ATC 52-3A

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

Earthquake Safety for Soft-Story Buildings: Documentation Appendices

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-52-3A Report, details the technical methods and data used to develop the policy recommendations and related analyses presented in the companion *Earthquake Safety for Soft-Story Buildings* volume (ATC-52-3 Report), which describes the risk of one vulnerable building type and recommends policies to reduce that risk. Several other CAPSS reports are also available in the series, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco*:

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

San Francisco has thousands of wood-frame buildings with a soft-story at the ground level. These buildings—used as apartments, condominiums, stores, and restaurants, among many other ways—are vulnerable to major damage in future earthquakes, with significant consequences on San Francisco's residents and way of life. The risk of these buildings, the impacts of likely damage, and a recommended policy for the City to reduce the risk are presented in a companion report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco*, *Earthquake Safety for Soft-Story Buildings*, developed for the City of San Francisco as part of the Community Action Plan for Seismic Safety (CAPSS) project.

This report presents the technical methods, sources, assumptions, and calculations behind the results in the companion *Earthquake Safety for Soft-Story Buildings* report. While that report is written for a broad audience, this report will be of interest primarily 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.

We offer our sincere thanks to all of the volunteer participants in the CAPSS Advisory Committee meetings, other project meetings, and the project workshop that focused on the development of recommendations for this special class of buildings. The names and affiliations of these individuals are provided in the list of Project Participants section at the end of this report.

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EXECUTIVE SUMMARY

This volume presents the analysis methods that were used to produce the companion report *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings*. The purpose of this volume is to provide detailed information about how the Community Action Plan for Seismic Safety (CAPSS) project team developed the numbers and policy conclusions in that report. Some sections in this companion volume are quite technical in nature and will be of interest primarily to technical specialists; other sections could be interesting to general readers with a desire for detailed knowledge in particular topics.

This overview provides a brief description of each appendix in this volume, to help orient readers toward those parts that may be of interest to them. It also provides a brief summary of the key recommendations and findings from the report *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings*, taken from that report's Executive Summary.

1. Overview of This Report

Overview of Appendix 1: Description of DBI's Inventory of Multi-Family Wood-Frame Buildings

This appendix discusses the process that was used to collect data on multi-family wood-frame buildings in San Francisco. It describes the San Francisco Department of Building Inspection (DBI) survey used to collect this data and the participants in the survey process. It also discusses limitations of the data collected.

Overview of Appendix 2: Analysis of DBI Database of Multi-Family Wood-Frame Buildings

This appendix summarizes the contents of the database of wood-frame buildings with three or more stories and five or more residential units. Data are discussed and presented in a variety of forms, including categorizing buildings (mid-block and corner) by the size of their openings at the ground floor, their number of stories and units, whether or not they are located in a liquefaction or landslide zone, their first floor use, and their date of construction.

Overview of Appendix 3: Maps of Multi-Unit Wood-Frame Buildings

This appendix shows maps of the locations of wood-frame buildings in San Francisco with three or more stories and five or more residential units. It includes maps of all of these buildings, as well as the subset of 2,800 buildings that were analyzed in depth by the CAPSS project. Maps with National Earthquake Hazards Reduction Program (NHERP) soil categories and liquefaction susceptibility are also included.

Overview of Appendix 4: Design of Conceptual Retrofits and Development of Capacity Curves

This appendix presents the conceptual retrofits that were designed for four prototype, wood-frame soft-story buildings. Plans and sketches of each of the prototype buildings are presented, along with the process to select these prototypes. The process and rationale used to develop conceptual retrofits are described, and plans for three conceptual retrofits for each prototype building are presented (a total of 12 retrofits). Capacity curves are presented for each of these buildings, with no retrofit and with each of the retrofits developed. There is some discussion of materials properties and the performance of the study buildings.

Overview of Appendix 5: Cost Estimates for Retrofits

This appendix presents detailed construction cost estimates for the prototype buildings studied. Cost estimates are presented in tabular form for four buildings, each with three possible retrofit approaches. These cost estimates are based on the schematic plans presented in the previous appendix.

Overview of Appendix 6: Procedures to Evaluate Seismic Hazards

This appendix describes the scenario earthquakes that were used to produce loss estimates. It describes how the ground shaking was estimated for those events. It discusses local site conditions and the process used to evaluate susceptibility to liquefaction.

Overview of Appendix 7: Component Fragility Functions for Older Wood-Frame Construction

This appendix describes how fragility functions that were used to estimate losses to San Francisco's wood-frame soft-story buildings were developed. Laboratory tests and observations of earthquake performance were used to estimate the fragility of building components. Drift thresholds associated with various building-component damage states were associated with values of peak transient interstory drift. Damage states were equated with performance categories developed by San Francisco Planning and Urban Research (SPUR) and with ATC-20 post-earthquake safety inspection placard colors *green*, *yellow*, and *red*.

Overview of Appendix 8: Seismic Vulnerability of Four Soft-Story Wood-Frame Index Buildings and Their Retrofits

This appendix describes how seismic vulnerability relationships were developed for the project's four index or prototype buildings. These relationships give the mean damage factor (repair cost as a fraction of replacement cost) and damage state probabilities for each building as functions of spectral acceleration response, earthquake magnitude, fault rupture distance, and NEHRP site soil classes.

Overview of Appendix 9: Estimates of Earthquake Scenario Losses to Large Soft-Story Wood-Frame Buildings in San Francisco

This appendix describes the process used to select a loss-estimation methodology and presents the results of that work. It describes how the seismic hazard and capacity and fragility analyses described previously were combined to produce loss and damage estimates for multifamily wood-frame soft-story buildings. It also applies this method to wood-frame corner buildings in the Marina District of San Francisco for Loma Prieta earthquake shaking levels and compares the results to observed damage.

Overview of Appendix 10: Community and Economic Impacts of Soft-Story Risk and Mitigation

This appendix evaluates socio-economic issues related to San Francisco's wood-frame soft-story buildings. It begins by analyzing the types of residents and businesses that occupy soft-story buildings in San Francisco. It then examines the impacts of both a retrofit policy for soft-story wood-frame residences and a major earthquake on tenants, businesses, and building owners.

Overview of Appendix 11: Soft-Story Mitigation Programs in Other Communities

This appendix describes programs developed in other communities to regulate and study the risk of wood-frame soft-story buildings, as of Fall 2008. Detailed information is provided about programs in the cities of Berkeley, Fremont, Santa Monica and Los Angeles. Brief descriptions of activities in Oakland, San Jose, Burbank, San Leandro, and Campbell are also included.

Overview of Appendix 12: Incentives to Encourage Seismic Retrofits

This appendix reviews numerous types of incentives that can be offered to encourage building owners to undertake voluntary seismic retrofits or to ease the burden of conducting mandated seismic retrofits. When possible, specific experiences of communities that have tried various types of incentives are described, and San Francisco-specific information relating to the feasibility of various incentives is discussed.

2. Summary of Recommendations and Findings in Companion Report

Key Recommendations in Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings

The report recommends that:

- **The Department of Building Inspection should establish a program that requires owners of wood-frame buildings built before May 21, 1973 with three or more stories and five or more residential units to evaluate the seismic safety of their buildings and to retrofit them if they are found to be seismically deficient.** Many of these buildings have "soft-stories" and are highly vulnerable to damage and collapse in earthquakes. Soft-story buildings have a weak ground floor, because perimeter walls have large openings for garage doors and windows, because they often lack interior partitions, and/or because building materials have deteriorated over time.
- **Buildings should be retrofitted to a standard that will allow many of them to be occupied after a large earthquake.** Keeping San Franciscans in their homes helps to avert a post-earthquake shelter crisis, lessens the demands placed upon emergency response services, and allows residents to remain in their neighborhoods and to help to revive them. It is feasible to retrofit this type of building so that many residents can remain in their homes after a large earthquake, even though some damage would occur and utilities might not function.

- **The City should immediately offer incentives to encourage voluntary retrofits.** The program described in this report will take time to launch, but the risk is urgent and should be addressed immediately. To get owners moving on making their buildings safer, the City should offer incentives to owners who retrofit, including expediting plan review, rebating permit fees, offering planning incentives, and seeking voter approval of a City-funded loan program. Buildings voluntarily retrofitted to an acceptable standard should be exempt from requirements created by the recommended program. Incentives need not be limited to the buildings addressed in this report.
- **The Department of Building Inspection should form a working group to develop a detailed plan to implement the recommended program.**

Many other types of buildings in San Francisco pose great threats to the City in earthquakes. In addition to addressing the building types analyzed in this report, the City should pursue policies to make other types of buildings that are at risk of major damage and collapse in future earthquakes safer.

Key Findings in Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings

Retrofitting multi-unit, wood-frame buildings would reduce the consequences of earthquakes to San Francisco. It would retain significant amounts of housing, preserve architectural and cultural attributes, conserve energy and resources, and improve public safety. Retrofitting would shorten the time that the City requires to recover from the next large earthquake. Although other types of buildings are also vulnerable to earthquake damage and also need to be retrofitted, the buildings addressed in this report are particularly vulnerable and can be retrofitted relatively easily.

Many multi-story buildings have a structural weakness due to large openings in their perimeter walls and to a lack of interior partition walls at the ground level. Usually, perimeter wall openings at the ground level make way for garage doors or large windows. Interior spaces used for retail and garages often have few partition walls. The open condition makes the ground level significantly weaker and more flexible than the floors above it. This condition is called a "soft-story." During strong earthquake shaking, these "soft" ground level walls cannot support the side-to-side or front-to-back movement of the stiff and heavy mass of the stories above them, leading to damage and, in the worst cases, to collapse.

There are approximately 4,400 wood-frame buildings built before May 21, 1973[1] in San Francisco with three or more stories and five or more residential units. All of these buildings may have a soft-story condition[1]. CAPSS studied these buildings to understand better how they are being used, how they would perform in future earthquakes, how building performance could be changed through retrofitting, and what would be involved in retrofitting them.

CAPSS analyzed a subset of these buildings, to gain insight into how best to manage the larger number of potentially vulnerable buildings. CAPSS identified and

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[1] May 21, 1973 is the date when the San Francisco Building Code was amended to prevent design flaws that often resulted in soft-story conditions. Buildings constructed after that date, even those with open perimeter walls, should have adequate strength and stiffness at the ground level to resist earthquakes.

evaluated roughly 2,800 buildings that have the largest perimeter wall openings and are, therefore, expected to have significant soft-story weaknesses. Findings show that dramatic damage to this subset of buildings is likely, but that vulnerability could be easily remedied:

- As they now stand, 43 to 85 percent of the multi-unit, wood-frame buildings studied by CAPSS would be posted with a red UNSAFE placard (red-tagged) after a magnitude 7.2 earthquake on the San Andreas fault. This represents 1,200 to 2,400 red-tagged buildings. Red-tagged buildings have severe damage and cannot be occupied after an earthquake, until they are either repaired or replaced. Their residents would need to find new homes for those months or years that it would take to make repairs. The extensive damage predicted to these buildings suggests that buildings with smaller perimeter wall openings at the ground level would also be susceptible to significant damage.
- A quarter of these red-tagged buildings would be expected to collapse. This represents 300 to 850 multi-unit buildings. Collapses threaten lives. These buildings, most of which contain rent-controlled apartments, would be rebuilt differently, using modern materials and design. Owners might not choose to rebuild them as apartment buildings. If they did, then state law dictates that the units would not be covered by rent control. The demographics and architectural character of neighborhoods that experience many collapses could change significantly.
- Nearly 8 percent of the City's population, or about 58,000 people, live in this subset of buildings. The buildings house close to 2,000 businesses that employ an estimated 7,000 people. Without retrofit, the heavy damage that these buildings are likely to sustain would disrupt many neighborhoods for years after an earthquake. Tens of thousands of people would be displaced from their homes and neighborhoods and would not contribute to bringing them back to life. Small businesses along neighborhood shopping streets would suffer severe impacts.
- Seismic retrofits make a big difference and would dramatically reduce the number of collapsed buildings. With retrofit, collapses could be reduced to less than 1 percent of these buildings.
- Retrofitting all of the buildings in this subset to a recommended level that would allow most of them to be occupied after a large earthquake would cost approximately $260 million[2]. These retrofits would eliminate $1.5 billion in damage after a magnitude 7.2 earthquake on the San Andreas Fault. Even so, many retrofitted buildings would still require costly repairs.
- Seismic retrofits at the recommended level are likely to cost in the range of $60,000 to $130,000 per building for direct construction costs. Retrofit construction would last for two to four months and could be limited to the ground floor level, meaning that residents of upper level apartments could stay in their homes. However, construction could have significant impacts on residents and small businesses located at street level in these buildings. Ground floor tenants might temporarily need to close, relocate or deal with considerable construction inconvenience. Tenants occupying the upper floors would experience noise, dust, vibrations and other inconveniences during construction.

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[2] The dollar values mentioned were calculated during the Fourth Quarter of 2008.

- The subset of buildings studied can be found throughout the City but the buildings are most common in the Mission, Western Addition, Richmond, Pacific Heights, North Beach, and Marina neighborhoods.

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APPENDIX 1: DESCRIPTION OF DBI'S INVENTORY OF MULTI-FAMILY WOOD-FRAME BUILDINGS

1.1 Overview

The San Francisco Department of Building Inspection (DBI) developed a database of all wood-frame buildings in the City that have five or more residential units and three or more stories. This database includes information about characteristics that affect a building's earthquake performance. It was developed by DBI staff and volunteer professionals, who walked many City blocks to note specific building characteristics. These data were used by the Community Action Plan for Seismic Safety (CAPSS) project team to analyze the risk of multi-family buildings in future earthquakes.

1.2 Process Used to Develop Database

DBI staff began by reviewing City databases with information about buildings, in particular the Housing Database, maintained by the Housing Inspection Division within the DBI. This database contains information about all properties in San Francisco with three or more residential units. The database includes information about the number of residential units, number of stories, and type of construction.

Analysis of this database indicated that there were approximately 4,500 three-unit buildings with three or more stories, 3,500 four unit-buildings, and 6,000 buildings with five or more units. DBI decided to focus its survey on those buildings with five or more units because that was a manageable number of buildings to survey, because the City's Unreinforced Masonry Building (UMB) program addressed buildings with five or more units, and because the five-unit cutoff is used elsewhere in City codes. It chose to focus on buildings with three or more stories, because those are believed to be more vulnerable to earthquake shaking than are buildings with fewer stories.

DBI approached two local professional organizations for help in organizing the survey: the Structural Engineers Association of Northern California (SEAONC) and the Earthquake Engineering Research Institute, Northern California Chapter (EERI-NC). Volunteers from both of these organizations worked with DBI to plan the survey process.

DBI, SEAONC and EERI-NC developed a form for volunteers to complete during the walking survey. This form included the following information:

- Address
- Number of stories
- Number of dwelling units
- Whether the first floor was wood frame (Yes or No)
- Whether there was clear evidence of seismic retrofit (Yes or No)

- Whether a building was located on a corner (Yes or No)
- Whether a building was located on a sloped site (Yes or No)
- First floor uses
- The percent open at the first story, for all visible sides
- Other comments

DBI input address and unit number information into the survey form for the approximately 6,000 buildings identified from the Housing Database as being wood-frame, three or more stories, and five or more residential units. Information on the City block and lot numbers, a numbering scheme used by the City to identify locations, was also input. A separate form was printed for each city block. These forms were paired with City maps that showed the locations of the buildings identified in the Housing Database.

DBI, SEAONC and EERI-NC mobilized approximately 150 volunteers to participate in a survey, walking City blocks in neighborhoods with many multifamily, wood-frame buildings. Volunteers from SEAONC and EERI-NC were joined by members of the San Francisco branches of the American Institute of Architects (AIA), American Society of Civil Engineers (ASCE), and graduate students from the University of California at Berkeley, San Francisco State University, and Stanford University. A number of these volunteers were identified to serve as team leaders and to manage the efforts of a subset of volunteers. Each team leader was responsible for collecting data for a specific area of the City.

DBI, SEAONC and EERI-NC created training materials for the volunteers, to teach them how to complete the survey forms consistently. All volunteers participated in a training session on the morning of February 24, 2007. This training clarified issues such as the following:

- The percent open on each side of the first floor should be estimated in multiples of 10%
- Doors, large openings, windows and nominal piers between openings count as open areas
- Stories that are partially above ground and partially below ground count as a story, in accordance with standing DBI definitions, but attics with pitched roofs do not count as a story
- Only evidence of seismic retrofits that is clearly visible should be noted
- Corner buildings have street frontage on more than one side
- Buildings should have more than six feet change in elevation from the downhill side to the uphill side to be considered as being located on a sloped site

The walking survey occurred on February 24, 2007. All of the volunteers met at DBI's offices in the morning, received training in the survey program, were divided into groups, and were given maps and survey forms with information for the area they would be surveying. Volunteers were told to verify the data provided from City databases, to correct any information (such as number of units) that was incorrect, and to add any buildings to the form that were not listed but that met the program's criteria. The survey forms all included blank lines for adding buildings. Volunteers surveyed City blocks for a half or full day, then reconvened to give the data they had collected to organizers and to discuss issues.

During this one day event, volunteers were able to survey approximately 50 percent of City blocks, and about 75 percent of wood-frame buildings with three or more units. In the following months, DBI staff members surveyed the remaining City blocks. A small number of City blocks were surveyed using digital image databases, such as http://www.mapjack.com/, instead of having volunteers walking each block. A small number of wood-frame buildings with three or more stories and five or more residential units were not included in the database, because DBI staff knew those buildings to be constructed after the May 1973 code changes, which eliminated most soft-story conditions, were in effect. DBI staff and interns manually entered the data collected by volunteers into an Excel spreadsheet.

The next appendix describes the way that this database was used for the Community Action Plan for Seismic Safety (CAPSS) project.

1.3 Limitations of Database

The DBI database provides an accurate picture of the citywide and neighborhood characteristics of multi-family wood-frame buildings. It is a useful tool to analyze the City's risk from wood-frame soft-story buildings and to guide broad policy decisions. It is not an accurate list of wood-frame soft-story buildings, nor is it, in its current state, a list of buildings that the City should use to notify building owners of requirements of any future programs. To know definitively whether or not a specific building has a soft-story, a qualified engineer must evaluate it in detail; that level of effort was not possible for this survey.

The DBI survey collected information about one characteristic—the portion of open wall line at the first story—that is a rough but reasonable indicator of whether or not a building has a soft story. This information is useful for characterizing the building stock as a whole and for estimating the broad effects of certain policy options, but it does not include all relevant information for individual buildings, such as the amount and characteristics of interior walls in each building, and the building's proximity to neighbor buildings. San Francisco is a large city, and DBI staff and volunteers were able to walk most, but not all, blocks. As described above, some areas were surveyed using online resources for digital images of buildings. In some neighborhoods, specific areas were not surveyed, because they were known by DBI staff to have buildings constructed after code changes eliminated most soft-story conditions in new construction. Due to differences in surveying techniques and individuals, there may be inconsistencies, errors and omissions in the database.

APPENDIX 2: ANALYSIS OF DBI DATABASE OF MULTI-FAMILY WOOD-FRAME BUILDINGS

The Department of Building Inspection (DBI) surveyed all wood-frame buildings that have three or more stories and five or more residential units, as described in Appendix 1. This section summarizes the data collected by that survey. It also describes characteristics of the surveyed buildings that were assessed through comparison with other City databases. DBI data were matched with the following other databases:

- San Francisco City Assessor's Data;
- San Francisco Planning Department database of properties with historic characteristics;
- Map of liquefaction risk: *Preliminary Maps of Quaternary Deposits and Liquefaction Susceptibility, Nine-Counties San Francisco Bay Region: A Digital Database (*Knudsen, et al., 2000);
- *California Geological Survey Seismic Hazard Zones Map*;
- Dun and Bradstreet Data (findings from matching to this database are described in Appendix 10); and
- United States Census (findings from matching to this database are described in Appendix 10).

2.1 Overview

DBI provided the CAPSS project team with a database containing 5,472 entries. After review and revision by the project team to consolidate all information into single building records, there were 4,572 buildings in the database. (The reduction in number is primarily due to condominiums having been listed as individual data records.) The survey and subsequent analyses yielded the following information:

- 4,374 of these buildings were built before the May 21, 1973 Building Code was in effect;
- 2,928 of these buildings (64%) were identified by the project team as having significant openings in their exterior walls, meaning that they are 80% open or more on one side or 50% open or more on two sides; and
- 2,830 of these buildings meet the openness criteria described, have square footage data in the City's assessor's file, and have a known lot and block number (location identifiers).

Openings in exterior walls are a good indicator that buildings may have a "soft" or weak ground floor and be highly vulnerable to earthquake shaking. However, it is not known if these are soft-story buildings, until they are analyzed by an engineer. Further, buildings without significant exterior openings can also have weak ground floors.

In this appendix, results are sometimes reported separately for corner buildings, because they are presumed to have more risk. However some mid-block buildings may not have directly adjacent buildings and may also face higher risk.

Findings are presented by neighborhood, as defined by the Department of Public Works. This scheme of dividing the city was used in the preliminary CAPSS earthquake loss analysis conducted early on in the project. Golden Gate Park, the Presidio and Treasure Island are excluded from the study (see Figure 2-1).

For the mid-block and corner buildings surveyed, the following characteristics were documented:

- Openings of various sizes at the ground floor;
- Number of stories and units;
- Located in a liquefaction or landslide zone;
- First floor use; and
- Date of construction.

Note that some wood-frame buildings with three or more stories and five or more units were not surveyed by DBI, because they were known to be built after May 1973. DBI's database may contain errors and omissions. The findings presented here should be viewed as indicative of city trends for this building type, rather than as definitive numbers.

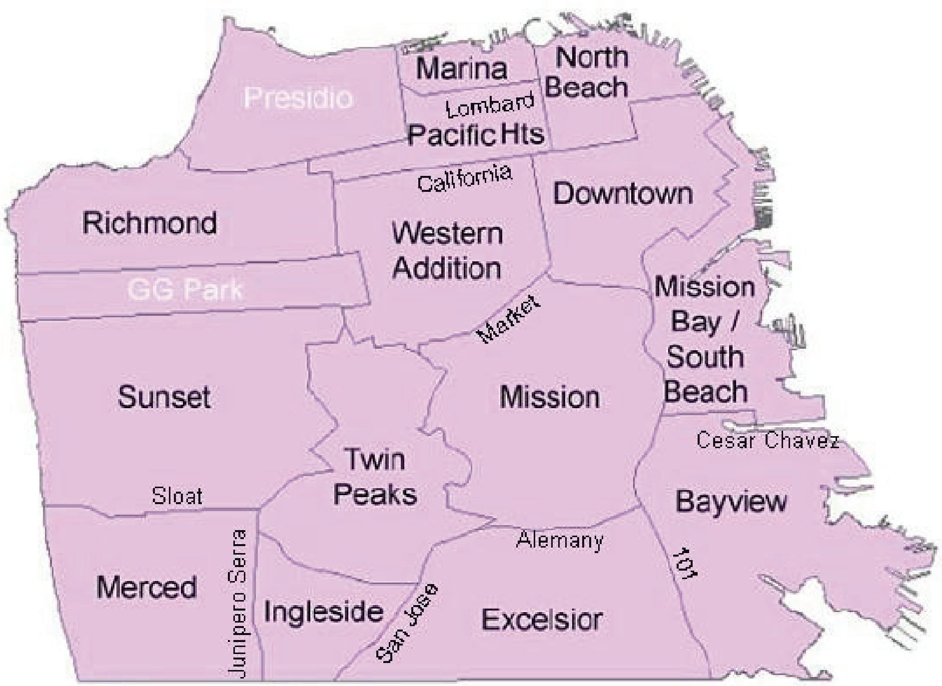


Figure 2-1 Neighborhood division used by the CAPSS project, taken from the Department of Public Works. The Presidio and Golden Gate (GG) Park (shown with white print) are excluded from this study.

2.2 Openness Characteristics

The total number of wood-frame buildings with three or more stories, and five or more residential units in DBI's database, by neighborhood, along with the number of buildings that have significant openings at the ground floor and the number that are corner buildings with significant openings, are summarized in Table 2-1.

Table 2-1 Total Number of Buildings and Buildings with Significant Openings (80% or More Open on One Side or 50% or More Open on Two Sides) in DBI Database, by Neighborhood

Neighborhood	Number of Wood-Frame Buildings with 3+Stories, 5+Units	Number of Buildings with Significant Openings at Ground Floor	Number of Corner Buildings with Significant Openings
Bayview	2	0	0
Downtown	194	111	39
Excelsior	37	32	20
Ingleside	10	3	2
Marina	362	265	114
Merced	1	0	0
Mission	809	531	187
Mission Bay	24	21	6
North Beach	781	364	130
Pacific Heights	504	330	98
Richmond	434	367	158
Sunset	236	190	87
Twin Peaks	119	102	53
Western Addition	1,053	608	236
Unknown	6	4	3
TOTAL	4,572	2,928	1,133

The definition for significant ground floor openings used for the CAPSS analysis is 80% open or more on one side or 50% open or more on two sides. There are other reasonable definitions. Table 2-2 provides information on the range of openness for the most open side of multifamily wood-frame buildings with three or more stories and five or more residential units that are included in DBI's database. Table 2-3 provides information on the range of openness for the two most open sides for corner buildings, presented by the number of buildings. Table 2-4 provides information on the range of openness for the two most open sides for corner buildings, presented by the number of residential units. A building categorized as 100% open has no wall on one side, only columns.

The total number of buildings in Tables 2-2, 2-3, and 2-4 differs slightly from the totals in Table 2-1, due to various data discrepancies. It is most accurate to round these numbers to two significant digits.

Table 2-2 Range of Ground-Floor Openness on Most Open Side in Wood-Frame Buildings with Three Stories or More and Five Residential Units or More

Percent Open on Most Open Side	Mid Block Buildings		Corner Buildings	
	Number of Buildings	Number of Residential Units	Number of Buildings	Number of Residential Units
0-9%	34	295	18	265
10-19%	61	646	62	588
20-29%	99	924	67	811
30-39%	88	775	53	650
40-49%	79	847	40	445
50-59%	219	2,169	104	1,064
60-69%	245	2,189	134	1,448
70-79%	296	2,639	127	1,651
80-89%	376	3,401	145	1,570
90-99%	760	6,723	512	5,954
100%	590	5,407	306	4,070
TOTAL	2,849	26,026	1,568	18,516

Table 2-3 Range of Ground-Floor Openness on the Two Most Open Sides for Corner Buildings, by Number of Buildings

2nd Most Open Side	Most Open Side*											
	0-9%	10-19%	20-29%	30-39%	40-49%	50-59%	60-69%	70-79%	80-89%	90-99%	100%	Total
0-9%	18	35	36	14	10	20	30	16	35	186	33	433
10-19%		27	21	16	5	14	11	15	17	66	12	204
20-29%			10	14	9	22	15	14	15	36	19	154
30-39%				9	12	16	14	13	9	25	22	120
40-49%					4	15	15	15	15	19	23	106
50-59%						17	31	24	17	46	55	190
60-69%							18	18	15	39	44	134
70-79%								12	14	29	33	88
80-89%									8	30	26	64
90-99%										36	22	58
100%											17	17
Total	18	62	67	53	40	104	134	127	145	512	306	1,568

*note: grey highlight indicates buildings that are 80% or more open on one side or 50% or more open on two sides.

Table 2-4 Range of Ground-Floor Openness on the Two Most Open Sides for Corner Buildings, by Number of Residential Units

2nd Most Open Side	Most Open Side*											
	0-9%	10-19%	20-29%	30-39%	40-49%	50-59%	60-69%	70-79%	80-89%	90-99%	100%	Total
0-9%	265	323	420	141	109	204	320	88	336	2,037	371	**4,614**
10-19%		265	311	205	39	124	107	142	146	652	137	**2,128**
20-29%			80	203	106	277	200	170	168	412	217	**1,833**
30-39%				101	126	133	138	113	102	273	215	**1,201**
40-49%					65	172	140	207	168	204	267	**1,223**
50-59%						154	352	292	197	543	591	**2,129**
60-69%							191	295	202	453	667	**1,808**
70-79%								344	168	310	480	**1,302**
80-89%									83	524	386	**993**
90-99%										546	308	**854**
100%											431	**431**
Total	**265**	**588**	**811**	**650**	**445**	**1,064**	**1,448**	**1,651**	**1,570**	**5,954**	**4,070**	**18,516**

*note: grey highlight indicates buildings that are 80% or more open on one side or 50% or more open on two sides.

2.3 Number of Stories

Table 2-5 provides the distribution of number of stories in the inventory of wood-frame buildings with three or more stories and five or more residential units. The totals in Table 2-5 vary from totals in other tables, due to various discrepancies in the databases used to compile this information. However, the overall general numbers and overall trends shown in this table are consistent with numbers reported elsewhere.

Table 2-5 Number of Stories in Multi-Family Wood-Frame Buildings

Building Type	3 stories		4 stories		5 or more stories	
	Number of Buildings	Number of Residential Units	Number of Buildings	Number of Residential Units	Number of Buildings	Number of Residential Units
All buildings	1,662	13,395	2,630	28,965	121	2,159
Buildings with significant ground floor openings	1,087	9,197	1,594	17,809	55	1,082
Corner buildings with significant ground floor openings	387	3,783	626	8,184	27	586

(Significant ground-floor openings refers to buildings that are 80% open or more on one side or 50% open or more on two sides.)

2.4 Landslide and Liquefaction Zones

The number of buildings with significant openings at the ground floor are reported in Table 2-6. The zone data were developed through use of the following maps:

- Liquefaction hazard: *Preliminary Maps of Quaternary Deposits and Liquefaction Susceptibility, Nine-Counties San Francisco Bay Region: A Digital Database* (Knudsen, et al., 2000).
- Landslide hazard: *California Geological Survey Seismic Hazard Zone Map.*

Table 2-6 Buildings with Significant Openings in the Ground Floor Located in Liquefaction and Landslide Zones, by Neighborhood

Neighborhood	Number of Buildings in Very High Liquefaction Zone	Number of Corner Buildings in Very High Liquefaction Zone	Number of Buildings in Landslide Zone	Number of Corner Buildings in Landslide Zone
Bayview	0	0	0	0
Downtown	35	13	0	0
Excelsior	0	0	0	0
Ingleside	0	0	0	0
Marina	148	67	0	0
Merced	0	0	0	0
Mission	100	29	3	1
Mission Bay	1	1	0	0
North Beach	45	20	4	1
Pacific Heights	26	14	0	0
Richmond	0	0	0	0
Sunset	13	7	1	1
Twin Peaks	0	0	16	10
Western Addition	13	2	0	0
TOTAL	381	153	24	13

2.5 First Floor Use

The number of buildings with significant ground floor openings having different uses at the ground floor level are provided in Table 2-7. This information has been divided by neighborhood but is not presented here, due to its complexity. Neighborhoods with significant numbers of buildings with ground floor openings and ground floor commercial use are: North Beach, Mission, and Western Addition.

Table 2-7 First Floor Use of Buildings with Significant Openings

First Floor Use	Number of Buildings with Significant Openings	Number of Corner Buildings with Significant Openings
Commercial	395	199
Garage & Commercial	90	59
Garage/Parking	1,917	713
Basement	5	0
Residential	423	111
Hotel/Motel	14	8
Unknown	84	43
TOTAL	2,928	1,133

2.6 Date of Construction

Data summarizing the number of buildings with significant ground opening by date of construction and neighborhood are provided in Table 2-8. Date of construction comes from City Assessor's Data. Note however, that all buildings in the Assessor's data have a date of construction. All apartment buildings built before June 1979 are covered by rent control law. An estimated 2,592 buildings with significant openings at the ground level are apartment buildings and presumably are covered by rent control law.

Table 2-8 Year of Construction of Buildings with Significant Ground Floor Openings, by Neighborhood

Neighborhood	Pre-1900	1900-1909	1910-1919	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979	Post-1980
Bayview	0	0	0	0	0	0	0	0	0	0
Downtown	0	37	49	11	0	0	1	2	1	9
Excelsior	0	3	0	5	0	0	5	9	4	5
Ingleside	0	0	0	0	0	0	0	3	0	0
Marina	0	3	2	193	24	0	12	14	7	8
Merced	0	0	0	0	0	0	0	0	0	0
Mission	10	194	72	84	4	1	21	103	16	15
Mission Bay	0	1	2	1	0	0	2	14	1	0
North Beach	0	114	111	61	6	4	12	24	13	14
Pacific Heights	1	86	38	89	6	4	31	57	9	5
Richmond	0	17	20	147	8	4	27	115	21	3
Sunset	0	6	6	37	0	4	41	69	21	3
Twin Peaks	0	0	0	2	1	1	11	69	13	1
Western Addition	10	212	71	163	6	4	44	60	22	14
TOTAL	21	673	371	793	55	22	207	539	128	77

APPENDIX 3: MAPS OF MULTI-UNIT WOOD-FRAME BUILDINGS

This appendix contains maps showing locations of various groupings of wood-frame buildings with three or more stories and five or more residential units. Figure 3-1 shows all such buildings, Figure 3-2 shows all such buildings, but differentiates those with significant first floor openings from all others. Buildings with significant ground-floor openings are those with 80% or more openings on one side, or with 50% or more openings on two sides. Figure 3-3 shows only wood-frame buildings with three or more stories and five or more residential units with significant ground-floor openings. Figure 3-4 shows the same buildings as Figure 3-3 (those with significant first-floor openings) plotted on a map of the National Earthquake Hazards Reduction Program (NEHRP) soil types. Figure 3-5 shows all wood-frame buildings with three or more stories and five or more residential units, plotted on a map showing very high liquefaction susceptibility zones.

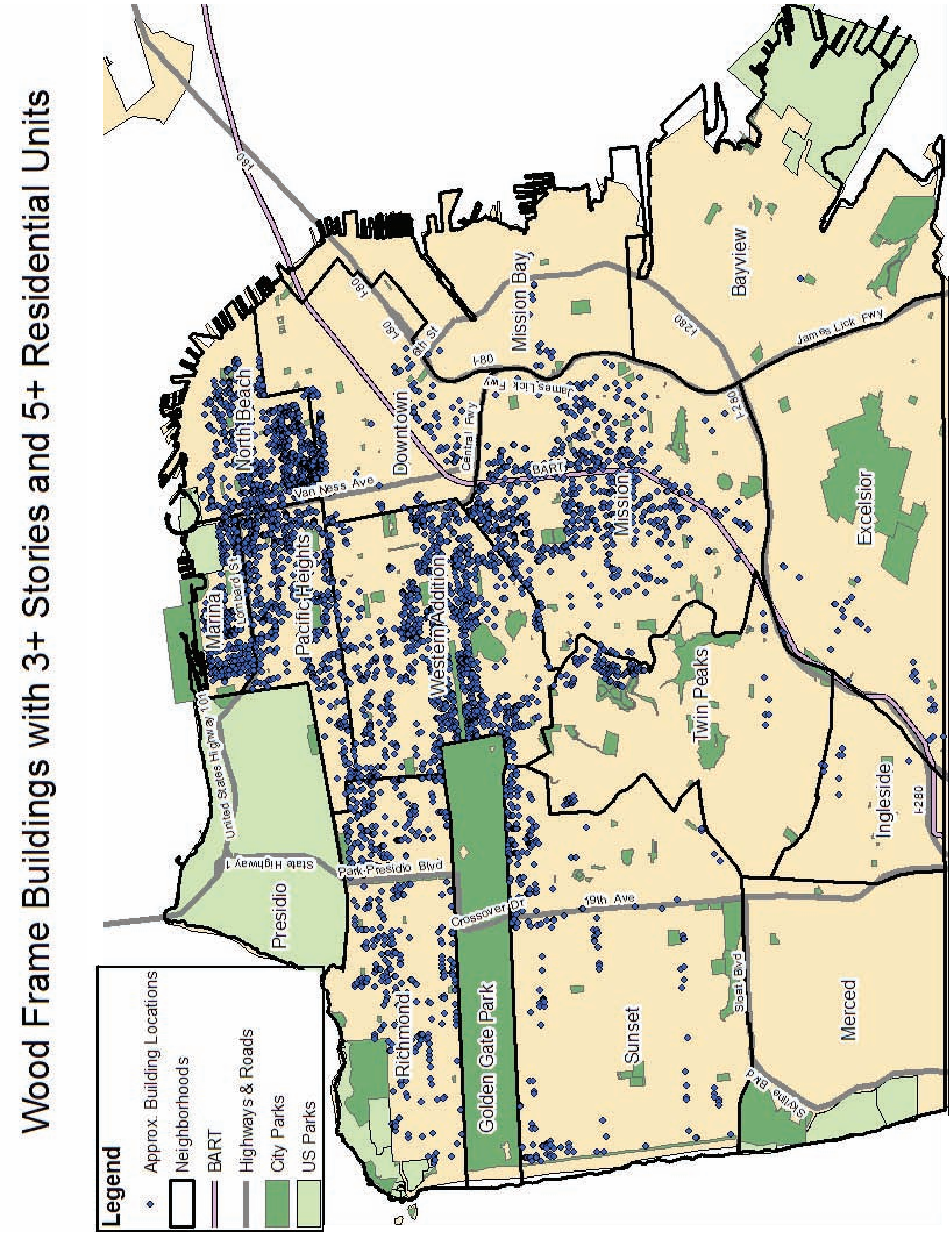


Figure 3-1 Map showing all wood-frame buildings with 3 or more stories and 5 or more residential units.

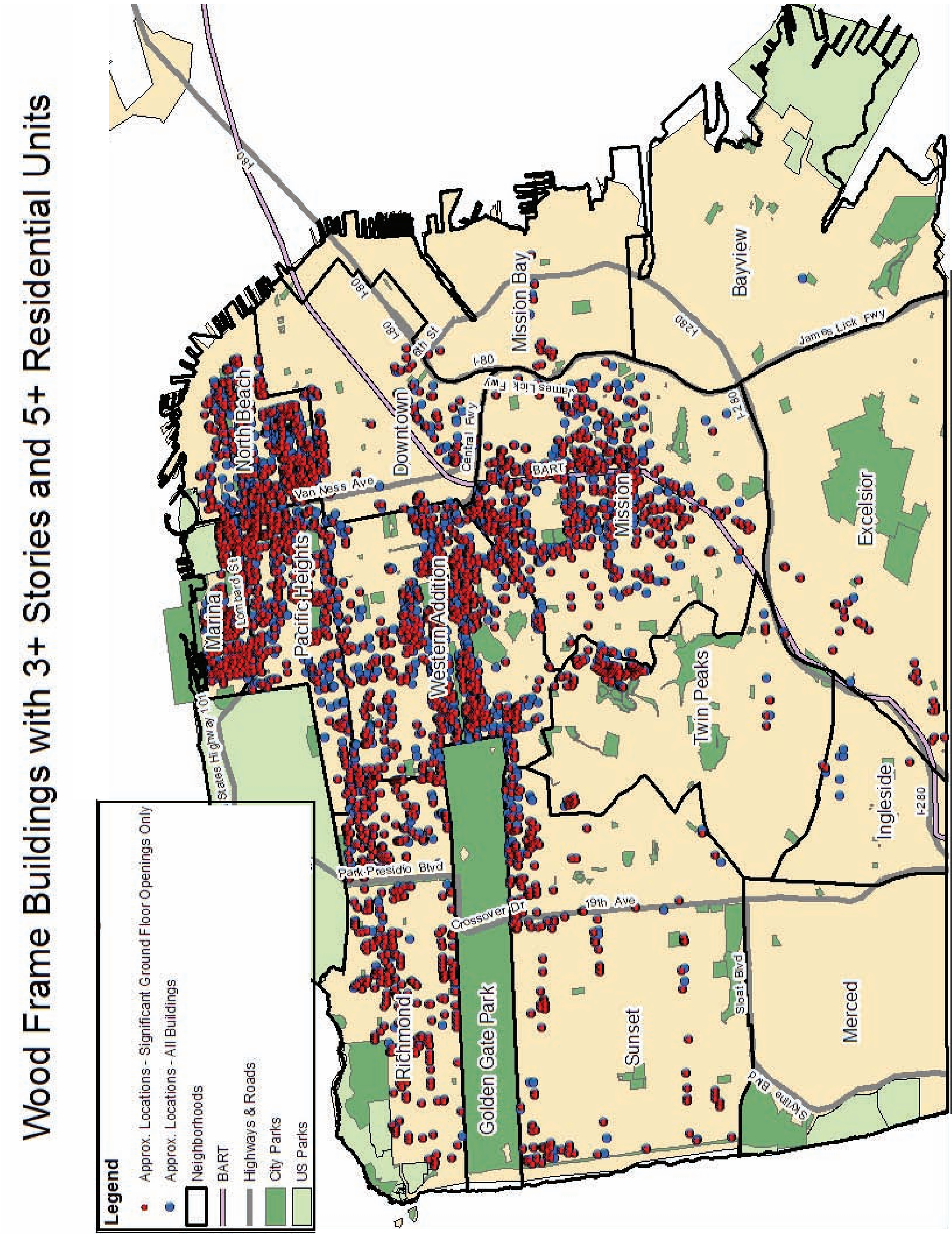


Figure 3-2 Map showing two groups of wood-frame buildings with 3 or more stories and 5 or more residential units: those with significant ground floor openings and all others.

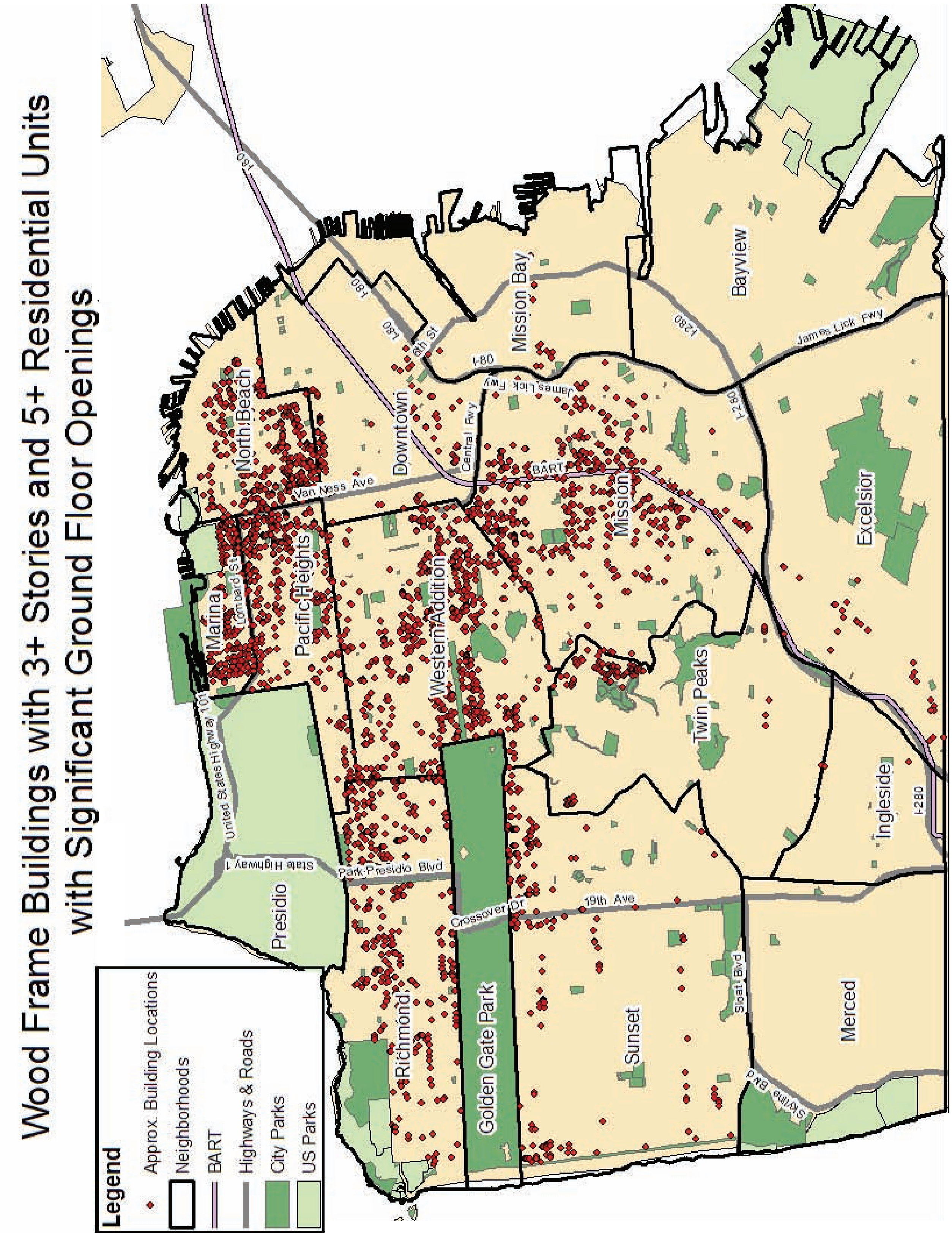


Figure 3-3 Wood-frame buildings with 3 or more stories and 5 residential units with significant ground-floor openings.

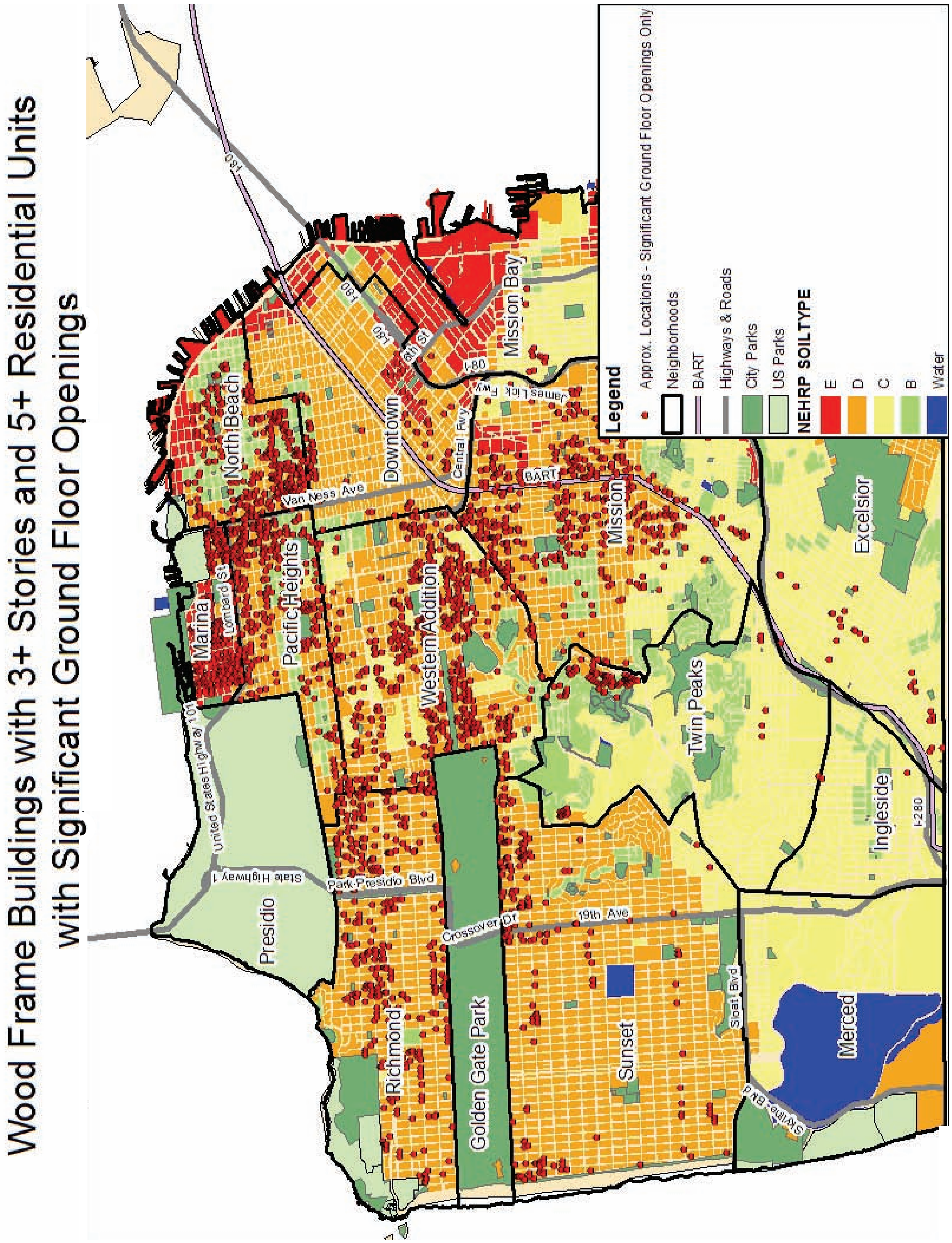


Figure 3-4 Map showing NEHRP soil type and wood-frame buildings with 3 or more stories and 5 or more residential units with significant ground-floor openings.

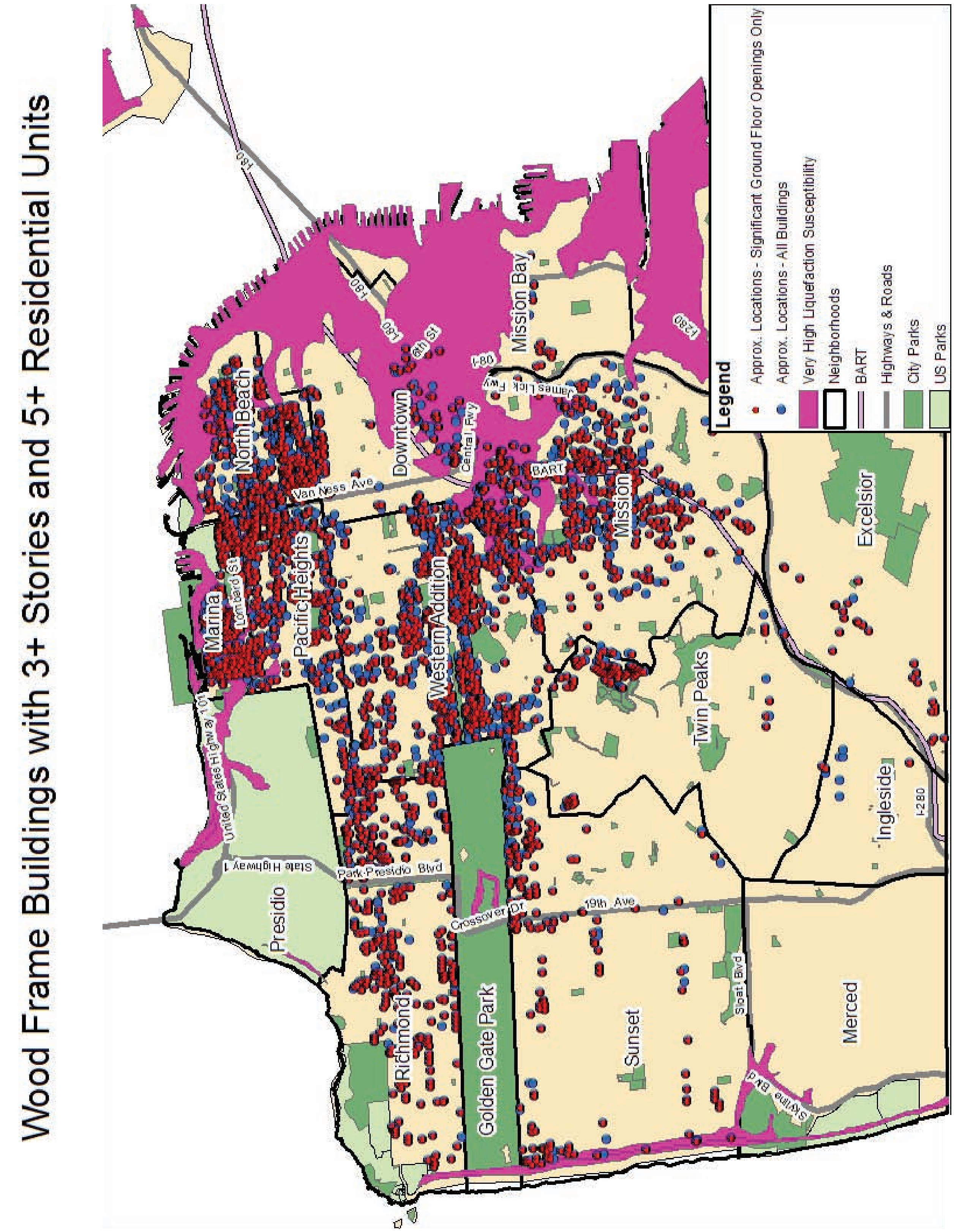


Figure 3-5 Map showing very high liquefaction susceptibility and wood-frame buildings with 3 or more stories and 5 or more residential units, including those with significant floor openings and all others.

APPENDIX 4: DESIGN OF CONCEPTUAL RETROFITS AND DEVELOPMENT OF CAPACITY CURVES

4.1 Introduction

Four San Francisco open wall Index Buildings were selected for study. The term "open wall" is used to describe buildings with ground stories in which the amount of exterior or interior wall is significantly less than at the stories above. For each Index Building, conceptual seismic retrofits were developed for three levels of performance. Capacity curve parameters of spectral acceleration and displacement at yield and peak capacity were developed to allow for analysis of earthquake losses and costs of retrofit construction.

