 4-4 provides a summary of the total square footage and number of parcels assigned to each Tax Assessor's Use Code. As shown, the occupancies with the greatest square footage are apartments, single-family homes, offices and flats/duplexes. Together, these occupancies account for about 75% of the exposure.

Data fields relevant for the construction of customized mapping scheme relationships include CONSTRTYPE, YR_BUILT, and STORIES. Table 4-5 provides a breakdown of Planning Department data by Construction Type, and highlights the fact that most construction (in terms of building square footage and number of parcels) is wood-frame construction. A summary of construction by age categories

Table 4-3 Data Field Description for Planning Department Database

Field Name	Field Description
MAPBLKLOT	Parcel Identifier (combination of Block Number + Lot Number)
LANDUSE	Land use code
LOT_NUM	Lot Number
BLOCK_NUM	Block Number
RESTYPE	Type of Residence (for residential parcels only)
RESUNITS	Number of residential housing units
TRACT	Census tract number (150 represented)
PLANDIST	Planning District (15 represented)
EMPLOYEES	Number of employees
LOT_AREA	Parcel lot area in square feet
STORIES	Number of stories
BLDG_SQFT	Building area in square feet
YR_BUILT	Year of construction
ASSRUSE	Assessor's Use Code
CONSTRTYPE	Construction Type

Table 4-4 Summary of Building Square Footage and Parcel Count by Assessor's Use Code from the 2001 Planning Department Building Database

Assessor's Use Code (ASSRUSE)	Bldg Sq. Ft.	% of Total Sq. Ft.	Total # Parcels
<no use code>			9,165
APARTMENT HOUSE	98,562,607	18.8%	12,545
APARTMENT HOUSE AND COMMERCIAL STORE	3,759,126	0.7%	244
BANKS	1,183,851	0.2%	117
CHURCHES, CONVENTS, RECTORIES OR WELFARE	3,142,185	0.6%	525
CLUBS, LODGES, FRATERNAL ORGANIZATIONS	2,466,316	0.5%	116
COMMERCIAL GARAGE	4,252,135	0.8%	264
COMMERCIAL STORE	26,443,970	5.0%	2,890
COMMERCIAL STORES/CONDOMINIUM	412,852	0.1%	152
CONDOMINIUM	11,578,221	2.2%	8,831
CONVALESCENT HOMES, NURSING HOMES	1,247,658	0.2%	63
CO-OP UNITS	2,754,103	0.5%	63

Table 4-4 Summary of Building Square Footage and Parcel Count by Assessor's Use Code from the 2001 Planning Department Building Database (continued)

Assessor's Use Code (ASSRUSE)	Bldg Sq. Ft.	% of Total Sq. Ft.	Total # Parcels
DWELLING (ONE UNIT)	158,228,546	30.1%	95,159
DWELLING UNIT PLUS APARTMENTS	680,224	0.1%	305
DWELLING UNITS PLUS FLATS - ONE PARCEL	42,927	0.0%	15
FIRST CLASS HOTEL	14,897,426	2.8%	54
FLAT PLUS APARTMENT ON ONE PARCEL	121,376	0.0%	34
FLAT PLUS STORE	10,213,161	1.9%	2,713
FLATS AND DUPLEX	62,656,207	11.9%	21,322
GAS STATIONS	208,292	0.0%	169
GOLF COURSE	93,429	0.0%	2
HOSPITALS	1,793,926	0.3%	28
HOTEL	9,928,669	1.9%	570
HOTEL PLUS COMMERCIAL UNITS (H2 WITH COMMERCIAL)	449,345	0.1%	26
INDUSTRIAL	22,296,534	4.2%	2,245
INDUSTRIAL WAREHOUSE	1,580,278	0.3%	95
LIVE-IN STUDIOS	1,124,452	0.2%	579
MISCELLANEOUS (OTHER THAN LISTED)	1,178,471	0.2%	348
MOTELS	1,450,440	0.3%	77
OFFICE - CONDOMINIUM	1,048,250	0.2%	31
OFFICE AND COMMERCIAL	618,923	0.1%	10
OFFICE BUILDINGS	76,546,634	14.6%	1,185
PARKING LOT	3,603	0.0%	5
PARKING STALL CONDOMINIUM	68,200	0.0%	2
PUBLIC PROPERTY AND BUILDINGS	85,298	0.0%	50
SCHOOLS	2,331,858	0.4%	146
SHOPPING CENTER	287,480	0.1%	3
SINGLE STRUCTURE OVER MULTIPLE LOTS (D AND F ONLY)	12,256	0.0%	4
THEATRES	683,975	0.1%	47
TIME SHARE	41,261	0.0%	3
TWO DWELLING UNITS ON ONE PARCEL	135,090	0.0%	53
VACANT OR OPEN SPACE	195,390	0.0%	84
TOTAL	**524,804,945**	**100%**	**160,339**

(categorized to reflect known vulnerabilities) is given in Table 4-6. In San Francisco, a significant amount of construction occurred before 1934. The average year of construction weighted by building area, for the entire city is 1937. Finally, Table 4-7 categorizes the inventory data by height category, defined for consistency with HAZUS®99's height classes: low rise is 1-3 stories, mid-rise is 4-7 stories, and high-rise is 8 or more stories. As shown in Table 4-7, most construction in the City is low-rise.

In addition to the building inventory data, a significant amount of Geographical Information System (GIS) map data (in ESRI ArcView Shape File format) were also

Table 4-5 Summary of Building Square Footage and Parcel Count by Construction Type from the 2001 Planning Department Building Database

CONSTRTYPE	Bldg Sq. Ft.	% of Total Sq. Ft.	Total # Parcels
<null>			9,165
BRICK	26,170,248	5.0%	924
CONCRETE	68,977,571	13.1%	4,904
FRAME	340,686,051	64.9%	143,381
REINF CONCRETE	1,424,379	0.3%	218
STEEL	7,370,380	1.4%	584
STEEL FRAME	80,176,316	15.3%	1,163
TOTAL	**524,804,945**	**100%**	**160,339**

Table 4-6 Summary of Building Square Footage and Parcel Count by Age Category from the 2001 Planning Department Building Database

Age Category	Total Bldg Sq. Ft.	% of Total Sq. Ft.	Weighted Average Year Built	Total # Parcels
Pre-1934	285,139,035	54%	1915	85,755
1934-1939	18,229,285	3%	1937	9,279
1940-1949	38,342,482	7%	1944	22,715
1950-1959	40,271,300	8%	1955	12,908
1960-1972	53,653,192	10%	1966	8,205
1973-1976	17,559,323	3%	1974	1,844
1977-1997	66,409,502	13%	1985	9,867
1998-2002	1,758,042	0%	1999	420
invalid	3,114,047	1%		20
Null	328,737	0%		9,326
TOTAL	**524,804,945**	**100%**	1937	**160,339**

Table 4-7 Summary of Building Square Footage and Parcel Count by Height Category from the 2001 Planning Department Building Database

Height Class	Total Bldg Sq. Ft.	% of Total Sq Ft	Total # Parcels
Low-Rise	369,702,097	70%	143,621
Mid-Rise	65,017,762	12%	2,565
High-Rise	82,613,588	16%	628
Null	7,468,909	1%	13,523
Invalid	2,589	0%	2
TOTAL	**524,804,945**	**100%**	**160,339**

received from the San Francisco Department of Public Works. Included in the base map data were map layers of City Block Boundaries, which were used to build a replacement base map layer for use in HAZUS®99.

4.1.3 City Block Level Analysis

For the CAPSS project, the default HAZUS®99 census tract representation for all data layers and inventory tables was replaced with data aggregated to the city block level. The 152 census tracts used by HAZUS®99 were replaced with 5,323 city blocks. To accomplish this replacement, several substitute GIS map layers were required, as follows:

- ArcView Shape files for the layer "SRCT" – replacement "census tract" boundaries, actually reflecting city block boundaries. The character field normally storing census tract numbers was populated with City Block numbers, concatenated with the Federal Information Processing Standard (FIPS) code for San Francisco County ("06075"). For example, city block "0001" became pseudo-tract "060750001".
- ArcView Shape files for the layer "SRBNDRY" – a replacement study region boundary file, matching the boundary represented by the map of city blocks.
- ArcView Shape files for the layer "TMPSRCT" – a duplicate SRCT layer used by HAZUS®99 for thematic mapping.

Map layers provided by the Department of Public Works also included neighborhood boundary maps, which were used to aggregate and report summary loss statistics. To facilitate this neighborhood level reporting, a city block to neighborhood relationship table was built using GIS.

4.1.4 Assigning Tax Assessor's Data to HAZUS® Occupancy Classes

The central inventory database within HAZUS®99 is the building square footage table, organized by HAZUS®99 specific occupancy class (see Table 4-4, for example) and census tract. To develop the replacement city block-level aggregate square footage table (SOSQFT.DBF), the Assessor's Use Code in the Planning Department database was mapped to the various HAZUS®99 specific occupancy classes, as shown in Table 4-8.

The CAPSS project team developed one custom occupancy class referred to as "duplex". This custom occupancy class represents two-unit residential buildings.

RES3, for CAPSS, represents residential buildings with three or more units. The occupancy class RES2 (mobile homes) was not used.

Table 4-8 Mapping of San Francisco Assessor's Use Codes into HAZUS®99 Occupancy Classes

Assessor's Use Code (ASSRUSE)	HAZUS®99 Specific Occupancy
APARTMENT HOUSE	RES3
APARTMENT HOUSE AND COMMERCIAL STORE	RES3
BANKS	COM5
CHURCHES, CONVENTS, RECTORIES OR WELFARE	REL1
CLUBS, LODGES, FRATERNAL ORGANIZATIONS	COM8
COMMERCIAL GARAGE	COM10
COMMERCIAL STORE	COM1
COMMERCIAL STORES/CONDOMINIUM	COM1
CONDOMINIUM	RES3
CONVALESCENT HOMES, NURSING HOMES	RES6
CO-OP UNITS	RES3
DWELLING (ONE UNIT)	RES1
DWELLING UNIT PLUS APARTMENTS	RES3
DWELLING UNITS PLUS FLATS - ONE PARCEL	RES3
FIRST CLASS HOTEL	RES4
FLAT PLUS APARTMENT ON ONE PARCEL	RES3
FLAT PLUS STORE	RES3
FLATS AND DUPLEX	duplex
GAS STATIONS	COM3
GOLF COURSE	COM8
HOSPITALS	COM6
HOTEL	RES4
HOTEL PLUS COMMERCIAL UNITS (H2 WITH COMMERCIAL)	RES4
INDUSTRIAL	(IND1-6)
INDUSTRIAL WAREHOUSE	IND2
LIVE-IN STUDIOS	RES3
MISCELLANEOUS (OTHER THAN LISTED)	<omitted>
MOTELS	RES4
OFFICE - CONDOMINIUM	COM4
OFFICE AND COMMERCIAL	COM4
OFFICE BUILDINGS	COM4
PARKING LOT	COM10

Table 4-8 Mapping of San Francisco Assessor's Use Codes into HAZUS®99 Occupancy Classes (continued)

Assessor's Use Code (ASSRUSE)	HAZUS®99 Specific Occupancy
PARKING STALL CONDOMINIUM	COM10
PUBLIC PROPERTY AND BUILDINGS	GOV1
SCHOOLS	EDU1
SHOPPING CENTER	COM1
SINGLE STRUCTURE OVER MULTIPLE LOTS (D AND F ONLY)	<omitted>
THEATRES	COM9
TIME SHARE	RES3
TWO DWELLING UNITS ON ONE PARCEL	RES3
VACANT OR OPEN SPACE	<omitted>

Mixed-use occupancy classes (e.g., "Apartment House and Commercial Store", "Hotel plus Commercial Units") were classified according to the predominant use. In other words, if most of the building square footage was expected to be dedicated to apartments, the building was classified as an apartment building.

One complication in the occupancy mapping process occurred because of the generic "Industrial" use code in the Tax Assessor's database. Because HAZUS®99 uses six different industrial occupancy classes (see Table 4-1), assumptions were required to distribute the actual building square footage classified by the Assessor as "Industrial" across the six HAZUS®99 industrial classes. A review of the HAZUS®99 default industrial square footage data for San Francisco provided the distribution shown in Table 4-9. While the actual square footage data from the Assessor is expected to be more accurate than the HAZUS®99 default data, the relative distribution among the various industrial sub-classes in the default data (which is based on employment and

Table 4-9 Industrial Square Footage Distribution from the HAZUS®99 Default Inventory Database for San Francisco

HAZUS®99 Specific Occupancy Class		Percent of Total Industrial Square Footage in the HAZUS®99 Default Data
IND1	Heavy Industrial	12%
IND2	Light Industrial	44%
IND3	Food/Drugs/ Chemicals	13%
IND4	Metals/Mineral Processing	2%
IND5	High Technology	1%
IND6	Construction (Offices)	28%
Total		100%

other data) is assumed to provide a reasonable representation of the relative contribution of each sub-class. Accordingly, to develop the detailed square footage occupancy table from Assessor's data, the relative percentages for each industrial sub-class (e.g., IND1, IND2) from the HAZUS®99 default were applied to the total actual "industrial" square footage from the Assessor's data to estimate the distribution among the various HAZUS®99 industrial occupancy classes.

When the occupancy mapping assignments were completed, building square footage and building counts were aggregated by HAZUS®99 specific occupancy class and city block. A summary of the resulting square footage data by HAZUS®99 specific occupancy class is given in Table 4-10. As shown, a few occupancies have no exposure. In some cases, this reflects the realities of building use in San Francisco; little or no agricultural use is expected within the City. In other cases, this reflects the following limitations of Assessor's data:

- In general, only taxable structures are well represented in Assessor's data, resulting in the underestimation of exposure for government-owned buildings, such as government offices (GOV1 & GOV2) and schools (EDU1 & EDU2). The CAPSS project focuses only on privately-owned buildings. However, a small number of government-owned buildings appear in the Assessor's data. This square footage represents a small fraction of all government-owned properties in the City. Therefore, while a small number of government buildings are included in the analysis, the CAPSS analysis cannot be used for any meaningful analysis of impacts to government facilities.
- Some Assessor's use codes may not include sufficient detail to populate selected occupancies. For example, Medical office/clinics (COM7) do not appear as their own use code within the Assessor's data, but are likely included within the data for either Hospitals (COM6) or Offices (COM4). Similarly, no use code for Wholesale (COM2) appears in the Assessor's use codes. These buildings are likely included with Retail (COM1) in the occupancy class for "commercial stores".
- While there may be few mobile homes in San Francisco, mobile homes are generally underrepresented in any California Assessor's database; prior to 1980, mobile homes were subject to vehicle license fees collected by the DMV, rather than local property taxes collected by the Assessor.
- Replacement of the HAZUS®99 default building inventory databases using detailed, locally-available building data required the development of a variety of inventory tables, listed in Table 4-11. Some represented a complete replacement of default proxy data at the census tract level with local data characterized according to HAZUS®99's specific occupancy categories and aggregated to the city block level. Others did not require the incorporation of local data, but required updating for error-free operation because of the change in base map (e.g., from census tract to city block). A complete list of HAZUS®99 files that were replaced for the CAPSS project is provided in Appendix A.

Table 4-10 Resulting Square Footage Distribution by HAZUS®99 Occupancy Class for San Francisco

HAZUS®99 Specific Occupancy Class	Total Sq. Ft.	% of Total Sq. Ft.
RES1	146,011,000	28.6%
duplex	62,474,100	12.2%
RES2	0	0.0%
RES3	129,195,200	25.3%
RES4	26,725,800	5.2%
RES5	0	0.0%
RES6	1,247,600	0.2%
COM1	27,145,300	5.3%
COM2	0	0.0%
COM3	208,300	0.0%
COM4	78,214,400	15.3%
COM5	1,184,000	0.2%
COM6	1,793,900	0.4%
COM7	0	0.0%
COM8	2,559,800	0.5%
COM9	683,800	0.1%
COM10	4,324,100	0.8%
IND1	2,676,100	0.5%
IND2	11,391,400	2.2%
IND3	2,899,000	0.6%
IND4	445,200	0.1%
IND5	223,200	0.0%
IND6	6,243,200	1.2%
AGR1	0	0.0%
REL1	3,142,000	0.6%
GOV1	85,200	0.0%
GOV2	0	0.0%
EDU1	2,331,900	0.5%
EDU2	0	0.0%
TOTAL	**511,204,500**	**100%**

Table 4-11 HAZUS®99 Building Inventory Data Files Requiring Replacement

File Name	Description
SOSQFT.DBF	Building Square Footage by Specific Occupancy & “Census Tract”
BLDCNTSO.DBF	Building Count by Specific Occupancy & “Census Tract”
BLDCNTGO.DBF	Building Count by General Occupancy & “Census Tract”
BLDCNTMB.DBF	Building Count by Model Building Type & “Census Tract”
BLDCNTGB.DBF	Building Count by General Building Type & “Census Tract”
FTCTMAP.DBF	Foundation type mapping scheme assignment (needed to facilitate use of city blocks as custom units of analysis)
SOSQFTT.DBF	Square Footage Totals by Specific Occupancy

4.1.5 Overview of Mapping Schemes between Occupancy and Structure Type

Within HAZUS®99, specific occupancy to model building type “mapping schemes” provide the distribution of square footage among the 36 model building types (see Table 4-2) for each use or occupancy. In other words, a mapping scheme relates buildings of a certain use (e.g., multi-family dwellings) to the structural systems used to construct those buildings (e.g., a certain percentage are wood frame of a particular height, seismic design level, and building quality). The mapping scheme distributions determine which vulnerability functions will be used to estimate damage and loss for each specific occupancy class.

HAZUS®99 includes nine different versions of each model building type (see Table 4-12), differentiated by combinations of seismic design level (low-, moderate- and high-seismic design) and building quality/seismic performance level (code/typical, inferior/poor, and superior), resulting in a total of 324 model building type variants. In the default mapping scheme data for California, several of the combinations are not used (printed in italics in the table), including “High-Inferior”, “Moderate-Inferior”, and “Moderate-Superior”. Further, the application of “High-Superior” is limited to three special occupancy classes; prisons (RES6), hospitals (COM6), and government facilities used for emergency response (GOV2).

Table 4-12 Seismic Design Levels and Building Quality or Seismic Performance Levels used in HAZUS®99 Mapping Schemes

Seismic Design Level	Building Quality or Seismic Performance Level		
	Code/Typical	Inferior/Poor	Superior
High Seismic Design	High-Code	*High-Inferior*	High-Superior
Moderate Seismic Design	Moderate-Code	*Moderate-Inferior*	*Moderate-Superior*
Low Seismic Design	Low-Code	Low-Inferior	Low-Superior

4.1.6 Use of One Mapping Scheme Citywide

Mapping schemes are associated with individual census tracts. The mapping scheme assignment is stored in the database file “SOCTMAP.DBF” listing each census tract and its assigned mapping scheme. A HAZUS®99 study region can make use of more than one mapping scheme at a time, and any available mapping scheme can be assigned to any individual or group of census tracts from within the HAZUS®99 graphical user interface.

For the CAPSS project, one set of mapping scheme tables was developed to represent the City of San Francisco as a whole. The CAPSS custom mapping scheme was developed from available data on building age, construction material and occupancy, historical building patterns, and engineering judgment.

While the ideal representation of a building inventory might appear to be mapping schemes for each census tract or for sections of a study area, the development of multiple mapping schemes can take a significant amount of time, and generally requires both structural engineering expertise and database management skills. As part of the second FEMA-sponsored HAZUS® pilot test, EQE International developed HAZUS® building inventory files for the City of Boston from Assessor's data, which included a total of 460 million square feet of exposure on just over 100,000 parcels. In a test of one city-wide mapping scheme versus 22 mapping schemes for sub-regions of the City, EQE found only a 5% change in building-related losses (EQE, 1996).

4.1.7 Overview of CAPSS Custom Mapping Scheme

As the starting point for mapping scheme development, citywide data summaries were generated, aggregating the square footage data and parcel counts by detailed Assessor's occupancy class, HAZUS®99 specific occupancy class, and construction type. Additional profiles were developed, including similar summaries further broken down to include building height (low-, mid- and high-rise), or the decade in which it was built. This information was reviewed by an experienced structural engineer, who recommended distributions across the HAZUS®99 model building types, by occupancy, considering construction type and building height. Year of construction was used to assign Design Level categories; structures built before 1950 were generally assumed to be "Low" seismic design, those built between 1950 and 1972 were assumed to be of "Moderate" seismic design, and those built in 1973 or later were assumed to be of "High" seismic design. These categorizations were applied to the data, and were used to build the distributions required to generate the HAZUS®99 mapping scheme.

The mapping scheme development process, and the challenges associated with its implementation, may best be explained with an example. For this example, we examine data associated with the occupancy class "Gas Stations", categorized as COM3 within HAZUS®99. Table 4-13 summarizes the relevant available data on construction type, age, and height. As expected, all such facilities are of low-rise construction. After review, and in consideration of known construction practices for gas stations, the participating structural engineer recommended the following basic model building type assignments:

- "Brick" buildings will be URM when built prior to 1933, RM1 when built after.
- "Steel" buildings will be a mix of S3 (75%), and S4 (25%), except for the oldest group of structures (pre-1933), which may be S5.
- "Concrete" buildings used as gas stations are most often C2.
- "Wood" buildings will be classified as W2.

The resulting model building type distributions, including design level and quality, are noted in the final column of the table. HAZUS®99 requires integer percent values in the mapping scheme tables, resulting in potential round-off error, omission of model building types representing <1% of exposure, and requiring manual review to ensure totals sum to 100%.

Table 4-13 Extracted Data for Gas Stations and Resulting Mapping Scheme Assignments

General Construction Type	Decade or Year Built	Height Class	Total SF	% of Occupancy Exposure	Mapping Scheme Assignment (MBT/Design/Quality)
Brick	Pre 1933	Low-Rise	1,375	0.7%	1% URML/Low/Typical
Wood	Pre 1933	Low-Rise	4,421	2.2%	2% W2/Low/Typical
Concrete	1940-1949	Low-Rise	12,926	6.4%	6% C2L/Low/Typical
Steel	Pre1933	Low-Rise	574	13.5%	10% S3L/Low/Typical 3% S4L/Low/Typical
Steel	1940-1949	Low-Rise	26,600		
Steel	1950-1959	Low-Rise	3,699	37.8%	28% S3L/Moderate/Typical
Steel	1960-1972	Low-Rise	72,548		9% S4L/Low/Typical
Wood	1950-1959	Low-Rise	7,150	4.2%	4% W2/Moderate/Typical
Wood	1960-1972	Low-Rise	1,362		
Brick	1960-1972	Low-Rise	1,542	0.8%	1% RM1L/Moderate/Typical.
Concrete	1960-1972	Low-Rise	1,369	0.7%	1% C2L/Moderate/Typical
Steel	1973-1976	Low-Rise	1,690	25.2%	19% S3L/High/Typical
Steel	1977-1997	Low-Rise	49,175		6% S4L/High/Typical
Wood	1977-1997	Low-Rise	7,332	3.6%	4% W2/High/Typical
Concrete	1998-2002	Low-Rise	10,000	5.0%	5% C2L/High/Typical

The custom mapping scheme data developed for San Francisco were further refined to reflect common retrofit activities, as follows:

1. 10% of soft-story single-family wood-frame structures were assumed to have been retrofitted. Retrofitted structures were modeled as non-soft-story single-family wood-frame structures.
2. 90% of URM structures are assumed to have been retrofitted. Retrofitted URM structures were modeled as reinforced masonry bearing walls with wood or metal deck diaphragms (RM1), at the moderate code level.
3. 10% of steel frame structures with unreinforced masonry infill walls (S5) at the low design level are assumed to have been retrofitted. Retrofitted structures are modeled as the same building type, but at the moderate design level.
4. 20% of concrete shear wall structures (C2) at the low design level are assumed to have been retrofitted. Retrofitted structures are modeled as the same building type, but at the moderate design level.

5. 10% of concrete-frame structures with unreinforced masonry infill walls (C3) at the low design level are assumed to have been retrofitted. Retrofitted structures are modeled as the same building type, but at the moderate design level.
6. 10% of precast concrete tilt-up wall structures (PC1) at the moderate design level are assumed to have been retrofitted. Retrofitted structures are modeled as the same building type, but at the high design level.

4.1.8 Custom Mapping Scheme for Older Concrete Buildings

Non-ductile concrete buildings, referred to as "Concrete built before 1980" in the main report ATC (2010), were assumed to include all concrete-frame buildings with unreinforced masonry infill walls (HAZUS®99 model building type C3), and moderate and low seismic design level concrete shear wall structures (C2)[1]. HAZUS®99 results by model building type are aggregated over the three design levels. To ensure accessibility to the non-ductile concrete results, the data for the moderate and low design level C2 structures were stored separately from the high design level C2 structures, in the "bin" for precast concrete frames with concrete shear walls (PC2). For more discussion of non-standard storage techniques used to facilitate the CAPSS custom analysis, see Section 4.3.

Table 4-14 provides a summary of the final CAPSS mapping scheme data for structures assumed to be non-ductile concrete, developed as described above, from available data on building age, basic construction material and occupancy, historical building patterns, and engineering judgment. The table provides the final mapping scheme data (inclusive of modifications for mitigation) broken down by design level, model building type and height, and building quality (e.g., C3L Code is C3 low-rise, code/typical quality). For the purposes of the CAPSS study, most structures were assumed to have been constructed according to the code in place at the time of construction; the quality level was assumed to be "Code" or "Typical". Because it has been assumed that modern (i.e., high design level) concrete shear-wall buildings are unlikely to be non-ductile, and because concrete-frame with URM infill construction is not allowed under modern California building codes, zero value mapping scheme data for the high design level has been omitted from the table. The final column provides the aggregate non-ductile concrete mapping scheme percentage for each specific occupancy class.

As shown, a significant portion of industrial construction (40-45%), and that of a few other occupancies, is assumed to be non-ductile concrete. However, these occupancies represent a small percent of the overall building inventory in the City. Table 4-15 provides an estimate of the total square footage of assumed non-ductile concrete construction, determined by multiplying the mapping scheme percentages for each specific occupancy class by the estimated building square feet (stored in HAZUS®99 in units of 1,000 square feet). In total, there is an estimated 51 million square feet of potentially non-ductile concrete construction, representing 10% of the building inventory overall. Most of the assumed non-ductile concrete construction (71%) is concentrated in four occupancies: RES3/Apartments (20% of estimated non-ductile concrete building square footage), COM1/Retail (20%), COM4/Offices

[1] While alternative definitions might also consider some concrete moment frame buildings (C1) as potentially non-ductile, these were not included in the non-ductile category utilized in the CAPSS project. There are assumed to be few of these structures built before 1980.

(17%), and RES4/Hotels (14%). Together, the six industrial occupancies account for another 20% of the assumed non-ductile concrete building square footage.

Table 4-14 Summary of CAPSS Final Mapping Scheme Data for Assumed Non-Ductile Structures

	Low Design Level (% of occupancy)			Moderate Design Level (% of occupancy)			Low Design Level (% of occupancy)			Moderate Design Level (% of occupancy)			Total
OCC	C3L Code	C3M Code	C3H Code	C3L Code	C3M Code	C3H Code	PC2L Code	PC2M Code	PC2H Code	PC2L Code	PC2M Code	PC2H Code	% occ NDC
RES1	0	0	0	0	0	0	0	0	0	0	0	0	0
duplex	0	0	0	0	0	0	0	0	0	0	0	0	0
RES3	1	6	0	0	1	0	0	0	0	0	0	0	8
RES4	4	17	1	0	2	0	0	0	0	0	1	2	27
RES5	0	0	0	0	0	0	0	0	0	0	0	0	0
RES6	1	16	0	0	2	0	2	0	0	8	14	0	43
COM1	19	7	0	2	1	0	1	0	0	6	1	0	37
COM2	0	0	0	0	0	0	0	0	0	0	0	0	0
COM3	0	0	0	0	0	0	6	0	0	2	0	0	8
COM4	4	4	1	0	0	0	0	0	0	1	0	1	11
COM5	6	0	0	1	0	0	0	0	0	7	0	0	14
COM6	0	0	0	0	0	0	0	0	0	0	5	0	5
COM7	0	0	0	0	0	0	0	0	0	0	0	0	0
COM8	3	15	0	0	2	0	0	0	0	5	0	0	25
COM9	6	0	0	1	0	0	0	0	0	0	0	0	7
COM10	32	0	0	4	0	0	2	0	0	1	2	0	41
IND1	21	4	0	2	0	0	5	0	0	13	0	0	45
IND2	18	4	0	2	0	0	4	0	0	12	0	0	40
IND3	21	4	0	2	0	0	5	0	0	13	0	0	45
IND4	21	4	0	2	0	0	5	0	0	13	0	0	45
IND5	21	4	0	2	0	0	5	0	0	13	0	0	45
IND6	21	4	0	2	0	0	5	0	0	13	0	0	45
AGR1	0	0	0	0	0	0	0	0	0	0	0	0	0
REL1	14	1	0	2	0	0	1	0	0	8	1	0	27
GOV1	0	0	0	0	0	0	0	0	0	0	0	0	0
GOV2	0	0	0	0	0	0	0	0	0	0	0	0	0
EDU1	8	10	0	1	1	0	0	0	0	8	0	0	28
EDU2	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-15 Estimated Square Footage for Assumed Non-Ductile Concrete Structures

HAZUS®99 Specific Occupancy	Percent of Occ. Mapped as NDC (see Table 4-14)	Total Square Footage for Occ. (1,000 sq ft)	Estimated NDC Square Footage (1,000 sq ft)
RES1	0	146,011	0
duplex	0	62,474	0
RES3	8	129,195	10,336
RES4	27	26,726	7,216
RES5	0	0	0
RES6	43	1,248	536
COM1	37	27,145	10,044
COM2	0	0	0
COM3	8	208	17
COM4	11	78,214	8,604
COM5	14	1,184	166
COM6	5	1,794	90
COM7	0	0	0
COM8	25	2,560	640
COM9	7	684	48
COM10	41	4,324	1,773
IND1	45	2,676	1,204
IND2	40	11,391	4,557
IND3	45	2,899	1,305
IND4	45	445	200
IND5	45	223	100
IND6	45	6,243	2,809
AGR1	0	0	0
REL1	27	3,142	848
GOV1	0	85	0
GOV2	0	0	0
EDU1	28	2,332	653
TOTAL		**511,205**	**51,145**

4.1.9 Custom Mapping Scheme for Wood-Frame Residences

The CAPSS project team developed eight custom model building types to represent San Francisco’s residential wood-frame building stock. The eight types are:

- Single-family wood-frame soft-story, pounding on both sides
- Single-family wood-frame soft-story, pounding on one side
- Single-family wood-frame soft-story, freestanding (no pounding)
- Single-family wood-frame, not soft-story
- Two-unit wood-frame soft-story

- Two-unit wood-frame, not soft-story
- Multi-family wood-frame, soft-story
- Multi-family wood-frame, not soft-story

Because HAZUS®99 in its default configuration has only two basic wood-frame structure types, special handling was required to accommodate the eight different wood-frame structure types. See Section 4.3 for more information about non-standard storage methods.

A soft story is a condition in which a particular floor of a building is substantially weaker and more flexible in resisting horizontal forces than the other floors in the building. If this condition exists, that floor will deflect more than other floors in the building when exposed to earthquake shaking, and is more likely to collapse. Such a condition is well known to exist in San Francisco, where many buildings have off-street parking on the ground floor, resulting in a ground floor soft story. Corner stores and commercial buildings also tend to have this condition, due to the lack of interior partitions in the retail commercial space, and the large window openings on the street, especially in corner commercial buildings, which often have two street sides, with large window openings. Pounding refers to the situation in which two adjacent buildings are very close to each other, such that when they deflect laterally under strong ground shaking, they will collide with or 'pound' each other, causing mutual damage. Pounding has been observed as a major source of damage in urban earthquakes.

The aggregate total estimated square footage associated with each sub-class of wood frame residential structure, as modeled in HAZUS®99, is provided in Table 4-16. The estimated square footages are determined by multiplying the mapping scheme percent for each sub-class by the total occupancy square footage for RES1, duplex, or RES3 construction, as appropriate. A total of 54% of single-family home square footage is assumed to be soft-story, with an estimated square footage greater than 78 million square feet. This corresponds to 15% of the total building inventory square footage for the City. Similarly, 54% of duplexes, totaling nearly 34 million square feet, are assumed to be soft-story, representing 7% of the overall inventory. In addition, 58% of multi-family residential structure square footage is also assumed to be soft-story, adding an additional 75 million square feet (15% of overall inventory), and bringing the total soft-story residential square footage estimate to more than 187.5 million square feet (37% of the total building inventory square footage).

4.1.10 Field Sampling

Because such a large fraction of San Francisco's building stock is of wood construction, the CAPSS project team made a special effort to characterize this type of building's seismic vulnerability. A survey was made of each of the 14 San Francisco neighborhoods to determine what fraction of each neighborhood's buildings might have special seismic vulnerabilities, such as soft stories or pounding.

A 'windshield survey' was designed to ascertain what fraction of San Francisco's buildings might have soft stories or pounding vulnerabilities. Based on statistical analysis, it was determined that it would be sufficient to sample about 30 or so buildings in each neighborhood, or about 420 buildings in the city. Since it was desired to know the prevalence of soft stories for both corner buildings (where it was thought the condition would be very frequent) and 'in-block' buildings (i.e., non-corner buildings), about 30 corner buildings and 30 in-block buildings would need to be sampled in each neighborhood, for a total of about 840 buildings in the City. The actual windshield survey was conducted by Structus Inc. engineers; for each neighborhood randomly selected buildings were photographed. Photographs were taken of wood buildings and reinforced concrete buildings. In all, approximately 2,000 photographs were taken, and collected in the volume *CAPSS Photo Survey* (ATC, 2003).

Table 4-16 Estimated Square Footage for Wood-Frame Residential Structures

	Percent of Occupancy (Mapping Scheme Percentage)	Total Occupancy Square Footage (1,000 sq ft) as stored in HAZUS	Estimated Wood Frame Sub-Category Square Footage (1,000 sq ft)
RES1 – Single Family		**146,011**	
Wood-frame soft-story, pounding on both sides	28%		40,883
Wood-frame soft-story, pounding on one side	22%		32,122
Wood-frame soft-story, freestanding (no pounding)	4%		5,840
Wood-frame, not soft-story	46%		67,165
Duplex/Two-Unit		**62,474**	
Wood-frame soft-story	54%		33,736
Wood-frame, not soft-story	46%		28,738
Multi-family Residential Structures*		**129,195**	
Wood-frame soft-story	58%		74,933
Wood-frame, not soft-story	27%		34,883

* 15% of Multi-family residential building square footage is constructed of materials other than wood frame.

For the field sampling, a "gap" was defined as an interbuilding space equivalent to the sum of the expected lateral displacement of neighboring buildings. In practice, this was not calculated but was judged to be any significant space visually observable between neighbor buildings in photographs. Some buildings have gaps to their neighbors but the street fronts are boarded up to make it appear as if there are no gaps. This could not be accounted for in the survey.

Table 4-17 summarizes the results of the survey, by neighborhood.

This survey information was combined with the actual building exposure data from the Planning Department database (in terms of square feet) to develop city-wide percentages for use in the HAZUS®99 mapping scheme. That is, the total square footage of wood-frame single-family and multi-family homes in each neighborhood was multiplied by the survey percentages, and then aggregated city-wide to develop the final mapping scheme percentages provided in Table 4-16.

4.1.11 Building Count

The HAZUS®99 model uses building square footage to conduct its analysis. For the CAPSS study, building square footage by occupancy is taken directly from Assessor's data, and building square footage by structural type is developed using

Table 4-17 Wood-Frame Windshield Survey Results by Neighborhood

Neighborhood	Adjacency	Soft Story	Not Soft Story
Bayview	No gap (adjacent building on both sides)	33%	21%
	Gap on 1 side	26%	9%
	Gap on 2 sides	3%	9%
	Total	62%	38%
Downtown	No gap	69%	0%
	Gap on 1 side	22%	8%
	Gap on 2 sides	0%	0%
	Total	92%	8%
Excelsior	No gap	35%	17%
	Gap on 1 side	11%	17%
	Gap on 2 sides	3%	17%
	Total	49%	51%
Ingleside	No gap	28%	13%
	Gap on 1 side	13%	13%
	Gap on 2 sides	2%	31%
	Total	43%	57%
Marina	No gap	63%	7%
	Gap on 1 side	23%	2%
	Gap on 2 sides	2%	4%
	Total	88%	12%
Merced	No gap	4%	2%
	Gap on 1 side	18%	4%
	Gap on 2 sides	9%	65%
	Total	30%	70%
Mission	No gap	32%	7%
	Gap on 1 side	30%	14%
	Gap on 2 sides	2%	14%
	Total	64%	36%
Mission Bay	No gap	32%	13%
	Gap on 1 side	30%	13%
	Gap on 2 sides	0%	11%
	Total	62%	38%
North Beach	No gap	58%	13%
	Gap on 1 side	16%	11%
	Gap on 2 sides	0%	2%
	Total	75%	25%

Table 4-17 Wood Frame Windshield Survey Results by Neighborhood (continued)

Neighborhood	Adjacency	Soft Story	Not Soft Story
Pacific Heights	No gap	29%	4%
	Gap on 1 side	37%	8%
	Gap on 2 sides	4%	19%
	Total	69%	31%
Richmond	No gap	40%	12%
	Gap on 1 side	40%	6%
	Gap on 2 sides	0%	2%
	Total	80%	20%
Sunset	No gap	33%	8%
	Gap on 1 side	25%	10%
	Gap on 2 sides	2%	22%
	Total	60%	40%
Twin Peaks	No gap	16%	6%
	Gap on 1 side	25%	7%
	Gap on 2 sides	16%	28%
	Total	58%	42%
Western Addition	No gap	19%	5%
	Gap on 1 side	27%	8%
	Gap on 2 sides	13%	27%
	Total	60%	40%

mapping schemes based on available data supplemented with expert judgment, as described in Section 4.1.4. However, since most people do not think in terms of square footage, these figures are translated into an estimated number of buildings to help users interpret the study.

HAZUS®99 has an internal model to generate an estimated count of buildings from aggregate square footage, wherein a single typical building size is assumed for each occupancy class (e.g., single-family homes are assumed to be 1,500 square feet and office buildings are assumed to be 35,000 square feet). The CAPSS study bypassed that internal model and used San Francisco Assessor's parcel information instead. As a first cut estimate, each record in the Assessor's file was assumed to represent a building. This assumption is generally sound for most occupancies, with the exception of condominium buildings. Each condominium unit is listed as a separate record in the Assessor's data, because each is a taxable parcel. This means that this method of estimating the number of buildings produces an overestimate of the number of multi-family dwellings (RES3). The estimated building count by occupancy developed from the Assessor's parcel data appears in Table 4-18.

The San Francisco Planning Department currently uses an estimate of 112,000 single family homes; this estimate is for the end of 2009[2]. This number is in general use by the Planning Department, Department of Building Inspection, and other City departments. The CAPSS project team elected to use this number as its estimate of single-family homes for consistency with other City documents, even though this number varies from the estimated number of single family homes derived from the Assessor's data. It is not clear why these numbers differ; the original source of the number used by the Planning Department appears to be the Census. The CAPSS project team also used the Planning Department's estimate of 19,000 two-unit residences. The Department of Building Inspection maintains a detailed database with information about residential buildings with three or more units. The estimated building count for RES3 buildings is taken from the Department of Building Inspection's database, which should correct for the error introduced by condominium buildings. The adjusted building count as used in the final CAPSS study, also appears in Table 4-18.

Table 4-18 Estimates of Building Count from Assessor's Data and Other City Sources

Building Occupancy	Estimated Number Using Assessor's Data	Adjusted Estimate Using Other City Sources
Single Family Residences (RES1)	95,000	112,000
Two unit Residences (duplex)	21,000	19,000
Three or more unit Residences (RES3)	25,000	23,000
Other Residences (RES 4-6)	800	800
Commercial Buildings (COM 1-10)	5,000	5,000
Industrial Buildings (IND 1 – 6)	2,100	2,100
Other (REL1, GOV1, EDU1)	700	700
Total	**150,000**	**160,000**

4.1.12 Building Valuation

The Tax Assessor's database contains data on building values, but this valuation data is based on values at the time of property ownership transfer with some modest annual increase thereafter[3] and does not typically represent replacement value. Replacement value is a better measure of the real loss an owner would sustain than assessed value, as repairs are effectively priced equivalent to replacement value.

Default replacement costs used in HAZUS®99 are based on industry standard national average models contained in the 1994 edition of "Means Square Foot Costs" (R.S. Means, 1994). For each specific occupancy class, a representative building cost

[2] San Francisco Planning Department, 2010.

[3] Proposition 13 in 1978 amended the California Constitution so that the assessed value (the value of the property as recorded in the tax rolls) may only be increased by a maximum of 2% per year, until and unless the property undergoes a change in ownership. Since replacement values have increased at a more rapid rate (the Consumer Price Index for the period 1979-2002 averaged 4.6% per annum), the net effect is that many properties in the City's database had valuations significantly less than replacement value.

per square foot was taken from Means, and then disaggregated into contributions from the structure (including the foundation and substructure), and nonstructural components subject to drift-related damage and acceleration-related damage.

Within HAZUS®99, structural repair costs (per square foot) are stored in tables, by specific occupancy category and model building type, for each damage state. It is assumed that repairs in the "Complete" damage state will equal 100% of the replacement cost of the structure. In the "Extensive" damage state, repair costs are assumed to be equal to 50% of the replacement cost, while "Moderate" and "Slight" damage are assumed to be 10% and 2% of replacement cost, respectively.

For the CAPSS project, the 1994-vintage HAZUS®99 default building replacement costs were updated to reflect costs of building construction in San Francisco in 2009. A number of architects, construction professionals, and developers were surveyed on costs to construct various types and sizes of buildings in San Francisco. The findings of this survey were reviewed by the CAPSS Advisory Committee. As an example, the findings of this survey were that it cost approximately $350 per square foot to construct a multi-family apartment building.

The 1994 square foot replacement cost in HAZUS®99 for RES3 is $98.00 per square foot, after application of the location factor used to scale national average costs to costs appropriate to San Francisco construction. This was updated to $350 per square foot by adjusting the regional cost modifier or "location factor". A location factor of 450% was used. Table 4-19 shows the replacement cost per square foot used for each occupancy class, after application of this location factor.

Within HAZUS®99, building contents values are determined as a fixed percent of building replacement value, with the percent varying by occupancy, as shown in Table 4-20. For the CAPSS study, it was decided that a smaller "location factor" multiplier should be applied for contents value estimation. Accordingly, a multiplier of 245% was utilized (rather than 450%) to estimate contents value from structure value, using the occupancy-specific content to structure value ratios given in Table 4-20.

Finally, rental costs (the cost to rent temporary space to house businesses located in damaged buildings) and disruption costs (the cost of shifting or transferring a damaged business to a new location) are utilized by HAZUS®99 to estimate total building damage-related relocation costs. Rental costs were updated based on San Francisco-specific economic data. HAZUS®99's default rental and disruption costs, along with the updated San Francisco-specific values utilized in the CAPSS project are given in Table 4-21.

Table 4-19 Square Foot Replacement Costs Used by CAPSS Study

Occupancy Class	2009 Cost per Square Foot
RES1	$360
duplex	$360
RES3	$350
RES4	$470
RES5	$534
RES6	$470
COM1	$322
COM2	$279
COM3	$390
COM4	$446
COM5	$693
COM6	$651
COM7	$585
COM8	$617
COM9	$460
COM10	$157
IND1	$332
IND2	$279
IND3	$538
IND4	$538
IND5	$538
IND6	$279
AGR1	$279
REL1	$513
GOV1	$406
GOV2	$612
EDU1	$418
EDU2	$516

Table 4-20 HAZUS®99 Percent of Structure Value Used to Estimate Contents Value

Occupancy	Percent of Structure Value Used to Estimate Contents Value
RES1	50
Duplex	50
RES3	50
RES4	50
RES5	50
RES6	50
COM1	100
COM2	100
COM3	100
COM4	100
COM5	100
COM6	150
COM7	150
COM8	100
COM9	100
COM10	50
IND1	150
IND2	150
IND3	150
IND4	150
IND5	150
IND6	100
AGR1	100
REL1	100
GOV1	100
GOV2	150
EDU1	100
EDU2	150

Table 4-21 HAZUS®99 Default and CAPSS Custom Rental & Disruption Costs

	Default HAZUS®99 Rental Costs		CAPSS Custom Rental Costs		Default HAZUS®99 Disruption Costs Utilized in CAPSS Study
Occupancy	**$/SF/month**	**$/SF/day**	**$/SF/month**	**$/SF/day**	**$/SF**
RES1	0.5	0.02	2.0	0.066	0.6
Duplex	0.5	0.02	2.0	0.066	0.6
RES3	0.45	0.02	1.8	0.059	0.6
RES4	1.5	0.05	5.0	0.164	0.6
RES5	0.3	0.01	1.2	0.039	0.6
RES6	0.55	0.02	2.2	0.072	0.6
COM1	0.85	0.03	2.0	0.066	0.8
COM2	0.35	0.01	1.4	0.046	0.7
COM3	1	0.03	3.0	0.099	0.7
COM4	1	0.03	3.0	0.099	0.7
COM5	1.25	0.04	5.0	0.164	0.7
COM6	1	0.03	4.0	0.132	1.0
COM7	1	0.03	4.0	0.132	1.0
COM8	1.25	0.04	5.0	0.164	0.0
COM9	1.25	0.04	5.0	0.164	0.0
COM10	0.25	0.01	1.0	0.033	0.0
IND1	0.15	0.01	0.6	0.020	0.0
IND2	0.2	0.01	0.8	0.026	0.7
IND3	0.2	0.01	0.8	0.026	0.7
IND4	0.15	0.01	0.6	0.020	0.7
IND5	0.25	0.01	1.0	0.033	0.7
IND6	0.1	0	0.4	0.013	0.7
AGR1	0.5	0.02	2.0	0.066	0.5
REL1	0.75	0.03	2.0	0.066	0.7
GOV1	1	0.03	2.0	0.066	0.7
GOV2	1	0.03	2.0	0.066	0.7
EDU1	0.75	0.03	2.0	0.066	0.7
EDU2	1	0.03	2.0	0.066	0.7

4.2 Additional Inventory Inputs

4.2.1 Population Data

To facilitate the city block-level analysis of human impacts, such as casualties and displacement, city block-level population data were required. HAZUS®99's demographics tables include selected data taken directly from the 1990 census (e.g., population, households), but also includes derived population estimates by occupancy and time of day (daytime and nighttime residential population, daytime commercial and industrial population, and commuting population) used in the casualty model.

While updated (2000) census data were available at the time the CAPSS inventory was compiled (2001-2003), updated HAZUS®99 population parameters were not. For consistency across parameters, 1990 data were used. Census block level population data and parameters were disaggregated to the city block level using GIS analyses; they were disaggregated proportionally by area.

4.2.2 Utility Systems

In addition to estimating population displacement based on building damage, the HAZUS®99 shelter module utilizes simplified methods to consider damage to water and power systems and associated outage as an additional cause of displacement. Required utility inventory data supporting these models are limited to distribution line length data by census tract (generally proxied as a fixed percentage of total street centerline length within the tract, estimated from Census TIGER line files), and by distribution line sub-class. When the fixed percentage of street centerline length representing the distribution system is 100%, it assumes that there is a pipeline or distribution line running down every street.

Default potable water distribution line files tabulate pipeline lengths by census tract, equivalent to total street center line length (100%), further categorized as ductile pipe (assumed to be 20%) and brittle pipe (80%). Electric power distribution line lengths generally total 150% of street centerline length, and are subdivided into 60% cables on wood poles, 30% cables on metal poles, and 10% buried cables. Other distribution line data used in HAZUS®99 are wastewater distribution pipeline data (60% of street centerline length, categorized as 60% brittle, 40% ductile), natural gas distribution pipeline data (40% of street centerline length, categorized as 10% brittle, 90% ductile), and communication circuit data (40% of street centerline length, categorized as 70% underground, 25% aboveground on wood poles, 5% on metal poles).

For the CAPSS analysis, default distribution line files at the census tract level were replaced with equivalent files constructed at the city block-level, wherein a GIS analysis was required to estimate total street length by city block.

4.3 Non-Standard Storage Methods to Facilitate Custom Analysis

To facilitate extraction of results for custom building types, occupancies and building types with little or no exposure were used to store data for other building types of interest. Some of the many changes and techniques used to accomplish this are the following:

1. For single-family (RES1) wood-frame structures, vulnerability functions for soft-story structures expected to suffer pounding on both sides were stored in the normal manner as W1 (Wood, light frame), vulnerability functions for soft-story structures expected to suffer pounding on one side were stored as S1M-HC (Steel moment frame, mid-rise: high seismic design level, code quality), and vulnerability functions for freestanding soft-story structures were stored as S3 (Steel light frame). Vulnerability functions for non-soft story structures were stored as MH-LC (Mobile Homes: low seismic design level, code quality). The S1M and MH model building types were used for this “off-book” storage because they had negligible or no exposure. The exposure for S3 structures, which was small, was reclassified as braced steel-frame (S2).

2. Exposure data (e.g., square footage) for buildings classified by the Assessor as “Flats and Duplex” were stored under occupancy class RES2 (Mobile Homes).

Two model building types were used to represent the range of expected building types: vulnerability functions for soft-story duplexes/flats were stored as S1M-LC (Steel moment frame, mid-rise: low seismic design level, code quality), while functions for non-soft story duplexes/flats were stored as MH-HC (Mobile Homes: high seismic design level, code quality).

3. For multi-family wood frame structures (RES3, wood only), vulnerability functions for soft-story structures were stored as C1L-HC (Concrete moment frame, low-rise: high seismic design level, code quality), and functions for non-soft-story structures were stored as C1M-HC (Concrete moment frame, mid-rise: high seismic design level, code quality). Both of these model building types were unused in the custom mapping scheme developed for the CAPSS project. Concrete moment frame construction was assumed to be utilized primarily for high-rise structures.
4. Non-ductile concrete-frame structures, referred to as "Concrete built before 1980" in the main report (ATC, 2010), were assumed to include all concrete frame buildings with unreinforced masonry infill walls (C3), and moderate and low seismic design level concrete shear wall structures (C2). To enable access to results for C2 buildings treated as moderate and low seismic design level independent of those at the high design level (HAZUS®99 aggregates results across design levels for each model building type), their vulnerability functions were stored as precast concrete frames with concrete shear walls (PC2), a structure type that was not used in the CAPSS custom mapping scheme.
5. Custom vulnerability functions for retrofitted low- and mid-rise unreinforced masonry buildings (URM) were stored as RM2L-LC (Low-rise reinforced masonry bearing walls building with precast concrete diaphragms: low seismic design level, code quality) and RM2L-MC (Low-rise reinforced masonry bearing walls building with precast concrete diaphragms: moderate seismic design level, code quality), respectively. Again, the structure types used to store the custom CAPSS structure types were not used in the CAPSS custom mapping scheme.

This nonstandard storage method necessitated modifications to a significant number of additional underlying tables storing information tabulated by model building type, including casualty rate tables, replacement cost tables, and debris model parameter tables.

Debris data modifications were limited to updates to accommodate off-book storage—i.e., debris model data for S1M, MH, and S3 were updated to store default W1 debris parameter data (duplexes were assumed to be constructed similarly to single-family homes), and C1L and C1M were updated to store W2 debris parameter data. PC2 debris data were also updated to match C2 default data to accommodate extraction of non-ductile concrete building results.

Casualty model data modifications were also limited to updates to accommodate off-book storage—i.e., casualty model parameters for S1M, MH, and S3 were updated to store default W1 parameter data, and C1L and C1M were revised to reflect W2 parameter data. PC2 casualty data were also updated to match C2 default data to accommodate extraction of non-ductile concrete building results.

4.4 Inventory Data

This section presents, in Tables 4-22 and 4-23, selected inventory data used in the CAPSS analysis.

Table 4-22 Building Square Footage and Valuation by Occupancy Class

Occupancy Class	Building Area in Thousand Square Feet	Building Value ($ Millions)
RES1	146,011	52,564
Duplex	62,474	22,491
RES3	129,195	45,231
RES4	26,726	12,568
RES5	0	-
RES6	1,248	587
COM1	27,145	8,734
COM2	0	-
COM3	208	81
COM4	78,214	34,845
COM5	1,184	820
COM6	1,794	1,167
COM7	0	-
COM8	2,560	1,578
COM9	684	315
COM10	4,324	677
IND1	2,676	889
IND2	11,391	3,173
IND3	2,899	1,560
IND4	445	240
IND5	223	120
IND6	6,243	1,739
AGR1	0	-
REL1	3,142	1,612
GOV1	85	35
GOV2	0	-
EDU1	2,332	974
EDU2	0	-
Total	**511,205**	**191,999**

Table 4-23 Building Square Footage and Valuation by Structural Category

Model Building Type	Building Area in Thousand Square Feet	Building Value ($ Millions)
CAPSS Custom: single-family soft story pounding both sides	40,883	14,718
CAPSS Custom: single-family soft story pounding one side	32,122	11,564
CAPSS Custom: single-family soft story freestanding	5,840	2,103
CAPSS Custom: single-family without soft story	67,165	24,179
CAPSS Custom: Duplex/flat with soft story	33,736	12,145
CAPSS Custom: Duplex without soft story	28,738	10,346
CAPSS Custom: multi-family soft story	74,933	26,234
CAPSS Custom: multi-family not soft story	34,883	12,212
W2 (non RES occupancies)	19,392	7,678
S1L	251	163
S1H	18,499	8,118
S2L	1,361	552
S2M	1,419	571
S2H	26,907	11,784
S4L	3,888	1,447
S4M	5,185	2,033
S4H	10,156	4,776
S5L	1,186	548
S5M	3,150	1,452
S5H	13,907	6,158
C1H (post-1980)	1,836	784
C2L (post-1980)	3,056	1,167
C2L (pre-1980)	7,704	2,731
C2M (post-1980)	2,955	1,288
C2M (pre-1980)	921	383
C2H (post-1980)	2,074	801
C2H (pre-1980)	1,317	600
C3L (pre-1980)	18,830	6,586
C3M (pre-1980)	21,325	8,453
C3H (pre-1980)	1,049	474
PC1	2,616	836
RM1L	2,472	917
RM1M	3,634	1,313
CAPSS Custom: Retrofitted URM	14,020	5,451
RM2M	382	149
RM2H	1,710	622
URML	317	102
URMM	1,384	562
Total	**511,205**	**191,999**

CHAPTER 5: VULNERABILITY

The term "vulnerability" refers to how likely a building, or other element of a city, is likely to be damaged at a specified level of earthquake shaking. This chapter explains the vulnerability parameters used by the CAPSS study to characterize the buildings of San Francisco in HAZUS®.

5.1 HAZUS® Vulnerability Functions

HAZUS® has a library of building seismic vulnerability functions, and a methodology for using these to determine damage states (i.e., none, slight, moderate, extensive, and complete) and cost of damage. These vulnerability functions exist for different building structural categories, and are assigned through the mapping scheme to different occupancy categories derived from City databases. This process is described in the preceding chapter.

For most model building types in the CAPSS analysis, default HAZUS®99 vulnerability functions were used based on the mapping scheme assignments of model building type, height, seismic design level (low-, moderate- and high-seismic design) and building quality/seismic performance level (code/typical, inferior/poor, and superior).

However, the HAZUS®99 library of capacity functions has some limitations. For example, for wood buildings, HAZUS®99 has only two wood building types[4]: a 'house', and a 'commercial' type, which is insufficient to characterize the variation in wood building stock in San Francisco. Also, HAZUS®99 does not explicitly account for soft stories nor for torsional effects.

5.2 CAPSS Custom Vulnerability Functions

As described earlier, CAPSS developed eight custom wood-frame residential model building types. In addition, CAPSS defined two custom structural categories for retrofitted unreinforced masonry (URM) buildings: retrofitted low-rise URM buildings, and retrofitted mid-rise URM buildings. Custom vulnerability parameters, described below, were developed for these custom model building types.

HAZUS®99 vulnerability functions include the following parameters that were developed for the CAPSS custom building types:

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[4] In fact, HAZUS®99 permits variations on these two basic model building types for three seismic design levels, and three quality conditions, so that it can be claimed that there are 18 wood-frame building types in HAZUS®99. However, none of these variations represent the structural characteristics of houses or larger residences with garages or open commercial space at the ground level that are so common in San Francisco.

- *Capacity curves*: A capacity curve, also called a pushover curve, relates a building's lateral load resistance to its lateral displacement. It provides an estimate of a building's deflection for any given earthquake response spectrum.
- *Damping*: Damping accounts for the reduction of vibrations in the building.
- *Structural and nonstructural fragility curves*: Fragility functions provide the probability of a structure with a certain spectral displacement of being in or exceeding each of HAZUS®' damage states (i.e., none, slight, moderate, extensive, or complete).
- *Kappa factors*: This factor represents the deterioration of the lateral-force-resisting system with repeated cycles of lateral displacement.

Other parameters used by HAZUS®99 for each building type were not adjusted.

The following sections describe how each of these parameters was treated for the eight custom wood-frame building types and two custom retrofitted URM building types. In general, the custom wood-frame structures without soft stories were assigned default HAZUS®99 vulnerability parameters for wood-frame buildings (either W1 or W2, depending on building size) because these were deemed reasonable assumptions for these structures.   Duplex, or two-unit wood-frame structures, were assumed to perform largely the same as single-family wood-frame structures and were assigned the same vulnerability parameters. Duplexes were placed in their own category primarily so results could be reported separately, since different policy approaches may apply to these building types. Custom retrofitted URM structures were generally assigned HAZUS®99 default parameters for RM1 moderate/code buildings, based on recommendations from NIBS (2002) and engineering judgment.

5.2.1 Custom Capacity Curves

Custom capacity curves were developed for typical San Francisco single-family wood-frame soft-story structures and multi-family wood-frame soft-story structures.

The single-family soft-story capacity curve was first derived from calculations using typical dimensions and material properties appropriate to the City of San Francisco, considering their age, materials of construction, and typical configurations based on review of typical building plans obtained from San Francisco Department of Building Inspection. Figures 5-1 and 5-2 show typical building plans for these structures. Dimensions and weights appear in Table 5-1. From these typical structures, displacement and acceleration at yield points and ultimate capacity were calculated. This yield point data are essentially what was used in the final set of parameters, while the ultimate capacity parameters were modified based on judgment. The revised parameters are similar to the ultimate capacity parameters used in other instances in the HAZUS®99 program, and with expectations of engineers familiar with these building types. If significantly different parameters were used, recalibration of the HAZUS®99 program might be required. The single-family soft-story capacity curve was also used for duplexes, due to the similarity of their bracing systems. At one time, consideration had been given to differentiating in-block buildings that would have pounding on none, one, or two sides; however, it was decided it would be more appropriate to address pounding through variation in damping.

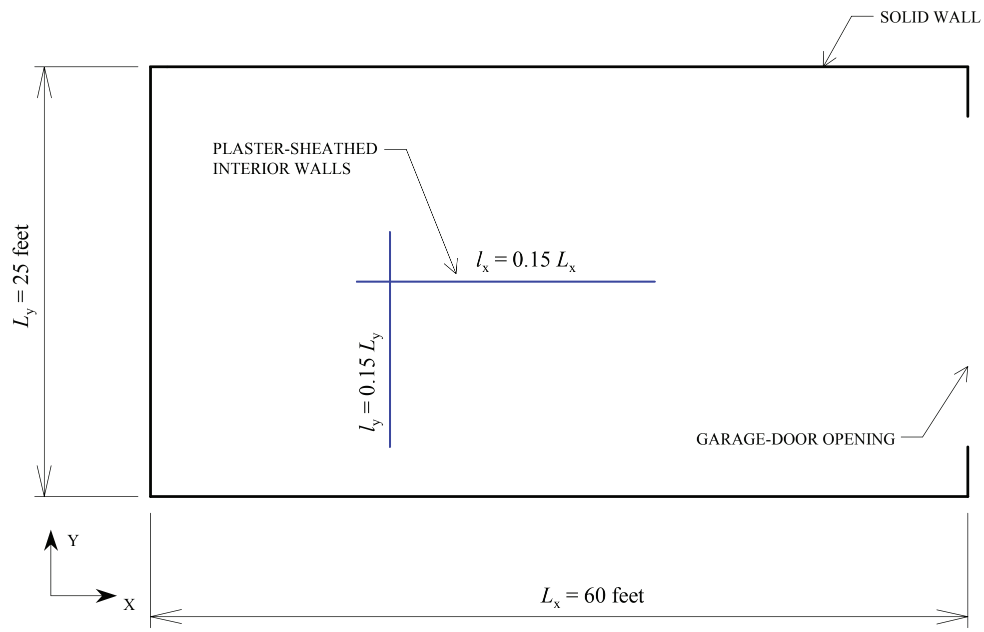

Figure 5-1 Typical garage-level building plan for single-family building with soft story, showing exterior solid-wall construction of stucco over straight wood sheathing over wood studs, as well as interior plaster on metal-lath walls as a percentage of exterior walls. Not to scale.

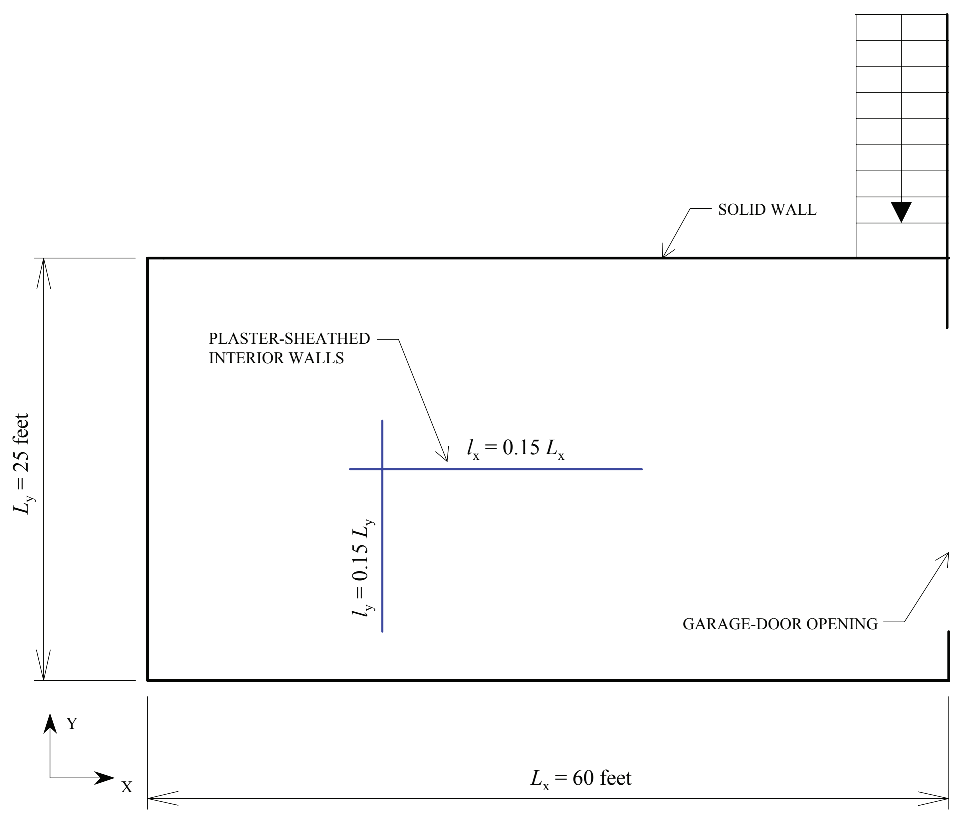

Figure 5-2 Typical garage-level building plan for single-family building without soft story, showing exterior solid-wall construction of stucco over straight wood sheathing over wood studs, as well as interior plaster on metal-lath walls as a percentage of exterior walls. Not to scale.

Table 5-1 Weights and Dimensions of Typical Wood-Frame Residences

Dimensions	Multi-family dwellings	Single family dwellings
L_x (see Figure 5-1)	75 ft	60 ft
L_y (see Figure 5-1)	50 ft	25 ft
Height	52 ft	26 ft
Stories	4	2
% openings in exterior walls	50%	20%
Weights		
Roof (21 psf)	78750 lbf	31500 lbf
Floors & partitions (22 psf)	247500 lbf	33000 lbf
Exterior walls (stucco over wood sheathing) (20 psf)	130000 lbf	70720 lbf

Like the single-family soft-story capacity curve, the multi-family soft-story curve was first also derived from calculations using typical dimensions and material properties appropriate to the City of San Francisco. Figures 5-3 and 5-4 show typical building plans for these structures. Dimensions and weights appear in Table 5-1. From these typical structures, displacement and acceleration at yield points and ultimate capacity were calculated. The yield point data are essentially what was used in the final set of parameters, while the ultimate capacity parameters were modified based on capacity curve information from the four model buildings developed for a previous CAPSS report (ATC, 2009a) and judgment. The revised parameters are similar to the with ultimate capacity parameters used in other instances in the HAZUS®99 program, and with expectations of engineers familiar with these building types.

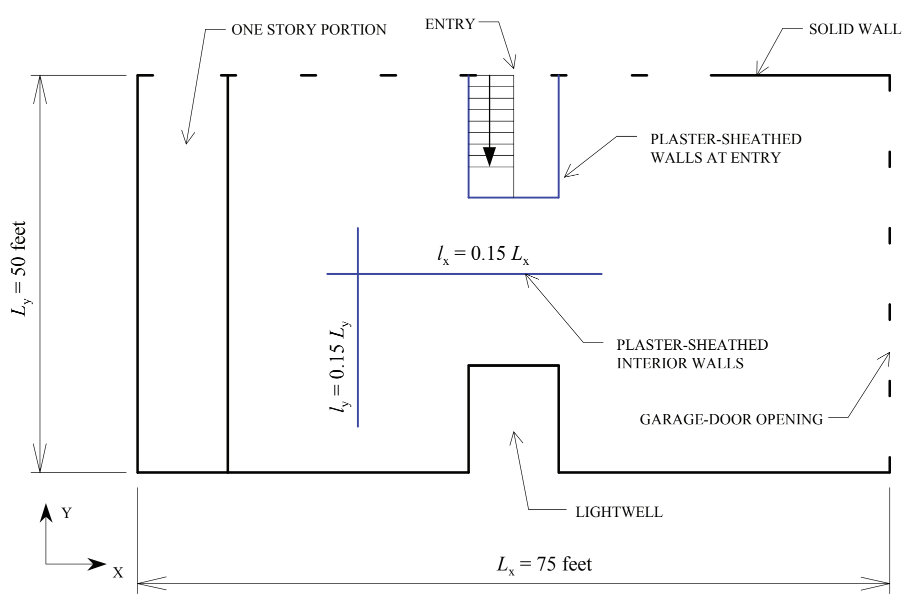

Figure 5-3 Typical garage-level building plan for corner apartment building with soft story, showing exterior solid-wall construction of stucco over straight wood sheathing over wood studs, as well as interior plaster on metal-lath walls as a percentage of exterior walls. Not to scale.

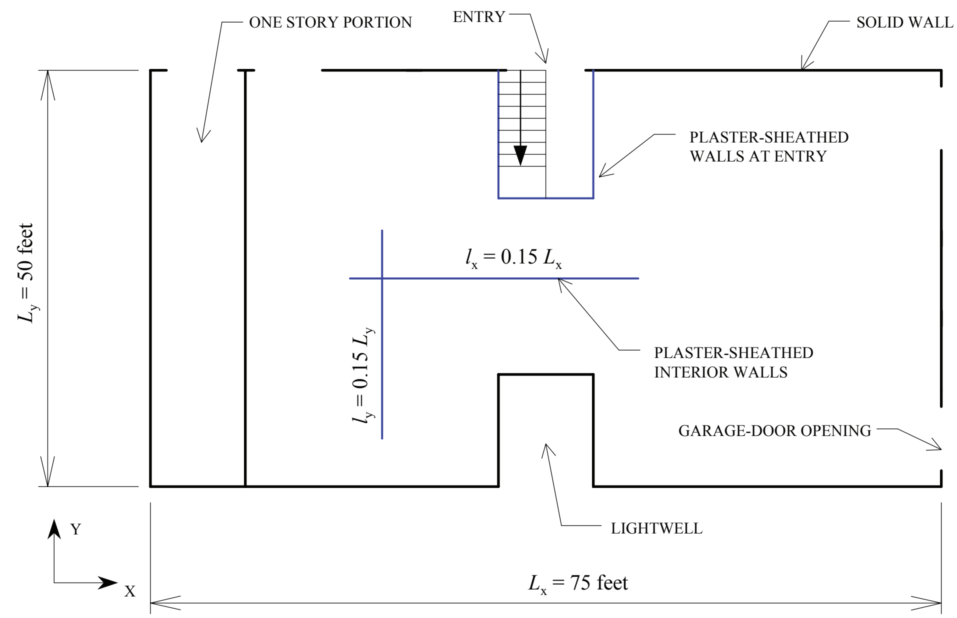

Figure 5-4 Typical garage-level building plan for corner apartment building without soft story, showing exterior solid-wall construction of stucco over straight wood sheathing over wood studs, as well as interior plaster on metal-lath walls as a percentage of exterior walls. Not to scale.

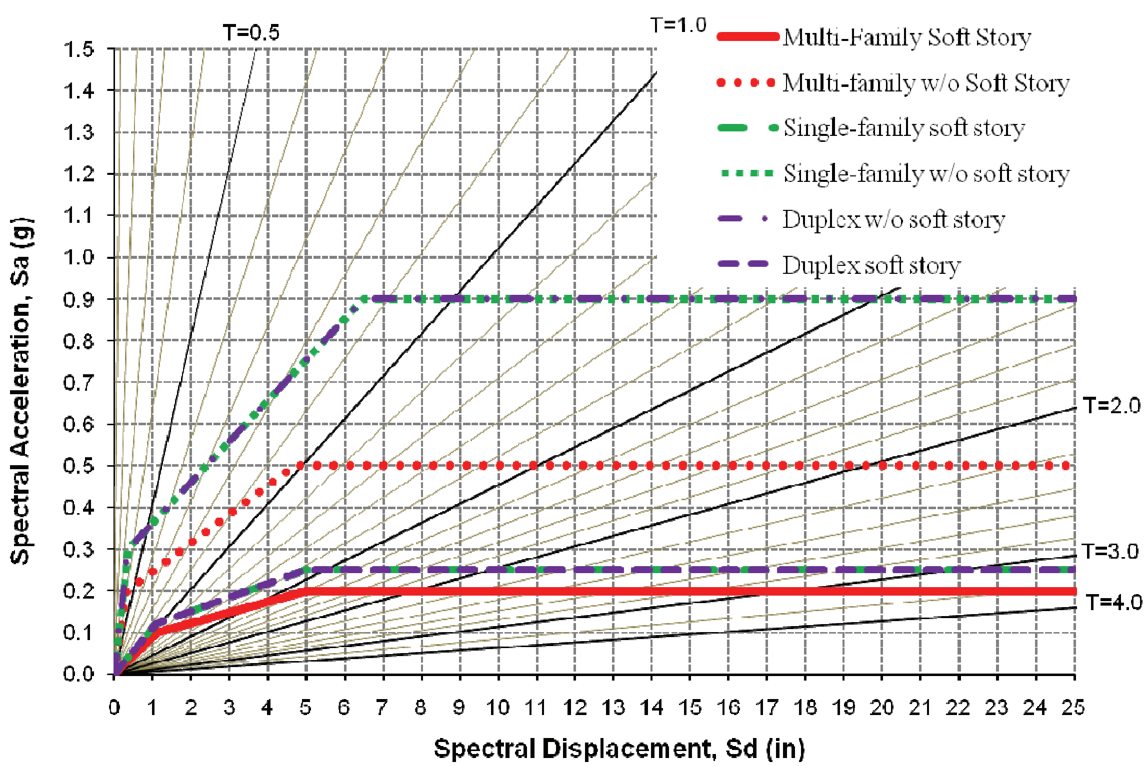

Figure 5-5 Plot of custom wood-frame capacity curves. Sa, spectral acceleration; Sd, spectral displacement; T, period (sec.).

Figure 5-5 shows all wood-frame custom capacity curves.

Single-family wood-frame structures without a soft story and duplex wood-frame structures without a soft story were assigned default HAZUS®99 capacity parameters for W1 Moderate/Code. Multi-family wood-frame structures without a soft story were assigned default HAZUS®99 capacity parameters for W2 Moderate/Code.

Retrofitted low-rise and mid-rise URM buildings were assigned default HAZUS® capacity parameters for RM1L Moderate/Code and RM1M Moderate/Code, respectively.

Table 5-2 presents the capacity parameters used for the CAPSS custom structural types.

Table 5-2 CAPSS Custom Capacity Curve Parameters*

Building Type	D_y (in)	A_y (g)	D_u (in)	A_u (g)
Single-family wood-frame soft story, pounding on both sides	1.1	0.12	5	0.25
Single-family wood-frame soft story, pounding on one side	1.1	0.12	5	0.25
Single-family wood-frame soft story, freestanding (no pounding)	1.1	0.12	5	0.25
Single-family wood-frame, not soft story (*default HAZUS®99 W1 Moderate/Code*)	0.36	0.3	6.475	0.9
Duplex wood-frame soft story	1.1	0.12	5	0.25
Duplex wood-frame, not soft story (*default HAZUS®99 W1 Moderate/Code*)	0.36	0.3	6.475	0.9
Multi-family residence wood-frame soft story	1.1	0.1	5	0.2
Multi-family residence wood-frame, not soft story (*default HAZUS®99 W2 Moderate/Code*)	0.313	0.2	4.698	0.5
Retrofitted low-rise URM (*default HAZUS®99 RM1L Moderate/Code*)	0.32	0.267	3.836	0.533
Retrofitted mid-rise URM (*default HAZUS®99 RM1M Moderate/Code)*	0.692	0.222	5.535	0.444

* All tabulated values (capacity and fragility) have been taken from tables utilized by the HAZUS®99 software, and may vary slightly from those given in the HAZUS®99 Technical Manual. A_y is the yield strength, D_y is the displacement at yield strength, A_u is the ultimate strength, D_u is the displacement at the ultimate strength. Yield strength is related to the resistive force when yielding, or nonlinearity, first occurs. Ultimate strength is related to the maximum capable resistive force.

5.2.2 Custom Damping

For wood-frame structures, HAZUS®99 uses a default damping factor of 15%. This default value was maintained for five of the eight custom wood-frame types: both types of multi-family residences, duplexes without soft stories, single-family wood-frame homes without soft stories, and freestanding single-family homes (i.e., those with no pounding from neighbor buildings).

The damping factor was changed for three of the custom wood-frame types to model the effects of pounding. Pounding is when buildings interact with each other during earthquake shaking. Damping for single-family soft-story homes with pounding from both sides was increased to 35% to represent the energy absorbed through this process. Damping for single-family soft-story homes with pounding from one side was increased to 25%. Damping for soft-story duplexes was also increased, although there were no estimates made for how many duplexes have pounding from two, one, or zero sides. It was assumed that some duplexes would be in each of these categories, thus justifying the use of a middle level assumption of 25% for damping. Pounding was only modeled in these three types to limit the complexity of the model and to explore the impacts of this phenomenon. Using these inputs, the HAZUS®99 model estimated that pounding would affect damage. The difference in the damage ratio for buildings with pounding from both sides and those with no pounding ranged from 4% to 10%, depending upon the scenario.

The adjustments to damping factors for wood-frame residences experiencing pounding were guided by an analysis, conducted with the original intention to incorporate pounding by amplifying the capacity curves, but later changed to alter the damping, instead. The response of the building accounting for the pounding effect was estimated on a statistical basis. Based on analysis, the expected period of the typical buildings under consideration is about 1.0 second. From structural dynamics it is known that under broadband excitations, the steady state response of the building is dominated by its natural period of vibration. Since the study was based on estimating the relative reduction in response, the choice of the amplitude of excitation was irrelevant. For deriving statistical estimates of the equivalent damping for the effect of pounding, 4000 samples of harmonic function were generated to model the response of the adjacent buildings. The period and amplitude of those sample functions were assumed to be lognormally distributed with the following parameters:

	Mean	Covariance (COV)
Period	1.0 s	15%
Amplitude	10 inch	10%

In order to model the pounding effect the following assumptions are made:

1. The gap between the two buildings is much smaller than the expected maximum displacement of the buildings;
2. The buildings have equal reactive weights; and
3. There is no loss of energy due to pounding.

Under the above assumptions, one can show that after impact, the buildings simply exchange velocities, so that each building follows the displacement path of free vibration of the other building, as shown in the generated sample time history in Figure 5-6.

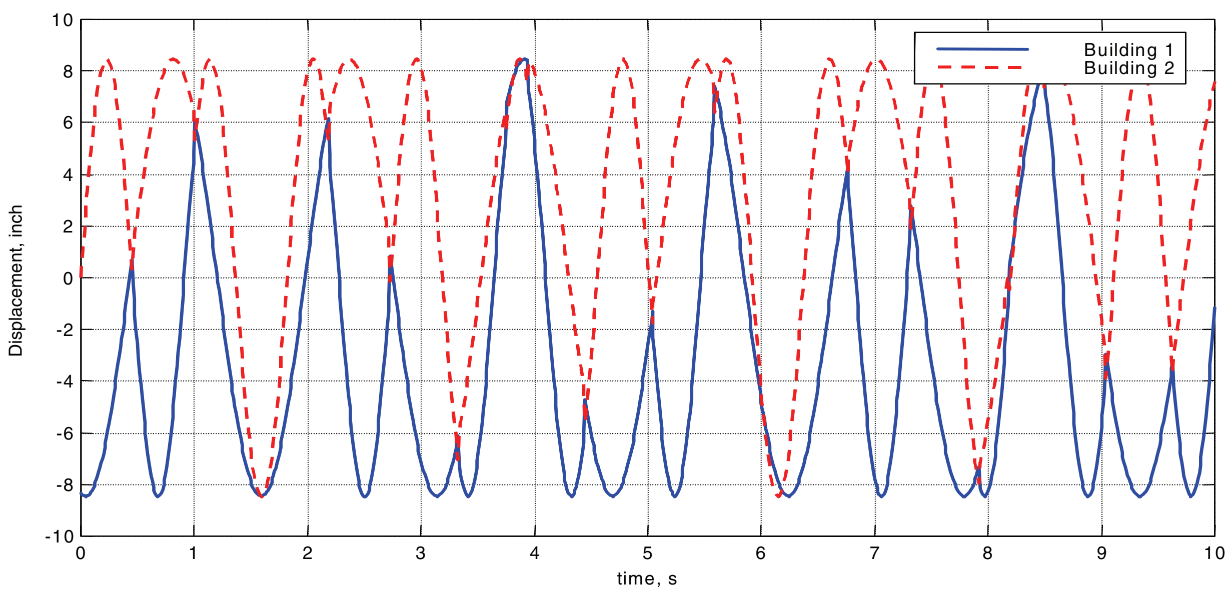

Figure 5-6 Schematic time history for pounding analysis—two buildings with somewhat varying fundamental periods oscillate, and exchange velocities when they pound.

In reality there is energy dissipation due to pounding, and the third assumption above does not hold. This assumption was made in order to derive simple statistics for pounding, namely the frequency of pounding and the amplitude at which the pounding occurs.

The equivalent damping is computed using the definition of logarithmic decrement:

$$\delta = \ln \frac{u_i}{u_{i+1}} = \frac{2\pi\varepsilon}{\sqrt{1-\varepsilon^2}}$$

where $\varepsilon = u_i$ is the expected amplitude of the response, and u_{i+1} is the expected amplitude at which the pounding occurs. For the resulting equivalent damping ratios the amplification of the capacity spectra were computed using the definitions given in ATC-40 (ATC, 1996) that are used for reducing the demand for equivalent damping. Those results are summarized in Table 5-3, where the expected displacement and the expected maximum displacement refer to the mean values of these two quantities.

Table 5-3 Results of Pounding Analysis

Building Setup	Average Number of Pounding Occurrences in 10 Seconds	Ratio of the Expected Displacement at Pounding to the Expected Maximum Displacement	COV Using 4000 Sample Functions	Equivalent Damping Ratio
Adjacent building on one side only	14	0.32	0.04	18%
Adjacent building on both sides (“no gap”)	22	0.20	0.05	25%

Damping for custom retrofitted URM buildings was kept at the default level for reinforced masonry buildings.

Table 5-4 presents damping parameters used for each custom structural type.

Table 5-4 CAPSS Custom Damping Assignments

Building Type	Damping
Single-family wood-frame soft story, pounding on both sides	35%
Single-family wood-frame soft story, pounding on one side	25%
Single-family wood-frame soft story, freestanding (no pounding)	15%
Single-family wood-frame, not soft story (*default HAZUS®99 W1 Moderate/Code*)	15%
Duplex wood-frame soft story	25%
Duplex wood-frame, not soft story (*default HAZUS®99 W1 Moderate/Code*)	15%
Multi-family residence wood-frame soft story	15%
Multi-family residence wood-frame, not soft story (*default HAZUS®99 W2 Moderate/Code*)	15%
Retrofitted low-rise URM (*default HAZUS®99 RM1L Moderate/Code*)	10%
Retrofitted mid-rise URM (*default HAZUS®99 RM1M Moderate/Code)*	10%

5.2.3 Custom Fragility Curves

HAZUS® uses fragility functions to determine the level of damage to a building's structural and non-structural elements that are sensitive to drift (such as partition walls, and veneer and other finishes). These functions include median and lognormal standard deviation (β) values of spectral displacement for the onset of each damage state.

Particular care is required to develop fragility functions for soft-story structures. During earthquake shaking, most of a soft-story building's lateral displacement occurs in the floor with the soft story (in San Francisco, this is typically the ground floor). This is in contrast to most other types of buildings in which displacement is more or less equally distributed among all floors. Because displacement is concentrated in one floor, soft-story buildings can suffer significant damage and even collapse at much lower total displacements than their counterparts without soft stories. The custom fragility parameters developed for CAPSS soft-story wood-frame building types were developed by reviewing research conducted for a previous CAPSS report (ATC, 2009) combined with engineering judgment, which was based on the concentration of lateral displacements in the first story.

HAZUS®99 default fragility parameters were used for the custom wood-frame building types without soft stories. Single-family homes and duplexes without soft stories were assigned default fragility parameters for W1 moderate/code. Multi-family residences without soft stories were assigned default fragility parameters for W2 moderate/code.

Retrofitted URM buildings were assigned default fragility parameters for reinforced masonry moderate/code.

HAZUS®99 default fragility parameters were deemed adequate for nonstructural drift-sensitive components in all of the custom building types.

Table 5-5 presents the structural fragility parameters used for CAPSS custom structure types, and Table 5-6 presents the non-structural drift-sensitive components fragility parameters.

5.2.4 Custom Kappa Factors

It was necessary to provide kappa values for the CAPSS custom structure types. The default kappa values for HAZUS®99 W1 Moderate/Code were applied to all custom wood-frame structure types, and the default values for RM1 moderate/code were applied to the custom retrofitted URM types.

Table 5-7 presents the kappa values used for the CAPSS custom structure types.

5.2.5 Casualty Rates

The casualty model utilized by HAZUS® consists of casualty rates (for four injury severity levels) for each building type, associated with each of HAZUS®' four damage states. Since the custom vulnerability models will impact each building type's expected damage state distribution, but not the underlying damage state definitions, it was determined that a change to the casualty models was not required (other than to accommodate the "off-book" storage). HAZUS®99 default casualty rates for W1 buildings were applied to all single-family residences and duplexes, while the default W2 casualty rates were applied to wood-frame multi-family residences.