4.2 CAPSS Retrofit Design Charette

Plans and street front elevations for candidate Index Buildings were compiled by San Francisco DBI staff for consideration. With the candidate buildings as a starting point, a design charette was held on 12 September 2008 to get input on selection of Index Buildings, retrofit approaches, and performance expectations. The charette attendees included design engineers, contractors, San Francisco DBI representatives and project members. The attendee list is included in the list of Project Participants (back of document).

Discussion of performance expectations was framed around comparison of building code forces levels, ASCE 41 performance objectives (ASCE, 2006), and four levels of performance defined by the San Francisco Planning + Urban Research Association (SPUR). See section 5 of the SPUR report, "The Resilient City: Defining What San Francisco Needs from Its Seismic Mitigation Policies," for further discussion of the SPUR performance levels (SPUR, 2009). The four SPUR levels are:

- Level A: Safe and operational;
- Level B: Safe and usable during repair;
- Level C: Safe and usable after repair; and
- Level D: Safe but not repairable.

The participants were asked which levels they believed were possible and practical to design for, and how they would approach design for the levels of interest. These questions led to far-ranging responses, varying from the highest performance level (SPUR Level A) being prudent for some buildings, to the expense of obtaining a high performance level being much too great, and moderate-to-low performance being reasonable targets. Methods proposed to achieve performance in retrofit design included using a percentage of current building code forces levels to targeting drift limits for each performance, such as those suggested in ASCE 41 Table C3-1 (ASCE, 2006).

Participants pointed out a number of other issues that affect both safety and habitability of buildings following an earthquake. These included the availability of water, power, and other services not controlled by the property owner; the effects of nonstructural damage, including heating systems, and; the effects of damage to masonry chimneys and veneer. These items complicate targeting higher levels of performance.

4.3 Selection of Index Buildings

Using the candidate Index Buildings compiled by DBI staff, four buildings were selected for study. It was decided to use two corner buildings and two mid-block buildings. Variables chosen included the number of stories, the size of the building footprint, and the construction materials. Hillside buildings were not included, because a large number of the buildings are on relatively level sites, and because there were concerns regarding the accuracy of hillside building analysis. Each of the Index Buildings has an open-wall ground floor, accommodating parking and storage areas, while the upper stories have residential units with a significant amount of interior partition wall. The open wall ground floor could, in other cases, be used for commercial space; the use of the ground floor does not have a great impact for the buildings and retrofits chosen. Table 4-1 describes characteristics of the four Index Buildings. Plans and illustrations for the four Index Buildings are provided in Figures 4-1 through 4-12.

Table 4-1 Description of Index Buildings Selected for Study

Building Number	Location in Block	Number of Stories	Plan Area Per Floor (Ft^2)	Number of Units	Interior Wall Finish
1	Corner	3	3610	6	Plaster & wood lath
2	Corner	4	5800	8	Plaster & wood lath
3	Mid-block	4	2270	6	Plaster & wood lath
4	Mid-block	3	1750	4	Gypsum Wallboard

4.4 Retrofit Designs

Three levels of retrofit design were selected as being reasonable to pursue and were applied to all four Index Buildings. The SPUR levels were used as a target for performance. It must be kept in mind, however, that using a performance description for a target does not translate into certainty that the performance description will be met for individual buildings. Significant variations in building configuration, building construction, and earthquake ground motion will yield a range of performance for buildings with the same target performance.

Retrofit 1 targeted SPUR Level D as the intended performance. This was approached by identifying and retrofitting the specific exterior wall lines that were clearly vulnerable. This approach assumed that by addressing the obvious vulnerability, the performance of the building would increase to match the performance of similar buildings without the obvious vulnerability. Typical retrofit measures included steel moment frames and oriented strand board (OSB) shear walls being added in the ground story. Locations of and reasons for vertical retrofit elements are shown in Table 4-2.

Table 4-2 Retrofit 1 Elements

Building	Element	Location	Reason
1	Steel moment frames	Street front	Obvious lack of bracing wall length
	OSB shear walls	Transverse end walls	Obvious lack of bracing wall length, vulnerability observed in CUREE-Caltech Wood-Frame Project testing
2	Steel moment frames	Street front	Obvious lack of bracing wall length
	OSB shear walls	Street front	Obvious lack of bracing wall length
3	OSB shear walls	Transverse direction	Obvious lack of transverse bracing
4	OSB shear walls	Rear transverse wall and longitudinal walls	Lack of transverse bracing was addressed by sheathing existing walls. This requires a significantly lower level of effort than adding new steel elements for this building type.

Retrofit 2 targeted SPUR Level C as the intended performance. This was approached by providing retrofits of all of the vertical resisting elements in the entire ground story. Retrofit 2, like Retrofit 1, typically involved use of steel moment frames and OSB shear walls. A greater extent of OSB shear wall was provided in Retrofit 2 than in Retrofit 1.

Retrofit 3 targeted performance in the range between SPUR Levels B and C. This was approached by replacing the steel moment frames with steel cantilevered columns, while maintaining the seismic force level used for proportioning the system. Because the cantilevered columns are designed using an R factor of 2.5 rather than the moment frame R of 8, their use led to lower deflections, which should translate to a lower cost of repair.

In proportioning the retrofit systems, the seismic demand used an S_{DS} of 1.17. This is based on a mapped S_1 value that falls near the center of San Francisco and a default site class D. Vertical elements for all three retrofit levels were proportioned using 75% of the equivalent lateral seismic force required by the *San Francisco Building Code* (SFBC) (City and County of San Francisco, 2007). In addition, vertical elements were checked against SFBC drift requirements. The seismic design coefficients for the systems used are shown in Table 4-3. A triangular vertical distribution was used, consistent with new building design.

The design of the retrofits was carried out on a line by line basis, in the spirit of ASCE 7 (ASCE, 2005) Section 12.2.3.2, which allows the R factor to vary by line but is limited to buildings of two stories or less. This approach is of great benefit in retrofits that incorporate vertical elements with varying R factors.

Retrofit plans for the three levels and four buildings are provided in Figures 4-13 through 4-23.

Table 4-3 Seismic Design Coefficients for Vertical Elements Used in Retrofit Designs

Vertical Element Type	R factor	C_d factor	Allowable Drift
OSB Shear Wall	6.5	4	.02h
Special Steel Moment Frame	8	5.5	.02h
Special Cantilevered Column	2.5	2.5	.02h

4.5 Development of Capacity Parameters

For each of the Index Buildings, a series of capacity curves were developed to describe the building load-deflection behavior. From these curves, yield and peak capacity forces and displacements were identified and converted to spectral accelerations and displacements.

For development of the capacity curves, load deflection behavior from a variety of sources was viewed. These sources included:

Plaster over wood lath:

- Forest Products Laboratory (1956), Test 11
- Ben Schmid (Schmid, 1984)
- ASCE 41 (ASCE, 2006)

Straight horizontal sheathing:

- Forest Products Laboratory (1956), Test 4
- AF&PA Special Design Provisions for Wind and Seismic (SPDWS) (AF&PA, 2005),
- ASCE 41 (ASCE, 2006)

Gypsum wallboard:

- ASCE 41 (ASCE, 2006)

OSB shear walls:

- AF&PA SDPWS (AF&PA, 2005)

Using these references, capacities and deflections were identified for a typical one story wall at yield and peak capacity. For the most part, best estimate values from available information were used. In the case of gypsum wallboard, used exclusively in the upper stories of Index Building 4, four sources of existing data provided two low capacities and two high capacities; the low values were chosen, since they could confidently be met or exceeded. Use of the high values would have made Building 4 performance similar to Buildings 1 and 2. The values used are shown in Table 4. These values assume the sheathing material being applied to one face of the wall and are adjusted where sheathing is applied to both faces. It should be noted that testing of wood shear wall systems generally does not reveal a clearly discernable yield point, where stiffness changes significantly but rather, shows loss of stiffness starting at very low load levels. For this reason, a yield point is considered to be artificial in wood frame systems. However, because definition of a yield was required for loss estimation analysis, yield was identified consistent with ASCE 41 default assumptions.

Table 4-4 Shear Wall Capacities and Deflections at Yield and Peak Loads

Sheathing Material	Yield Capacity	Deflection at Yield	Peak Capacity	Deflection at Peak
Plaster over Wood Lath	350 plf	0.5”	400 plf	0.7”
Straight Horizontal Sheathing	160 plf	0.8”	200 plf	3.0”
Gypsum Wallboard	67 plf	0.1”	100 plf	0.5”
OSB Sheathing	67% peak capacity per ASCE 41	Per SDPWS deflection equation	Per SDPWS tabulated nominal capacity	Per SDPWS deflection equation

For steel moment frames and steel cantilevered columns, yield force and deflection were calculated based on initial member yield. Peak capacity was calculated assuming that a full plastic hinge had developed and including a multiplier of 1.1, to account for strain hardening effects. Deflection at peak capacity was calculated using ASCE 41 tabulated multipliers between yield and peak capacity displacements.

These material values were used as bi-linear load deflection curves, and the yield and peak capacities for each story and building were developed from these curves. For vertical distribution of seismic demands, a triangular seismic force distribution was used. Building deflections were calculated for the longitudinal and transverse directions at the center of the floor considering combined materials and, where applicable, increased in deflection due to diaphragm rotation. Resulting bi-linear capacity curves are provided in Figures 4-24 through 4-27.

4.6 Comments on Building Behavior

As part of the calculation of the push over curves, it was possible to compare the seismic capacities of the ground floor to upper floors. From this, some observations can be drawn regarding the need to retrofit upper stories of open-wall buildings. Upper story yield and peak capacities used in developing the capacity curves were dependant exclusively on the interior finish material: plaster over wood lath for Buildings 1, 2 and 3, and gypsum wallboard for Building 4. The contribution of other materials was minimal, due to high flexibility and low capacity. Using this approach, up to peak capacity of the ground floor retrofit, the upper stories of Buildings 1 and 2 remained at or below yield capacity for the plaster. This suggested that, given the construction materials and the retrofit approaches used in this study, it is very reasonable to limit the retrofit work to the ground story, without concern that damage causing life-safety concerns will occur at upper floors. For Building 3 in the transverse direction and Building 4, upper story capacities did control the building peak capacity for some of the retrofits. Although this suggests that damage might occur in upper stories, the history of performance of residential light-frame construction suggests that this is not as big a concern as the analysis suggested.

Building 1 displayed significant torsional response under longitudinal loading, in both the original building configuration and Retrofit 1. In the original building configuration, the center of rigidity was at the rear longitudinal wall, while in Retrofit 1, the center of rigidity moved very close to the street front at the added moment frames. The effect of the torsion is to put very high demands on the end transverse walls. For a ground motion at an angle to the primary axes, the combination of direct and torsional load on these walls is significant and of concern. Significant damage to end transverse walls was identified in CUREE-Caltech Project testing of an open wall building on the Berkeley shake table (Mosalam et al., 2002). The particular vulnerability of this geometry of building should be taken into consideration. This behavior was not an issue on Building 2, due to the contribution of interior walls.

Figure 4-1 Index Building 1 elevation.

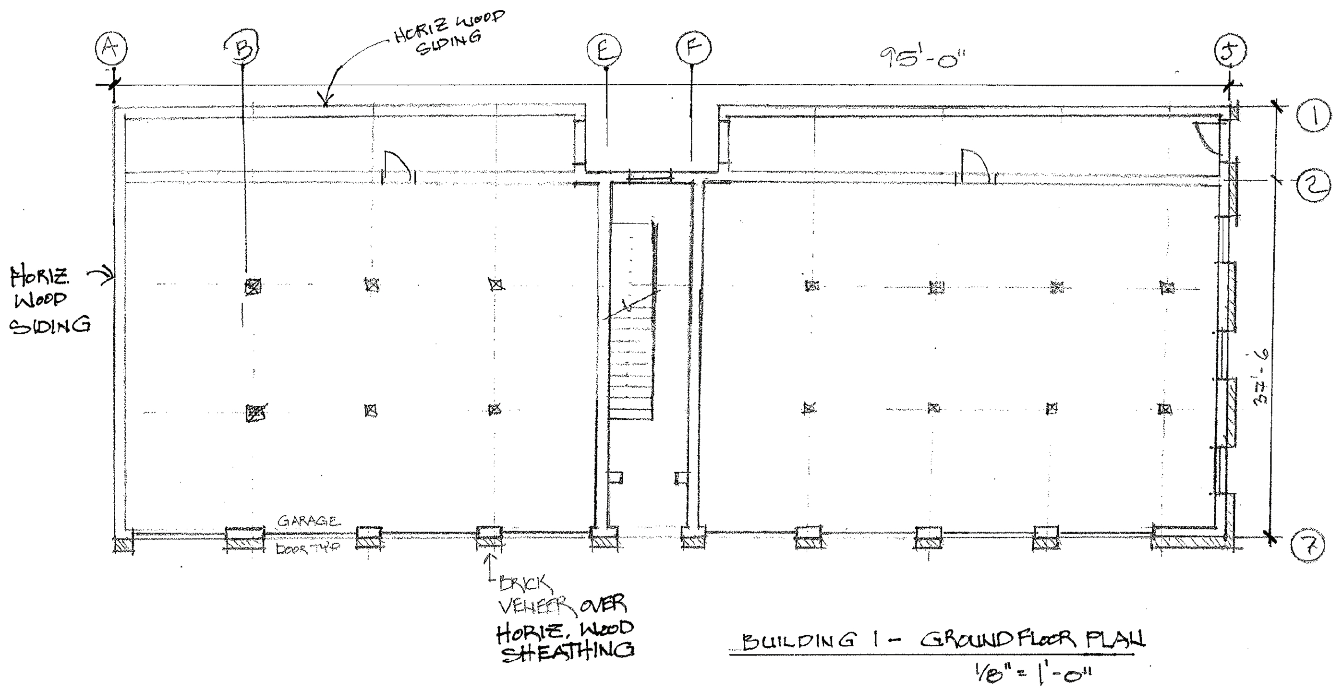


Figure 4-2 Index Building 1 ground floor plan.

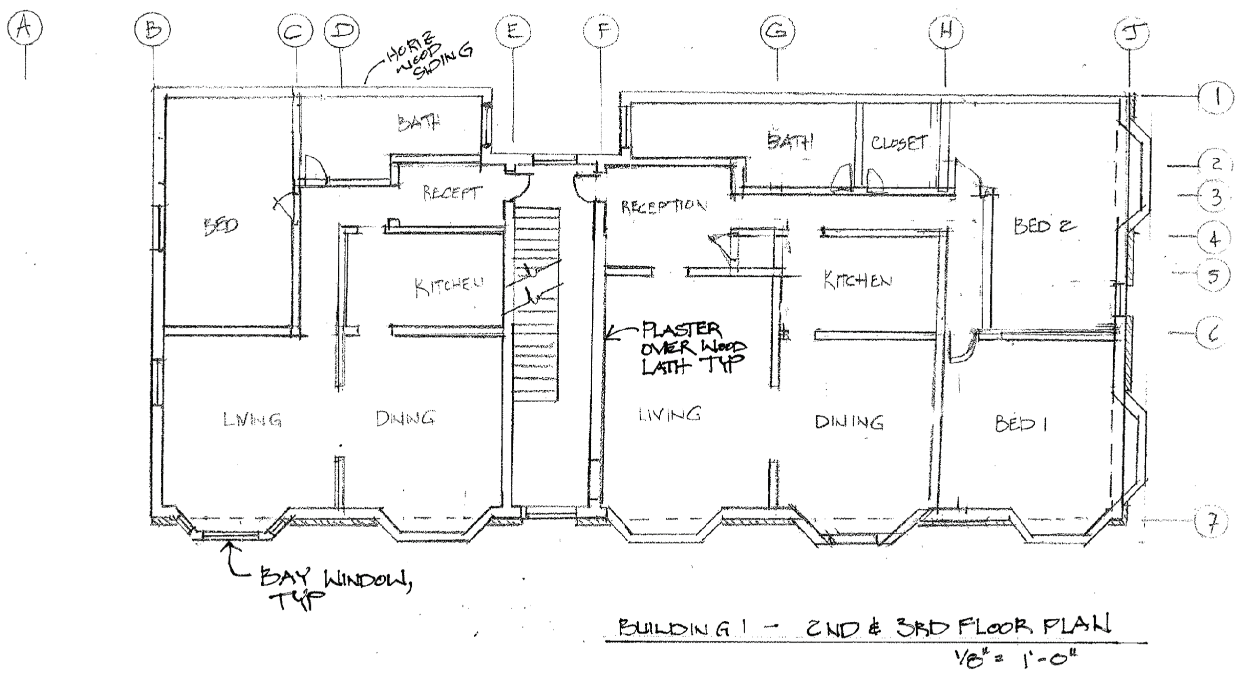


Figure 4-3 Index Building 1 second and third floor plan.

Figure 4-4 Index Building 2 elevation.

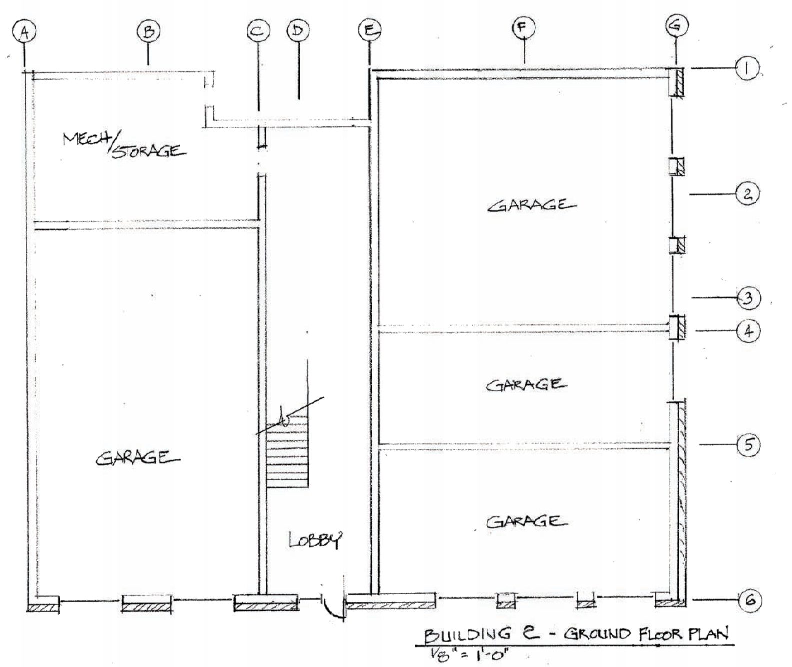


Figure 4-5 Index Building 2 ground floor plan.

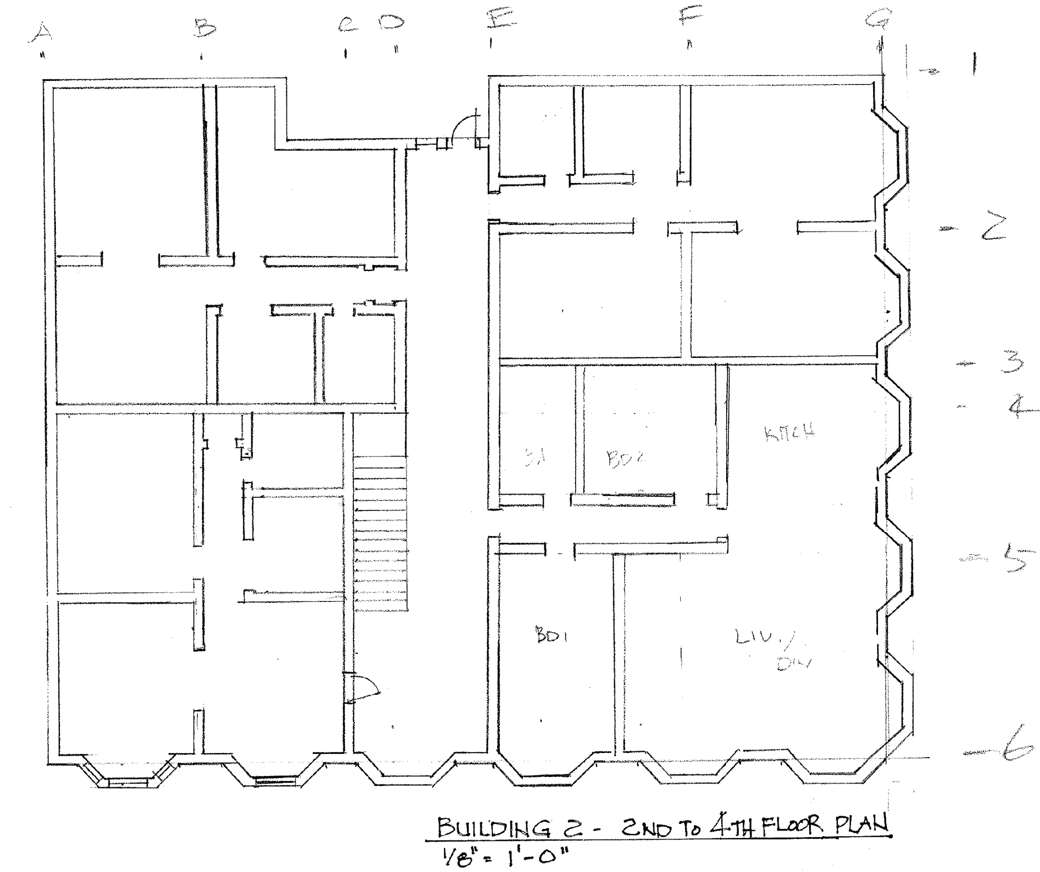


Figure Index 4-6 Building 2 second to fourth floor plan.

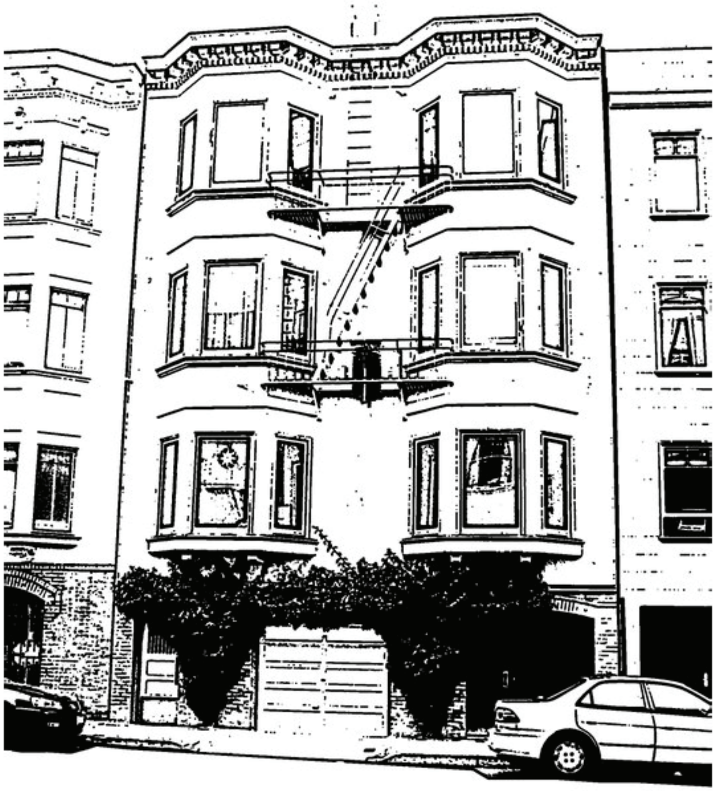


Figure 4-7 Index Building 3 elevation.

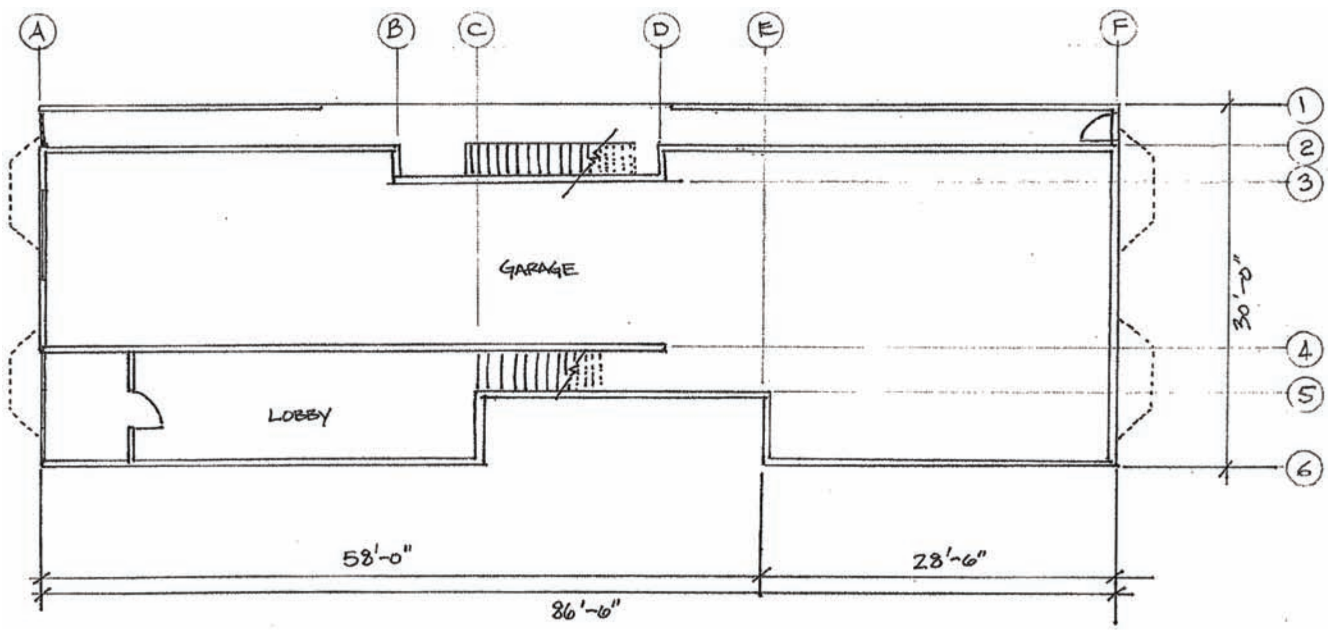


Figure 4-8 Index Building 3 ground floor plan.

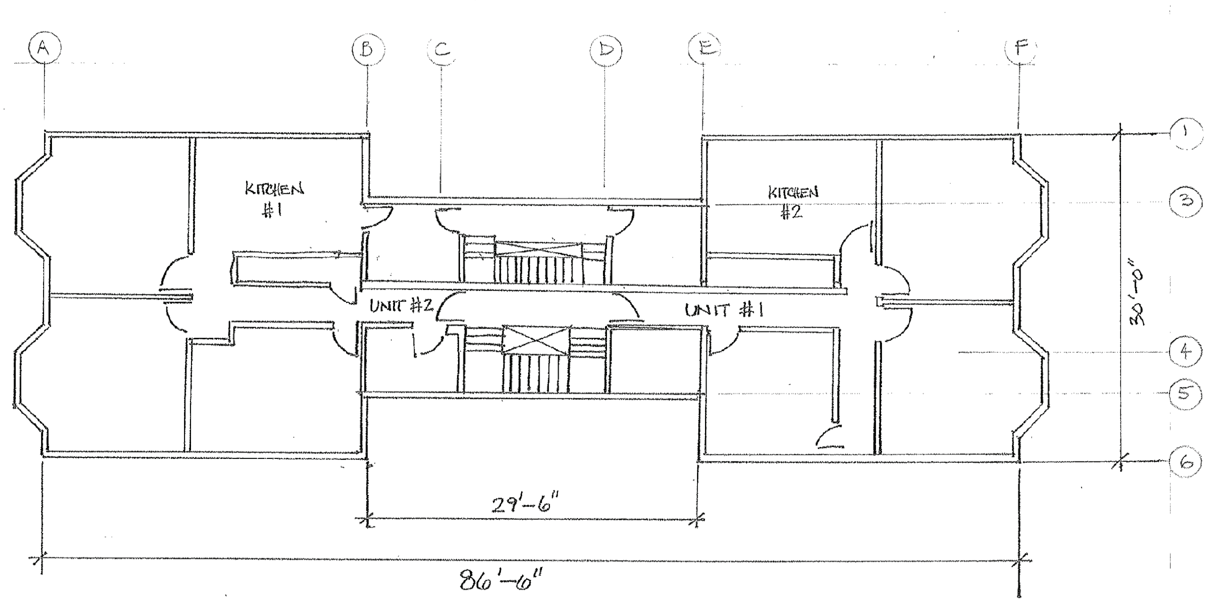


Figure 4-9   Index Building 3 second to fourth floor plan.

Figure 4-10   Index Building 4 elevation.

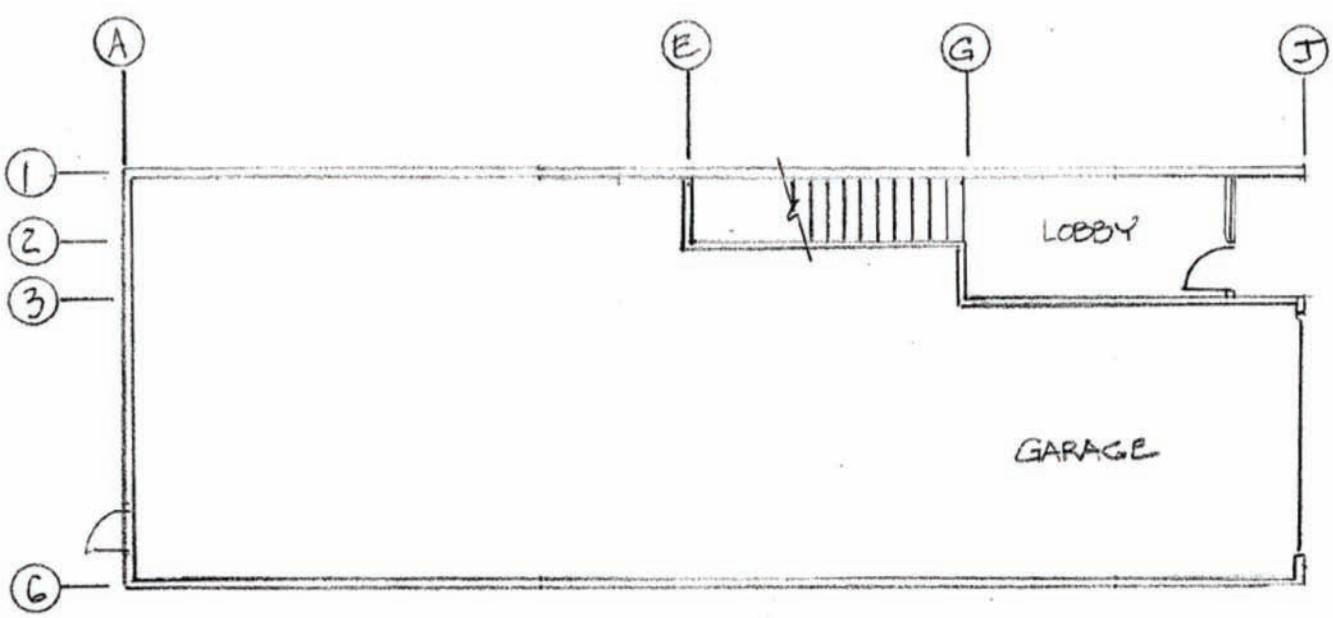


Figure 4-11 Index Building 4 ground floor plan.

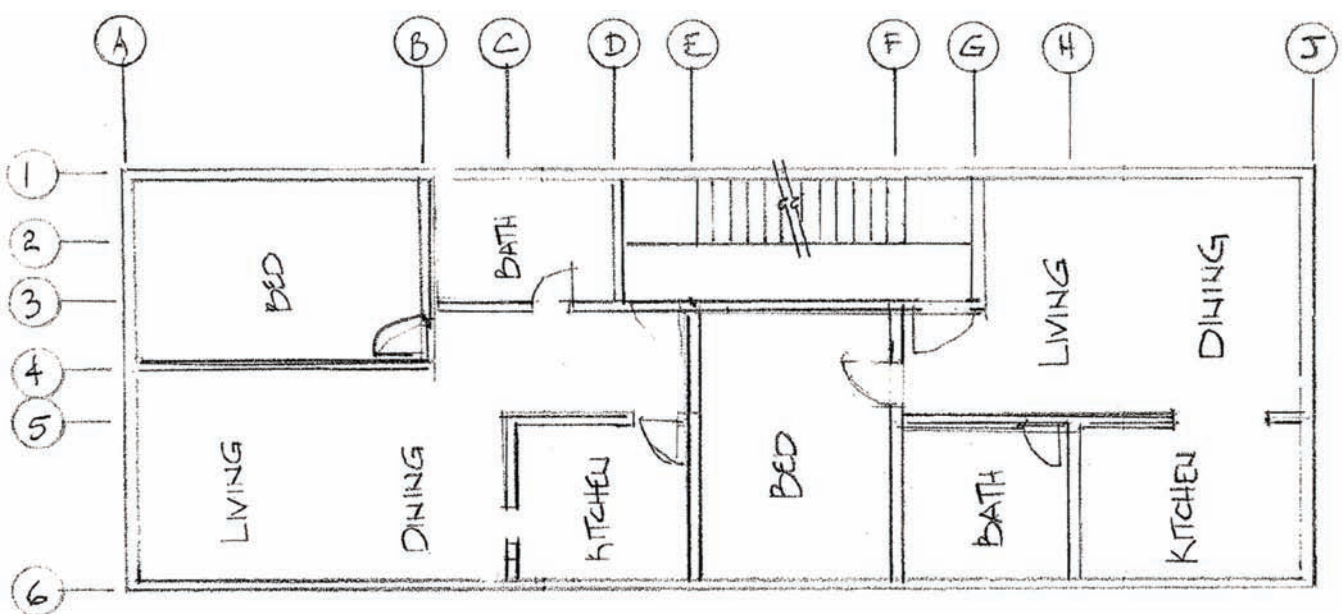


Figure 4-12 Index Building 4 second to fourth floor plan.

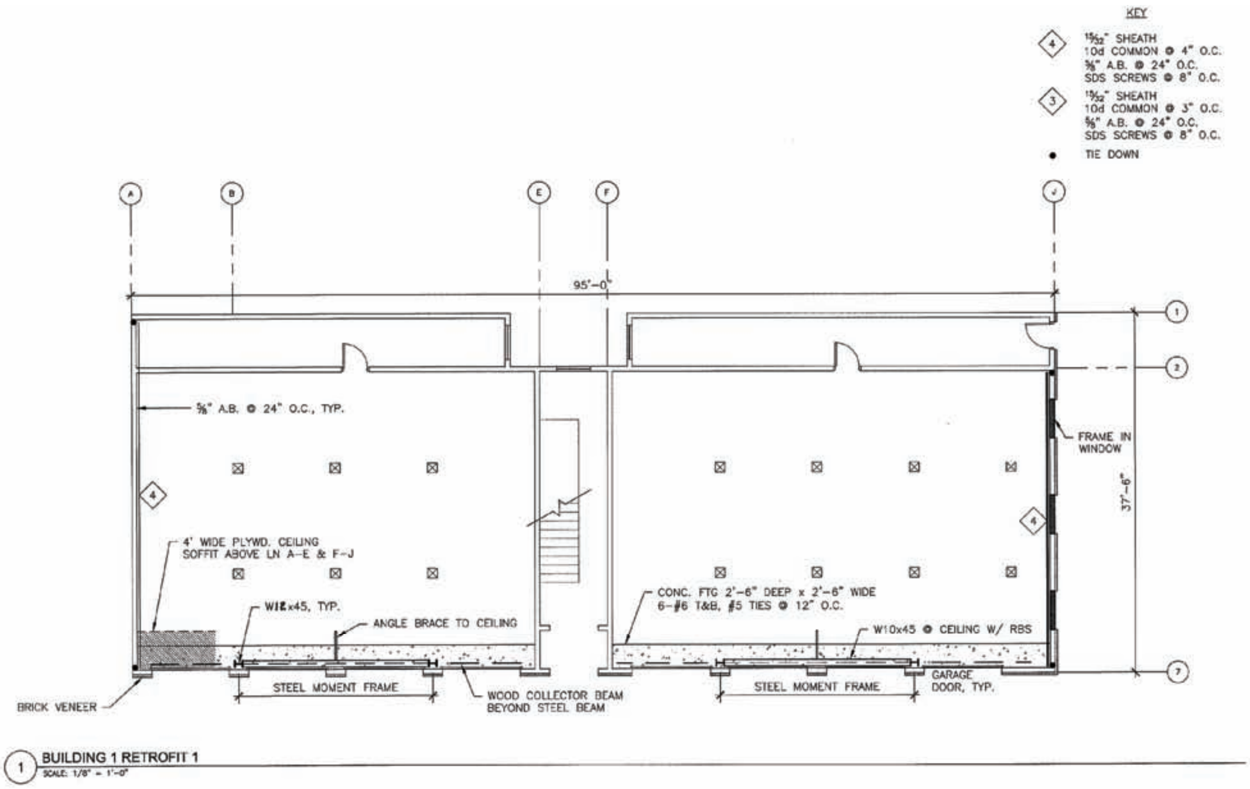


Figure 4-13 Conceptual Retrofit 1, Index Building 1.

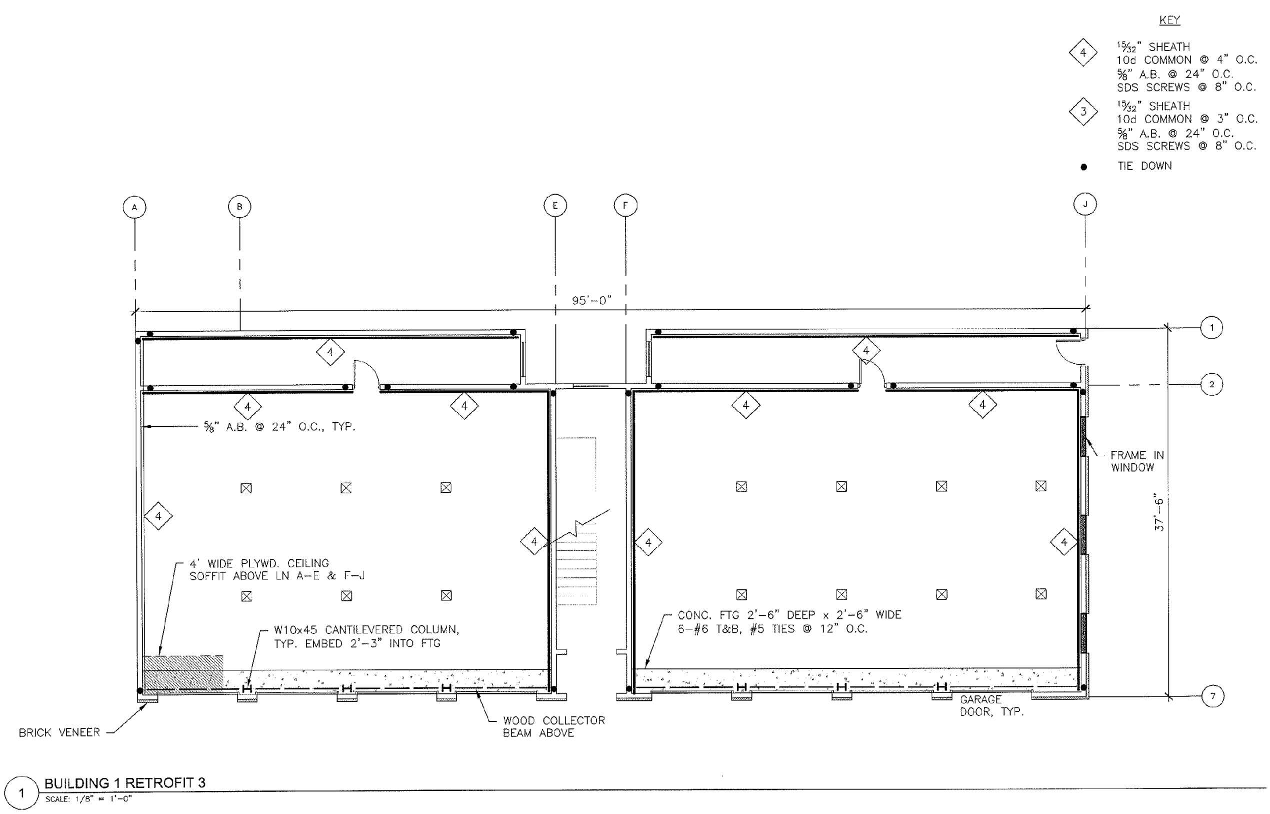


Figure 4-14 Conceptual Retrofit 3, Index Building 1.

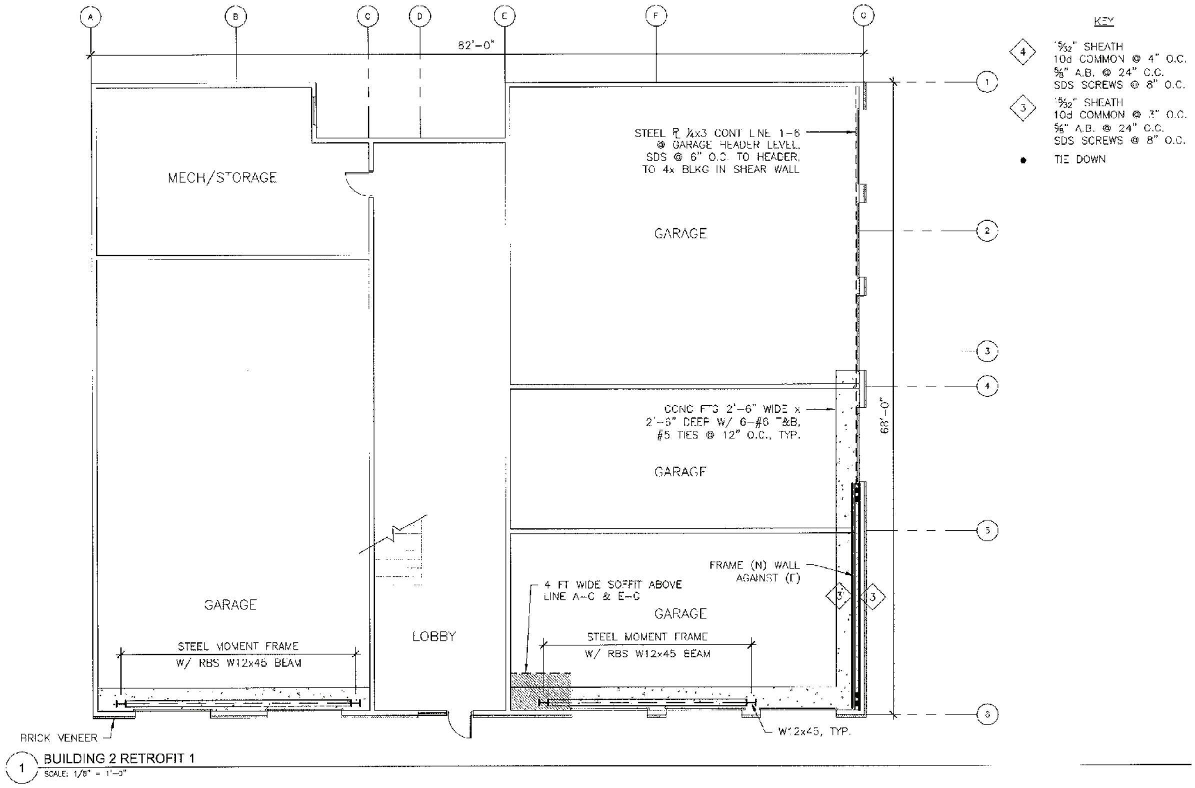


Figure 4-15 Conceptual Retrofit 1, Index Building 2.

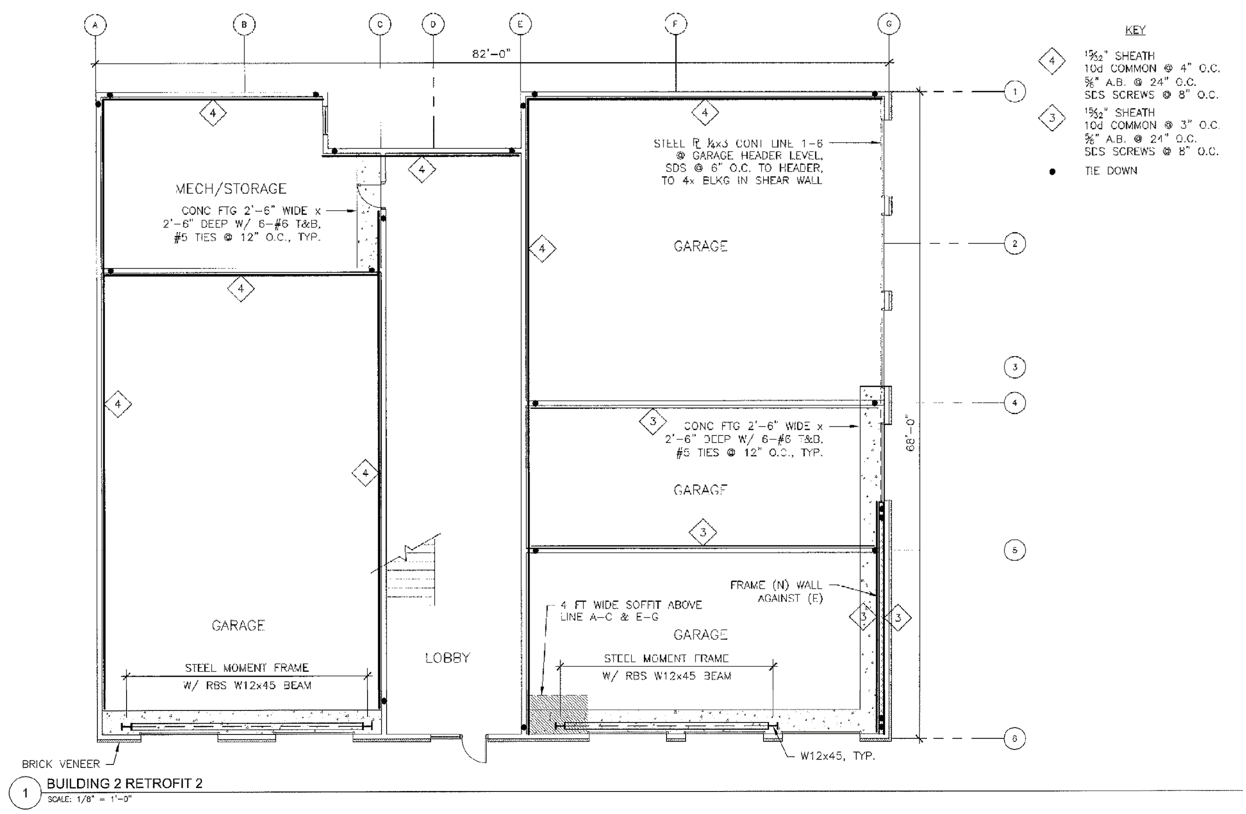


Figure 4-16 Conceptual Retrofit 2, Index Building 2.

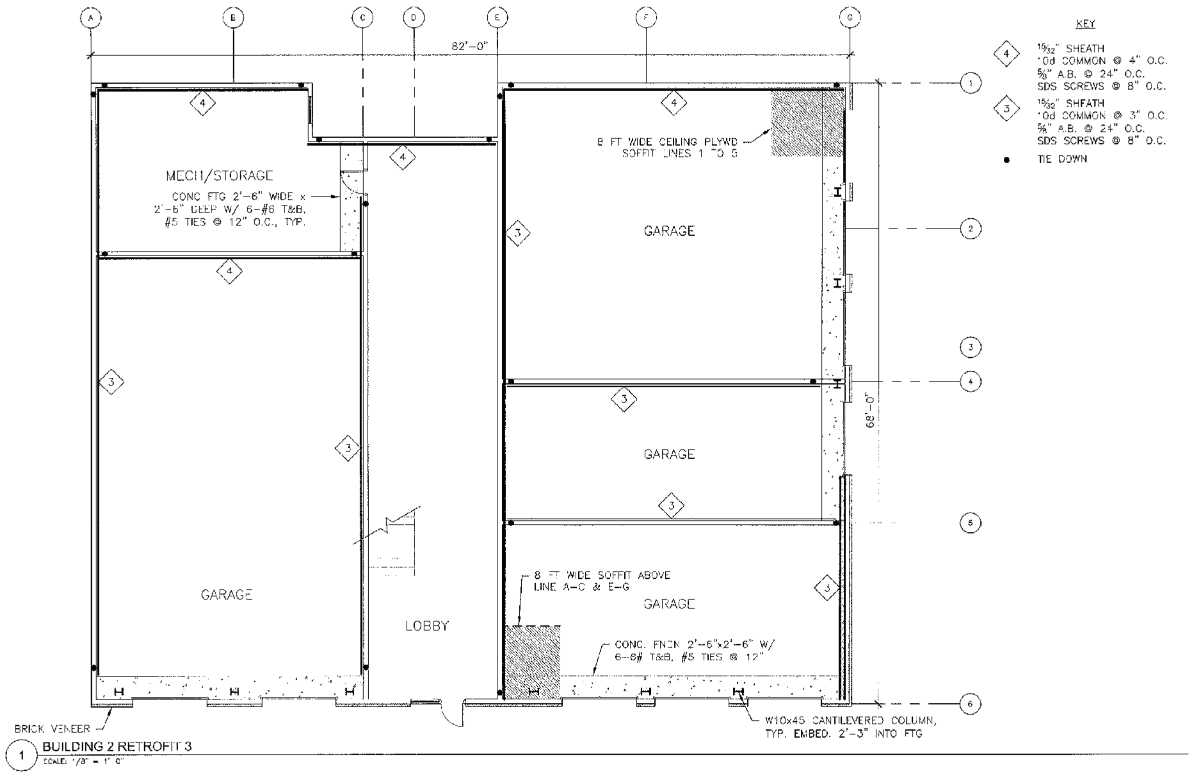


Figure 4-17 Conceptual Retrofit 3, Index Building 2.

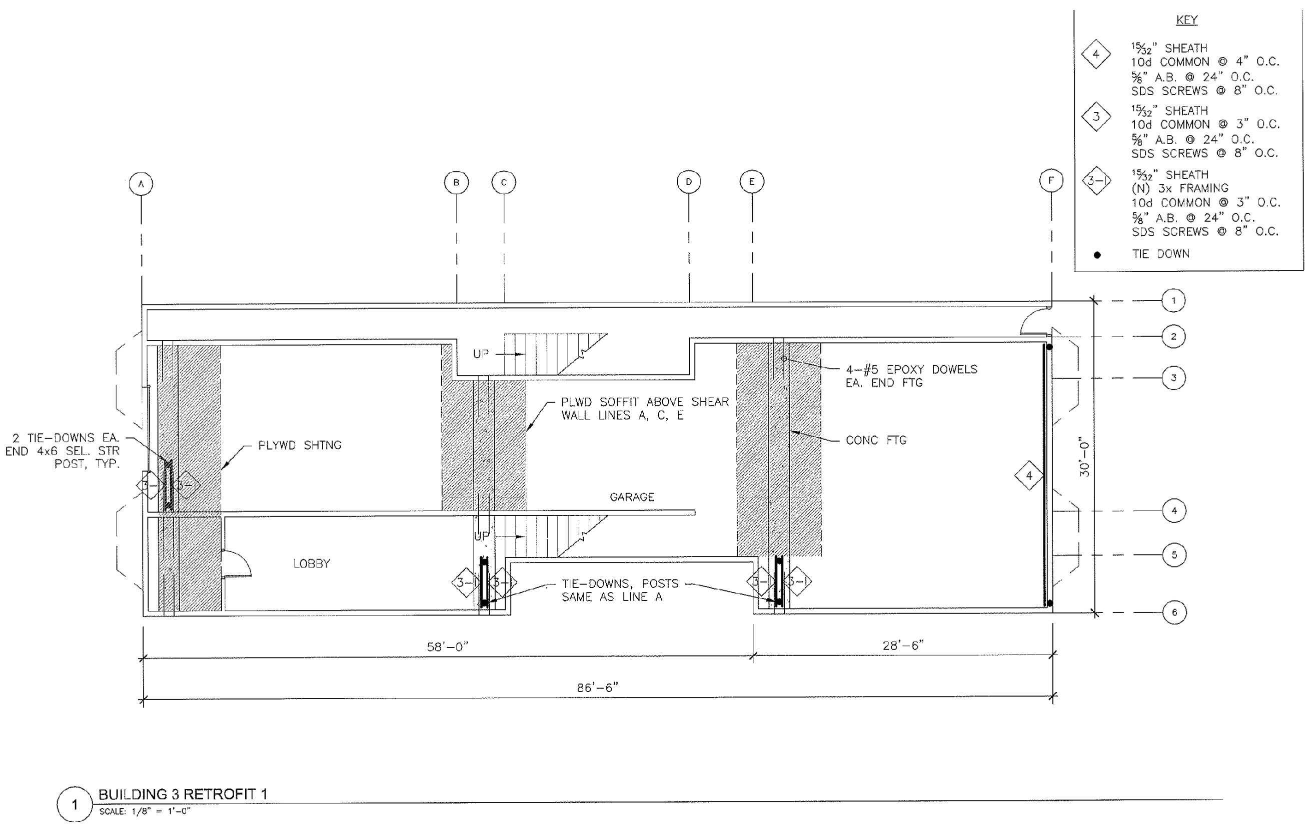


Figure 4-18 Conceptual Retrofit 1, Index Building 3.