Table 5-5 CAPSS Custom Structural Fragility Curve Data

Building Type	Spectral Displacement (inches)							
	Slight		Moderate		Extensive		Complete	
	Median	β	Median	β	Median	β	Median	β
Single-family wood-frame soft story (includes buildings with pounding on both sides, on one-side, and freestanding)	0.5	0.84	1.25	0.86	3.30	0.89	7.70	1.04
Single-family wood-frame, not soft story (*HAZUS®99 default W1 Moderate/Code*)	0.5	0.84	1.25	0.86	3.86	0.89	9.45	1.04
Duplex wood-frame soft story	0.5	0.84	1.25	0.86	3.30	0.89	7.70	1.04
Duplex wood-frame, not soft story (*HAZUS®99 default W1 Moderate/Code*)	0.5	0.84	1.25	0.86	3.86	0.89	9.45	1.04
Multi-family residence wood-frame soft story	0.75	0.97	1.06	0.93	3.00	0.88	7.00	1.00
Multi-family residence wood-frame, not soft story (*HAZUS®99 default W2 High/Inferior*)	0.69	0.97	2.07	0.93	6.91	0.88	17.28	1.00
Retrofitted low-rise URM (*default HAZUS®99 RM1L Moderate/Code*)	0.72	0.96	1.25	1.0	3.37	1.05	9.45	0.94
Retrofitted mid-rise URM (*default HAZUS® RM1M Moderate/Code)*	1.2	0.82	2.08	0.82	5.61	0.8	15.75	0.88

Note: All tabulated values (capacity and fragility) have been taken from tables utilized by the HAZUS®99 software, and may vary slightly from those given in the HAZUS®99 Technical Manual.

Table 5-6 CAPSS Custom Non-Structural Drift-Sensitive Components Fragility Curve Data

Building Type	Spectral Displacement (inches)							
	Slight		Moderate		Extensive		Complete	
	Median	β	Median	B	Median	β	Median	β
All single-family wood-frame buildings (including all soft story and not soft story) (*HAZUS®99 default W1 Moderate/Code*)	0.5	0.89	1.01	0.91	3.15	0.9	6.3	1.04
All duplex wood-frame buildings (including both soft story and not soft story) (*HAZUS®99 default W1 Moderate/Code*)	0.5	0.89	1.01	0.91	3.15	0.9	6.3	1.04
All wood-frame multi-family residential buildings (including soft story and not soft story) (*HAZUS®99 default W2 Moderate/Code*)	0.86	0.94	1.73	0.98	5.4	1.0	10.8	0.9
Retrofitted low-rise URM (*default HAZUS®99 RM1L Moderate/Code*)	0.72	1.01	1.44	1.06	4.5	1.11	9.0	1.01
Retrofitted mid-rise URM (*default HAZUS®99 RM1M Moderate/Code)*	1.8	0.89	3.6	0.85	11.25	0.84	22.5	0.98

Note: All tabulated values (capacity and fragility) have been taken from tables utilized by the HAZUS®99 software, and may vary slightly from those given in the HAZUS®99 Technical Manual.

Table 5-7 CAPSS Custom Kappa Factors

Building Type	Kappa/Code/ Short Dur.	Kappa/Code/ Medium Dur.	Kappa/Code/ Long Dur.
Single-family wood-frame soft story, pounding on both sides*	0.9	0.6	0.3
Single-family wood-frame soft story, pounding on one side*	0.9	0.6	0.3
Single-family wood-frame soft story, freestanding (no pounding)*	0.9	0.6	0.3
Single-family wood-frame, not soft story*	0.9	0.6	0.3
Duplex wood-frame soft story*	0.9	0.6	0.3
Duplex wood-frame, not soft story*	0.9	0.6	0.3
Multi-family residence wood-frame soft story*	0.9	0.6	0.3
Multi-family residence wood-frame, not soft story*	0.9	0.6	0.3
Retrofitted low-rise URM (*default HAZUS®99 RM1L Moderate/Code*)	0.8	0.4	0.2
Retrofitted mid-rise URM (*default HAZUS®99 RM1M Moderate/Code)*	0.8	0.4	0.2

* All wood-frame models utilized HAZUS®99 default kappa values for W1 moderate code.

CHAPTER 6: ESTIMATING LOSSES DUE TO GROUND SHAKING

The inputs described in previous chapters were entered into the HAZUS®99 model to produce estimated losses in a variety of forms. Estimated losses are presented in a summarized form in the main report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts* (ATC, 2010). This chapter presents results in more detail, appropriate for a technical reader. This chapter also presents the methods used to aggregate, summarize, and interpret the HAZUS®99 output to make it comprehensible to a non-technical audience.

6.1 Aggregation of Results

The loss estimates are aggregated in a variety of ways for presentation in the main report:

- by building use,
- by building structure type, and
- by City neighborhoods.

The way results were grouped for each of these categorizations is discussed in the sections that follow.

The HAZUS® loss estimates are calculated at the city block-level for each of the occupancy and model building categories used. Earthquake damage and losses are available for each of the 5,323 blocks studied for all 22 occupancies[5] and over 60 model building types[6] used in the study, although some occupancies and model building types will have no presence in some blocks. However, project results are not presented at this level of detail for important reasons. First, this level of detail is overwhelming and the loss estimates are more useful and easier to understand when aggregated into broader categories. Second, HAZUS® results are more accurate when they cover a larger area. There are numerous assumptions that go into the HAZUS® inputs, such as inventory assumptions about where specific types of buildings are located, that are accurate from a citywide perspective but may be inaccurate at a more detailed level and could produce misleading results at the city block-level.

The 22 HAZUS® categories for occupancy are aggregated into seven categories of building use for presentation in the main report, as shown in Table 6-1.

[5] HAZUS has additional occupancy classes that were not assigned building square footage for this study.

[6] This considers variation in structural system, height, code level, and quality.

Table 6-1 CAPSS Building Use Categories and HAZUS® Occupancy Classes

CAPSS Building Use	HAZUS® Occupancy Class
Single-family Residences	RES1
Two unit Residences	Duplex (CAPSS custom class)
Three or more unit Residences	RES3
Other Residences	RES4 – 6
Commercial Buildings	COM1 – 10
Industrial Buildings	IND1 – 6
Other	REL1, GOV 1 – 2, EDU 1 – 2

The model building types used by the CAPSS project team, including HAZUS® default model building types and CAPSS custom types, are grouped into 13 categories for the CAPSS report, as shown in Table 6-2.

Table 6-2 CAPSS Building Structure Type and HAZUS® Model Building Types

CAPSS Structure Categories	HAZUS® Model Building Types
Wood-frame single-family soft story	CAPSS custom single-family wood-frame soft-story, pounding on both sides; CAPSS custom single-family wood-frame soft-story, pounding on one side; CAPSS custom single-family wood-frame soft-story, freestanding (no pounding)
Wood-frame two-unit residential soft story	CAPSS custom duplex wood-frame soft-story
Wood-frame three or more unit residential soft story	CAPSS custom multi-family residence wood-frame soft-story
Wood-frame single-family not soft story	CAPSS custom single-family wood-frame, not soft-story
Wood-frame two-unit residential not soft story	CAPSS custom duplex wood-frame, not soft-story
Wood-frame three or more unit residential not soft story	CAPSS custom multi-family residence wood-frame, not soft-story
Concrete built before 1980	C3L, C3M, C3H, C2L, C2M, C2H (pre 1980 only)
Tilt-up concrete	PC1
Modern concrete	C1H, C2L, C2M, C2H (post 1980 only)
Steel moment and braced frame	S1L, S1M, S2L, S2M, S2H
Unreinforced masonry, retrofitted	CAPSS custom retrofitted low-rise URM; CAPSS custom retrofitted mid-rise URM
Unreinforced masonry, unretrofitted	URML, URMM
Other	RM1L, RM1M, RM2M, RM2H, W2 (non RES), S4L, S4M, S4H, S5L, S5M, S5H

Results are often presented by neighborhood. The CAPSS project team uses 14 neighborhoods defined by the Department of Public Works. This division scheme was selected among many possible ways to divide the City by the project's Advisory Committee. A map of San Francisco neighborhoods as used in this study is shown in Figure 6-1.

Figure 6-1 Neighborhood divisions used by the CAPSS project team.

6.2 Presenting Results in Terms of Post-Earthquake Building Functionality

The CAPSS Advisory Committee determined that it was important to view earthquake damage estimates in terms on the functionality of buildings after an earthquake. This concept grew out of a report published by San Francisco Planning and Urban Research (SPUR) in 2009 that defined recovery targets for the City in terms of building functionality.

The CAPSS project team developed a scheme to relate HAZUS® damage states to post-earthquake functionality. Four functionality states were developed, adapted from those defined by SPUR[7]. The CAPSS damage states, described below, omit the explicit concept of safety.

[7] 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.

- *Usable, light damage.* Buildings experience only minor damage and residents could continue to use them. This report does not assess the likelihood of utilities—water, sewer, power, etc.—being functional, which would influence whether occupants choose to remain in these buildings.
- *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 experience heavy damage and could not be occupied until repaired. Few, if any, buildings in this state would be demolished. Repaired rental units would, therefore, 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 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.

HAZUS®99 uses five damage states (none, slight, moderate, extensive, and complete). These states correspond to varying percentages of economic losses and other impacts, and are defined with descriptions of physical damage in the HAZUS®99 technical manual (NIBS, 2002). HAZUS®99 damage estimates can be reported in terms of a damage state distribution. In other words, for each of the CAPSS city blocks, HAZUS®99 produced estimates of the percentage of square footage of each model building type in each of these five damage states.

The CAPSS project team developed a relationship between its four functionality states and the five HAZUS®99 damage states. Two methods were considered for doing this. The first method considered was to use engineering judgment to translate the physical damage descriptions by model building type associated with each damage state into the four CAPSS functionality states. The second method considered was to base the relationships on the HAZUS®99 shelter module. This module estimates the number of households that will be displaced after a scenario. The CAPSS project team elected to pursue the second option—the HAZUS®99 estimation of displaced people—since this concept closely relates to the concept behind the CAPSS functionality states. The HAZUS®99 model has been extensively used and peer reviewed, and it seemed better to use the approach that had more precedent.

Some changes were made to the HAZUS®99 displaced population formula based on the CAPSS technical review process. For example, HAZUS®99 assumes that all single-family wood-frame homes with extensive damage can be occupied. The CAPSS project team chose to reduce that to 90%. In a number of places, expert judgment needed to be used to extend the HAZUS®99 model to other areas. For example, HAZUS®99 has no model for building repairability, an issue of considerable interest to the CAPSS project team because this affects rent control and historic building issues in San Francisco. To construct this model, the CAPSS project team relied on guidance from City officials, and assumes that San Francisco has a bias towards making owners repair their buildings and avoiding demolitions. In general, it was assumed that nearly all wood-frame buildings that did not collapse would be repaired in San Francisco. This assumption may not make sense for other communities.

Table 6-3 presents how the building square footage in various HAZUS®99 damage states was allocated into the four CAPSS functionality states.

Table 6-3 HAZUS®99 Damage States to CAPSS Functionality States

HAZUS® Damage States	% of Square Footage in HAZUS® State Assigned to CAPSS State			
	Usable, Light Damage	Usable, Moderate Damage	Repairable, Cannot Be Occupied	Not Repairable
None	100%	0%	0%	0%
Slight	100%	0%	0%	0%
Moderate	0%	100%	0%	0%
Extensive	0%	RES1: 90% Duplex: 50% RES3: 10% Other: 50%	RES1: 10% Duplex: 50% RES3: 90% Other: 50%	0%
Complete	0%	0%	RES1: 85% Duplex: 85% RES3 Woodframe: 75% RES3 Other: 25% Other: 25%	RES1: 15% Duplex: 15% RES3 Woodframe: 25% RES3 Other: 75% Other: 75%

6.3 Detailed Results

The main report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts* (ATC, 2010), presents HAZUS®99 results in a variety of ways, and this information is not repeated here. This section presents results in additional ways, generally at a greater level of detail. These estimates are intended to be used for citywide policymaking, and conclusions drawn when results are viewed at greater levels of detail than presented in the main report can be misleading without a thorough understanding of the assumptions that underlie the models.

Selected detailed results are presented in Tables 6-4 to 6-13 for all four CAPSS scenarios. Additional results are presented for the magnitude 7.2 San Andreas fault scenario. Additional results were extracted from the HAZUS®99 model for this scenario because it is used as an example in the main report.

Table 6-4 Damage Ratio[8] by Structure Type for the Four CAPSS Scenarios

Model Building Type	San Andreas Magnitude 6.5	Hayward Magnitude 6.9	San Andreas Magnitude 7.2	San Andreas Magnitude 7.9
CAPSS Custom: single-family soft story pounding both sides	14%	6%	21%	30%
CAPSS Custom: single-family soft story pounding one side	17%	7%	24%	35%
CAPSS Custom: single-family soft story freestanding	19%	10%	27%	40%
CAPSS Custom: single-family without soft story	7%	2%	10%	15%
CAPSS Custom: Duplex/flat with soft story	15%	10%	23%	34%
CAPSS Custom: Duplex without soft story	5%	2%	8%	13%
CAPSS Custom: multi-family soft story	16%	13%	23%	35%
CAPSS Custom: multi-family not soft story	5%	3%	7%	13%
W2 (non RES occupancies)	9%	8%	14%	27%
S1L	6%	4%	11%	24%
S1H	9%	10%	13%	19%
S2L	6%	4%	10%	21%
S2M	8%	8%	12%	18%
S2H	7%	8%	12%	17%
S4L	10%	9%	14%	25%
S4M	6%	6%	9%	15%
S4H	4%	5%	7%	12%
S5L	10%	9%	20%	42%
S5M	8%	9%	15%	31%
S5H	8%	9%	13%	25%
C1H (post-1980)	7%	8%	12%	16%
C2L (post-1980)	7%	7%	10%	13%
C2L (pre-1980)	11%	9%	15%	27%
C2M (post-1980)	7%	7%	9%	13%
C2M (pre-1980)	5%	4%	9%	16%
C2H (post-1980)	5%	5%	8%	12%
C2H (pre-1980)	6%	8%	10%	16%
C3L (pre-1980)	14%	14%	24%	43%
C3M (pre-1980)	8%	8%	14%	31%
C3H (pre-1980)	9%	10%	14%	27%
PC1	12%	11%	15%	22%
RM1L	9%	7%	14%	25%
RM1M	5%	4%	8%	13%
CAPSS Custom: Retrofitted URM	8%	7%	11%	19%
RM2M	7%	6%	12%	28%
RM2H	7%	8%	12%	19%
URML	16%	13%	22%	39%
URMM	12%	13%	20%	37%
Average	**10%**	**7%**	**16%**	**25%**

[8] Damage Ratio is defined as building repair cost divided by building replacement cost.

Table 6-5 Detailed Casualty Estimates for the Four CAPSS Scenarios

Time of Day	Casualty Severity[a]	San Andreas Magnitude 6.5	Hayward Magnitude 6.9	San Andreas Magnitude 7.2	San Andreas Magnitude 7.9
2:00 am	1	3,557	2,237	5,643	9,609
	2	743	451	1,257	2,334
	3	56	36	104	224
	4	101	67	190	418
2:00 pm	1	2,485	2,265	4,703	10,565
	2	554	510	1,170	3,009
	3	63	62	153	449
	4	123	121	298	882
5:00 pm	1	1,787	1,495	3,171	6,540
	2	389	329	760	1,784
	3	39	37	88	243
	4	75	71	169	473

a. *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®99.

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.

Source: FEMA (1999) and NIBS (2002).

Table 6-6 Dollar Losses to Buildings by Model Building Types for the Four CAPSS Scenarios

Model Building Type	Losses in $ Millions			
	San Andreas Magnitude 6.5	Hayward Magnitude 6.9	San Andreas Magnitude 7.2	San Andreas Magnitude 7.9
CAPSS Custom: single-family soft story pounding both sides	$2,071	$904	$3,116	$4,445
CAPSS Custom: single-family soft story pounding one side	1,913	858	2,776	3,993
CAPSS Custom: single-family soft story freestanding	409	200	571	833
CAPSS Custom: single-family without soft story	1,640	375	2,359	3,681
CAPSS Custom: Duplex/flat with soft story	1,861	1,188	2,794	4,113
CAPSS Custom: Duplex without soft story	551	257	842	1,318
CAPSS Custom: multi-family soft story	4,199	3,525	6,131	9,243
CAPSS Custom: multi-family not soft story	569	366	866	1,634
W2 (non RES occupancies)	655	603	1,052	2,079
S1L	10	7	19	39
S1H	718	818	1,019	1,522
S2L	33	23	57	113
S2M	43	45	66	103
S2H	868	994	1,407	2,039
S4L	142	124	209	356
S4M	122	130	186	306
S4H	191	215	327	552
S5L	56	50	107	229
S5M	121	128	212	444
S5H	488	547	799	1,560
C1H (post-1980)	54	64	95	129
C2L (post-1980)	84	78	111	154
C2L (pre-1980)	291	253	411	731
C2M (post-1980)	93	95	122	172
C2M (pre-1980)	19	17	34	62
C2H (post-1980)	41	42	64	97
C2H (pre-1980)	39	46	59	98
C3L (pre-1980)	940	904	1,550	2,853
C3M (pre-1980)	660	640	1,205	2,656
C3H (pre-1980)	41	49	67	130
PC1	98	89	124	183
RM1L	84	66	125	225
RM1M	67	49	105	175
CAPSS Custom: Retrofitted URM	421	399	608	1,041
RM2M	10	9	18	42
RM2H	45	51	72	116
URML	17	14	22	39
URMM	68	73	110	207
Total	**$19,731**	**$14,289**	**$29,818**	**$47,715**

Table 6-7 Dollar Losses to Buildings by Occupancy Class for the Four CAPSS Scenarios

Occupancy Class	Losses In $ Millions			
	San Andreas Magnitude 6.5	Hayward Magnitude 6.9	San Andreas Magnitude 7.2	San Andreas Magnitude 7.9
RES1	$6,034	$2,337	$8,823	$12,952
Duplex	2,412	1,445	3,636	5,431
RES3	5,192	4,208	7,781	12,496
RES4	677	752	1,213	2,508
RES5	-	-	-	-
RES6	35	20	65	136
COM1	853	752	1,418	2,729
COM2	-	-	-	-
COM3	7	5	11	21
COM4	2,995	3,433	4,564	7,374
COM5	59	44	104	219
COM6	65	43	126	269
COM7	-	-	-	-
COM8	110	102	185	365
COM9	32	29	54	110
COM10	61	60	111	223
IND1	115	107	159	253
IND2	417	388	570	883
IND3	201	188	279	444
IND4	31	28	43	68
IND5	15	14	21	34
IND6	225	210	312	496
AGR1	-	-	-	-
REL1	135	82	229	461
GOV1	2	2	3	6
GOV2	-	-	-	-
EDU1	60	41	110	237
EDU2	-	-	-	-
Total	**$19,731**	**$14,289**	**$29,818**	**$47,715**

Table 6-8 Debris Estimates for the Four CAPSS Scenarios

Type of Debris	Amount of Debris in Million Tons			
	San Andreas M6.5	Hayward M6.9	San Andreas M7.2	San Andreas M7.9
Light Debris: Brick, Wood and Other Debris	1.5	1.2	2.4	4.1
Heavy Debris: Concrete and Steel	2.4	2.2	4.4	8.7
Total	**3.9**	**3.4**	**6.8**	**12.8**

Table 6-9 HAZUS® Structural Damage State Distribution by Occupancy Class, Magnitude 7.2 San Andreas Scenario

Building Occupancy	Floor Area in Each Damage State (in Thousand Square Feet)				
	None	Slight	Moderate	Extensive	Complete
RES1	19,761	38,769	49,022	24,050	14,680
Duplex	10,607	16,282	19,150	10,253	6,321
RES3	18,908	21,898	39,317	29,117	20,043
RES4	3,333	6,587	10,866	4,303	1,629
RES5	-	-	-	-	-
RES6	218	311	469	186	61
COM1	4,564	6,052	8,874	5,207	2,466
COM2	-	-	-	-	-
COM3	55	47	61	36	10
COM4	6,995	15,669	32,087	17,814	5,625
COM5	275	262	355	214	78
COM6	436	380	567	291	121
COM7	-	-	-	-	-
COM8	493	589	814	450	209
COM9	71	113	224	183	94
COM10	924	902	1,366	802	336
IND1	441	495	742	638	359
IND2	1,970	2,209	3,081	2,637	1,506
IND3	478	536	804	691	389
IND4	73	82	123	106	60
IND5	37	41	62	53	30
IND6	1,029	1,154	1,731	1,488	837
AGR1	-	-	-	-	-
REL1	597	806	1,036	508	198
GOV1	30	31	16	6	2
GOV2	-	-	-	-	-
EDU1	543	588	756	332	110
EDU2	-	-	-	-	-
Total	**71,837**	**113,805**	**171,523**	**99,366**	**55,163**

Table 6-10 HAZUS® Structural Damage State Distribution by Neighborhood, Magnitude 7.2 San Andreas Scenario

Neighborhood	Floor area in each damage state (in thousand square feet)				
	None	Slight	Moderate	Extensive	Complete
Bayview	2,626	3,766	4,952	3,324	2,113
Downtown	16,454	26,846	47,255	25,200	9,474
Excelsior	4,144	8,033	10,528	4,995	2,922
Ingleside	886	2,446	3,675	1,748	1,055
Marina	1,175	1,603	2,332	2,334	1,930
Merced	394	1,100	1,806	978	613
Mission	9,610	14,238	19,439	11,508	6,818
Mission Bay	3,238	4,430	8,258	6,450	3,393
North Beach	7,399	8,073	11,094	6,055	3,300
Pacific Heights	5,090	6,372	8,804	4,863	2,828
Richmond	4,934	8,770	12,777	8,185	5,561
Sunset	5,497	11,570	16,759	10,614	7,185
Twin Peaks	2,524	5,431	7,404	3,331	1,929
Western Addition	7,866	11,126	16,440	9,782	6,042
Total	**71,837**	**113,805**	**171,523**	**99,366**	**55,163**

Table 6-11 HAZUS® Structural Damage State Distribution by Model Building Type, Magnitude 7.2 San Andreas Scenario

Building Occupancy	Floor Area in Each Damage State (in Thousand Square Feet)				
	None	Slight	Moderate	Extensive	Complete
CAPSS Custom: single-family soft story pounding both sides	1,135	6,960	16,091	10,291	6,404
CAPSS Custom: single-family soft story pounding one side	638	4,499	12,123	8,860	6,009
CAPSS Custom: single-family soft story freestanding	80	656	2,064	1,741	1,301
CAPSS Custom: single-family without soft story	17,890	26,590	18,675	3,077	943
CAPSS Custom: Duplex/flat with soft story	759	5,090	12,847	9,089	5,956
CAPSS Custom: Duplex without soft story	9,817	11,170	6,294	1,125	324
CAPSS Custom: multi-family soft story	4,799	3,484	24,693	24,014	17,987
CAPSS Custom: multi-family not soft story	11,968	14,461	7,039	1,141	220
W2 (non RES occupancies)	4,084	5,746	6,112	2,521	924
S1L	70	63	66	36	16
S1H	946	3,594	8,140	4,883	953
S2L	549	324	310	135	40
S2M	176	408	611	186	40
S2H	1,451	4,975	13,395	5,923	1,168
S4L	906	706	1,078	895	301
S4M	1,100	1,504	1,938	528	120
S4H	1,016	2,719	4,849	1,333	237
S5L	129	159	359	340	199
S5M	224	585	1,129	768	444
S5H	659	2,499	5,194	3,622	1,949
C1H (post-1980)	77	314	965	402	75
C2L (post-1980)	1,192	1,100	465	249	47
C2L (pre-1980)	1,544	1,855	2,231	1,618	451
C2M (post-1980)	695	1,214	767	231	48
C2M (pre-1980)	177	278	356	87	22
C2H (post-1980)	192	781	884	189	29
C2H (pre-1980)	102	368	583	208	53
C3L (pre-1980)	1,504	2,267	4,974	5,791	4,305
C3M (pre-1980)	1,718	3,616	7,853	5,023	3,100
C3H (pre-1980)	40	166	383	293	168
PC1	595	620	809	472	119
RM1L	759	440	628	484	161
RM1M	936	1,004	1,273	370	51
CAPSS Custom: Retrofitted URM	3,416	2,895	4,684	2,217	385
RM2M	66	72	156	70	20
RM2H	149	318	797	363	83
URML	27	49	92	89	60
URMM	75	178	415	425	289
Total	**71,659**	**113,725**	**171,321**	**99,088**	**55,001**

Table 6-12 Economic Losses for Magnitude 7.2 San Andreas Scenario With and Without Liquefaction, by Occupancy

Building Occupancy	Building Damage ($1,000)		Total Direct Economic Loss ($1,000)	
	With Liquefaction	Without Liquefaction	With Liquefaction	Without Liquefaction
RES1	$8,822,678	$8,498,646	$11,141,053	$10,726,590
Duplex	3,636,352	3,412,620	4,096,807	3,828,480
RES3	7,781,132	7,260,716	10,445,556	9,774,644
RES4	1,213,085	985,884	2,136,414	1,814,660
RES5	0	0	0	0
RES6	64,953	61,450	115,412	109,715
COM1	1,418,296	1,220,019	1,871,224	1,589,593
COM2	0	0	0	0
COM3	11,016	8,832	15,790	12,601
COM4	4,563,921	2,958,028	6,798,744	4,489,383
COM5	104,110	93,769	138,995	124,710
COM6	125,677	122,011	224,691	218,562
COM7	0	0	0	0
COM8	185,323	159,260	306,332	268,220
COM9	54,334	44,166	86,748	71,812
COM10	110,938	101,269	126,371	114,526
IND1	159,236	120,291	210,255	151,470
IND2	569,718	422,761	780,583	559,733
IND3	279,278	210,853	371,250	268,627
IND4	42,682	32,126	55,329	39,724
IND5	21,208	15,857	27,961	19,948
IND6	312,196	235,892	387,176	284,539
AGR1	0	0	0	0
REL1	229,269	213,931	308,293	286,442
GOV1	3,340	2,212	4,662	3,086
GOV2	0	0	0	0
EDU1	109,652	100,139	148,589	135,165
EDU2	0	0	0	0
Total	**$29,818,394**	**$26,280,732**	**$39,798,235**	**$34,892,230**

Table 6-13 Total Direct Economic Loss by Occupancy and Component of Loss, Magnitude 7.2 San Andreas Scenario

Occupancy	Capital Stock Losses ($Millions)				Income Losses ($Millions)				Total Direct Economic Losses (Capital Stock & Income, $Millions)
	Structure Damage[a]	Non-Structural Damage[a]	Contents Damage	Inventory Loss	Relocation Loss	Capital Related (Income) Loss	Rental Income Loss	Wage Loss	
RES1	$2,908	$5,915	$618	-	$1,288	-	$412	-	$11,141
RES2 (Duplex)	1,226	2,410	234	-	196	-	31	-	4,097
RES3	2,453	5,328	371	-	837	-	1,457	-	10,446
RES4	377	836	96	-	10	81	544	192	2,136
RES5	-	-	-	-	-	-	-	-	-
RES6	20	45	6	-	0	9	15	20	115
COM1	739	679	216	4	124	4	90	16	1,871
COM2	-	-	-	-	-	-	-	-	-
COM3	4	7	2	-	1	0	1	1	16
COM4	1,604	2,960	771	-	687	182	530	64	6,799
COM5	36	68	18	-	13	0	4	0	139
COM6	37	89	29	-	41	8	2	18	225
COM7	-	-	-	-	-	-	-	-	-
COM8	62	124	31	-	-	41	17	32	306
COM9	22	32	8	-	-	5	8	12	87
COM10	81	30	7	-	-	-	8	-	126
IND1	68	91	44	3	-	1	1	2	210
IND2	239	330	161	3	34	1	9	3	781
IND3	120	160	77	3	9	0	2	1	371
IND4	18	24	12	0	1	0	0	0	55
IND5	9	12	6	0	1	0	0	0	28
IND6	134	178	57	3	9	1	1	3	387
AGR1	-	-	-	-	-	-	-	-	-
REL1	88	142	39	-	34	1	3	2	308
GOV1	1	3	1	-	0	0	0	0	5
GOV2	-	-	-	-	-	-	-	-	-
EDU1	35	75	21	-	16	0	1	1	149
EDU2	-	-	-	-	-	-	-	-	-
TOTAL	**$10,282**	**$19,537**	**$2,824**	**$16**	**$3,300**	**$335**	**$3,137**	**$367**	**$39,798**

a. Structural damage and non-structural damage are combined to determine building damage.

CHAPTER 7: FIRE FOLLOWING EARTHQUAKE ANALYSIS

This chapter summarizes analyses performed for the CAPSS project to estimate the potential losses due to fire following earthquake. HAZUS99® provides estimates of fire following earthquake losses, but is known to have errors (FEMA, 2001), so an independent methodology was employed.

7.1 Overview

San Francisco is at significant risk due to fire following earthquake. This chapter describes analyses of fire following earthquake for San Francisco. This analysis has been conducted with the support and assistance of the San Francisco Fire Department (SFFD).

Given the total destruction of much of the city in the 1906 earthquake and fire, San Francisco's post-earthquake fire risk should be obvious. However, much has changed since 1906, and the degree to which the city is today at such risk is less clear. Today, San Francisco is the most densely-settled large city in the state of California, the second-most densely-populated large city in the United States, and the financial, cultural, and transportation center of the San Francisco Bay Area. The analysis described in this chapter uses the current situation in order to estimate today's risk.

Fire following earthquake refers to a series of events initiated by a large earthquake, with each event having several possible outcomes. These events include whether or not a building or industrial facility is damaged by shaking, whether or not an ignition occurs in such a location, whether or not the ignition grows into a serious fire, whether or not (and at what time) such a fire is reported, whether or not the fire department responds, whether or not they have water in the hydrants…and so on. Such a chain of uncertain events is termed a *stochastic process*, the analysis of which involves many possible outcomes. The analysis presented here evaluates each link in the chain of events to determine how often the outcome is a few small fires, or a number of large fires, or one or more multi-block conflagrations. Due to the uncertainty involved in each step, the results of the analysis are necessarily probabilistic in nature—that is, it cannot be said definitely that this or that will happen, it can only be said that such and such will happen with a certain probability. The value of the analysis is not so much in the precision of the numbers, as in the degree to which it quantifies that it is likely that losses will be small, or catastrophic.

7.1.1 Fires and Fire Following Earthquake

Fires occur following all earthquakes that significantly shake a human settlement, but are generally only a very significant problem in a large metropolitan area predominantly comprised of densely-spaced buildings. In such circumstances, multiple simultaneous ignitions can lead to catastrophic conflagrations that by far are the dominant agent of damage for that event. This, of course, occurred in San Francisco in 1906, when 80% of the damage was due to fire rather than shaking.

More recently, about 110 fires broke out after the 1994 Northridge earthquake in Los Angeles; however, this was a relatively modest earthquake (magnitude 6.7) on the edge of a great metropolitan area, so that the fires were largely contained and major spread did not occur. About the same number of fires occurred the next year in the 1995 Kobe, Japan, magnitude 6.8 earthquake. In that case, the fire department was greatly hampered by many broken water mains as well as transportation difficulties, and significant fire spread occurred, producing

> *"a total of 294 fires, resulting in the destruction of about 66 million m^2 of residential and industrial land ... 215 fires broke out on the day of the earthquake, fifty-one of which spread to an area more than 1,000 m^2 and thirty-one fires spread to more than 3,000 m^2...7,538 houses and buildings were destroyed by these fires... Kobe City Fire Department reported a total of 175 incidents of fire, 128 of which were reported through the "119" emergency telephone service while the rest were unreported" (Nagano, 1995)*

The method for determining fire following earthquake losses for a given region, in summary, consists of collecting data on the building stock, ground conditions, water supply, fire service, and related systems. These data were employed in an approach (Scawthorn, Yamada, and Iemura, 1981; Scawthorn, Eidinger, and Schiff, 2005) that considers these factors in a stochastic framework that estimates ignitions caused by the earthquake, and tracks fire spread as a function of fuel (i.e., the building stock and contents), wind, firefighting activities, and other parameters.

Although a combination of a professional fire service, improved water supply, and better building practices has largely eliminated non-earthquake-related large urban conflagrations in San Francisco, there is still a gap to be addressed: fire following earthquake. This is due to the correlated effects of a large earthquake simultaneously causing numerous ignitions, degrading building fire-resistive features, dropping pressure in water supply mains, saturating communications and jamming transportation routes, thus allowing some fires to grow into conflagrations that outstrip local resources. It is not sufficiently appreciated that the key to modern fire protection is a well-drilled rapid response by professional firefighters in the early stages of structural fires, arriving in time to suppress the fires while that is still relatively feasible. A typical response goal for urban fire departments, for example, is four minutes from time of report to arrival (SFFD averaged 4.92 minutes in 2008). If suppression is delayed, due either to delayed response or lack of water, a single structural fire can quickly spread to neighboring buildings and grow to the point where an entire municipalities' fire resources are required, and perhaps even assistance from neighboring communities. This is for a single ignition. Simply put, most fire departments are not sized or equipped to cope with the fires following a major earthquake. A major earthquake and its associated fires is a low probability event which, however, may have very high consequences.

7.1.2 Modeling of Fire Following Earthquake

A full probabilistic methodology for analysis of fire following earthquake, developed in the late 1970s (Scawthorn, Yamada, and Iemura, 1981) and applied to major cities in western North America (Scawthorn and Khater, 1992), Japan, and other regions, was employed here for San Francisco. A monograph (Scawthorn, Eidinger, and Schiff, 2005) details the current state-of-the-art in modeling fire following earthquake, so that only a brief review is presented here. The steps in the process are as follows:

- *Occurrence of the earthquake*. Damage is caused to buildings and contents, even if the damage is as simple as knocking candles or lamps over.
- *Ignition.* Whether a structure has been damaged or not, ignitions will occur due to earthquakes. The sources of ignitions are numerous, and include overturned heat sources, abraded and shorted electrical wiring, spilled chemicals having exothermic reactions, and friction of some materials rubbing together.
- *Discovery.* At some point, the fire resulting from the ignition will be discovered, if it has not self-extinguished (this aspect is discussed further below). In the confusion following an earthquake, the discovery may take longer than it might otherwise.
- *Report.* If it is not possible for the person or persons discovering the fire to immediately extinguish it, fire department response will be required. For the fire department to respond, a report to the fire department has to be made. Communications system dysfunction and saturation will delay many reports.
- *Response.* The fire department then has to respond, but is impeded by non-fire damage emergencies it may have to respond to (e.g., building collapse) as well as transportation disruptions.
- *Suppression.* The fire department then has to suppress the fire. If the fire department is successful, it moves on to the next incident. If the fire department is not successful, it continues to attempt to control the fire, but it spreads, and becomes a conflagration. Success or failure hinges on numerous factors including water supply functionality, building construction and density, and wind and humidity conditions. If unable to contain the fire, the process ends when the fuel is exhausted or when the fire comes to a firebreak.

In summary, the steps in the process are shown in Figure 7-1.

This process is also shown in Figure 7-2, which is a Fire Department Operations Time Line. Time is a critical parameter in the fire following earthquake problem. In this figure, the horizontal axis is time, beginning at the time of the earthquake, while the vertical axis presents a series of horizontal bars of varying width. Each of these bars depicts the development of one fire, from ignition through growth or increasing size (size is indicated by the width or number of bars). Fire following earthquake is a highly non-linear process, modeling of which does not have great precision. In many cases, the only clear result is differentiation between situations of a few small fires versus major conflagration.

This process can be employed in several modes, two of which are:

- *Scenario events*, in which earthquake epicenter and magnitude, and as many other parameters as may be of interest, are precisely specified or ‘determined’. Other parameters of interest might include rupture direction, time of day, season, or wind speed. Other key parameters, such as ground motion and building

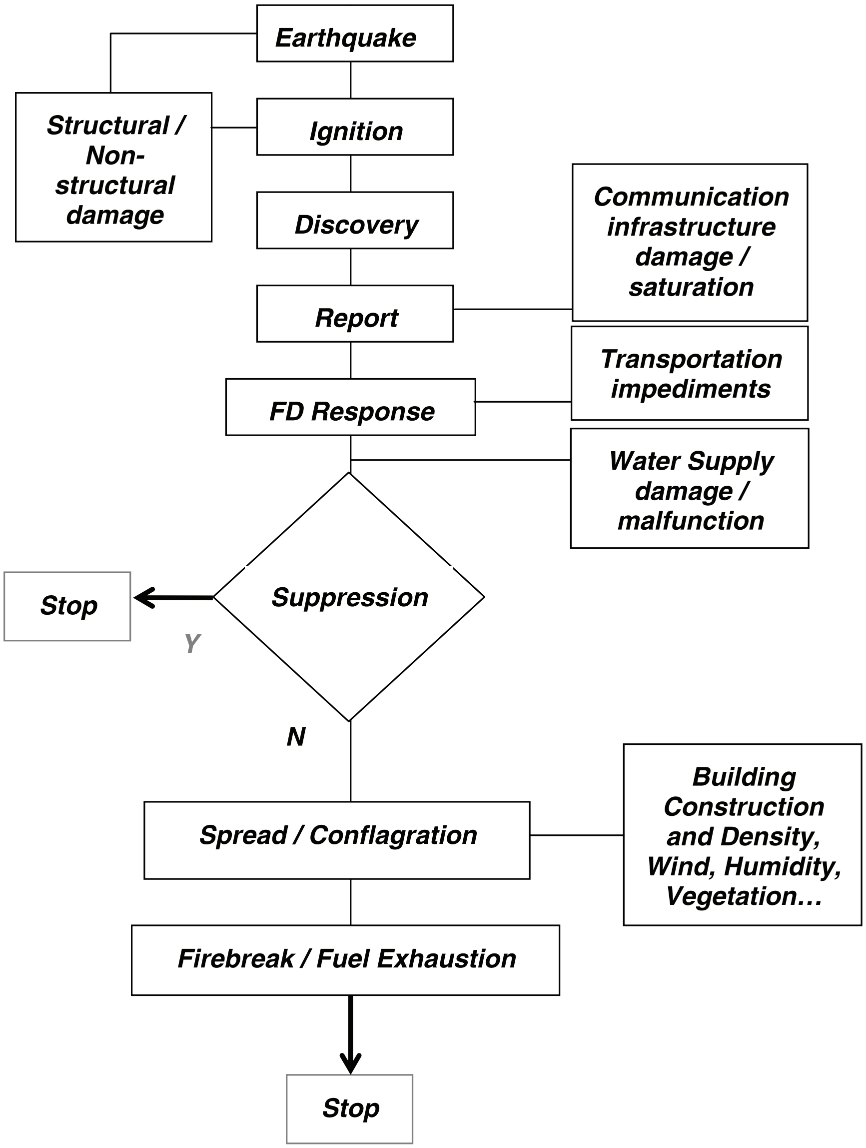

Figure 7-1 Fire following earthquake process (Scawthorn, Eidinger, and Schiff, 2005).

damage, might also be precisely defined, or their inherent uncertainty might be recognized with a probabilistic distribution. In this manner some parameters are 'deterministic' and others probabilistic, but scenario studies are usually termed 'deterministic'.

- *Probabilistic analyses,* on the other hand, typically try to recognize the inherent uncertainty in key parameters (for example, event epicenter and magnitude, ground motion, and wind speed), and employ closed form or numerical methods to consider fully the range of variables. In these studies many parameters are typically treated as deterministic, but the studies are usually termed 'probabilistic', particularly when integration over the range of event location and magnitude is performed. Because probabilistic studies typically involve significant amounts of computation, specialized software has been developed.

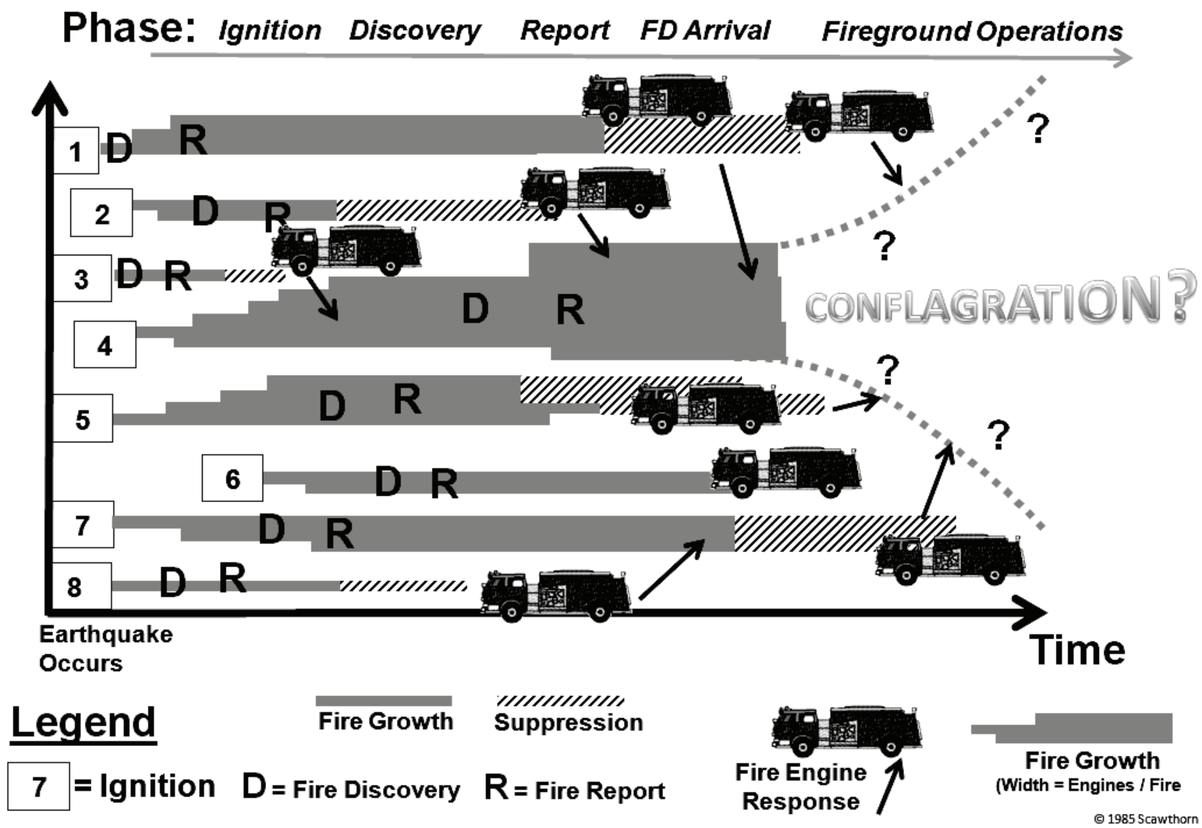

Figure 7-2 Fire department operations time line (Scawthorn, Eidinger, and Schiff, 2005).

This study is a deterministic study for four earthquake scenarios, which will be described more fully in the next section.

7.1.3 Previous Work

Explicit quantification of potential fire following earthquake losses for San Francisco was first performed in the mid-1980s under National Science Foundation and insurance industry support (Scawthorn, 1987). That study examined the effects of a repeat of the 1906 earthquake (essentially the same as the magnitude 7.9 San Andreas scenario here), finding that in San Francisco, on average, 75 ignitions would occur and, for average wind conditions, about 8.6% of the building value would be destroyed by fire following earthquake, equivalent in 2010 dollars to $21.5 billion. That study was updated (Scawthorn and Khater, 1992), revising the losses for San Francisco downward to about a 4% mean loss (equivalent in 2010 dollars to $10 billion) considering variation on a number of factors, with however, losses being significantly higher under adverse meteorological conditions. Grossi and Muir-Wood (2006) have estimated that the fire following earthquake insured loss in San Francisco would be about $3 billion.

Throughout this chapter, reference is made to San Francisco's experience in the April 1906 magnitude 7.9 earthquake and subsequent fires, and the October 1989 M_w 6.9 Loma Prieta earthquake and subsequent fires. These two events should be well-known to most readers and their details will not be elaborated here. Further information on these two events can be found from many sources, including specific discussion of relevance to the current topic (Scawthorn et al., 2006, Scawthorn et al., 1991).

7.2 Data Collection

7.2.1 Scenario Earthquakes

The four earthquake events for this study were specified by the CAPSS project, and are shown in Table 7-1. The maximum peak ground acceleration (PGA) for any one city block for each scenario is also shown in Table 7-1. While the San Andreas fault magnitude 7.9 scenario event is a much larger event overall than the San Andreas fault magnitude 6.5 scenario event (total energy release is more than 100 times greater in the magnitude 7.9 event), the PGA for the San Andreas fault magnitude 6.5 scenario event is still large (the magnitude 6.5 maximum PGA is 80% of the magnitude 7.9 maximum PGA).

Table 7-1 CAPSS Earthquake Scenarios, Including Maximum PGA

Event	Fault / segment	Max PGA
San Andreas fault, Magnitude 7.9	San Andreas	0.67g
San Andreas fault, Magnitude 7.2	San Andreas / Peninsula	0.61g
San Andreas fault, Magnitude 7.5	San Andreas / Peninsula	0.55g
Hayward fault, Magnitude 6.9	Hayward / North & South	0.36g

Ground failure is a major effect of most earthquakes, and can take several forms, such as liquefaction or landsliding. Failure of the ground was widespread in 1906, occurred in the Marina in the 1989 Loma Prieta earthquake, and can be expected to occur in future San Francisco earthquakes. Assessing potential ground failure is important for analysis of fire following earthquake since ground failure is likely to cause high rates of underground pipe breakage, thus disrupting firefighting water supply and potentially damaging gas mains. San Francisco is recognized to have a significant potential for ground failure in some parts of the City, and this potential has been mapped by various agencies and experts. Figure 7-3 shows a map of liquefaction susceptibility used in the CAPSS project, overlaid by the SFFD Infirm Zones. These zones were identified by the Fire Department (and named appropriately) following the 1906 earthquake, for special consideration in the design of the Department's Auxiliary Water Supply System (AWSS, discussed further below).

7.2.2 San Francisco Building Density and Construction

Two key parameters for estimation of fire following earthquake losses are building density and materials of construction. Detailed data at the city block level, for 5,323 blocks, was used, including estimates of total floor area by 66 different building types, categorized by material of construction, height, and applicable building code era. Figure 7-4 shows San Francisco's building inventory in terms of total floor area per block for wood (shades of red), and fire resistive (shades of gray) buildings. The

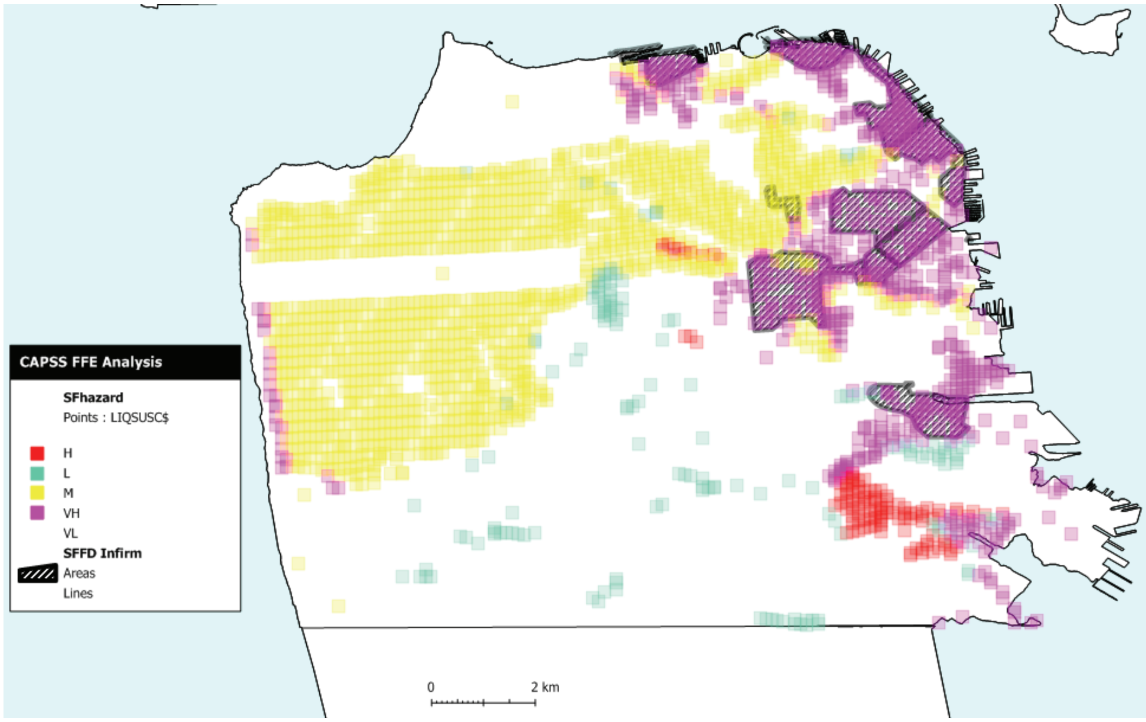

Figure 7-3 Liquefaction susceptibility overlaid by San Francisco Fire Department infirm areas. H: high; L: low; M: moderate VH: very high; VL: very low. (Source: SPA Risk).

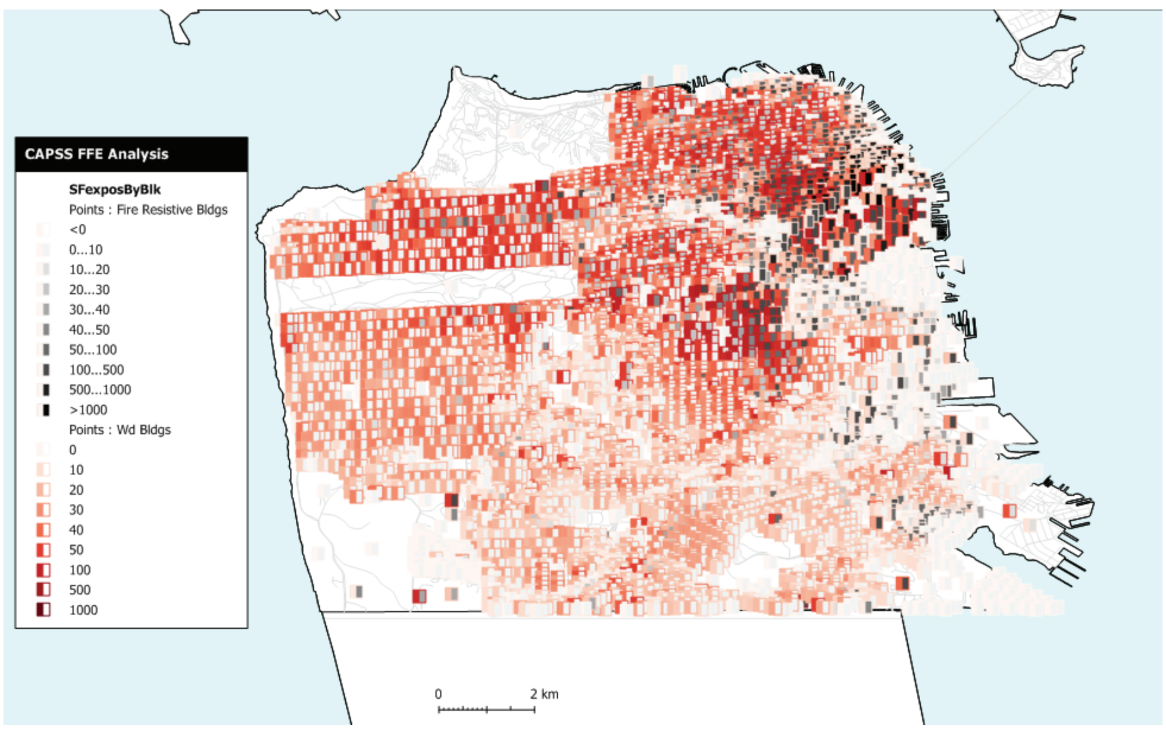

Figure 7-4 San Francisco building inventory, total floor area per block for wood (shades of red), and fire resistive (shades of gray) buildings. The more 'red' an area, the higher the total floor area of wood buildings. Most of the City, especially north and east of Golden Gate Park, is clearly dense wood construction, while downtown has little wood. (Source: SPA Risk).

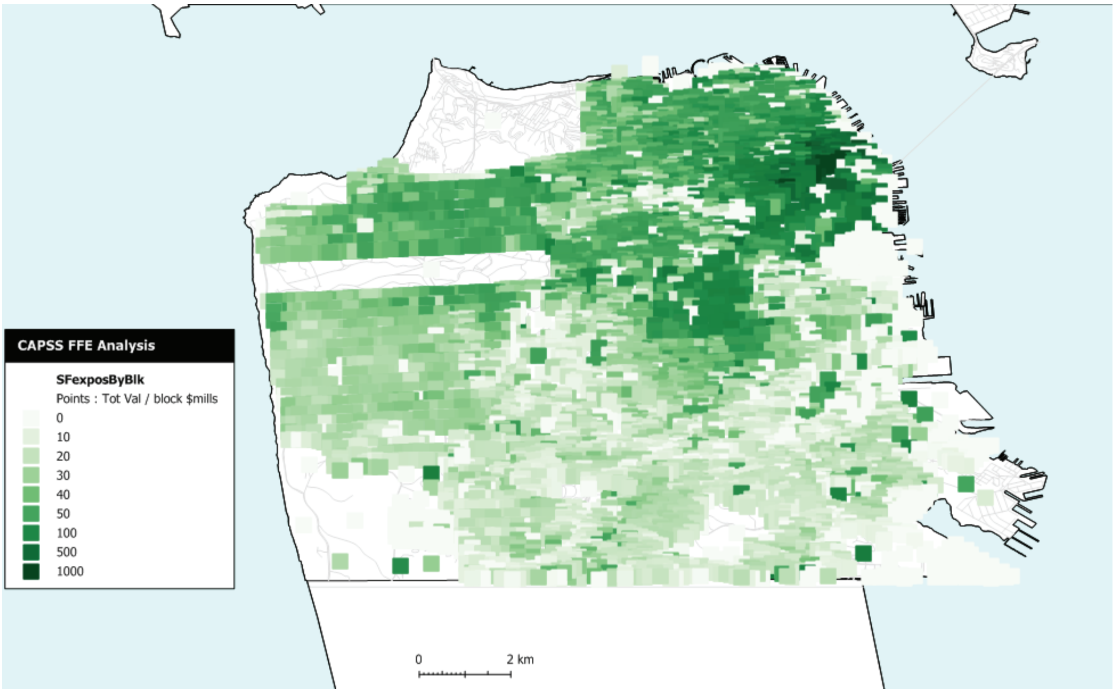

Figure 7-5 San Francisco building inventory value at the block level (millions $). (Source: SPA Risk).

more 'red' an area, the higher the total floor area of wood buildings. Most of the City, especially north and east of Golden Gate Park, is clearly dense wood construction, while downtown has little wood. The total floor area for all buildings in this database is approximately 510 million sq. ft.[9], with a total replacement value of about $205 billion. The distribution of building value at the block level is shown in Figure 7-5 (recent major development in Mission Bay area is not included).

The average building total floor area per block in San Francisco is 95,000 sq. ft., while the maximum is 4.3 million sq. ft. Block sizes vary significantly in San Francisco[10], especially in the older portion of the city, but example dimensions[11] are 310 x 670 ft (Richmond), 490 x 340 ft (downtown), and 275 x 658 ft (Hunter's Point). GIS data for blocks and lots were sampled in various parts of the city, shown in Figure 7-6, arriving at an estimated average block size (i.e., sum of lots) of about 140,000 sq. ft. Typical street widths[12] were sampled from the GIS data as well as Google Earth, shown in Figure 7-7, and vary from 60 ft. downtown, 70 and 75 ft. in many parts of the city, to 80 ft. in the Sunset. Selected streets such as Market Street are much wider and constitute significant fire breaks (although in 1906, the fire jumped even this broad street).

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[9] However, this represents only buildings under the purview of the Dept. of Building Inspection, and omits public and selected other buildings.

[10] Even defining a 'block' is problematic, as many 'blocks' are bisected by alleys, and street patterns are extremely irregular in certain parts of the city, such as around Peaks.

[11] Measured center-of-intersection to center-of-intersection, so therefore including a full street width on both length and width of the block dimension.

[12] Measured face-of-building to face-of-building.

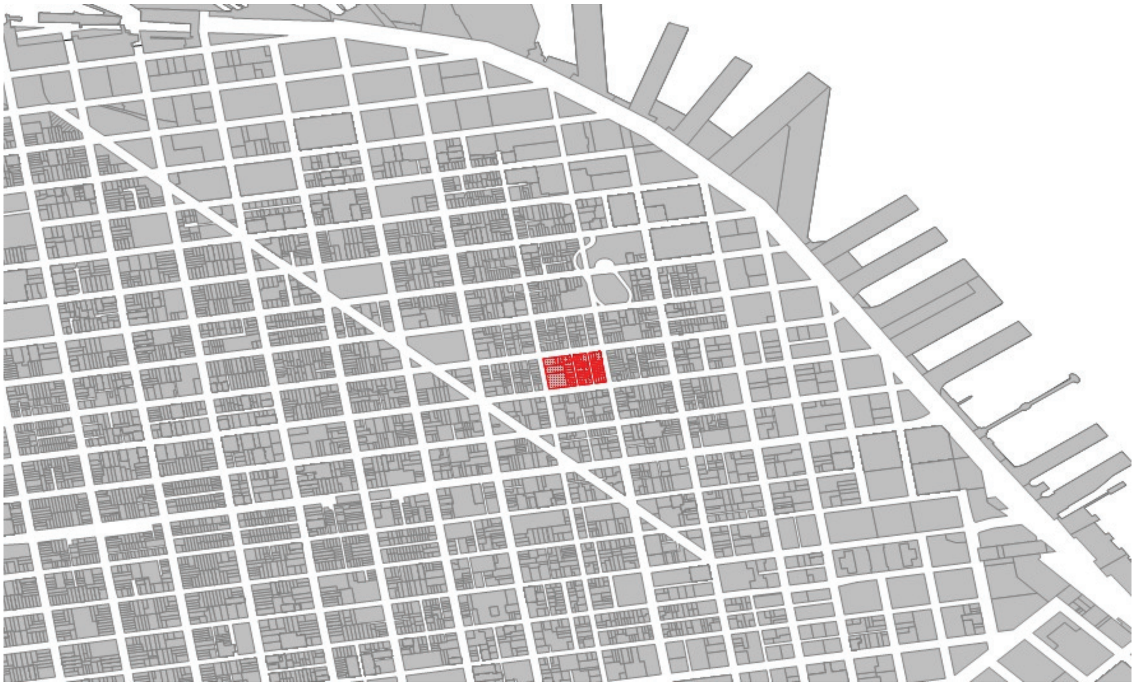

Figure 7-6 GIS data, block and lot, San Francisco.

Figure 7-7 Street width (building face-building face) sampled from Google Earth (example: 27th Ave between Moraga and Noriega).

7.2.3 San Francisco Fire Department and Allied Resources

Data were collected on the San Francisco Fire Department's (SFFD) resources. SFFD protects the 46.7 square mile City and County of San Francisco, whose 2009 resident population was estimated to be 815,000[13], and whose daytime maximum

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[13] http://quickfacts.census.gov/qfd/states/06/06075.html

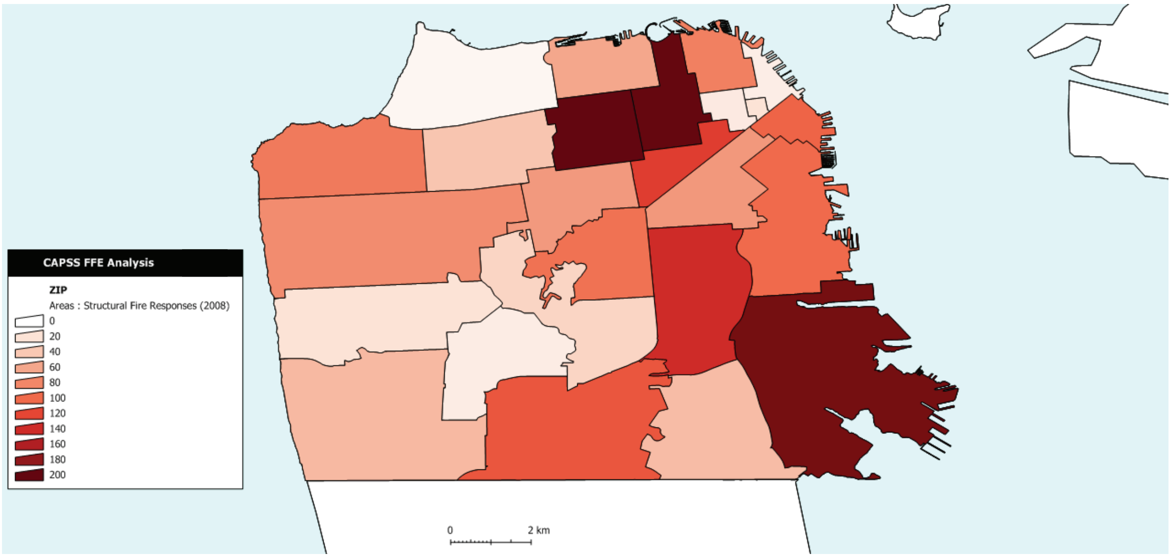

Figure 7-8 *San Francisco Fire Department 2008 structural fire responses, by zip code (total responses 1,980). (Source: SPA Risk).*

population may at times reach 1.5 million. San Francisco city limits include the former military installations of the Presidio and Treasure Island. SFFD also provides protection at San Francisco International Airport, where it maintains three stations. In 2008, SFFD responded to 1,980 structural fires, as shown in Figure 7-8.

Figure 7-9 and Table 7-2 show locations of SFFD's 42 fire stations within the City. These stations were reviewed for seismic adequacy in the mid-1980s (EQE/AGS, 1989) and subsequently most of the stations were rebuilt or seismically retrofitted, so that today the great majority of stations may be considered as seismically reliable in the four scenario events considered here.

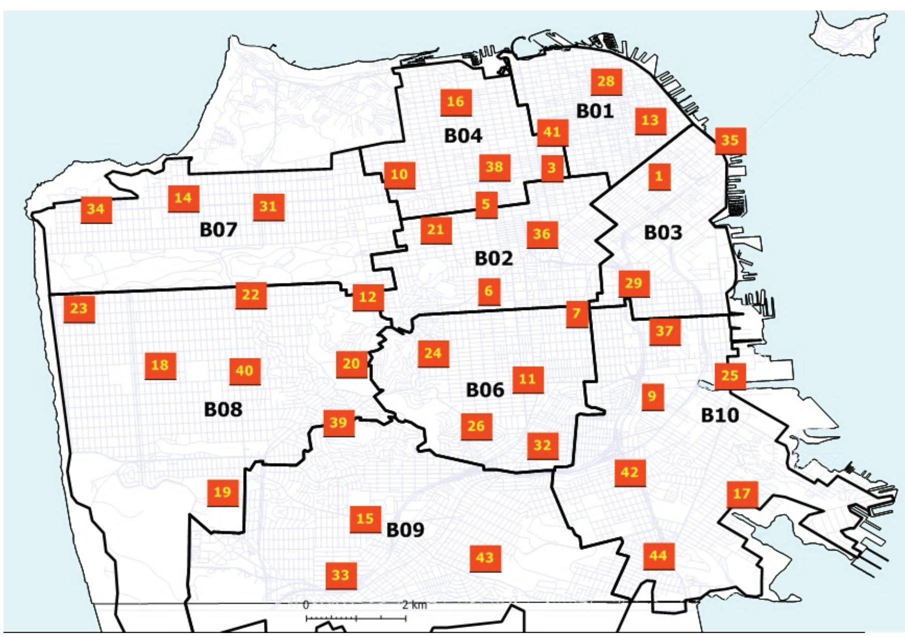

Figure 7-9 *San Francisco Fire Department fire station locations and Battalion Districts.*

Table 7-2 San Francisco Fire Department Fire Stations and Apparatus

Station	Address	Engine	Truck	Other
1	676 Howard St.	1	1	Rescue Squad
2	1340 Powell St.	1	1	Battalion 1 Chief
3	1067 Post St.	1	1	
5	1301 Turk St.	1	1	Division 2 Chief
6	135 Sanchez St.	1	1	
7	2300 Folsom St.	1	1	Division 3 Chief
8	36 Bluxome St.	1	1	Battalion 3 Chief
9	2245 Jerrold St.	1	1	Battalion 10 Chief
10	655 Presidio Ave.	1	1	
11	3880-26th St.	1	1	Battalion 6 Chief
12	1145 Stanyan St.	1	1	
13	530 Sansome St.	1	1	
14	551-26th Ave.	1	1	
15	1000 Ocean Avenue	1	1	Battalion 9 Chief
16	2251 Greenwich St.	1	1	
17	1295 Shafter St.	1	1	Portable Water Supply System (PWSS) Hose Tender
18	1935-32nd Avenue	1	1	
19	390 Buckingham Way	1	1	
20	285 Olympia Way	1		
21	1443 Grove St.	1		
22	1290-16th Avenue	1		PWSS Hose Tender
23	1348-45th Avenue	1		
24	100 Hoffman St.	1		
25	3305-3rd Street	1		
26	80 Digby St.	1		
28	1814 Stockton St.	1		
29	299 Vermont St.	1		
31	441-12th Ave.	1		Battalion 7 Chief
32	194 Park St.	1		
33	#8 Capitol Ave.	1		
34	499-41st Ave.	1		Cliff Rescue Unit
35	Pier 22-1/2, Fireboats 1 & 2 (no Engine at present)			
36	109 Oak St.	1		Hazardous Materials Unit, Battalion 2 Chief
37	798 Wisconsin St.	1		
38	2150 California St.	1		PWSS Hose Tender, Battalion 4 Chief
39	1091 Portola St.	1		
40	2155-18h Ave.	1		Battalion 8 Chief
41	1325 Leavenworth St.	1		
42	2430 San Bruno Ave.	1		
43	720 Moscow St.	1		
44	1298 Girard St.	1		
48	Treasure Island (849 Ave. D)	1	1	PWSS Hose Tender
51	Presidio of S. F. (Lincoln Blvd.)	1		
Total		**42**	**19**	

Under normal operations, SFFD operates one engine from each station, as well as one truck or another apparatus or other equipment from selected stations[14], for a total of 42 engines and 19 trucks. SFFD also has on average five reserve engines that would be put in service in an earthquake emergency[15], with some delay, since they are not normally stocked with hose and equipment. SFFD also operates two dedicated fireboats, which are discussed further below.

SFFD has approximately 1,750 uniformed firefighters, including Chief of Department, officers, and firefighters. Each duty shift typically has about 325 officers and firefighters, not counting non-firefighter paramedics and emergency medical technicians on SFFD ambulances. SFFD also maintains a volunteer San Francisco Fire Reserve (http://sffd-fire-reserve.org/) that currently numbers approximately 30 personnel, and who are useful at support tasks such as deploying 5" hose, portable hydrants, and picking up hose; however, they have no firefighting or rescue experience. Many firefighters live outside the City. In 1989 a general recall order was issued, and many SFFD personnel responded within several hours, including many who had not actually heard of the recall order.

SFFD also supports the Neighborhood Emergency Response Team (NERT) program. NERT is a free training program for individuals, neighborhood groups, and community-based organizations in San Francisco, through which individuals learn the basics of personal preparedness and prevention. The training includes hands-on disaster skills that will help individuals respond to a personal emergency as well as act as members of a neighborhood response team. Since 1990, the NERT program has trained more than 17,000 San Francisco residents to be self-reliant in a major disaster.

For comparison, in 1906, the San Francisco Fire Department protected approximately 400,000 persons occupying an urbanized area of approximately 21 square miles. The department consisted of a total of 585 full-paid fire force personnel resident within the City and on duty at all times, and deployed in 57 companies (38 engine, one hose, ten ladder, one hose tower, and seven chemical). The rated pumping capacity of the 38 first line and 15 relief and reserve engines totaled 35,100 gallons per minute (gpm) (NBFU, 1905). Table 7-3 compares the City Fire Department in 1906 and today. While the population and area have more than doubled, the number of fire engines has barely increased (only fire engines are compared here, as they are the only apparatus that supplies water for fire suppression). However, when the capabilities of the City's two fireboats, and the AWSS (discussed below) are taken into account, the total pumping capacity has more than doubled, demonstrating the great value of the fireboats and the AWSS (and economy, as the staffing costs for these assets are relatively modest).

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[14] 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.

[15] This was done in the 1989 Loma Prieta earthquake, including putting in service an engine from the Fire Department's Museum. However, post-incident review indicated the capability and amounts of reserve engines, hose, and other vital equipment were not satisfactory, and should be improved.

7.2.4 Water Supply and Other Infrastructure

Water supply is critical to firefighting. A great irony is that San Francisco is surrounded on three sides by the largest body of water on earth, yet suffered one of the world's greatest conflagrations in 1906 due to lack of firefighting water. As a result of that experience, San Francisco today has, in addition to the normal potable water supply system (herein termed the Municipal Water Supply System), an extensive system of fire-fighting-specific water supplies, the understanding of which is vital to an analysis of fire following earthquake risk in San Francisco. First, the potable water system is briefly discussed, and then the other systems are discussed, referring the reader to citations for more detail.

Table 7-3 Comparison of San Francisco Fire Department, 1906 and Today

	1906	2010
Population Protected (thous.)	400	815
Area Protected (sq. mi.)	21	46.7
SFFD personnel[a]	585	1750
Engine companies	38	42
Fireboats	-	2
Auxiliary Water Supply System (AWSS)[b]	Proposed	Yes
Cisterns	23	172
Total SFFD Pumping Capacity (gallons per minute, gpm)		
Pumping Capacity (gpm)		
engines only	35,100	50,400
engines + fireboats	35,100	70,400
engines + fireboats + AWSS	35,100	90,400
Pump. Cap. Per capita (gpm pc)		
engines only	0.09	0.06
engines + fireboats	0.09	0.09
engines + fireboats + AWSS	0.09	0.11
Pump. Cap. Per Firefighter (gpm /ff) [c]		
engines only	60	29
engines + fireboats	60	40
engines + fireboats + AWSS	60	52

Notes:

a. In 1906, the 585 firefighters were virtually all resident in San Francisco, while today a significant number of SFFD personnel reside outside the City.

b. The AWSS was proposed by Chief Dennis Sullivan and others in 1905, but was repeatedly turned down by the San Francisco Board of Supervisors as too expensive (see text).

c. Based on all 1750 uniformed personnel today – if only on-duty firefighters are considered, or on-duty plus those likely to quickly return to duty in a major earthquake, the 52 gpm/ff would be closer to 150~250 gpm/ff.

Municipal Water Supply System

San Francisco's Municipal Water Supply System provides water from 18 different reservoirs and a number of smaller storage tanks. The water is stored at different levels, creating zones, or districts, where water is distributed within certain ranges of pressures. There are 23 different pressure districts, of which the Sunset and University Mound Reservoir Systems are the largest. Figure 7-10 shows a plan view of the Sunset Reservoir System, in which the trunk, or feeder, mains are indicated. The pipelines in this portion of the feeder main network range in diameter from 10 to 60 in., and vary in composition from riveted and welded steel to cast iron. There are approximately 300 mi. of feeder pipelines in the Municipal System. Distribution pipelines are principally 4, 6, and 8 in. in diameter. They receive water from the feeder main network for delivery to hydrants and buildings. There are approximately 850 mi. of distribution piping in the Municipal System.

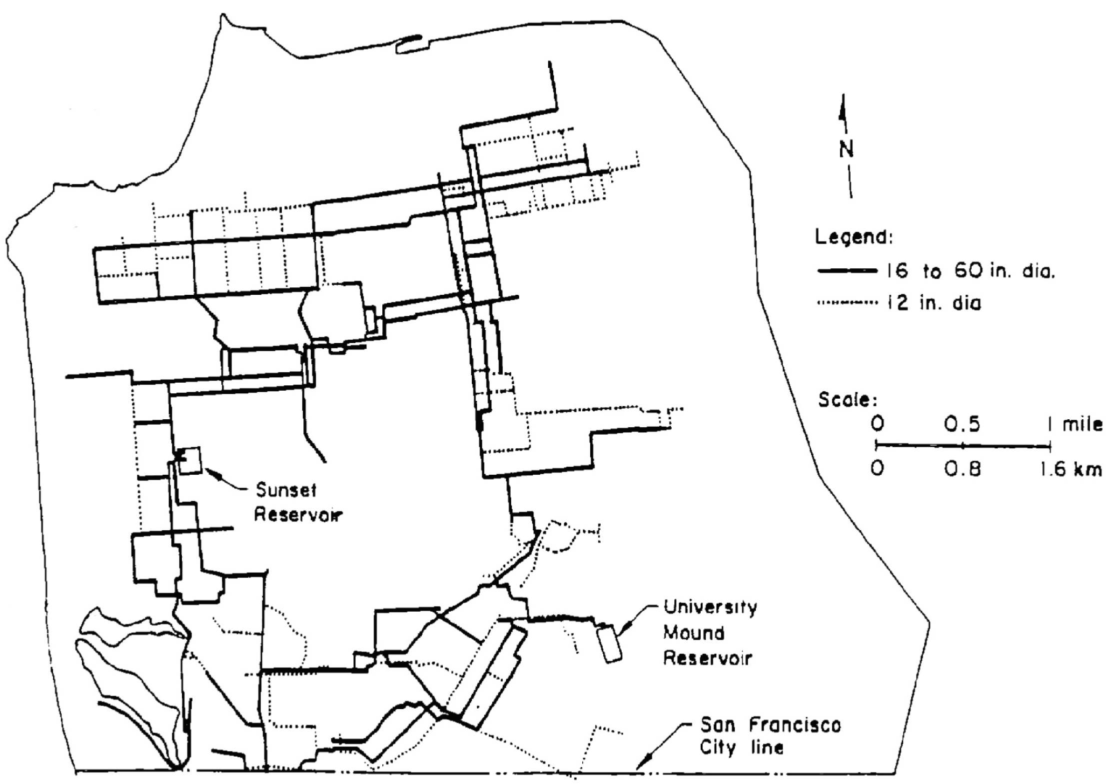


Figure 7-10 San Francisco Sunset Reservoir System portion (only) of Municipal Water Supply System (adapted from O'Rourke et al., 1990).

In the 1989 Loma Prieta earthquake, damage was relatively low throughout the Municipal System in areas outside the Marina, with a total of 30 breaks. Within the Marina, there were 123 repairs in an area with approximately 37,000 ft. of pipelines belonging to the Municipal System (and 7,500 ft. of pipelines belonging to the Auxiliary Water Supply System) (O'Rourke et al., 1990).

Information on the Municipal System for a detailed analysis was not available for this study. As an approximation, Municipal System distribution piping was assumed to lie under all city streets, creating a 'proxy' system equivalent to about 1,200 miles of pipe, which approximately corresponds to the known total of 1,130. A relation for estimation of pipe breaks (O'Rourke and Ayala, 1993) was employed to estimate the number of pipe breaks for the San Andreas fault magnitude 7.9 scenario. This ‘proxy’ analysis estimates there will likely be over 1,100 breaks in the Municipal System, as shown in Figure 7-11, where estimated pipe breaks are shown in red overlaid on estimated San Andreas fault magnitude 7.9 event ground velocity. Note that the estimation of the pipe breaks is a random process, so that only the general distribution, and not specific locations, of breaks are meaningful. As can be seen in the figure, high concentrations of breaks can be expected in high hazard ‘infirm’ zones such as Mission and Islais Creeks, and a relatively low number of breaks on better soils in the northeast quadrant of the city. Of interest is the relatively large number of breaks spread over a broad area in the Richmond and Sunset, due to the high ground motion amplitudes closer to the San Andreas fault. This number of breaks is likely to result quickly in much of the Municipal System losing pressure, a situation similar to that in 1906 (in which over 28,000 breaks were sustained, including service line breaks).

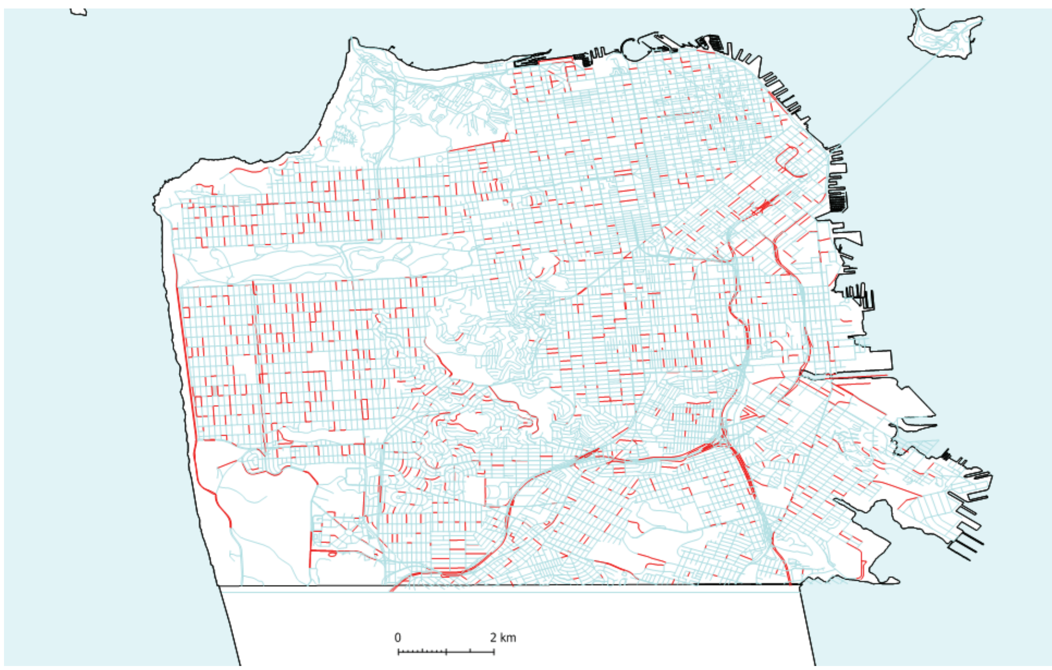


Figure 7-11 San Francisco proxy Municipal Water Supply System with estimated pipe sections with breaks shown in red, for San Andreas fault magnitude 7.9 scenario. The estimation of the pipe breaks is a random process, so that only the general distribution, and not specific locations, of breaks are meaningful.

Auxiliary Water Supply System

The need for a ‘high pressure water supply system’ was recognized in San Francisco prior to the 1906 earthquake, but had not yet been implemented due to its being deemed ‘too expensive’ (Tobriner, 1989; Dalessandro, 2005). Following the 1906 conflagration, the need was obvious, and San Francisco built the high pressure Auxiliary Water Supply System, which was largely completed by 1912. Space does not permit a detailed description of the Auxiliary System here (see Scawthorn, O’Rourke and Blackburn, 2006 for a detailed description). In summary, the Auxiliary System consists of several major components (see Figures 7-12 and 7-13):

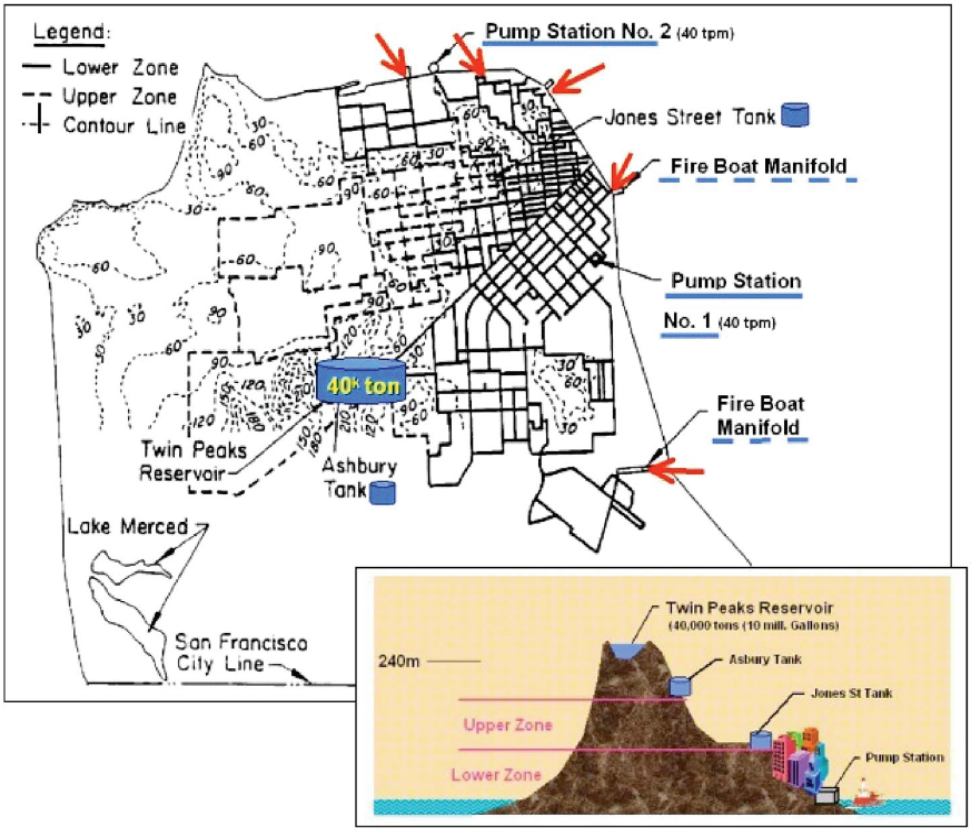


Figure 7-12 San Francisco Auxiliary Water Supply System overall schematic. (adapted from Scawthorn, O'Rourke, and Blackburn, 2006).

- *Static Supplies*: The main source of water under ordinary conditions is a 10-million-gallon reservoir centrally located on Twin Peaks, the highest point within San Francisco (approximately 750 ft. elevation).
- *Pump Stations*: Because the Twin peaks supply may not be adequate under emergency conditions, two pump stations exist to supply salt water from San Francisco Bay; each has 10,000 gpm at 300 psi capacity. Both pumps were originally steam-powered but were converted to diesel power in the 1970's.
- *Pipe Network*: The Auxiliary System-supplied water is conveyed to dedicated street hydrants by a special pipe network that, by the end of the 1980s, had a total length of approximately 120 miles (200 km). The pipe is bell and spigot, originally extra heavy cast iron (e.g., 1" or 25 mm wall thickness for 12" or 300 mm diameter), and more recent extensions are heavy ductile iron (e.g., 0.625" or 15mm wall thickness for 12" or 300 mm diameter). Restraining rods connect pipe lengths across joints at all turns, tee joints, hills, and other points of likely stress.
- *Fireboats*: A major deficiency in 1906 was the lack of a fireboat to be able to pump large volumes of water from San Francisco Bay. Today, two powerful fireboats are provided, the Phoenix and the Guardian, capable of pumping 9,600 and 24,000 gallons per minute (respectively, at 150 psi) into the Auxiliary System, in addition to the two pump stations. The pipe network has manifold connections located at several points along the City's

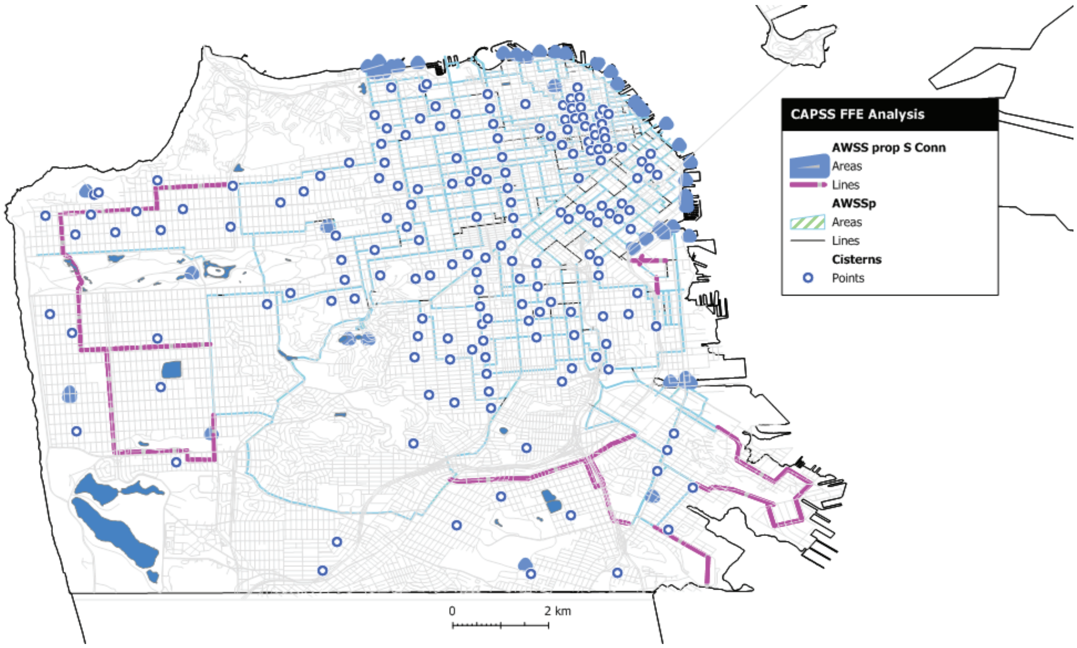


Figure 7-13 Auxiliary Water Supply System pipe network (magenta are some of the extensions that were proposed to be constructed with the 2010 Prop. B funding), suction connections (large blue 'blobs') and cisterns (smaller blue circles with white center). Note that actual changes to the system may vary from what is shown because this figure was taken from a document developed during the planning stages of this expansion. (Source: San Francisco Department of Public Works).

waterfront in order to permit the City's two fireboats to act as additional "pump stations", drafting from San Francisco Bay and supplying the Auxiliary System.