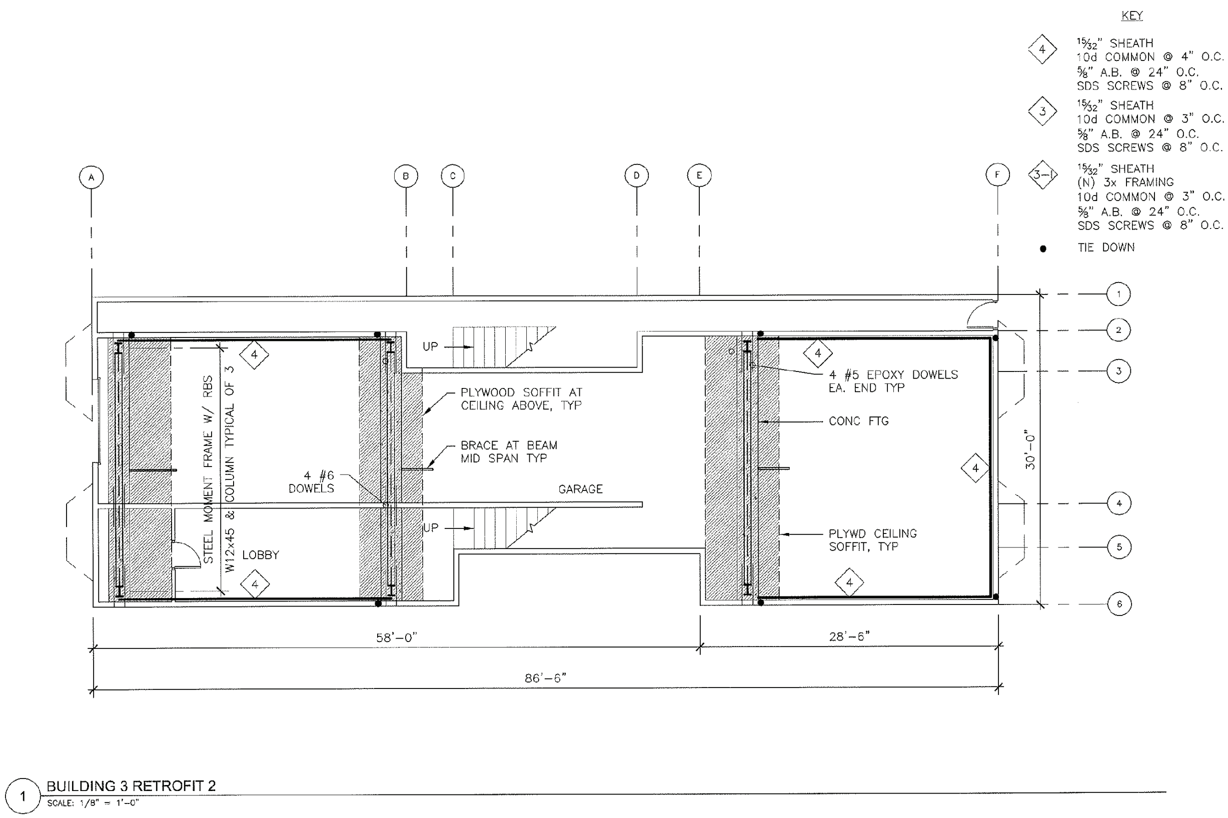


Figure 4-19 Conceptual Retrofit 2, Index Building 3.

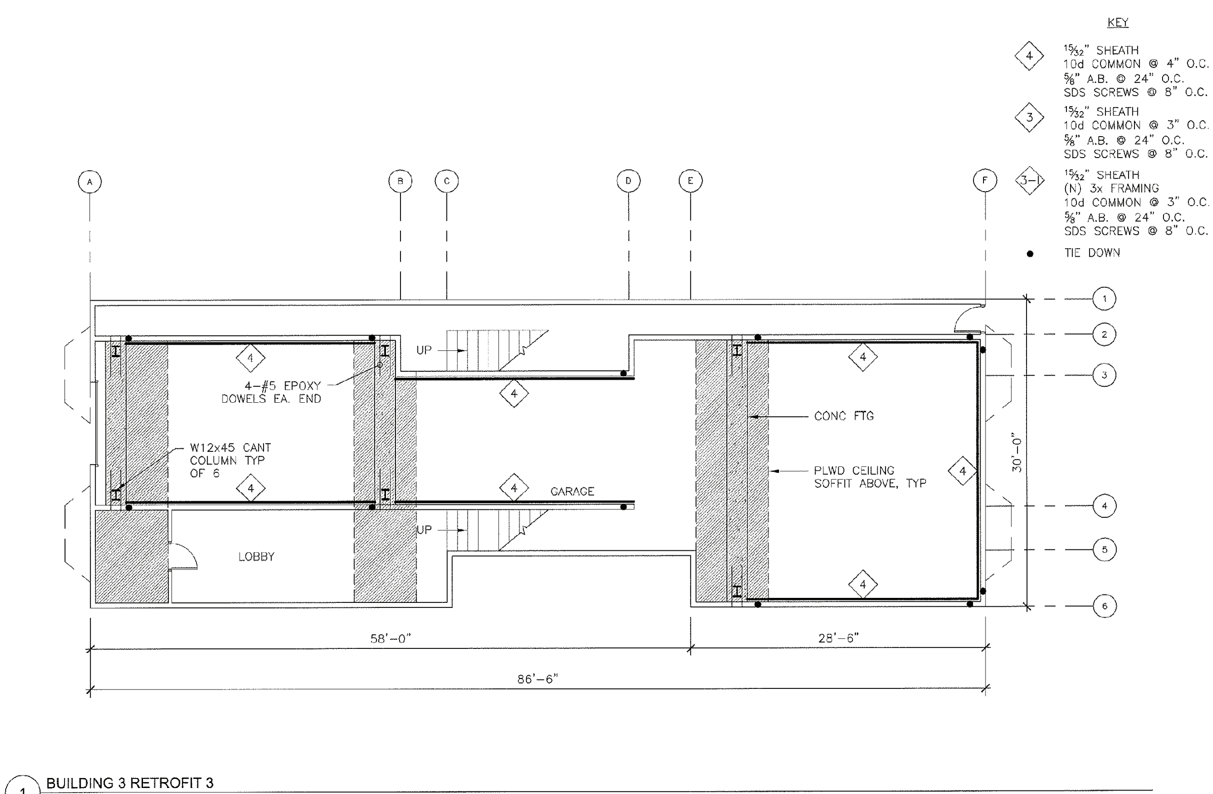


Figure 4-20 Conceptual Retrofit 3, Index Building 3.

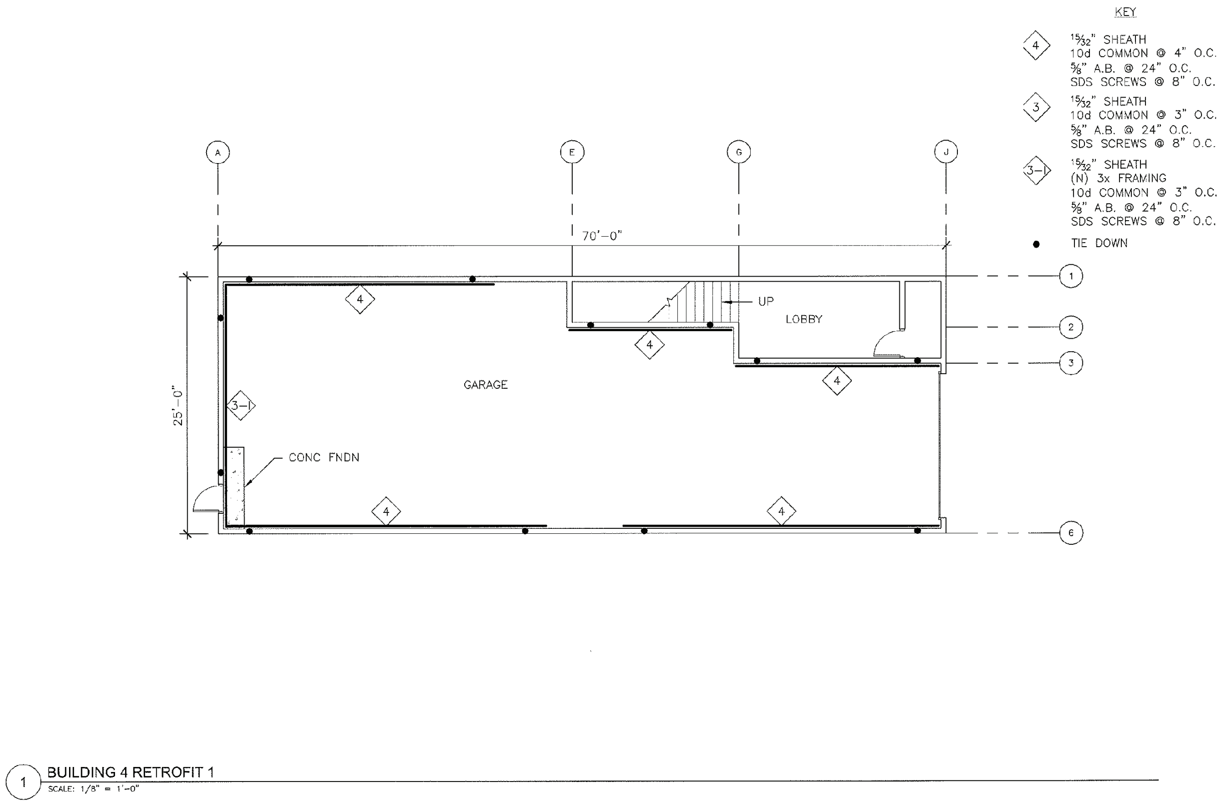


Figure 4-21 Conceptual Retrofit 1, Index Building 4.

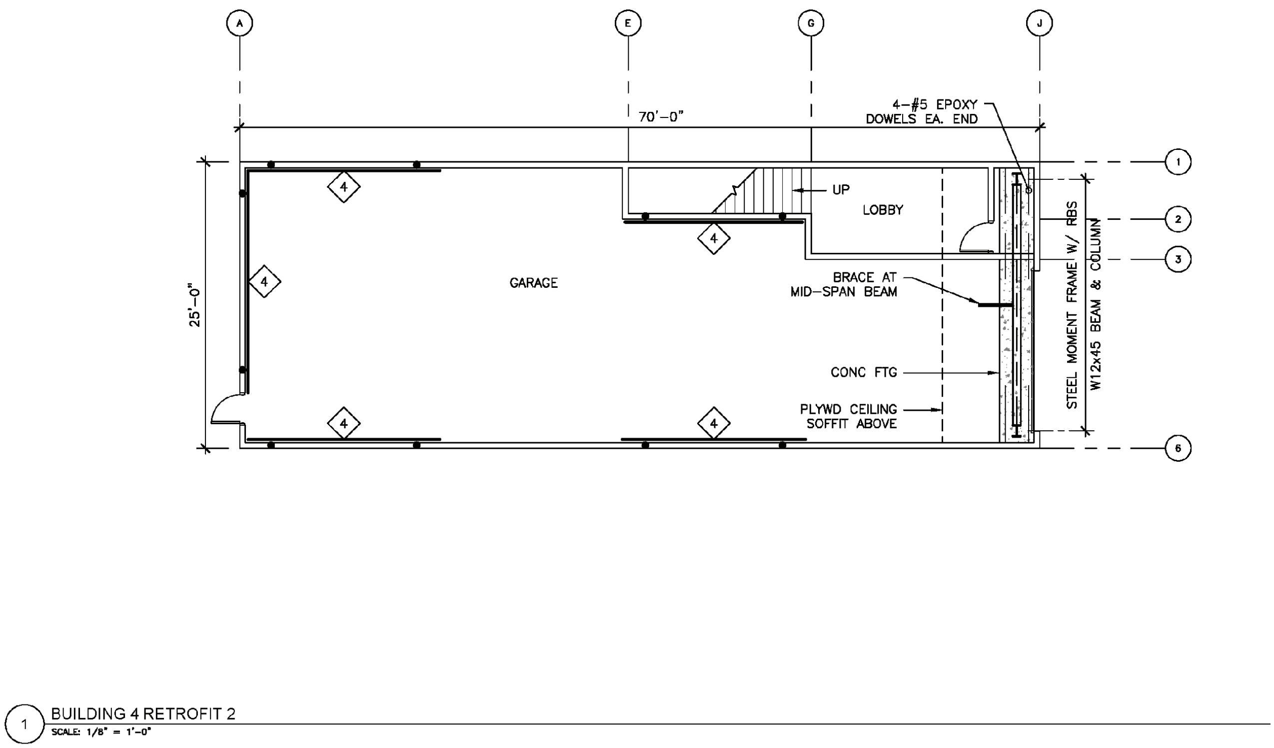


Figure 4-22 Conceptual Retrofit 2, Index Building 4.

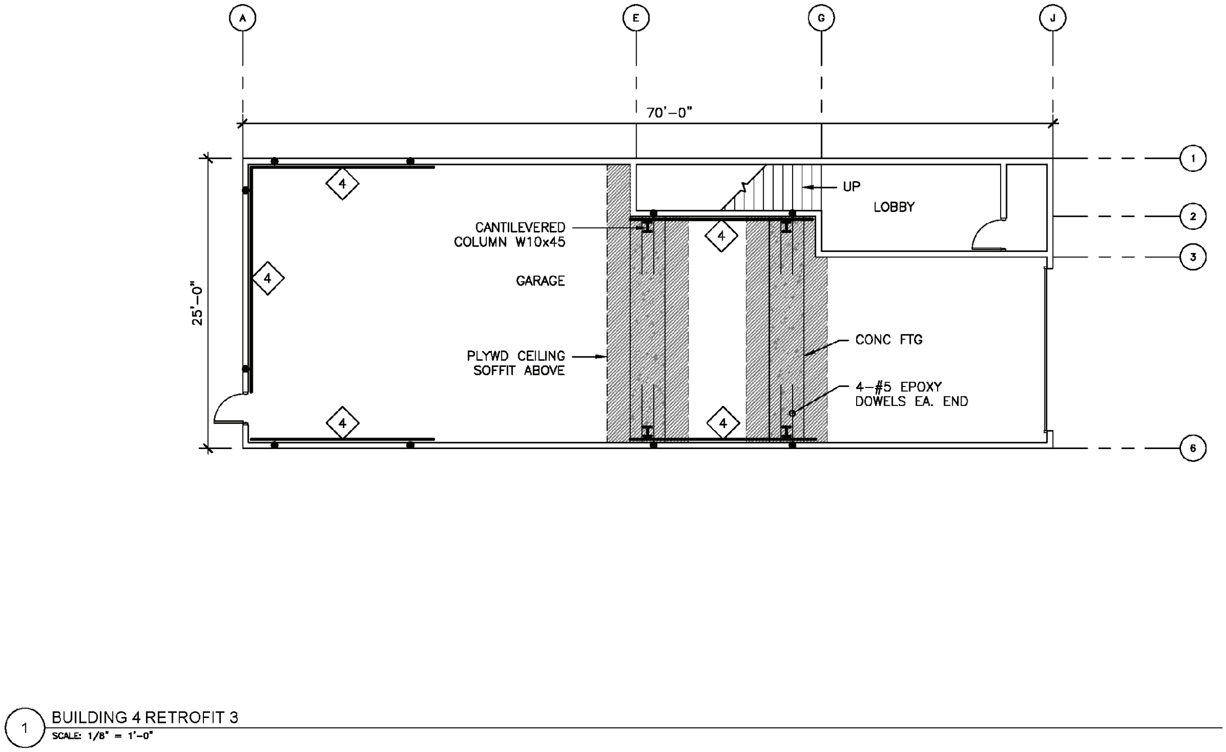


Figure 4-23 Conceptual Retrofit 3, Index Building 4.

Building 1

$$S_a = \frac{F}{\alpha W} \qquad S_d = \frac{\Delta}{PF_N}$$

Weight of Building	k	425	
		PF_N	0.8
		α	1.3

Direction	Scheme		Force k	Displ in	Spectral Accel (S_a) g	Spectral Displ (S_d) in
Transverse Direction	No Retrofit				0	0
		Yield	26.5	0.63	0.078	0.48
		Ultimate	37.7	0.88	0.111	0.68
	Retrofit 1				0	0
		Yield	See No Retrofit			0.00
		Ultimate			0.000	0.00
	Retrofit 2				0	0
		Yield	77	0.65	0.226	0.50
		Ultimate	116	1.17	0.341	0.90
	Retrofit 3				0	0
		Yield	See Retrofit 2			0.00
		Ultimate			0.000	0.00
Longitudinal Direction	No Retrofit		0	0	0	0
		Yield	15.2	0.88	0.045	0.68
		Ultimate	19	1.1	0.056	0.85
	Retrofit 1				0	0
		Yield	31	1.3	0.091	1.00
		Ultimate	54	3.8	0.159	2.92
	Retrofit 2				0	0
		Yield	81	0.3	0.238	0.23
		Ultimate	135	1.3	0.397	1.00
	Retrofit 3				0	0
		Yield	119	0.8	0.350	0.62
		Ultimate	147	1.7	0.432	1.31

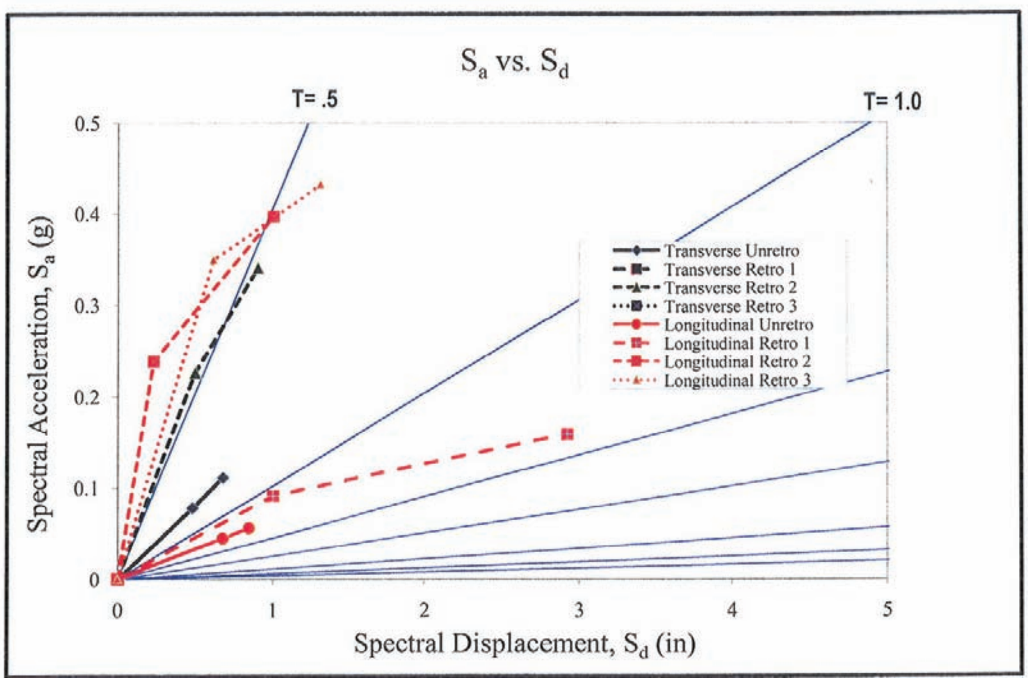


Figure 4-24 Index Building 1 capacity curves.

Building 2

$S_a = \frac{F}{\alpha W}$ $S_d = \frac{\Delta}{PF_N}$

Weight of Building	k	865	
		PF_N	0.8
		α	1.3

Direction	Scheme		Force k	Displ in	Spectral Accel (S_a) g	Spectral Displ (S_d) in
Transverse Direction	No Retrofit				0	0
		Yield	41	0.66	0.059	0.51
		Ultimate	47	0.92	0.068	0.71
	Retrofit 1				0	0
		Yield	71	0.82	0.103	0.63
		Ultimate	81	1.07	0.117	0.82
	Retrofit 2				0	0
		Yield	143	0.96	0.207	0.74
		Ultimate	223	2.17	0.322	1.67
	Retrofit 3				0	0
		Yield	146	1.18	0.211	0.91
		Ultimate	307	3.4	0.444	2.62
Longitudinal Direction	No Retrofit				0	0
		Yield	32	0.67	0.046	0.52
		Ultimate	37	0.92	0.053	0.71
	Retrofit 1				0	0
		Yield	80	0.96	0.116	0.74
		Ultimate	100	1.67	0.145	1.28
	Retrofit 2				0	0
		Yield	136	1.24	0.197	0.95
		Ultimate	209	3.4	0.302	2.62
	Retrofit 3				0	0
		Yield	167	1.41	0.241	1.08
		Ultimate	209	3.4	0.302	2.62

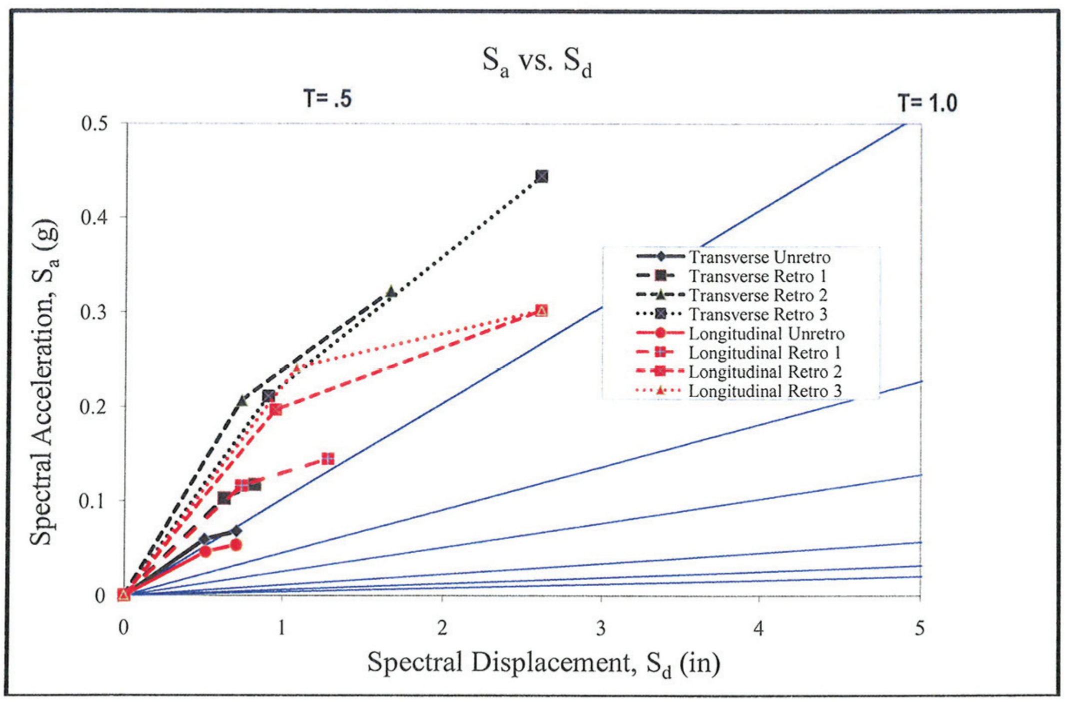


Figure 4-25 Index Building 2 capacity curves.

Building 3

$$S_a = \frac{F}{\alpha W} \qquad S_d = \frac{\Delta}{PF_N}$$

	Weight of Building	k	412		PF_N	0.8
					α	1.3

Direction	Scheme		Force k	Displ in	Spectral Accel (S_a) g	Spectral Displ (S_d) in
Transverse Direction	No Retrofit				0	0
		Yield	4	0.9	0.012	0.69
		Ultimate	5	3.1	0.015	2.38
	Retrofit 1				0	0
		Yield	43	1.4	0.130	1.08
		Ultimate	63	3.8	0.191	2.92
	Retrofit 2				0	0
		Yield	78	2	0.237	1.54
		Ultimate	89	2.4	0.270	1.85
	Retrofit 3				0	0
		Yield	78	1.5	0.237	1.15
		Ultimate	89	2.3	0.270	1.77
Longitudinal Direction	No Retrofit				0	0
		Yield	41	0.8	0.124	0.62
		Ultimate	56	1.1	0.170	0.85
	Retrofit 1				0	0
		Yield	41	0.8	0.124	0.62
		Ultimate	56	1.1	0.170	0.85
	Retrofit 2				0	0
		Yield	49	0.6	0.149	0.46
		Ultimate	74	1.8	0.225	1.38
	Retrofit 3				0	0
		Yield	74	0.8	0.225	0.62
		Ultimate	111	2.1	0.337	1.62

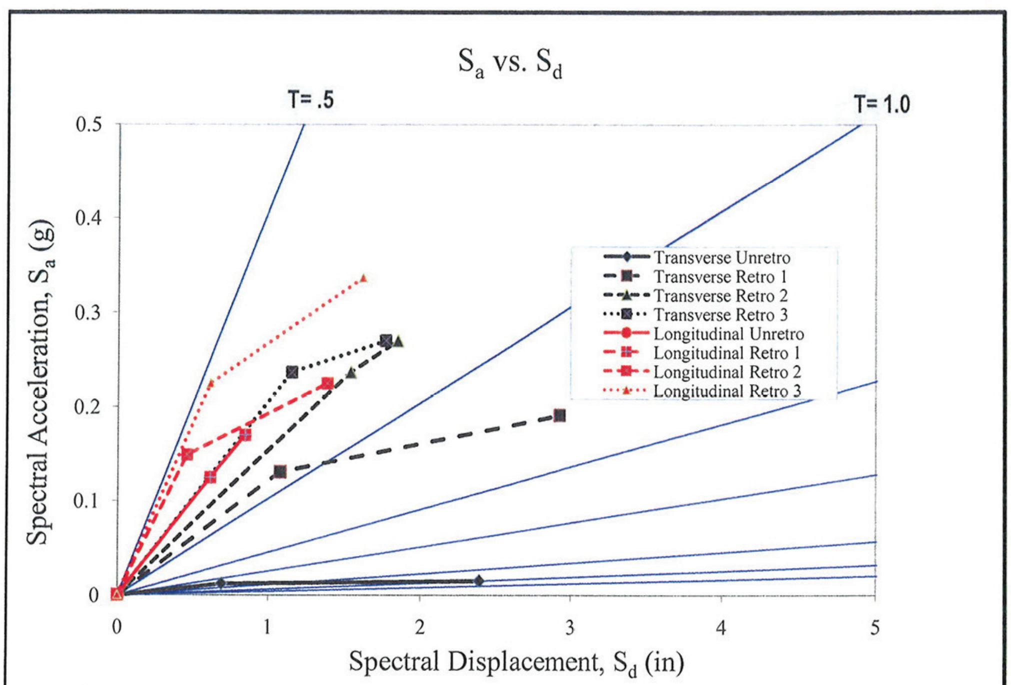


Figure 3. Spectral Acceleration versus Spectral Displacement Building 3

Figure 4-26 Index Building 3 capacity curves.

Building 4

$$S_a = \frac{F}{\alpha W} \qquad S_d = \frac{\Delta}{PF_N}$$

Weight of Building	k	155	PF_N	0.8
			α	1.3

Direction	Scheme		Force k	Displ in	Spectral Accel (S_a) g	Spectral Displ (S_d) in
Transverse Direction	No Retrofit				0	0
		Yield	1	0.1	0.008	0.08
		Ultimate	4	2	0.032	1.54
	Retrofit 1				0	0
		Yield	9	0.7	0.073	0.54
		Ultimate	15	1.4	0.121	1.08
	Retrofit 2				0	0
		Yield	9	0.3	0.073	0.23
		Ultimate	15	0.9	0.121	0.69
	Retrofit 3				0	0
		Yield	9	0.3	0.073	0.23
		Ultimate	15	0.9	0.121	0.69
Longitudinal Direction	No Retrofit				0	0
		Yield	6	0.2	0.048	0.15
		Ultimate	14	0.6	0.113	0.46
	Retrofit 1				0	0
		Yield	19	0.2	0.153	0.15
		Ultimate	29	0.7	0.234	0.54
	Retrofit 2				0	0
		Yield	19	0.3	0.153	0.23
		Ultimate	29	0.8	0.234	0.62
	Retrofit 3				0	0
		Yield	19	0.3	0.153	0.23
		Ultimate	29	0.8	0.234	0.62

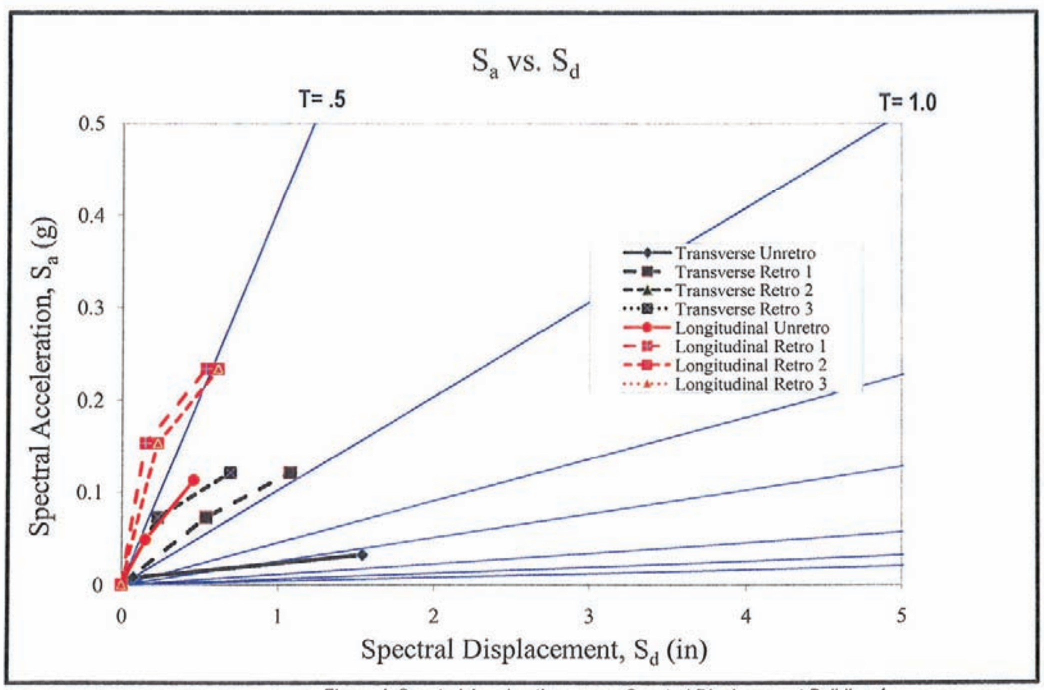


Figure 4. Spectral Acceleration versus Spectral Displacement Building 4

Figure 4-27 Index Building 4 capacity curves.

APPENDIX 5: COST ESTIMATES FOR RETROFITS

This section presents detailed construction cost estimates for retrofitting the four prototype buildings described in Appendix 4. Cost estimates are presented in Tables 5-1 through 5-16 for each of the three retrofit schemes developed for each prototype (index) building. These costs were estimated in November 2008.

These are complete cost estimates for direct construction costs only. They include labor, materials, equipment, permit fees, a contingency fee, and an overhead and profit fee. They do not include the following costs:

- complex finish work;
- engineering or architectural design fees;
- any triggered code upgrades;
- ADA upgrades for commercial properties; or
- relocation of conflicting utilities.

Table 5-1 Building 1: Summary of Cost Estimates for All Schemes

Division	Description	Scheme 1: Moment Frames & Limited Shear Walls		Scheme 2: Moment Frames & Greater Shear Walls		Scheme 3: Cantilevered Columns & Greater Shear Walls	
		Subtotal	Total	Subtotal	Total	Subtotal	Total
1	**General Conditions**		**$9,905**		**$12,349**		**$11,549**
	Personnel	4,000		5,000		5,000	
	Small Tools	500		500		500	
	Temporary Utilities	125		125		125	
	Clean - Up	1,400		1,525		1,525	
	Debris Removal	1,150		1,725		1,725	
	Testing & Inspections	2,730		3,474		2,674	
2	**Sitework**		**$9,070**		**$12,670**		**$12,670**
	Demolition	5,750		9,350		9,350	
	Structural Excavation	3,320		3,320		3,320	
3	**Concrete**		**$11,600**		**$11,600**		**$11,600**
	Reinforcing Steel	4,420		4,420		4,420	
	Concrete Footing	6,920		6,920		6,920	
	Finish Slab	260		260		260	
4	**Masonry**						
	None						
5	**Metals**		**$11,700**		**$11,700**		**$8,220**
	Structural Steel	11,700		11,700		8,220	
6	**Carpentry**		**$8,442**		**$25,602**		**$25,952**
	Rough Carpentry	7,762		24,922		25,272	
	Finish Carpentry	680		680		680	
7	**Moisture Protection**						
	None						
8	**Doors, Windows, & Glass**						
	None						
9	**Finishes**		**$3,188**		**$7,374**		**$7,374**
	Lath & Plaster	1,500		2,250		2,250	
	Drywall	918		4,104		4,104	
	Painting	770		1,020		1,020	
10	**Specialties**						
	None						
11	**Equipment**						
	None						
12	**Furnishings**						
	None						
13	**Special Construction**						
	None						
14	**Conveying Systems**						
	None						
15	**Mechanical**						
	None						
16	**Electrical**						
	None						
	Subtotal	53,905	**$53,905**	81,295	**$81,295**	77,365	**$77,365**
	Building Permit @ 2.4%		**$1,294**		**$1,951**		**$1,857**
	Contingency @ 15%		**$8,086**		**$12,194**		**$11,605**
	Subtotal		**$63,284**		**$95,440**		**$90,826**
	Overhead & Profit @ 25%		**$15,821**		**$23,860**		**$22,707**
	Total		**$79,106**		**$119,300**		**$113,533**

Items not included in estimates:
- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8” Type X sheetrock and fire taped
- clearing garages of cars and tenants’ possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-2 Building 1: Cost Estimate for Scheme 1

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions**									
	Subtotal for Division:									
	$9,905									
	Personnel:									
	Foreman w/truck & phone - 2 hours/day - 4 weeks	40	hours	$100	$4,000					$4,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temporary Sanitation	1	months					$125	$125	$125
	Clean Up:									
	Daily Clean Up - 1 man, 1 hour/day	20	hours	$25	$500					$500
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	2	each			$575	$1,150			$1,150
	Special Inspections:									
	Welding	1	lump sum					$1,200	$1,200	$1,200
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	6	hours					$93	$558	$558
	Shear panel nailing	4	hours					$93	$372	$372
2	**Sitework**									
	Subtotal for Division:									
	$9,070									
	Demolition:									
	Cut and remove 4' strip of ceiling plaster, 500 sf.	32	hours	$45	$1,440					$1,440
	Remove interior plaster from shear walls and intersecting walls, 720 sq. ft.	32	hours	$45	$1,440					$1,440
	Sawcut, load and haul 6" concrete floor slab, 168 lf. 5 cy.	1	lump sum						$2,870	$2,870
	Structural Excavation:									
	Excavate new footing at garage entries	26	cubic yard	$70	$1,820					$1,820
	Load dump truck (loader)	6	hours					$150	$900	$900
	Haul away dirt (dump truck)	8	hours					$75	$600	$600
3	**Concrete**									
	Subtotal for Division:									
	$11,600									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 84 lf. 2600#. Delivered cages.	1	lump sum					$3,700	$3,700	$3,700
	Place cages in footings	16	hours	$45	$720					$720
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 4x6x35/32. 84 lf.	32	cubic yard	$26	$840	$140	$4,480			$5,320
	Concrete pump	1						$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3'	4	hours	$65	$260					$260
4	**Masonry**									
	Subtotal for Division:									
	$0									

Table 5-2 Building 1: Cost Estimate for Scheme 1 (continued)

Division	Description	Quantity	Unit	Labor Unit Cost	Labor	Material Unit Cost	Material	Subcontractor Unit Cost	Subcontractor	Total
5	**Metals** Subtotal for Division: **$11,700**									
	Structural Steel: Steel moment frames, 8' x 20', 10WF45 w/RBS. 2 ea. Erected on anchor bolts in new concrete footings & field welded.	1	lump sum					$11,700	$11,700	$11,700
6	**Carpentry** Subtotal for Division: **$8,442**									
	Rough Carpentry: • Additional studs @ shear wall plywood joints and misc framing @ windows. Material.	156	board ft.			$1	$148			$148
	• Additional studs @ shear wall plywood joints and misc framing @ windows. Labor.	4	hours	$60	$240					$240
	• Drill and epoxy anchor bolts.	35	each	$35	$1,225	$45	$1,575			$2,800
	• Drill and epoxy hold downs.	4	each	$35	$140	$110	$440			$580
	• Additional 4x4 posts and tie downs. 48 bf material @ $1.20/bf.	4	each	$30	$120	$15	$60			$180
	• Clips to framing above shear walls.	68	linear ft.	$4	$240	$5	$340			$580
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 168 bf.	168	board ft.			$2	$319			$319
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 42 lf.	16	hours	$60	$960					$960
	• Shear wall sheathing. 15/32 plywood.	612	sq. ft.	$1	$765	$1	$490			$1,255
	• Set anchor bolts for steel frames	4	hours	$75	$300					$300
	• Set anchor bolts for steel frames	4	each			$100	$400			$400
	Finish Carpentry • Exterior siding in 3 ea 4x4 windows	8	hours	$60	$480		$200			$680
7	**Moisture Protection** Subtotal for Division: **$0**									
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									

Table 5-2 Building 1: Cost Estimate for Scheme 1 (continued)

Division	Description	Quantity	Unit	Labor: Unit Cost	Labor: Labor	Material: Unit Cost	Material: Material	Subcontractor: Unit Cost	Subcontractor: Subcontractor	Total
9	**Finishes** Subtotal for Division: **$3,188**									
	Plaster:									
	Patch openings in ceilings.	500	sq. ft.					$3	$1,500	$1,500
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped.	612	sq. ft.					$2	$918	$918
	Painting:									
	Plaster soffit, seal and 2 coats.	500	sq. ft.					$1	$500	$500
	Steel beams, 10" WF.	72	linear ft.					$2	$144	$144
	2 ea 2x12 collector beams	84	linear ft.					$2	$126	$126
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$16,390		$9,602		$27,913	$53,905
				Subtotal Check:	$53,905		Permits @ 2.4%			$1,294
							Contingency @ 15%			$8,086
				Division Subtotal Check:	$53,905		Subtotal			$63,284
							Overhead & Profit @ 25%			$15,821
							TOTAL			**$79,106**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8" Type X sheetrock and fire taped
- clearing garages of cars and tenants' possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-3 Building 1: Cost Estimate for Scheme 2

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions** Subtotal for Division: **$ 12,349**									
	Personnel:									
	Foreman w/truck & phone. 2 hours/day - 5 weeks	50	hours	$100	$5,000					$5,000
	Small Tools:		lump sum						$500	$500
	Temporary Utilities:									
	Temp. Sanitation	1	months					$125	$125	$125
	Clean - Up:									
	Daily Clean up - 1 man, 1 hr/d	25	hours	$25	$625					$625
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	3	each			$575	$1,725			$1,725
	Special Inspections:									
	Welding	1	lump sum					$1,200	$1,200	$1,200
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	12	hours					$93	$1,116	$1,116
	Shear panel nailing	6	hours					$93	$558	$558
2	**Sitework** Subtotal for Division: **$ 12,670**									
	Demolition:									
	Cut and remove 4' strip of ceiling plaster. 734 sq. ft.	48	hours	$45	$2,160					$2,160
	Remove interior plaster from shear walls and intersecting walls. 2850 sf.	96	hours	$45	$4,320					$4,320
	Sawcut, load and haul 6" concrete floor slab. 168 lf. 5	1	lump sum						$2,870	$2,870
	Structural Excavation:									
	Excavate new footing at garage entries.	26	cubic yards	$70	$1,820					$1,820
	Load dump truck (loader)	6	hours					$150	$900	$900
	Haul away dirt (dump truck).	8	hours					$75	$600	$600
3	**Concrete** Subtotal for Division: **$ 11,600**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 84 lf. 2600#. Delivered cages.	1	lump sum					$3,700	$3,700	$3,700
	Place cages in footings	16	hours	$45	$720					$720
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 4x6x35/32. 84 lf.	32	cubic yard	$26	$840	$140	$4,480			$5,320
	Concrete pump	1						$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3' x84'.	4	hours	$65	$260					$260

Table 5-3 Building 1: Cost Estimate for Scheme 2 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
4	**Masonry** Subtotal for Division: **$ 0.00**									
5	**Metals** Subtotal for Division: **$ 11,700**									
	Structural Steel: Steel moment frames, 8' x 20', 10WF45 w/RBS. 2 ea. Erected on anchor bolts in new concrete footings with field welding.	1	lump sum					$11,700	$11,700	$11,700
6	**Carpentry** Subtotal for Division: **$ 25,602**									
	Rough Carpentry:									
	• Additional studs @ shear wall plywood joints and misc framing @ windows. Material.	492	board ft.			$1	$246			$246
	• Additional studs @ shear wall plywood joints and misc framing @ windows. Labor.	12	hours	$60	$720					$720
	• Drill and epoxy anchor bolts.	135	each	$35	$4,725	$45	$6,075			$10,800
	• Drill and epoxy hold downs.	17	each	$35	$595	$110	$1,870			$2,465
	• Additional 4x4 posts and tie downs. 48 bf material @ $1.20/bf.	17	each	$15	$255	$15	$255			$510
	• Clips to framing above shear walls.	304	linear ft.	$4	$1,073	$5	$1,520			$2,593
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 168 bf.	168	board ft.			$2	$319			$319
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 42 lf.	16	hours	$60	$960					$960
	• Shear wall sheathing. 15/32 plywood.	2,736	sq. ft.	$1	$3,420	$1	$2,189			$5,609
	• Set anchor bolts for steel frames. Labor.	4	hours	$75	$300					$300
	• Set anchor bolts for steel frames. Material.	4	each			$100	$400			$400
	Finish Carpentry Exterior siding in 3 ea 4x4 windows	8	hours	$60	$480		$200			$680
7	**Moisture Protection** Subtotal for Division: **$ 0.00**									

Table 5-3 Building 1: Cost Estimate for Scheme 2 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
8	**Doors, Windows, & Glass** Subtotal for Division: **$ 0.00**									
9	**Finishes** Subtotal for Division: **$ 7,374**									
	Plaster:									
	Patch openings in ceilings.	750	sq. ft.					$3	$2,250	$2,250
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped.	2,736	sq. ft.					$2	$4,104	$4,104
	Painting:									
	Plaster soffit, seal and 2	750	sq. ft.					$1	$750	$750
	Steel beams, 10" WF.	72	linear ft.					$2	$144	$144
	2 ea 2x12 collector beams	84	linear ft.					$2	$126	$126
10	**Specialties** Subtotal for Division: **$ 0.00**									
11	**Equipment** Subtotal for Division: **$ 0.00**									
12	**Furnishings** Subtotal for Division: **$ 0.00**									
13	**Special Construction** Subtotal for Division: **$ 0.00**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$ 0.00**									
16	**Electrical** Subtotal for Division: **$ 0.00**									
				Subtotal:	$29,173		$19,279		$32,843	$81,295
				Subtotal Check:	$81,295		Permits @ 2.4%			$1,951
							Contingency @ 15%			$12,194
				Division Subtotal Check:	$81,295		Subtotal			$95,440
							Overhead & Profit @ 25%			$23,860
								TOTAL		**$119,300**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8” Type X sheetrock and fire taped
- clearing garages of cars and tenants’ possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-4 Building 1: Cost Estimate for Scheme 3

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions** Subtotal for Division: **$11,549**									
	Personnel:									
	Foreman w/truck & phone. 2 hours/day - 5 weeks	50	hours	$100	$5,000					$5,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temp. Sanitation	1	months					$125	$125	$125
	Clean - Up:									
	Daily Clean up - 1 hour/day	25	hours	$25	$625					$625
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	3	each			$575	$1,725			$1,725
	Special Inspections:									
	Welding	1	lump sum					$400	$400	$400
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	12	hours					$93	$1,116	$1,116
	Shear panel nailing	6	hours					$93	$558	$558
2	**Sitework** Subtotal for Division: **$12,670**									
	Demolition:									
	Cut and remove 4' strip of ceiling plaster. 734 sf.	48	hours	$45	$2,160					$2,160
	Remove interior plaster from shear walls and intersecting walls. 2850 sf.	96	hours	$45	$4,320					$4,320
	Sawcut, load and haul 6" concrete floor slab. 168 lf. 5 cy.	1	lump sum						$2,870	$2,870
	Structural Excavation:									
	Excavate new footing at garage entries.	26	cubic yd.	$70	$1,820					$1,820
	Load dump truck (loader)	6	hours					$150	$900	$900
	Haul away dirt (debris box)	8	each					$75	$600	$600
3	**Concrete** Subtotal for Division: **$11,600**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 84 lf. 2600#. Delivered cages.	1	lump sum					$3,700	$3,700	$3,700
	Place cages in footings	16	hours	$45	$720					$720
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 4x6x35/32. 84 lf.	32	cubic yd.	$26	$840	$140	$4,480			$5,320
	Concrete pump	1	lump sum					$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 252 sf.	4	hours	$65	$260					$260

Table 5-4 Building 1: Cost Estimate for Scheme 3 (continued)

Division	Description	Quantity	Unit	Labor Unit Cost	Labor	Material Unit Cost	Material	Subcontractor Unit Cost	Subcontractor	Total
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$8,220**									
	Structural Steel:									
	Steel moment cantilevered columns, 10', 10WF45. 6 ea. Delivered.	1	lump sum					$6,100	$6,100	$6,100
	Hang 6 ea steel columns ready for embedment in footing.	32	hours	$60	$1,920		$200			$2,120
6	**Carpentry** Subtotal for Division: **$25,952**									
	Rough Carpentry:									
	• Additional studs @ shear wall plywood joints and misc framing @ windows. Material.	492	board ft.			$1	$246			$246
	• Additional studs @ shear wall plywood joints and misc framing @ windows. Labor.	12	hours	$60	$720					$720
	• Drill and epoxy anchor bolts.	135	each	$35	$4,725	$45	$6,075			$10,800
	• Drill and epoxy hold downs.	17	each	$35	$595	$110	$1,870			$2,465
	• Additional 4x4 posts and tie downs. 48 bf material @ $1.20/bf.	17	each	$15	$255	$15	$255			$510
	• Clips to framing above shear walls.	304	linear ft.	$4	$1,073	$5	$1,520			$2,593
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 168 bf.	168	board ft.			$2	$319			$319
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 42 lf.	16	hours	$60	$960					$960
	• Shear wall sheathing. 15/32 plywood.	2,736	sq. ft.	$1	$3,420	$1	$2,189			$5,609
	• Set anchor bolts for steel frames. Labor.	6	hours	$75	$450					$450
	• Set anchor bolts for steel frames. Material.	6	each			$100	$600			$600
	Finish Carpentry									
	Exterior siding in 3 ea 4x4 windows	8	hours	$60	$480		$200			$680
7	**Moisture Protection** Subtotal for Division: **$0**									

Table 5-4 Building 1: Cost Estimate for Scheme 3 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									
9	**Finishes** Subtotal for Division: **$7,374**									
	Plaster:									
	Patch openings in ceilings.	750	sq. ft.					$3	$2,250	$2,250
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped.	2,736	sq. ft.					$2	$4,104	$4,104
	Painting:									
	Plaster soffit, seal and 2 coats.	750	sq. ft.					$1	$750	$750
	Steel beams, 10" WF.	72	linear ft.					$2	$144	$144
	2 ea 2x12 collector beams	84	linear ft.					$2	$126	$126
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$31,243		$19,679		$26,443	$77,365
				Subtotal Check:	$77,365		Permits @ 2.4%			$1,857
							Contingency @ 15%			$11,605
				Division Subtotal Check:	$77,365		Subtotal			$90,826
							Overhead & Profit @ 25%			$22,707
							TOTAL			**$113,533**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8" Type X sheetrock and fire taped
- clearing garages of cars and tenants' possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-5 Building 2: Summary of Cost Estimates for All Schemes

Division	Description	Scheme 1: Moment Frames & Limited Shear Walls		Scheme 2: Moment Frames & Greater Shear Walls		Scheme 3: Cantilevered Columns & Greater Shear Walls	
		Subtotal	Total	Subtotal	Total	Subtotal	Total
1	**General Conditions**		**$9,516**		**$12,535**		**$11,235**
	Personnel	4,000		5,000		5,000	
	Small Tools	500		500		500	
	Temporary Utilities	125		125		125	
	Clean - Up	1,400		1,525		1,025	
	Debris Removal	575		1,725		1,725	
	Testing & Inspections	2,916		3,660		2,860	
2	**Sitework**		**$8,317**		**$15,057**		**$12,820**
	Demolition	4,857		11,387		8,640	
	Structural Excavation	3,460		3,670		4,180	
3	**Concrete**		**$12,165**		**$13,685**		**$13,685**
	Reinforcing Steel	5,125		6,013		5,125	
	Concrete Footing	6,780		7,281		8,040	
	Finish Slab	260		390		520	
4	**Masonry**						
	None						
5	**Metals**		**$12,675**		**$12,675**		**$12,030**
	Structural Steel	12,675		12,675		12,030	
6	**Carpentry**		**$4,809**		**$22,353**		**$10,495**
	Rough Carpentry	4,809		22,353		10,495	
7	**Moisture Protection**						
	None						
8	**Doors, Windows, & Glass**						
	None						
9	**Finishes**		**$1,164**		**$13,666**		**$11,827**
	Lath & Plaster	432		4,872		4,872	
	Drywall	432		6,696		5,022	
	Painting	300		2,098		1,933	
10	**Specialties**						
	None						
11	**Equipment**						
	None						
12	**Furnishings**						
	None						
13	**Special Construction**						
	None						
14	**Conveying Systems**						
	None						
15	**Mechanical**						
	None						
16	**Electrical**						
	None						
	Subtotal	48,645	**$48,645**	89,970	**$89,970**	72,091	**$72,091**
	Building Permit @ 2.4%		**$1,167**		**$2,159**		**$1,730**
	Contingency @ 15%		**$7,297**		**$13,496**		**$10,814**
	Subtotal		**$57,110**		**$105,625**		**$84,635**
	Overhead & Profit @ 25%		**$14,277**		**$26,406**		**$21,159**
	Total		**$71,387**		**$132,031**		**$105,794**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8" Type X sheetrock and fire taped
- clearing garages of cars and tenants' possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-6 Building 2: Cost Estimate for Scheme 1

Division	Description	Quantity	Unit	Labor Unit Cost	Labor	Material Unit Cost	Material	Subcontractor Unit Cost	Subcontractor	Total
1	**General Conditions** Subtotal for Division: **$9,516**									
	Personnel:									
	Foreman w/truck & phone. 2 hrs/d - 4 wks.	40	hours	$100	$4,000					$4,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temp. Sanitation	1	months					$125	$125	$125
	Clean - Up:									
	Daily Clean up - 1 man, 1 hr/d	20	hours	$25	$500					$500
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	1	each			$575	$575			$575
	Special Inspections:									
	Welding	1	lump sum					$1,200	$1,200	$1,200
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	6	hours					$93	$558	$558
	Shear panel nailing	6	hours					$93	$558	$558
2	**Sitework** Subtotal for Division: **$8,317**									
	Demolition:									
	Cut and remove 4' strip of ceiling plaster. 88 lf, 352 sf.	24	hours	$45	$1,080					$1,080
	Remove interior plaster from shear walls and intersecting walls. 24 x 9 =216 sf.	8	hours	$45	$360					$360
	Sawcut, load and haul 6" concrete floor slab. 200 lf. 5 cy.	1	lump sum					$3,417	$3,417	$3,417
	Structural Excavation:									
	Excavate new footing at garage entries.	28	cubic yd.	$70	$1,960					$1,960
	Load dump truck (loader)	6	hrs					$150	$900	$900
	Haul away dirt (dump truck).	8	hrs					$75	$600	$600
3	**Concrete** Subtotal for Division: **$12,165**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 100 lf. 3100#. Delivered cages.	1	lump sum					$4,405	$4,405	$4,405
	Place cages in footings	16	hours	$45	$720					$720
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 4x6x35/31. 100 lf.	31	cubic yd.	$27	$840	$140	$4,340			$5,180
	Concrete pump	1	each					$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3' x84'.	4	hours	$65	$260					$260

Table 5-6 Building 2: Cost Estimate for Scheme 1 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$12,675**									
	Structural Steel: Steel moment frames, 2 ea. (8'x22' & 8'x24'), 12WF45 w/RBS. Erected on anchor bolts in new concrete footings & field welded.	1	lump sum					$12,675	$12,675	$12,675
6	**Carpentry** Subtotal for Division: **$ $4,809**									
	Rough Carpentry:									
	New wall framing with 3"oc shear nailing in 1/2' ply on both sides.	24	linear ft.	$60	$1,440	$20	$480			$1,920
	• Anchor bolts.	11	each	$10	$110	$15	$165			$275
	• Tie downs.	4	each	$10	$40	$25	$100			$140
	• Clips to framing above shear walls.	24	linear ft.	$4	$85	$5	$120			$205
	• Collector and connections to floor above @ moment frames. 2 ea.	64	linear ft.	$9	$560	$4	$256			$816
	• Plywood soffit, 1/2" on existing floor joists.	264	sq. ft.	$2	$462	$1	$211			$673
	• Collector plate, 1/4" x 3" x 66 lf	1	each	$280	$280	$100	$100			$380
	• Set anchor bolts for steel frames	4	each	$75	$300	$25	$100			$400
7	**Moisture Protection** Subtotal for Division: **$0**									
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									