- *Cisterns*: San Francisco has 172 underground cisterns, largely in the northeast quadrant of the City, but with newer cisterns in outer residential areas.

The Auxiliary System is a remarkably well-designed system for reliably furnishing large amounts of water for firefighting purposes under normal conditions, with many special features to increase reliability in the event of an earthquake. A key aspect of San Francisco's ability to maintain, and even extend this unique system, is that it is, by City charter, owned and operated by the fire department. The Auxiliary System is intended to be just that: an auxiliary system, to supplement the use of the municipal water supply system for fighting large fires, under non-earthquake as well as earthquake conditions. This is an important point—it does not remain undisturbed, waiting for an earthquake. Rather, the department uses it at most greater alarm incidents, thereby gaining valuable experience, confirming its continued functionality and reliability, and justifying the system's existence. Another point is that the underground piping system was designed from the beginning to be highly earthquake resistant—the piping is extra heavy-walled, and has restrained joints to resist pullout at numerous locations.

Following the 1906 earthquake, the significance of the 'infirm zones' was clearly recognized, and the Auxiliary System was designed so that, while Auxiliary System pipe passes through these zones, the system can be quickly isolated should pipelines in those zones fail. In modern times, the gate valves isolating the infirm zones have been motorized and can be remotely controlled via radio. As a result of the elevation of the Twin Peaks reservoir, and the capacity of the pumping stations and the fireboats, very high pressures, in excess of 300 psi, can be sustained in the Auxiliary System. This pressure assures a high volume supply, but is too high for many applications, and can be reduced via Gleeson valves – a patented pressure reduction valve invented in the San Francisco Fire Department shops. The Gleeson valve permits a firefighter to attach one or several handlines to an Auxiliary System hydrant, and apply firestreams as if from a fire engine. Thus, the Auxiliary System reduces the need for fire engines, and permits a continuous water curtain to be sprayed from a line of hydrants along a defensive line.

Designed almost a century ago with great foresight and skill, the San Francisco Auxiliary System was intended to be a seismically reliable water supply system for fire protection. Even so, the 1989 Loma Prieta earthquake damaged a few components of the Auxiliary System. This was the main reason for lowered pressure in the Lower Zone (the Upper Zone was not affected) and prevented the system from supplying water to the Marina fires.

A major enhancement to the Auxiliary System was added in the 1980s with the addition of a Portable Water Supply System (PWSS), which greatly extends the reach of the Auxiliary System. Figure 7-14 illustrates how the Portable System works. In the 1989 Loma Prieta earthquake, it was the Portable System working together with the fireboat Pheonix that finally provided the water that allowed the fire to be extinguished. Today, SFFD has four PWSS hose tenders, one of which is stationed on Treasure Island for the foreseeable future, so that only three may be available in the event of a large earthquake. SFFD seeks to acquire 18 redesigned PWSS units, each containing trailers for hose, portable hydrants and other parts, a pump engine, and a high-pressure monitor, or water cannon. The monitors can spray water curtains, and NERT could be trained to assist with the units.

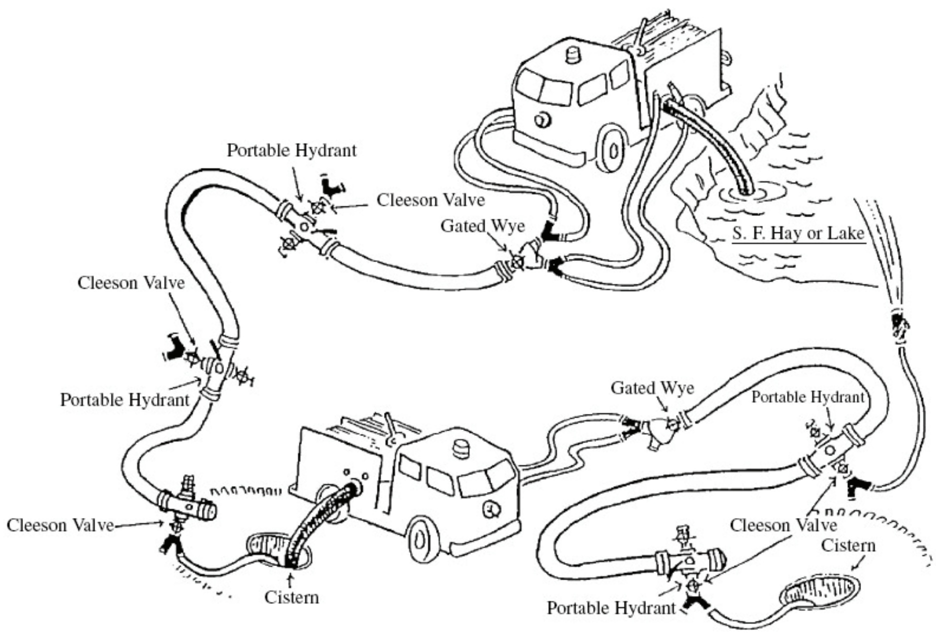


Figure 7-14 San Francisco Portable Water Supply System. (Source: PWSS Limited).

Recognizing that the Auxiliary System was impaired during the 1989 Loma Prieta earthquake, a modest earthquake relative to the scenario events considered in this study, the number of potential breaks that might occur in the Auxiliary System were estimated for the given scenario events. Figure 7-15 shows the resulting 19 estimated breaks in red, overlaid on a map of San Andreas fault magnitude 7.9 scenario peak ground velocity (PGV). While the number of breaks is relatively small when compared with the Municipal System, these few breaks could significantly diminish, or even eliminate, the Auxiliary System as a useful fire-fighting system in the event of a major earthquake. However, timely command decisions to close motorized gate valves and make up for break losses with the use of the two pump stations and the fireboats, could maintain the utility of the Auxiliary System immediately following the earthquake. This aspect should be the focus of specialized procedures and training by SFFD.

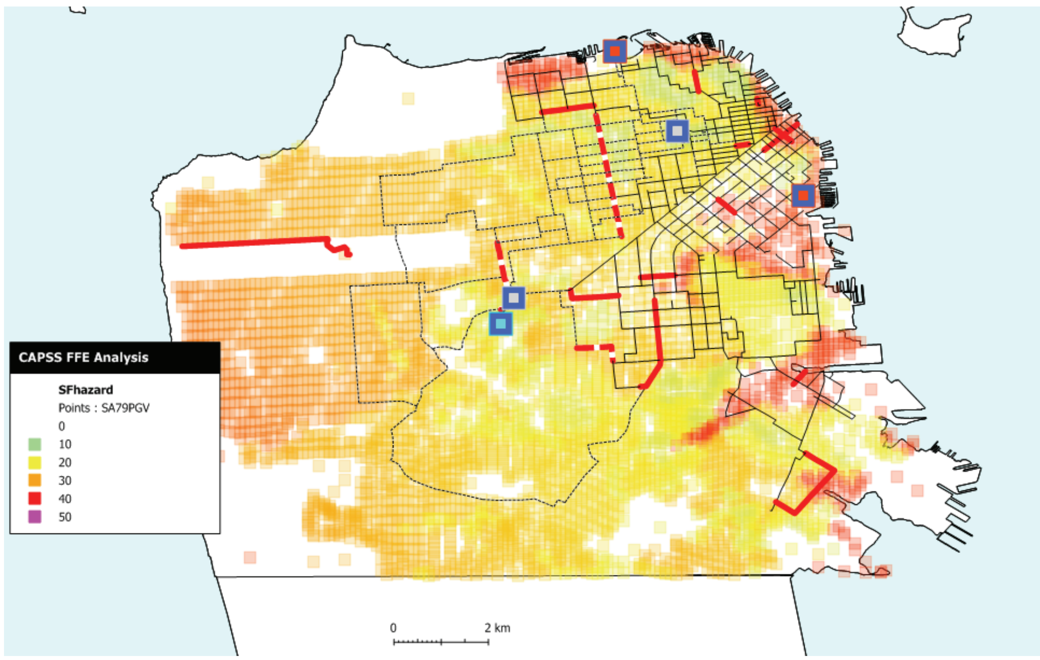


Figure 7-15 Auxiliary Water Supply System with estimated pipe breaks shown in red, overlaid on San Andreas fault magnitude 7.9 event (SA79) peak ground velocity (inches per second). The estimation of the pipe breaks is a random process, so that only the general distribution, and not specific locations, of breaks are meaningful. (Source: SPA Risk).

7.2.5 Wind Speed

Windspeed is an important factor in fire spread. Data were collected on windspeed frequency in San Francisco and are shown in Figure 7-16.

7.3 Analysis and Results

This section presents a summary of the fire following earthquake analyses performed for the four scenario events, and results. Because of the stochastic nature of the fire following earthquake process, there is not an exact solution as to where ignitions will occur, or the size of the final burnt area. Rather, the analysis takes into account the variation or uncertainty of key parameters through a random sampling of these parameters' underlying frequency of occurrence, and then employs the resulting set of randomly-selected parameters in the model outlined above, to create one trial. This process is repeated numerous times, the result of which is a distribution of the frequency of ignitions, pipe breaks, fire spread and other parameters, and a distribution of the frequency of the overall burn area. For the analysis and main results here, typically 1,000 trials were performed for each scenario (this is discussed further below).

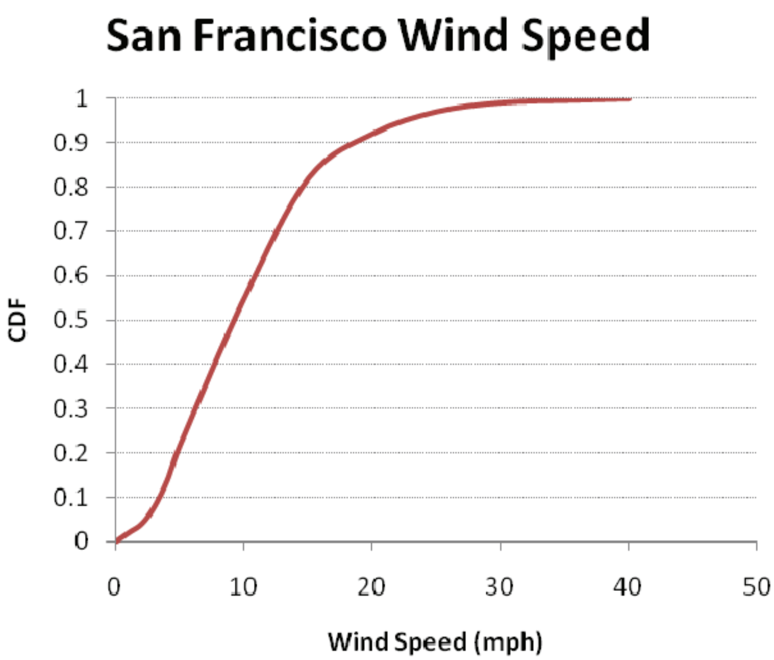


Figure 7-16 San Francisco wind speed (City average) curve indicating the probability that a particular wind speed is attained but not exceeded. CDF: cumulative distribution function.

7.3.1 Ignitions

Based on methods developed for FEMA and the HAZUS®99 program (documented in SPA Risk, 2009), and employing data presented above, the total number of fire ignitions likely to occur given various patterns of ground shaking was estimated for each scenario. Ignition sources would likely be similar to causes in the 1994 Northridge earthquake, which is the best U.S. dataset for recent fires following an earthquake—about half of all ignitions would be electricity-related, a quarter gas-related, and the remainder due to a variety of causes, including chemical reaction, shown in Table 7-4 (Scawthorn, Cowell, and Borden, 1998). Although electric power often fails during the earthquake shaking in high shaking intensity areas, electrically-caused ignitions still occur, due either to arcing before power fails, stored energy in electrical appliances, or when power is restored. Also based on the Northridge experience, about half of all ignitions would typically occur in single-family residential dwellings, with another 26% in multi-family residential occupancies—that is, about 70% of all ignitions occur in residential occupancies, Table 7-5 (Scawthorn, Cowell, and Borden, 1998). Educational facilities would be a small percentage of all ignitions (3% in Northridge), and most of these are due to exothermic reactions of spilled chemicals in chemistry laboratories.

Another issue for San Francisco is ignitions in high-rise buildings, clearly a concern, due (a) to the potential for large life loss, and (b) high property values. While difficult to foresee, it is possible that fire department response to high-rise fires will be simply to try to ensure safe evacuation of occupants, and not to engage in aggressive fire attack (which, simply put, would require too many resources spread too thin). Recent earthquakes (1995 Kobe, 2010 Chile) did not cause any high-rise fires. If high-rise fires do occur, they may in many cases not spread to a significant degree, due to modern fire protection features such as compartmentation and sprinklers. However, as seen in the 7 World Trade Center fire and collapse, in the late afternoon of September 11, 2001, these features may not protect a high-rise in the absence of aggressive fire-fighting.

Table 7-4 General Sources of Ignition, Los Angeles Fire Department Data, 1994 Northridge Earthquake

Source	Fraction
Electrical	56%
Gas-related	26%
Other	18%

Table 7-5 Property Use for 77 Los Angeles Fire Department Earthquake-Related Fires, 4:31 TO 24:00 hrs, January 17, 1994

General Property Use	Fraction
One- or Two-Family Residential	45%
Multi-Family Residential	26%
Public Roadway	8%
Office	5%
Primary / Secondary School	3%
Vacant Property	3%
Restaurant	1%
Commercial	1%
Power Production/Distribution	1%
Other	5%
Unknown	1%

The actual number of ignitions varies with each trial of each ground shaking simulation, so that the frequency distribution of ignitions for the four scenarios is shown in Figure 7-17 and Table 7-6.

The results indicate that on average, about 95 fires would be expected following a M_w 7.9 San Andreas event, 73 fires following a M_w 7.2 San Andreas event, 57 following a M_w 6.5 San Andreas event, and 37 following a Hayward M_w 6.9 event.

However, these are mean values (the medians are similar), with considerable variation. For example, for the San Andreas M_w 7.9 event, Table 7-6 shows that there is an 18% probability of the number of ignitions being less than 60, and a 25%

probability of the number of ignitions being greater than 120, and 10% chance of the ignitions being greater than 140.

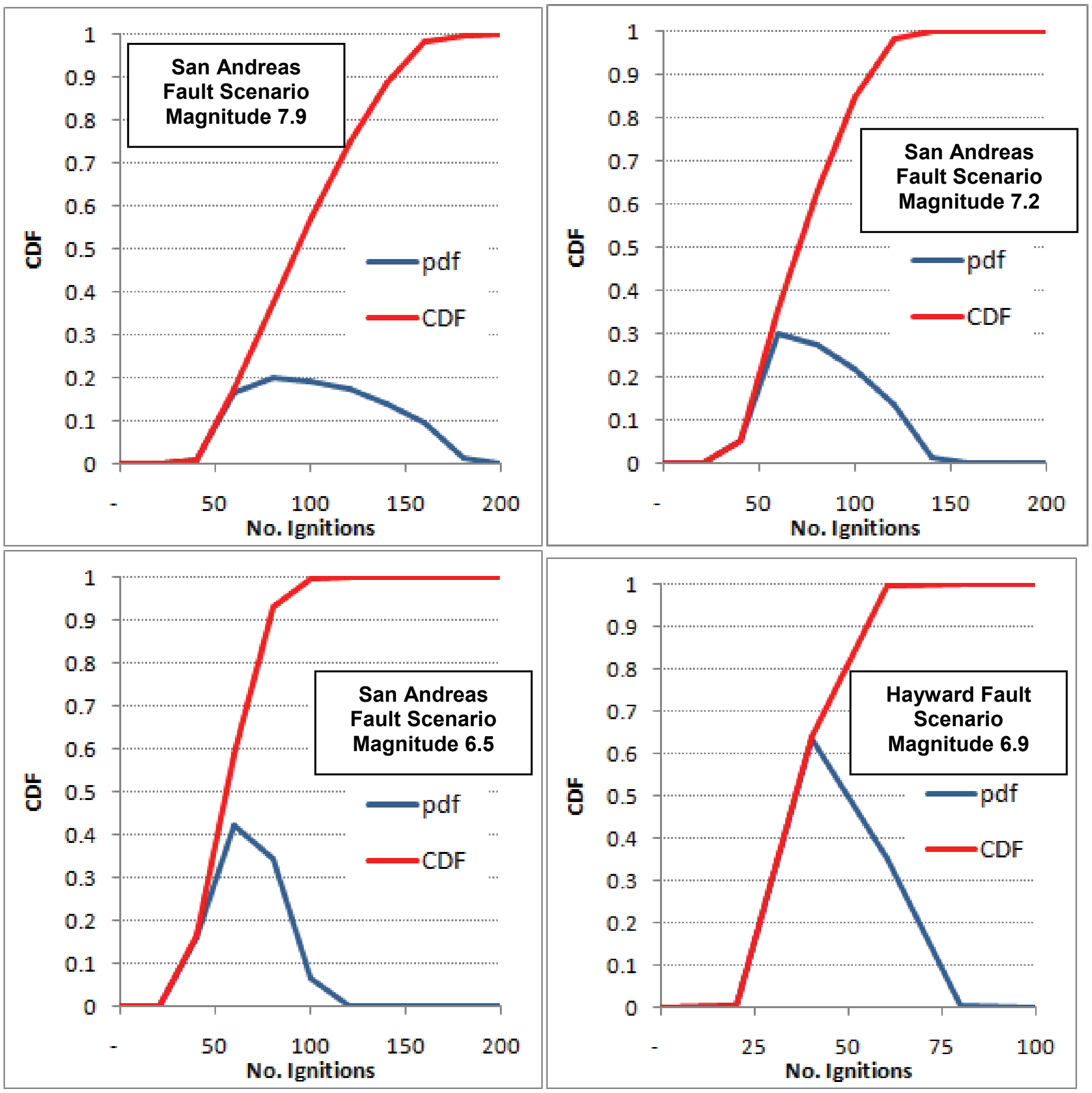


Figure 7-17 Frequency distribution of ignitions, four scenario events. CDF: cumulative distribution function; pdf: probability density function;.

7.3.2 Initial Response

Depending on the specific event, the hundred or so ignitions requiring fire department response will initially be responded to by citizens—they will be able to suppress some fires, which are not included in the overall estimate. When they realize the fire is beyond their capabilities, they will call the fire department. Attempts to report via telephone will almost universally be unsuccessful, not so much due to damage to the telephone system as much as simple saturation of the system and emergency call centers.

Experience shows that uninjured citizens on the scene will respond rationally (Van Anne and Scawthorn, 1989) rescuing as many people as possible and protecting exposures. Water supply from mains (discussed below) will often be unavailable.

Table 7-6 Frequency Distribution of Ignitions, Four Scenario Events

Number of Ignitions	SA M_w 7.9		SA M_w 7.2		SA M_w 6.5		Hayward M_w 6.9	
	pdf	CDF	pdf	CDF	pdf	CDF	pdf	CDF
0	0	0	0	0	0	0	0	0
20	0	0	0	0	0.00	0.00	0.01	0.01
40	0.01	0.01	0.05	0.05	0.16	0.17	0.64	0.64
60	0.16	0.18	0.30	0.36	0.42	0.59	0.35	1.00
80	0.20	0.38	0.27	0.63	0.34	0.93	0.01	1
100	0.19	0.57	0.22	0.85	0.07	1.00	0	1
120	0.18	0.75	0.14	0.99	0.00	1	0	1
140	0.14	0.89	0.01	1	0	1	0	1
160	0.10	0.99	0	1	0	1	0	1
180	0.01	1.00	0	1	0	1	0	1
200	0.00	1	0	1	0	1	0	1

pdf = probability density function, which in this context is a measure of the likelihood of having that number of ignitions.
CDF = Cumulative Distribution Function, which in this context is a measure of the likelihood of having that number, or a smaller number, of ignitions.

The initial response of fire companies and personnel in the regions of strong shaking will be to self-protect during violent shaking, and as soon as possible, open the doors and remove all engines from the fire stations. Typically within five minutes, they will either have self-dispatched to an observed smoke column, responded to a citizen still alarm, or been instructed to mobilize with other companies into a strike team.

For the purposes of this study, a survey was conducted of over 60 SFFD fire officers. The survey found that, lacking communications with battalion or headquarters, more than half the officers would self-dispatch to the nearest fire. In any event, given situations when the number of fires outnumbers the number of engines (typically the case for the larger event scenarios considered here), SFFD fire service resources will be completely committed, and in need of assistance from outside the region. The primary needs will be personnel, additional hose, hard suction hose, foam, light equipment (gloves, hand tools, Self Contained Breathing Apparatus), and heavy equipment (cranes, bulldozers, backhoes). Additional fire apparatus (pumpers and ladder trucks) will not be the primary need, initially, but will still prove useful as extra-regional strike teams arrive. In the initial stage, personnel needs may be significantly supplemented by NERT teams, but will be more significantly strengthened by the recall of off-duty trained firefighters. Off-duty personnel can be expected to have doubled staffing within 3-6 hours, and tripled it within 12-24 hours. While responding, an issue will be how these personnel join with their companies, and there will be some inefficiencies as personnel instead join first available companies. Nevertheless, arrival of off-duty personnel will be important, to relieve on-duty personnel nearing their physical limits.

Emergency dispatch centers will be overwhelmed and doing as much as possible to triage events and dispatch resources. Reports of fires during the initial period will be haphazard. An anecdote demonstrates this—the first knowledge the San Francisco

Fire Department Emergency Operations Center had of the Marina fire in the 1989 Loma Prieta earthquake was from television news reports (despite several companies having responded already to the fire). Quickly gaining accurate and complete situational awareness is still a challenge. For purposes of this analysis, it has been assumed that all engines respond to fires, and that each engine responds to the fire nearest to it. The net result of this assumption is unclear—in reality, some engines will respond to non-fire emergencies (e.g., building collapse), and some department radio communications will be functional, allowing more efficient allocation of resources with some engines responding to fires other than the nearest.

7.3.3 Fire Growth and Spread

Depending on the specific event, only a fraction of San Francisco's initial ignitions will be responded to, and some fraction will grow in size and develop into conflagrations. Growth and spread varies with materials and density of construction, functionality of sprinklers where they exist, active fire suppression, wind speed, and other factors. While physics-based models for fire spread are currently emerging (Cousins, 2003; Aoki, 1990; Himoto and Tanaka, 2008; Lee et al., 2008), their data demands are prohibitive, so that established empirical relations (Scawthorn, Eidinger, and Schiff, 2005) for fire spread were employed here.

7.3.4 Lifelines

The performance of lifelines, such as water supply, gas integrity, electric power, communications, and transportation, is integral to the fire following earthquake process.

Water supply may be severely impacted, depending on the scenario event. In addition, San Francisco has its unique Auxiliary Water Supply System. In order to estimate the availability of adequate water for firefighting, limited analyses were performed for both the Municipal Water Supply System and Auxiliary System. Additionally, number and proximity of suction connections and cisterns were considered, along with the capacity of SFFD's Portable Water Supply System, to arrive at an overall Water Supply Factor for each scenario. The Water Supply Factor varies between 0 and 1 and is a measure of the availability of adequate fire-fighting water, with Water Supply Factor = 0 indicating no water, and 1 indicating completely adequate water. Figure 7-18 shows a map of Water Supply Factor (shades of blue) for the San Andreas fault magnitude 7.9 event, with example Municipal System breaks overlaid. Note that the darker the shade of blue, the more adequate the water supply, and that Water Supply Factor is estimated based on all sources of water (e.g., Municipal System, Auxiliary System pipe network, cisterns, suction connections), not just the Municipal System.

The performance of the natural gas system was not explicitly considered in this analysis for the following reasons: (a) gas-related ignitions are included in the ignition algorithms; (b) while gas-related ignitions typically account for a significant portion of the total number of ignitions, these ignitions are probably not greatly affected by the performance of the gas pipelines. That is, while some ignitions have been caused by broken gas main flares in the street (e.g., Balboa Blvd. in the 1994 Northridge earthquake), most gas-related ignitions occur within buildings and are fueled by modest amounts of gas leaking in the building under residual pressure. However, the recent (September 9, 2010) San Bruno transmission gas main explosion and fire, in which eight persons died and 38 homes were destroyed (and others damaged) shows the potential damage arising from a broken gas main. While the San

Bruno pipeline was a large high-pressure transmission main, of a type that can be found in San Francisco only in the southeast quadrant of the City (see Figure 7-19) there are high-pressure distribution mains throughout the City. PG&E has done extensive work in the last several decades to upgrade its transmission and distribution system in the San Francisco Bay Area.

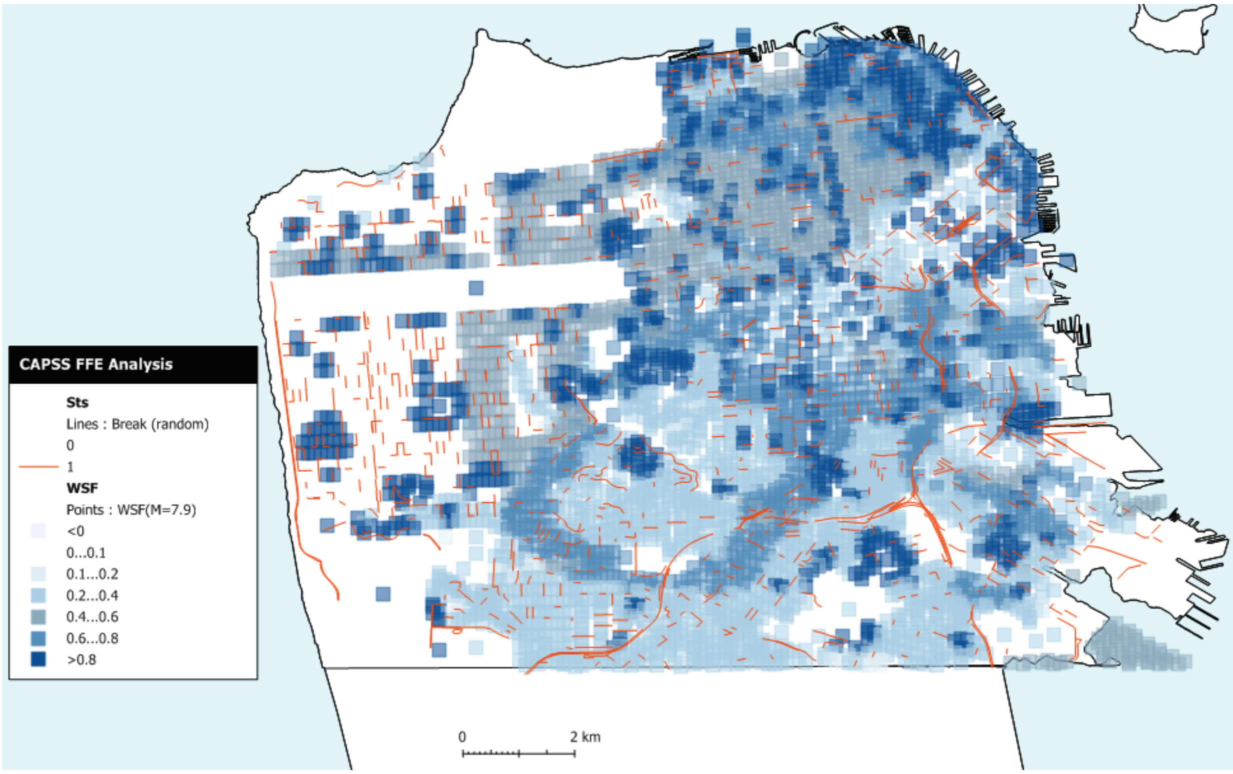


Figure 7-18 San Andreas fault magnitude 7.9 event: example Municipal Water Supply System breaks overlaid on map of Water Supply Factor (WSF) for this scenario. WSF = 0 indicates no water (colored white), and 1 indicates completely adequate water (dark blue) – the darker the shade of blue the more adequate the water supply. Note that WSF is estimated based on all sources of water (Municipal Supply, Auxiliary Supply pipe network, cisterns, suction connections, and other system sources). (Source: SPA Risk).

The performance of the electric power system was not explicitly considered in this analysis for the following reasons: (a) electricity-related ignitions are included in the ignition algorithms; and (b) while electric-related ignitions typically account for a significant portion of the total number of ignitions, many of these ignitions are 'prompt' ignitions, occurring in the few seconds before electric power fails. Later ignitions, on restoration of electric power, typically occur much later, are not included in the ignition algorithms used here, and have typically been easily dealt with by fire departments in past earthquakes. PG&E has done extensive work in the last several decades to upgrade its electric power system in the San Francisco Bay Area, and the effects of this on the fire following earthquake problem are unclear—if electric power continues through and after the earthquake, more ignitions may occur in damaged buildings. In the 1989 Loma Prieta earthquake, electric power failed very quickly in San Francisco, and was only gradually restored over several days, as sections of the gas and power systems were checked by PG&E.

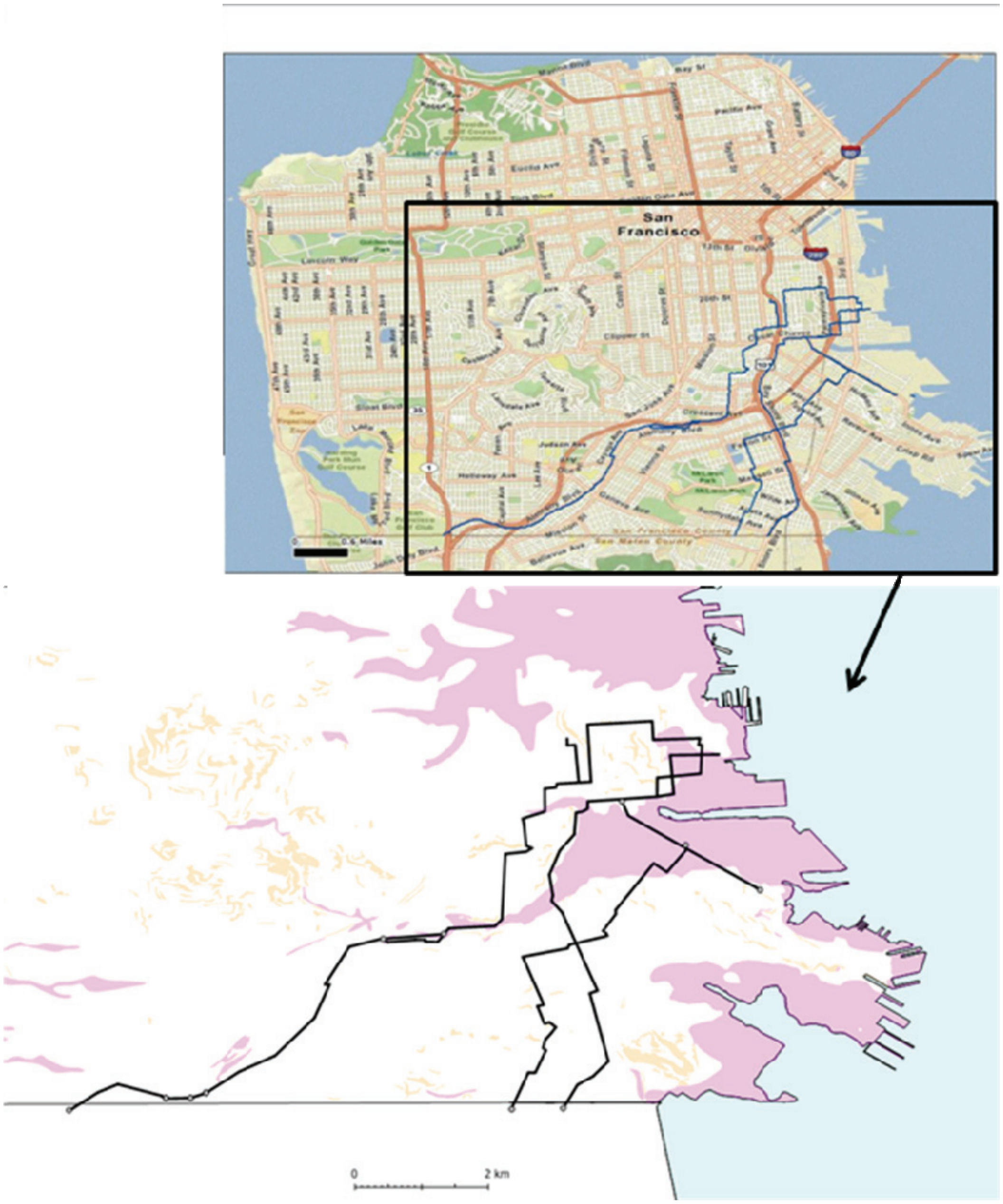


Figure 7-19 Top: pressure gas transmission lines in San Francisco. Bottom: overlain on geologic hazards (yellow is landslide hazard, purple is liquefaction or other soft-soil ground hazard). (Pipeline data taken from National Pipeline Mapping System (https://www.npms.phmsa.dot.gov/PublicViewer/composite.jsf?state=CA&county=06075)

Communications systems, particularly telephone, will sustain some damage but probably not enough to reduce general functionality following the scenario event. However, saturation of the network and of emergency call centers will reduce relevant functionality to a great degree, for several hours or more. This effective lack of telephone service will result in delayed reporting, with consequences as discussed above.

The transportation system most relevant to fire following earthquake is the road network, which in San Francisco is highly gridded, with few bottlenecks, so that performance of the network within the city is unlikely to be a significant factor. While some roads will be blocked due to ground failure, or building or local bridge collapse, bypasses should be generally available.

7.3.5 Final Damage Estimates

Using the above methodology, one thousand trials were run for each of the four scenario events. Time of day, wind speed, ground motions, ignition rates, and other relevant parameters were varied for each trial. Results are shown in Figures 7-20 and 7-21, and Tables 7-7 and 7-8.

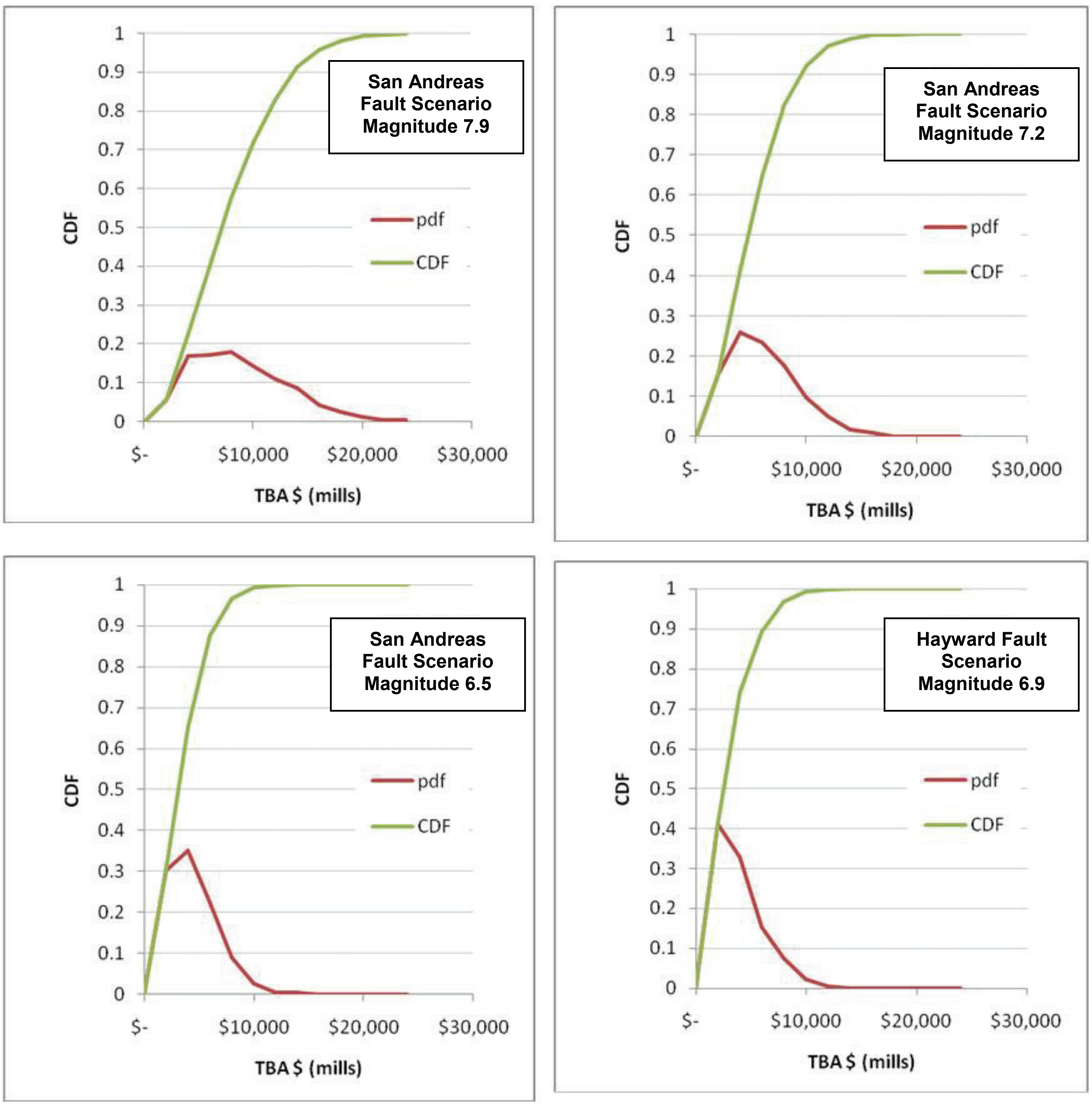


Figure 7-20 Frequency distribution for final total burnt area (TBA), four scenario events. CDF: cumulative distribution function; pdf: probability density function; mills: millions.

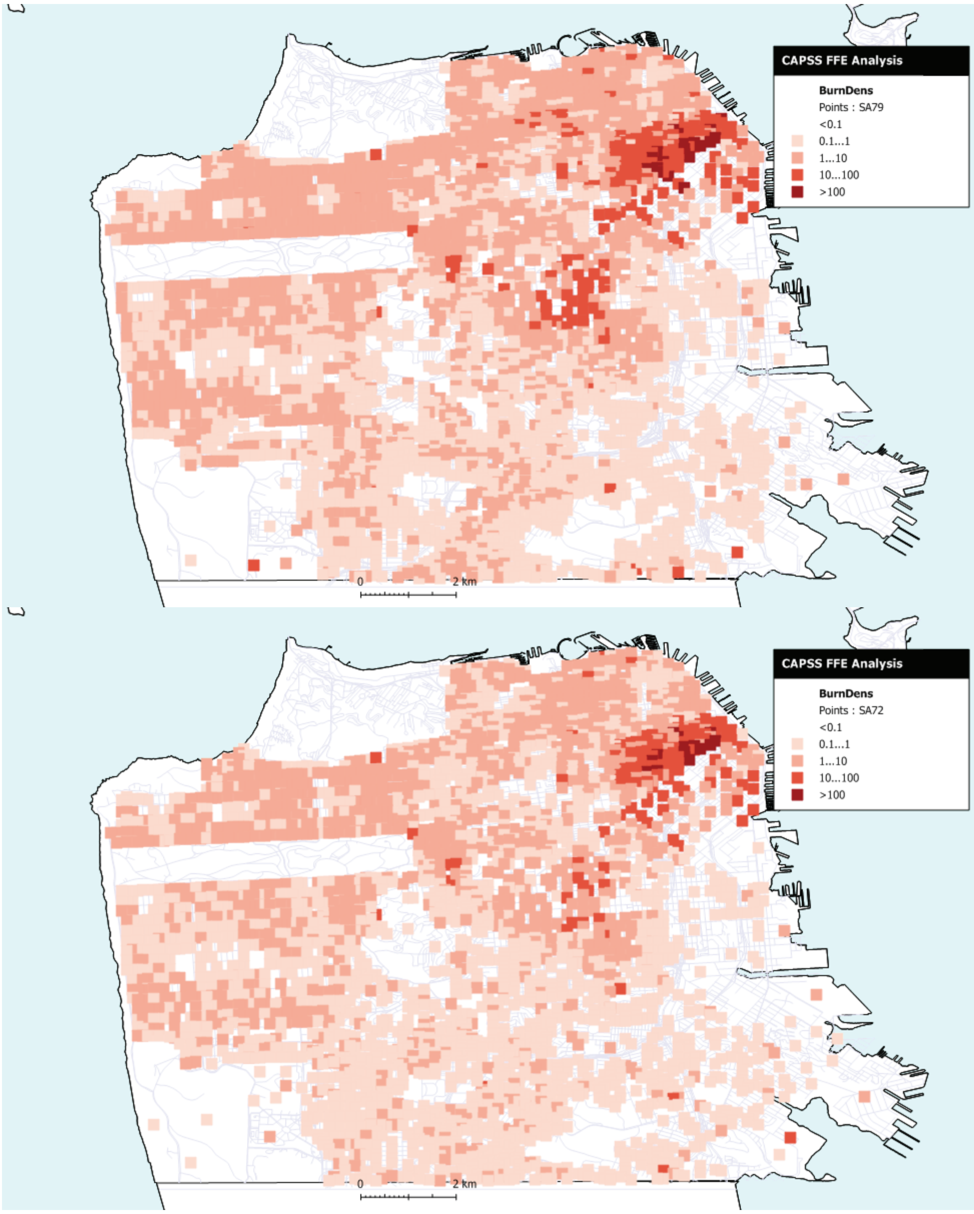


Figure 7-21 Distribution of burn density per block (millions $): top, San Andreas fault magnitude 7.9 scenario; bottom, San Andreas fault magnitude 7.2 scenario. (Source: SPA Risk).