Table 5-6 Building 2: Cost Estimate for Scheme 1 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
9	**Finishes** Subtotal for Division: **$1,164**									
	Plaster:									
	Patch openings in ceilings.	144	sq. ft.					$3	$432	$432
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped.	216	sq. ft.					$2	$432	$432
	Painting:									
	Plaster soffit, seal and 2 coats.	144	sq. ft.					$1	$144	$144
	Steel beams, 10" WF.	78	linear ft.					$2	$156	$156
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$13,897		$6,447		$28,301	$48,645
				Subtotal Check:	$48,645		Permits @ 2.4%			$1,167
							Contingency @ 15%			$7,297
				Division Subtotal Check:	$48,645		Subtotal			$57,110
							Overhead & Profit @ 25%			$14,277
							TOTAL			**$71,387**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8" Type X sheetrock and fire taped
- clearing garages of cars and tenants' possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-7 Building 2: Cost Estimate for Scheme 2

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions** Subtotal for Division: **$12,535**									
	Personnel:									
	Foreman w/truck & phone. 2 hours/day - 5 weeks	50	hours	$100	$5,000					$5,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temp. Sanitation	1	months					$125	$125	$125
	Clean - Up:									
	Daily Clean up - 1 man, 1 hr/d	25	hours	$25	$625					$625
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	3	each			$575	$1,725			$1,725
	Special Inspections:									
	Welding	1	lump sum					$1,200	$1,200	$1,200
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	12	hours					$93	$1,116	$1,116
	Shear panel nailing	8	hours					$93	$744	$744
2	**Sitework** Subtotal for Division: **$15,057**									
	Demolition:									
	Cut and remove 4' strip of ceiling plaster. 396 lf, 1200 sf.	56	hours	$45	$2,520					$2,520
	Remove interior plaster from shear walls and intersecting walls. 400 x 9 =3600 sf.	112	hours	$45	$5,040					$5,040
	Sawcut, load and haul 6" concrete floor slab. 224 lf. 5 cy.	1	lump sum					$3,827	$3,827	$3,827
	Structural Excavation:									
	Excavate new footing at garage entries.	31	cubic yd.	$70	$2,170					$2,170
	Load dump truck (loader)	6	hours					$150	$900	$900
	Haul away dirt (dump truck).	8	hours					$75	$600	$600
3	**Concrete** Subtotal for Division: **$13,685**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 112 lf. 3400#. Delivered cages.	1	lump sum					$4,933	$4,933	$4,933
	Place cages in footings	24	hours	$45	$1,080					$1,080
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 4x6x35/31. 100 lf.	34	cubic yd.	$27	$921	$140	$4,760			$5,681
	Concrete pump	1	each					$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3' x84'.	6	hours	$65	$390					$390

Table 5-7 Building 2: Cost Estimate for Scheme 2 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$12,675**									
	Structural Steel: Steel moment frames, 2 ea. (8'x22' & 8'x24'), 12WF45 w/RBS. Erected on anchor bolts in new concrete footings & field welded.	1	lump sum					$12,675	$12,675	$12,675
6	**Carpentry** Subtotal for Division: **$22,353**									
	Rough Carpentry:									
	New wall framing with 3"oc shear nailing in 1/2' ply on both sides.	24	linear ft.	$60	$1,440	$20	$480			$1,920
	• Drill and epoxy anchor bolts.	164	each	$10	$1,640	$15	$2,460			$4,100
	• Drill and epoxy tie downs, add 4x4.	22	each	$10	$220	$25	$550			$770
	• Clips to framing above shear walls.	372	linear ft.	$1	$480	$3	$1,116			$1,596
	• Add studs @ shear panel joints.	1,116	board ft.	$0	$240	$0	$502			$742
	• Shear wall sheathing on existing studs, 15/32 plywood.	3,348	sq. ft.	$1	$4,185	$1	$2,678			$6,863
	• Collector and connections to floor above @ cantilevered columns. 2 ea 2x12, 110 lf.	110	linear ft.	$8	$880	$4	$440			$1,320
	• Plywood soffit, 1/2" on existing floor joists.	1,624	sq. ft.	$2	$2,842	$1	$1,299			$4,141
	• Set anchor bolts for steel cols.	9	each	$75	$675	$25	$225			$900
7	**Moisture Protection** Subtotal for Division: **$0**									
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									

Table 5-7 Building 2: Cost Estimate for Scheme 2 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
9	**Finishes** Subtotal for Division: **$13,666**									
	Plaster:									
	Patch openings in ceilings.	1,624	sq. ft.					$3	$4,872	$4,872
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped. 372 lf x 9 = 3564 sf.	3,348	sq. ft.					$2	$6,696	$6,696
	Painting:									
	Plaster soffit, seal and 2 coats.	1,624	sq. ft.					$1	$1,624	$1,624
	Steel beams, 10" WF.	72	linear ft.					$2	$144	$144
	Collector beams	110	linear ft.					$3	$330	$330
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$31,248		$16,236		$42,486	$89,970
				Subtotal Check:	$89,970		Permits @ 2.4%			$2,159
							Contingency @ 15%			$13,496
				Division Subtotal Check:	$89,970		Subtotal			$105,625
							Overhead & Profit @ 25%			$26,406
							TOTAL			**$132,031**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8" Type X sheetrock and fire taped
- clearing garages of cars and tenants' possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-8 Building 2: Cost Estimate for Scheme 3

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions** Subtotal for Division: **$11,235**									
	Personnel:									
	Foreman w/truck & phone. 2 hrs/d - 5 wks.	50	hours	$100	$5,000					$5,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temp. Sanitation	1	months					$125	$125	$125
	Clean Up:									
	Daily Clean Up - 1 hour/day	25	hours	$25	$625					$625
	Final Clean Up	16	hours	$25	$400					$400
	Flagman	20	hours	$25						$0
	Debris removal:									
	Debris box	3	each			$575	$1,725			$1,725
	Special Inspections:									
	Welding	1	lump sum					$400	$400	$400
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	12	hours					$93	$1,116	$1,116
	Shear panel nailing	8	hours					$93	$744	$744
2	**Sitework** Subtotal for Division: **$12,820**									
	Demolition:									
	Cut and remove 4' strip of ceiling plaster. 480 lf, 1624 sf.	80	hours	$45	$3,600					$3,600
	Remove interior plaster from shear walls and intersecting walls. 400 x 9 =3600 sf.	112	hours	$45	$5,040					$5,040
	Sawcut, load and haul 6" concrete floor slab. 200 lf. 5 cy.	1	lump sum					$3,417	$273,333	$0
	Structural Excavation:									
	Excavate new footing at garage entries.	34	cubic yd.	$70	$2,380					$2,380
	Load dump truck (loader)	8	hours					$150	$1,200	$1,200
	Haul away dirt (dump truck).	8	hours					$75	$600	$600
3	**Concrete** Subtotal for Division: **$13,685**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 100 lf. 2600#. Delivered cages.	1	lump sum					$4,405	$4,405	$4,405
	Place cages in footings	16	hours	$45	$720					$720
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 4x8x35/38.	38	cubic yd.	$29	$1,120	$140	$5,320			$6,440
	Concrete pump	1	lump sum					$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 366 sf	8	hours	$65	$520					$520

Table 5-8 Building 2: Cost Estimate for Scheme 3 (continued)

Division	Description	Quantity	Unit	Labor Unit Cost	Labor	Material Unit Cost	Material	Subcontractor Unit Cost	Subcontractor	Total
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$12,030**									
	Structural Steel:									
	Steel moment cantilevered columns, 10', 10WF45. 9 ea. Delivered.	1	lump sum					$9,150	$9,150	$9,150
	Hang 9 ea steel columns ready for embedment in footing.	48	hours	$60	$2,880					$2,880
6	**Carpentry** Subtotal for Division: **$10,495**									
	Rough Carpentry:									
	• Drill and epoxy anchor bolts.	11	each	$10	$110	$15	$165			$275
	• Drill and epoxy tie downs, add 4x4.	4	each	$10	$40	$25	$100			$140
	• Clips to framing above shear walls.	24	linear ft.	$4	$85	$5	$120			$205
	• Add studs @ shear panel joints.	1,116	board ft.	$0	$240	$0	$502			$742
	• Shear wall sheathing on existing studs, 15/32 plywood.	3,348	sq. ft.	$1	$4,185	$1	$2,678			$6,863
	• Collector and connections to floor above @ moment frames. 2 ea.	64	linear ft.	$9	$560	$4	$256			$816
	• Plywood soffit, 1/2" on existing floor joists.	264	sq. ft.	$2	$462	$1	$211			$673
	• Collector plate, 1/4" x 3" x 66 lf	1	each	$280	$280	$100	$100			$380
	• Set anchor bolts for steel frames	4	each	$75	$300	$25	$100			$400
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 168 bf.		bf			$2	$0			$0
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 42 lf.		hours	$60	$0					$0
	• Shear wall sheathing. 15/32 plywood.		sq. ft.	$1	$0	$1	$0			$0
	• Set anchor bolts for steel frames. Labor.		hours	$75	$0					$0
	• Set anchor bolts for steel frames. Material.		each			$100	$0			$0
	Finish Carpentry									
	Exterior siding in 3 ea 4x4 windows		hours	$60	$0					$0
7	**Moisture Protection** Subtotal for Division: **$0**									

Table 5-8 Building 2: Cost Estimate for Scheme 3 (continued)

Division	Description	Quantity	Unit	Labor Unit Cost	Labor	Material Unit Cost	Material	Subcontractor Unit Cost	Subcontractor	Total
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									
9	**Finishes** Subtotal for Division: **$11,827**									
	Plaster:									
	Patch openings in ceilings.	1,624	sq. ft.					$3	$4,872	$4,872
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped.	3,348	sq. ft.					$2	$5,022	$5,022
	Painting:									
	Plaster soffit, seal and 2 coats.	1,624	sq. ft.					$1	$1,624	$1,624
	Steel beams, 10" WF.	72	linear ft.					$2	$144	$144
	2 ea 2x12 collector beams	110	linear ft.					$2	$165	$165
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$28,547		$11,278		$305,600	$72,091
				Subtotal Check:	$345,425		Permits @ 2.4%			$1,730
							Contingency @ 15%			$10,814
				Division Subtotal Check:	$72,091		Subtotal			$84,635
							Overhead & Profit @ 25%			$21,159
								TOTAL		**$105,794**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8” Type X sheetrock and fire taped
- clearing garages of cars and tenants’ possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-9   Building 3: Summary of Cost Estimates for All Schemes

Division	Description	SCHEME 1 Shear Walls Only		SCHEME 2 Moment Frames & Shear Walls		SCHEME 3 Cantilevered Columns & Shear Walls	
		Subtotal	Total	Subtotal	Total	Subtotal	Total
1	**General Conditions**		**$8,502**		**$11,713**		**$11,488**
	Personnel	4,000		5,000		5,000	
	Small Tools	500		500		500	
	Temporary Utilities	125		250		250	
	Clean - Up	1,400		1,525		1,525	
	Debris Removal	575		1,150		1,725	
	Testing & Inspections	1,902		3,288		2,488	
2	**Sitework**		**$7,403**		**$9,833**		**$9,731**
	Demolition	4,653		7,083		7,463	
	Structural Excavation	2,750		2,750		2,268	
3	**Concrete**		**$10,264**		**$10,264**		**$8,462**
	Reinforcing Steel	4,064		4,064		3,102	
	Concrete Footing	5,940		5,940		5,100	
	Finish Slab	260		260		260	
4	**Masonry**						
	None						
5	**Metals**		**$0**		**$20,475**		**$8,220**
	Structural Steel	0		20,475		8,220	
6	**Carpentry**		**$11,021**		**$16,846**		**$19,945**
	Rough Carpentry	11,021		16,846		19,945	
7	**Moisture Protection**		**$351**		**$1,701**		**$2,349**
	Insulation	351		1,701		2,349	
8	**Doors, Windows, & Glass**						
	None.						
9	**Finishes**		**$2,733**		**$4,253**		**$5,093**
	Lath & Plaster	1,422		1,914		2,058	
	Drywall	837		1,701		2,349	
	Painting	474		638		686	
10	**Specialties**						
	None						
11	**Equipment**						
	None						
12	**Furnishings**						
	None						
13	**Special Construction**						
	None						
14	**Conveying Systems**						
	None						
15	**Mechanical**						
	None						
16	**Electrical**						
	None						
	Subtotal	40,274	**$40,274**	75,085	**$75,085**	65,287	**$65,287**
	Building Permit @ 2.4%		**$967**		**$1,802**		**$1,567**
	Contingency @ 15%		**$6,041**		**$11,263**		**$9,793**
	Subtotal		**$47,282**		**$88,150**		**$76,647**
	Overhead & Profit @ 25%		**$11,820**		**$22,038**		**$19,162**
	Total		**$59,102**		**$110,188**		**$95,809**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8" Type X sheetrock and fire taped
- clearing garages of cars and tenants' possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-10 Building 3: Cost Estimate for Scheme 1

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions** Subtotal for Division: **$8,502**									
	Personnel:									
	Foreman w/truck & phone. 2 hours/day - 4 weeks	40	hours	$100	$4,000					$4,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temporary Sanitation	1	months					$125	$125	$125
	Clean - Up:									
	Daily Clean up - 1 man, 1 hr/d	20	hours	$25	$500					$500
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	1	each			$575	$575			$575
	Special Inspections:									
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	6	hours					$93	$558	$558
	Shear panel nailing	8	hours					$93	$744	$744
2	**Sitework** Subtotal for Division: **$7,403**									
	Demolition:									
	Cut and remove 1' strip of ceiling plaster @ walls plus removed soffit. 474 sf.	36	hours	$45	$1,620					$1,620
	Remove interior plaster from shear walls and intersecting walls. 26 x 9 = 234 sf.	10	hours	$45	$450					$450
	Sawcut, load and haul 6" concrete floor slab. 152 lf. 4 cy.	1	lump sum						$2,583	$2,583
	Structural Excavation:									
	Excavate new footing at garage entries.	20	cubic yd.	$70	$1,400					$1,400
	Load dump truck (loader)	6	hours					$150	$900	$900
	Haul away dirt (dump truck).	6	hours					$75	$450	$450
3	**Concrete** Subtotal for Division: **$10,264**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 76 lf. 2350#. Delivered cages.	1	lump sum					$3,344	$3,344	$3,344
	Place cages in footings	16	hours	$45	$720					$720
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 25 cy. 76 lf.	25	cubic yd.	$34	$840	$140	$3,500			$4,340
	Concrete pump	1	lump sum					$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3' x 76'.	4	hours	$65	$260					$260

Table 5-10 Building 3: Cost Estimate for Scheme 1 (continued)

Division	Description	Quantity	Unit	Labor Unit Cost	Labor	Material Unit Cost	Material	Subcontractor Unit Cost	Subcontractor	Total
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$0**									
	None.									
6	**Carpentry** Subtotal for Division: **$11,021**									
	Rough Carpentry:									
	• Framing @ shear wall plywood joints and new shear walls. Material.	284	board ft.			$1	$298			$298
	• Framing @ shear wall plywood joints and new shear walls. Labor.	8	hours	$60	$480					$480
	• Shear wall sheathing. Struc 1 plywood.	558	sq. ft.	$1	$698	$1	$502			$1,200
	• Soffit sheathing. Struc 1 plywood.	448	sq. ft.	$2	$672	$1	$403			$1,075
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 76 lf.	304	board ft.			$2	$578			$578
	• Collector beam and connections to floor above @ door opening head. Labor	24	hours	$60	$1,440					$1,440
	• Drill and epoxy anchor bolts & rebar dowels.	54	each	$35	$1,890	$45	$2,430			$4,320
	• Drill and epoxy hold downs w/4x6 post	2	each	$70	$140	$110	$220			$360
	• Set hold downs w/4x6 post	6	each	$35	$210	$100	$600			$810
	• Clips to framing above shear walls.	44	linear ft.	$5	$240	$5	$220			$460
7	**Moisture Protection** Subtotal for Division: **$351**									
	Insulation: Batt insulation in new exterior shear walls.	234	sq. ft.	$1	$117	$1	$234			$351
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									

Table 5-10 Building 3: Cost Estimate for Scheme 1 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
9	**Finishes** Subtotal for Division: **$2,733**									
	Plaster: Patch openings in ceilings.	474	sq. ft.					$3	$1,422	$1,422
	Drywall: Cover shear walls, 5/8 type x, fire taped.	558	sq. ft.					$2	$837	$837
	Painting: Plaster soffit, seal and 2 coats.	474	sq. ft.					$1	$474	$474
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$16,577		$9,560		$14,137	$40,274
				Subtotal Check:	$40,274		Permits @ 2.4%			$967
							Contingency @ 15%			$6,041
				Division Subtotal Check:	$40,274		Subtotal			$47,282
							Overhead & Profit @ 25%			$11,820
							TOTAL			**$59,102**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8" Type X sheetrock and fire taped
- clearing garages of cars and tenants' possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-11 Building 3: Cost Estimate for Scheme 2

Division	Description	Quantity	Unit	Labor Unit Cost	Labor	Material Unit Cost	Material	Subcontractor Unit Cost	Subcontractor	Total
1	**General Conditions** Subtotal for Division: **$11,713**									
	Personnel:									
	Foreman w/truck & phone. 2 hours/day - 5 weeks	50	hours	$100	$5,000					$5,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temp. Sanitation	2	months					$125	$250	$250
	Clean - Up:									
	Daily Clean up - 1 man, 1 hr/d	25	hours	$25	$625					$625
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	2	each			$575	$1,150			$1,150
	Special Inspections:									
	Welding	1	lump sum					$1,200	$1,200	$1,200
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	6	lump sum					$93	$558	$558
	Shear panel nailing	10	hours					$93	$930	$930
2	**Sitework** Subtotal for Division: **$9,833**									
	Demolition:									
	Cut and remove 1' strip of ceiling plaster @ walls plus removed soffit. 638 sf.	52	hours	$45	$2,340					$2,340
	Remove interior plaster from shear walls and intersecting walls. 126 x 9 = 1134 sf.	48	hours	$45	$2,160					$2,160
	Sawcut, load and haul 6" concrete floor slab. 152 lf. 4 cy.	1	lump sum						$2,583	$2,583
	Structural Excavation:									
	Excavate new footing at garage entries.	20	cubic yd.	$70	$1,400					$1,400
	Load dump truck (loader)	6	hours					$150	$900	$900
	Haul away dirt (dump truck).	6	hours					$75	$450	$450
3	**Concrete** Subtotal for Division: **$10,264**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 76 lf. 2350#. Delivered cages.	1	lump sum					$3,344	$3,344	$3,344
	Place cages in footings	16	hours	$45	$720					$720
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 25 cy. 76 lf.	25	cubic yd.	$34	$840	$140	$3,500			$4,340
	Concrete pump	1						$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3' x 76'.	4	hours	$65	$260					$260

Table 5-11 Building 3: Cost Estimate for Scheme 2 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$20,475**									
	Structural Steel: Steel moment frames, 8' x 26' W12x45 w/RBS. 3 ea. Erected on anchor bolts in new concrete footings with field welding. Braced at midpoint to diaphragm above.	1	lump sum					$20,475	$20,475	$20,475
6	**Carpentry** Subtotal for Division: **$16,846**									
	Rough Carpentry:									
	• Framing @ shear wall plywood joints. Material.	192	board ft.			$1	$202			$202
	• Framing @ shear wall plywood joints. Labor.	6	hours	$60	$360					$360
	• Shear wall sheathing. Struc 1 plywood.	1,134	sq. ft.	$1	$1,418	$1	$1,021			$2,438
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 76 lf.	304	board ft.			$2	$578			$578
	• Collector beam and connections to floor above @ door opening head. Labor	24	hours	$60	$1,440					$1,440
	• Soffit sheathing. Struc 1 plywood.	512	sq. ft.	$2	$768	$1	$461			$1,229
	• Drill and epoxy anchor bolts & rebar dowels.	104	each	$35	$3,640	$45	$4,680			$8,320
	• Drill and epoxy hold downs w/4x6 post	2	each	$70	$140	$110	$220			$360
	• Set hold downs w/4x6 post	6	each	$35	$210	$100	$600			$810
	• Clips to framing above shear walls.	126	linear ft.	$4	$480	$5	$630			$1,110
7	**Moisture Protection** Subtotal for Division: **$1,701**									
	Insulation: Batt insulation in new exterior shear walls.	1,134	sq. ft.	$1	$567	$1	$1,134			$1,701
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									

Table 5-11 Building 3: Cost Estimate for Scheme 2 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
9	**Finishes** Subtotal for Division: **$4,253**									
	Plaster:									
	Patch openings in ceilings.	638	sq. ft.					$3	$1,914	$1,914
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped.	1,134	sq. ft.					$2	$1,701	$1,701
	Painting:									
	Plaster soffit, seal and 2 coats.	638	sq. ft.					$1	$638	$638
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$ $0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$23,268		$14,175		$37,643	$75,085
				Subtotal Check:	$75,085		Permits @ 2.4%			$1,802
							Contingency @ 15%			$11,263
				Division Subtotal Check:	$75,085		Subtotal			$88,150
							Overhead & Profit @ 25%			$22,038
							TOTAL			**$110,188**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8" Type X sheetrock and fire taped
- clearing garages of cars and tenants' possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-12 Building 3: Cost Estimate for Scheme 3

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions** Subtotal for Division: **$11,488**									
	Personnel:									
	Foreman w/truck & phone. 2 hrs/d - 5 wks.	50	hours	$100	$5,000					$5,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temp. Sanitation	2	month					$125	$250	$250
	Clean - Up:									
	Daily Clean up - 1 man, 1 hr/d	25	hours	$25	$625					$625
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	3	each			$575	$1,725			$1,725
	Special Inspections:									
	Welding	1	lump sum					$400	$400	$400
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	6	hours					$93	$558	$558
	Shear panel nailing	10	hours					$93	$930	$930
2	**Sitework** Subtotal for Division: **$9,731**									
	Demolition:									
	Cut and remove 1' strip of ceiling plaster @ walls plus removed soffit. 686 sf.	54	hours	$45	$2,430					$2,430
	Remove interior plaster from shear walls and intersecting walls. 174 x 9 = 1566 sf.	64	hours	$45	$2,880					$2,880
	Sawcut, load and haul 6" concrete floor slab. 116 lf. 3 cy.	1	lump sum						$2,153	$2,153
	Structural Excavation:									
	Excavate new footing at garage entries.	15	cubic yd.	$70	$1,068					$1,068
	Load dump truck (loader)	6	hours					$150	$900	$900
	Haul away dirt (dump truck).	4	hours					$75	$300	$300
3	**Concrete** Subtotal for Division: **$8,462**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 58 lf. 1800#. Delivered cages.	1	lump sum					$2,562	$2,562	$2,562
	Place cages in footings	12	hours	$45	$540					$540
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 58 lf.	19	cubic yd.	$44	$840	$140	$2,660			$3,500
	Concrete pump	1						$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3' x 58'.	4	hours	$65	$260					$260

Table 5-12 Building 3: Cost Estimate for Scheme 3 (continued)

Division	Description	Quantity	Unit	Labor Unit Cost	Labor	Material Unit Cost	Material	Subcontractor Unit Cost	Subcontractor	Total
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$8,220**									
	Structural Steel:									
	Steel moment cantilevered columns, 10', 12WF45. 6ea. Delivered.	1	lump sum					$6,100	$6,100	$6,100
	Hang 6 ea steel columns ready for embedment in footings.	32	hours	$60	$1,920		$200			$2,120
6	**Carpentry** Subtotal for Division: **$19,945**									
	Rough Carpentry:									
	• Framing @ shear wall plywood joints. Material.	265	board ft.			$1	$278			$278
	• Framing @ shear wall plywood joints. Labor.	8	hours	$60	$480					$480
	• Shear wall sheathing. Struc 1 plywood.	1,566	sq. ft.	$1	$1,958	$1	$1,409			$3,367
	• Soffit sheathing. Struc 1 plywood.	512	sq. ft.	$2	$768	$1	$461			$1,229
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 58 lf.	232	board ft.			$2	$441			$441
	• Collector beam and connections to floor above @ door opening head. Labor	20	hours	$60	$1,200					$1,200
	• Drill and epoxy anchor bolts & rebar dowels.	112	each	$35	$3,920	$45	$5,040			$8,960
	• Drill and epoxy hold downs w/4x6 post	14	each	$70	$980	$110	$1,540			$2,520
	• Clips to framing above shear walls.	174	linear ft.	$3	$600	$5	$870			$1,470
7	**Moisture Protection** Subtotal for Division: **$2,349**									
	Insulation:									
	Batt insulation in new exterior shear walls.	1,566	sq. ft.	$1	$783	$1	$1,566			$2,349
8	**Doors, Windows, & Glass** Subtotal for Division: **$ $0**									

Table 5-12 Building 3: Cost Estimate for Scheme 3 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
9	**Finishes** Subtotal for Division: **$5,093**									
	Plaster:									
	Patch openings in ceilings.	686	sq. ft.					$3	$2,058	$2,058
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped.	1,566	sq. ft.					$2	$2,349	$2,349
	Painting:									
	Plaster soffit, seal and 2 coats.	686	sq. ft.					$1	$686	$686
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$27,152		$16,190		$21,945	$65,287
				Subtotal Check:	$65,287		Permits @ 2.4%			$1,567
							Contingency @ 15%			$9,793
				Division Subtotal Check:	$65,287		Subtotal			$76,647
							Overhead & Profit @ 25%			$19,162
							TOTAL			**$95,809**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8” Type X sheetrock and fire taped
- clearing garages of cars and tenants’ possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-13 Building 4: Summary of Cost Estimates for All Schemes

Division	Description	SCHEME 1 Shear Walls Only		SCHEME 2 Moment Frames & Shear Walls		SCHEME 3 Cantilevered Columns & Shear Walls	
		Subtotal	Total	Subtotal	Total	Subtotal	Total
1	**General Conditions**		**$9,352**		**$10,091**		**$9,291**
	Personnel	4,000		4,000		4,000	
	Small Tools	500		500		500	
	Temporary Utilities	125		125		125	
	Clean - Up	1,400		1,400		1,400	
	Debris Removal	1,725		1,150		1,150	
	Testing & Inspections	1,602		2,916		2,116	
2	**Sitework**		**$4,854**		**$4,976**		**$6,774**
	Demolition	3,814		3,656		4,794	
	Structural Excavation	1,040		1,320		1,980	
3	**Concrete**		**$1,819**		**$4,953**		**$6,372**
	Reinforcing Steel	709		1,693		2,478	
	Concrete Footing	980		3,000		3,634	
	Finish Slab	130		260		260	
4	**Masonry**						
	None						
5	**Metals**		**$0**		**$7,475**		**$3,157**
	Structural Steel	0		7,475		3,157	
6	**Carpentry**		**$13,017**		**$9,475**		**$10,314**
	Rough Carpentry	13,017		9,475		10,314	
7	**Moisture Protection**		**$1,917**		**$1,134**		**$1,134**
	Insulation	1,917		1,134		1,134	
8	**Doors, Windows, & Glass**						
	None						
9	**Finishes**		**$2,493**		**$2,238**		**$2,750**
	Lath & Plaster	426		828		1,212	
	Drywall	1,917		1,134		1,134	
	Painting	150		276		404	
10	**Specialties**						
	None						
11	**Equipment**						
	None						
12	**Furnishings**						
	None						
13	**Special Construction**						
	None						
14	**Conveying Systems**						
	None						
15	**Mechanical**						
	None						
16	**Electrical**						
	None						
	Subtotal	33,451	**$33,451**	40,342	**$40,342**	39,792	**$39,792**
	Building Permit @ 2.4%		**$803**		**$968**		**$955**
	Contingency @ 15%		**$5,018**		**$6,051**		**$5,969**
	Subtotal		**$39,272**		**$47,362**		**$46,715**
	Overhead & Profit @ 25%		**$9,818**		**$11,840**		**$11,679**
	Total		**$49,090**		**$59,202**		**$58,394**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8” Type X sheetrock and fire taped
- clearing garages of cars and tenants’ possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-14 Building 4: Cost Estimate for Scheme 1

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions** Subtotal for Division: **$9,352**									
	Personnel:									
	Foreman w/truck & phone. 2 hours/day - 4 weeks.	40	hours	$100	$4,000					$4,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temp. Sanitation	1	months					$125	$125	$125
	Clean - Up:									
	Daily Clean up - 1 man, 1 hr/d	20	hours	$25	$500					$500
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	3	each			$575	$1,725			$1,725
	Special Inspections:									
	Concrete cylinders	1	lump sum					$300	$300	$300
	Epoxied dowels	6	hours					$93	$558	$558
	Shear panel nailing	8	hours					$93	$744	$744
2	**Sitework** Subtotal for Division: **$4,854**									
	Demolition:									
	Cut and remove 1' strip of ceiling plaster @ walls. 142 sf.	16	hours	$45	$720					$720
	Remove interior plaster from shear walls and intersecting walls. 150 x 9 = 1350 sf.	56	hours	$45	$2,520					$2,520
	Sawcut, load and haul 6" concrete floor slab. 16 lf. 0.5 cy.	1	lump sum					$574	$574	$574
	Structural Excavation:									
	Excavate new footing at garage entries.	2	cubic yd.	$70	$140					$140
	Load dump truck (loader)	4	hours					$150	$600	$600
	Haul away dirt (dump truck).	4	hours					$75	$300	$300
3	**Concrete** Subtotal for Division: **$1,819**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 8 lf. 250#. Delivered cage.	1	lump sum					$529	$529	$529
	Place cages in footings	4	hours	$45	$180					$180
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab w/o pump. 8 lf.	3	cubic yd.	$187	$560	$140	$420			$980
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3' x 8'.	2	hours	$65	$130					$130

Table 5-14 Building 4: Cost Estimate for Scheme 1 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$0**									
	None.									
6	**Carpentry** Subtotal for Division: **$13,017**									
	Rough Carpentry:									
	• Framing @ shear wall plywood joints and new shear walls. Material.	342	board ft.			$1	$359			$359
	• Framing @ shear wall plywood joints and new shear walls. Labor.	8	hours	$60	$480					$480
	• Shear wall sheathing. Struc 1 plywood.	1,278	sq. ft.	$1	$1,598	$1	$1,150			$2,748
	• Drill and epoxy anchor bolts & rebar dowels.	76	each	$35	$2,660	$45	$3,420			$6,080
	• Drill and epoxy hold downs w/4x6 post	12	each	$70	$840	$110	$1,320			$2,160
	• Clips to framing above shear walls.	142	linear ft.	$3	$480	$5	$710			$1,190
7	**Moisture Protection** Subtotal for Division: **$1,917**									
	Insulation: Batt insulation in new exterior shear walls.	1,278	sq. ft.	$1	$639	$1	$1,278			$1,917
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									
9	**Finishes** Subtotal for Division: **$2,493**									
	Plaster: Patch openings in ceilings.	142	sq. ft.					$3	$426	$426
	Drywall: Cover shear walls, 5/8 type x, fire taped.	1,278	sq. ft.					$2	$1,917	$1,917
	Painting: Plaster soffit, seal and 2 coats.	150	sq. ft.					$1	$150	$150

Table 5-14 Building 4: Cost Estimate for Scheme 1 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$16,347		$10,382		$6,723	$33,451
				Subtotal Check:	$33,451		Permits @ 2.4%			$803
							Contingency @ 15%			$5,018
				Division Subtotal Check:	$33,451		Subtotal			$39,272
							Overhead & Profit @ 25%			$9,818
								TOTAL		**$49,090**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8" Type X sheetrock and fire taped
- clearing garages of cars and tenants' possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-15 Building 4: Cost Estimate for Scheme 2

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions** Subtotal for Division: **$10,091**									
	Personnel:									
	Foreman w/truck & phone. 2 hrs/d - 4 wks.	40	hours	$100	$4,000					$4,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temp. Sanitation	1	mounths					$125	$125	$125
	Clean - Up:									
	Daily Clean up - 1 man, 1 hr/d	20	hours	$25	$500					$500
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	2	each			$575	$1,150			$1,150
	Special Inspections:									
	Welding	1	lump sum					$1,200	$1,200	$1,200
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	6	hours					$93	$558	$558
	Shear panel nailing	6	hours					$93	$558	$558
2	**Sitework** Subtotal for Division: **$4,976**									
	Demolition:									
	Cut and remove 1' strip of ceiling plaster @ walls plus removed soffit. 276 sf.	28	hours	$45	$1,260					$1,260
	Remove interior plaster from shear walls and intersecting walls. 90 x 9 = 810 sf.	32	hours	$45	$1,440					$1,440
	Sawcut, load and haul 6" concrete floor slab. 48 lf. 1 cy.	1	lump sum					$956	$956	$956
	Structural Excavation:									
	Excavate new footing at garage entries.	6	cubic yd.	$70	$420					$420
	Load dump truck (loader)	4	hours					$150	$600	$600
	Haul away dirt (dump truck).	4	hours					$75	$300	$300
3	**Concrete** Subtotal for Division: **$4,953**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 24 lf. 750#. Delivered cages.	1	lump sum					$1,423	$1,423	$1,423
	Place cages in footings	6	hours	$45	$270					$270
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 24'.	7	cubic yd.	$60	$420	$140	$980			$1,400
	Concrete pump	1	lump sum					$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3' x 24'.	4	lump sum	$65	$260					$260

Table 5-15 Building 4: Cost Estimate for Scheme 2 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$7,475**									
	Structural Steel: Steel moment frame, 8' x 24' W12x45 w/RBS. 1 ea. Erected on anchor bolts in new concrete footings with field welding. Braced at midpoint to diaphram above.	1	lump sum					$7,475	$7,475	$7,475
6	**Carpentry** Subtotal for Division: **$9,475**									
	Rough Carpentry:									
	• Framing @ shear wall plywood joints. Material.	216	board ft.			$1	$227			$227
	• Framing @ shear wall plywood joints. Labor.	6	hours	$60	$360					$360
	• Shear wall sheathing. Struc 1 plywood.	756	sq. ft.	$1	$945	$1	$680			$1,625
	• Soffit sheathing. Struc 1 plywood.	192	sq. ft.	$2	$288	$1	$173			$461
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 24 lf.	96	board ft.			$2	$182			$182
	• Collector beam and connections to floor above @ door opening head. Labor	8	hours	$60	$480					$480
	• Drill and epoxy anchor bolts & rebar dowels.	46	each	$35	$1,610	$45	$2,070			$3,680
	• Drill and epoxy hold downs w/4x6 post	10	each	$70	$700	$110	$1,100			$1,800
	• Clips to framing above shear walls.	84	linear ft.	$3	$240	$5	$420			$660
7	**Moisture Protection** Subtotal for Division: **$1,134**									
	Insulation: Batt insulation in new exterior shear walls.	756	sq. ft.	$1	$378	$1	$756			$1,134
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									

Table 5-15 Building 4: Cost Estimate for Scheme 2 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
9	**Finishes** Subtotal for Division: **$2,238**									
	Plaster:									
	Patch openings in ceilings.	276	sq. ft.					$3	$828	$828
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped.	756	sq. ft.					$2	$1,134	$1,134
	Painting:									
	Plaster soffit, seal and 2 coats.	276	sq. ft.					$1	$276	$276
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$14,471		$7,738		$18,133	$40,342
				Subtotal Check:	$40,342		Permits @ 2.4%			$968
							Contingency @ 15%			$6,051
				Division Subtotal Check:	$40,342		Subtotal			$47,362
							Overhead & Profit @ 25%			$11,840
							TOTAL			**$59,202**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8” Type X sheetrock and fire taped
- clearing garages of cars and tenants’ possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

Table 5-16 Building 4: Cost Estimate for Scheme 3

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
1	**General Conditions** Subtotal for Division: **$9,291**									
	Personnel:									
	Foreman w/truck & phone. 2 hours/day - 5 weeks.	40	hours	$100	$4,000					$4,000
	Small Tools:	1	lump sum					$500	$500	$500
	Temporary Utilities:									
	Temporary Sanitation	1	months					$125	$125	$125
	Clean - Up:									
	Daily Clean up - 1 man, 1 hr/d	20	hours	$25	$500					$500
	Final Clean up	16	hours	$25	$400					$400
	Flagman	20	hours	$25	$500					$500
	Debris removal:									
	Debris box	2	each			$575	$1,150			$1,150
	Special Inspections:									
	Welding	1	lump sum					$400	$400	$400
	Concrete cylinders	1	lump sum					$600	$600	$600
	Epoxied dowels	6	hours					$93	$558	$558
	Shear panel nailing	6	hours					$93	$558	$558
2	**Sitework** Subtotal for Division: **$6,774**									
	Demolition:									
	Cut and remove 1' strip of ceiling plaster @ walls plus removed soffit. 404 sf.	32	hours	$45	$1,440					$1,440
	Remove interior plaster from shear walls and intersecting walls. 90 x 9 = 810 sf.	32	hours	$45	$1,440					$1,440
	Sawcut, load and haul 6" concrete floor slab. 80 lf. 2 cy.	1	lump sum					$1,914	$1,914	$1,914
	Structural Excavation:									
	Excavate new footing at garage entries.	9	cubic yd.	$70	$630					$630
	Load dump truck (loader)	6	hours					$150	$900	$900
	Haul away dirt (dump truck).	6	hours					$75	$450	$450
3	**Concrete** Subtotal for Division: **$6,372**									
	Reinforcing steel:									
	6 ea #6's t&b w/#5 stirrups @ 12"oc. 40 lf. 1240#. Delivered cages.	1	lump sum					$1,938	$1,938	$1,938
	Place cages in footings	12	hours	$45	$540					$540
	Concrete footing:									
	Place concrete in 2'-6" x 2'-6" footing plus floor slab. 40 lf.	12	cubic yd.	$29	$354	$140	$1,680			$2,034
	Concrete pump	1						$1,600	$1,600	$1,600
	Finish slab on grade:									
	Smooth trowel finish concrete garage slab at top of footing. 3' x 40'.	4	hours	$65	$260					$260

Table 5-16 Building 4: Cost Estimate for Scheme 3 (continued)

Division	Description	Quantity	Unit	Labor Unit Cost	Labor	Material Unit Cost	Material	Subcontractor Unit Cost	Subcontractor	Total
4	**Masonry** Subtotal for Division: **$0**									
5	**Metals** Subtotal for Division: **$3,157**									
	Structural Steel:									
	Steel moment cantilevered columns, 10', 12WF45. 2ea. Delivered.	1	lump sum					$2,237	$2,237	$2,237
	Hang 6 ea steel columns ready for embedment in footings.	12	hours	$60	$720		$200			$920
6	**Carpentry** Subtotal for Division: **$10,314**									
	Rough Carpentry:									
	• Framing @ shear wall plywood joints. Material.	216	board ft.			$1	$227			$227
	• Framing @ shear wall plywood joints. Labor.	6	hours	$60	$360					$360
	• Shear wall sheathing. Struc 1 plywood.	756	sq. ft.	$1	$945	$1	$680			$1,625
	• Soffit sheathing. Struc 1 plywood.	320	sq. ft.	$2	$480	$1	$288			$768
	• Collector beam and connections to floor above @ door opening head. 2 ea 2x12, 40 lf.	160	board ft.			$2	$304			$304
	• Collector beam and connections to floor above @ door opening head. Labor	14	hours	$60	$840					$840
	• Drill and epoxy anchor bolts & rebar dowels.	46	each	$35	$1,610	$45	$2,070			$3,680
	• Drill and epoxy hold downs w/4x6 post	10	each	$70	$700	$110	$1,100			$1,800
	• Clips to framing above shear walls.	84	linear ft.	$3	$290	$5	$420			$710
7	**Moisture Protection** Subtotal for Division: **$1,134**									
	Insulation:									
	Batt insulation in new exterior shear walls.	756	sq. ft.	$1	$378	$1	$756			$1,134
8	**Doors, Windows, & Glass** Subtotal for Division: **$0**									

Table 5-16 Building 4: Cost Estimate for Scheme 3 (continued)

Division	Description	Quantity	Unit	Labor		Material		Subcontractor		Total
				Unit Cost	Labor	Unit Cost	Material	Unit Cost	Subcontractor	
9	**Finishes** Subtotal for Division: **$2,750**									
	Plaster:									
	Patch openings in ceilings.	404	sq. ft.					$3	$1,212	$1,212
	Drywall:									
	Cover shear walls, 5/8 type x, fire taped.	756	sq. ft.					$2	$1,134	$1,134
	Painting:									
	Plaster soffit, seal and 2 coats.	404	sq. ft.					$1	$404	$404
10	**Specialties** Subtotal for Division: **$0**									
11	**Equipment** Subtotal for Division: **$0**									
12	**Furnishings** Subtotal for Division: **$0**									
13	**Special Construction** Subtotal for Division: **$0**									
14	**Conveying Systems** Subtotal for Division: **$0**									
15	**Mechanical** Subtotal for Division: **$0**									
16	**Electrical** Subtotal for Division: **$0**									
				Subtotal:	$16,386		$8,875		$14,530	$39,792
				Subtotal Check:	$39,792		Permits @ 2.4%			$955
							Contingency @ 15%			$5,969
				Division Subtotal Check:	$39,792		Subtotal			$46,715
							Overhead & Profit @ 25%			$11,679
							TOTAL			**$58,394**

Items not included in estimates:

- relocating any conflicting utilities
- painting new shear walls: walls are not painted, but instead are covered with 5/8” Type X sheetrock and fire taped
- clearing garages of cars and tenants’ possessions before construction
- no code upgrade construction for remainder of building
- costs are current for November, 2008; there is no allowance for inflation

APPENDIX 6: PROCEDURES TO EVALUATE SEISMIC HAZARDS

6.1 Seismic Setting

San Francisco is in the Coast Ranges geomorphic province that is characterized by northwest-southeast trending faults. San Francisco lies between the San Andreas fault zone to the west and the Hayward fault zone to the east, as shown on Figure 6-1. The major active faults near San Francisco are the San Andreas, Hayward, San Gregorio, Rodgers Creek and Calaveras faults. In 1999, the Working Group on California Earthquake Probabilities (WGCEP) at the U.S. Geologic Survey (USGS) predicted a 70-percent probability of a magnitude 6.7 or greater earthquake occurring in the San Francisco Bay Area by the year 2030. More specific estimates of the probabilities for different faults in the Bay Area are presented in Table 6-1.

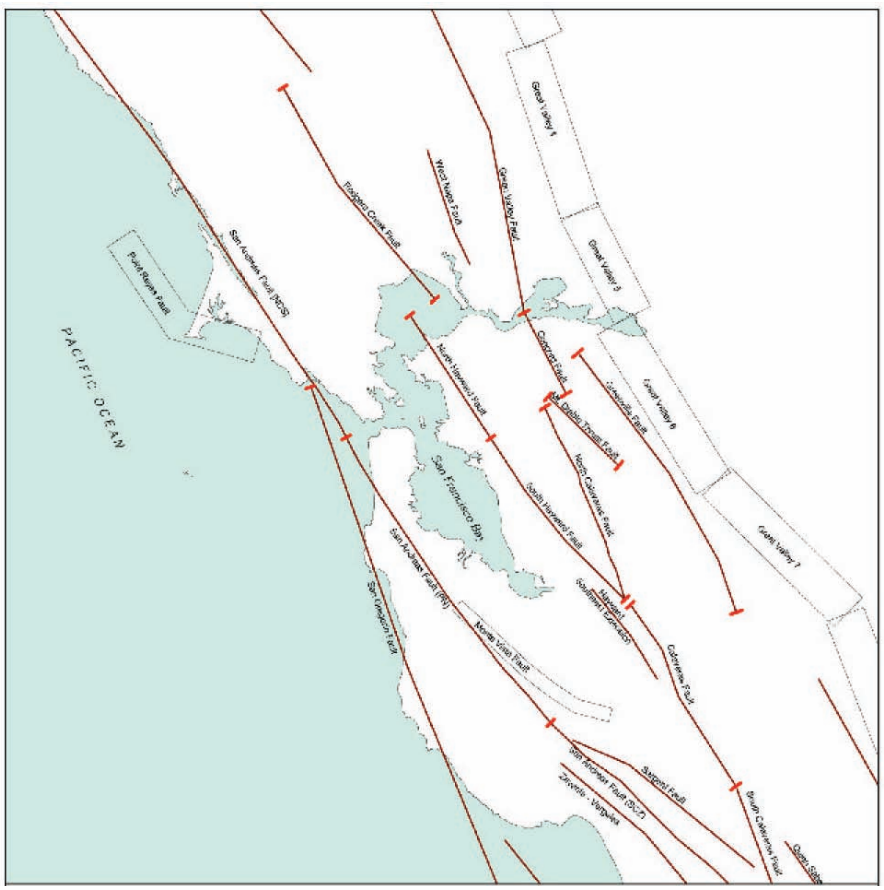


Figure 6-1 *Map of major faults in the San Francisco bay area (Source: Treadwell & Rollo).*

Table 6-1 WGCEP (1999) Estimates of 30-Year Probability (2000 to 2030) of a Magnitude 6.7 or Greater Earthquake

Fault	Probability (percent)
Hayward-Rodgers Creek	32
San Andreas	21
Calaveras	18
San Gregorio	10
Concord-Green Valley	6
Greenville	6

The Hayward, San Andreas and Calaveras fault systems have the highest probabilities of generating a magnitude 6.7 or greater earthquake before 2030. Because the San Andreas and Hayward fault systems are closer to San Francisco and have the highest probabilities, these faults pose greatest threat in terms of levels of ground shaking in San Francisco.

6.2 San Andreas Fault System

The dominant fault structure in the coastal California region is the San Andreas fault system. The San Andreas fault extends from the Mendocino Coast in Northern California to the Gulf of California, Mexico. Since 1800, four major earthquakes have been recorded on the San Andreas fault in the Bay Area. In 1836 an earthquake with an estimated maximum intensity of VII on the Modified Mercalli Intensity (MMI) scale occurred east of Monterey Bay on the San Andreas fault (Toppozada and Borchardt, 1998). The estimated magnitude for this earthquake is about 6¼. In 1838, an earthquake occurred with an estimated intensity of about VIII-IX (MMI), corresponding to a magnitude of about 7½. The San Francisco earthquake of 1906 caused the most significant damage in the history of the Bay Area in terms of loss of lives and property damage. This earthquake created a surface rupture along the San Andreas fault from Shelter Cove to San Juan Bautista, approximately 470 kilometers in length. It had a maximum intensity of XI (MMI), a magnitude of about 7.9 (Wallace, 1990), and was felt 560 kilometers away in Oregon, Nevada, and Los Angeles. The most recent earthquake to affect the Bay Area was the Loma Prieta earthquake of October 17, 1989, in the Santa Cruz Mountains with a magnitude of 6.9. Although there is some debate as to which fault the Loma Prieta earthquake occurred on, it possibly occurred on the San Andreas fault.

The northern San Andreas fault is subdivided into four fault segments. Each of these segments is capable of rupturing either independently or in conjunction with adjacent segments. These segments include the North Coast North, North Coast South, Peninsula and the San Cruz Mountains segment. The 1906 earthquake ruptured these four segments. The closest segment to San Francisco is the Peninsula segment. For a repeat of a 1906-type event on the San Andreas fault, magnitude 7.94 earthquake, the WGCEP (1999) calculated a recurrence interval of 361 years. They assigned a maximum magnitude earthquake of 7.2 to the Peninsula segment, with a 21 percent probability of a magnitude 6.7 or larger earthquake in the time period from 2000 to 2030 on this segment of the San Andreas fault.

6.3 Hayward Fault

The Hayward fault extends from Mount Misery, east of San Jose, to Point Pinole on San Pablo Bay. It is divided into two segments: the northern and southern Hayward fault. They are 35 and 52 km in length, respectively. The Rodgers Creek fault is the northern continuation of the Hayward fault. In 1868 an earthquake with an estimated maximum intensity of X on the MMI scale occurred on the southern segment (between San Leandro and Fremont) of the Hayward fault. The estimated magnitude for the earthquake is 6.9.

The WGCEP (1999) estimated the highest probability of the next magnitude 6.7 or greater earthquake in the Bay Area on the Hayward-Rodgers Creek fault system, with a 32 percent probability in the time period from 2000 to 2030. The WGCEP has assigned a maximum magnitude of 6.63 and 6.88, with corresponding recurrence periods of 387 and 371 years to the northern and southern segments, respectively. The WGCEP also assigned a maximum magnitude of 7.1 for a rupture of the total Hayward fault (north and south segments) with a recurrence time of 523 years.

6.4 Estimation of Ground Motions

To estimate the ground motion during an earthquake at each intersection in San Francisco, a deterministic analysis was performed using four scenario earthquakes. 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). 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.

6.5 Scenario Earthquakes

The four scenario earthquakes considered in this study are:

1. 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 361 years (WGCEP, 1999). For comparison, the 1998 *San Francisco Building Code* definition of Design Basis Earthquake is 10 percent probability of exceedance in 50 years, which is equivalent to a 475-year return period.
2. 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).
3. A moment magnitude 6.5 on the Peninsula segment of the San Andreas fault. The WGECP estimates a 21 percent probability of a magnitude 6.7 or greater earthquake occurring on the San Andreas in the next 30 years.
4. A magnitude 6.9 on the Hayward fault.

6.6 Attenuation Relationships

We used three recent spectral attenuation relationships for estimating spectral accelerations in this study. They are:

- Abrahamson and Silva (1997);

- Campbell (1997); and
- Sadigh *et al*. (1997).

Each of these attenuation relationships provides 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, for the sake of consistency.

6.7 Amplification of Ground Shaking—Local Site Conditions

Amplification of ground shaking to account for local site conditions is based on the site classes and soil amplification factors proposed for the *1997 NEHRP Provisions for Seismic Regulations for New Buildings and Other Structures (NEHRP Provisions).* The classification is based on the average shear wave velocity of the upper 30 meters of the local Geology, as shown in Table 6-2.

The United States Geological Survey (USGS) has developed a map of the San Francisco Bay Area, which delineates the site class types based on the NEHRP classification (ArcInfo files were downloaded from the USGS site at samoa.wr.usgs.gov). Figure 6-2 presents site classes for the City and County of San Francisco.

Table 6-2 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

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 proposed for use 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; these values were then adjusted using the NEHRP soil amplification values for site class E, as presented in Table 6-3.

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 HAZUS®99-SR1 Technical Manual.

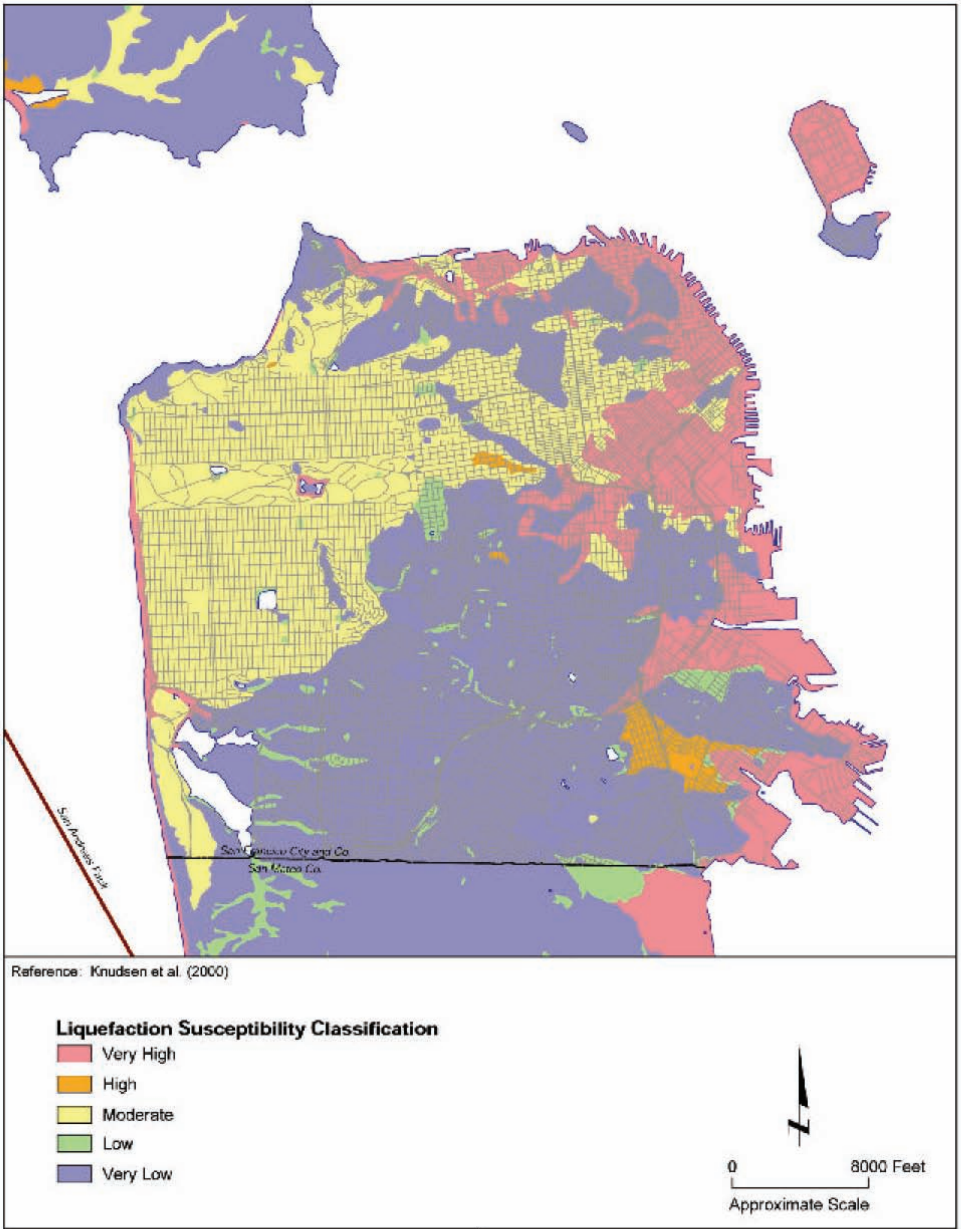


Figure 6-2 Liquefaction susceptibility map of San Francisco (Source: Treadwell & Rollo).

Table 6-3 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*

6.8 Liquefaction Susceptibility

Liquefaction is a phenomenon in which 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) have 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 are not considered to pose a liquefaction hazard.

Peak ground acceleration (PGA) value is used to evaluate liquefaction potential. We used a qualitative approach to evaluate liquefaction potential. Table 6-4 presents general estimates of the threshold PGA required to trigger liquefaction for each of the liquefaction susceptibility ratings, as discussed by Knudsen et al. (2000). The PGA's that are presented in Table 6-4 are estimates only and are provided to indicate relative levels of shaking necessary to liquefy different geologic units. Figure 6-3 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 exceeds the threshold PGA, the area was designated as liquefiable. 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 may be needed in designating certain areas of the City as liquefiable for a particular earthquake scenario.

Table 6-4 Threshold PGA Required to Trigger Liquefaction

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

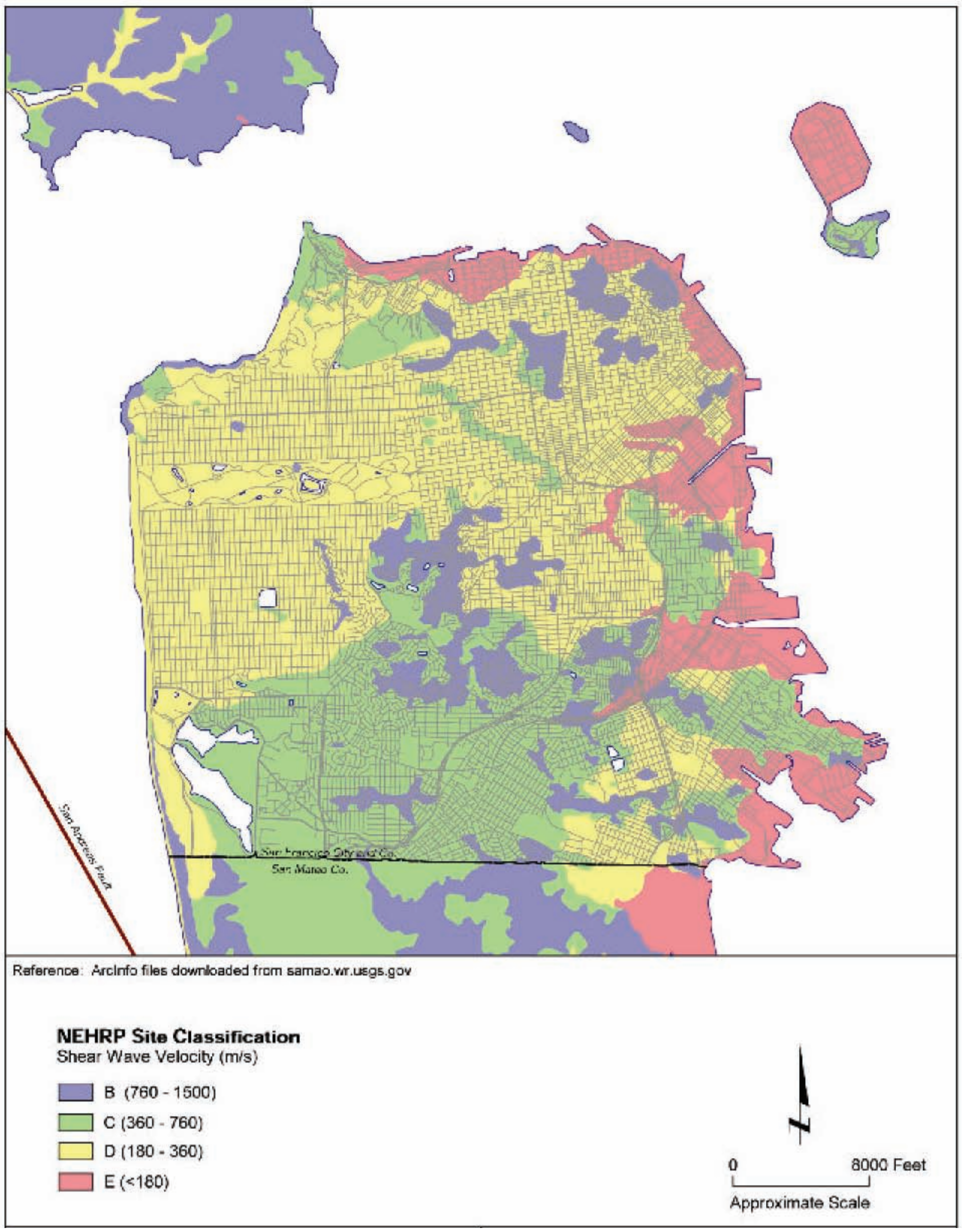


Figure 6-3 NEHRP site classification map of San Francisco. (Source: Treadwell & Rollo).

APPENDIX 7: COMPONENT FRAGILITY FUNCTIONS FOR OLDER WOOD-FRAME CONSTRUCTION

7.1 Executive Summary

Fragility functions for older (pre-1940), large, soft-story wood-frame dwellings were developed based on laboratory tests and post-earthquake observations for use in a study for the City of San Francisco's Community Action Plan for Seismic Safety (CAPSS). The functions are expressed in terms of San Francisco Planning and Urban Research Association (SPUR) performance categories A, B, C, D, and E, which equate with ATC-20 post-earthquake safety evaluation (ATC-1989) green, yellow, and red tag (placard) colors and HAZUS®-MH damage states, as shown in Table 7-1. Drifts associated with green and yellow tags were estimated using laboratory testing of common building components. The drift at which red-tagging occurs was estimated either from drift at which straight sheathing reaches ultimate strength (nails severely deformed), or from estimates by Deierlein (personal communication) of the transient drift (5%) at which wood-frame buildings experience 2% residual drift. Collapse was estimated using two approaches: (1) based on a fraction of square footage in the complete structural damage state (the HAZUS®-MH approach), or (2) based on a survey of corner apartment buildings in the Marina District by Harris and Egan (1992) after the 1989 Loma Prieta earthquake. For each damage state, Table 7-1 shows a range of median drift capacities interpreted from the evidence. Figure 7-1 illustrates fragility functions, estimated by different methods, for the various damage states shown in Table 7-1.

Table 7-1 Comparison of Various Damage State Characterizations and Estimates of Building Drift Capacities

Damage State				Spectral Displacement, Inches	
SPUR		ATC-20 tag	HAZUS®	Median S_d	β
A	Safe and operational	Green	Slight	0.06 - 0.4	1.0
B	Safe and usable during repair	Green	Moderate	0.4 - 1.5	1.0
C	Safe and usable after repair	Yellow	Extensive	1.5 - 3.0	1.0
D	Safe but not repairable	Red (no collapse)	Complete	3.0 - 5.0	1.0
E	Partial or complete collapse	Red (collapse)	Collapse	(a) - 13	0.6

Notes:
(a) lower-bound uses standard HAZUS®-MH approach for collapse

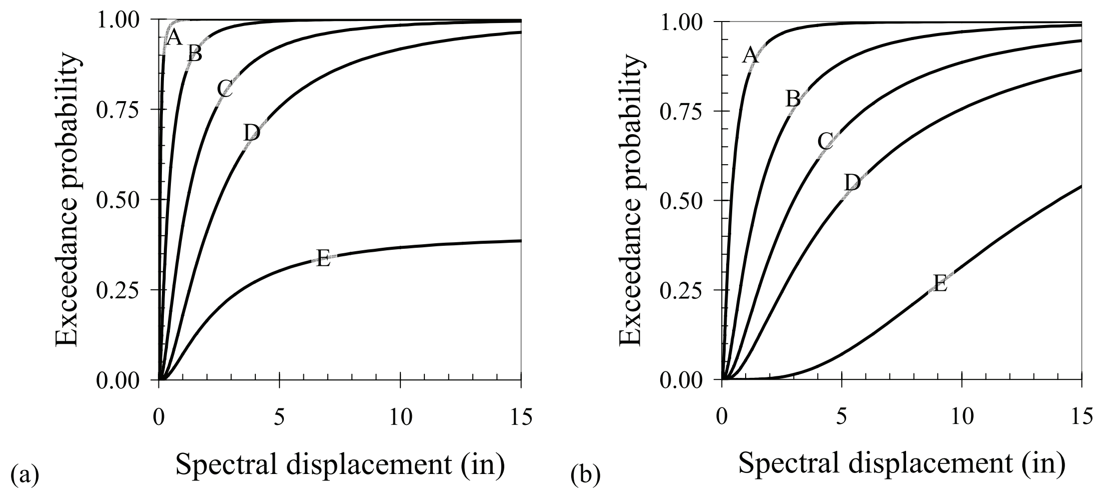


Figure 7-1 CAPSS soft-story fragility functions (a) using the lower spectral displace, S_d, values interpreted from tests and a HAZUS®-MH approach to collapse, and (b) using the larger S_d values from tests and using earthquake evidence of collapse fragility. See Table 7-1 for definitions of A, B, C, D, and E.

7.2 Objectives and Scope of Work

Soft-story wood-frame buildings in California have been observed to be particularly susceptible to collapse in earthquakes. This report proposes fragility information for use in estimating seismic risk to wood-frame, multifamily dwellings at least three stories tall, with at least five housing units and with soft-story conditions on the ground floor. This type of construction is of particular concern to the City of San Francisco. Several buildings of this type collapsed in the 1989 Loma Prieta earthquake, killing several people. Soft-story wood-frame buildings represent an ongoing concern, especially since a larger or closer rupture of the northern San Andreas fault could cause far greater damage than did the 1989 Loma Prieta earthquake, and it seems realistic to assume that these older, multifamily wood-frame dwellings with a soft-story at ground level would be particularly heavily damaged. Furthermore, there are so many buildings of this type in San Francisco that a larger or closer earthquake might eliminate a large fraction of San Francisco's housing.

CAPSS is estimating the risk posed by older soft-story wood-frame multifamily dwellings by creating models of four representative Index Buildings, and analyzing their seismic vulnerability as-is and under one or more practical seismic retrofit options. For various reasons, for this analysis of wood-frame buildings, the CAPSS project team is using the HAZUS®-MH methodology (FEMA 2003a) as encoded in the "Cracking an open safe" approach of Porter (2009c). This approach requires developing pushover curves and component fragility functions through the following tasks:

1. Identifying common building components of buildings constructed in this era and developing fragility functions for them, i.e., relationships between component forces or deformation and the probability of various levels of damage to those components;
2. Developing seismic vulnerability relationships for these buildings, i.e., relating overall repair cost as a fraction of replacement cost (new structure) to spectral acceleration response; and

3. Selecting or designing a loss-estimation methodology, performing the loss calculations, and presenting the methodology and results in meetings and in a written report.

The study described in this appendix addresses the first of these tasks.

7.3 Background on HAZUS®-MH

Like other second-generation performance-based earthquake engineering analyses, HAZUS®-MH (FEMA, 2003a) uses fragility functions for damageable building components as one important aspect of its assessment. These fragility functions relate the probability of various levels of physical damage to a structural response parameter, such as peak transient interstory drift or peak floor acceleration. In HAZUS®-MH and the ongoing FEMA-funded ATC-58 project, which seeks to bring second-generation performance-based earthquake engineering analyses to professional practice, such fragility functions are typically expressed in the form of lognormal cumulative distribution functions, i.e.,

$$P\left[D \geq d \middle| R = r\right] = \Phi\left(\frac{\ln\left(r/\theta\right)}{\beta}\right) \tag{1}$$

where *D* denotes a number that refers to the uncertain damage state of a given component; *d* denotes a particular value of *D*; *R* denotes the demand to which the component is subjected (generally a measure of structural response, i.e., a member force or deformation); *r* is a particular value of *R*; Φ is the cumulative standard normal (Gaussian) distribution function, and; θ and β are its parameters, referred to here as the median capacity and logarithmic standard deviation of capacity, respectively. A fragility function is completely defined by identifying the component to which it refers; defining the damage state in question, generally in terms of the repair efforts required to restore it to the undamaged state; defining the demand parameter *R*, and; by fixing the values of θ and β. Methods to derive these values from experimental data or other empirical observations are detailed in Porter et al. (2007).

HAZUS®-MH considers only two structural response parameters: spectral displacement (denoted by S_d) and spectral acceleration (S_a) at the performance point in a capacity-spectrum-method (pushover) structural analysis. The pushover curve in a HAZUS®-MH analysis has a linear part from the origin to yield (denoted by *Dy,Ay*), a perfectly plastic portion beyond the ultimate point (denoted by *Du,Au*), and an elliptical transition between the two, as illustrated in Figure 7-2. Beyond yield, hysteretic energy dissipation adds to elastic damping, so effective damping exceeds elastic. The point on the pushover curve where it intersects an idealized response spectrum (essentially a constant-acceleration segment and a constant-velocity segment) with the same effective damping ratio is the performance point, (D^*, A^*), for that earthquake. The parts of the building that are assumed to be primarily sensitive to displacement use D^* as the response parameter *r* in Equation (1); these parts are the structural components and parts of the nonstructural systems such as veneer, nonbearing walls, and partitions. The parts of the building that are assumed to be acceleration-sensitive use A^* as the parameter *r*: these parts include building contents, parapets, and most building service equipment.

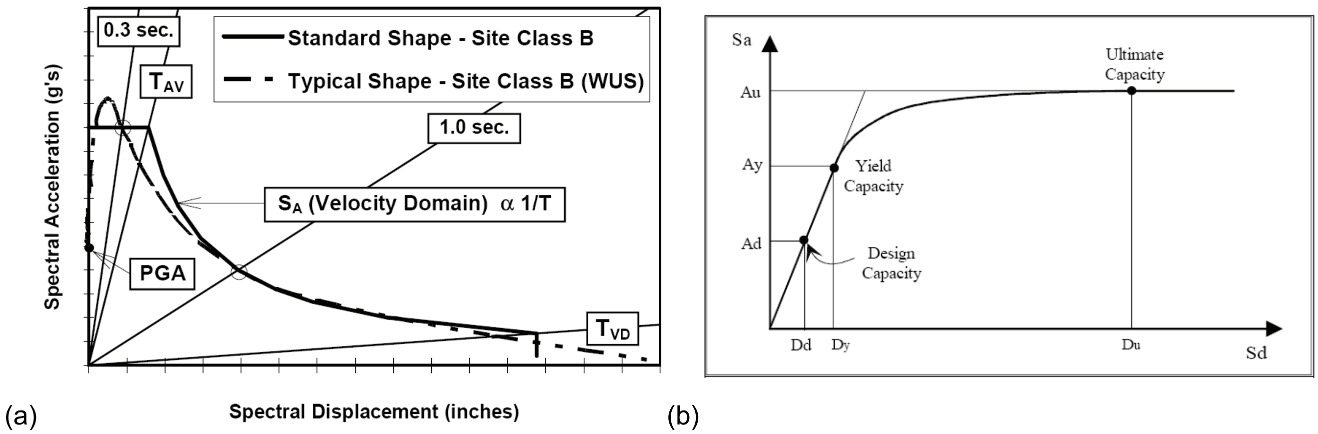


Figure 7-2 HAZUS®-MH standard response spectrum shape and capacity curve (FEMA, 2003a).

HAZUS®-MH considers only three aggregate components: the structural system (drift-sensitive), drift-sensitive nonstructural components, and acceleration-sensitive nonstructural components. Each of these components is taken as being in one of several damage states: slight, moderate, extensive, complete, and, for the structural component, collapse. The damage states are defined qualitatively but are associated with the mean damage factors (repair cost as a fraction of the total facility replacement cost) shown in Table 7-2. The three components need not be in the same damage state, so the sum and inferred range of the damage factors (shown in columns 5 and 6 of the table) simply gives a sense of the damage state; still, these sums and inferred ranges are useful for comparison with the damage states of ATC-13 (ATC, 1985), which give the damage factors for its damage states listed in Table 7-2. The table is significant, because it implies that HAZUS's "complete" damage state approximately equates with ATC-13's damage state 6, Major, while HAZUS collapse equates with ATC-13 damage state 7, Destroyed. These points will become relevant later.

Table 7-2 HAZUS®-MH and ATC-13 Damage States and Damage Factors

Damage State	Structural	Nonstructural Drift-Sensitive	Nonstructural Acceleration-Sensitive	Sum	Inferred Range	Equivalent ATC-13 Damage States	ATC-13 Range
Slight	0.003	0.009	0.008	0.02	0 - 0.05	2-3, Slight to Light	0 - 0.10
Moderate	0.014	0.043	0.043	0.10	0.05 - 0.20	3-4, Light to Moderate	0.01 - 0.30
Extensive	0.069	0.213	0.131	0.41	0.20 - 0.60	4-5, Moderate to Heavy	0.10 - 0.60
Complete	0.138	0.425	0.437	1.00	0.60 - 1.00	6. Major	0.60 - 1.00
Collapse	0.138	0.425	0.437	1.00	1.00	7. Destroyed	1.00

The probabilistic damage state of each component is estimated using fragility functions in the form of lognormal cumulative distribution functions, each involving two parameter values: median and logarithmic standard deviation of the distribution. The HAZUS®-MH documentation offers a library of fragility functions for these three components, for each of four to five damage states and each of 128 different combinations of structure type and code era. That library is designed for societal-level risk assessment, rather than reflecting the detailed behavior of particular subcategories of dwellings. It treats all large wood-frame buildings (>5000 sq. ft., as in the typical large multifamily dwelling dealt with here) with four structure types: W2 pre-code, low code, moderate code, and high code. Most of the buildings examined here would be considered W2 pre-code. Thus, HAZUS®-MH may not provide adequate fragility information to distinguish the damageability of, for example, soft-story versus non-soft-story or brick-veneer vs. straight-sheathed buildings. The developers offer the Advanced Engineering Building Module (FEMA, 2003b) to handle such cases, but the user is required to provide the relevant fragility parameters.

Therefore, to ensure that the behavior of these particular buildings was modeled appropriately for this CAPSS study, it was necessary to develop new fragility functions that reflect the behavior of the components that probably dominate the building's force-deformation behavior, damage, and life-safety impacts. Considering the common features of this category of construction, and the likelihood that the wood-frame walls dominate the response, damage, and loss, it was necessary to create fragility functions for the categories of wall listed in Table 7-3.

Table 7-3 Wall Categories Examined in This Study

Type	Description
Straight Sheathed	2x4 full-sawn redwood studs @ 16 inches on center, toe-nailed to top and bottom plates, 1x12 horizontal straight sheathing, three 8d nail each board each stud
Stucco	Straight sheathed + 3/4-inch stucco
Brick Veneer	Straight sheathed + brick veneer (1 wythe of full bricks), flexible anchors
Wood Lath & Plaster	Wood lath and plaster interior sheathing

These wall categories needed to be associated with one of the three component categories of HAZUS®-MH. The straight sheathing is purely structural. The lath and plaster and the stucco might be considered either structural or nonstructural drift-sensitive. The brick veneer can be considered nonstructural drift-sensitive.

The fragility functions developed in this study needed to relate the spectral displacement to damage states expressed by SPUR (2008) for the post-earthquake condition of the building after the "expected" earthquake, i.e., an event producing shaking with 10% exceedance probability in 50 years. Table 7-4 provides the SPUR performance categories and descriptions.

7.4 Tests of Straight Sheathing

Little testing data that addresses the fragility of these components appears to exist, with three notable exceptions. Trayer (1956) reports on racking tests of various contemporary wood-frame wall specimens. Each specimen was approximately 9-feet high and 14-feet long, with 2x4 studs of No. 1 common well-seasoned southern yellow pine at 16-inch centers with 2x4 top and bottom plates of the same material and a double stud at each end. Each plate was connected to each stud with two 16d common nails through the plate into the ends of the studs. No vertical load was applied to the wall; to prevent overturning, hold-down rods connected the top plate to

Table 7-4 SPUR (2008) Performance Categories

Label	Description	Tag*
A	*Safe and Operational.* This defines a performance standard now in place and used for new essential facilities such as hospitals and emergency operations centers. Buildings will experience only very minor damage and will have energy power, gas, water, wastewater, and telecommunications systems to back-up any disruption to the normal utility services.	Green
B	*Safe and usable during repair*. This defines a new performance standard that is needed for buildings that will be used to shelter-in-place and for some emergency operations. Buildings will experience damage and disruption to their utility services, but no significant damage to the structural system. They may be occupied without restriction and are expected to receive a green tag (INSPECTED placard, building inspected and deemed safe for occupancy) after "expected" earthquake.	Green
C	*Safe and usable after repair.* This is the current minimum design standard for new, non-essential buildings. Buildings may experience significant structural damage that will require repairs prior to resuming unrestricted occupancy and therefore are expected to receive a yellow tag (RESTRICTED USE placard, building inspected and found to be damaged with restricted access) after "expected" earthquake.	Yellow
D	*Safe but not repairable.* This level of performance is below the standard accepted for new, non-essential buildings, but is often used as a performance goal for existing buildings undergoing voluntary rehabilitation. Buildings may experience extensive structural damage and may be on the verge of collapse. They will need to be demolished as soon as possible and therefore, are expected to receive a red tag (UNSAFE placard, building inspected, found to be seriously damaged and unsafe to occupy) after "expected" earthquake.	Red (No Collapse)
E	*Unsafe: Partial or complete collapse.* Damage that will likely lead to significant casualties in the event of an "expected" earthquake. These are the "killer" buildings that need to be addressed by a mandatory seismic mitigation program.	Red (Collapse)

* ATC-20 placard color

the testing floor on either side of the test specimen 1 to 2 feet from the end of the specimen. The specimen was subjected to in-plane, pseudostatic loading by a force applied along the axis of the upper plate (Figure 7-3). The manner of measuring the force is unclear. Displacement was measured by observing the displacement of the top plate relative to a fixed vertical line.

The author reports tests to 50 specimens with and without openings, and with various finishes, two of which are relevant here. One finish was horizontal straight sheathing on one side with square-edged 1x8, also of the same material, nailed with two 8d nails at each stud crossing. The author does not report any observations of physical damage to these specimens: for example, no mention of nail pullout, nail tear through, or splitting of framing members. There is no indication on the force-deformation curve of a sudden physical change, from which one might infer a particular damage state, and there are no observations related to unloading or residual displacement after unloading. The only indication of a particular damage state is the point of ultimate strength, where connections begin to lose strength. This is reported to occur at a drift of approximately 3 inches, or a drift ratio of 2.8%.

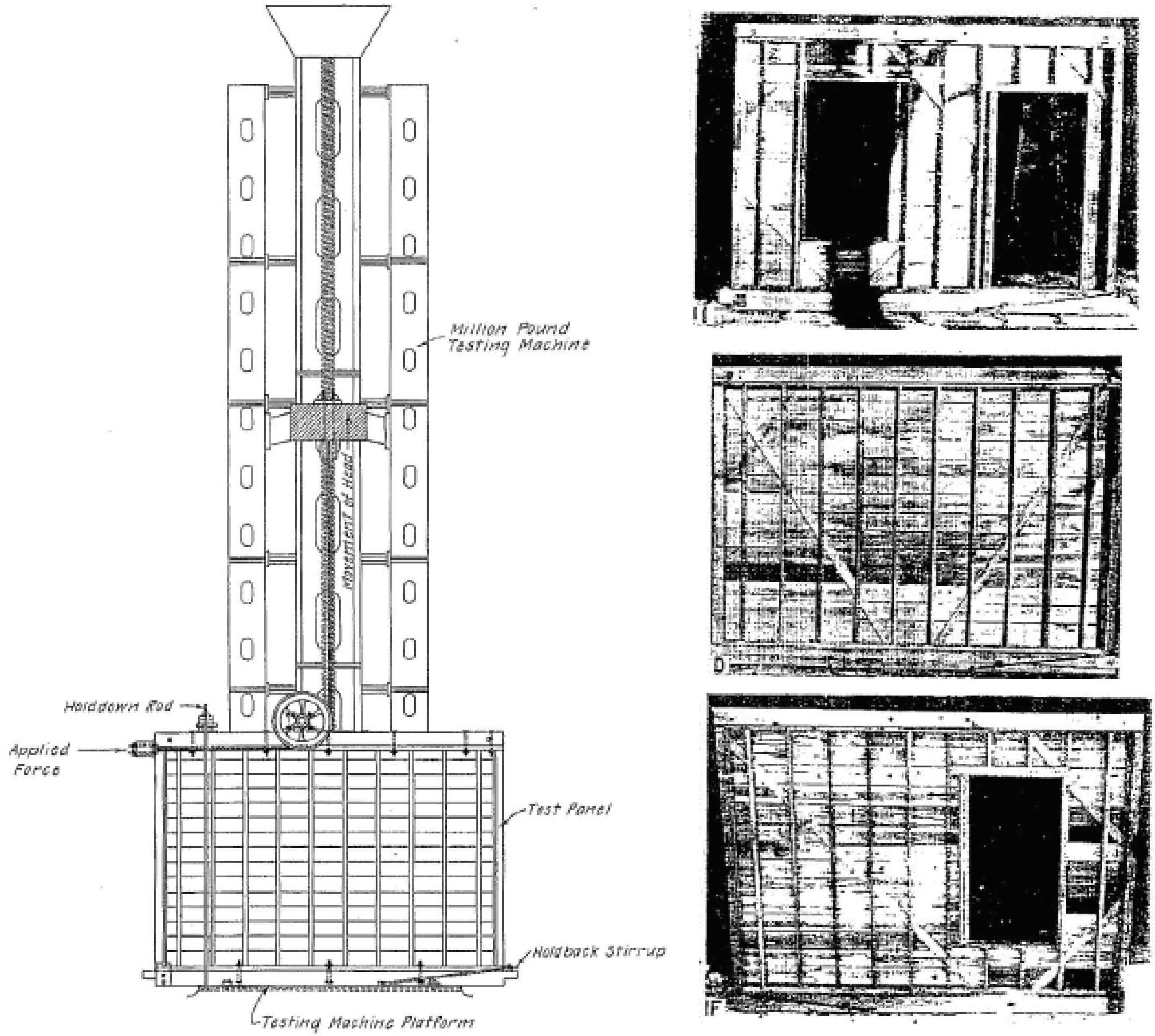


Figure 7-3 Test setup and some specimens discussed by Trayer (1956).

Trayer (1956) reports that the tests also included 6-inch straight sheathing, and 8-inch sheathing with three 8d nails at each board and stud crossing, and that both stiffness and strength were largely unchanged by these variations., He explains this by pointing out that it is the bending stiffness of the nail and the lever arm between the two adjacent nails that provide the wall's stiffness and strength. Adding a third nail in the middle of the board at the stud crossing adds neither to stiffness nor strength, as that is the neutral axis. Although with 6-inch boards, the lever arm between nails is reduced, there are proportionately more boards, and therefore more nails, for a given height of wall.

More recently, Elkhoraibi and Mosalam (2007a, b) report on full-scale dynamic tests of a two-story house and two wood-frame wall specimens with straight sheathing

(Figure 7-4). The former was tested on a shake table and the latter, by hybrid simulation and representing the lower-floor longitudinal walls of the prototype house. In hybrid simulation, the behavior of the rest of the (generally well-understood) building is computationally simulated, with force or displacements imposed dynamically on the physical substructure whose characteristics are of interest. The response of the real specimen is fed back into the computation model in real or near-real-time. The specimens are constructed of 2x4 studs at 16 inch centers, end-nailed to the double 2x4 top plate with 2-16d common nails and toe-nailed to a 3x6 sill plate with 3-16d common nails. The straight sheathing is 1x12 shiplap siding, with 3-8d common nails per board at each stud crossing. The walls are braced by V-shaped 2×4 diagonal blocking between studs (2–16d toe common nails). All lumber is Douglas Fir-Larch.

The authors' focus is not on specimen damageability but rather on a procedure for switching between force and deformation control for input to the real specimen. Limited damage data are presented. From a sample force-deformation plot that the authors provided (Figure 7-5), it appears that the combined specimens reach an ultimate-strength limit state near the end of the largest negative cycle, near 3 inches of drift (3% drift), similar to the 2.8% drift at ultimate observed by Trayer (1956) in tests of 1x8 straight-sheathed walls. They observed connection failure in the braces shown in Figure 7-6, and confirm that the deformation is accommodated by bending of the nail at the interface between the sheathing and framing.

Figure 7-4 Straight-sheathed house prototype and specimens representing the lower floor longitudinal wall tested in hybrid simulation by Elkhoraibi and Mosalam (2007).

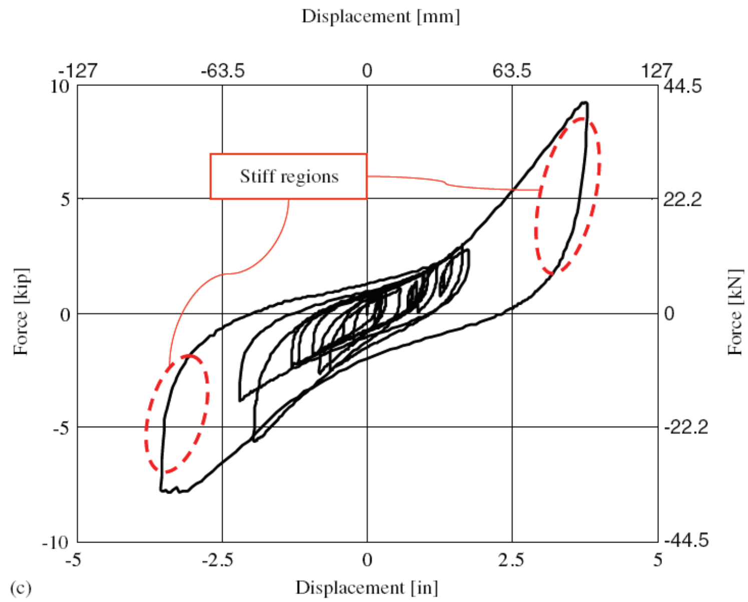


Figure 7-5 Force deformation response from hybrid simulation of the specimen shown in Figure 7-4 (Elkhoraibi and Mosalam 2007).

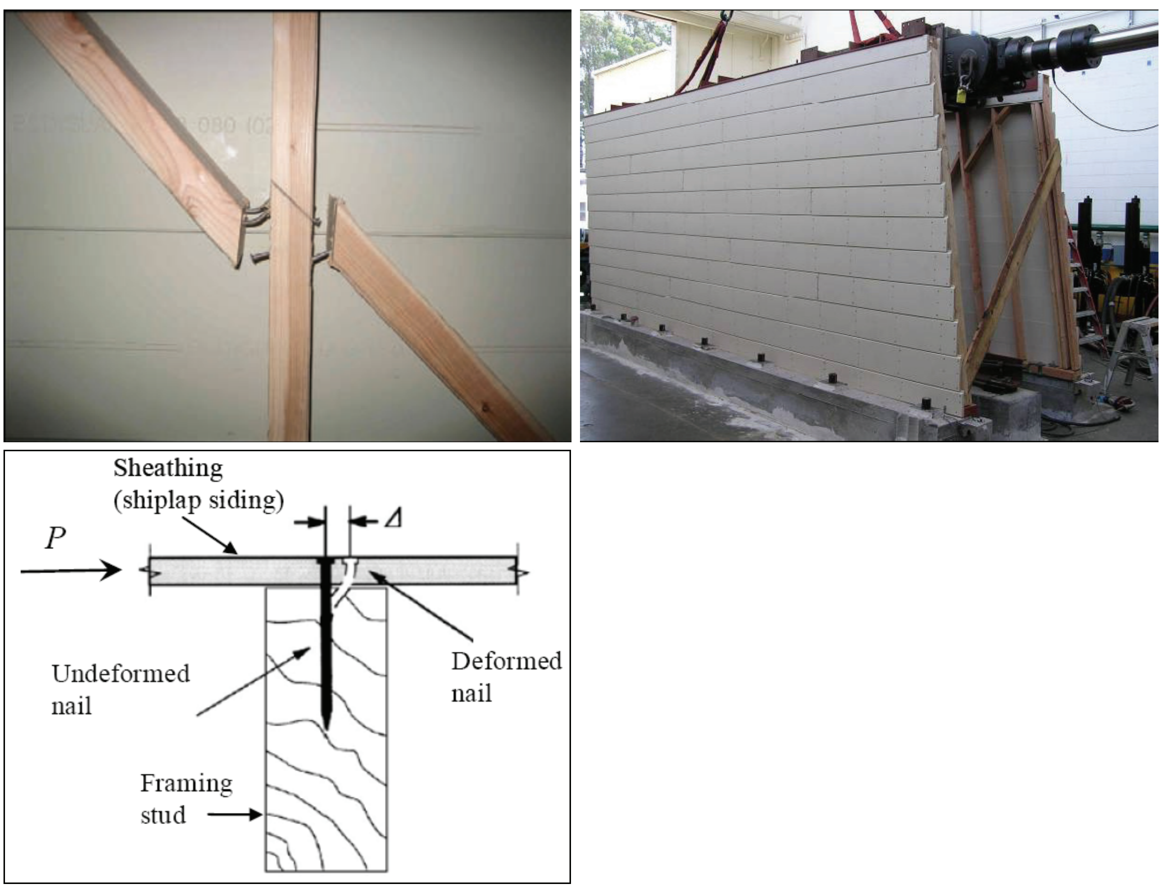


Figure 7-6 Damage and deformed shape observed in hybrid simulation tests by Elkhoraibi and Mosalam (2007).

7.5 Tests of Wood Lath and Plaster

Trayer (1956) also reports on the performance of wood lath and plaster: 4-foot horizontal boards nailed to studs with 3d nails and with a ¼-inch vertical gap between each lath course. A ¾-inch ground coat was applied, along with a finish coat of unspecified thickness. Wall testing was performed after one week of aging. Lath and plaster ceilings tend to crack after about 35 to 45 years and continue to deteriorate until they need replacement, after about 80 to 100 years, but lath and plaster walls are usually dependable for 100 to 120 years or more. Therefore, 1956 tests of new walls are probably appropriate to the fragility of 70-year-old walls.

Trayer (1956) reports that walls with openings tended to develop cracks at the corners of openings, when the drift reached "a few hundredths of an inch." This is consistent with the statement that cracks developed when in-plane loading reached 800 to 1300 lb in a specimen with an in-plane shear stiffness of 12.9 kip/in (secant stiffness measured at 0.1 in displacement), indicating cracking drift ratios between 0.057 to 0.093% peak transient drift. One could associate that damage state with the requirement to re-plaster corners of openings and to repaint the room. Another limit state is reported: a sudden drop in load as displacement increases, which occurs in the walls with openings at displacements of 0.75 to 1.5 in (0.69 to 1.39% drift). Also reported is that in panels with both plaster and wood sheathing, "The plaster was badly cracked under distortions of less than an inch."

In walls without openings, Trayer (1956) states that cracking initiated at drifts of 9.9 to 10.8 kip, which appears to relate to a peak transient drift of 0.4 to 0.6 in, or a drift ratio of 0.37 to 0.56%.

In another study, Schmid (1984) performed *in situ* in-plane cyclic racking tests of two lath and plaster wall specimens without openings in an existing Los Angeles building. Each specimen (Figure 7-7) was 8-foot by 8-foot, cut from the structure on its ends and top edge by removing a 1-foot-6-inch segment of wall at each end and a 1-foot-4-inch segment of the wall at the top edge below the girder above. Force was imposed by operating one of two calibrated hydraulic jacks inserted at the level of the top plate at each end of the specimen, reacting with the adjacent 8x8 column. Displacement was measured by observing dial indicators accurate to 0.001 inch. At least six load reversals were imposed, as illustrated in Figure 7-8.

Schmid (1984) reports that cracks appeared in the plaster of specimen 1 at displacements of 0.445 in and -0.407 in (0.46 and 0.42%, respectively), and in specimen 2 at displacements of 0.246 and -0.196 in (0.26 and 0.20%, respectively). Specimen 2 differed from specimen 1, in that it had an existing crack. Ultimate strength was reached in specimens 1 and 2 at 1.56 in and 1.30 in (1.62 and 1.35%), respectively. Readily available images of the specimens after testing are of poor quality, having been duplicated and scanned, but Figure 7-9, from Schmid (1984), should give a sense of the ultimate-strength limit state. Lath and plaster test results from Trayer (1956) and Schmid (1984) are recapped in Table 7-5.

7.6 Tests and Observations of Masonry Veneer

Figure 7-10 shows several instance of masonry veneer fallen from straight-sheathed wood-frame walls in various earthquakes. In each case, the masonry appears to have been self-supporting and anchored to the wall either by flexible metal connectors or by nails, with a gap of 1-2 inches between the sheathing and the wall.

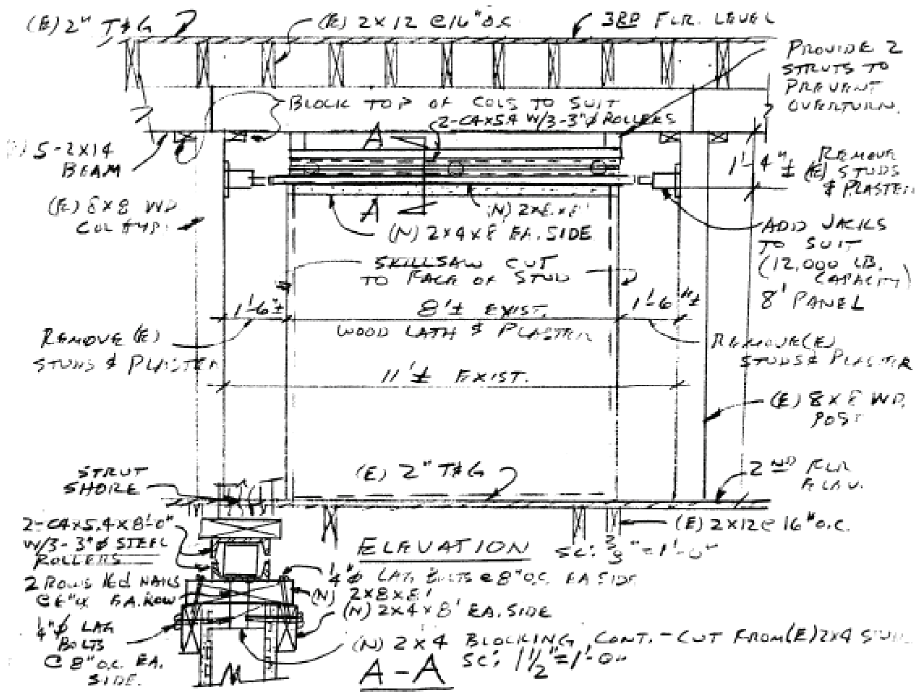


Figure 7-7 In situ testing of lath and plaster walls (Schmid, 1984).

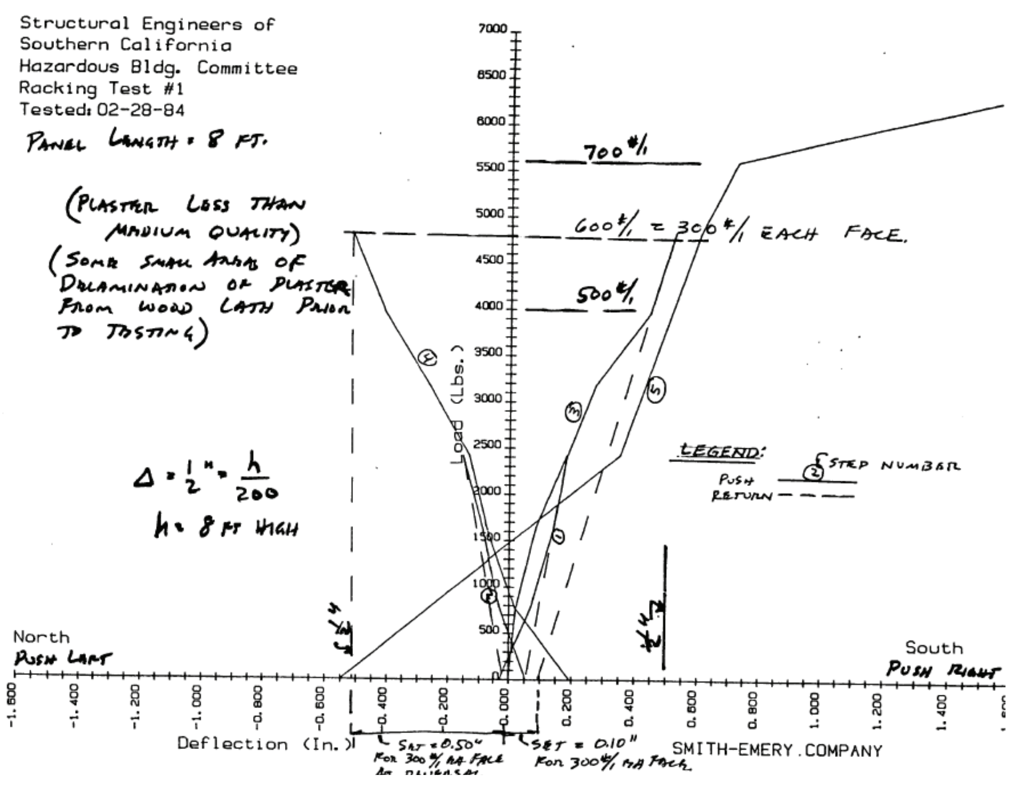


Figure 7-8 Loading history for an in situ test of a lath and plaster wall in a Los Angeles building (Schmid, 1984).

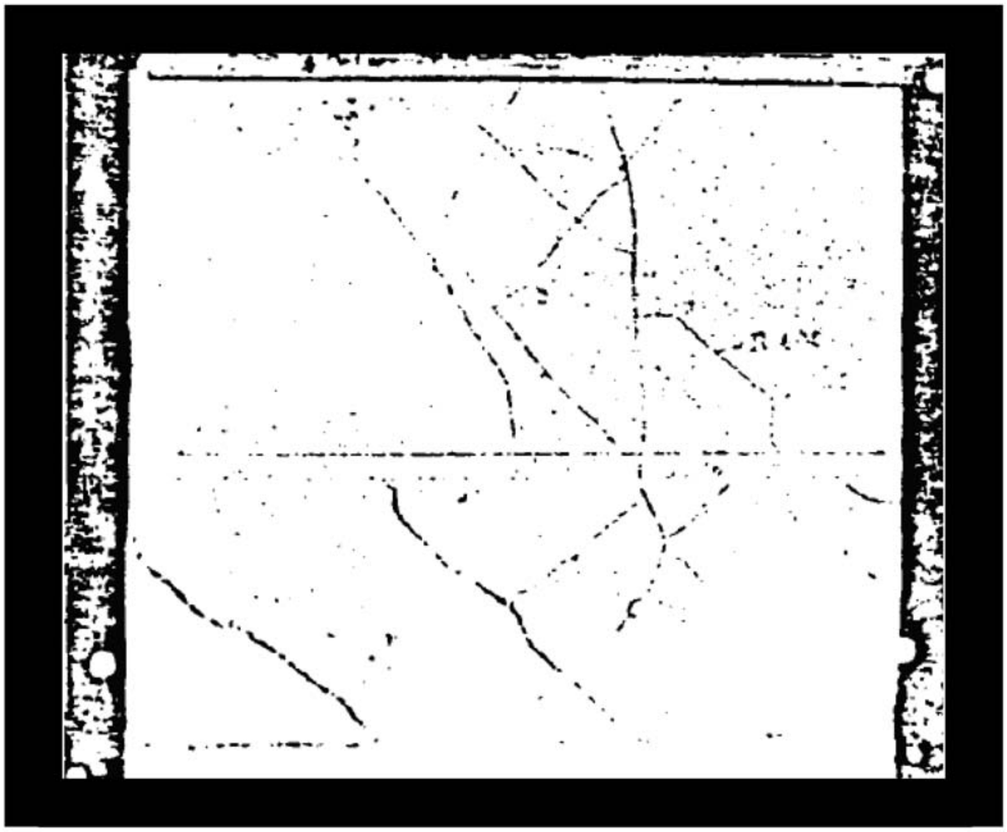


Figure 7-9 In situ testing specimen of wall with lath and plaster finish, after testing (Schmid 1984).

Table 7-5 Summary of Lath and Plaster Pseudostatic In-Plane Racking Tests

Id	Author	Lath And Plaster Wall Specimen	Limit State	Drift, %
1	Trayer (1956)	New wall with window, door openings	Cracks at openings	0.057
2	Ditto	Ditto	Ditto	0.093
3	Ditto	New wall without openings	Cracks appear	0.37
4	Ditto	Ditto	Ditto	0.56
5	Schmid (1984)	E wall 1 no prior cracks, + shear	Ditto	0.46
6	Ditto	Ditto, − shear	Ditto	0.42
7	Ditto	E wall 2 with prior cracks, + shear	New cracks appear	0.26
8	Ditto	Ditto, − shear	Ditto	0.20
9	Ditto	E wall 1 no prior cracks	Ultimate strength	1.62
10	Ditto	E wall 2 with prior cracks	Ditto	1.35

Figure 7-10 Damaged masonry veneer over straight-sheathed wood-frame walls in (a) 1994 Northridge earthquake (the Masonry Society, via Klingner 2003); (b) 1925 Santa Barbara earthquake (Huber, via Earthquake Engineering Online Archive); (c) 1961 Hollister earthquake (Steinbrugge via Earthquake Engineering Online Archive); (d) 1965 Puget Sound earthquake (Steinbrugge, via Earthquake Engineering Online Archive).

Klingner (2004) reports that in the 1994 Northridge and 2003 Mexico earthquakes, anchored masonry veneer “experienced a large fraction of the damage observed to modern masonry…. Anchored veneer was often attached using either corrugated ties fastened to the building, or corrugated dovetail ties, which were attached to channel slots fastened to the building. Veneer was damaged when ties or channel slots detached from the structure, or when the veneer detached from the ties. In no cases was actual tensile failure of the tie itself observed. Tie attachment failures show the need to connect ties with nails or screws to the structural system, and not just to the sheathing, and to control the deformation permitted by corrugated ties. Many ordinary nails, even correctly driven into wood, are not capable of developing the required anchoring forces.”

Laboratory tests are still ongoing into the performance of masonry veneer. Okail *et al*. (2008) presented some results of in-progress Network for Earthquake Engineering Simulation (NEES) test research: shake-table test results of modern anchored brick masonry veneer with corrugated metal ties or rigid metal ties on wood stud walls, subjected to in-plane and out-of-plane shaking. Ten specimens of either 4-foot-wide x 8-foot-high blank panels or 8x8-foot panels with a 4x4-foot window opening were shaken with a 1.1g peak ground acceleration (PGA) Sylmar record or a 2g Tarzana record from the Northridge earthquake, with amplitudes scaled to achieve various levels of excitation of roughly 0.9, 1.4, and 2.6g peak ground acceleration. The tests did not impose deformation at the top edge, and there was no superimposed load. When the records were scaled so that each achieved first 0.9g and then 1.4g PGA, and the walls were subjected to them, they performed satisfactorily. Subjecting the walls to the records scaled to the maximum level caused complete damage to specimens, regardless of the type of anchor. Failure came in the form of collapse of the masonry above the window openings, or of the piers to either side of the window, or of the entire wall. (The results would therefore seem to be indicative of the effects of inertial forces on a single story of veneer, rather than strain incompatibility between veneer and framing. For reference, 0.9, 1.4, and 2.6g PGA for scaled versions of these two records is roughly equivalent to 1.3, 2.0, and 3.8g of 5%-damped spectral acceleration response at 0.3-sec period, or 0.8, 1.2, and 2.2g with 17.5% damping ratio, using the R_A factor offered by Newmark and Hall (1982).

The NEES researchers have found that in-plane behavior of the walls tested so far tended to be a combination of sliding and rocking of the veneer, and that out-of-plane behavior is governed by pullout from the framing of the nails connecting the anchor to the framing. In-plane excitation also caused nails connecting the anchors to the framing to pry loose or to extract from the framing. They observed diagonal cracking at the base of window corners, indicative of rocking of the pier beside the window. They also observed that ties ruptured and pulled out of the masonry and that ties deformed at the holes where screws connected them to the framing, allowing the screw to pull through the hole and remain attached to the framing, while the anchor became detached.

Jalil et al. (1992) studied the performance of the building at 2 Alhambra St, San Francisco, in the 1989 Loma Prieta earthquake (Figure 7-11). In the earthquake, this four-story corner apartment building in the San Francisco Marina District was observed to have lost all of its brick veneer sheathing at the bottom story on three facades. The authors performed an elastic response spectrum structural analysis of the building with and without masonry veneer, using a record from the nearby California Strong-Motion Instrumentation Program (CSMIP) Station 58222, modified to account for site soil. They find that in the likely fundamental period range of the building, 0.3 to 0.4 sec, the 5%-damped spectral acceleration response imposed on the building was approximately 150 in/sec^2, or approximately 0.4g. (Dividing by R_A value to account for wood frame elastic damping of perhaps 15-20% suggests a 17.5%-damped S_a of approximately 0.3g.) The authors do not offer an opinion of the deformation at which the veneer delaminated, although they do suggest that veneer fell off before the ground story drift reached 1%. Their analyses suggest that the ground story would have experienced drifts of 0.055 and 0.156 inch its orthogonal directions with the veneer (i.e., approximately 0.055 and 0.156%), and 0.78 and 0.98 inch without the veneer (0.78 and 0.98%).

Figure 7-11 Veneer damage to 2 Alhambra St, San Francisco, 1989 Loma Prieta earthquake (Jalil et al. 1992).

Thurston and Beattie (2008) also performed racking tests of a single-story, full-scale prototype house with modern brick veneer over wood frame, characteristic of construction in New Zealand. Piers were of various widths. The bricks had holes that the authors credited with improving the veneer's performance relative to solid clay bricks. Nonetheless, it may be noteworthy that, regardless of pier width, the authors estimate a substantial loss of stiffness occurs when the wood-frame wall deflects more than approximately 2 cm.

7.7 Literature on the Performance of Stucco Walls

Interpreting experimental testing by the CUREE-Caltech Wood-Frame Project, Porter et al. (2002) developed two fragility functions for stucco sheathing with metal lath: one for a cracking damage state repaired by patching and repainting, and a second for fracture of the connection between the framing or sheathing and the stucco, which must be repaired by demolishing and replacing the stucco. The former seems to dominate when metal lath is properly embedded in the stucco and connected to the framing; deformation is accommodated by cracking of the stucco. The latter seems to dominate when metal lath is not properly embedded in the stucco, and deformation is accommodated by delamination of the stucco from the lath. Stucco on wood lath (of special concern in this CAPSS study) would seem to be very different from stucco with well-embedded metal lath, akin to the difference between plain concrete and reinforced concrete, so the first failure mode addressed by the Porter et al. (2002) seems irrelevant. Loss of bond between the lath and stucco, however, seems perfectly relevant, so the second failure mode and associated fragility function might be applicable. The function was a lognormal fragility function with a median capacity of 1.2% drift and a logarithmic standard deviation of 0.5.

7.8 Observations of Red-Tagging and Structural Collapse

Red- tagging. ATC-20 (Applied Technology Council, 1989) is the *de facto* standard methodology for post-earthquake safety inspections of buildings. It suggests that if a building has between 1 and 2 inches of residual drift after an earthquake (i.e., 1-2% drift ratio in the ground floor), then it is reasonable to post it as unsafe to enter or occupy. The larger number seems to be a better threshold for wood-frame construction, which can tolerate greater residual drift before its P-delta effects are likely to become a concern. Based on work for the ongoing ATC-58 project, Deierlein (person communication) suggests that approximately 5% transient drift in the ground floor of a wood-frame shear wall can result in 2% residual drift in that floor.

One retrofit considered in the CAPSS study is to add steel frames or cantilever columns, changing the lateral force resisting system on the ground story to a dual system of wood-frame shear wall and steel frame (see Appendix 4). Deierlein suggests that for a steel frame, the ratio of residual drift to transient drift is 4:7; this suggests that the 2-inch residual drift that is likely to trigger red-tagging would occur with 3.5% transient drift, or roughly 4.4 inches of spectral displacement. It is not clear which value should be used, but the figure for wood frame seems justified.

Deierlein indicates that there is significant uncertainty in this ratio of 5:2, with a logarithmic standard deviation of 0.8, so the values of 5 to 6 inches of transient drift producing 2 inches of residual drift are highly uncertain. One additional data point is provided in Figure 7-12, which shows safety inspection tag colors in the San Francisco Marina District, after the 1989 Loma Prieta earthquake. It shows, for example, that approximately 33 corner buildings were red tagged (including 6 that collapsed).