Another way to consider the range of losses is to identify the bounds within which the losses will fall half of the time. Table 7-9 shows the range within which ignitions, total dollar losses (billions $), and total burnt building floor area will be half of the time. Correspondingly, half of the time the losses will be outside (i.e., less or more than) the ranges shown.

By way of reference, $1 billion is approximately equivalent in replacement value to 2,000 single family houses, or five TransAmerica Pyramid high-rises. The significance of these results is not in their precision, but rather in their overall magnitude.

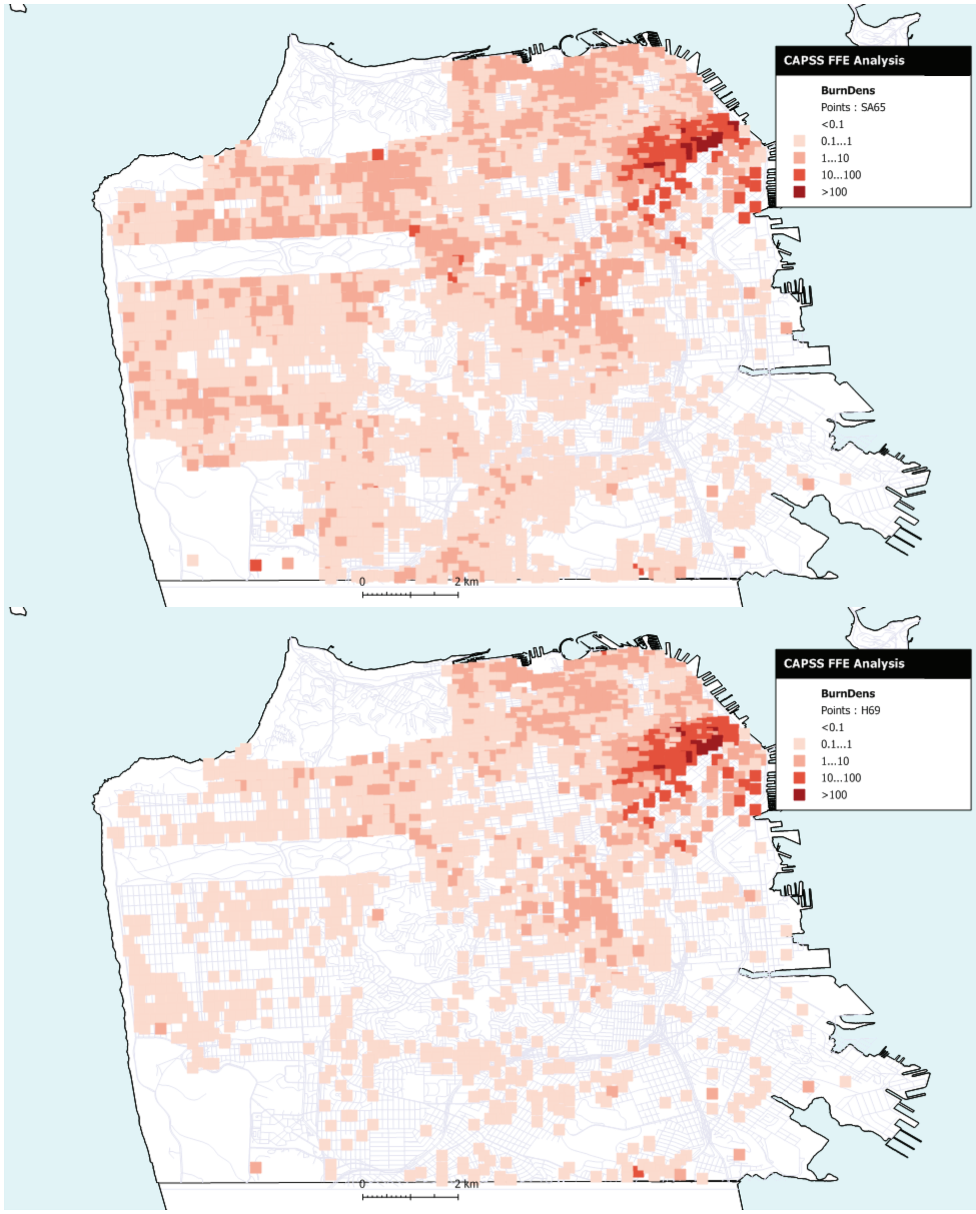


Figure 7-21 Distribution of burn density per block (millions $) (continued): top, San Andreas fault magnitude 6.5 scenario; bottom, Hayward fault magnitude 6.9 scenario. (Source: SPA Risk).

7.3.6 Validation

It is useful to validate these results, to the extent possible. San Francisco is a rather unique setting so that comparable settings and experience are almost non-existent. The most relevant data for validation is the experience of the 1989 Loma Prieta earthquake, in which the city was moderately shaken, had a few building collapses and deaths, and over two dozen fires. The Loma Prieta earthquake was modeled using the above methodology, with the overall mean number of ignitions derived from a 1,000 trial simulation for the event estimated to be 15.7, as compared with an

Table 7-7 Results Summary Statistics

	Scenario			
	San Andreas Magnitude 7.9	San Andreas Magnitude 7.2	San Andreas Magnitude 6.5	Hayward Magnitude 6.9
Mean Loss (million sq ft)	16.7	11.1	7.3	6
Median Total Burn Area (TBA)	15.3	10.3	6.6	5.0
Standard Deviation TBA	9.4	6.7	4.7	4.4
Average No. of Fires	95.1	73.1	57	37.8
Median No. of Fires	92	72	56	37
Mean $ Loss (million $)	7,674	5,122	3,387	2,947
Mean Loss (% total $ value)	3.74%	2.50%	1.65%	1.44%
Median $ Loss (million $)	7,035	4,746	3,040	2,480
Standard Deviation Dollar Loss (million $)	4,325	3,074	2,182	2,153
Max $ Loss (million $)	22,472	18,239	12,508	12,160

Table 7-8 Frequency of Losses for Four Scenario Events

Total Burn Area (TBA) $ (mills)	San Andreas Magnitude 7.9			San Andreas Magnitude 7.2			San Andreas Magnitude 6.5			Hayward Magnitude 6.9		
	no.	pdf	CDF	no.	pdf	CDF	no.	pdf	CDF	no.	Pdf	CDF
-	0	-	-	0	-	-	0	-	-	0	-	-
2,000	56	0.06	0.06	155	0.16	0.16	301	0.30	0.30	412	0.41	0.41
4,000	169	0.17	0.23	259	0.26	0.41	351	0.35	0.65	328	0.33	0.74
6,000	172	0.17	0.40	233	0.23	0.65	223	0.22	0.88	154	0.15	0.89
8,000	179	0.18	0.58	177	0.18	0.82	90	0.09	0.97	75	0.08	0.97
10,000	142	0.14	0.72	98	0.10	0.92	27	0.03	0.99	24	0.02	0.99
12,000	110	0.11	0.83	50	0.05	0.97	5	0.01	1.00	6	0.01	1.00
14,000	86	0.09	0.91	17	0.02	0.99	3	0.00	1.00	1	0.00	1.00
16,000	43	0.04	0.96	9	0.01	1.00	0	-	1.00	0	-	1.00
18,000	25	0.03	0.98	1	0.00	1.00	0	-	1.00	0	-	1.00
20,000	12	0.01	0.99	1	0.00	1.00	0	-	1.00	0	-	1.00
22,000	3	0.00	1.00	0	-	1.00	0	-	1.00	0	-	1.00
24,000	3	0.00	1.00	0	-	1.00	0	-	1.00	0	-	1.00
> 24,000	0	0	1	0	0	1	0	0	1	0	0	1

pdf = probability density function, which in this context is a measure of the likelihood of having that loss.
CDF = cumulative distribution function, which in this context is a measure of the likelihood of having that, or a smaller, loss.

Table 7-9 50% Bounds for Losses to Buildings Due to Fire Following Earthquake

Scenario	25% ~ 75% Confidence Range		
	Ignitions	Loss ($ billions)	Total Burnt Building Floor Area (million sq. ft.)
San Andreas Magnitude 7.9	68 ~ 120	$ 4.1 ~ $ 10.3	11.2 ~ 28.2
San Andreas Magnitude 7.2	52 ~ 89	$ 2.8 ~ $ 6.8	7.7 ~ 18.6
San Andreas Magnitude 6.5	48 ~ 70	$ 1.7 ~ $ 5.1	4.7 ~ 14.0
Hayward Magnitude 6.9	27 ~ 46	$ 1.3 ~ $ 4.0	3.6 ~ 11.0

actual 18 that occurred in San Francisco within 24 hours of the earthquake. Further results are shown in Figures 7-22 and 7-23. Figure 7-22 shows peak ground acceleration as estimated by the U. S. Geological Survey (USGS) for the event, overlaid with the actual ignitions that occurred within 24 hours of the earthquake (red triangles) and with one distribution of ignitions drawn at random from a 1,000 trial simulation (squares). Ignitions that occurred after the first 24 hours are shown as smaller dots. One fire is estimated to, and did, occur in the Marina, and a roughly comparable distribution of estimated and real events can been seen throughout most of the City, with the exception of the Financial District, where more events are estimated than did occur. This disparity may be due to the rapid loss of electric power in the event.

Figure 7-23 shows the frequency of losses for the 1,000-trial simulation for this event, statistics of which are shown in Table 7-10.

Accurate estimates of the fire following earthquake losses in the Loma Prieta event are not available, but the losses almost certainly did not exceed $10 million. While the validation median results are significantly higher ($122 million), note that the frequency distribution of losses is rather broad, and that the estimate indicates about a 35% probability of the losses being $35 million or less.

7.3.7 Sensitivity of Results

Another issue of value to consider is the sensitivity of the above results to variation in key parameters. In a simulation, there are two aspects to sensitivity—the normal question of sensitivity to key inputs, and the question of whether the 1,000 trials employed in the simulations were sufficient in number.

Regarding whether a sufficient number of trials were employed, Figure 7-24 examines the variation and robustness of results for the San Andreas magnitude 7.9 scenario versus the total number of simulations, carried out to 10,000 trials. The top figure shows the average number of fires with increasing trials, and the bottom figure shows the average total burnt area (thousands of sq. ft.). By both measures, simulation results clearly stabilize after several hundred trials.

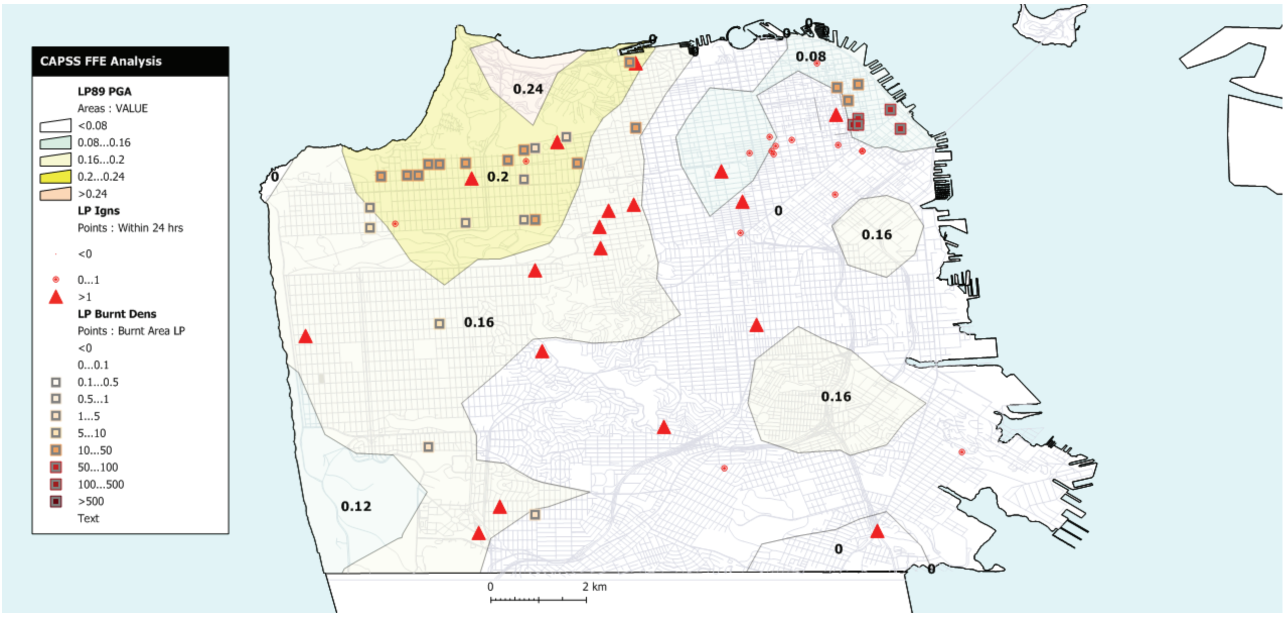


Figure 7-22 Loma Prieta earthquake validation of fire following earthquake analyses: Peak ground acceleration (PGA in g) values estimated by the USGS are shown as colored zones, which are overlaid with the actual ignitions that occurred within 24 hours of the earthquake (red triangles) and one distribution of ignitions drawn at random from a 1,000 trial simulation (squares). Ignitions that occurred after the first 24 hours are shown as smaller dots. (Source: SPA Risk).

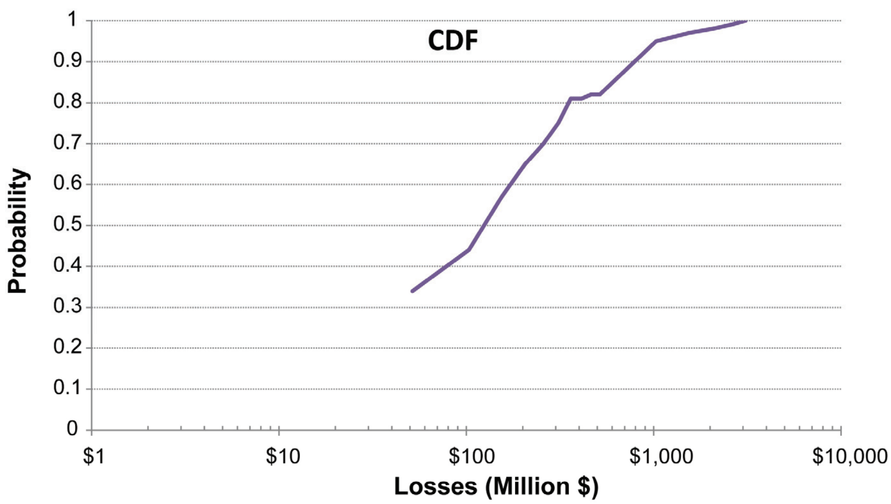
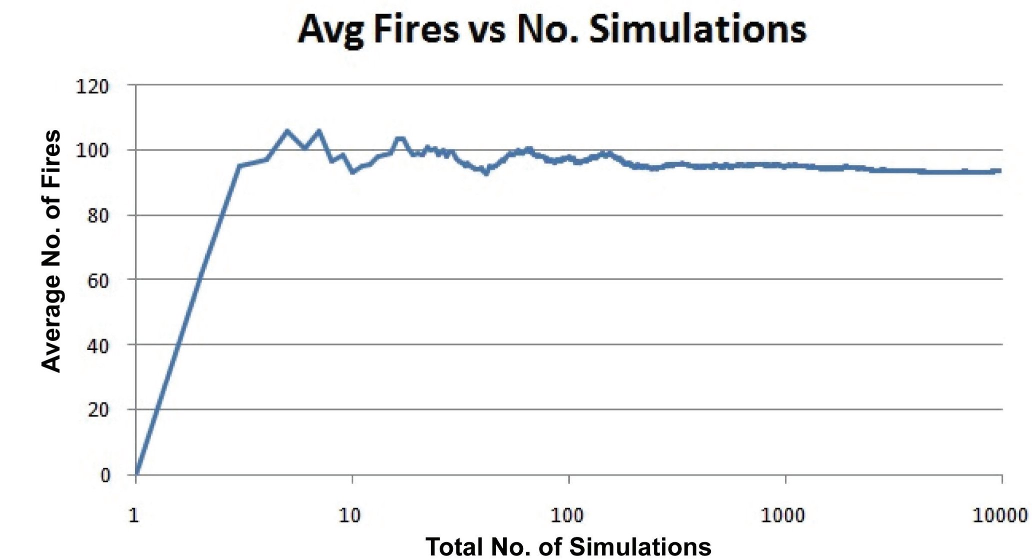


Figure 7-23 Loma Prieta earthquake validation of fire following earthquake analyses: frequency of simulated losses, in millions of dollars, showing median loss of $122 million, and about a 35% probability of the losses being $55 million or less. CDF: cumulative distribution function.

Table 7-10 Estimates of Losses from Loma Prieta Validation

Mean Loss ($ Millions)	$283
Median Loss ($ Millions)	$122
Standard Deviation ($ Millions)	$474
Covariance (COV)	1.67



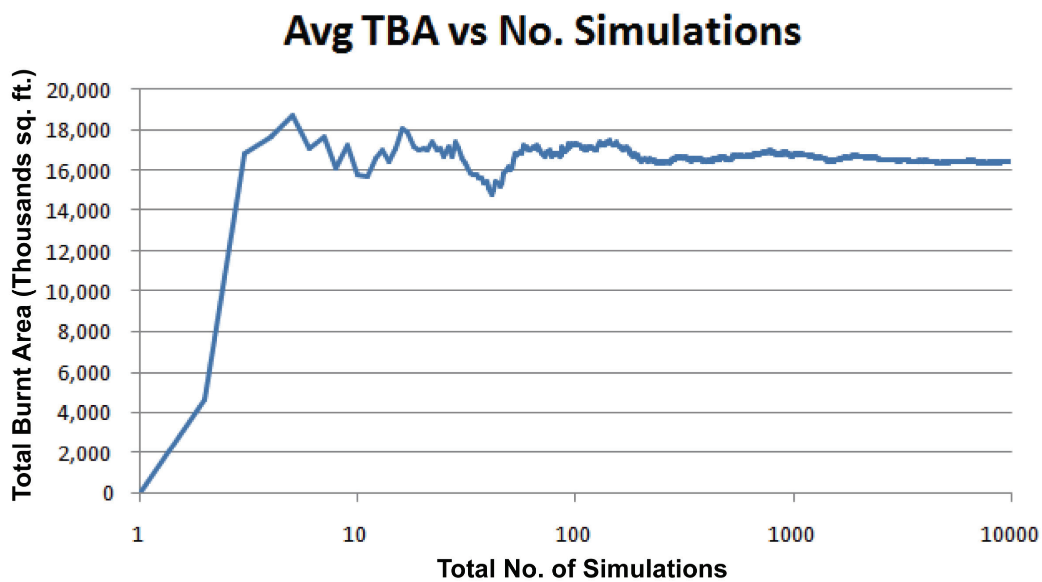


Figure 7-24 Examination of robustness of results for San Andreas fault magnitude 7.9 scenario vs. total number of simulations: top, average number of fires; bottom, average Total Burnt Area (thousands of sq. ft.).

Regarding sensitivity of results versus variation in key inputs, Table 7-11 shows results for given changes in key parameters, using the Loma Prieta validation model. The most sensitive input is the time of day of the earthquake. Loma Prieta occurred at 5:04pm, which examination of national fire statistics (non-earthquake) shows is about the period of the day with the highest frequency of fire incidents. Conversely, early in the morning (e.g., 5:00 am, as used in the sensitivity study) is the period of lowest frequency. The change due to time of day is significant, as shown in the table, where it can be seen that it reduces the average number of ignitions, with a correspondingly much greater drop in total burnt area (the effect is highly nonlinear, especially at the higher numbers of ignitions – a few non-responded fires results in a major conflagration). The next most sensitive parameter is the Water Supply Factor. Without water, most of the fires in San Francisco will turn into conflagrations.

Overall, the number of trials employed, and the robustness of the results to changes in key inputs, appears satisfactory.

Table 7-11 Sensitivity of Simulation for Loma Prieta Event to Variation in Inputs

San Francisco Fire Following Earthquake Study Validation Sensitivity Using Loma Prieta Model											
Inputs	**Base Case**	**Changed Value 0f Variable (Variables Shown At Left)**									
Average windspeed (m/s)	0	10									
Time of earthquake	1700		500								
Average dimension of single family dwelling (m)	16.6						12	20			
Average separation of single family dwellings (m)	3.4						0	5			
Average Fire Break Width (m)	24.4			29.28	19.52						
Water Supply Factor (WSF)	1					0					
Initial delay (mins)	5								0		
Number of Engines	42									32	12
Change in input				20%	-20%					-24%	-71%
SUMMARY RESULTS											
Mean Loss (millions sq ft)	0.5	0.7	0.2	0.5	0.6	0.8	0.5	0.5	0.5	0.6	1.1
Mean Dollar Loss (millions $)	$ 258	$ 318	$79	$ 241	$ 278	$ 360	$ 258	$ 258	$258	$ 291	$482
Average No. Fires	15.7	15.7	13.5	15.7	15.7	15.7	15.7	15.7	15.7	16.1	15.9
EFFECT[16]		23%	-70%	-7%	8%	39%	0%	0%	0%	13%	87%

7.3.8 Presentation and Use of the Results

Use of the results presented above is fairly straightforward: The results are only for losses from fire following earthquake, and are 'independent' of earthquake shaking losses. In fact, a correlation exists between shake and fire following earthquake losses, but in general reasonable accuracy is satisfied by treating the shake and fire following earthquake losses as independent, due to the fact that both losses are typically a small fraction of the overall values at risk. The implication of their being regarded as independent is that the problem of 'burning the rubble' is more easily

[16] Change in dollar losses relative to the Base Case, calculated by dividing the Specific Case less Base Case by the Base Case. For example, the Effect of Average Windspeed is calculated as: ($318-$258)/$258, or 23%.

dealt with. That is, total losses due to shake and fire following earthquake can be estimated as:

$$Lt = Ls + Lf - Ls*Lf$$

where Lt = total loss

Ls = shake loss

Lf = fire following earthquake loss

And the losses are expressed as a fraction of total values at risk (i.e., the formulation does not work if absolutely values of loss, in dollars, are used).

This formulation is equivalent to $A \cup B = A + B - A \cap B$ (i.e., the typical Venn diagram).

In the companion CAPSS report *Here Today-Here Tomorrow: The Road to Earthquake Resilience in San Francisco*, *Potential Earthquake Impacts* (ATC, 2010), the results of this analysis use the above formula to identify the average amount of burned area that had not already been damaged by earthquake shaking. The area used to represent the shaking loss was all of the square footage of building space in the HAZUS®99 "Complete" damage state and half of the building square footage in the HAZUS®99 "Extensive" damage state. This square footage roughly correlates to the square footage that is described as unsafe for occupancy in other sections of that report. The figures used in this calculation and the results appear in Table 7-12.

Table 7-12 Estimates of Burned Area not Previously Damaged by Shaking

Scenario	Building floor space (thousand sq. ft)		Average area burned (incl. areas damaged by shaking) (million sq. ft)	Average area burned not previously damaged by shaking (million sq. ft)
	Half of HAZUS ® 99 Extensive Damage State	All of HAZUS®99 Complete Damage State		
Hayward fault, Magnitude 6.9	266	21	6.0	2.6
San Andreas fault, Magnitude 6.5	33.7	30	7.3	6.4
San Andreas fault, Magnitude 7.2	49.7	55	11.1	8.8
San Andreas fault, Magnitude 7.9	65.6	1,13	16.7	11

CHAPTER 8: ANALYSIS OF LOSSES DUE TO BUSINESS INTERRUPTION

The CAPSS project team analyzed the citywide economic impacts within San Francisco resulting from business interruptions associated with a magnitude 7.2 earthquake on the San Andreas Fault, using the IMPLAN input-output model. A magnitude 7.2 earthquake is expected to create significant property damage in the City, forcing some businesses to cease operations until they can re-open in their existing or new locations. When businesses shut down, even temporarily, the loss of revenue ripples through the local economy, creating a negative multiplier effect. Businesses do not support other businesses; workers do not spend their incomes on consumer goods. This analysis uses HAZUS®99 estimates of lost revenues from business interruption, in conjunction with the IMPLAN input-output model, to estimate the economic impacts of business interruption following a magnitude 7.2 earthquake along the San Andreas Fault in San Francisco.

This analysis does not account for business interruption losses associated with fire damage or damage to utility or transportation systems. As noted in the last section of this chapter, these impacts would also represent a significant impact on the local economy.

8.1 IMPLAN Input-Output Model

Regional and national input-output models are used by economists as a tool to understand the complex interactions among the various parts of an economy. There are two basic types of models available to assess the economic impacts of an activity: regional input-output models and customized dynamic econometric models. 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." In this study, the projected loss of gross receipts for each HAZUS®99 occupancy class make up the "events" in the IMPLAN model.

In 1976, the U. S. Department of Agriculture (USDA) Forest Service, in conjunction with the University of Minnesota, developed the IMPLAN model in response to the National Forest Management Act, which required the USDA Forest Service to create five-year management plans that estimated the local socio-economic impacts associated with various land use alternatives. In 1988, the University of Minnesota began offering the use of the IMPLAN model to non-Forest Service users. Finally, in 1993, through a technology transfer agreement, the Minnesota IMPLAN Group, a private enterprise, was formed with the purpose of maintaining and distributing the IMPLAN software and databases.

At the heart of the model is a national input-output dollar flow table called the Social Accounting Matrix (SAM). Unlike other static input-output models, which just measure the purchasing relationships between industry and household sectors, SAM also measures the economic relationships between government, industry, and household sectors, allowing IMPLAN to model transfer payments such as unemployment insurance. Thus, for the specified region, the input-output table accounts for all the dollar flows among the different sectors within the economy.

The model uses national production functions for nearly 500 industries, including for completeness, government and households, to determine how an industry spends its operating receipts to produce its commodities. Using construction as an example, IMPLAN uses a production function based on the average national construction firm to determine how a firm in the construction industry[17] spends each dollar of outlay on goods and services to produce a dollar's worth of output.[18] The model also uses a national matrix to determine the byproducts[19] that each industry generates.

In order to estimate county-level impacts, IMPLAN combines national industry production functions with county-level economic data. IMPLAN collects data from a variety of economic data sources to generate average output, employment, and productivity for each of the industries in a given county. It also collects data on average prices for all of the goods sold in the local economy. In the case of a county and a regional model, IMPLAN uses average county data to estimate the impacts to the county, and averages all of the economic data across the region's counties to estimate the impacts to the region. In addition, IMPLAN gathers data on the types and amount of output that each industry generates within the county. This allows the model to determine how much of each production input (e.g., wood, steel, labor for the construction industry) the firm can buy locally, within the county or region. In the case of labor, the model accounts for county and regional commute patterns, so as not to overestimate the impacts from labor spending its income in the local economy. Finally, the IMPLAN model uses county-level data on the prices of goods and household expenditures to determine the consumption functions of county households and local government, taking into account the availability of each commodity within the specified locale.

IMPLAN combines this data to generate a series of type-SAM multipliers for the local economy. The multiplier measures the amount of total economic activity that results from an industry (or household) spending an additional dollar in the local economy. Based on these multipliers, IMPLAN generates a series of tables to show the economic event's *direct*, *indirect*, and *induced* impacts to gross receipts, or output, within each of the model's 500 industries. These outputs are described below:

- *Direct Impacts*. Direct impacts refer to the dollar value of economic activity available to circulate through the economy. The direct impacts may equal the operating budget (or gross revenues) of an industry, or less, depending on several factors. The direct impacts do not include payments to capital, inventory, federal

[17] An industry consists of businesses that produce goods and services. The goods and services are known as commodities. IMPLAN Pro User's Guide, 2000.

[18] IMPLAN Pro User's Guide, 2000.

[19] The byproducts refer to any secondary commodities that the industry creates.

taxes, or state and local taxes, as payments of these types do not circulate through the economy.

- *Indirect Impacts.* The indirect impacts refer to the "inter-industry impacts of the input-output analysis."[20] In the construction example, this would include payments for construction inputs such as wood, steel, office supplies, and any other non-labor payments that the construction firm would purchase in the building process.
- *Induced Impacts.* The induced impacts refer to the impacts of household expenditures in the model.[21] When households earn income, they spend part of that income on goods and services. The model treats households as an "industry" in determining their local expenditure patterns in the model, based on the availability of goods and services within the locale. In the construction example, the induced impacts include the expenditures of construction laborers, as well as the expenditures of persons who work in industries represented in the indirect impacts. The model accounts for local commute patterns in the area. If 20 percent of construction workers who work in the county live outside of the county, the model will allocate 80 percent of labor's disposable income into the model to generate induced impacts. As with industries, the model excludes payments to federal and state taxes and savings based on the area's average local tax and savings rates. Thus, only the disposable incomes from local workers are included in the model.

8.2 Methodology

This section discusses the methodology used to determine the loss of gross receipts from business interruption that are the basis for the IMPLAN analysis. The analysis combines gross receipt losses from HAZUS®99 to generate inputs for the IMPLAN model to use in estimating the total economic impacts of business interruption. The methodology described here is essentially identical to that used in the U. S. Geological Survey 2008 Open File Report 2008-1150, *The Shakeout Scenario* ("Shakeout Report"), in order to remain consistent with other accepted analyses.

HAZUS®99 returns a variety of data points that describe the different cost impacts of an earthquake. These include:

- Building Damage Losses;
- Building Contents Losses;
- Inventory Losses;
- Output Losses (Gross Receipts);
- Rental Income Losses;
- Income Losses (Wages and Proprietors' Income); and
- Relocation Losses.

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[20] IMPLAN Pro User's Guide, 2000.

[21] Ibid.

The first three cost categories refer to losses to capital stock. Output Losses represent the loss of gross receipts or revenues. Rental Income Losses represent either the loss of rental income for commercial uses, or the loss of income as displaced households are forced to secure a new/temporary residence. Income Losses represent the lost wages to workers and proprietors while businesses are out of operation. Finally, Relocation Losses accrue to landlords and represent the cost of relocating tenants while the buildings are under repair.

HAZUS®99 returns these costs for each occupancy class, and reports these results at the neighborhood level; however, since the smallest area for which IMPLAN is effective is the county level, this analysis focuses on the citywide losses per occupancy class.[22]

8.2.1 Commercial Losses

Although HAZUS®99 reports a variety of cost impacts, only the Output Losses are entered into IMPLAN for commercial occupancies, as these represent the lost revenue that does not circulate through the local economy during business interruption.

8.2.2 Residential Losses

In order to estimate the losses associated with residential uses, the analysis uses the Rental Income Losses projected by HAZUS®99. Rental income losses have two interpretations, depending on the residential use category, as discussed below:

- *Owner-Occupied Residential Uses.* For owner-occupied residential uses, Rental Income Losses effectively represent the lost income that households use to secure a new residence while their existing home is repaired or replaced. As the household could have otherwise spent this income on consumer goods, or other non-rent uses, this represents a loss to local economic activity.
- *Income-Generating Residential Uses.* In the case of income-generating residential uses, such as multi-family apartment complexes or nursing homes, the Rental Income Losses literally represent lost gross receipts as tenants do not pay rent during the business interruption.

In order to convert the HAZUS®99 outputs outlined above into IMPLAN inputs, this analysis uses the same bridge between HAZUS®99 occupancy class and IMPLAN sector as does the 2008 Shakeout Report, shown in Table 8-1.[23] For those HAZUS®99 occupancy classes that bridge to more than one IMPLAN sector, costs for the given occupancy class are distributed into its corresponding IMPLAN sectors proportionately, relative to each IMPLAN sector's value of operations, or total gross receipts. As such, sectors with large economic contributions to the local economy experience large losses, while sectors that represent a small portion of the local economy experience smaller losses from business interruption.

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[22] Boundaries of San Francisco city and San Francisco county are the same.

[23] Rose and Wei (2008).

Table 8-1 HAZUS®99 Occupancy Class to IMPLAN Sector Bridge

HAZUS®99 Occupancy Class	IMPLAN Sectors[a]	IMPLAN Sector Number (2000-2006)	IMPLAN Sector Number (2007-)[b]
RES1	Owner Occupied Dwellings	509	361
RES2 (Duplex)	Owner Occupied Dwellings	509	361
RES3	Real Estate	431	360
RES4	Hotels	479, 480	411, 412
RES5	Owner Occupied Dwellings	509	361
RES6	Health Services	379, 464-468	309, 394-398
COM 1	Retail Trade	401-412, 501,502	320-331, 433, 434
COM2	Wholesale Trade	390	319
COM3	Other Services	432,448,469,470,482-490,492,494	362, 378, 399, 400, 401, 414-422, 424, 426
COM4	Transportation and Utilities	391-395, 397, 399-400, 497, 30, 495, 498	332-336, 338, 339-340, 430, 31, 428, 431
COM5	Banks and Financial Institutions	430	354
COM6	Health Services	379, 464-468	309, 394-398
COM7	Health Services	379, 464-468	309, 394-398
COM8	Entertainment and Recreation	419-422, 471-478, 481	347-349, 351, 409-410, 413
COM9	Entertainment and Recreation	419-422, 471-478, 481	347-349, 351, 409-410, 413
COM10	Other Services	432,448,469,470,482-490,492,494	362, 378, 399, 400, 401, 414-422, 424, 426
IND1	Other Heavy Industry	202, 224-301, 304-305, 344-362	169, 181-233, 236, 276-294
IND2	Other Light Industry	107-111, 136-141, 172-181, 306-309, 312-321, 323-338, 341-343, 363-378, 380-389, 413-416	87-94, 113-114, 142-152, 237-240, 242, 244-256, 257, 258-271, 273-275, 296-308, 216, 232, 310-318, 341-344
IND3	Food, Drugs, and Chems	46-91, 142-171	41-74, 115-141
IND4	Mining and Metals Processing and Manufacturing	19-29, 203-223, 339-340	20-30, 170-180, 272
IND5	High Tech	302-303, 310-311	234-235, 241, 243
IND6	Construction	33-45	37-39
AGR1	Agriculture	1-18, 449	1 -19, 379
REL1	Government and Non-NAICS	398, 491, 493, 496, 499-500, 504-508	427, 422, 425, 429, 432, 436, 435, 437, 439, 440
GOV1	Government and Non-NAICS	398, 491, 493, 496, 499-500, 504-508	427, 422, 425, 429, 432, 436, 435, 437, 439, 440
GOV2	Government and Non-NAICS	398, 491, 493, 496, 499-500, 504-508	427, 422, 425, 429, 432, 436, 435, 437, 439, 440
EDU1	Education Services	461-463, 503	391-393, 438
EDU2	Education Services	461-463, 503	391-393, 438

Notes:
(a) Per 2008 Shakeout Report.
(b) IMPLAN changed their sectoring scheme in 2007. The new sector numbers represent the updated scheme.
Sources: Shakeout Report, 2008; Adam and Wei, 2009; HAZUS®99; Bay Area Economics.

8.3 Findings

HAZUS®99 estimates that a magnitude 7.2 San Andreas earthquake would result in operating losses of $2.9 billion in San Francisco (see Table 8-2). This figure captures losses in both residential and commercial occupancies, and represents lost gross sales activity and income associated with residential uses.

Table 8-2 Loss from Operations, HAZUS®99 Results for Magnitude 7.2 San Andreas Fault Scenario

HAZUS®99 Occupancy Class	Output Loss[a] ($ x $1,000)	Rental Income Loss[b] ($ x $1,000)	Operating Losses[c] ($ x $1,000)
RES1	$0	$411,862	$411,862
RES2 (Duplex)	$0	$30,638	$30,638
RES3	$0	$1,456,553	$1,456,553
RES4	$427,515	$544,147	$544,147
RES5	$0	$0	$0
RES6	$44,443	$15,034	$15,034
COM1	$37,034	$89,985	$37,034
COM2	$0	$0	$0
COM3	$1,361	$796	$1,361
COM4	$178,304	$530,312	$178,304
COM5	$989	$4,031	$989
COM6	$40,781	$2,129	$40,781
COM7	$0	$0	$0
COM8	$73,516	$16,980	$73,516
COM9	$26,477	$7,860	$26,477
COM 10	$0	$8,441	$0
IND1	$9,009	$1,420	$9,009
IND2	$11,884	$9,338	$11,884
IND3	$4,137	$2,205	$4,137
IND4	$487	$87	$487
IND5	$688	$367	$688
IND6	$12,719	$898	$12,719
AGR1	$0	$0	$0
REL1	$10,130	$3,435	$10,130
GOV1	$14	$89	$14
GOV2	$0	$0	$0
EDU1	$10,330	$725	$10,330
EDU2	$0	$0	$0
TOTAL			**$2,876,094**

Notes:
(a) Output losses are a product of HAZUS®99, and represent total gross operating receipts.
(b) Rental income losses are a product of HAZUS®99, representing lost rental income from tenants and costs of securing alternative housing for homeowners.
(c) Operating Losses equal to Output Loss (i.e., gross receipt losses) for commercial uses, and Rental Income Losses for residential uses.
Sources: Shakeout Report, 2008, Rose and Wei, 2009; HAZUS®99; Bay Area Economics.

Using the IMPLAN input-output model in conjunction with HAZUS®99 estimates of operating losses reveals the total San Francisco citywide economic losses associated with business interruptions following a magnitude 7.2 earthquake. As Table 8-3 shows, $2.9 billion in direct operating losses would result in total citywide economic losses of $4.3 billion.

Table 8-3 San Francisco Citywide Economic Impacts for Magnitude 7.2 San Andreas Fault Scenario

HAZUS®99 Occupancy Class	Output Loss[a] ($ x 1,000)			
	Direct	Indirect	Induced	Total
RES1	-$411,862	-$127,409	-$80,203	-$619,474
RES2 (Duplex)	-$30,638	-$9,478	-$5,966	-$46,082
RES3	-$1,456,553	-$216,048	-$366,464	-$2,039,065
RES4	-$544,147	-$164,896	-$218,520	-$927,563
RES5	$0	$0	$0	$0
RES6	-$15,034	-$3,303	-$6,833	-$25,170
COM1[b]	-$18,344	-$3,976	-$7,991	-$30,311
COM2	$0	$0	$0	$0
COM3	-$1,361	-$426	-$531	-$2,318
COM4	-$178,304	-$56,136	-$77,083	-$311,523
COM5	-$989	-$235	-$247	-$1,471
COM6	-$40,781	-$8,960	-$18,534	-$68,275
COM7	$0	$0	$0	$0
COM8	-$73,516	-$30,752	-$25,886	-$130,154
COM9	-$26,477	-$11,076	-$9,323	-$46,876
COM10	$0	$0	$0	$0
IND1	-$9,009	-$2,505	-$2,523	-$14,037
IND2	-$11,884	-$4,003	-$4,059	-$19,946
IND3	-$4,137	-$948	-$740	-$5,825
IND4	-$487	-$125	-$151	-$763
IND5	-$688	-$160	-$330	-$1,178
IND6	-$12,719	-$2,890	-$4,619	-$20,228
AGR1	$0	$0	$0	$0
REL1	-$10,130	-$894	-$5,300	-$16,324
GOV1	-$14	-$1	-$7	-$22
GOV2	$0	$0	$0	$0
EDU1	-$10,330	-$1,403	-$5,239	-$16,972
EDU2	$0	$0	$0	$0
	-$2,857,404	**-$645,624**	**-$840,549**	**-$4,343,577**

(a) Output losses represent total gross operating receipts.
(b) Retail direct impacts do not match HAZUS®99 Output Losses because IMPLAN treats retail uses differently from other industry's uses, as it does not include the value of retail inventories inits direct economic impacts.

Sources: Shakeout Report, 2008; Rose and Wei, 2009; HAZUS®99; Bay Area Economics.

8.3.1 Direct Impacts

Direct impacts represent the dollars available to flow through the local economy and create multiplier effects. Using HAZUS®99 Operating Loss estimates as a proxy for economic activity, IMPLAN estimates that the direct citywide impact of business interruptions following a magnitude 7.2 San Andreas Fault earthquake would be a loss of approximately $2.9 billion. This is slightly less than the total HAZUS®99 output loss estimates because IMPLAN does not consider the value of retail inventory as a direct impact, available to flow through the local economy.[24]

8.3.2 Indirect and Induced Impacts

The projected HAZUS®99 loss estimates act as inputs to the IMPLAN computerized input-output model to generate the indirect and induced impacts of economic activities within the City of San Francisco.

Indirect Impacts. According to IMPLAN, the business interruption losses would generate a loss of approximately $645.6 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.

Induced Impacts. In addition to the indirect impacts, the business interruption losses would also generate induced citywide losses of approximately $840.5 million, or lost household expenditures. 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. As households spend their incomes on purchasing retail goods, eating out, medical treatment, and housing-related expenditures, these sectors tend to dominate induced impacts.

Multiplier. Dividing the City's total lost output by its direct output yields an economic multiplier that measures the economic activity of every dollar lost. Thus, every dollar of economic loss that would occur from business interruptions following a magnitude 7.2 San Andreas Fault quake would generate a loss of approximately $1.52 in total citywide economic impacts.

8.4 Conclusions

The IMPLAN analysis estimates that $2.9 billion in business interruption losses due to building damage would result in total citywide economic losses of $4.3 billion. According to IMPLAN, the output of the entire citywide economy in 2009 was $154.2 billion. Thus, the total losses from business interruptions following a magnitude 7.2 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.[25] This suggests that the economic effects of the earthquake would be equal to or greater than a recession.

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[24] Because the majority of retail goods are made outside of the City, IMPLAN assumes that only the local retail mark-up flows through the local economy.

[25] http://www.imf.org/external/pubs/ft/fandd/2009/03/basics.htm

These impacts would be over and above the following impacts estimated by using HAZUS®99 (see Table 6-13):

- $29.8 billion in building damage
- $2.8 billion in damage to building contents and inventory
- $702 million in income and wage losses
- $3.3 billion in relocation losses

Furthermore, this analysis does not account for business interruption losses associated with fire or damage to utilities and transportation systems. These impacts can be significant. For example, in the 2008 Shakeout Report, which evaluated a magnitude 7.8 San Andreas Fault earthquake in the Los Angeles region, total impacts due to these factors represented 88 percent of the total business interruption losses. Losses due to building damage only represented 12 percent of total business interruption losses. The 2008 Shakeout Report also notes that behavioral responses to the quake could also affect the local economy. For example, people's fear about earthquakes could compel them to leave the region or forestall investments in the area. Taking all these factors into account, the 2008 Shakeout Report states that the magnitude 7.8 San Andreas Fault earthquake in the Los Angeles region could lead to a six to 10 percent decline in economic output, well in excess of historic recessions.