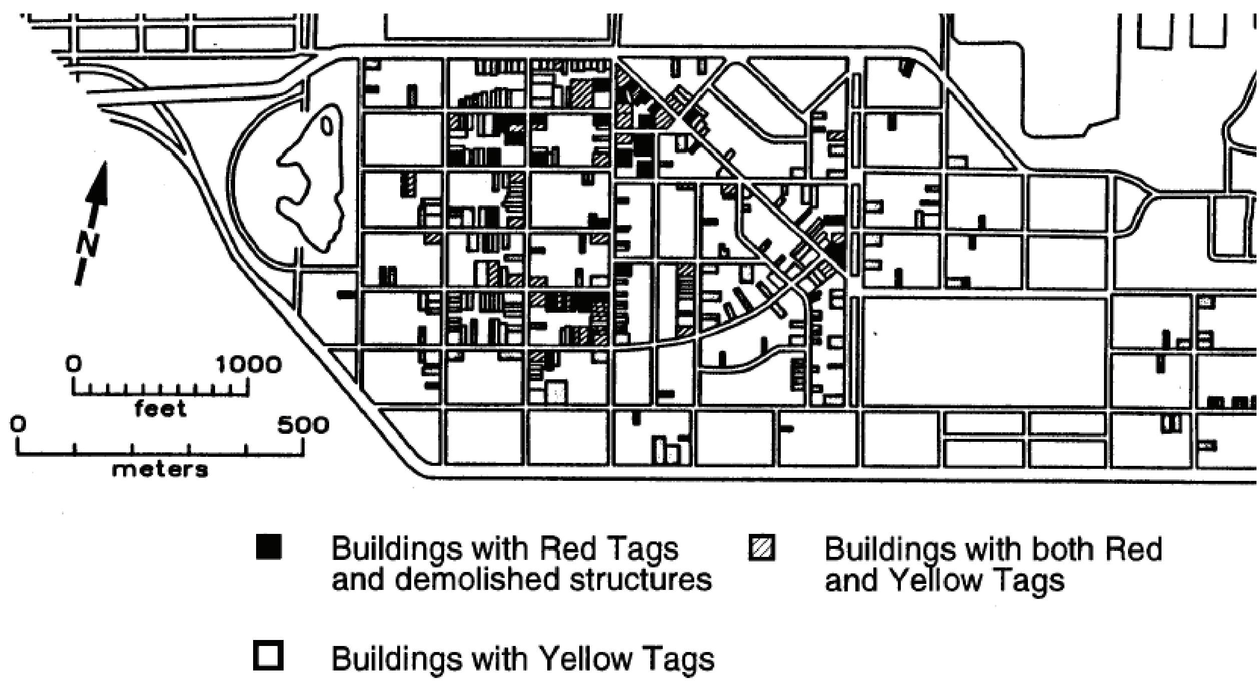
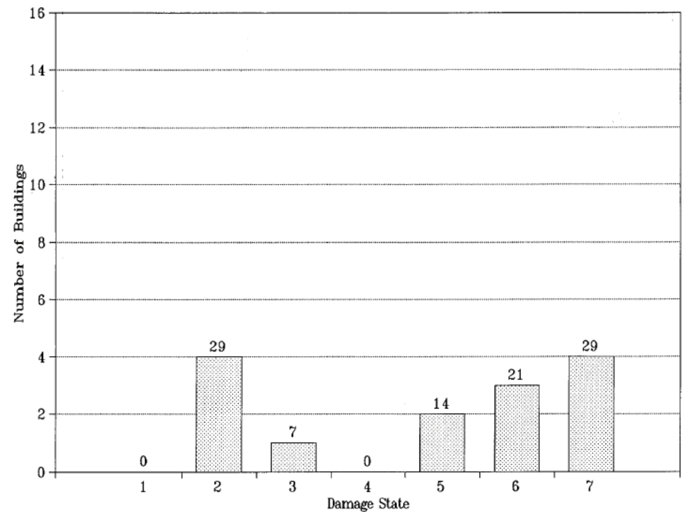


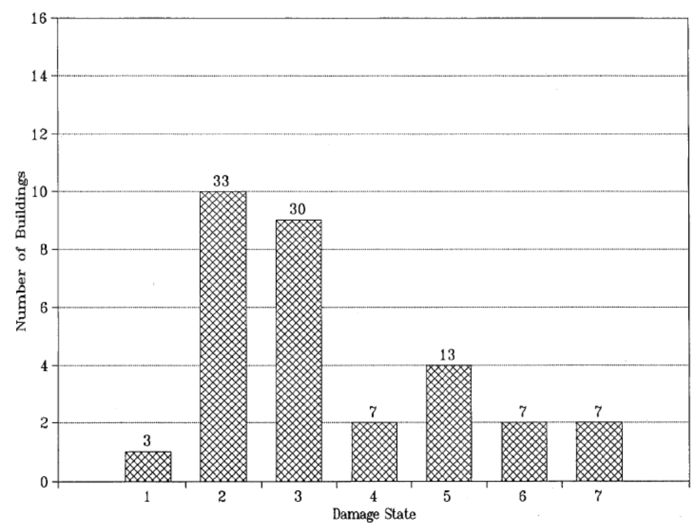
Figure 7-12 Safety tags in the San Francisco Marina District after the 1989 Loma Prieta earthquake (Seekins et al. 1990 via Scawthorn et al. 1992).

Collapse. The HAZUS®-MH methodology does not attempt to express collapse fragility functions and instead, estimates the building area that experiences collapse as a fraction of the building area that experiences the complete damage state; the fraction is denoted by P_c, which for ordinary W1 or W2 construction (FEMA, 2003a) take as 0.03. In the case of an *n*-story apartment building, collapse is likely to involve the ground floor, or 1 n^{th} of the building area; therefore, the fraction of all buildings that collapse, given that they are in the complete damage state, would be n times P_c. Note that HAZUS®-MH assumes that the typical W1 is one story tall, and the typical W2 is two stories tall. P_c is given as 0.03 in both cases.

Harris and Egan (1992) offer some observations relevant to P_c of the performance of four-story corner apartment buildings in San Francisco Marina District after the 1989 Loma Prieta earthquake. They observed eleven such buildings to have experienced ATC-13 (ATC, 1985) damage states 6 or 7, where 6 indicates repair costing at least 60% of replacement cost, and 7 indicates collapse. As noted earlier, ATC-13 (ATC, 1985) damage state 6 (major), appears to equate in terms of damage factor with HAZUS's "complete" damage state, while 7 (destroyed) equates with HAZUS's "collapse."



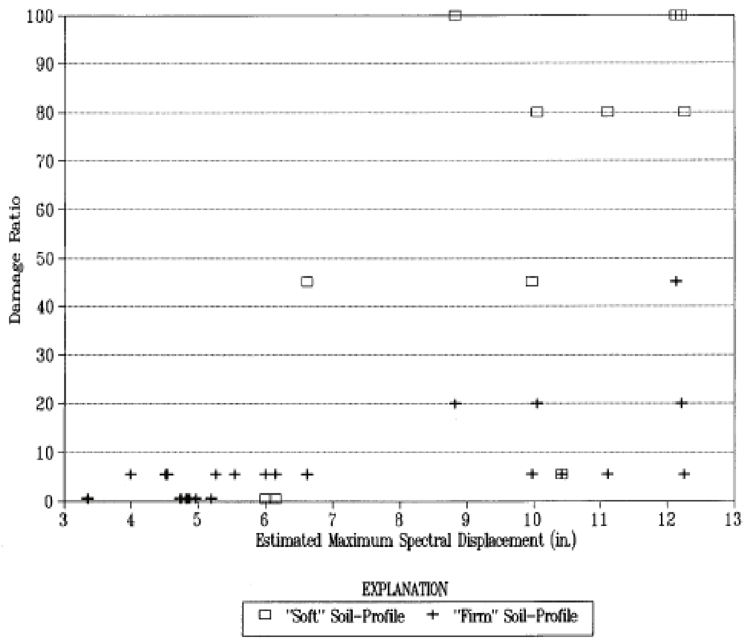
(a) Figure 6.—Number of buildings in "soft"-soil-profile zone versus damage state. Most (64 percent of) buildings were assigned to damage states 5 (heavy) through 7 (destroyed). Numbers at top of bars indicate percentage of total.



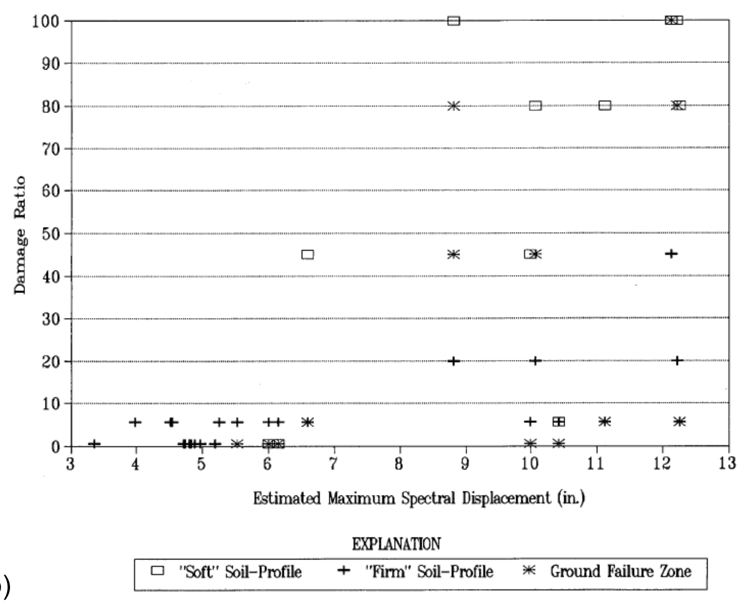
(b) Figure 8.—Number of buildings in ground-failure zones versus damage state. Buildings are spread across all damage states but are concentrated at lower end. Numbers at top of bars indicate percentage of total.

Figure 7-13 Harris and Egan (1992) observed performance of 4-story wood-frame corner apartment buildings in the San Francisco Marina District: (a) buildings on soft soil; and (b) buildings on sites with ground failure.

Harris and Egan (1992) also provide some data relevant to a fragility approach to collapse. They estimate that in the 1989 Loma Prieta earthquake, of seven four-story corner apartment buildings on firm or soft (but not failed) soil that experienced $12 \leq S_d < 13$ in, three collapsed and four did not. In the range of $8 \leq S_d < 12$ inches, one of eleven collapsed. The data are shown in Figure 7-14. It is difficult to see three collapses at $S_d \approx 12$ inches in Figure 7-14a, but the total must sum to four, as in Figure 7-13a, so it is reasonable to conclude that there are three data points at 12 inch spectral displacement and 100% loss, and one at 9 inches. No buildings with $4 \leq S_d < 8$ inches collapsed.



(a)



(b)

Figure 7-14 Collapse capacity of Marina District corner apartment buildings: performance of corner apartment buildings in the San Francisco Marina District in the1989 Loma Prieta earthquake on (a) soft or firm soil, (b) all soil profiles (Harris and Egan, 1992).

7.9 Component Fragility Analysis

With these tests and other observations in mind, consider now how to interpret them in terms of limit states at various levels of spectral displacement.

Straight sheathing. There appear to be two readily available observations of the drift at which straight sheathing experiences connection fracture: 2.8% and 3.0%, from Trayer (1956) and Elkhoraibi and Mosalam (2007a,b), respectively. The median capacity is therefore taken to be 2.9% peak transient drift at the story level of the wall, or roughly 2.9 inches for a 96-inch wall. To express this in terms of spectral displacement of the equivalent single-degree-of-freedom (SDOF) oscillator, one can calculate:

$$S_d = \Delta_1 \cdot \frac{\left(S_d / \Delta_r\right)}{\left(\Delta_1 / \Delta_r\right)} \tag{2}$$

where Δ_1 denotes the drift (in inches) of the ground story, Δ_r denotes the roof displacement, and the ratio S_d/Δ_r denotes the modal factor denoted by α_2 in HAZUS®-MH (FEMA 2003a). Cobeen (personal communication) estimates the ratio Δ_1/Δ_r near ultimate to be 0.75 in index buildings 1 and 2 under as-is conditions, and 0.6 to 0.65 under seismic retrofit. The modal factor α_2 or S_d/Δ_r is estimated to be approximately 0.75 in FEMA (2003a). Thus, under as-is conditions, the spectral displacement equals the ground-floor displacement multiplied by 0.75/0.75, or unity. Under seismic retrofit, the factor is 0.75/0.60, or 1.25.

For example, Jalil et al. (1992), in their analysis of 2 Alhambra St., estimated that ground-floor displacement accounted for approximately 65-75% of the roof drift of the four-story apartment building, compared with the 25% it would have been if the deformed shape were linear: 70%/25% = 2.8. See Figure 7-15. Therefore the drift capacity of the siding, when measured in terms of the SDOF oscillator's drift ratio rather than the story drift ratio, will be taken as 2.9% divided by 2.8, or 1.0%. The height of the equivalent SDOF oscillator is taken to be 0.7 to 0.8 times the building height, which in the present case is on the order of 25 to 35 ft, so the oscillator is taken as having a height of 21 to 24 ft (30 ft x 0.7 to 0.8), or approximately 250 to 290 inches. To measure the capacity of the straight sheathing in terms of the spectral displacement of the oscillator, one multiplies the drift ratio of the oscillator by its height, e.g., 0.010 x 290 inches, or 2.9 inches. Thus, at roughly 3 inches of spectral displacement (in the HAZUS sense), one would expect the ground-floor sheathing to have experienced 2.9% peak transient drift, perhaps enough to require its demolition and replacement, though perhaps not enough to represent an immediate collapse risk, as will be discussed later. Under seismic retrofit, the ground story would experience 2.9 inches of drift at S_d = 3.6 inches.

Lath and plaster interior finish. The test results summarized in Table 7-5 can be interpreted to suggest three damage states: (1) a light damage state associated with cracks near window and door openings, repairable by patching and repainting; (2) a moderate damage state associated with cracks in walls without openings, repairable by more extensive patching and repainting; and (3) an ultimate-strength data state with heavy cracking that would seem to require demolition and replacement of the plaster with gypsum wallboard. The median for damage state 1 (using Test IDs 1 and 2 in Table 7-5) is taken as 0.073% peak transient drift in the story of interest, or roughly 0.073 inches, which would equate with S_d = 0.073 in under as-is conditions, or 0.09 under retrofitted conditions. For damage state 2, drawing on observations 3-8 in Table 7-5, the median capacity is 0.36% drift, equivalent to $S_d \approx 0.36$ inches under as-is conditions or 0.45 under retrofitted conditions. For damage state 3, from observations 9 and 10, the median drift capacity for ultimate strength (requiring demolition and replacement) is 1.5% drift, equivalent to $S_d = 1.5$ to 1.9 inches (as-is and retrofitted, respectively).

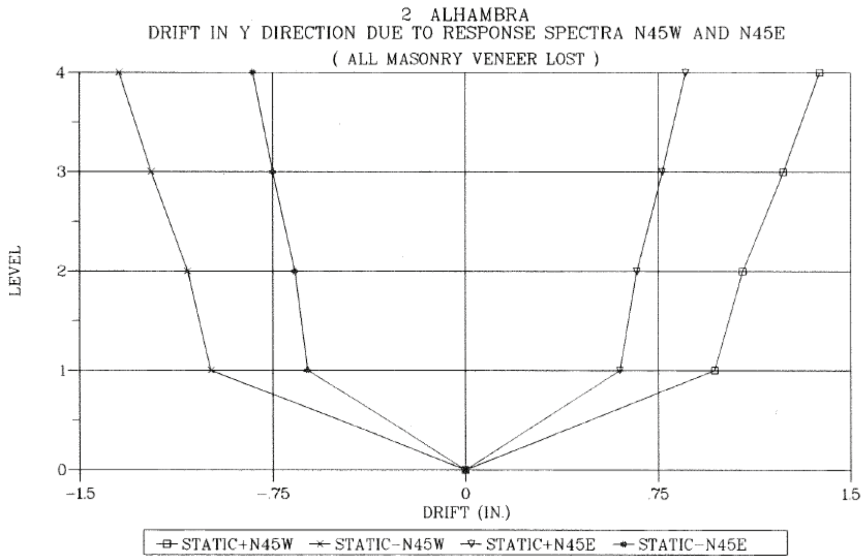


Figure 7-15 Estimated mode shape of 2 Alhambra after loss of masonry veneer (Jalil et al., 1992).

Brick veneer. There is little evidence on which to base a drift capacity associated with failure of brick veneer. As noted above, Jalil et al. (1992) estimated that the first story lost its brick veneer at drifts below 1%, and one might arbitrarily select a first-story drift of 0.4% as the median capacity, equivalent to $S_d = 0.4$ to 0.5 inch; this might be selected for simplicity, because it is the same range for S_d at which cracks appear throughout ground-floor stucco. Alternatively, if one believes that inertial forces are more strongly related to veneer failure, as seems to be the direction in which the NEES project is proceeding, then the capacity of the brick veneer is something less than $S_a = 0.3$g. The HAZUS developers suggest that brick veneer is drift-sensitive (FEMA, 2003a, Table 5.2), so for consistency's sake, a median capacity of the first-story veneer is somewhat arbitrarily assigned as 0.4 inch (as-is) or 0.5 inch (retrofitted).

Stucco. Consistent with the CUREE-Caltech Wood-Frame Project work, the median drift capacity of ground-story stucco is assigned as 1.2%, equivalent to $S_d = 1.2$ inches (as-is) 1.5 inches (retrofitted). This range is close enough to the drift at which lath and plaster exhibit large cracks that the drift level for stucco delaminating is taken as 1.5 to 1.9 inches

Red tagging. As previously described, Deierlein (personal communication) estimates that 5 inches of transient drift implies 2 inches of residual drift. Here, that would equate with a spectral displacement of perhaps 5 inches under as-is conditions or 6.2 inches under seismic retrofit. According to Harris and Egan's (1992) drift estimates (Figure 7-14b), there were perhaps 35 to 45 corner apartment buildings in the San Francisco Marina District in the 1989 Loma Prieta earthquake that experienced spectral displacements of 5 inches or more. The exact number is not known, because the symbols in Figure 7-14b tend to overlap; nor is the safety tag color associated with each of the buildings represented in the figure known. However, the estimate of 35 to 45 buildings with $S_d \geq 5$ inches roughly equates with the approximately 33 red-tagged or collapsed corner buildings reported by Seekins *et al*. (1990; Figure 11), so together these two observations tend to support Deierlein's estimate.

It was the opinion of the CAPSS Project Engineering Panel in its January 2009 meeting that the retrofitted buildings could tolerate up to 8 inches of transient drift before triggering a red tag, as opposed to the 6.2 inches suggested above.

HAZUS®-MH approach to collapse. If we denote by N_4 the number of buildings in the HAZUS complete but not collapsed damage state, and by N_5 the number of buildings that experience collapse, then the fraction of buildings in the complete damage state that collapse can be taken as $N_5/(N_4 + N_5)$. If a four-story soft-story building collapses, typically it is the ground story that collapses, and the upper stories do not; therefore, only one-fourth the building area has collapsed. Letting P_c denote the fraction of building area that collapses given complete damage, for four-story buildings where collapse always means the collapse of the whole first story,

$$P_c \approx \frac{N_5}{4\left(N_4 + N_5\right)} \qquad (3)$$

Recall the equivalence of HAZUS's complete damage state and ATC-13's major damage state, and the equivalence between HAZUS's collapse damage state and ATC-13's destroyed damage state. Recall also Harris and Egan's (1992) estimate of five corner apartment buildings in the ATC-13 major damage state, and six destroyed (Figure 7-13). No buildings on firm soil experienced either damage state, so they are ignored for purposes of calculating P_c. Thus, if all Marina District buildings are included for purposes of evaluating Equation (3), $N_4 = 5$ and $N_5 = 6$, so $P_c \approx 6/(4*11) = 0.14$. If only those that were not on failed soil are considered, $N_4 = 3$ and $N_5 = 4$, so $P_c \approx 4/(4*7) = 0.14$, the same as before.

What if we assume that HAZUS's complete damage state is broader than the ATC-13 major plus destroyed damage states (ATC-13 damage states 6 and 7) and includes those in the heavy damage state (ATC-13 damage state 5)? Then, using Figure 7-13a, $P_c = 4/(4*9) = 0.11$; using both Figure 7-13a and Figure 7-13b, $P_c = 6/(4*17) = 0.088$. Not shown in either figure is that Harris and Egan (1992) estimated that three buildings on firm-soil profiles experienced ATC-13 damage state 5, which would lead to $P_c = 6/(4*20) = 0.075$.

So depending on how one equates the ATC-13 and HAZUS damage states, P_c for corner buildings might be anywhere from 0.075 to 0.14. Both in order to acknowledge this uncertainty and to avoid the appearance of unjustified accuracy, let us take $P_c = 0.1$.

None of the buildings in the Harris and Egan (1992) dataset is known to have been seismically retrofitted, and it seems unlikely that any had been. No other data appear to be readily available to inform P_c for retrofits 1 through 3. Let us assume, therefore, that seismic retrofit 1 would reduce P_c by perhaps one-third to one-half, say to 0.06 (double the value assumed in HAZUS®-MH for W1 and W2), and that retrofits 2 and 3 would virtually eliminate ground-story collapse, possibly shifting any collapse to the second floor. For retrofits 2 and 3, P_c will be taken as 0.015, half the value for W1 or W2.

Fragility approach to collapse. A fragility approach was recommended by the CAPSS Project Engineering Panel in a January 2009 meeting. Recall that the data in Harris and Egan (1992) seem to suggest three collapses out of seven buildings at 12 inch spectral displacement, one collapse out of eleven buildings at 9 inches, and none with $4 \leq S_d < 8$ inches collapsed. Fitting a curve to these points suggests a median collapse capacity of approximately 13 inches, and a logarithmic standard deviation of 0.2.

This uncertainty value includes uncertainty associated with structural response given ground motion (since the models were simplistic), and collapse given structural response (since it seems likely that there would be variability in collapse between real buildings known to have experienced the same level of structural response). It largely excludes variability in ground motion given magnitude and distance, since the buildings are relatively close together (little intra-event variability), and the data are drawn from a single earthquake (no inter-event variability). For future earthquakes, one can consider an additional contribution of perhaps 0.6 (the value of $\sigma_{\ln Y}$ for T = 1 sec in Boore et al. 1997), which is SRSS'd with the value of 0.2 (SRSS: square root of the sum of the squares) to produce a total logarithmic standard deviation of 0.63.

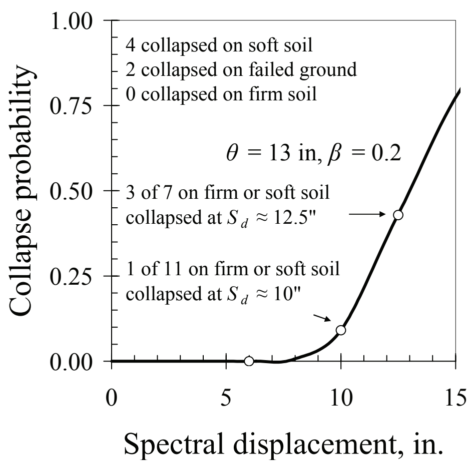


Figure 7-16 Collapse fragility function inferred from the Harris and Egan (1992) data.

7.10 Summary

To review: in laboratory tests of wood lath and plaster walls by Trayer (1956) and Schmid (1984), at $S_d \approx 0.06$ inch, small cracks appeared near corners of openings in lath and plaster walls. At $S_d \approx 0.4$ inch, small cracks appeared throughout the ground-floor lath and plaster walls, calling for more significant patching and repainting. A study by Jalil et al. (1992) suggests that at about the same level of drift, the brick veneer begins to fall off. Earlier fragility analysis of stucco finish in Porter et al. (2002) suggests that at $S_d \approx 1.5$ inches, ground-floor stucco delaminates from the wood lath and requires demolition and replacement. At about the same level of drift, from Trayer's (1956) and Schmid's (1984) test results, the ground-floor lath and plaster walls exhibit large cracks.

From tests by Trayer (1956) and Elkhoraibi and Mosalam (2007a,b), one can estimate that at $S_d \approx 3.0$ inches, nails in straight sheathing have become so heavily deformed in exterior straight sheathing that the finish requires demolition and replacement, though the building might not represent an immediate collapse hazard.

At $S_d \approx 5$ inches, Deirelein's (2007) analysis suggests that a reasonable estimate of residual drift in the ground floor is 2 inches, which would trigger a red tag. This figure tends to be supported by the fact that Harris and Egan (1992) suggest that in the San Francisco Marina District during the 1989 Loma Prieta earthquake, 35 to 45 corner apartment buildings experienced 5 inches of drift or more, and according to Seekins et al. (1990), approximately 33 corner buildings were red-tagged or collapsed.

At $S_d \approx 13$ inches, collapse occurs, as shown by an examination of Harris and Egan's (1992) estimates of spectral displacement and damage to corner apartment buildings in the Marina District in 1989. (The assumption is that other large soft-story wood-frame buildings in San Francisco will behave like those in the Marina District in 1989.) Using the HAZUS®-MH approach to collapse, the evidence from Harris and Egan's (1992) damage-state estimates of the same buildings suggests that P_c, the fraction of building area in the complete damage state that has collapsed, was approximately 0.1.

The damage-state descriptions just summarized can be compared with those of the HAZUS®-MH damage states for W1, whose relevant portions are quoted in Table 7-6. The table shows a range of S_d values at which these damage states seem to occur, with the lower figure reflecting as-is conditions, and the upper figure for

Table 7-6 Relationship Between Experimental Observations and Damage States

Tag	Experimental Observations	S_d, in.[a]	HAZUS Structural Damage
Green	Small cracks appear near corners of openings in lath and plaster walls	0.06 - 0.07	*Slight:* Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry veneer.
	Small cracks appear throughout the ground-floor lath and plaster walls; brick veneer begins to fall off	0.4 - 0.5	*Moderate:* Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels
	Ground-floor stucco delaminates from wood lath; ground-floor lath and plaster walls exhibit large cracks	1.5 - 1.9	
Yellow	Nails heavily deformed in exterior straight sheathing	2.9 - 3.6	*Extensive:* Permanent lateral movement of floors and roof… partial collapse of "room-over-garage" or other "soft-story" configuration
Red	Residual drift in the ground floor ≥ 2 inches; no collapse	5 - 8	*Complete*: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse. Approximately 3% of the total area of W1 buildings with Complete damage is expected to be collapsed.
	Collapse occurs P_c = 0.1 (as-is) to 0.015 (retrofit 3)[b]	13-?	

Notes:
a. Lower value in range refers to as-is conditions, upper to retrofitted conditions.
b. P_c is used for the conventional HAZUS®-MH approach, and drift for use with fragility.

retrofit. The table also shows the approximate ATC-20 safety inspection result. There is an imperfect match between the experimental observations and HAZUS®-MH structural damage state description, especially for HAZUS' slight and moderate damage states.

A preliminary equivalence was made in consultation with structural engineering members of the CAPSS project Advisory Committee in October 2008, and revised in consultation with members of the CAPSS Project Engineering Panel and other members of the CAPSS project team in January 2009. The former assignments were more conservative than the latter. That is, in the January 2009 consultation, HAZUS damage states were associated with higher values of spectral displacement.

7.11 Conclusions

Experimental and earthquake evidence is sufficient to create new fragility functions for common building components of large residential San Francisco wood-frame buildings. Table 7-7 shows the final relationships between SPUR performance level, ATC-20 tag color, HAZUS®-MH structural damage state, and several values of median spectral displacement: those derived from the experiments discussed above (labeled "CAPSS"); the judgment of the January 22, 2009 meeting of the Project Engineering Panel, and the HAZUS®-MH capacities for the structural component of W1 and W2 pre-code structure types. The column labeled β refers to the logarithmic standard deviation of capacity proposed for use here. HAZUS®-MH offers β values for W1 and W2 pre-code that are all approximately 1.0, which are used here, except for collapse, where a value of 0.6 is used, as discussed above. The table shows two ranges for CAPSS fragility parameters, reflecting the ambiguity in mapping from experimental damage states to HAZUS and SPUR damage states. In each case, a range "X-Y" means that X would be the median for as-is conditions, Y for retrofitted conditions. "Lower" refers to the lesser of the two ranges—note that using lower values tends to result in higher damage estimates—while "upper" is the larger of the two, producing lower damage at a given value of shaking intensity.

Table 7-7 Damage State Characterizations and Proposed Fragility Parameters

Damage State			Median Spectral Displacement, Inches					β
SPUR	ATC-20 Tag	HAZUS	PEP[c] Judgment	W1 Precode	W2 Precode	CAPSS[a]		
						Lower	Upper	
A	Green	Slight	0.5	0.4	0.69	0.06 - 0.07	0.4 - 0.5	1.0
B	Green	Moderate	1.5	1.0	1.71	0.4 - 0.5	1.5 - 1.9	1.0
C	Yellow	Extensive	3	3.09	5.29	1.5 - 1.9	2.9 - 3.6	1.0
D	Red	Complete	6 – 8	7.56	12.96	2.9 - 3.6	5 - 8	1.0
E	Collapse	Collapse	12	N/A	N/A	b	13 - ?	0.6

Notes:

a: where a range "X-Y" is given, X refers to as-is conditions, Y to retrofitted. "Lower" refers to the lesser of the two ranges—note that using lower values tends to result in higher damage estimates—while "upper" is the larger of the two, producing lower damage at a given value of shaking intensity.

b: use HAZUS®-MH approach to estimate area collapsed, as fraction of area in "complete" damage.

c: Decisions made during CAPSS Project Engineering Panel (January 22, 2009 meeting)

APPENDIX 8: SEISMIC VULNERABILITY OF FOUR SOFT-STORY WOOD-FRAME INDEX BUILDINGS AND THEIR RETROFITS

8.1 Executive Summary

Described in this appendix is the derivation of motion-damage relationships (vulnerability functions) for the four Index Buildings described in Appendix 4, considering both as-is and retrofitted configurations. The derived relationships are based on several related City of San Francisco Community Action Plan for Seismic Safety (CAPSS) project efforts, including (1) the development of fragility functions for major components common to multi-family, soft-story, wood-frame dwellings (see Appendix 7); (2) the development of capacity curves for the as-is and retrofitted configurations of the four multi-family, soft-story, wood-frame Index Buildings (see Appendix 4); and (3) a non-iterative approach to the capacity spectrum method of structural analysis (described herein) to create seismic vulnerability functions (relationships) that provide damage and loss estimates as a function of 5%-damped spectral acceleration response at 0.3 sec and 1.0 sec periods. The relationships derived herein provide the mean damage factor (repair cost as a fraction of replacement cost) and damage-state probabilities for each as-is and retrofitted configuration of the four Index Buildings as functions of spectral acceleration response, earthquake magnitude, distance to fault rupture, and National Earthquake Hazard Mitigation Program (NEHRP) site soil class. The results, illustrated in Figures 8-1 through 8-3, were developed to study seismic risk mitigation options for the City of San Francisco. They may be useful for other purposes as well.

8.2 Objectives and Scope of Work

The CAPSS project sought, among other things, to assess the impacts of various realistic earthquake scenarios on the City's housing stock, with emphasis on one of its more widespread and vulnerable classes of housing: older, wood-frame, multi-family dwellings (with five or more housing units) with soft-story conditions. The relevant housing stock was idealized via four "Index Buildings" shown in Figure 8-4: (1) a 3,600-sq. ft., three-story pre-World War II (WWII), wood frame with garage door openings along one entire side of the building, with few transverse walls at ground level; (2) a 5,800-sq. ft., four-story pre-WWII, wood-frame corner building with garage door openings along two sides of the building and internal walls at ground level between several parking spaces; (3) a 2,300-sq. ft., midblock, pre-WWII, four-story building with a neighbor on both sides; and (4) a 1,800-sq. ft., midblock, three-story 1950s building, > 80% open on ground-floor façade, with neighbors on both sides.

This study focused on the development of seismic vulnerability functions for the four Index Buildings.

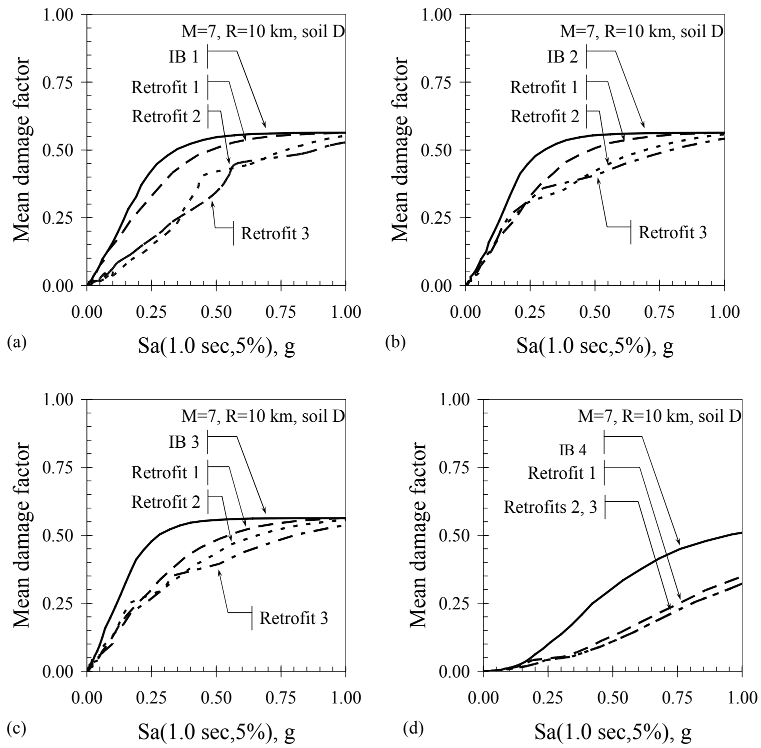


Figure 8-1 Vulnerability functions for the four Index Buildings (IB) as a function of spectral acceleration, Sa(1.0 sec, 5% damped).

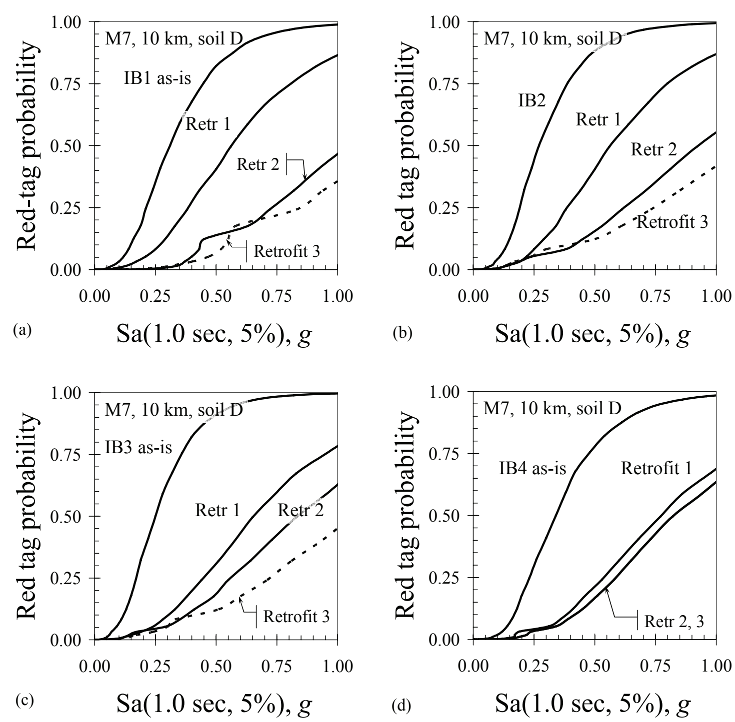


Figure 8-2 Red-tag probability as a function of spectral acceleration, Sa(1.0 sec, 5% damped), for the four Index Buildings (IB).

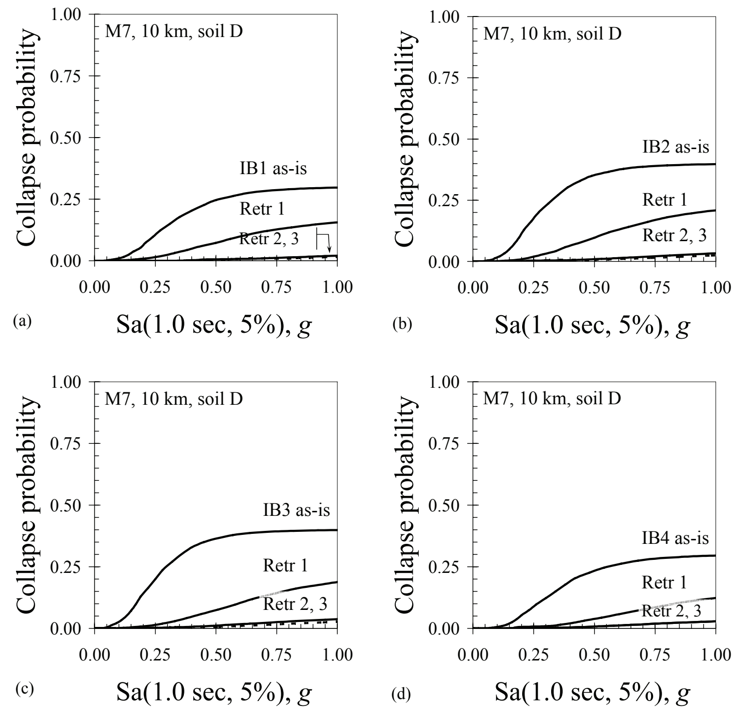


Figure 8-3 *Collapse probability as a function of spectral acceleration, Sa(1.0 sec, 5% damped), for the four Index Buildings (IB).*

Figure 8-4 *Index Buildings: four older, soft-story, wood-frame, multi-family dwellings representing a realistic range of performance of buildings of this class in San Francisco: (1) corner, 3 story, no interior walls at garage level, one street facade ≥ 80% open at ground floor; (2) corner, 4 story, both street facades ≥ 50% open at ground floor; (3) mid-block, 4 story, pre-WWII, neighbors on both sides; (4) mid-block, 3 story, post-1950, neighbors on both sides. Square footage is 3,600, 5,800, 2,300, and 1,800 sq. ft., respectively.*

8.3 Available Vulnerability Methodologies

The Pacific Earthquake Engineering Research (PEER) Center methodology (e.g., Porter et al., 2002) and HAZUS®-MH methodology (FEMA, 2003a) both offer the means to relate probabilistic damage, economic, or life-safety losses to ground motion measures, such as 5%-damped elastic spectral acceleration response. The PEER approach models a building at the level of detail of structural design, uses multiple 2-dimensional (2-D) or 3-D nonlinear dynamic structural analyses, and applies fragility functions at the level of individual wall segments.

The HAZUS®-MH approach, by contrast, idealizes a building as a single-degree-of-freedom (SDOF) nonlinear oscillator and employs the capacity spectrum method of structural analysis. It simplifies a building as comprising only three aggregate components: structural, nonstructural drift-sensitive, and nonstructural acceleration sensitive, each with five or six somewhat qualitative damage states. When both approaches are applied carefully, the PEER approach offers far greater resolution, but it is far more labor intensive, largely because of the effort involved in creating a probabilistic structural model, and it can be computationally expensive for large buildings modeled in three dimensions. The HAZUS®-MH approach offers less fidelity to the behavior of real buildings but has been used to hindcast societal losses with ± 50% accuracy in the 1989 Loma Prieta and 1994 Northridge earthquakes (FEMA, 2001). The HAZUS®-MH approach has produced what are deemed to be realistic estimates of losses in a future repeat of the 1906 San Francisco earthquake (Kircher *et al*. 2006) and in a possible future magnitude 7.8, 300-km-long rupture of the southern San Andreas fault (Jones et al. 2008). For purposes of the CAPSS study, the HAZUS®-MH approach is practical, and the PEER approach is not. Furthermore, since CAPSS aims at societal-level risk assessment, the fidelity offered by a HAZUS®-MH approach is deemed adequate.

HAZUS®-MH reflects old, large wood-frame buildings with the seismic vulnerability model W2 pre-code. HAZUS®-MH also contains another building type for wood-frame construction (W1), but this type is generally smaller than the Index Buildings, both in terms of height (W1 is idealized with a one-story building) and area (W1 has an area of less than 5,000 sq. ft.). The HAZUS®-MH W2 type alone cannot distinguish the effects of building configuration or details such as soft-story and the detailed seismic retrofits examined here. The HAZUS®-MH Advanced Engineering Building Module (AEBM; FEMA, 2003b) provides the means to calculate the seismic performance of particular buildings. However, the AEBM was found to have a programming flaw in calculating the performance point, when it lies on the constant-velocity portion of the idealized response spectrum with effective damping greater than 5%. It is unclear how frequently and severely the flaw impacts results. A patch was not available at the time of this work.

Because of these challenges to using HAZUS®-MH and the AEBM, an alternative approach developed by Porter (2009b) was used here. The alternative honors all HAZUS®-MH modeling assumptions, while avoiding the use of AEBM and the requirement for iterative calculation of the performance point. It has been peer reviewed and its results, independently duplicated by several researchers.

8.4 Selected Methodology

This CAPSS effort concerns the effort of relating 5%-damped spectral acceleration response at 0.3 sec or 1.0-sec periods to damage and loss, not the calculation of loss given some scenario shaking. The interested reader is referred to Porter (2009b,c) for details on the methodology. In brief, one must create a pushover curve, referred to as a capacity curve in the HAZUS®-MH methodology, which relates the peak acceleration of the equivalent SDOF nonlinear oscillator to its displacement, i.e., in the space of spectral displacement (S_d) and spectral acceleration (S_a) response. As shown in Figure 8-5, the capacity curve has a linear portion between the origin and a yield point denoted by (D_y, A_y), a perfectly plastic portion when displacement exceeds an ultimate point denoted by (D_u, A_u), and a portion of an ellipse connecting the two segments. It is discretized into a number of points; Porter (2009b) uses 51 equally logarithmically spaced values of S_d between 0.01 inch and 1000 inches, though for low- and mid-rise wood-frame buildings, a useful upper limit is more like 10 inches to perhaps 100 inches. At each S_d value, one calculates the corresponding S_a value and the effective damping ratio, denoted by B_{eff} and calculated as

$$B_{eff} = B_E + \kappa\left(\frac{Area}{2\pi S_d S_a}\right) \tag{1}$$

where B_E is the elastic damping of the model building type, κ is a degradation factor, and *Area* is the area enclosed by the hysteresis loop, as in Figure 8-5. Ignoring the rounded corners,

$$Area \approx 4S_a\left(S_d - \frac{S_a}{A_y/D_y}\right) \tag{2}$$

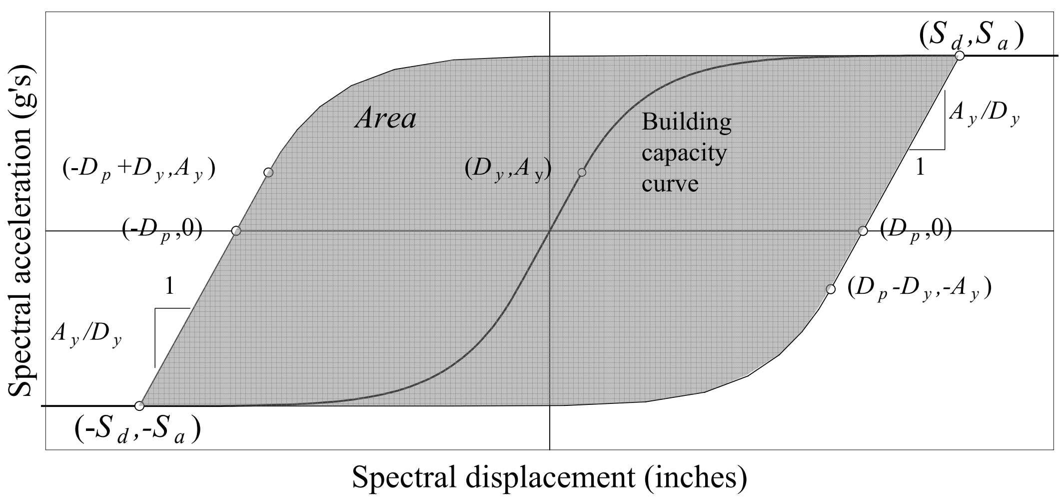


Figure 8-5 Establishing effective damping ratio at HAZUS®-MH performance point (Porter, 2009b).

Omitting details, the performance point (S_d, S_a, B_{eff}) lies on an idealized, site-soil-adjusted response spectrum with the same effective damping ratio and called the *demand spectrum*. Considering the effect of damping and site soil amplification, the demand spectrum is then related to a 5%-damped site-soil-adjusted response spectrum referred to as the *index spectrum*. The index spectrum has a constant-acceleration portion parameterized via its 5%-damped spectral acceleration response at 0.3 sec period denoted by S_a(0.3 sec, 5%), and a constant-velocity portion parameterized via S_a(1.0 sec, 5%). The relationships between the spectral acceleration response at 0.3 and 1.0 sec on both demand and index spectra, and whether the performance point lies on the constant-acceleration, or constant-velocity portions of the demand spectrum, depend on several parameters: the earthquake magnitude, M; fault distance, R; mean shearwave velocity in the top 30m of soil, Vs30; and whether the site is near a plate boundary or in a continental interior.

Probabilistic structural damage at the performance point is then calculated using fragility functions of the form:

$$
\begin{aligned}
P\left[D=d \middle| S_d = x\right] &= 1-\Phi\left(\frac{\ln\left[x/\theta_1\right]}{\beta_1}\right) && d=0 \\
&= \Phi\left(\frac{\ln\left[x/\theta_d\right]}{\beta_d}\right)-\Phi\left(\frac{\ln\left[x/\theta_{d+1}\right]}{\beta_{d+1}}\right) && 1 \le d \le 3 \\
&= \left(1-P_c\right)\Phi\left(\frac{\ln\left[x/\theta_4\right]}{\beta_4}\right) && d=4 \\
&= P_c\Phi\left(\frac{\ln\left[x/\theta_4\right]}{\beta_4}\right) && d=5
\end{aligned}
\qquad (3)
$$

where $P[D = d|S_d = x]$ denotes the probability of structural damage state, *d,* given that S_d takes on some particular value, *x*, and Φ denotes the cumulative standard normal distribution. The parameters θ_i, β_i, and P_c denote, respectively, the median and logarithmic standard deviation values of the component capacity to resist damage state, *i*, and the fraction of buildings in the complete damage state that are expected to be collapsed. Damage to the nonstructural drift-sensitive component is similar, except that only four damage states are considered. Damage to the nonstructural acceleration-sensitive component is also similar, again with only four damage states and instead of conditioning on S_d, it uses S_a as the input to the fragility functions.

An alternative to Equation 3 can be formulated, wherein collapse fragility is explicitly modeled, as in

$$
\begin{aligned}
P\left[D=d \middle| S_d = x\right] &= 1-\Phi\left(\frac{\ln\left[x/\theta_1\right]}{\beta_1}\right) && d=0 \\
&= \Phi\left(\frac{\ln\left[x/\theta_d\right]}{\beta_d}\right)-\Phi\left(\frac{\ln\left[x/\theta_{d+1}\right]}{\beta_{d+1}}\right) && 1 \le d \le 4 \\
&= \Phi\left(\frac{\ln\left[x/\theta_5\right]}{\beta_5}\right) && d=5
\end{aligned}
\qquad (4)
$$

where θ_5 and β_5 represent median and logarithmic standard deviation of spectral displacement associated with collapse (a damage state that applies only to the structural component). In either case, given structural response S_d and S_a, Equations 3 and 4 each produce a probability mass function for the damage state of the structural, nonstructural drift-sensitive, and nonstructural acceleration-sensitive building components. These uncertain damage states are denoted here by D_1, D_2, and D_3, respectively. With these probability mass functions available, the expected value of repair cost is calculated as

$$E\left[L\right]=\sum_{d=1}^{5}P\left[D_1=d\left|S_d=x\right.\right]L_{1d}+\sum_{d=1}^{4}P\left[D_2=d\left|S_d=x\right.\right]L_{2d}+\sum_{d=1}^{4}P\left[D_3=d\left|S_a=x\right.\right]L_{3d} \quad (5)$$

where L_{1d}, L_{2d}, and L_{3d} represent the repair cost to the same three components, given that the component is in damage state, d.

8.5 Parameter Values for CAPSS Index Buildings

Pushover curve parameters D_y, A_y, D_u, and A_u are taken from analysis by Cobeen (summarized in Appendix 4), and are recapped in Table 8-1, along with calculated elastic period, T_E, and ductility capacity, μ (=D_u/D_y). Units of D, A, T_E, and μ are inches, fraction of gravity, seconds, and unitless, respectively. Several checks

Table 8-1 Capacity Curve Parameters for Four Index Buildings

Index Building	D_y	A_y	D_u	A_u	T_E	μ
Building 1. 3-story corner building one side > 80% open no walls between garages	0.57	0.06	0.76	0.08	1.00	1.32
Index Building 1 Retrofit 1. New wood shearwalls at garage end walls, steel frames at garage doors	0.70	0.08	1.41	0.13	0.92	2.02
Index Building 1 Retrofit 2. Ditto but new wood shearwalls at all ground-floor walls	0.34	0.23	0.95	0.37	0.39	2.79
Index Building 1 Retrofit 3. Ditto but cantilever columns at garage openings instead of moment frames	0.55	0.28	1.08	0.38	0.45	1.96
Building 2. 4-story corner building both sides > 50% open, walls between garages	0.51	0.05	0.71	0.06	1.00	1.38
Index Building 2 Retrofit 1. Ditto with new steel frames both facades	0.68	0.11	1.03	0.13	0.80	1.51
Index Building 2 Retrofit 2. Ditto but wood shearwalls all interior garage walls	0.84	0.20	2.09	0.31	0.65	2.49
2r3. Ditto but cantilever columns at garage openings instead of moment frames	0.99	0.23	2.62	0.37	0.67	2.64
Building 3. 4-story midblock building pre-WWII, front façade > 80% open	0.65	0.04	1.42	0.05	1.31	2.18
Index Building 3 Retrofit 1. Ditto, plus transverse wood-frame shearwalls	0.81	0.13	1.57	0.18	0.81	1.93
Index Building 3 Retrofit 2. Ditto, transverse steel frames and longitudinal shearwalls	0.84	0.19	1.60	0.25	0.68	1.90
Index Building 3 Retrofit 3. Ditto, cantilever columns not steel frames, more longitudinal shearwalls	0.84	0.23	1.69	0.30	0.61	2.01
Building 4. 3-story midblock 1950s building front façade > 80% open	0.11	0.02	0.84	0.06	0.75	7.75
Index Building 4 Retrofit 1. Ditto, plus wood-frame shearwalls on longitudinal end walls and back wall	0.29	0.11	0.76	0.17	0.53	2.65
Index Building 4 Retrofit 2. Ditto, plus steel moment frame at front	0.23	0.11	0.65	0.17	0.47	2.83
Index Building 4 Retrofit 3. Ditto, but cantilever columns inboard instead of steel moment frame at front	0.23	0.11	0.65	0.17	0.47	2.83

imply internal consistency and reasonable comparison with HAZUS®-MH, as follows:

1. Ultimate strengths (A_u) increase with retrofit level;
2. Periods generally decrease with retrofit, though Index Building 1 Retrofit 3 has slightly longer period than Index Building 1 Retrofit 2, as does Index Building 2 Retrofit 3 versus Index Building 2 Retrofit 2, which at first glance appears questionable, given the greater number of columns with roughly same member size (W10x45) as columns in the bents (W10x45 and W12x45 in Building 1 Retrofit 3 and Building 2 Retrofit 3, respectively), and the presumably nearly fixed base of the W10 cantilever columns.
3. Ductility capacity D_u/D_y generally increases, from 1.3 to 2.8, though D_u/D_y drops from Index Building 1 Retrofit 2 to Index Building 1 Retrofit 3.
4. Ultimate strengths for as-is Building Index1 and as-is Building Index 2 are 25-33% that of HAZUS®-MH values for W2 pre-code (A_u = 0.25g), which seems reasonable.
5. Ultimate strengths for Index Building 1 Retrofit 3 and Index Building 2 Retrofit 3 are between W2 low-code and moderate-code (A_u = 0.25g and 0.5g, respectively), which seems reasonable.
6. Periods for as-is Building Index 1, Index Building 1 Retrofit 1, and all variants of as-is Building Index 2 are longer than HAZUS®-MH W2, which has T_E = 0.4, despite comparable height. However, HAZUS®-MH W2 assumes two 12-foot stories, so perhaps half the mass per square foot above first story, ~1-2x stiffness per square foot at first story, and no soft-story, so one would expect periods of 1.4 to 2.8 times longer than HAZUS®-MH W2 for the as-is buildings, which is what is observed.
7. Ductility capacities are small compared with all HAZUS W2 even pre-code, which has D_u/D_y = 15. However the HAZUS®-MH figure seems unrealistic.

Median capacities for the drift-sensitive components are taken from Porter (2009b, see Appendix 7) and are recapped in Table 8-2. Since the mapping from observable damage states to HAZUS®-MH damage states was shown to be uncertain, a second alternative for median capacities is shown in Table 8-3. Other values are taken as the HAZUS®-MH defaults, as recapped in Table 8-2.

8.6 Results

The methodology presented in Porter (2009b,c) and summarized above was employed to develop a vulnerability function for each of the Index Buildings listed in Table 8-1. The calculations were performed for every combination of 16 variants of the Index Buildings, one occupancy type (multi-family residential, denoted by RES3 in HAZUS®-MH), 5 NEHRP site soil classes (A, B, C, D, and E), four earthquake magnitudes (5, 6, 7, and 8), four site distances (10, 20, 40, and 80 km), and one seismic region: western United States. The mean damage factor results are compiled in a database table laid out as shown in Table 8-4. The fragility results are compiled in a database table laid out as shown in Table 8-5.

Table 8-2 Parameters Employed in Study, Alternative 1

Parameter		Source
κ_S	Degradation factor short-duration event (M ≤ 5.5)	IB1-3 as-is: 0.40 = HAZUS®-MH wood frame > 5000 sq. ft. pre-code Retrofits 1-3: 0.60, 0.80, 0.90 resp. = low-, mod-, high-code IB4 as is: 0.80 = HAZUS®-MH wood frame > 5000 sq. ft.mod code IB4 retrofit 1: 0.85, retrofits 2-3: 0.90 = ditto, high code
κ_M	Ditto, medium duration (5.5 < M < 7.5)	IB1-3 as-is: 0.2, retrofit 1: 0.3, retrofit 2: 0.4, retrofit 3: 0.6 IB4 as-is: 0.4, retrofits 1: 0.5, retrofits 2-3: 0.6
κ_L	Ditto, long duration (M ≥ 7.5)	IB1-3 as-is: 0.0, retrofit 1: 0.1, retrofit 2: 0.2, retrofit 3: 0.4 IB4 as-is: 0.2, retrofits 1: 0.3, retrofits 2-3: 0.4
B_E	Elastic damping ratio	Porter *et al*. (2002): 10%, from system identification of strong-motion records from several California wood-frame buildings
θ_{11}	Median S_d where structural component reaches or exceeds “slight” damage	IB1-3: Porter (2009a): 0.06 in; from lab tests of older materials IB4: 0.86 in. = HAZUS®-MH for mod-code wood frame > 5000 sq. ft.
θ_{12}	Ditto, moderate	IB1-3: Ditto, 0.4 in. for buildings with brick veneer, else 1.2 in. IB4: 2.14 in. = HAZUS®-MH for mod-code wood frame > 5000 sq. ft.
θ_{13}	Ditto, extensive	IB1-3: Ditto, 1.2 in. IB4: 6.62 in. = HAZUS®-MH for mod-code wood frame > 5000 sq. ft.
θ_{14}	Ditto, complete	IB1-3: Ditto, 2.5 in. IB4: 16.2 in. = HAZUS®-MH for mod-code wood frame > 5000 sq. ft.
P_c	Fraction of building area collapsed, given complete damage	IB1-2 as-is: 14%, from San FranciscoMarina District 1989 IB1-2 retrofits 1-3: 6%, 1.5%, 1.5%, respectively IB3-4 as-is: 3%, retrofits 1-3: 2%, 1.5%, 1% respectively
θ_{21}	Median S_d for slight nonstructural drift-sensitive damage	Taken same as θ_{11}
θ_{22}	Ditto, moderate	Taken same as θ_{12}
θ_{23}	Ditto, extensive	Taken same as θ_{13}
θ_{24}	Ditto, complete	Taken same as θ_{14}

Note: IB = Index Building

Table 8-2 Parameters Employed in Study, Alternative 1 (continued)

	Parameter	Source
θ_{31}	Ditto, S_a, nonstructural acceleration-sensitive, slight	HAZUS®-MH default for wood frame > 5000 sq. ft.: 0.2g
θ_{31}	Ditto, S_a, nonstructural acceleration-sensitive, slight	HAZUS®-MH default for wood frame > 5000 sq. ft.: 0.2g
θ_{32}	Ditto, moderate	Ditto: 0.4g
θ_{33}	Ditto, extensive	Ditto: 0.8g
θ_{34}	Ditto, complete	Ditto: 1.6g
β_{11}	Log standard deviation of S_d where structural component reaches or exceeds "slight" damage	Ditto: 1.0
β_{12}	Ditto, moderate	Ditto: 1.0
β_{13}	Ditto, extensive	Ditto: 1.0
β_{14}	Ditto, complete	Ditto: 1.0
β_{21}	Ditto, nonstructural drift-sensitive, slight	Ditto: 1.0
β_{22}	Ditto, moderate	Ditto: 1.0
β_{23}	Ditto, extensive	Ditto: 1.0
β_{24}	Ditto, complete	Ditto: 1.0
β_{31}	Ditto, S_a, nonstructural acceleration-sensitive, slight	Ditto: 0.7
β_{32}	Ditto, moderate	Ditto: 0.7
β_{33}	Ditto, extensive	Ditto: 0.7
β_{34}	Ditto, complete	Ditto: 0.7
L_{11}	Repair cost, structural, slight, fraction of replacement cost	HAZUS®MH default for multi-family dwelling: 0.003
L_{12}	Ditto, moderate	Ditto: 0.014
L_{13}	Ditto, extensive	Ditto: 0.069
L_{14}	Ditto, complete	Ditto: 0.138
L_{15}	Ditto, collapse	Ditto: 0.138
L_{21}	Ditto, nonstructural drift-sensitive, slight	Ditto: 0.009
L_{22}	Ditto, moderate	Ditto: 0.043
L_{23}	Ditto, extensive	Ditto: 0.213
L_{24}	Ditto, complete	Ditto: 0.425
L_{31}	Ditto, nonstructural acceleration-sensitive, slight	Ditto: 0.008
L_{32}	Ditto, moderate	Ditto: 0.043
L_{33}	Ditto, extensive	Ditto: 0.131
L_{34}	Ditto, complete	Ditto: 0.437

In Table 8-4, the record is interpreted this way: if a CAPSS Index Building 1 were standing on site class E in the western United States, and it were shaken at intensity S_a(1.0 sec, 5%) = 0.16g, then on average, the repairs would cost 28% of the replacement cost of the building. "M" (magnitude) and "R" (distance) are used only

Table 8-3 Fragility Parameters Employed in Study, Alternative 2

Parameter		Source
θ11	Median S_d where structural component reaches or exceeds "slight" damage	IB1-3: Porter (2009a): 0.4 in; from lab tests of older materials IB4: 0.86 in. = HAZUS®-MH for mod-code wood frame > 5000 sq. ft.
θ12	Ditto, moderate	IB1-3: Ditto, 1.5 in. for buildings with brick veneer, else 1.2 in. IB4: 2.14 in. = HAZUS®-MH for mod-code wood frame > 5000 sq. ft.
θ13	Ditto, extensive	IB1-3: Ditto, 3.0 in. IB4: 6.62 in. = HAZUS®-MH for mod-code wood frame > 5000 sq. ft.
θ14	Ditto, complete	IB1-3: Ditto, 5.0 in. as-is, 8 in retrofit IB4: 16.2 in. = HAZUS®-MH for mod-code wood frame > 5000 sq. ft.
θ15	Ditto, collapse	IB1-3: 13 in. IB4: 24 in. = 1.5 x θ14
θ21	Median S_d for slight nonstructural drift-sensitive damage	Taken same as θ11
θ22	Ditto, moderate	Taken same as θ12
θ23	Ditto, extensive	Taken same as θ13
θ24	Ditto, complete	Taken same as θ14
θ31	Ditto, S_a, nonstructural acceleration-sensitive, slight	HAZUS®-MH default for wood frame > 5000 sq. ft.: 0.2g
θ32	Ditto, moderate	Ditto: 0.4g
θ33	Ditto, extensive	Ditto: 0.8g
θ34	Ditto, complete	Ditto: 1.6g

Note: IB = Index Building

Table 8-4 Sample Layout of Vulnerability-Function

IB	Occ	Domain	M	R	Siteclass	IM	$S_S F_a$	$S_1 F_v$	L
CAPSS1	RES3	WUS	7	80	E	Sa10	0.25	0.16	0.28
CAPSS1	RES3	WUS	7	80	E	Sa10	0.28	0.19	0.33

Notes:

IB: Index Building (e.g., CAPSS1r1 = CAPSS Index Building 1, retrofit 1).
Occ: HAZUS occupancy class (e.g., RES3 = multi-family dwelling).
Domain: whether the function is appropriate for western United States ("WUS") or central and eastern US ("CEUS")—only WUS is used here.
M: approximate magnitude.
R: approximate distance to the earthquake source zone.
Siteclass: NEHRP site soil classification (A, B, C, D, or E).
IM Performance point indicator.
$S_S F_a$,: 5%-damped, site-soil-adjusted spectral accel. response at 0.3 sec period.
$S_1 F_v$,: 5%-damped, site-soil-adjusted spectral accel. response at 1.0 sec period.
L: mean damage factor, which here gives the expected value of repair cost as a fraction of replacement cost new.

Table 8-5 Sample Layout of Fragility-Function[a]

IB	Occ	Domain	M	R	Siteclass	IM	S_SF_a	S_1F_v	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
CAPSS1	RES3	WUS	7	80	E	Sa10	0.25	0.16	1.00	0.92	0.61	0.32	0.03
CAPSS1	RES3	WUS	7	80	E	Sa10	0.28	0.19	1.00	0.95	0.69	0.41	0.04

[a] Note: See Table 8-4 for definitions of parameter in columns 1 through 10 (from left); P11 through P15 refer to the probability that the structural component reaches or exceeds damage states 1 through 5: slight, moderate, extensive, complete, and collapse, respectively.

for spectral shape and duration effects, and “IM” indicates whether the performance point corresponds to a point on the constant-acceleration portion of the index spectrum (“Sa03”) or on the constant-velocity portion of the index spectrum (“Sa10”) and therefore, which of the two subsequent intensity measures is probably more appropriate to use to estimate loss:. Each record in Table 8-4 is only valid for an earthquake of magnitude between 6.5 and 7.5, at a distance of roughly 80 km. The record also says that the same loss could be expected for S_a(0.3 sec, 5%) = 0.25g, but that one should probably use S_a(1.0 sec, 5%) as the intensity measure instead.

In Table 8-5, P11 through P15 refer to the probability that the structural component reaches or exceeds damage states 1 through 5: slight, moderate, extensive, complete, and collapse, respectively. The first record means that the building is almost certainly damaged at least slightly when shaken at S_a(1.0 sec, 5%) = 0.16g, that there is 92% probability of at least moderate damage, 61% probability of extensive damage, 32% probability of complete damage, and that 3% of building area at this level of shaking would be collapsed.

The resulting data tables are too voluminous to present here, but some sample, summary charts are provided in Figure 8-6. The vulnerability functions show mean damage factor on the y-axis as a function of 1.0-sec, 5%-damped spectral acceleration response on the x-axis. “Mean damage factor” refers to the average repair cost as a fraction of the replacement cost (new, not depreciated) of the building. The x-axis is limited to 1.0g (roughly six times the shaking in the Marina District in the 1989 Loma Prieta earthquake) because this is the largest shaking estimated by the CAPSS hazard modeler Treadwell and Rollo (authors of Appendix 6) anywhere in San Francisco, in the earthquake scenarios that they examined. The vulnerability functions show that the retrofits generally reduce damage by up to 30-70% depending on shaking intensity, but that the benefit is limited when S_a(1.0 sec, 5%) exceeds about 0.5g (roughly three times the shaking experienced in the Marina District in the 1989 Loma Prieta earthquake).

The vulnerability functions shown here are labeled M = 7, R = 10 km, soil = D, because the HAZUS®-MH methodology holds that these parameters affect the shape of the response spectrum and effective damping and thus, they affect structural response, damage, and loss. The vulnerability functions shown in Figure 8-6 are limited to $5.5 < M < 7.5$, $R \leq 15$ km, and the average shearwave velocity in the top 30 m of soil is limited to the range $600 \leq Vs30 \leq 1200$ ft/sec.
The vulnerability functions asymptote to a mean damage factor near 0.6. The reason stems from the fact that the Index Buildings have low values for A_u, as low as 0.05g for one Index Building and in no case higher than 0.4g. Under the capacity spectrum method of structural analysis, the building cannot experience acceleration greater

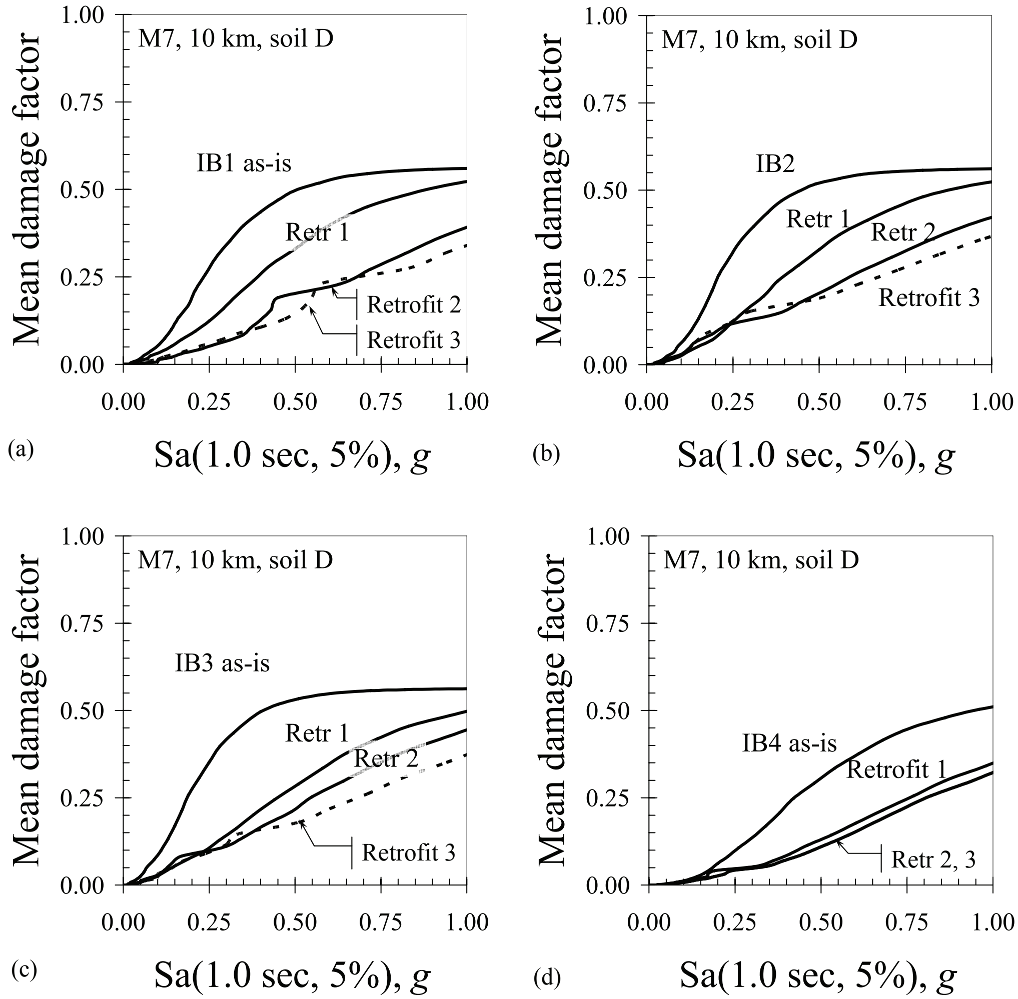


Figure 8-6 Vulnerability functions for Index Buildings 1-4 under the more conservative (lower-loss) fragility alternatives: (a) Index Building 1 (IB1), (b) Index Building 2 (IB2), (c) Index Building 3 (IB3), and (d) Index Building 4 (IB4). The x-axis shows 1-sec, 5% damped spectral acceleration response on NEHRP site class D. The y-axis shows damage factor, which is the average repair cost as a fraction of the replacement cost of the building.

than A_u. The building's acceleration-sensitive nonstructural components, which represent 44% of building value, cannot experience acceleration greater than A_u. The HAZUS®-MH default fragility functions for these components have median capacities of 0.2g for slight damage, 0.4g for moderate damage, and 0.8 and 1.6g for extensive and complete damage. Consequently, there is a low probability that this 44% of building value ever experiences greater than slight or moderate damage, associated with loss of 0.8% and 4.3% of building value, respectively. As a result, there is a low probability that the total repair cost ever exceeds 60% of building replacement cost. Presumably the acceleration-sensitive building components in the ground story are destroyed if the ground story collapses, but this fact is not addressed in FEMA (2003a).

Another notable feature of the vulnerability functions is that they are sometimes not smooth. The wiggles in these curves are artifacts of the fact that the estimated loss is actually a function of two measures of ground motion: S_a(0.3 sec, 5%) and S_a(1.0 sec, 5%). At low levels of ground motion, S_a(0.3) controls the structural response and is used as the intensity measure for purposes of calculating damage and loss; at higher levels, S_a(1.0) controls and is used. The wiggles in the plots of loss versus S_a(1.0) occur at the transition between the two domains. In practice, and as applied here, the proper intensity measure is used.

Not shown in the sample vulnerability functions but apparent in the tables, is that magnitude has a significant impact on loss given S_a, largely because of its modeled impact on effective damping. Distance and site soil class make little difference given M and S_a, largely because at fixed values of M and S_a, distance and site class primarily affect the period at the intersection between the constant-acceleration and constant-velocity portions of the response spectra, which rarely matters. S_a(1.0 sec, 5%) is usually the preferred intensity measure, i.e., the performance point is usually on the constant-velocity portion of the demand spectrum.

Figure 8-7 shows the red-tag fragility functions for these sixteen variants of the four Index Buildings. It suggests, for instance, that when Index Buildings 1 or 2 are subjected to $S_a(1.0) \approx 0.17$g, as estimated from the USGS *ShakeMap* of the Marina

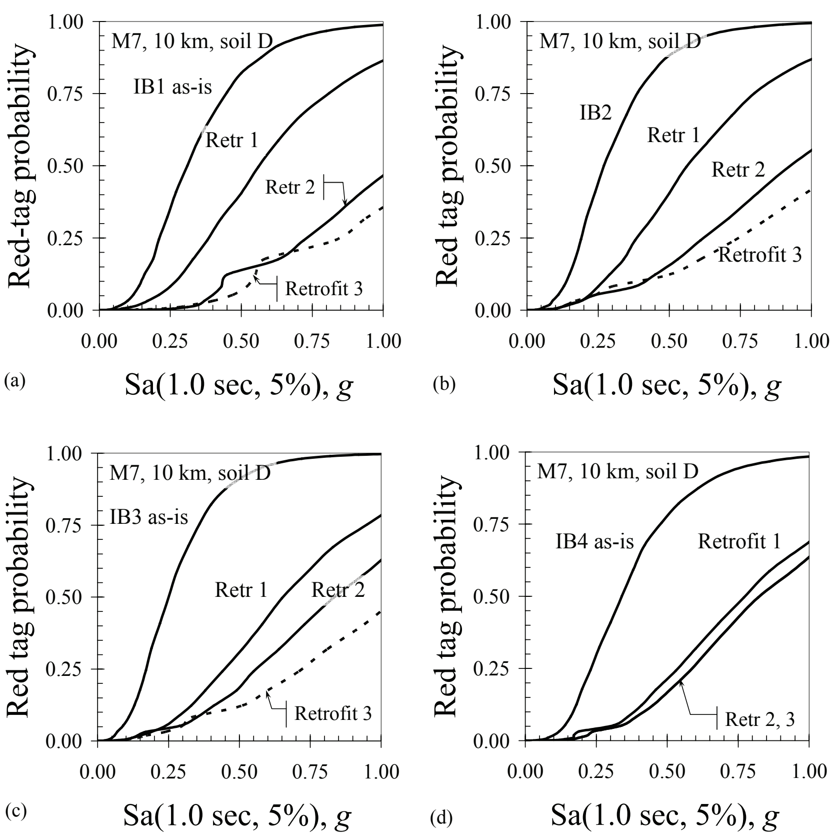


Figure 8-7 Post-earthquake red-tag probability as a function of spectral acceleration, Sa(1.0 sec, 5% damped), for (a) Index Building 1 (IB1), (b) Index Building 2 (IB2), (c) Index Building 3 (IB3), and (d) Index Building 4 (IB4).

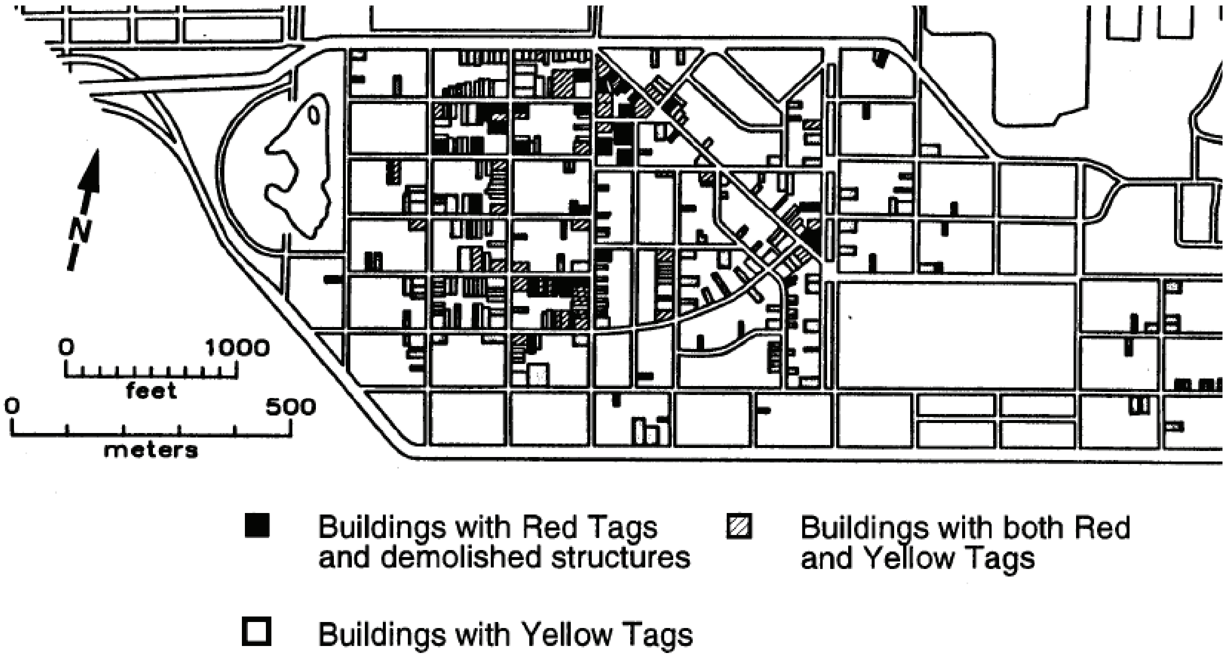


Figure 8-8 Post-earthquake safety tags in the San Francisco Marina District after the 1989 Loma Prieta earthquake (Seekins et al., 1990 via Scawthorn et al., 1992).

District in the 1989 Loma Prieta earthquake, then approximately 20% to 25% would be red-tagged. A San Francisco Department of Building Inspection (DBI) database lists 111 soft-story corner buildings in the Marina District. One would therefore estimate approximately 22 to 28 red tags in corner soft-story buildings in the Marina in 1989. There appear to have been about 33, as shown in Figure 8-8, suggesting an underestimate but perhaps reasonable agreement. Figure 8-9 shows collapse probability for the Index Buildings. At $S_a(1.0) \approx 0.17$g, one would expect a 5 to 10% collapse rate among the approximately 111 corner soft-story buildings in the Marina. There were six, again suggesting reasonable agreement.

8.7 Conclusions

A set of relationships between shaking intensity, damage, and loss was created for four buildings that are characteristic of soft-story multi-family wood-frame dwellings in San Francisco. Vulnerability and fragility functions were also created for three retrofits of each building, for a total of sixteen variants of the four Index Buildings described in Appendix 4. The relationships were calculated using the HAZUS®-MH framework (FEMA, 2003a). While simpler and offering less fidelity than a second-generation performance-based earthquake engineering model, the HAZUS®-MH methodology has been shown in several instances to produce realistic aggregate results. (A second-generation performance-based earthquake engineering approach would employ a multi-degree-of-freedom structural model examined using nonlinear dynamic structural analysis, along with disaggregated fragility functions, damage, and loss estimates, but would have exceeded the available resources for this project.)

A vulnerability-calculation procedure was applied that honors all HAZUS®-MH methodologies, while avoiding the iteration of the capacity spectrum method and a programming error recently discovered in the HAZUS®-MH Advanced Engineering

Building Module. The results appear to hindcast reasonably the experience of corner soft-story apartment buildings in the Marina District in the 1989 Loma Prieta earthquake.

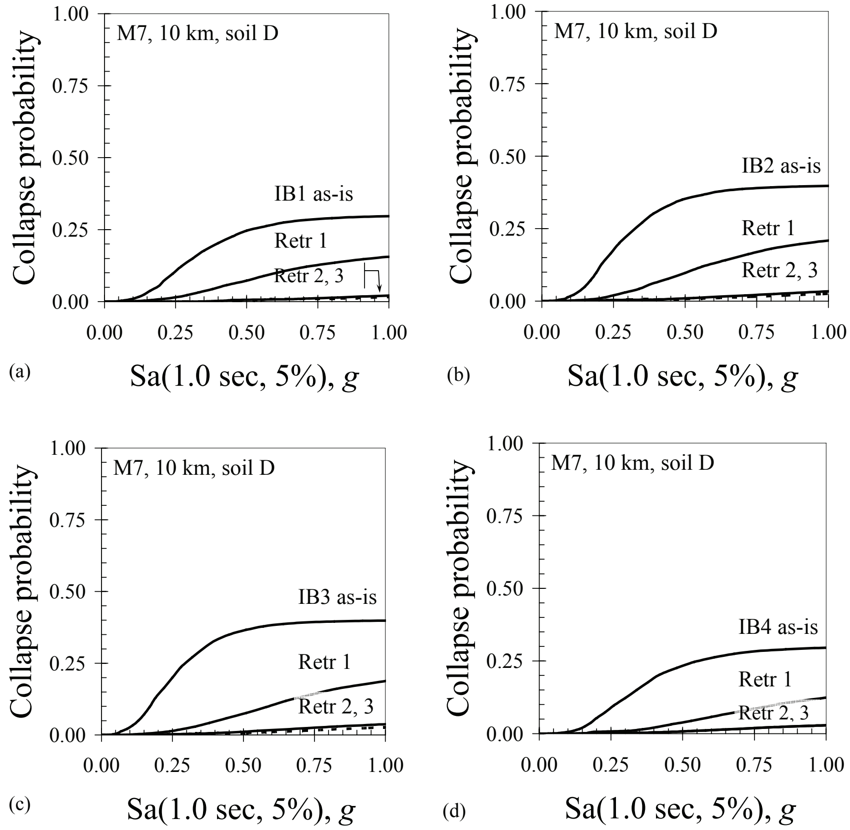


Figure 8-9 Collapse probability as a function of spectral acceleration, Sa(1.0 sec, 5% damped) for (a) Index Building 1 (IB1), (b) Index Building 2 (IB2), (c) Index Building 3 (IB3), and (d) Index Building 4 (IB4).

APPENDIX 9: ESTIMATES OF EARTHQUAKE SCENARIO LOSSES TO LARGE SOFT-STORY WOOD-FRAME BUILDINGS IN SAN FRANCISCO

9.1 Executive Summary

San Francisco has 2,800 wood-frame, soft-story buildings with at least three stories and five dwellings each. “Soft-story” means that the lowest story is much weaker or more flexible than those above it. Here, that means that one ground-story façade is at least 80% open (i.e., the wall has window and door openings covering at least 80% of the gross area of the ground-story façade), or that two are at least 50% open. These buildings, which perform poorly in earthquakes, house 58,000 people—8% of the population—in 29,000 dwelling units. To inform public policy, a study for San Francisco’s Community Action Plan for Seismic Safety (CAPSS) quantified the risk. The impacts on these buildings were estimated for four large, hypothetical, realistic earthquakes.

In one scenario (a magnitude 7.2 earthquake on the San Andreas fault), 80% of these buildings are expected to be posted unsafe to occupy, and 30% are expected to collapse—that is, in just this one class, over 2,000 buildings are expected to be posted unsafe (rendering 46,000 persons homeless) and over 800 buildings (housing 17,000 persons) are expected to collapse. These results seem realistic: average shaking Citywide in this scenario is expected to be four times stronger than in the Marina District in the 1989 Loma Prieta earthquake, where approximately one in four corner soft-story apartment buildings were posted as unsafe to enter or occupy (red-tagged) or collapsed.

Retrofitting ground stories with cantilever steel columns and wood sheathing reduces red tags to fewer than 10%. It reduces collapses to fewer than one in one hundred. Retrofitting of these buildings would cost $260 million, equivalent to $10,000 to $20,000 per dwelling unit, depending on building details. The methodology is validated by comparison to actual experience in the 1989 Loma Prieta earthquake.

9.2 Objectives and Scope of Work

Soft-story conditions make wood-frame buildings significantly more vulnerable. Buildings like these collapse at lower excitation than do other wood-frame buildings of comparable size. To quantify the number of such buildings in San Francisco, volunteer structural engineers working under the direction of the San Francisco Department of Building Inspection (DBI) performed a sidewalk survey of at least 4,400 residential wood-frame buildings in the city, in order to ascertain a number of potentially seismically important parameters: height, number of housing units, evidence of retrofit, corner versus mid-block location, sloped versus level site, first story use, and openness of each ground-level façade. To this database was added information from the county tax assessor and from a Dun & Bradstreet database: square footage, year built, number of businesses, and number of employees.

The efforts (described in this appendix) to quantify the risk that these buildings pose in large San Francisco earthquakes were undertaken at the direction of Mayor Gavin Newsom. The study objective was to estimate the damage and potential repair costs in each of several scenario earthquakes and to quantify costs and benefits that might result from practical seismic rehabilitation to these buildings.

The work considered only those buildings that have three or more stories, five or more housing units, and soft-story conditions meeting either of two criteria: at least 80% open on one street-level façade or at least 50% open on two. This subset of buildings contains 29,000 housing units (7% of the total in San Francisco) and is home to 58,000 residents—8% of the city's population—along with 2,100 businesses and 6,900 employees.

9.3 Available Methodologies

Several methodologies exist to estimate earthquake risk. Commercial loss-estimation firms such as RMS, EQECAT, and AIR offer proprietary loss-estimation models, based in part on empirical seismic vulnerability functions developed from earthquake experience of various insurance companies. In general, however, these seismic vulnerability functions lack resolution of various categories of soft-story wood-frame construction with or without various seismic retrofit options, and they are generally unavailable for open review.

Early among open models (i.e., models whose derivation and parameter values are available for review), the ATC-13 effort led by the Applied Technology Council (ATC, 1985) developed probabilistic relationships between shaking intensity, measured in terms of Modified Mercalli Intensity (MMI), and the probability of each of 38 general building classes entering each of 7 discrete damage states (defined in terms of damage factor, meaning the repair cost as a fraction of replacement cost). The ATC-13 damage-probability matrices (DPMs) were derived from a modified Delphi process, in which multiple experts rendered initial judgments about seismic vulnerability, self-judged their level of expertise, and revised the initial estimates based on a review of estimates by others, to provide a basis for reconciling significant differences among experts. Their judgments were combined to create weighted average DPMs and relationships between MMI and the conditional probability distribution of damage factor. The ATC-13 methodology does not distinguish between varieties of wood-frame buildings, however, and cannot resolve the effects of soft-story construction or seismic retrofit.

The HAZUS®-MH methodology (FEMA, 2003a) was developed during the 1990s with the support of the Federal Emergency Management Agency (FEMA), and it reflects performance-based earthquake engineering principles. Instead of relying on expert opinion to relate shaking intensity directly to damage and loss, the HAZUS®-MH methodology applies engineering principles: it idealizes a building as a single-degree-of-freedom nonlinear damped harmonic oscillator, and applies the capacity spectrum method (CSM) of structural analysis to estimate the building's structural response in a particular earthquake. It applies relationships between structural response and damage developed from laboratory tests and earthquake experience, in order to estimate the probabilistic damage state of the building's various components, and it applies estimates of repair cost given each level of damage. HAZUS®-MH differentiates among eight classes of wood-frame construction based on size (two categories) and code era (four categories). It does not address soft-story construction or the benefits to be derived from various seismic retrofit options.

The HAZUS®-MH Advanced Engineering Building Module (AEBM; FEMA, 2003b) is software developed to model the seismic performance of individual buildings, by allowing the user to input the values of the various parameters of structural performance, damage, and loss. These are the same parameters as are used in the main HAZUS®-MH methodology (FEMA, 2003b), which provides some guidance on how to develop these parameters. The AEBM software has been found to have a programming flaw that causes it not to follow the HAZUS®-MH methodology accurately. As of this study, the frequency with which the flaw occurs has not been definitively established, nor had the severity of the error, when it does.

For this study, an adaptation of the HAZUS®-MH methodology was developed that honors all HAZUS®-MH principles but avoids the iteration sometimes required in the CSM, and that performs the calculations outside of HAZUS®-MH or the AEBM, thus avoiding the programming flaw. The methodology, detailed in Porter (2009c, d) and summarized in Appendix 8 of this volume, can be performed in a spreadsheet, database, or other programming environment. The methodology has been peer reviewed by six engineers and independently validated by three people. It produces tables relating probabilistic damage state and mean damage factor to shaking intensity in terms of $S_a(0.3, 5\%)$ and $S_a(1.0, 5\%)$, conditioned on magnitude, distance range, site soil classification, occupancy category, and seismic domain (plate boundary or continental interior). Mean damage factor is defined as the expected (average) repair cost as a fraction of replacement cost new. The adaptation of the HAZUS®-MH methodology developed for this study does not have the limitations of the foregoing models; rather, it has the capability to produce transparent and validated results.

9.4 Details of the Selected Methodology

Damage is estimated using Equation 9-1 and economic loss, according to Equation 9-2.

$$E\left[N_d\right] = \sum_{i=1}^{n} p_i\left[D = d \middle| S = s\right] \qquad (9\text{-}1)$$

$$E\left[L\right] = \sum_{i=1}^{n} R \cdot A_i \cdot y_i\left(s_i\right) \qquad (9\text{-}2)$$

In Equation 9-1, $E[N_d]$ refers to the expected value of the number of subject buildings in the study area that would be in damage state, *d,* after a given earthquake scenario. The damage states are red-tagging (e.g., posting a damaged building with a red UNSAFE ATC-20 placard), collapse, and the structural and nonstructural drift-sensitive damage states of HAZUS®-MH. See FEMA (2003a) or Kircher et al. (1997) for detail on the latter damage states. In the equation, n is the number of buildings under consideration, and $p_i[D = d|S = s]$ refers to the probability that the i^{th} building is in damage state d, given that it is subjected to shaking intensity s. In Equation 9-2, $E[L]$ refers to the expected value of repair cost L in a given earthquake scenario, R is the estimated replacement cost per square foot, A_i is the square footage of the i^{th} building, and $y_i(s_i)$ is the mean damage factor to the i^{th} building (damage factor means repair cost as a fraction of building replacement cost new), given that it is subjected to shaking of intensity s_i. Shaking intensity is measured either in terms of

S_a(0.3 sec, 5%) or S_a(1.0 sec, 5%), depending on whether a capacity-spectrum-method analysis indicates the performance point lies on the constant-acceleration or constant-velocity portion of an idealized acceleration response spectrum. See Porter (2009c) for more detail on that issue. In most cases relevant here, the performance point lies on the constant-velocity portion of the response spectrum.

9.5 Methodology Application to San Francisco Soft-Story Dwellings

Characteristics and Distribution of Index Buildings. The locations and square footage of each subject building were taken from the DBI database described in Appendix 1. Analysis of the San Francisco Department of Building Inspection database indicated that there are an estimated 29,000 housing units in 2,800 large wood-frame buildings with soft-story conditions. “Large” here means three or more stories and five or more housing units, and “soft-story” means that the building meets either or both of two criteria: one ground-story façade is at least 80% open, or two are each at least 50% open. They house approximately 58,000 people, representing 8% of the population and 7% of its stock of housing units.

Cobeen (see Appendix 4) designed four prototypical Index Buildings to represent the range of housing addressed here (Figure 9-1). The designs and three retrofits each were selected in consultation with DBI and consulting structural engineers. Each building in the exposed building stock was associated with the damageability information described in Appendix 7, as follows.

- Index Building 1 (IB1): This is a three-plus story corner building with garage openings on one side of the building only. Therefore, corner wood-frame buildings in the DBI database were associated with IB1 when they met the CAPSS “Significant Ground Floor Openings” criterion 1 (80% or more open on any one side), but did not meet criterion 2 (50% or more open on any two sides).
- Index Building 2 (IB2): This is a three-plus story corner building with ground-story openings for garages on two sides of the building. Corner wood-frame buildings in the DBI database were associated with IB2 when they met criterion 2 (at least 50% open on any two sides).
- Index Building 3 (IB3) is a mid-block structure built before 1950, which most likely has straight sheathing on the exterior wall and wood lath and plaster interior wall finish. Accordingly, mid-block soft-story buildings with three-plus stories and five-plus housing units, built before 1950 were associated with IB3.
- Index Building 4 (IB4) is a mid-block post-1950 building. The most important feature of IB4 is plywood sheathing on exterior walls and gypsum-board interior wall finish. IB4 is therefore likely to be stiffer, stronger, and more damage resistant than IB3. Therefore, mid-block soft-story buildings with three-plus stories and five-plus housing units built after 1950 were associated with IB4.

By associating buildings in the DBI database with Index Buildings 1 through 4 on this basis, it was found that the total building area is fairly evenly distributed among the four Index Buildings: 19% are Index Building 1, 25% are Index Building 2, 35% are Index Building 3, and 21% are Index Building 4. Most of the area is built at a location whose NEHRP site soil classification is D. The distribution of Index

Buildings and site conditions by type replacement cost, percent of dwelling units, percent of area and value are summarized in Table 9-1.

(1) (2) (3) (4)

Figure 9-1 CAPSS Index Buildings. Four older, soft-story, wood-frame, multi-family dwellings representing a realistic range of performance of buildings of this class in San Francisco: (1) corner, 3 story, no interior walls at garage level, one street facade ≥ 80% open at ground floor; (2) corner, 4 story, both street facades ≥ 50% open at ground floor; (3) mid-block, 4 story, pre-WWII, neighbors on both sides; (4) mid-block, 3 story, post-1950, neighbors on both sides. Square footage is 3,600, 5,800, 2,300, and 1,800 sq. ft., respectively.

Table 9-1 Area and Replacement Cost by Index Building and Site Class

Index Building (IB) / Site Class	Replacement Cost, $Billions	Percent of Units	Percent of Area and Value
IB1	$2.8	20%	19%
IB2	$3.5	26%	25%
IB3	$4.9	33%	35%
IB4	$3.0	21%	21%
Site class B	$1.6	10%	10%
Site class C	$1.2	8%	8%
Site class D	$10.5	73%	74%
Site class E	$1.1	8%	8%

Building adjacency. Several questions relating to building adjacency were considered: Do mid-block buildings, with buildings on either side to support them, actually collapse in earthquakes? Can they be modeled as Cobeen (Appendix 4) has done in the CAPSS study, as if they were freestanding, i.e., ignoring pounding? The issue of adjacency is important because this type of building appears to have collapsed in the 1906 San Francisco earthquake, based on the high number of mid-block wood-frame building collapses that appear in photographs of documents that archive the event: for example, Gilbert et al. (1907), Pierce et al. (1906), Klett and Lundgren (2006), and Tobriner (2006). Examples of such photographs are provided in Figure 9-2. However, it is unclear from most of the available photos how close the collapsed mid-block buildings were to their neighbors. The DBI database has no field for adjacency: the field surveyors did not record gap widths.

Based on the limited 1989 earthquake data available from the Marina District, where only one of the seven collapsed buildings was mid-block, it seems that mid-block soft-story buildings are less likely to collapse than are corner soft-story buildings, all else being equal. Ultimately a very simple approach was used here to deal with pounding and adjacency. The structural models described in Appendix 4 do not treat pounding or adjacency, and the loss model makes mid-block buildings less likely to collapse than corner buildings and at least as likely as the average pre-code one- or two-story wood-frame building. It does so by setting the vulnerability term, P_c (fraction of area collapsed in buildings with complete structural damage), for as-is Index Buildings 3 and 4 to the HAZUS®-MH default value of 3%, in contrast to the 10% figure used for corner buildings (see Appendix 7).

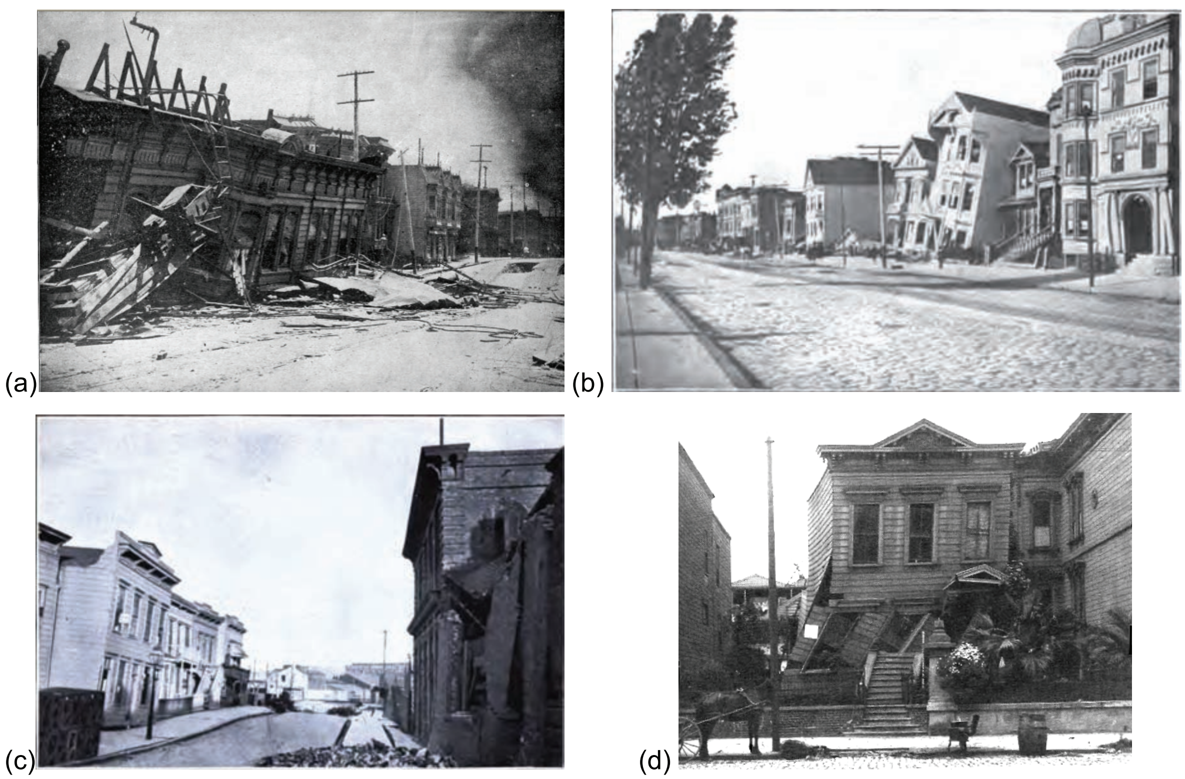


Figure 9-2 Collapses of large mid-block wood-frame building in the 1906 San Francisco earthquake: (a) Valencia St. Hotel (Pierce et al., 1906), (b) Howard St (Gilbert et al., 1907), (c) Dore St. between Bryant and Brannan (Gilbert et al., 1907), (d) unknown location, where collapse is associated with “cripple-wall and shear failure” (Tobriner, 2006).

Seismic Retrofits. As described in Appendix 4, three seismic retrofits were designed for each Index Building. The retrofits were designed to meet various performance objectives defined in SPUR (2008). Retrofit 1 is intended to meet SPUR performance category D, safe but not repairable, meaning that "Buildings may experience extensive structural damage and may be on the verge of collapse. They … are expected to receive a red tag (UNSAFE placard) after the expected earthquake." The "expected" earthquake is one that produces shaking with 10% exceedance probability in 50 years, and is approximated here by a magnitude 7.2 earthquake on the Peninsula segment of the San Andreas fault. Retrofit 1 generally comprises the addition of a steel frame at openings and some wood sheathing at existing walls. Retrofit 2 is intended to make the building meet SPUR performance category C, safe and usable after repair, meaning that the building "may experience significant structural damage that will require repairs prior to resuming unrestricted occupancy and therefore is expected to receive a yellow tag (RESTRICTED USE placard) after the expected earthquake." Retrofit 2 generally comprises the steel frame and more structural sheathing. Retrofit 3 is intended to make the building approximately satisfy SPUR performance category B, safe and occupiable during repair, meaning that "Buildings will experience damage and disruption to their utility services, but no significant damage to the structural system. They may be occupied without restriction and are expected to receive a green tag (INSPECTED placard) after the expected earthquake."

Detailed cost estimates (Appendix 5) of the retrofit designs (Appendix 4) indicate that the seismic retrofits would cost between $50,000 and $130,000 per building, as summarized in Table 9-2, or $6,000 to $30,000 per housing unit (apartment or condominium) per Table 9-3. The costs account for local construction costs, permit fees, removal and replacement of finishes and other materials at the ground floor during construction, and other contingencies. The costs do not include engineering design fees or business relocation or interruption expenses, and are appropriate for San Francisco construction in 2008. The detailed cost estimates of Appendix 5 are summarized in Table 9-2. It is noteworthy that retrofit 3, intended for better performance than retrofit 2, generally costs less. The total cost to retrofit all such buildings in the City is roughly $200 to 300 million, as shown in Table 9-4.

The Index Buildings have on average somewhat fewer dwellings per building than the average real building stock, and there are other differences between the Index Buildings and real building stock, so the real cost of retrofit per dwelling unit might differ somewhat from these figures, but a figure of $10,000 to $20,000 per dwelling unit agrees with the experience of several engineers consulted for this project.

Table 9-2 Summary of Retrofits Costs per Building

Retrofit	SPUR (2008) Performance Objective	Cost Per Building, $000			
		IB1	IB2	IB3	IB4
1. Steel frames, shearwalls	D, safe not repairable	$79	$71	$59	$49
2. Same, more shearwalls	C, safe, usable after repair	120	130	110	59
3. Cantilever columns + shearwalls	C or B, safe and usable during repair	110	110	96	58

Table 9-3 Retrofits Cost per Housing Unit (Using Number of Units per Index Building)

Retrofit	SPUR (2008) Performance Objective	Cost Per Unit, $000			
		IB1	IB2	IB3	IB4
1. Steel frames, shearwalls	D, safe but not repairable	$20	$6	$10	$12
2. Same, more shearwalls	C, safe and usable after repair	30	11	18	15
3. Cantilever columns + shearwalls	C or B, safe and usable during repair	28	9	16	15

Table 9-4 Total Estimated Retrofits Cost for All 2,800 Buildings

Retrofit	SPUR (2008) Performance Objective	Total Retrofit Cost, $ Million
1. Steel frames, shearwalls	D, safe but not repairable	$180
2. Same, more shearwalls	C, safe and usable after repair	$300
3. Cantilever columns + shearwalls	C or B, safe and usable during repair	$260

Shaking Intensity. During an earlier stage of the CAPSS project, Treadwell and Rollo estimated the shaking intensities across San Francisco for each of four scenario earthquakes: a magnitude 7.9 earthquake on the San Andreas fault, representing a repeat of the 1906 earthquake; a magnitude 7.2 event rupturing the Peninsula segment of the San Andreas fault; a magnitude 6.5 event on a smaller portion of the San Andreas fault, and a magnitude 6.9 event on the Hayward fault (see Appendix 6). The study predated the Next Generation Attenuation (NGA) relationships; see Power et al. (2008) for an overview of NGA. The authors used then-current leading attenuation relationships, an equally weighted average of the Abrahamson and Silva (1997), Campbell (1997), and Sadigh et al. (1997) relationships. They accounted for site soil amplification, using the median relationship for rock to reflect NEHRP site class B, the median relationship for soil to reflect site class D, and the average of the two to reflect site class C. The equally weighted average of the three relationships' median spectral acceleration response on rock, and the 1997 NEHRP amplification factors for site class E, were used to estimate shaking on site class E. The resulting maps of shaking intensity in terms of peak ground acceleration are shown in Figure 9-3. Maps measuring shaking in terms of 5%-damped, 0.3-sec and 1.0-sec spectral acceleration response were also generated, but are not shown here.

Treadwell and Rollo's estimates suggest average shaking on the order of S_a(1.0 sec, 5%) = 0.30g in the magnitude 6.9 Hayward fault event, 0.35g in the magnitude 6.5 San Andreas fault event, 0.50g in the magnitude 7.2 San Andreas fault event, and 0.67g in the magnitude 7.9 San Andreas fault event. "Average shaking" here means an equally weighted average of the S_a(1.0 sec, 5%) values estimated at the sites of each of the 2,800 large, soft-story wood-frame buildings considered in this study. For reference, the USGS ShakeMap for the 1989 Loma Prieta earthquake estimates that sites in the San Francisco Marina District on soft soil (NEHRP categories D or E) experienced roughly S_a(1.0 sec, 5%) = 0.17g, i.e., one-fourth to one-half the average citywide shaking of any of these four scenario events.

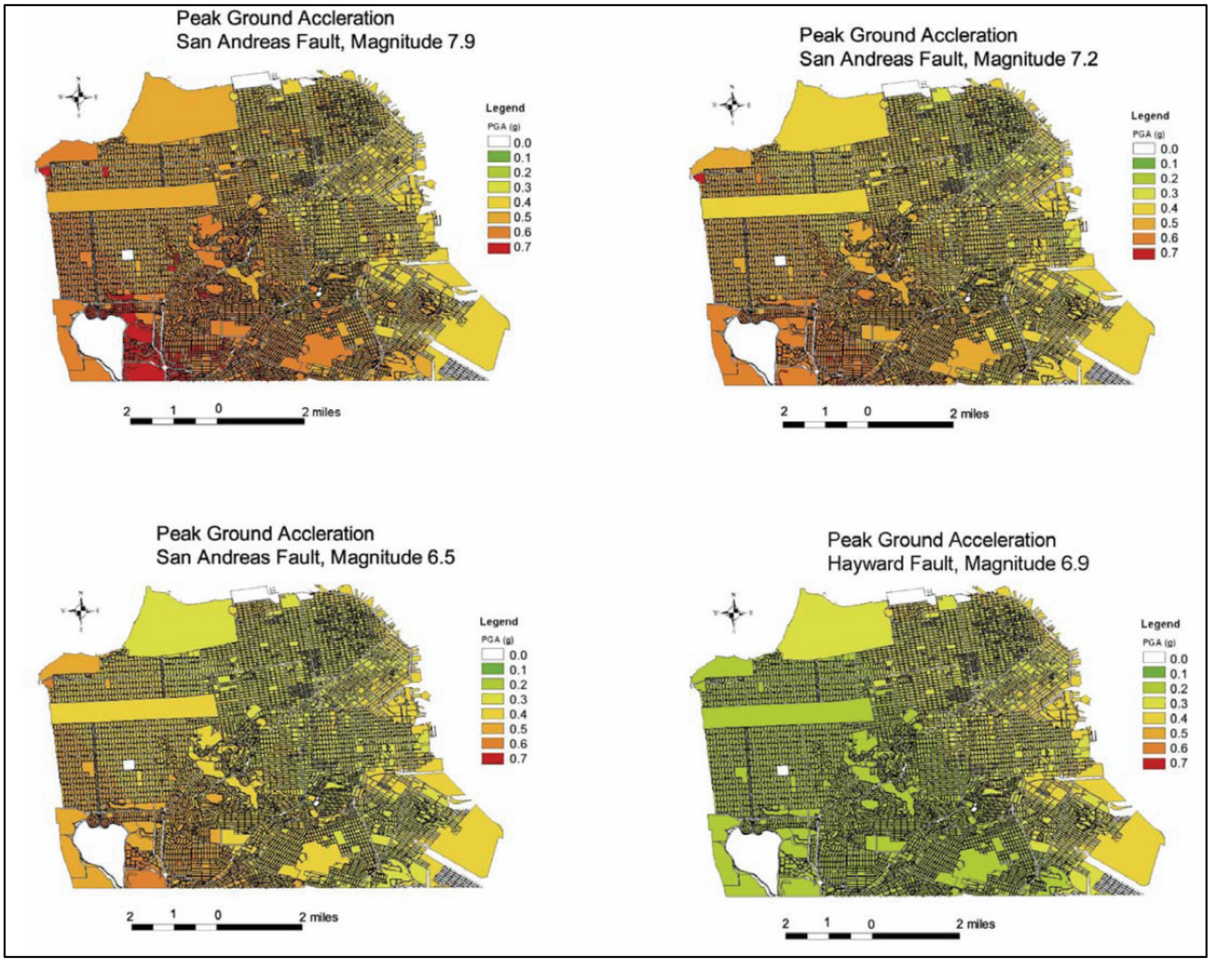


Figure 9-3 Shaking intensity in four scenario earthquakes. Source: internal ATC report prepared by Golesorkhi and Gouchon submitted to DBI in 2003 as one of the initial CAPSS project deliverables.