Notwithstanding these conclusions, certain industries would conceivably recover more rapidly following the earthquake. 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, but are not considered in this analysis.

CHAPTER 9: ANALYSIS OF SOCIAL AND ECONOMIC RESILIENCE OF SAN FRANCISCO

In recent years, particularly after Hurricane Katrina in 2005, the concept of "resilience"—as opposed to "resistance"—has emerged as a prominent topic in disaster research. While *resistance* focuses on pre-disaster mitigation measures to reduce losses, *resilience* concentrates on improving the ability of physical and socioeconomic systems to respond and recover in the wake of a disaster.

Disaster resilience has been defined as

> "the ability of social units (e.g., organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future disasters." (Bruneau, et al. 2003)

This chapter provides an overview of disaster resilience in the context of a major earthquake in San Francisco, based on a discussion of factors that affect resilience regionally and locally. It is not meant to provide a comprehensive review of resilience at the regional or local scale, which would require a thorough evaluation of infrastructure systems, disaster protocols among the private and public sectors, emergency services, and other factors. Instead, it offers a general introduction to San Francisco's disaster resilience, through qualitative and quantitative data.

9.1 Resilience Metrics

The Multidisciplinary Center for Earthquake Engineering Research (MCEER), sponsored by the National Science Foundation and headquartered at the University at Buffalo, has developed the R4 framework of resilience, outlined below:

- *Robustness*: the ability of systems to withstand disasters without significant loss of performance. The structural soundness of the Bay Bridge, for example, is a key factor related to local and regional robustness.
- *Redundancy*: the extent to which systems are capable of satisfying functional requirements if significant loss of function occurs. For example, following an earthquake, ferries may be used as a substitute for BART and other trans-bay transit services.
- *Resourcefulness*: the ability to diagnose, rank, and address problems through the mobilization of resources. One of the reasons why Hurricane Katrina proved so devastating to the community and economy was the inability to inject vital resources into the Gulf Region.
- *Rapidity*: the capacity to restore function in a timely way, and a function of a system's robustness, redundancy, and resourcefulness. Again, the Gulf Region's

slow recovery following Hurricane Katrina is directly due to gaps and weaknesses in these factors.

MCEER also states that resilience exists in four domains: the technical, organizational, social, and economic.

- The *technical* domain refers to the physical properties of systems.
- The *organizational* domain encompasses the organizations and institutions that must respond to a disaster. It includes both the public and private sectors, and both programmatic components (e.g., municipal disaster preparedness plans) and physical components (e.g., emergency shelters).
- The *social* dimension relates to socioeconomic factors that make a community more or less vulnerable to a disaster (e.g., income, language skills).
- Finally, the *economic* domain addresses the ability of the local and regional economy to adapt to and recover from a disaster.

These frameworks offer tools to evaluate the resilience of an area or economy, and will be referred to in the remainder of this report.

9.2 Regional Resiliency

In assessing San Francisco's resilience, one must first consider the broader Bay Area region, and its ability to withstand and recover from a major earthquake.[26] San Francisco operates as just one component of this regional economy, and cannot be evaluated in isolation. This section discusses various elements that impact the Bay Area's resiliency.

9.2.1 Regional and Local Disaster Planning

Resilience includes organizational factors in the public and private sectors, including programmatic components such as public disaster preparedness plans. The Bay Area region has a number of organizational systems in place to prepare for an earthquake and respond to it.

The Association of Bay Area Governments (ABAG) has taken the lead in regional disaster planning through its Regional Planning Committee (RPC). The RPC provides Bay Area cities and counties information to assist with long-term disaster recovery training, including how to access recovery funds, and how to evaluate and plan for housing, business, economic, and lifeline recovery. Through the RPC, ABAG provides a central location for the most up-to-date disaster recovery and best-practices information.

At the local level, ABAG reports mixed performance on disaster recovery planning. On the positive side, over 95 percent of Bay Area governments have plans for emergency communications and emergency power in their buildings. In addition, 86 percent of jurisdictions maintain a plan for protection of data and recovery of records. In terms of accessing Federal Emergency Management Agency (FEMA) funds following a disaster, 92 percent of Bay Area jurisdictions have designated a department to oversee the FEMA reimbursement claims process (ABAG, 2008).

[26] The Bay Area is defined as the counties of Alameda, Contra Costa, Solano, Sonoma, Napa, Marin, San Francisco, San Mateo, and Santa Clara.

However, areas for improvement remain. Only 60 percent of jurisdictions have a Local Hazard Mitigation Plan as part of their General Plan to ensure matching State funds are available for reconstruction. Moreover, only 36 percent of jurisdictions have documented pre-existing conditions of facilities. This documentation greatly facilitates the FEMA reimbursement process, as FEMA uses a "pre-existing conditions" standard to pay for claims. In addition, only 22 percent of jurisdictions have a repair and reconstruction ordinance, which also helps secure FEMA funding and helps ensure that mitigation measures are incorporated into the rebuilding process (ABAG, 2008).

Regarding the seismic safety of private residences, ABAG reports relatively poor preparedness among local jurisdictions. Only 16 percent of jurisdictions currently provide incentives for strengthening cripple walls of single-family residences. Among jurisdictions with multi-family soft story buildings, 11 percent have mandated strengthening rules or have provided incentives, while 20 percent had planned to do so by December 2009 (ABAG, 2008).

ABAG also states that jurisdictions lack ordinances that require or encourage the seismic retrofit of commercial structures, with the exception of unreinforced masonry (URM) buildings.[27] Most jurisdictions either are in the process of retrofitting local URM buildings or have a policy of notifying landlords (the minimum required by state law). ABAG found that 48 percent of the 75 jurisdictions with URM buildings have successfully retrofitted or vacated all of their URM buildings. In terms of programmatic recovery efforts, 83 percent of jurisdictions lack any plan to assist small businesses following a disaster. Small businesses are more vulnerable to disasters, and generally employ the bulk of local workers (San Francisco Department of Building Inspection, Community Action Plan for Seismic Safety (CAPSS) Project, 2009).

In addition to local governments, the regional utility systems have also planned for and begun to implement seismic preparedness initiatives. For example, both the East Bay Municipal Utility District (EBMUD) and PG&E provide their customers with online disaster planning strategies and checklists. EBMUD and PG&E also continue to improve the seismic safety of their facilities and update their own emergency response plans.[28]

9.2.2 Transportation Network

The Bay Area's transportation network includes its road, rail, and waterways, and public transportation modes that range from local (streetcars) to super-regional (Amtrak and CalTrain). In the event of an earthquake, the redundancy and robustness of the regional transportation network are crucial factors in regional economic resilience. Even if all of the Bay Area's buildings were seismically sound, failure of the transportation network could prevent workers from getting to their jobs and impact emergency personnel's response, thereby slowing the recovery process.

Fortunately, the Bay Area's transportation network is highly redundant. Rail systems like Amtrak and CalTrain run parallel to freeways, and ferry services offer alternative passage across the Bay. In fact, recognizing the value of waterways in transportation

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[27] Note that new and rehabilitated commercial buildings must be built to code and would therefore be considered seismically sound.

[28] http://quake.abag.ca.gov/recovery/

post-disaster, the California Legislature created the San Francisco Bay Area Water Emergency Transportation Authority (WETA) in 2007. WETA is tasked with providing transportation services in the event that bridges become impassible, and has developed the Emergency Water Transportation Systems Management Plan (EWTSMP). The EWTSMP specifies how WETA will coordinate public transportation ferry services in the event of an emergency. Under the EWTSMP, WETA will be in charge of coordinating all maritime emergency responses, as well as the transportation of passengers.

In terms of robustness, Caltrans has been working to stabilize the Bay Bridge and other area bridges since the 1989 Loma Prieta earthquake. Caltrans inspects each bridge at least once every two years, and continues to work on stabilizing the San Francisco-Oakland Bay Bridge, Richmond-San Rafael, Benicia-Martinez, San Mateo-Hayward, and Carquinez bridges, all of which required retrofitting after the Loma Prieta earthquake.

BART is also addressing the robustness of its systems through the Earthquake Safety Program. BART is upgrading the most vulnerable areas of its tracks and stations to ensure that the entire system can withstand an earthquake, and can come back online quickly and serve as a transportation lifeline. Under this program, BART is focusing its construction efforts on the original system constructed between 1972 and 1976, before BART implemented more stringent seismic requirements. In addition, BART will rank its efforts so as to upgrade the most used stations and tracks first. BART estimates that upgrades will be complete by 2013.[29]

Notwithstanding these efforts, local areas that rely primarily on private transportation are vulnerable to closures. For example, a 2003 ABAG study of potential earthquake damage shows that, depending on the earthquake scenario, up to 429 local San Francisco roads and 2,153 regional roads could be closed as a direct result of the earthquake.[30]

As another resiliency factor, the increasing prevalence of Wi-Fi, VOIP (Voice over Internet Protocol), and other communications advances, as long as utilities remain operational, allow many workers to remain productive, even if they cannot reach their places of employment.

9.2.3 Economic Base

As Table 9-1 shows, the regional economy is well diversified; the Professional and Technical Services sector represents the largest concentration of jobs, but only contains 18 percent of total regional jobs. Other major sectors include Government (13 percent), Education and Health Services (11 percent), Manufacturing, Retail Trade, and Leisure and Hospitality (all 10 percent). This diversity contributes to the region's economic resiliency as the employment base is not dependent on one or two sectors, and allows the economy to improvise, innovate, and perform resource substitution following a disaster.

Moreover, jobs are spread throughout the region, with concentrations in Alameda, San Francisco, and Santa Clara Counties. This geographic distribution improves the

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[29] http://www.bart.gov/about/projects/eqs/index.aspx.

[30] Depending on fault. Does not include closures from secondary impacts such as fires, etc. http://www.abag.ca.gov/bayarea/eqmaps/eqtrans/result.html.

Table 9-1 Bay Area Employment by County and Sector, 2008

Industry Sector	Alameda County		Contra Costa County		Marin County		Napa County		San Francisco County	
	Jobs	% Total	Jobs	% Total	Jobs	% Total	Jobs	% Total	Jobs	% Total
Natural Resources and Mining	882	0.1%	1,745	0.5%	626	0.6%	4,849	7.0%	291	0.1%
Construction	40,113	5.9%	24,731	7.3%	7,896	7.2%	3,980	5.8%	19,219	3.4%
Manufacturing	72,145	10.6%	20,885	6.2%	2,112	1.9%	11,941	17.3%	10,630	1.9%
Trade, Transportation, and Utilities	133,003	19.5%	61,108	18.0%	18,152	16.6%	9,418	13.7%	68,418	11.9%
Utilities	*(b)*	*(b)*	*2,052*	*0.6%*	*212*	*0.2%*	*199*	*0.3%*	*(b)*	*(b)*
Wholesale Trade	*39,092*	*5.7%*	*8,687*	*2.6%*	*2,644*	*2.4%*	*1,667*	*2.4%*	*12,354*	*2.2%*
Retail Trade	*66,805*	*9.8%*	*43,934*	*12.9%*	*14,341*	*13.1%*	*6,139*	*8.9%*	*44,240*	*7.7%*
Transportation and Warehousing	*(b)*	*(b)*	*6,435*	*1.9%*	*955*	*0.9%*	*1,414*	*2.1%*	*(b)*	*(b)*
Information	16,017	2.3%	11,762	3.5%	2,201	2.0%	707	1.0%	19,269	3.4%
Financial Activities	30,567	4.5%	26,619	7.8%	8,226	7.5%	2,545	3.7%	57,934	10.1%
Professional and Business Services	112,581	16.5%	48,886	14.4%	20,269	18.5%	6,165	9.0%	125,834	22.0%
Education and Health Services	81,265	11.9%	45,018	13.3%	15,831	14.5%	7,413	10.8%	56,085	9.8%
Leisure and Hospitality	56,265	8.2%	32,792	9.7%	13,366	12.2%	9,208	13.4%	78,868	13.8%
Other Services, except Public Adm.	33,692	4.9%	16,239	4.8%	5,966	5.5%	2,471	3.6%	37,760	6.6%
Unclassified	2,475	0.4%	1,226	0.4%	576	0.5%	178	0.3%	2,138	0.4%
Government[a]	103,792	15.2%	48,528	14.3%	14,152	12.9%	9,956	14.5%	96,678	16.9%
Total	**682,797**	**100.0%**	**339,539**	**100.0%**	**109,373**	**100.0%**	**68,831**	**100.0%**	**573,124**	**100.0%**
% of Bay Area Jobs	**20.4%**		**10.2%**		**3.3%**		**2.1%**		**17.2%**	

Industry Sector	San Mateo County		Santa Clara County		Solano County		Sonoma County		*Bay Area*	
	Jobs	% Total	Jobs	% Total	Jobs	% Total	Jobs	% Total	*Jobs*	*% Total*
Natural Resources and Mining	1,916	0.6%	3,960	0.4%	1,851	1.5%	5,955	3.1%	**22,075**	**0.7%**
Construction	17,834	5.2%	42,592	4.7%	9,171	7.3%	12,611	6.6%	**178,147**	**5.3%**
Manufacturing	29,674	8.7%	164,933	18.2%	9,460	7.5%	21,893	11.5%	**343,673**	**10.3%**
Trade, Transportation, and Utilities	74,317	21.7%	$135,558	15.0%	26,585	21.0%	35,231	18.5%	**561,790**	**16.8%**
Utilities	*(b)*	*(b)*	*1,772*	0.2%	*440*	*0.3%*	*823*	*0.4%*	**(b)**	**(b)**
Wholesale Trade	*(b)*	*(b)*	*40,383*	4.5%	*4,100*	*3.2%*	*7,759*	*4.1%*	**(b)**	**(b)**
Retail Trade	*35,484*	*10.4%*	*82,355*	9.1%	*17,686*	*14.0%*	*23,006*	*12.1%*	**333,990**	**10.0%**
Transportation and Warehousing	*26,179*	*7.6%*	*11,047*	1.2%	*4,359*	*3.4%*	*3,643*	*1.9%*	**(b)**	**(b)**
Information	18,813	5.5%	41,675	4.6%	1,584	1.3%	2,909	1.5%	**114,937**	**3.4%**
Financial Activities	20,530	6.0%	35,110	3.9%	4,802	3.8%	8,443	4.4%	**194,776**	**5.8%**
Professional and Business Services	65,434	19.1%	177,835	19.6%	10,654	*8.4%*	22,816	*12.0%*	**590,474**	**17.7%**
Education and Health Services	32,425	*9.5%*	102,771	11.3%	17,551	*13.9%*	23,237	*12.2%*	**381,596**	**11.4%**
Leisure and Hospitality	34,344	10.0%	75,963	8.4%	13,304	10.5%	21,042	11.0%	**335,152**	**10.0%**
Other Services, except Public Adm.	14,536	*4.2%*	32,480	3.6%	5,239	*4.1%*	8,483	*4.4%*	**156,866**	**4.7%**
Unclassified	1,191	0.3%	2,910	0.3%	429	0.3%	778	0.4%	**11,901**	**0.4%**
Government[a]	31,348	9.2%	90,675	10.0%	25,731	20.4%	27,249	14.3%	**448,109**	**13.4%**
Total	**342,362**	**100.0%**	**906,462**	100.0%	**126,361**	**100.0%**	**190,647**	**100.0%**	**3,339,496**	**100.0%**
% of Bay Area Jobs	**10.3%**		**27.1%**		**3.8%**		**5.7%**		**100.0%**	

Notes:

(a) Government employment includes workers in all sectors, not just public administration. For example, all public school staff are in the Government category.

(b) These entries indicate that data have been suppressed. The publication of unemployment insurance-covered employment and wage data for any industry is withheld when it is necessary to protect the identity of cooperating employers. The data will be suppressed if there are fewer than three establishments, or if a single employer makes up more than 80 percent of the employment in that industry.

Sources: California Employment Development Department (2009 data); Bay Area Economics.

Bay Area's economic resilience by essentially disseminating the risk of an earthquake across multiple nodes. In contrast, if a vast majority of jobs occurred in a single area, a severe disaster in that single area would have a much more significant impact on the regional economy.

9.2.4 Educational Institutions

The San Francisco Bay Area is home to a strong network of public and private educational institutions. The region's world-class research universities include the University of California, Berkeley; Stanford University; and the University of California, San Francisco. In addition, the California State University system has campuses in San Jose, the East Bay, and San Francisco, and dozens of smaller private institutions are located throughout the region.

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. Even after a major earthquake, they will continue to attract and produce intellectual and monetary capital, contributing to the Bay Area's organizational, social, and economic resilience.

9.2.5 Quality of Life

Urban theorists have postulated that economic development in a post-industrial economy requires a strong "Creative Class" of workers (Florida, 2002). The Creative Class includes scientists, academics, designers, artists and others whose economic function is to create new ideas, technology, and creative content, 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.

The Bay Area benefits 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; local, regional and state parks; and, some distance away, 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. The Bay Area would largely retain these amenities in the event of an earthquake, keeping it a location of choice for the Creative Class, and contributing to the region's social and economic resilience.

9.2.6 Household Incomes

The Bay Area's strong economy has supported a relatively affluent region. In 2009, the regional median household income was $76,900, 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 repair physical damage to their homes.

However, pockets of poverty exist throughout the region that would be less resilient on social and economic dimensions. Lower-income households will have more difficulty weathering a loss in employment following a disaster, and are less able to rebuild their units, particularly with the higher construction costs in the Bay Area.

Lower-income households are more likely, however, to rent their homes. Research on prior earthquakes shows that rental units, particularly multi-family structures, are rebuilt at a much slower rate following an earthquake. A 1994 study on residential rebuilding efforts after the 1989 Loma Prieta Earthquake found that one year after the earthquake, 90 percent of the multi-family units destroyed or rendered unserviceable were still out of service. Four years later, 50 percent of these units remained unrepaired (Comerio et al., 1994). The private market also favors the rebuilding of ownership housing over rental housing. An owner of a single-family home or condominium can directly link the value of the property to its condition and therefore has an immediate incentive to rebuild in the aftermath of a disaster. Conversely, for an owner of an apartment building, the incentive to rebuild is connected to the ability to enhance cash flow and service debt (Ibid.). Owners have little incentive to rebuild if construction costs cannot be recovered through rents.

9.2.7 Cost-of-Living

The region's affluence has led to a relatively high cost-of-living in the Bay Area. As of September 2009 the Bay Area's median home price was $365,000, compared to the statewide median home price of $251,000. Inner-ring Bay Area counties show even greater home values. In Santa Clara County, the median sales price was $505,000, while San Mateo and San Francisco had median prices of $603,000 and $675,000, respectively.

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, uses data from the Council for Community and Economic Research (C2ER) to compare the cost of living between U.S. cities. According to Sterling, 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 social and economic resilience factor following an earthquake. For example, higher construction costs may slow the rebuilding process. The region's high housing costs may also compel households to leave the Bay Area altogether, if their units are severely damaged. In the long run, however, it is likely that the region's technical, organizational, social, and economic strengths, will allow the Bay Area to re-establish itself and recover.

9.2.8 Municipal Fiscal Conditions

In addition to the state of the private sector, the state of local and State governments can either contribute to or detract from the region's resiliency. If the State and local jurisdictions are not able to devote resources to emergency services and repairing local infrastructure, the private economic agents (e.g., homeowners and landlords) may not be able to rebuild quickly or efficiently. During this economic downturn, the State and many local jurisdictions had to lay off workers or furlough workers to reduce their budgets. Many cities and counties have cut services to minimum levels and would have reduced staffing or financial capacity to respond to an earthquake emergency. Disaster planning efforts are similarly impacted. While municipal and

State finances will eventually recover in tandem with the economic cycle, the current fiscal concerns represent a weakness in the region's organizational resilience.

9.3 Socio-Economic Resilience in San Francisco

This section focuses on the socio-economic resilience of the City of San Francisco, discussing the city's employment and residential base.

9.3.1 Diversity and Mobility of Economic Base

San Francisco contains approximately 573,000 jobs, with employment well-distributed among several sectors. This diversity provides a measure of economic resilience. As shown in Table 9-2, the city's top five industries are:

- Professional and Technical Services (22 percent of total);
- Government (17 percent)[31];
- Leisure and Hospitality (14 percent);
- Financial Activities (10 percent), and
- Education and Health Services (10 percent).

Approximately three quarters of the city's jobs occur in these five sectors.

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 that appeal to workers in these sectors. In addition, its density benefits those firms that place a high value on inter-personal 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 draw.

Figure 9-1 illustrates the long term historic trends associated with these three 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.

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[31] Government includes all public sector employment, including public schools.

Table 9-2 San Francisco and Bay Area Employment by Sector, 2008

Industry Sector	San Francisco		Bay Area		San Francisco As Share of Bay Area
	Jobs	% Total	Jobs	% Total	
Professional and Technical Services	125,834	22.0%	590,474	17.7%	21.3%
Government[(a)]	96,678	16.9%	448,109	13.4%	21.6%
Leisure and Hospitality	78,868	13.8%	335,152	10.0%	23.5%
Financial Activities	57,934	10.1%	194,776	5.8%	29.7%
Education and Health Services	56,085	9.8%	381,596	11.4%	14.7%
Retail Trade	44,240	7.7%	333,990	10.0%	13.2%
Other Services, except Public Adm.	37,760	6.6%	156,866	4.7%	24.1%
Information	1 9,269	3.4%	114,937	3.4%	16.8%
Construction	19,219	3.4%	178,147	5.3%	10.8%
Wholesale Trade	12,354	2.2%	116,686	3.5%	10.6%
Manufacturing	1 0,630	1.9%	343,673	10.3%	3.1%
Unclassified	2,138	0.4%	11,901	0.4%	18.0%
Natural Resources and Mining	291	0.1%	22,075	0.7%	1.3%
Utilities	*(b)*	*(b)*	5,498	0.2%	*(b)*
Transportation and Warehousing	*(b)*	*(b)*	54,032	1.6%	*(b)*
Total[(d)]	**573,123**	**97.9%**	**3,339,496**	**96.7%**	**17.2%**

Notes:

(a) Government employment includes workers in all sectors, not just public administration. For example, all public school staff are in the Government category.

(b) 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.

(d) Totals may not add due to rounding and/or suppressed data.

Sources: California Employment Development Department (2009 data); Bay Area Economics.

Figure 9-2 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 Services sectors and the Technical Services sector 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 another potential concern, HAZUS®99 model runs conducted for the CAPSS project indicate that San Francisco's Downtown—the primary location of the city's finance and professional services sectors—would be significantly impacted by a magnitude 7.2 earthquake on the San Andreas fault. Specifically, two-thirds of the building area in Downtown would experience "moderate" to "complete" structural damage, suggesting reoccupancy may be delayed.

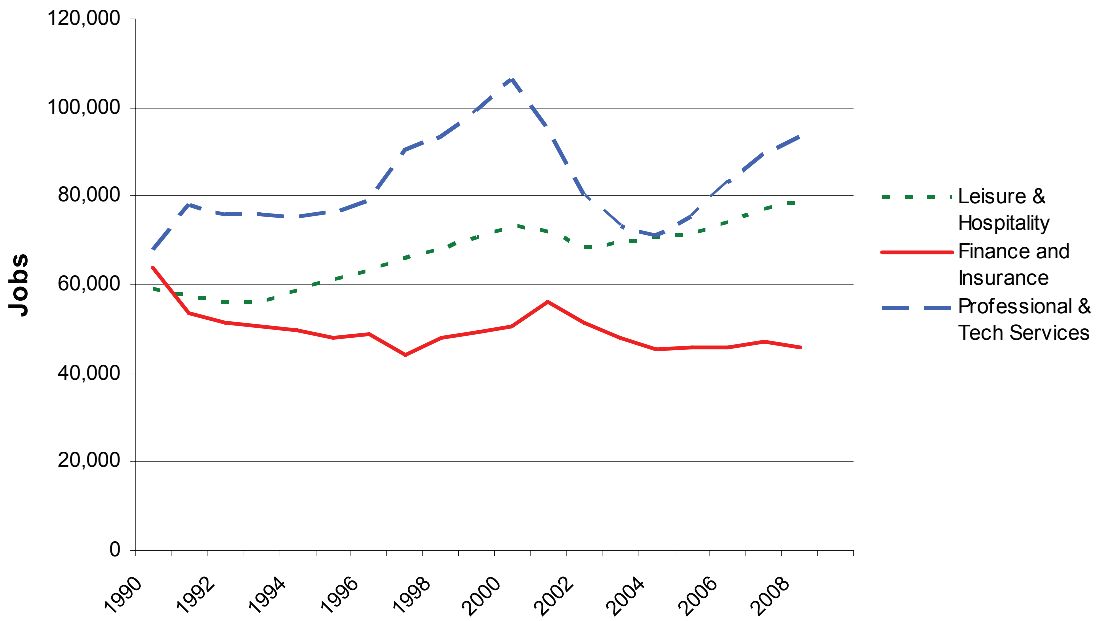

Figure 9-1 *San Francisco jobs in key sectors, 1990-2008 (Sources: California Employment Development Department (2009 data); Bay Area Economics).*

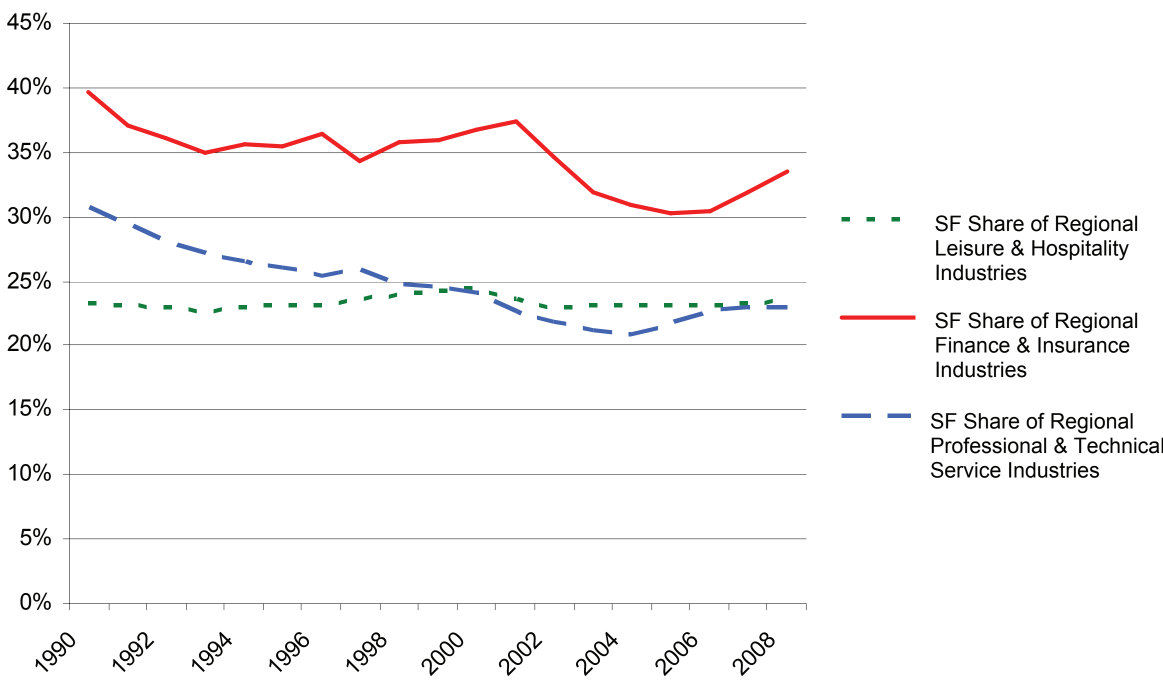

Figure 9-2 *San Francisco jobs as share of Bay Area jobs in key sectors, 1990-2008. (Sources: California Employment Development Department (2009 data); Bay Area Economics).*

The HAZUS®99 results, coupled with the long term employment trends discussed above, suggest that while the city will generally retain its status as a regional finance and professional services center over time, a major earthquake has the potential to accelerate the dispersal of these industries throughout the Bay Area. This dispersal may be more pronounced if San Francisco municipal services do not respond effectively and quickly, or if commercial buildings are rendered unsafe for extended periods. 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 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 in Sichuan, China found significant declines in tourism following the main shock (Yang et al., 2008). Analysis of the September 1997 earthquake in Umbria, Italy showed tourist 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 (Mazzocchi et al., 2001). 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 (Dolfman et al., 2007). Impacts like these 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 short-term impacts, however, in the long run, San Francisco would retain the unique characteristics and attractions that make it an international destination. These strengths, coupled with the Leisure and Hospitality industry's historic stability, suggest that a major earthquake would not damage San Francisco's long-term role in this regard.

9.3.2 Small Businesses

Small businesses, which comprise the vast majority of local firms, represent another critical issue in the resilience of San Francisco's economy. Almost 89 percent of San Francisco's businesses have up to 10 employees, and another seven percent have up to 25 employees. Altogether, firms with up to 25 workers contain 38 percent of the city's total jobs (see Table 9-3).

Small businesses are more vulnerable than large firms following a natural disaster, as they are less likely to carry insurance, and are rarely diversified in terms of products and services. They also lack the resources to address equipment and inventory damage, and interruptions in utility and transportation lifelines. Damages 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 profits are not dependent on a single store.

Table 9-3 San Francisco Firms and Jobs by Number of Employees in Firm

# of Employees	Firms		Jobs	
	Number	% of Total	Number	% of Total
0 - 4	55,793	76%	104,623	16%
5 - 10	9,285	13%	64,089	10%
11 - 25	4,742	6%	79,117	12%
26 - 50	1,959	3%	73,101	11%
51 - 75	509	1 %	32,467	5%
76 - 125	494	1 %	48,008	7%
126 +	547	1 %	253,608	39%
Total[a]	**73,329**	**100.0%**	**655,013**	**100.0%**

Notes:
(a) Total may be inconsistent with other tables due to varying data sources and enumeration methodologies.
Sources: Dun and Bradstreet (2008 data); Bay Area Economics.

Small retailers appear to be the most vulnerable to withstanding major earthquakes. In the case of the 1994 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 two years after the event (Petak et al., 2000).

A study of the 2001 Nisqually Earthquake in Washington State also highlighted the vulnerability of small retailers (Meszaros et al., 2002). Of the 13 industries surveyed, retail businesses reported higher rates of both direct physical losses (buildings and equipment), but also higher rates of 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.

9.3.3 Technical Resilience of Employment Centers

As discussed above, technical resilience refers to the physical properties of systems that support resiliency. This section addresses the technical resilience of key San Francisco job centers, drawing links between the location of the city's employment base, and the ability of commercial buildings to withstand a major earthquake.

As shown in Table 9-4, Downtown, which also includes Civic Center, SOMA, Tenderloin, Union Square, Chinatown, and Nob Hill, as well as a portion of the Embarcadero, contains 51 percent of the City's jobs, a clear indicator of its importance to the local economic base. Almost two-thirds of the City's jobs are in Downtown and Mission Bay combined.

Table 9-4 San Francisco Jobs by Neighborhood, 2008

Area	% of Total Jobs
Downtown	51%
Mission Bay	12%
Bayview	6%
Mission	6%
Western Addition	5%
North Beach	5%
Sunset	4%
Pacific Heights	3%
Richmond	2%
Excelsior	2%
Merced	1%
Twin Peaks	1%
Marina	1%
Ingleside	0%
Presidio	0%
Golden Gate Park	0%
Total	**100%**

Sources: Dun and Bradstreet (2008 data); Bay Area Economics.

Figure 9-3 shows the density of San Francisco jobs based on 2008 data from Dun and Bradstreet. The map shows high employment densities in Downtown, South of Market, the Civic Center area, Mission Bay, and along some of the city's commercial corridors such as Mission Street. Concentration is particularly pronounced in the Financial District, with densities above 500 jobs per acre.

As part of the CAPSS project, HAZUS®99 was used to estimate the impact of a magnitude 7.2 San Andreas Fault earthquake on each San Francisco neighborhood, with detailed findings by occupancy. These model runs can be used to evaluate the technical resilience of Downtown and Mission Bay, which together contain 63 percent of the City's jobs.

The model found that commercial buildings in Downtown would experience among the lowest levels of damage among San Francisco neighborhoods.[32] The model estimates that approximately 12 percent of commercial building value in Downtown would be damaged, a function of the high incidence of seismically-resistant building types, such as structures with steel-braced frames and steel frames with concrete shear walls. In comparison, the percent of commercial building value damage ranges from 10 to 20 percent across San Francisco neighborhoods. Notwithstanding these findings, in absolute terms this level of damage still comprises approximately $5.3 billion of commercial building value, and a major impact to the area's commercial base. Mission Bay is impacted even more significantly, experiencing damage to 19 percent of commercial building value, one of the highest rates among city neighborhoods.

[32] Commercial buildings include the following HAZUS®99 occupancies: RES4, COM1 to COM10, IND1 to IND6.

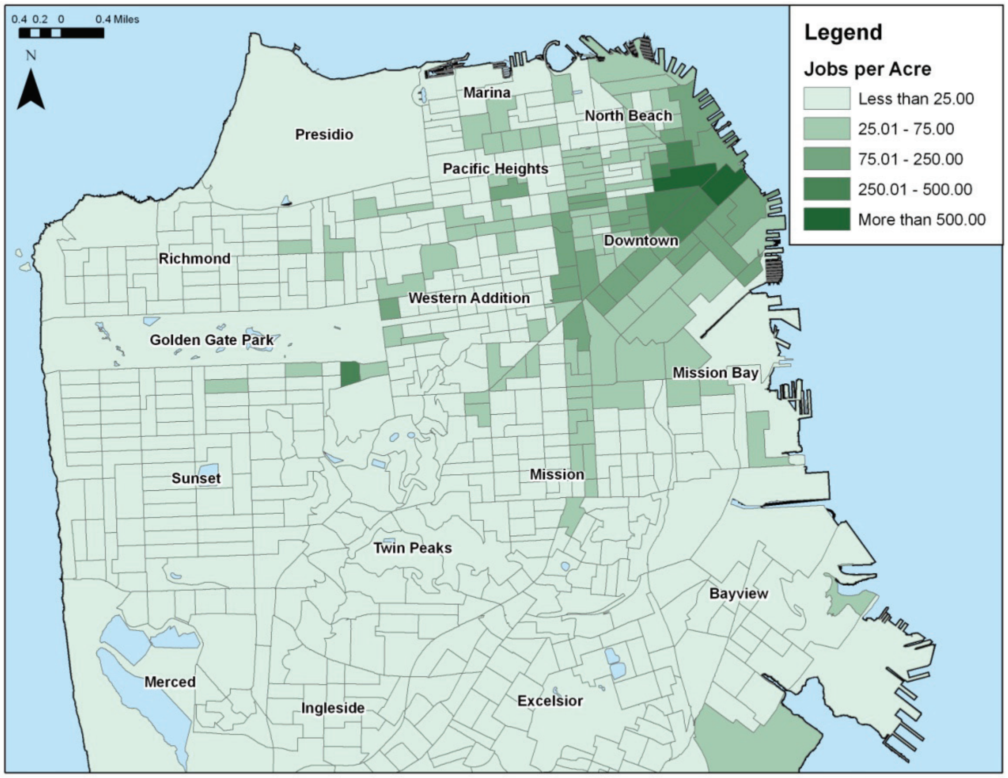

Figure 9-3 Map of San Francisco job density by block group, 2008. (Sources: Dun and Bradstreet (2008 data); Bay Area Economics).

These findings represent a particular earthquake scenario, namely a magnitude 7.2 earthquake on the San Andreas Fault. An equivalent earthquake on the Hayward Fault may have a different impact on Downtown and Mission Bay, particularly as these neighborhoods are located on the City's eastern edge, closer to the subject fault.

HAZUS®99 estimates of commercial building damage after a magnitude 6.8 earthquake on the Hayward Fault suggest that eight percent of building value would be damaged in Downtown. While lower than estimates of damage in the San Andreas Fault scenario, this level of damage is greater than in many other neighborhoods, where damage ranges from two to 15 percent of total commercial building value. Mission Bay would experience the greatest level of commercial building damage in this scenario, at 15 percent of total value.

9.3.4 Worker Access to Jobs

Following an earthquake, workers' ability to get to their jobs is another key component of a community's social and economic resilience. Returning to work allows workers to receive a paycheck, provides residents and firms access to necessary goods and services, and generally restarts the local economic engine.

Table 9-5 shows commute patterns in San Francisco, as reported by the 2000 Census.[33] Approximately 77 percent of San Francisco employed residents also work in the City, suggesting that the majority of San Francisco residents will be able to

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[33] Latest available data.

Table 9-5 San Francisco Commute Patterns, 2000

San Francisco Residents to Place of Work	Number	Percent	San Francisco Workers from Place of Residence	Number	Percent
San Francisco	*322,010*	*77.0%*	*San Francisco*	*322,010*	*54.8%*
Oakland	*8,870*	2.1%	Oakland	*30,365*	5.2%
South San Francisco	*8,785*	2.1%	Daly City	*24,910*	4.2%
Redwood City	*5,190*	1.2%	Berkeley	*9,790*	1.7%
San Mateo	*4,645*	1.1%	South San Francisco	*8,495*	1.4%
Palo Alto	*3,690*	0.9%	Pacifica	*7,125*	1.2%
Burlingame	*3,610*	0.9%	Richmond	*6,960*	1.2%
San Jose	*3,410*	0.8%	Alameda	*6,935*	1.2%
Berkeley	*3,175*	0.8%	San Mateo	*5,820*	1.0%
Other Bay Area[a]	42,730	10.2%	Other Bay Area[a]	132,505	22.6%
Other Places in CA[b]	10,737	2.6%	Other Places in CA[b]	28,209	4.8%
Out of State[c]	1,609	0.4%	Out of State[c]	3,997	0.7%
Total	**418,461**	**86.8%**	**Total**	**587,121**	**100.0%**
San Francisco Residents			**San Francisco Workers**		
Out-Commuting	**96,451**	**23.0%**	**In-Commuting**	**265,111**	**45.2%**

Notes:
(a) "Other Bay Area" includes other areas in Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma counties that are not specifically listed.
(b) "Other Places in CA" includes unincorporated areas within California.
(c) "Out of State" includes Census Designated Places (CDP's) that cannot be broken down into localities.
Sources: U.S. Census, 2000, Census Transportation Planning Package (CTPP); Bay Area Economics.

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-term impact on the local economy, and could ensure a slow recovery.

Modern communications technology does offer some workers the ability to telecommute, assuming utilities remain operational. Looking at San Francisco's major industries, the Financial Activities and Professional Services sectors could operate more effectively though telecommuting. Workers in the Government, Leisure and Hospitality, and Education and Health Services industries would be less able to function remotely.

9.3.5 Neighborhood Demographic Profiles

Higher incomes and educational attainment improve a community's social resilience following an earthquake, allowing households to weather unemployment, purchase necessary goods and services, and relocate to another job or another home as necessary. In turn, lower incomes, linguistic isolation, and a lack of familiarity/access to public assistance systems are negative resilience factors.

Although San Francisco is a generally affluent city, pockets of poverty exist throughout, and some neighborhoods are less disaster resilient than others, due to their socioeconomic characteristics. To draw comparisons between San Francisco neighborhoods and discuss implications for resiliency, household profile reports from Claritas were drawn for three sample areas. Claritas, a private data subscription service, produces annual demographic estimates benchmarked to the decennial U.S. Census, the American Community Survey (ACS), and other public data sources. The estimates are used to formulate profiles of different household types, which offer a demographic snapshot of a particular area. These "PRIZM" profiles consider household income and assets, educational attainment, race and ethnicity, occupation, age, tenure, and household composition. Appendix B contains a more detailed description of each of the PRIZM profiles discussed below.

For this study, the Marina, Sunset District, and Western Addition were chosen as sample neighborhoods because they represent a broad spectrum of San Francisco communities. In addition, these areas have relatively large shares of wood-frame soft story buildings, which are generally more vulnerable than many other building types in an earthquake (ATC, 2009a). The following discussion presents the PRIZM profiles for each neighborhood, as well as the associated implications for socioeconomic resiliency. The findings from these neighborhoods can be applied more broadly to other parts of San Francisco.

*Marina***.** The Marina is almost exclusively composed of "Young Digerati" and "Money and Brains" households. As shown in Table 9-6, these PRIZM segments make up 98 percent of neighborhood residents. These households are characterized by high incomes and income producing assets, advanced degrees, and professional/management-level occupations. The Young Digerati group tends to be aged 25 to 44 years old, while the Money and Brains households are generally 45 to 64 years old. Both segments are predominantly White.

In terms of socioeconomic resiliency, these households have the most resources to aid in recovery following an earthquake. At the same time, the Marina has one of the City's lowest homeownership rates; only 21 percent of households own their homes, compared to 35 percent citywide. (See Ownership section below for detailed homeownership data.) These characteristics suggest that Marina households are highly mobile, capable of relocating to other parts of the region, state, or country if necessary following an earthquake.

Sunset District. The Sunset District has a more varied demographic mix than the Marina. Table 9-6 shows that while the Money and Brains and Young Digerati segments make up over two-thirds of households, the neighborhood also contains "American Dreams," "Cosmopolitans," and "Bohemian Mix" segments. The American Dreams households are characterized by upper-middle incomes, college educations, and ethnic diversity. They range in age from 35 to 54 years, and are often comprised of first- and second-generation immigrants. Cosmopolitans feature college educated, ethnically diverse, empty-nest homeowners with upper-middle incomes. They are generally 55 years or older. Lastly, Bohemian Mix segment includes an ethnically diverse, progressive mix of young singles, couples, and families ranging from students to professionals. They are generally renters with a college education and upper-middle incomes.

These data indicate that the Sunset, while more diverse than the Marina, generally has middle- and upper-middle class residents that would also be able to recover effectively following an earthquake. Moreover, at 56 percent, the Sunset has one of the higher homeownership rates among San Francisco neighborhoods. Studies have shown that owner-occupied units are rebuilt and recover more rapidly than rental units following an earthquake, a positive indicator of the Sunset District's resiliency (Comerio et al., 1994).

Western Addition. Among the three sample neighborhoods, the Western Addition is the most diverse, largely because it spans a broad range of sub-areas including Hayes Valley, Japantown, Haight-Ashbury, the Fillmore, Cole Valley, and parts of Laurel Heights. The Young Digerati and Bohemian Mix segments together make up 61 percent of households in this area (see Table 9-6). The Money and Brains segments comprise another 15 percent of households. In addition, 12 percent of households are "Urban Achievers," characterized by young singles, couples, and families that are typically college-educated and ethnically diverse. A major share of these households are foreign-born and speak a language other than English.

Urban Achievers have lower-middle incomes, are generally renters, and are up to 35 years old. Lastly, eight percent of households are "Urban Elders." These households are generally renters over 55 years old, with low incomes and corresponding educational attainment levels. Altogether, these five PRIZM segments comprise 96 percent of households in the Western Addition. The balance is made up of households in the "American Dreams," "Cosmopolitans," "Close-In Couples," "Low-Rise Living," "City Roots," "Big City Blues," and "Multi-Culti Mosaic" segments. With the exception of Cosmopolitans and American Dreams segments, described earlier, these latter groups are characterized by greater ethnic diversity, lower incomes and educational levels, and fewer assets.

Given its diversity, the Western Addition's resiliency varies by subarea. More stable and affluent areas such as Cole Valley, Japantown, and Laurel Heights are demographically more akin to the Sunset District and other upper-middle class communities. These households do have the resources to support their recovery following an earthquake. In contrast, Hayes Valley and the Fillmore, which have a greater share of lower income households, will be slower to recover. Residents here have fewer resources to weather any disruptions in employment, and renter-occupied multi-family units are more prevalent.

In addition to these multi-faceted demographic profiles, the percent of households living below the federal poverty threshold serves as another indicator of a neighborhood's socioeconomic resiliency.[34] Again, lower-income households have fewer resources to allow them to recover from injuries, damage to their homes and possessions, and any downturn in the economy following a major earthquake. As shown in Figure 9-4, approximately eight percent of San Francisco households live below the poverty threshold.[35] In comparison, Bayview, Downtown, Mission Bay, the Western Addition, and North Beach, all have at least 10 percent of households below the federal poverty threshold.

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[34] The federal poverty threshold was originally developed in 1963-1964 by the Social Security Administration based on 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.

[35] Only includes family households.

Table 9-6 Neighborhood PRIZM Profiles, 2009

MARINA[a]		
PRIZM Segment	**Households**	**% of Total**
Young Digerati	5,782	72.5%
Money and Brains	1,998	25.1%
Bohemian Mix	161	2.0%
Urban Achievers	17	0.2%
The Cosmopolitans	7	0.1%
Close-In Couples	5	0.1%
American Dreams	2	0.0%
Total	**7,972**	**100.0%**
SUNSET[a]		
PRIZM Segment	**Households**	**% of Total**
Money and Brains	17,174	46.9%
Young Digerati	6,340	17.3%
American Dreams	5,552	15.2%
The Cosmopolitans	3,965	10.8%
Bohemian Mix	3,460	9.5%
Urban Achievers	68	0.2%
Urban Elders	30	0.1%
Close-In Couples	23	0.1%
Multi-Culti Mosaic	18	0.1%
City Roots	2	0.0%
Total	**36,632**	**100.0%**
WESTERN ADDITION[a]		
PRIZM Segment	**Households**	**% of Total**
Young Digerati	13,090	30.9%
Bohemian Mix	12,746	30.1%
Money and Brains	6,360	15.0%
Urban Achievers	4,994	11.8%
Urban Elders	3,281	7.8%
American Dreams	575	1.4%
The Cosmopolitans	487	1.2%
Close-In Couples	378	0.9%
Low-Rise Living	196	0.5%
City Roots	98	0.2%
Big City Blues	71	0.2%
Multi-Culti Mosaic	48	0.1%
Total	**42,324**	**100.0%**

Notes:
(a) Neighborhood boundaries, as defined by the City of San Francisco Planning Department.
Source: Claritas, 2009; Bay Area Economics

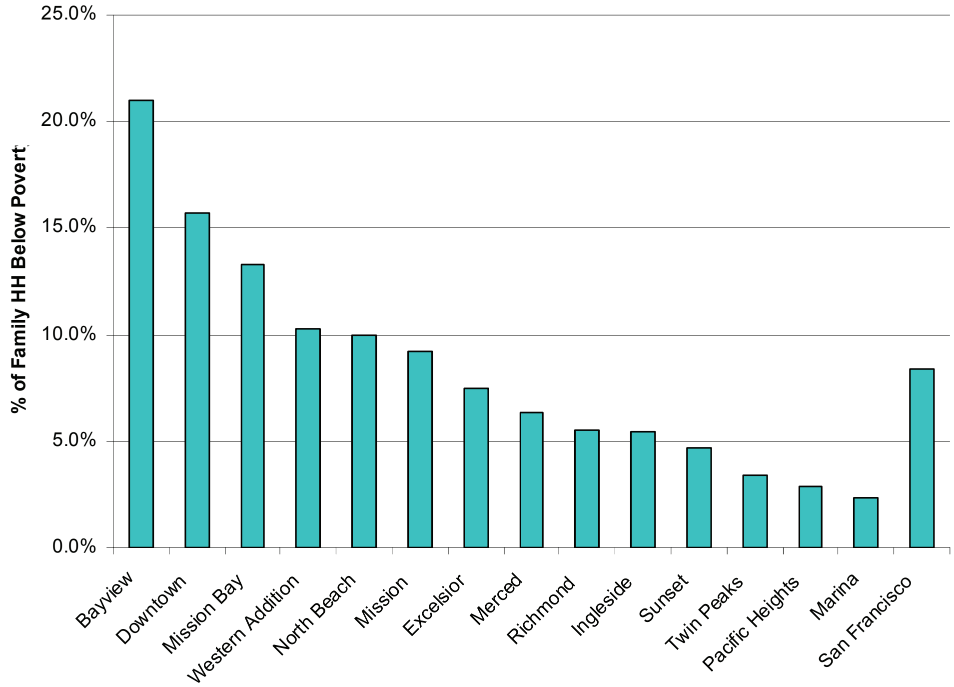

Figure 9-4 Percent of family households living below federal poverty threshold, in San Francisco neighborhoods, 2009. (Sources: Claritas, 2009; Bay Area Economics) .

9.3.6 Homeownership

The following discussion focuses on homeownership, one element of a residential area's social resilience.

Ownership housing tends to be rebuilt at a faster rate than multi-family rental housing following an earthquake. Table 9-7 presents homeownership rates and housing types by neighborhood in San Francisco. As shown, the City as a whole is comprised primarily of renters. Only 34 percent of San Francisco households own their homes. Homeownership rates are lowest in Downtown, North Beach, and the Western Addition—all neighborhoods 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.

As another factor that may impact the rebuilding process, absentee landlords (i.e., located outside the city) may be less prepared to inspect and repair their properties following a major earthquake. Assessing the damage, engaging contractors, working with tenants, and overseeing the construction is all more challenging if done remotely. However, the landlord's location is just one of many factors that will affect his or her ability and willingness to undertake repairs. Financial resources, experience as a property owner, relationship to the tenant, and other considerations will play an equal, if not greater role, in the landlord's responsiveness.

Tenancies-in-common (TICs) are another ownership structure that offers opportunities for more affordable homeownership. 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. The TIC format essentially allows co-owners

Table 9-7 San Francisco Unit Types and Homeownership Rates, 2009

Neighborhood	Unit Type				Tenure	
	Single-Family (Detached & Attached)	Multi-Family	Mobile Homes	Other	Owner Occupied	Renter Occupied
Downtown	2%	98%	0%	0%	8%	92%
North Beach	5%	95%	0%	0%	19%	81%
Western Addition	12%	88%	0%	0%	21%	79%
Marina	11%	89%	0%	0%	21%	79%
Pacific Heights	14%	85%	0%	0%	28%	72%
Merced	41%	59%	0%	0%	28%	72%
Mission	28%	72%	0%	0%	33%	67%
Mission Bay	13%	84%	0%	4%	35%	65%
Richmond	30%	70%	0%	0%	36%	64%
Bayview	67%	32%	1%	0%	52%	48%
Sunset	66%	34%	0%	0%	56%	44%
Excelsior	82%	17%	0%	0%	68%	32%
Twin Peaks	72%	28%	0%	0%	68%	32%
Ingleside	90%	9%	0%	0%	74%	26%
Other[a]	20%	80%	0%	0%	2%	98%
Total	**31%**	**69%**	**0%**	**0%**	**35%**	**65%**

Notes:
(a) Other neighborhoods include Golden Gate Park and the Presidio.
Sources: Claritas, 2009; Bay Area Economics.

to structure a mutually-agreed upon set of rights and responsibilities, including the right to sell an ownership interest.

Although data regarding the number of TICs is not available, anecdotal evidence suggests that TICs have become more common in San Francisco in recent years. As an advantage, TICs offer would-be buyers a way to bypass the City's condominium conversion regulations, and typically feature a discounted sales price due to the added complication and cost of financing a TIC. Recognizing this trend, certain lenders have begun offering specialized loans to serve the TIC market. These products typically require higher fees, rates, and down payments than a conventional mortgage.

Because TICs operate and are financed as owner-occupied units, from a resiliency standpoint, TICs can be considered akin to other ownership units. Generally speaking, TIC owners will be motivated to repair and improve their properties following a disaster, just as other conventional homeowners. Moreover, TICs generally occur in smaller multi-family structures which are relatively easy to rebuild compared to larger complexes. With TICs becoming increasingly common, lenders should also offer TIC owners credit to rebuild, though possibly at higher rates than a standard loan. It is worth noting, however, that the application of FEMA programs to this new and unique form of homeownership remains to be seen. In addition, buildings with multiple owners such as TICs and condominium complexes do pose more logistical and organizational challenges when undergoing repairs, due to the need to coordinate among multiple stakeholders. The unconventional financing structure of TICs with their multiple mortgage holders, may also present additional complexities in the repair process, thereby slowing recovery.

9.3.7 Technical Resilience of Residential Base

Again, technical resilience refers to the physical properties of systems that support resiliency. This section examines the technical resilience of key San Francisco neighborhoods, drawing links between the location of the city's residential base, and the ability of residential units to withstand a major earthquake.

Table 9-8 shows the number of residents by neighborhood in San Francisco. In total, the Mission, Sunset, Excelsior, Western Addition, and Downtown contain almost two-thirds of the city's residents.

Table 9-8 San Francisco Population by Neighborhood, 2009

Neighborhood	Population		Households	
	Number	% of Total	Number	% of Total
Mission	124,526	15.8%	50,758	15.3%
Sunset	99,994	12.7%	36,632	11.0%
Excelsior	93,556	11.9%	24,500	7.4%
Western Addition	85,735	10.9%	42,324	12.7%
Downtown	83,348	10.6%	46,307	13.9%
Richmond	65,876	8.4%	27,462	8.3%
North Beach	49,718	6.3%	26,773	8.0%
Twin Peaks	35,354	4.5%	14,777	4.4%
Bayview	33,898	4.3%	9,331	2.8%
Pacific Heights	31,863	4.0%	18,168	5.5%
Ingleside	26,562	3.4%	7,494	2.3%
Mission Bay	23,377	3.0%	11,726	3.5%
Merced	17,241	2.2%	6,785	2.0%
Marina	12,329	1.6%	7,972	2.4%
Other[a]	4,574	0.6%	1,587	0.5%
Total	**787,951**	**100.0%**	**332,596**	**100.0%**

Notes:
(a) Other neighborhoods include Golden Gate Park and the Presidio.
Sources: Claritas, 2009; Bay Area Economics.

Figure 9-5 presents this data in terms of resident density (persons per acre) by Census block group. Downtown and North Beach show the greatest concentrations of residents, greater than 120 persons per acre. High-density multi-family structures with larger households in the Tenderloin and Chinatown account for this pattern. The Mission District and Western Addition also have major concentrations of residents ranging from 60 to 120 persons per acre, again due to the number of multi-family buildings in these neighborhoods.

As with the City's employment base, HAZUS®99 model runs were used to characterize the technical resilience of San Francisco's neighborhoods. Figure 9-6 presents the HAZUS®99 output associated with a magnitude 7.2 earthquake on the San Andreas Fault. The chart compares each neighborhood's share of total residential building damage in the city with each neighborhood's share of total

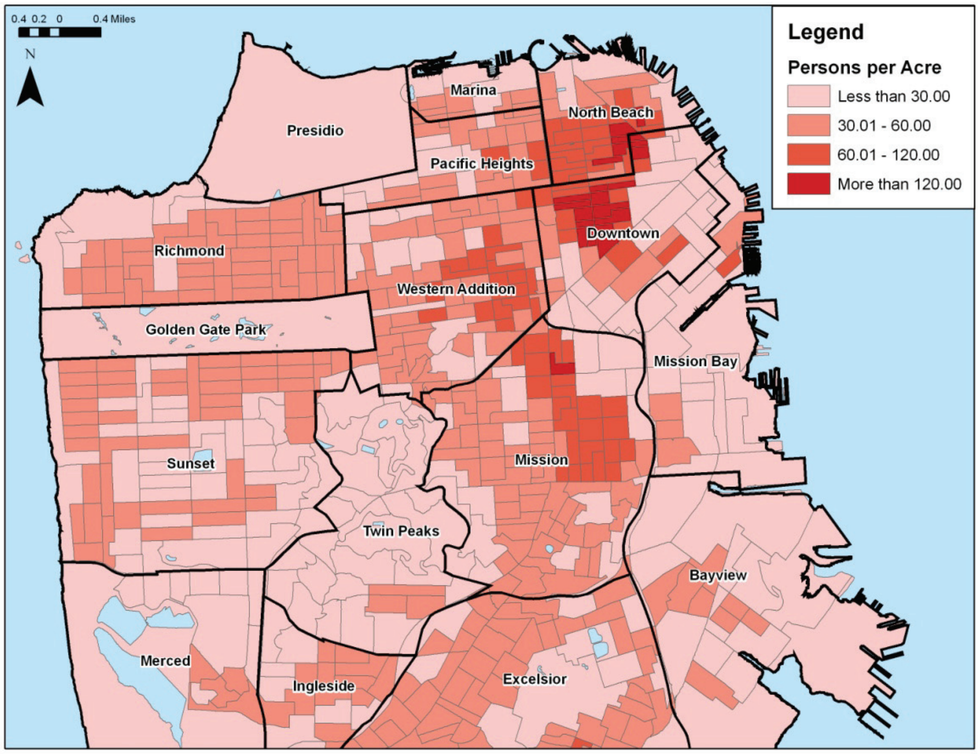

Figure 9-5 San Francisco residential density by block group, 2009. (Sources: Claritas, 2009; Bay Area Economics.)

households in the city.[36,37] This comparison helps identify areas where the level of damage (i.e., share of total damage in the city) appears out of scale with the neighborhood's size.

As shown, the Sunset, Mission, and Western Addition are expected to suffer the greatest share of the city's residential building damage. The level of projected damage in the Western Addition and Mission is consistent with these neighborhoods' share of the city's total households. However, the Sunset, along with a number of other neighborhoods, shows an inordinate degree of damage. Under this scenario, the Sunset would experience 18 percent of the total residential building damage, while only containing 11 percent of the city's households. Similarly, the Richmond is expected to suffer 13 percent of the total residential building damage in San Francisco, but only contains eight percent of total households. The Marina would also experience damage out of scale with its share of total households. Conversely, Downtown, which has 15 percent of the city's households, would only be subject to six percent of total residential building damage in San Francisco.

These findings only represent the impact of one particular scenario, namely a magnitude 7.2 earthquake on the San Andreas fault. Impacts can vary significantly under different scenarios. As shown in Figure 9-7, HAZUS®99 estimates of residential building damage after a magnitude 6.8 earthquake on the Hayward Fault

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[36] Residential buildings include the following HAZUS®99 occupancies: RES1 to RES4.

[37] In this analysis, damage is expressed as the dollar value of damaged structures.

show lower levels of damage in the Sunset and Richmond Districts, more in line with the number of households in those areas. However, Pacific Heights, North Beach, and the Marina would experience damage that is more out of scale with their respective share of total households. These findings are consistent with the fact that the San Andreas fault is located to the west of San Francisco, and would damage the City's western neighborhoods accordingly, while the Hayward Fault—east of the City—would impact eastern neighborhoods to a greater degree.

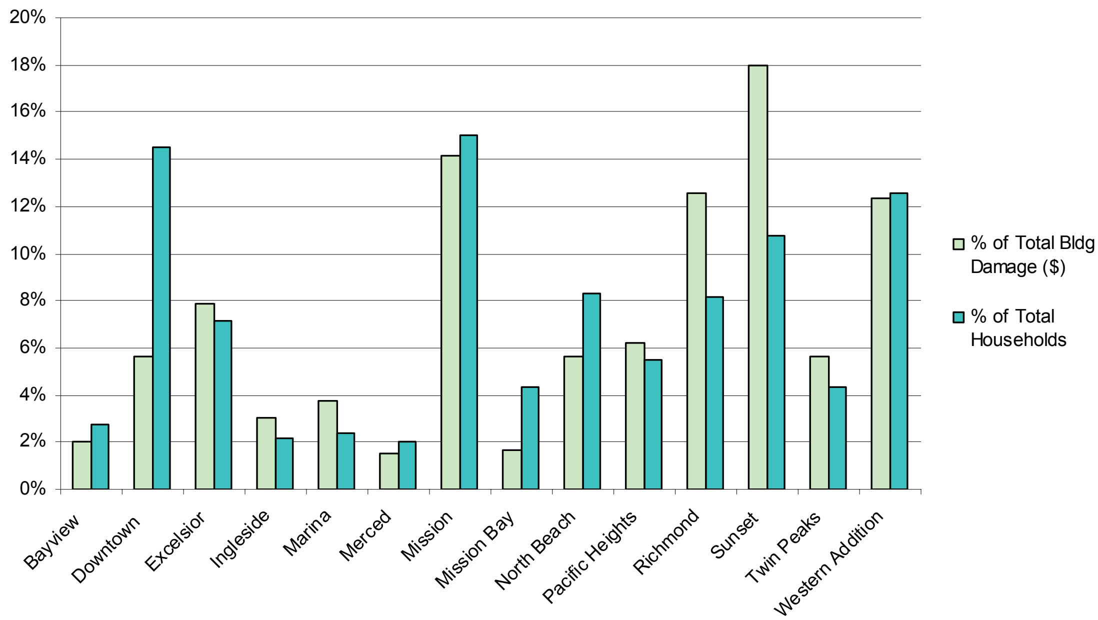

Figure 9-6 Share of total residential building damage and share of total households by neighborhood, magnitude 7.2 earthquake on San Andreas fault. (Sources: HAZUS®99; MMI Engineering; Bay Area Economics).

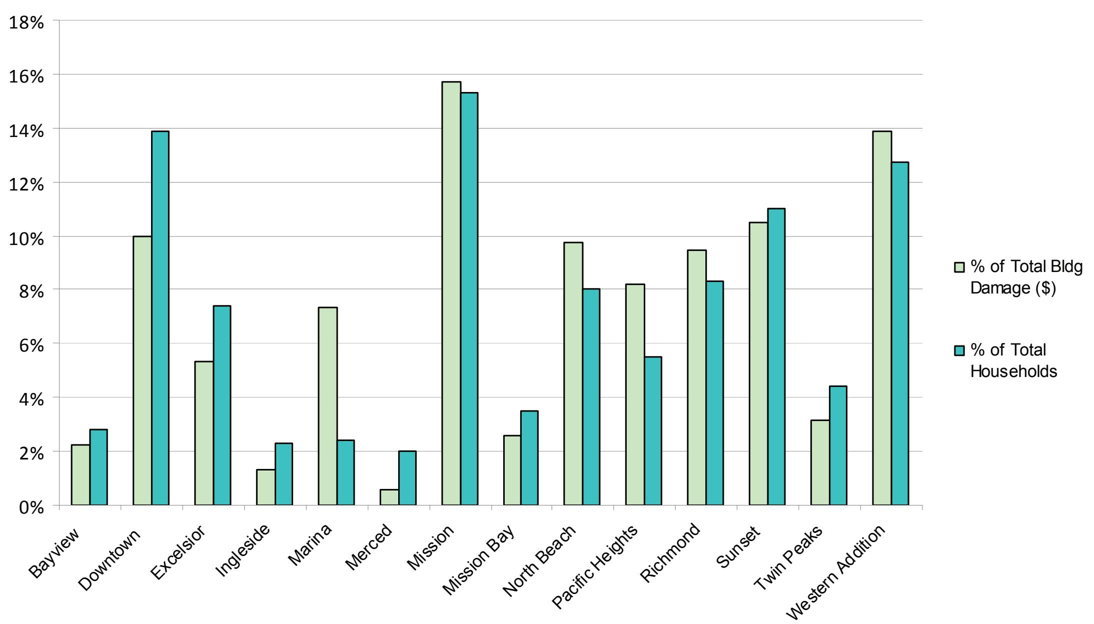

Figure 9-7 Share of total residential building damage and share of total households by neighborhood, magnitude 6.8 earthquake on Hayward fault. (Sources: HAZUS®99; MMI Engineering; Bay Area Economics).

In both scenarios, Downtown, which contains a major share of the City's households, suffers a lower share of total building damage than its size would suggest. This apparent technical resiliency stems partly from the presence of more seismically-resistant building types, such as steel-braced frames, and steel frames with concrete shear walls. However, these figures mask the fact that Downtown also contains a major share of older seismically-vulnerable structures, including unreinforced masonry buildings and those with concrete frames and concrete shear walls. In particular, these buildings occur in Chinatown, the Tenderloin, and portions of SOMA, and house many lower-income residents. As stated earlier, lower-income households are less socially and economically resilient, and would have more difficulty recovering from a major earthquake and damage to their homes. As such, addressing the seismic safety of these buildings should remain a priority for the city, even though Downtown as a whole may perform relatively well in a major earthquake.

9.4 Additional Social and Economic Data

This section presents Tables 9-9 to 9-12 with social and economic data for the City.

Table 9-9 San Francisco Household Income Distributions, 2009

Household Income	Number of HHs	Percent
Less than $10,000	25,712	7.7%
$10,000 to $14,999	12,951	3.9%
$15,000 to $19,999	12,670	3.8%
$20,000 to $24,999	11,147	3.4%
$25,000 to $29,999	11,276	3.4%
$30,000 to $34,999	11,403	3.4%
$35,000 to $39,999	11,733	3.5%
$40,000 to $44,999	12,090	3.6%
$45,000 to $49,999	11,876	3.6%
$50,000 to $59,999	23,555	7.1%
$60,000 to $74,999	30,345	9.1%
$75,000 to $99,999	41,964	12.6%
$100,000 to $124,999	31,857	9.6%
$125,000 to $149,999	22,393	6.7%
$150,000 to $199,999	26,306	7.9%
$200,000 to $249,999	14,037	4.2%
$250,000 to $499,999	13,676	4.1%
$500,000 and over	7,605	2.3%
Total	**332,596**	**100.0%**

Sources: Claritas, 2009; Bay Area Economics.

Table 9-10 Median Home Sales Price, San Francisco

Median Price, June 2009	$650,750
Household Income Needed to Afford Median Price[a]	$157,500
% of households that can afford median priced home, 2009	12%

Notes:
(a) Under following assumptions:

Annual Interest Rate (Fixed)	6.41%
Term of mortgage (Years)	30
Percent of sale price as down payment	20%
Initial property tax (annual)	1.16%
Mortgage Insurance as % of loan amount	0.00%
Annual homeowner's insurance rate as % of sale price	0.11%
PITI = Principal, Interest, Taxes, & Insurance	
% of household income available for PITI	30%

Sources: 2009 DQNews; Claritas, 2009; Freddie Mac (2008 data); California Department of Insurance (2008 data).

Table 9-11 Population and Households by Neighborhood and Socioeconomics, 2009

	Population				Race as Percent of Population							
Neighborhood	Persons	% of Total	Percent Age 65+	Percent Physically Disabled (a)	White	Black/ African American	Native American	Asian	Hawaiian/ Pacific Islander	Other	Multi Race	Hispanic / Latino
Bayview	33,898	4.3%	10.9%	9.9%	5.3%	38.2%	0.3%	28.5%	3.2%	0.2%	2.9%	21.4%
Downtown	83,348	10.6%	17.7%	13.1%	41.4%	8.1%	0.6%	31.6%	0.3%	0.5%	4.3%	13.2%
Excelsior	93,556	11.9%	15.0%	7.3%	12.5%	4.9%	0.2%	52.9%	0.9%	0.2%	2.8%	25.7%
Ingleside	26,562	3.4%	14.7%	8.1%	14.8%	16.1%	0.1%	51.0%	0.5%	0.2%	3.1%	14.1%
Marina	12,329	1.6%	14.6%	5.5%	83.9%	0.4%	0.1%	9.8%	0.1%	0.3%	2.2%	3.3%
Merced	17,241	2.2%	16.9%	6.3%	40.2%	3.6%	0.1%	42.7%	0.2%	0.4%	5.0%	7.8%
Mission	124,526	15.8%	9.8%	6.8%	50.3%	3.1%	0.3%	10.0%	0.2%	0.3%	3.3%	32.5%
Mission Bay	23,377	3.0%	10.0%	5.9%	57.6%	11.7%	0.4%	17.8%	0.6%	0.3%	3.5%	8.2%
North Beach	49,718	6.3%	21.0%	7.6%	53.2%	1.2%	0.1%	39.3%	0.1%	0.2%	2.3%	3.6%
Pacific Heights	31,863	4.0%	14.4%	4.8%	82.7%	1.1%	0.1%	10.1%	0.1%	0.3%	2.1%	3.5%
Richmond	65,876	8.4%	16.3%	6.8%	50.8%	1.2%	0.1%	39.7%	0.1%	0.4%	3.4%	4.3%
Sunset	99,994	12.7%	17.0%	6.6%	40.2%	1.0%	0.1%	50.4%	0.1%	0.3%	3.4%	4.5%
Twin Peaks	35,354	4.5%	18.8%	8.1%	56.9%	4.2%	0.2%	25.9%	0.2%	0.4%	3.8%	8.4%
Western Addition	85,735	10.9%	12.8%	7.6%	64.6%	10.0%	0.2%	13.6%	0.2%	0.4%	3.8%	7.0%
Other[c]	4,574	0.6%	1.5%	1.1%	71.6%	5.5%	0.3%	7.7%	0.9%	0.5%	3.0%	10.5%
Total	**787,951**	**100.0%**	**14.7%**	**7.7%**	**44.5%**	**6.2%**	**0.2%**	**31.0%**	**0.4%**	**0.3%**	**3.3%**	**13.9%**

Notes:
(a) Based on 2000 Census. 2009 figures not available.
(b) Reported for family households only.
(c) Other neighborhoods include Golden Gate Park and the Presidio.
Sources: Claritas, 2009; Bay Area Economics.

Table 9-11 Population and Households by Neighborhood and Socioeconomics, 2009 (continued)

	Households				
Neighborhood	**House-holds**	**% of Total**	**Percent Below Poverty[(b)]**	**Percent Owner**	**Percent Renter**
Bayview	9,331	2.8%	21.0%	52.0%	48.0%
Downtown	46,307	13.9%	15.7%	7.7%	92.3%
Excelsior	24,500	7.4%	7.4%	67.8%	32.2%
Ingleside	7,494	2.3%	5.4%	73.6%	26.4%
Marina	7,972	2.4%	2.3%	21.1%	78.9%
Merced	6,785	2.0%	6.4%	27.9%	72.1%
Mission	50,758	15.3%	9.2%	33.4%	66.6%
Mission Bay	11,726	3.5%	13.3%	35.3%	64.7%
North Beach	26,773	8.0%	10.0%	18.8%	81.2%
Pacific Heights	18,168	5.5%	2.9%	27.7%	72.3%
Richmond	27,462	8.3%	5.5%	36.2%	63.8%
Sunset	36,632	11.0%	4.7%	56.1%	43.9%
Twin Peaks	14,777	4.4%	3.4%	67.9%	32.1%
Western Addition	42,324	12.7%	10.3%	21.0%	79.0%
Other[(c)]	1,587	0.5%	7.6%	1.5%	98.5%
Total	**332,596**	**100.0%**	**8.4%**	**34.5%**	**65.5%**

Notes:
(a) Based on 2000 Census. 2009 figures not available.
(b) Reported for family households only.
(c) Other neighborhoods include Golden Gate Park and the Presidio.
Sources: Claritas, 2009; Bay Area Economics.

Table 9-12 Distribution of Housing Units and Buildings by Neighborhood

Neighborhood	Total Units: Housing Units	Total Units: Vacant	Unit Type: Single-Family (Detached & Attached)	Unit Type: Multi-Family	Unit Type: Mobile Homes	Unit Type: Other
Bayview	9,652	321	67.4%	32.0%	0.6%	0.0%
Downtown	51,185	4,878	2.0%	97.8%	0.2%	0.1%
Excelsior	25,143	643	82.4%	17.4%	0.3%	0.0%
Ingleside	7,706	212	90.2%	9.4%	0.3%	0.1%
Marina	8,410	438	10.6%	89.4%	0.0%	0.0%
Merced	7,055	270	40.8%	59.2%	0.0%	0.0%
Mission	52,801	2,043	28.0%	71.9%	0.0%	0.1%
Mission Bay	15,316	3,590	12.7%	83.5%	0.0%	3.7%
North Beach	29,153	2,380	5.1%	94.5%	0.3%	0.1%
Pacific Heights	19,294	1,126	14.5%	85.4%	0.0%	0.0%
Richmond	28,725	1,263	30.1%	69.9%	0.1%	0.0%
Sunset	37,908	1,276	65.7%	34.1%	0.1%	0.1%
Twin Peaks	15,332	555	71.8%	28.1%	0.1%	0.0%
Western Addition	44,266	1,942	11.6%	88.4%	0.0%	0.0%
Other[c]	2,769	1,182	19.9%	79.8%	0.0%	0.3%
Total	**354,715**	**22,119**	**31.1%**	**68.6%**	**0.1%**	**0.2%**

Neighborhood	Tenure: Owner Occupied	Tenure: Renter Occupied	Rent Controlled Units (75% of Rental Stock)[a]	BMR Units (30% of Rent Controlled)[b]	BMR Units as Percent of Total Units
Bayview	4,848	4,483	3,362	1,009	10.5%
Downtown	3,575	42,732	32,049	9,615	18.8%
Excelsior	16,609	7,891	5,918	1,775	7.1%
Ingleside	5,516	1,978	1,484	445	5.8%
Marina	1,685	6,287	4,715	1,415	16.8%
Merced	1,896	4,889	3,667	1,100	15.6%
Mission	16,975	33,783	25,337	7,601	14.4%
Mission Bay	4,135	7,591	5,693	1,708	11.2%
North Beach	5,039	21,734	16,301	4,890	16.8%
Pacific Heights	5,034	13,134	9,85 1	2,955	15.3%
Richmond	9,948	17,514	13,136	3,941	13.7%
Sunset	20,567	16,065	12,049	3,615	9.5%
Twin Peaks	10,034	4,743	3,557	1,067	7.0%
Western Addition	8,869	33,455	25,091	7,527	17.0%
Other[c]	24	1,563	1,172	352	12.7%
Total	**114,754**	**217,842**	**163,382**	**49,014**	**13.8%**

Notes:

a. The San Francisco Housing Data Book estimates that 75 percent of rental units are under rent control.

b. The San Francisco Rent Control Board estimates that only about 30 percent of rent controlled units are below-market rate because units can be rented at market rates once vacant. BAE estimates that as much as 40 to 60 percent of rent-controlled units may be at market rate based on tenant turnover data from the US Census.

c. Other neighborhoods include Golden Gate Park and the Presidio.

Sources: Claritas, 2009; Bay Area Economics.

APPENDIX A: LIST OF HAZUS®99 FILES REPLACED FOR CAPSS ANALYSES

Replacement File Name	Description
“SRBNDRY” Shape Files	study region boundary file (GIS)
“SRCT” Shape Files	city block boundary files (GIS)
“TMPSRCT” Shape Files	Duplicate city block boundary files required for thematic mapping (GIS)
SOSQFT.DBF	Building Square Footage by Specific Occupancy & city block
BLDCNTSO.DBF	Building Count by Specific Occupancy & city block
BLDCNTGO.DBF	Building Count by General Occupancy & city block
BLDCNTMB.DBF	Building Count by Model Building Type & city block
BLDCNTGB.DBF	Building Count by General Building Type & city block
FTCTMAP.DBF	Foundation type mapping scheme assignment (needed to facilitate use of city blocks as custom units of analysis)
SOSQFTT.DBF	Square Footage Totals by Specific Occupancy
POPHSNG.DBF	Demographic Inventory Data
SBTEXP.DBF	Economic Exposure by Model Building Type (empty file, populated from within HAZUS®99)
GBTEXP.DBF	Economic Exposure by General Building Type
SOEXP.DBF	Economic Exposure by Specific Occupancy
GOEXP.DBF	Economic Exposure by General Occupancy
T152A.DBF	Structural Repair Costs – Complete Damage State
T152B.DBF	Structural Repair Costs - Extensive Damage State
T152C.DBF	Structural Repair Costs - Moderate Damage State
T152D.DBF	Structural Repair Costs - Slight Damage State
T153.DBF	Nonstructural Acceleration Repair Costs
T154.DBF	Nonstructural Drift Repair Costs
T15A.DBF	Cost Modifiers
T1513.DBF	Rental and Disruption Costs Parameters
SOCTMAP.DBF	Census tract assignment to an occupancy mapping scheme
DFLT06H.GB	Occupancy mapping scheme file: header info (replaced with CAPSS-CW.GB)
DFLT06H.HGB	Occupancy mapping scheme file: high code (replaced with CAPSS-CW.HGB)
DFLT06H.LGB	Occupancy mapping scheme file: low code (replaced with CAPSS-CW.LGB)

Replacement File Name	Description
DFLT06H.MGB	Occupancy mapping scheme file: mod code (replaced with CAPSS-CW.MGB)
TCCH.DBF	Capacity Curves - High Design Level
TCCL.DBF	Capacity Curves - Low Design Level
TCCM.DBF	Capacity Curves - Mod. Design Level
TFCAH.DBF	Fragility Curves – Non-Structural Acceleration-Sensitive High Design Level
TFCAL.DBF	Fragility Curves - Non-Structural Acceleration-Sensitive Low Design Level
TFCAM.DBF	Fragility Curves - Non-Structural Acceleration-Sensitive Mod. Design Level
TFCDH.DBF	Fragility Curves - Non-Structural Drift Sensitive High Design Level
TFCDL.DBF	Fragility Curves - Non-Structural Drift Sensitive Low Design Level
TFCDM.DBF	Fragility Curves - Non-Structural Drift Sensitive Mod. Design Level
TFCSH.DBF	Fragility Curves - Structural High Design Level
TFCSL.DBF	Fragility Curves - Structural Low Design Level
TFCSM.DBF	Fragility Curves - Structural Mod. Design Level
T121A.DBF	Debris Unit Weight Parameters
T121B.DBF	Debris Unit Weight Parameters
T122.DBF	Debris Fraction Parameters
T123.DBF	Debris Fraction Parameters
T137A.DBF	Casualty Rates for Buildings - Complete Damage State, with collapse
T138A.DBF	Collapse Rates for Buildings – Complete Damage State
T1313.dbf	Outdoor Casualty Rates – Moderate Damage State
T1314.dbf	Outdoor Casualty Rates – Extensive Damage State
T1315.dbf	Outdoor Casualty Rates – Complete Damage State
CDL.DBF	Dist. Lines - Comm. Facility
EDL.DBF	Dist. Lines - Electrical Power
NDL.DBF	Dist. Lines - Natural Gas
PDL.DBF	Dist. Lines - Potable Water
WDL.DBF	Dist. Lines - Waste Water
DMNDSA.DBF	PESH - GBS - Spectral Acc.
DMNDSD.DBF	PESH - GBS - Spectral Disp.
DMNDSPCT.DBF	PESH - GBS - Spectral Vel.
EPFDMDL1.DBF	PESH - Electric Power Facility – Level 1
PPLDMDL1.DBF	PESH - Pot. Water Pipeline - Level 1

APPENDIX B: PRIZM SEGMENT PROFILES, CLARITAS DATA

<table>
<tr><th>Segment</th><th>Median HH Income[a]</th><th>Age Range</th><th>Kids</th><th>Home-ownership</th><th>Employment Level</th><th>Education</th><th>Income producing assets</th></tr>
<tr><td>American Dreams</td><td>$55,497</td><td>35-54</td><td>Family Mix</td><td>Homeowners</td><td>White Collar, Mix</td><td>College Grad</td><td>Above Avg.</td></tr>
<tr><td colspan="8">American Dreams is a living example of how ethnically diverse the nation has become: just under half the residents are Hispanic, Asian, or African-American. In these multilingual neighborhoods--one in ten speaks a language other than English--middle-aged immigrants and their children live in upper-middle-class comfort.</td></tr>
<tr><td>Big City Blues</td><td>$31,405</td><td><55</td><td>Family Mix</td><td>Renters</td><td>WC, Service, Mix</td><td>High School Grad</td><td>Low</td></tr>
<tr><td colspan="8">With a population that's almost 40 percent Latino, Big City Blues has the highest concentration of Hispanic Americans in the nation. But it's also the multi-ethnic address for low-income Asian and African-American households occupying older inner-city apartments. Concentrated in a handful of major metros, these middle-age singles and single-parent families face enormous challenges: low incomes, uncertain jobs, and modest educations. Roughly 25 percent haven't finished high school.</td></tr>
<tr><td>Bohemian Mix</td><td>$54,237</td><td><55</td><td>Family Mix</td><td>Renters</td><td>White Collar, Mix</td><td>College Grad</td><td>Moderate</td></tr>
<tr><td colspan="8">A collection of mobile urbanites, Bohemian Mix represents the nation's most liberal lifestyles. Its residents are an ethnically diverse, progressive mix of young singles, couples, and families ranging from students to professionals. In their funky rowhouses and apartments, Bohemian Mixers are the early adopters who are quick to check out the latest movie, nightclub, laptop, and microbrew.</td></tr>
<tr><td>City Roots</td><td>$27,691</td><td>65+</td><td>Mostly w/o Kids</td><td>Homeowners</td><td>Mostly Retired</td><td>Some High School</td><td>Below Avg.</td></tr>
<tr><td colspan="8">Found in urban neighborhoods, City Roots is a segment of downscale retirees, typically living in older homes and duplexes they've owned for years. In these ethnically diverse neighborhoods--more than a third are African-American or Hispanic--residents are often widows or widowers living on fixed incomes and maintaining low-key lifestyles.</td></tr>
<tr><td>Close-In Couples</td><td>$40,719</td><td>55+</td><td>Mostly w/o Kids</td><td>Homeowners</td><td>Mostly Retired</td><td>High School Grad</td><td>Above Avg.</td></tr>
<tr><td colspan="8">Close-In Couples is a group of predominantly older, African-American couples living in older homes in the urban neighborhoods of mid-sized metros. High school educated and empty nesting, these mostly older residents typically live in older city neighborhoods, enjoying their retirements.</td></tr>
<tr><td>The Cosmopolitans</td><td>$56,595</td><td>55+</td><td>Mostly w/o Kids</td><td>Homeowners</td><td>White Collar, Mix</td><td>Some College</td><td>High</td></tr>
<tr><td colspan="8">Educated, upper-midscale, and ethnically diverse, The Cosmopolitans are urbane couples in America's fast-growing cities. Concentrated in a handful of metros--such as Las Vegas, Miami, and Albuquerque--these households feature older, empty-nesting homeowners. A vibrant social scene surrounds their older homes and apartments, and residents love the nightlife and enjoy leisure-intensive lifestyles.</td></tr>
</table>

Segment	Median HH Income[a]	Age Range	Kids	Home-ownership	Employment Level	Education	Income producing assets
Low-Rise Living	$24,331	<55	Mostly w/ Kids	Renters	WC, Service, Mix	Some High School	Low
The most economically challenged urban segment, Low-Rise Living is known as a transient world for middle age, ethnically diverse singles and single parents. Home values are low--about half the national average--and even then less than a quarter of residents can afford to own real estate. Typically, the commercial base of Mom-and-Pop stores is struggling and in need of a renaissance.							
Money & Brains	$89,037	25-44	Family Mix	Mix, Owners	Management	Graduate Plus	High
The residents of Money & Brains seem to have it all: high incomes, advanced degrees, and sophisticated tastes to match their credentials. Many of these city dwellers are married couples with few children who live in fashionable homes on small, manicured lots.							
Multi-Culti Mosaic	$35,222	35-54	Family Mix	Homeowners	WC, Service, Mix	Some College	Below Avg.
An immigrant gateway community, Multi-Culti Mosaic is the urban home for a mixed populace of younger Hispanic, Asian, and African-American singles and families. With nearly a quarter of the residents foreign born, this segment is a mecca for first generation Americans who are striving to improve their lower-middle-class status.							
Urban Achievers	$35,409	<35	Family Mix	Renters	WC, Service, Mix	Some College	Low
Concentrated in the nation's port cities, Urban Achievers is often the first stop for up-and-coming immigrants from Asia, South America, and Europe. These young singles, couples, and families are typically college-educated and ethnically diverse: about a third are foreign-born, and even more speak a language other than English.							
Urban Elders	$24,535	55+	Mostly w/o Kids	Renters	Mostly Retired	Some High School	Below Avg.
For Urban Elders--a segment located in the downtown neighborhoods of such metros as New York, Chicago, Las Vegas, and Miami--life is often an economic struggle. These communities have high concentrations of Hispanics and African-Americans and tend to be downscale, with singles living in older apartment rentals.							
Young Digerati	$85,671	25-44	Family Mix	Mix, Owners	Management	Graduate Plus	High
Young Digerati are tech-savvy and live in fashionable neighborhoods on the urban fringe. Affluent, highly educated, and ethnically mixed, Young Digerati communities are typically filled with trendy apartments and condos, fitness clubs and clothing boutiques, casual restaurants and all types of bars--from juice to coffee to microbrew.							

Notes:

a. National household income, 2009.

Sources: Claritas PRIZM Market Segmentation System, 2010

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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) 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.

Projects are performed by a wide range of highly qualified consulting specialists from professional practice, academia, and research—a unique approach that enables ATC to assemble the nation's leading specialists to solve technical problems in structural engineering.

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