For reference, of the 111 corner, soft-story wood-frame buildings of three or more stories and five or more dwelling units in the Marina District that are shown in the DBI database, approximately 33 were red-tagged after the 1989 Loma Prieta earthquake (i.e., 30%), including 6 collapses (5%), per the map prepared by Seekins, Lew, and Kornfield (1990). Harris and Egan (1992) studied 74 soft-story apartment buildings in the Marina District and report that 11 of the 74 (15%) experienced major damage or collapsed. Here, major damage refers to ATC-13 (1985) damage state 6, equivalent to the HAZUS®-MH (FEMA, 2003a) complete damage state[1]. Collapse here means that at least the first story gravity system failed to the point that the second floor dropped to the ground, touching the first floor. Thus, the CAPSS scenarios produce shaking that is 2-to-4 times the 1989 shaking in the Marina District, which caused 30% of corner buildings to be red-tagged, 5% of them to

[1] This equivalence is only approximate, since ATC-13 damage states deal with the damage to the building as a whole, whereas in HAZUS®-MH one assigns a damage state to each of three general components separately.

collapse, and 15% to suffer total economic loss (repairs costing ≥ 60% of replacement cost).

Replacement Cost. Five local specialists were asked to give their estimates of the per-square-foot cost to build new multi-family wood-frame apartment buildings, with either garage or commercial space at the ground floor, in San Francisco in 2008. These specialists included a local architect, who had recently constructed this type of building; an employee of a local development company that had recently constructed this type of building; a local insurance agent; an insurance analyst, who worked with software that calculates building replacement costs, and; a risk modeling company that provided services to the insurance industry. These estimates ranged from $190 per square foot to $350 per square foot. The two lowest values came from insurance-company models that one specialist acknowledged were likely to be lower than actual building costs. The two highest estimates, both $350 per square foot, stated that this was a minimum cost and that actual construction costs could be higher. Estimates from local professionals working in San Francisco might reasonably be considered more credible than estimates generated from computer models; therefore, the two estimates from computer models were discarded. The average value of the remaining three estimates, $330 per square foot, was used was to estimate post-earthquake rebuilding and repair costs (calculated as a percentage of rebuilding costs). This value does not take into account that construction costs may be higher than normal after an earthquake, due to labor and materials shortages and other phenomena often collectively referred to as "demand surge."

At $330 per square foot replacement cost, these soft-story buildings have a total value of $8.1 billion. Residential content value is commonly estimated by insurers to represent roughly 40% of total replacement cost, so the total replacement cost of these multi-family dwellings is estimated to be approximately $14 billion.

Seismic Vulnerability Functions. Seismic vulnerability functions, $y(s)$, and fragility functions $p[D=d|S=s]$ were developed for each of the four Index Buildings for as-is and each of three retrofitted conditions (see Appendix 8). In general, the retrofits reduce damage by up to half, though at high levels of shaking, the benefit of retrofit is reduced. Note that the HAZUS®-MH methodology does not estimate the number of buildings in the collapsed damage state but rather, estimates the fraction of total square footage that is collapsed. In the case of soft-story wood-frame buildings, this would generally be the bottom floor; therefore, one can estimate the total square footage of subject buildings in which at least part of the building is collapsed by multiplying the fraction collapsed by the average number of stories, which here is roughly four.

The HAZUS®-MH structural damage states and SPUR performance levels can be approximately equated with safety tag (placard) colors as defined in ATC-20 (Applied Technology Council, 1989, 1995, 1999). ATC-20 is the *de facto* international standard for rapid and detailed post-earthquake safety evaluation of buildings. In this study, the HAZUS®-MH complete structural damage state and SPUR performance level D are equated with a red tag in ATC-20, indicating unsafe to enter or occupy. HAZUS®-MH's extensive structural damage and SPUR performance level C are equated with a yellow tag, indicating that restricted use is allowed. Lower HAZUS®-MH structural damage states and SPUR performance levels A and B are equated with green (INSPECTED) tag.

9.6 Results

Equations 9-1 and 9-2 were evaluated for each of four earthquake scenarios and four sets of retrofit conditions: all buildings as-is, and all buildings with retrofit 1, 2, and 3, respectively. Estimated losses are as follows. Under as-is conditions, the scenario earthquakes are estimated to cause 50-90% of soft-story multi-family dwellings to be red-tagged or collapse (see Table 9-5). The CAPSS Project Engineering Panel concluded that these figures represent an upper bound and interpreted them to produce a range of outcomes that they considered to be reasonable; these results are shown in Table 9-6.

Table 9-5 Estimated Damage to Housing Among *all* 2,800 Buildings in the Study, Based on Modeling

Scenario	Retrofit	SPUR Performance Level Among 2,800 Buildings (%)				
		A	B	C	D	E
Magnitude 6.9 Hayward Fault	As-is	15%	18%	19%	30%	18%
	1	50%	22%	18%	8%	2%
	2	68%	16%	10%	6%	0.3%
	3	72%	16%	9%	3%	0.2%
Magnitude 6.5 San Andreas Fault	As-is	9%	13%	17%	39%	22%
	1	38%	23%	23%	13%	4%
	2	56%	20%	15%	9%	1%
	3	59%	20%	15%	6%	0.3%
Magnitude 7.2 San Andreas Fault	As-is	2%	5%	9%	54%	31%
	1	17%	19%	28%	28%	8%
	2	35%	22%	24%	18%	1%
	3	44%	23%	21%	12%	0.7%
Magnitude 7.9 San Andreas Fault	As-is	0%	1%	2%	62%	35%
	1	4%	8%	21%	52%	14%
	2	10%	14%	26%	47%	3%
	3	13%	15%	26%	44%	3%

Note: SPUR performance levels are color-coded to indicate an equivalency with the ATC-20 UNSAFE placard/tag (red), RESTRICTED USE placard/tag (yellow), and INSPECTED (apparently safe) placard/tag (green).

Table 9-6 Estimated Damage Based on CAPSS Project Engineering Panel Interpretation of Modeling Results

Scenario	Retrofit	SPUR Performance Level Among 2,800 Buildings (%)			
		A-B	C	D	E
Magnitude 6.9 Hayward Fault	As-is	33 – 49%	19 – 27%	18 – 30%	6 – 18%
	1	72 – 75%	18 – 20%	4 – 8%	1 – 2%
	2	84 – 86%	10 – 11%	3 – 6%	0.2 – 0.3%
	3	88 – 89%	9 – 10%	2 – 3%	0.1 – 0.2%
Magnitude 6.5 San Andreas Fault	As-is	22 – 42%	17 – 27%	23 – 39%	8 – 23%
	1	61 – 66%	23 – 26%	6 – 13%	2 – 4%
	2	76 – 79%	15 – 17%	4 – 9%	0.3 – 0.5%
	3	79 – 81%	15 – 16%	3 – 6%	0.2 – 0.3%
Magnitude 7.2 San Andreas Fault	As-is	6 – 35%	9 – 23%	32 – 54%	11 – 31%
	1	36 – 48%	28 – 34%	14 – 28%	4 – 8%
	2	57 – 64%	24 – 27%	9 – 18%	0.5 – 1%
	3	67 – 71%	21 – 23%	6 – 12%	0.3 – 0.7%
Magnitude 7.9 San Andreas Fault	As-is	1 – 33%	2 – 18%	37 – 62%	12 – 35%
	1	13 – 35%	21 – 32%	26 – 52%	7 – 14%
	2	23 – 40%	27 – 35%	24 – 47%	1 – 3%
	3	28 – 44%	26 - 33%	22 - 44%	1 – 3%

Note: SPUR performance levels are color-coded to indicate an equivalency with the ATC-20 UNSAFE placard/tag (red), RESTRICTED USE placard/tag (yellow), and INSPECTED (apparently safe) placard/tag (green).

Here, SPUR performance level E means that at least a portion of the building, most likely the ground story, is likely to collapse during the hypothetical earthquake. SPUR performance level D (colored red in the table to indicate red-tag equivalency) means that after the hypothetical earthquake, the ground story of the building would be leaning at least two inches, which would tend to cause building safety inspectors to post the building as unsafe to enter or occupy under the ATC-20 post-earthquake inspection procedures (ATC, 1989). Under current City of San Francisco policy, these buildings would have to be repaired, unless they actually collapsed. SPUR performance level C (colored yellow, indicating a yellow tag equivalency) means that restricted use of the buildings would be allowed. SPUR performance levels A and B (color coded green to indicate a green tag equivalency) means that the buildings would be labeled "Inspected," and it would therefore be lawful to occupy these buildings, even if some repairs were required.

As discussed in Appendix 7, the HAZUS®-MH software (FEMA, 2003a) estimates building repair costs by using probabilistic damage states and associated mean damage factors for three aggregate components—the structural system, drift-sensitive non-structural components, and acceleration-sensitive nonstructural components. As used in this study, "mean damage factor" refers to the expected value of repair cost as a fraction of the total facility replacement cost. There is a mean damage factor for each component, each damage state, and each occupancy classification.

The HAZUS®-MH mean damage factors for multi-family dwellings were used, realizing that the assumptions about structure type embedded in these damage factors might not accurately represent losses in the particular building types examined in this CAPSS study. In other words the HAZUS®-MH damage factors for large wood-frame buildings might not reflect damage so concentrated at the ground story, which is the typical damage pattern anticipated for buildings addressed in this CAPSS study.

It is not known whether this is a significant concern or not, or whether the potential error is great or small. It was beyond the resources of this project to reexamine the basis for the default HAZUS®-MH mean damage factors (which, in any case, is not documented in sufficient detail in FEMA 2003a for such a purpose) or to determine whether the factors ought to be adjusted for the particular building types examined here.

However, because the primary interest of the CAPSS project was comparison between different shaking scenarios and retrofit options, the HAZUS®-MH damage factors seem reasonable to produce comparative results. Regardless, as discussed elsewhere in the CAPSS reports, calculation of economic losses associated with building damage for a large number of buildings has high levels of uncertainty, perhaps as great as ± 50% or more.

For this project, economic losses were calculated using typical HAZUS®-MH damage factors (see Table 7-2 in Appendix 7). Several rounds of analysis were conducted using varying fragility parameters. The repair costs are based on fragility parameter values near or at the lower bound presented in the column labeled "CAPSS" of Table 7-7 of Appendix 7, from an early round of analysis. The estimated damage presented in Table 9-5 in terms of SPUR performance categories was calculated using values at the upper bound of the same column and table, in a later round of analysis. If the upper-bound fragility values were used to estimate repair costs, then the results would show lower repair costs. The repair costs would be slightly lower than shown for pre-retrofit conditions, ranging from $2.5 to $4.4 billion for the four scenarios. After retrofit, repair costs would be significantly lower than those shown. The significance is that the savings from retrofit would be greater than reported in Table 2 of the main report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings* (ATC, 2009), resulting in savings of $900 million to $2.5 billion, depending on the earthquake scenario and retrofit scheme.

9.7 Validation

Treadwell and Rollo estimated two to four times greater shaking intensities in the four scenarios examined here, compared with the USGS's ShakeMap estimates of intensities in the San Francisco Marina District in the 1989 Loma Prieta earthquake. It seems reasonable, therefore, that the scenarios examined here would cause greater damage on average to soft-story buildings than occurred in the Marina District in the 1989 Loma Prieta earthquake. The same methodology presented above was applied to corner apartment buildings using estimates of ground shaking in the San Francisco Marina District during the 1989 Loma Prieta earthquake. The official USGS estimate of shaking in this area was S_a(1.0 sec, 5%) ≈ 0.17g. Based on this CAPSS study, Index Buildings 1 and 2 would have on average 39% probability of being in the "complete" structural damage state, including those buildings with some fraction of their floor area collapsed.

Table 9-7 provides a comparison, on an aggregated basis, of damage experienced by corner apartment buildings on all soil profiles in the Marina District in the 1989 Loma Prieta earthquake, versus a hindcast estimate of Loma Prieta earthquake damage considering only corner buildings (Index Buildings 1 and 2, this CAPSS study). The 1989 "observed" figures are calculated from Harris and Egan's (1992) estimates of the damage state to 74 corner apartment buildings in the San Francisco Marina District after the 1989 Loma Prieta earthquake. Agreement is reasonable, with the figures generally agreeing within ±50%. This CAPSS study does not reflect ground failure, but the "observed" figures do not change substantially by excluding buildings in the region that had ground failure in the 1989 earthquake.

Table 9-7 Comparison of Actual 1989 Damage and Hindcast Damage Estimates to Corner Buildings in the Marina District

HAZUS®-MH Structural Damage State	Approximate ATC-13 Damage State	1989 Estimate*	1989 Observed
None	None	5%	3%
Slight or moderate	Slight, light, moderate	56%	74%
Extensive or complete	Heavy, major, destroyed	39%	24%

**Hindcast, based on this CAPSS study.*

9.8 Summary and Conclusions

Analytical Framework. A study was undertaken to estimate the effects of several large, hypothetical but realistic earthquakes on some of the most seismically vulnerable buildings in San Francisco: wood-frame buildings of three or more stories with five or more housing units and soft-story conditions on the first floor. The study used the HAZUS®-MH analytical framework (FEMA, 2003a) to estimate the risk, but the analysis effort is implemented outside of HAZUS®-MH, in order to avoid a programming flaw in the HAZUS®-MH AEBM software (FEMA, 2003b) and to make the methodology more transparent. Several enhancements over the basic HAZUS®-MH methodology were made, such as adding new fragility information about particular components of San Francisco housing (e.g. straight sheathing and brick veneer). While this approach offers less fidelity than PEER-style dynamic nonlinear multi-degree-of-freedom (MDOF) analyses, the HAZUS®-MH framework is much simpler, more practical for these purposes, and has been shown in several instances to produce realistic aggregate results.

Large Soft-Story Wood-Frame Residential Buildings in San Francisco. Index Buildings were selected that approximately represent the range of existing soft-story wood-frame buildings in San Francisco. This selection was made in consultation with several DBI engineering staff and experienced consulting structural engineers. The study employed a house-by-house DBI database of important features and related the Index Buildings to the buildings in the DBI database through key observable parameters: corner vs. mid-block, and pre-1950 versus post-1950 construction. The buildings in the DBI database are approximately equally distributed among the four Index Buildings.

Soil and Hazard Information. The study's soil and shaking hazard model is based on results from Treadwell and Rollo's study during the initial stages of the CAPSS project (see Appendix 6 for additional information). Roughly three-fourths of the buildings addressed by this CAPSS study are estimated to be situated on soil of NEHRP site class D.

Structural and Component Fragility Models. Structural and component fragility models were developed for each of the as-is and retrofit configurations. The fragility functions were peer-reviewed, and are based on experimental data and observed earthquake performance of the dominant components of the Index Buildings: straight sheathing, lath and plaster walls, stucco exterior finish, and masonry veneer (Porter, 2009b). The benefit of adjacency (where buildings abut each other within inches or less and thus, may support each other in earthquakes) was addressed approximately, by making mid-block buildings one-third as likely to collapse as corner buildings, given that they experience complete structural damage.

Seismic Retrofits. The retrofit schemes for the four Index Buildings, as described in Appendix 4, are intended to meet enhanced performance objectives defined by SPUR (2008), ranging from safe but not repairable (performance category D, using "retrofit 1") to safe and usable during repair (performance category B, using "retrofit 3"). The estimated costs for these retrofit schemes, as developed in Appendix 5, are generally in the range of $10,000 to $20,000 per dwelling unit.

Loss Calculations. This CAPSS study employs a loss-calculation procedure ("cracking an open safe," Porter 2009c,d) that honors all HAZUS®-MH methodologies, while avoiding the iteration and a programming error recently discovered in AEBM (FEMA, 2003b). In addition to the peer-reviewed stepwise validation or quality assurance at each stage, the overall alternative procedure was validated by hindcasting with reasonable accuracy the damage to corner apartment buildings in the San Francisco Marina District during the 1989 Loma Prieta earthquake. The results therefore seem valid for the limited purposes of assessing community-wide retrofit policy alternatives. Losses were calculated for the entire stock of 2,800 buildings under as-is conditions and again for each retrofit scheme, i.e., assuming all the buildings were upgraded to retrofit 1, then 2, then 3. Losses were calculated for each of four earthquake scenarios, focusing on a magnitude 7.2 earthquake on the Peninsula segment of the San Andreas fault.

Results. The large but highly realistic magnitude 7.2 earthquake is estimated to be capable of causing half of the 2,800 large soft-story wood-frame dwellings in San Francisco to be red-tagged (after the earthquake), and 30% more to collapse. Most of the collapses are estimated to occur in corner buildings. There is a tendency to higher damage on softer soil, but three-fourths of the subject buildings are on NEHRP site class D. Seismic retrofit, involving new steel cantilever columns and shearwalls at the ground-floor level, could reduce collapses to fewer than 1 in 100 buildings, at a total cost throughout the City on the order of $260 million.

APPENDIX 10: COMMUNITY AND ECONOMIC IMPACTS OF SOFT-STORY RISK AND MITIGATION

10.1 Introduction

This appendix describes an effort under the San Francisco Community Action Plan for Seismic Safety (CAPSS) project to evaluate the socio-economic impacts of a retrofit policy for soft-story wood-frame residential buildings. Specifically addressed are the potential socio-economic impacts of a major earthquake on residential tenants, businesses, and building owners.

The study was developed to aid the CAPSS project team, the CAPSS Advisory Committee, City staff, the Board of Supervisors, and other stakeholders, as they formulated a seismic retrofit policy for San Francisco's residential soft-story buildings.

10.2 Methodology Overview

The study included the development of residential and business profiles that draw on a San Francisco Department of Building Inspection (DBI) database of wood-frame buildings in San Francisco with three or more floors and five or more units. The database identifies structures with an open-wall condition, defined here as (1) an opening of 80 percent or more in a ground floor exterior wall, or (2) openings of 50 percent or more on two ground floor exterior walls. These open-wall structures represent a major subset of soft-story buildings. The firm that conducted the study (Bay Area Economics) cross-referenced the DBI database with 2008 demographic data from Claritas, Inc. and 2008 data from Dun and Bradstreet to characterize residents and businesses in open-wall buildings.

To assess the socio-economic consequences of a mandatory seismic retrofit ordinance and major earthquake, Bay Area Economics (BAE) conducted a literature search of studies that evaluate the impacts of comparable ordinances on owners, occupants, and neighborhood character. The literature review also researched community impacts associated with Hurricane Katrina and the 1989 Loma Prieta and 1994 Northridge earthquakes.

In addition, BAE interviewed various individuals with expertise on these issues, including representatives from the San Francisco Apartment Association, the San Francisco Rent Board, members of the insurance industry, commercial lenders, the Federal Emergency Management Agency (FEMA), and building engineers on the CAPSS project team.

Finally, BAE conducted research on local rental market conditions, the San Francisco Rent Stabilization Ordinance, and economic factors that affect the city's residential rental market.

The following sections contain descriptions of the activities and findings of the efforts to develop a Residential Profile, a Business Profile, Impacts of a Seismic Retrofit Policy, and Impacts of a Major Earthquake.

10.3 Residential Profile

This section examines the demographic characteristics of residents of soft-story buildings, and compares these households to residents citywide. Specifically, the section outlines the distribution of soft-story units across San Francisco neighborhoods, and examines the homeownership rate, income, and ethnicity of households in these buildings.

As noted earlier, soft-story structures represent one of the most seismically vulnerable building types in San Francisco. Various characteristics can lead to a soft-story condition, the most common of which occurs when exterior structural walls contain a significant number of doorways, garage openings, and storefronts. This analysis focuses on these "open-wall" buildings as a major subset of all soft-story structures. An open-wall condition is defined here as (1) an opening of 80 percent or more in a ground floor exterior wall, or (2) openings of 50 percent or more on two ground floor exterior walls.

Figure 10-1 Earthquake-damaged soft story building.

10.3.1 Methodology

BAE utilized the following methodology to characterize households and residents currently residing in open-wall buildings in San Francisco. The resulting demographic profile offers a general perspective on residents of soft-story structures throughout the city.

Step 1: Cross-reference DBI database of wood-frame buildings with Census block groups.[2] The DBI maintains a database of wood-frame buildings in San Francisco with three or more floors and five or more units. Based on a sidewalk survey, the database identifies structures with an open-wall condition as defined above. BAE used a Geographic Information System (GIS) to map the open-wall buildings in the database and to identify the Census block groups in which they are located.

Step 2: Classify Census block groups according to their share of total units in open-wall buildings in San Francisco.[3] Through the GIS analysis discussed above, BAE calculated each Census block group's share of the total open-wall units in San Francisco. The city's 575 Census block groups were then placed into one of four categories according to their respective number of open-wall units for every 1,000 open-wall units in San Francisco (see Table 10-1). This study refers to these areas as "low," "medium," and "high" concentration areas.

[2] A "block group" is a US Census-defined geography that includes roughly two to six blocks in San Francisco. Block groups are the smallest geography that can be used to analyze demographic data such as ethnicity and household income.

[3] For the sake of brevity, residential units in open-wall buildings are referred to as "open-wall units."

Table 10-1 Block Group Categories by Open-Wall Unit Concentration

Category	Number of Open-Wall Units in Block Group for every 1,000 Open-Wall Units in San Francisco
No Open-Wall Units	0.00 units
Low Concentration	0.01 – 1.99 units
Medium Concentration	2.00 – 4.99 units
High Concentration	5.00 units or more

Source: Bay Area Economics.

Step 3: Describe residents and households in block groups with different concentrations of open-wall buildings. Using 2008 demographic data from Claritas, Inc., a private data vendor, BAE characterized residents and households in low, medium, and high concentration areas.

10.3.2 Findings

Wood-frame buildings with three or more stories and five or more units contain a significant portion of the city's residential units. The DBI database records 4,600 of these structures in San Francisco, which house approximately 45,200 units or 13 percent of the city's housing stock. An estimated 88,600 residents live in these buildings, or 11 percent of the city's total population.

A notable percentage of San Francisco residents live in open-wall buildings. The DBI survey identified 2,900 buildings[4] with an open-wall condition, which comprise 63 percent of all buildings in the DBI database. These buildings contain 29,200 residential units, or over 8 percent of San Francisco households. Based on the average household size of the Census block group in which each open-wall unit is located, an estimated 58,000 residents live in these open-wall buildings, or 8 percent of San Francisco's total population.

The Western Addition, Mission, Pacific Heights, Marina, and Richmond neighborhoods have the highest concentration of residential units in open-wall buildings. The presence of open-wall buildings varies significantly by neighborhood. As shown in Table 10-2, these five neighborhoods contain over 70 percent of San Francisco's open-wall units.

Households in areas with the highest concentration of open-wall units generally have higher incomes than the city as a whole. Conversely, households in areas with no open-wall units have lower median incomes. As shown in Table 10-3, high concentration areas have a median household income of $74,700, compared to $61,800 in areas with no open-wall units and $68,300 among households citywide.

The geographic distribution of open-wall units throughout the city explains, in part, these trends. As noted above, more affluent neighborhoods such as Pacific Heights, the Marina, and North Beach contain a major portion of San Francisco open-wall

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[4] The sample set of buildings used in this socio-economic analysis was slightly larger than the set of 2,800 buildings used in the engineering and loss estimation analysis (i.e., approximately 100 buildings used in this analysis were not included in the engineering and loss estimation analysis). The CAPSS Project Team believes the slight difference in size of the number of buildings analyzed does not skew the analysis results.

Table 10-2 Units and Residents in Open Wall Buildings by Neighborhood

Neighborhood	Units in Open Wall Buildings		Residents in Open Wall Buildings	
	Number	Percent of Total San Francisco Open Wall Units	Number (a)	Percent of Total San Francisco Residents in Open Wall Buildings
Western Addition	5,779	19.8%	11,087	19.1%
Mission	4,633	15.8%	11,326	19.5%
Pacific Heights	3,515	12.0%	5,735	9.9%
Marina	3,440	11.8%	5,224	9.0%
Richmond	3,411	11.7%	7,782	13.4%
North Beach	3,231	11.1%	6,039	10.4%
Sunset	1,738	5.9%	4,103	7.1%
Downtown	1,436	4.9%	2,535	4.4%
Twin Peaks	1,078	3.7%	1,828	3.2%
Excelsior	293	1.0%	1,098	1.9%
Mission Bay	167	0.6%	302	0.5%
Ingleside	22	0.1%	81	0.1%
Bayview	0	0.0%	0	0.0%
Merced	0	0.0%	0	0.0%
No Neighborhood	494	1.7%	879	1.5%
TOTAL	**29,237**	**100.0%**	**58,019**	**100.0%**

Notes:

(a) Number of residents in open-wall units based on the average household size for the Census block group in which each open-wall building is located.

Sources: San Francisco Department of Building Inspection; MMI Engineering; Bay Area Economics.

units, while lower-income neighborhoods such as the Bayview and Ingleside have relatively few open-wall buildings.

Households in areas with higher concentrations of open-wall units are slightly younger than the city as a whole. Residents in high concentration areas have a median age of 39.2 years, compared to 40.2 years among citywide residents and 40.6 years among residents in low concentration areas (see Table 10-3).

Households in areas with higher concentrations of open-wall units have lower homeownership rates. Only 19 percent of households in high concentration areas are homeowners, compared to 44 percent among households in areas with no open-wall units. Citywide, 35 percent of households own their home (see Table 10-3).

Areas with a high concentration of open-wall units have greater proportions of White residents and fewer African American, Asian American, and Hispanic residents. Approximately 66 percent of residents in high concentration areas are White, compared to just 32 percent in areas with no open-wall units and 44 percent in San Francisco as a whole. Additionally, the proportion of African American, Asian American, and Hispanic residents in high concentration areas is substantially lower than in areas with no open-wall units and in the city as a whole (see Table 10-3).

Table 10-3 Demographic Characteristics of Block Groups by Concentration of Open Wall Units

Characteristic	No Units	Low Concentration	Medium Concentration	High Concentration	Citywide
Median Income	$61,823	$73,833	$68,980	$74,738	$68,309
Home Ownership Rate	43.9%	39.7%	23.3%	18.6%	34.6%
White	31.8%	44.5%	54.0%	65.7%	43.7%
African American	10.4%	3.8%	3.7%	3.2%	6.4%
American Indian/Alaska Native	0.2%	0.2%	0.2%	0.2%	0.2%
Asian American	38.9%	32.2%	24.0%	17.7%	31.6%
Native Hawaiian/Pacific Islander	0.8%	0.2%	0.2%	0.1%	0.4%
Some Other Race	0.3%	0.4%	0.3%	0.3%	0.3%
Two or More Races	3.3%	3.3%	3.0%	2.9%	3.2%
Hispanic	14.2%	15.4%	14.5%	9.8%	14.0%
Median Age	40.6	40.6	39.7	39.2	40.2

Sources: Claritas, 2008; Bay Area Economics.

Again, this finding is largely due to the underlying demographic profile of the neighborhoods that contain a large share of San Francisco's open-wall units. As Table 10-4 shows, the Marina, Pacific Heights, and the Western Addition have the

highest proportion of White residents in San Francisco. These three neighborhoods contain 44 percent of the city's open-wall units. These same neighborhoods also have lower proportions of African American, Asian American, and Hispanic residents.

Neighborhood-specific demographic trends among areas with low, medium, and high concentrations of open-wall units can vary from citywide patterns. As noted above, underlying neighborhood demographics strongly influence the citywide analysis of low, medium, and high concentration areas. To examine trends on a more fine-grained level, BAE conducted detailed case studies of three neighborhoods that contain a large share of San Francisco's open-wall units. Table 10-5 presents the findings from these studies of the Mission, the Western Addition, and the Richmond District.

The analysis found that Western Addition trends parallel citywide findings, with high concentration areas having higher household incomes and a greater percentage of White residents than the neighborhood as a whole.

However, the analysis did reveal some variation between Mission and Richmond District trends and citywide demographic patterns. First, contrary to citywide findings, high concentration areas in both neighborhoods are less affluent than low concentration areas and the neighborhood as a whole.

Second, in both neighborhoods, areas with open-wall units have a larger share of racial minorities than areas with no open-wall units. In the Mission, areas with open-wall units have a larger percentage of Hispanic residents, while in the Richmond, more Asian Americans live in areas with open-wall units.

Table 10-4 Race and Ethnicity by Neighborhood

Neighborhood	White	African American	American Indian/Alaska Native	Asian American	Native Hawaiian/ Pacific Islander	Some Other Race	Two or More Races	Hispanic
Marina	83.7%	0.4%	0.1%	10.3%	0.1%	0.3%	2.0%	3.2%
Pacific Heights	82.4%	1.1%	0.1%	10.4%	0.1%	0.2%	2.0%	3.7%
Western Addition	66.3%	7.8%	0.2%	14.7%	0.2%	0.5%	3.5%	6.8%
North Beach	62.0%	1.3%	0.1%	30.1%	0.1%	0.2%	2.2%	3.9%
Mission Bay	56.4%	11.7%	0.4%	17.9%	0.5%	0.4%	3.5%	9.2%
Twin Peaks	56.0%	4.8%	0.2%	25.9%	0.2%	0.4%	3.8%	8.6%
Mission	51.3%	4.0%	0.3%	11.3%	0.2%	0.3%	3.3%	29.2%
Richmond	49.3%	1.2%	0.1%	41.3%	0.1%	0.4%	3.3%	4.3%
Downtown	45.5%	7.3%	0.4%	31.1%	0.3%	0.5%	4.1%	10.7%
Merced	42.6%	1.8%	0.1%	46.0%	0.2%	0.3%	3.0%	6.0%
Sunset	39.3%	1.0%	0.1%	51.4%	0.1%	0.3%	3.2%	4.5%
Ingleside	13.8%	16.6%	0.1%	52.3%	0.5%	0.2%	2.8%	13.6%
Excelsior	12.4%	3.5%	0.1%	54.3%	0.6%	0.2%	2.7%	26.1%
Bayview	5.4%	33.5%	0.2%	35.9%	2.1%	0.2%	2.6%	20.1%
Total	**59.5%**	**4.1%**	**0.1%**	**25.0%**	**0.2%**	**0.3%**	**3.0%**	**7.7%**

Sources: Claritas, 2008; Bay Area Economics.

10.3.3 Summary of Findings

San Francisco has approximately 4,600 wood-frame buildings with three or more stories and five or more units, containing approximately 45,200 units or 13 percent of San Francisco's housing stock. Of these buildings, approximately 2,900 have an open-wall condition, containing 29,200 residential units, or over 8 percent of all households in San Francisco. These open-wall structures represent a major subset of soft-story buildings, a highly vulnerable structural condition in a major earthquake.

The concentration of open-wall buildings varies significantly by neighborhood, suggesting that different areas of the city would be impacted more than others by an earthquake retrofit policy or seismic event. In particular, the Western Addition, Mission, Pacific Heights, Marina, and Richmond contain over 70 percent of the city's units in open-wall buildings.

The findings from a citywide demographic analysis of areas with a low, medium, and high concentration of open-wall units are largely driven by underlying neighborhood profiles. Households in high concentration areas generally are younger, have higher incomes, and are more likely to rent their homes. High concentration areas also have larger proportions of White residents and fewer African American, Asian American, and Hispanic residents. These patterns are consistent with demographic characteristics in neighborhoods such as the Marina, Pacific Heights, and North Beach, which have a large share of open-wall units.

Table 10-5 Demographic Characteristics of Block Groups by Neighborhood

Characteristic	No Units	Low Concentration	Medium Concentration	High Concentration	Neighborhood Wide
Mission District					
Median Income	$86,648	$88,022	$63,198	$66,696	$76,565
Homeownership Rate	51.4%	39.3%	21.2%	17.6%	33.6%
White	54.7%	50.9%	42.8%	51.4%	49.5%
African American	6.6%	2.0%	2.5%	3.3%	3.2%
American Indian/Alaska Native	0.3%	0.3%	0.3%	0.3%	0.3%
Asian American	14.5%	9.3%	9.5%	9.9%	10.4%
Native Hawaiian/Pacific Islander	0.3%	0.2%	0.2%	0.2%	0.2%
Some Other Race	0.4%	0.4%	0.2%	0.3%	0.3%
Two or More Races	3.6%	3.2%	2.8%	3.0%	3.1%
Hispanic	19.7%	33.6%	41.7%	31.6%	32.9%
Western Addition					
Median Income	$60,767	$67,132	$70,124	$75,250	$69,712
Homeownership Rate	26.6%	23.5%	18.8%	18.5%	21.1%
White	50.9%	60.6%	65.4%	70.8%	63.6%
African American	16.6%	10.5%	9.9%	8.2%	10.5%
American Indian/Alaska Native	0.1%	0.1%	0.3%	0.2%	0.2%
Asian American	20.6%	17.2%	12.8%	9.5%	14.2%
Native Hawaiian/Pacific Islander	0.1%	0.4%	0.2%	0.2%	0.2%
Some Other Race	0.5%	0.6%	0.4%	0.3%	0.5%
Two or More Races	4.1%	3.7%	3.5%	3.8%	3.7%
Hispanic	7.1%	6.8%	7.6%	7.0%	7.1%
Richmond District					
Median Income	$112,386	$79,266	$69,661	$69,850	$74,296
Homeownership Rate	63.6%	41.0%	32.7%	25.9%	36.2%
White	57.4%	47.9%	48.0%	54.1%	49.4%
African American	1.9%	1.2%	1.1%	1.5%	1.2%
American Indian/Alaska Native	0.2%	0.1%	0.1%	0.2%	0.1%
Asian American	33.1%	42.9%	42.1%	37.3%	41.1%
Native Hawaiian/Pacific Islander	0.0%	0.1%	0.1%	0.1%	0.1%
Some Other Race	0.2%	0.4%	0.4%	0.4%	0.4%
Two or More Races	2.3%	3.5%	3.5%	2.4%	3.2%
Hispanic	4.9%	3.9%	4.8%	4.1%	4.3%

Sources: Claritas, 2008; BAE, 2008

Case studies of the Mission, the Western Addition, and the Richmond indicate that neighborhood-level demographics can vary from citywide trends. Most notably, within the Mission and Richmond Districts, areas with a high concentration of open-wall units have lower household incomes than the neighborhood as a whole. In addition, in both the Mission and Richmond Districts, areas with open-wall units have a larger share of racial minorities than do areas with no open-wall units.

Notwithstanding the citywide trends expressed here, it is important to note that lower-income households do in fact reside in soft-story buildings. As discussed in subsequent sections on this report, these households would be more economically vulnerable in the event of a major earthquake.

10.4 Business Profile

This section describes the businesses occupying soft-story wood-frame buildings, analyzing their number of employees, location, and industry, and comparing these figures with businesses throughout the city.

10.4.1 Methodology

For this analysis, BAE cross-referenced a Dun and Bradstreet database of all San Francisco businesses with the DBI database of wood-frame buildings with three or more stories and five or more units. The Dun and Bradstreet database contained businesses' street address, size, and industry. Through GIS mapping, BAE determined which businesses were located in open-wall buildings in San Francisco. As the DBI database only includes residential and mixed-use structures, the businesses identified in this analysis likely operate on the ground floor of these buildings.

Figure 10-2 Example San Francisco street-side business

10.4.2 Findings

Just under one third of the city's open-wall buildings contain commercial uses. Businesses operate in approximately 900 of the 2,900 residential open-wall buildings in San Francisco.

Businesses and workers located in open-wall buildings represent a small percentage of all businesses and workers in San Francisco. Of the 73,000 businesses in San Francisco, 2,100 businesses, or just under 3 percent, operate in residential open-wall buildings. These businesses employ 6,900 people, accounting for 1 percent of jobs in the city.

The Western Addition, Mission, North Beach, and Pacific Heights contain the largest shares of San Francisco businesses operating in residential open-wall buildings.[5] As Table 10-6 shows, these four neighborhoods account for 68 percent of all open-wall businesses in the city. Not surprisingly, the neighborhoods that have a high concentration of San Francisco's open-wall units also contain a large proportion of the city's open-wall businesses.

Open wall businesses are concentrated in the retail, services, and food service industries. As shown in Table 10-7, 17 percent of open-wall businesses are in the retail trade industry, as compared to 12 percent of all San Francisco businesses. In addition, 13 percent of open-wall businesses are in the services industry, while 9 percent are in the accommodation and food service industry. These data reflect the

[5] For the sake of brevity, this report refers to businesses in open-wall buildings as "open-wall businesses."

Table 10-6 Open Wall Businesses by Neighborhood

Neighborhood	Number of Businesses		Employees (a)	
	Number	Percent of Total Businesses in Open Wall Buildings	Number	Percent of Total Employees in Open Wall Buildings
Western Addition	474	22.8%	1,456	21.2%
Mission	362	17.4%	1,257	18.3%
North Beach	308	14.8%	1,070	15.6%
Pacific Heights	264	12.7%	770	11.2%
Richmond	183	8.8%	518	7.5%
Marina	171	8.2%	598	8.7%
Sunset	118	5.7%	346	5.0%
Downtown	96	4.6%	446	6.5%
Twin Peaks	49	2.4%	227	3.3%
Excelsior	44	2.1%	166	2.4%
Mission Bay	7	0.3%	23	0.3%
Ingleside	1	0.0%	2	0.0%
Bayview	0	0.0%	0	0.0%
Golden Gate Park	0	0.0%	0	0.0%
Merced	0	0.0%	0	0.0%
Presidio	0	0.0%	0	0.0%
TOTAL	**2,077**	**100.0%**	**6,879**	**100.0%**

Notes:
(a) Represents the number of people employed at specific addresses, rather than throughout the company.
Sources: Dun and Bradstreet, 2008; MMI Engineering; Bay Area Economics.

fact that small retail shops and restaurants, along with professional and personal service establishments, often locate in mixed-use buildings along commercial corridors in San Francisco.

Open wall buildings contain an extremely high proportion of small businesses. As shown in Table 10-8, 84 percent of open-wall businesses employ fewer than five people, compared to 76 percent of all San Francisco businesses. An additional 11 percent of open-wall businesses have between five and ten employees. The small size of businesses in open-wall buildings suggests that many are independent, locally-owned enterprises.

10.4.3 Summary of Findings

Approximately 31 percent of the 2,900 residential open-wall buildings in San Francisco are mixed-use buildings with a commercial use on the ground floor. These enterprises represent a small proportion of all businesses citywide; less than 3 percent of the city's firms operate in open-wall buildings, employing about 1 percent of all employees in San Francisco. The Western Addition, Mission, North Beach, and Pacific Heights neighborhoods contain a large share of these employers.

Table 10-7 Open Wall and San Francisco Businesses by Industry Sector

Industry Sector	Open Wall Businesses		All Businesses	
	Number	Percent	Number	Percent
Retail Trade	354	17.0%	8,546	11.7%
Professional, Scientific, and Technical Services	344	16.6%	14,331	19.5%
Other Services, except Public Administration	262	12.6%	7,033	9.6%
Administrative and Waste Services	211	10.2%	7,930	10.8%
Accommodation and Food Services	182	8.8%	3,933	5.4%
Health Care and Social Assistance	122	5.9%	6,334	8.6%
Real Estate and Rental and Leasing	117	5.6%	3,499	4.8%
Construction	84	4.0%	3,595	4.9%
Information	84	4.0%	3,054	4.2%
Wholesale Trade	80	3.9%	3,438	4.7%
Finance and Insurance	75	3.6%	4,448	6.1%
Manufacturing	57	2.7%	2,417	3.3%
Arts, Entertainment, and Recreation	50	2.4%	1,482	2.0%
Educational Services	28	1.3%	1,220	1.7%
Transportation and Warehousing	22	1.1%	1,077	1.5%
Agriculture, Forestry, Fishing and Hunting	2	0.1%	238	0.3%
Management of Companies and Enterprises	2	0.1%	313	0.4%
Public Administration	1	0.0%	368	0.5%
Mining	-	0.0%	28	0.0%
Utilities	-	0.0%	45	0.1%
TOTAL	**2,077**	**100.0%**	**73,329**	**100.0%**

Sources: Dun and Bradstreet, 2008; Bay Area Economics.

The data show that a large share of these firms are small retail shops, restaurants, and other personal and professional service businesses. In addition, almost 95 percent of open-wall businesses are small firms employing fewer than 10 people, suggesting they are independent, locally-owned enterprises.

10.5 Impacts of Seismic Retrofit Policy

This section addresses the impacts of a retrofit policy from the perspective of building owners, residents, and commercial tenants of open-wall buildings. To assess the socio-economic consequences of a mandatory seismic retrofit ordinance, BAE conducted a literature search of studies that evaluate the impacts of comparable ordinances on owners, occupants, and neighborhood character. While the literature on hazards mitigation is expansive, no single study has assessed the impacts on these affected groups in a systematic way.

Table 10-8 Distribution of Businesses by Size

Number of Employees	Open Wall Businesses		All Businesses	
	Number	Percent	Number	Percent
0 – 4	1,742	83.9%	55,793	76.1%
5 – 10	224	10.8%	9,285	12.7%
11 – 25	88	4.2%	4,742	6.5%
26 – 50	19	0.9%	1,959	2.7%
51 – 75	3	0.1%	509	0.7%
76 - 125	1	0.0%	494	0.7%
126 +	0	0.0%	547	0.7%
Total	**2,077**	**100.0%**	**73,329**	**100.0%**

Sources: Dun and Bradstreet, 2008; BAE, 2008

BAE also interviewed various stakeholders and individuals with expertise on this issue, including representatives from the San Francisco Apartment Association, the San Francisco Rent Board, members of the insurance industry, commercial lenders, and building engineers on the CAPSS project team.

Finally, BAE conducted research on local rental market conditions, the San Francisco Rent Stabilization Ordinance, and economic factors that affect the city's residential rental market.

10.5.1 Impacts on Building Owners

The San Francisco Rent Stabilization Ordinance governs owners' ability to pass seismic retrofit costs through to residential tenants. The Ordinance allows landlords to pass through the full cost of any seismic retrofit required by law, with a maximum increase of 10 percent of the tenant's base rent in any 12 month period, amortized over 20 years.

Capital improvements that are not required by law are subject to a different set of pass-through regulations. For properties with one to five residential units, 100 percent of the certified capital improvement costs may be passed through to tenants. For properties with over five units, only 50 percent of the certified capital improvement costs may be passed through to tenants. Therefore, under the current Ordinance, landlords of buildings with six or more units would only be able to recoup 50 percent of total retrofit costs, if it were not a mandatory requirement by the City.

Approximately 97 percent of the open-wall buildings identified in the DBI database were built prior to 1980 and would therefore be subject to the Ordinance, which applies to buildings built before July 1979.

The Rent Stabilization Ordinance pass-through allowance appears sufficient to cover the cost of seismic retrofits. Table 10-9 compares the monthly debt service of a seismic retrofit to the permitted capital improvement pass-through to tenants. The analysis assumes a retrofit cost of $132,000, based on the cost estimates prepared by the CAPSS team, as well as a 20 year amortization period, 8.0 percent interest rate,

Table 10-9 Allowable Rent Increase for Retrofit vs. Monthly Debt Service

Cost Category	Amount
Average monthly rent in San Francisco (a)	$2,400
Maximum allowable increase (10% of base rent) (b)	$240
Estimated retrofit cost (c)	$132,031
Monthly debt service (amortized over 20 years @ 8% interest)	$1,104
Monthly debt service per unit (6 unit building)	$184

Notes:
- (a) Average rent for third quarter 2008.
- (b) Assumes Rent Stabilization Ordinance allows 100% of qualified retrofit costs may be passed through to renters.
- (c) Conservatively assumes highest cost estimate from Young & Associates. Estimates range from $49,100 to $132,000.

Source: Young & Associates; RealFacts; San Francisco Rent Board; Bay Area Economics.

and six-unit building.[6] This analysis also assumes that the Rent Stabilization Ordinance will be amended to allow 100 percent of all qualified seismic upgrades to be passed onto tenants. Rent data is drawn from RealFacts, a private subscription data service. Under these assumptions, the building owner would have a monthly debt-service of $184, which falls well within the $240 monthly pass-through allowance.

However, in many cases, building owners will be unable to pass through retrofit costs, because the units are already offered at market rate rents. Under San Francisco's Rent Stabilization Ordinance, the Rent Board sets a maximum annual rent increase, based on changes to the San Francisco Bay Area Consumer Price Index. Since 1998, this maximum increase has ranged from 0.6 to 2.9 percent. However, when the unit is vacated, the owner may raise rents to market rate levels. Under this system, the more often that units turn over, the more likely it is that rents will be at market rates.

Census data suggests that a significant portion of the city's rental units are at or near market rents due to ongoing tenant turnover. The 2000 Census reports that 24 percent of rental units are re-occupied every year, 43 percent turn over every two years, and 61 percent turn over every five years.[7]

Basic real estate economic principles dictate that the market sets the maximum rent that a landlord can charge. Therefore, when rents in a building are already at market rates, a landlord who attempts to pass through seismic retrofit costs risks greater vacancies. Assuming occupancy of up to three years allows for a rent that is at or close to market rates, this analysis suggests that landlords have a limited ability to pass through costs to 40 to 60 percent of the city's apartments. As such, landlords may choose to forgo a capital improvement pass-though petition with the Rent Board

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[6] The amortization period and interest rate are based on Rent Stabilization Ordinance requirements.

[7] In the Mission, Western Addition, Marina, and Pacific Heights, neighborhoods with a large share of open-wall units, the annual turnover rate ranges from 20 percent to 31 percent.

if roughly half of the units in any given multifamily building cannot absorb a rent increase.

In part due to this dynamic, few building owners petition the Rent Board for capital improvement pass-throughs. Interviews with experienced Rent Board staff indicate that as few as 400 owners a year might apply for a capital improvement pass-through of any kind.[8] In fact, a 1992 study of LA Earthquake Hazard Reduction Ordinance found only 25 percent of owners who completed a unreinforced masonry (URM) building retrofit sought a rent increase, in part because rents were already at market rates (Comerio, 1993).

The financial impact of seismic retrofit costs on building owners will vary according to each owner's particular economic circumstances. A major property owner with a diversified investment portfolio would be able to absorb these costs over time. By contrast, a "mom and pop" owner that relies on the property as a major source of income, has a significant amount of outstanding debt, or is heavily invested in the property, would be more negatively impacted by additional retrofit costs, assuming that he or she could not pass through these costs to tenants.

In general, San Francisco building owners do not rely on their properties as a primary income source. In 2003, the San Francisco Board of Supervisors commissioned a survey of owners and tenants of multifamily rental building in San Francisco[9] (BAE, 2003) The survey revealed that building owners were employed and tended to be in executive or professional occupations working in San Francisco. Most of the respondents did not work primarily as property owners or managers. Owners had relatively high household incomes in comparison with San Francisco tenants, all San Francisco households, and property owners nationwide. For the owners, median annual household income was estimated at $90,900, compared to $44,800 for tenants, and $55,200 for San Francisco households overall. Most owners received the majority of their income from sources other than their rental properties in the city; only one-fourth relied on these properties for half or more of their income. The most frequently stated reason for purchasing property was for income from rents, and only 16 percent reported purchasing the property for retirement security. Less than one-fifth of the owners indicated that they were only breaking even or losing money on their properties, nearly the same as nationwide rates, where a far lower proportion of units are covered by rent control.

Notwithstanding these survey results, it is important to note that a significant portion of San Francisco landlords do in fact rely on their properties as a major source of income. These owners, along with smaller-scale landlords, would be potentially negatively impacted by a mandatory retrofit ordinance. Programs such as affordable loan pools and adjustments to the Rent Stabilization Ordinance would help to mitigate the financial effects of the retrofit requirement.

In the short term, restrictive credit markets may limit the ability of landlords to secure financing for seismic improvements. Due to ongoing turmoil in the national and international credit markets, landlords will encounter difficulty in securing

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[8] Interview with Joe Grubb, former Director of San Francisco Rent Board, November 11, 2008.

[9] Survey respondents totaled 693 multifamily rental building owners, representing six percent of the total rental housing stock in San Francisco.

affordable financing for seismic improvements. Literature reviews also indicate that lenders often provide less favorable financing terms for seismic improvements, which do not increase the property's value (i.e., allow for higher rents). In fact, experience in other cities has shown that when seismic upgrading is required, owners use the retrofit as an opportunity to repair other code violations and do cosmetic rehabilitation work, in order to command higher rents as turnover occurs (Comerio, 1987).

To the extent that a retrofit policy initially targets one class of buildings, these owners will remain at a financial disadvantage relative to other owners. However, in the long run, as the retrofit policy is implemented by more building owners and expanded to address other building types, the market can be expected to reach a new equilibrium and to create a "level playing field" for all owners. Moreover, as seismic safety eventually becomes a more recognized standard, and as demand increases for seismically-sound homes, tenants may actually assign a premium to these units, conferring an advantage to owners of retrofitted buildings.

10.5.2 Impacts on Residential Tenants

Seismic retrofits to address a soft-story condition can be limited to the ground floor of residential and mixed-use buildings. Therefore, residential tenants living above the ground floor are protected from displacement during construction. However, CAPSS team engineers estimate that construction will likely affect ground floor parking and storage for two to four months. To compensate tenants for these losses, landlords may have to pay for alternate parking and storage and/or reduce rents, until the retrofit is complete.

Under San Francisco Rent Stabilization law, eviction can occur only if the improvement and/or rehabilitation work makes the unit hazardous, unhealthy, and/or uninhabitable while work is in progress.[10] If these criteria are present and tenants are evicted, then they have the right to reoccupy the unit after the work is complete. Should the owner choose to "recover possession of the unit" (i.e., prevent re-occupancy), he or she is required to pay a relocation fee. The current relocation payment set by the Rent Stabilization Board is $4,744 per tenant and an addition $3,164 for disabled, elderly, or tenants with minor children, up to $14,234 for capital improvements. However, because seismic retrofits can be limited to the ground floor, it appears unlikely that tenants will be forced to relocate during construction.

In rare cases, landlords may use the retrofit as an opportunity to remove existing occupants and replace them with higher-income tenants. A report on the 1981 Los Angeles URM Earthquake Hazards Reduction Ordinance found that several landlords did in fact use rehabilitation work in this manner (Alesch and Petak, 1983). The study also reported that in some cases, the cost of seismic retrofitting was illegally passed through to the renters. In these instances, building owners ignored the rent stabilization law and increased rents among tenants who were afraid to complain or did not know their rights.

These practices remain a threat in lower-income San Francisco neighborhoods and in situations where long-term tenants rely on the Rent Stabilization Ordinance to continue living in their unit at below-market rents. Landlord and tenant education,

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[10] Chapter 37, San Francisco Administrative Code, San Francisco Rent Stabilization Ordinance, Rules and Regulations, Section 12.15.

the ongoing participation of tenants-rights advocates, and active enforcement of the City's Rent Stabilization Ordinance will help to mitigate these impacts. Ultimately, however, illegal rent pass-throughs and evictions will be relatively limited, simply because a significant share of San Francisco units are already at or close to market rate rents, as discussed above.

10.5.3 Impacts on Commercial Tenants

Because San Francisco's Rent Stabilization Ordinance does not apply to commercial tenants, lease rates are already at market, and landlords have a limited ability to pass through seismic retrofit costs. A 1990 study reporting on the impacts of the Los Angeles Earthquake Hazard Reduction Ordinance found that few owners were able to pass through costs to commercial tenants, because rents were already as high as the market could bear (Blair-Tyler and Gregory, 1990). In the few cases where rents were raised, the increase did not cover the full cost of seismic rehabilitation. Long-term leases will also prevent landlords from passing costs on to commercial tenants.

The proposed retrofits will have a negative impact on ground-floor businesses during construction. During construction, which generally lasts for two to four months, businesses can expect a substantial amount of noise, space constraints, visual disturbance, and dust, disrupting normal operations and customers. In the 1990 Los Angeles study, building owners commented that it was in their best interest to retain tenants and rental income and thus, they tried to do the work in phases so as not disturb business. Despite these efforts, however, the retrofit activity did force many businesses to close during construction.

Small businesses will have difficulty recovering from any closure or relocation. As noted earlier, small businesses make up a major share of commercial tenants in soft-story buildings; almost 95 percent of these businesses have up to ten employees. With limited savings, small profit margins, and reliance on a steady revenue stream to pay for inventory and debt, many small businesses, particularly in the retail and food service industry, do not have the resources to withstand a prolonged closure or relocation.

Seismic retrofit ordinances have a limited impact on the mix of local land uses. The 1990 Los Angeles study developed detailed case studies of four different neighborhoods, to examine the effect of the Earthquake Hazard Reduction Ordinance on local land uses. The study ultimately viewed the shifts in occupancy as a normal pattern of land use change in these neighborhoods, rather than a direct impact of the Ordinance. Building owners reported that when tenants moved out permanently, new tenants with similar businesses moved in. In some neighborhoods, the rate of turnover represented approximately the same rate of turnover for non-URM buildings. To the extent that local businesses were supplanted with national tenants, this trend was already occurring throughout the neighborhood, and the seismic work provided an opening for changes that might have been destined to occur under normal circumstances.

The likelihood of displacement can be viewed as a factor of the existing strength of businesses. The 1990 Los Angeles study indicated that the Earthquake Hazard Reduction Ordinance affected businesses to a greater degree in neighborhoods where the existing commercial tenants were already *underperforming.*

Once completed, the retrofits will have a minimal impact on leasable area. The CAPSS team engineers report that the proposed retrofit solutions do not occupy a significant amount of space and only require the installation of steel posts at key points of the structure. Plywood shear wall will also have no effect on the leasable commercial area. Therefore, building owners can expect the commercial space to return to full use, once construction is complete.

10.5.4 Summary of Findings

This study finds that the proposed seismic retrofits can be confined to the ground floor and that construction will generally not lead to tenant displacement. In cases where a long-term tenant occupies the unit, and the Rent Stabilization Ordinance has kept rents below market-rate levels, landlords may raise rents to cover the retrofit costs. In fact, based on citywide average rents, the San Francisco Rent Stabilization Ordinance appears to provide a sufficient allowance for landlords to cover the cost of seismic retrofits. This finding assumes that the Ordinance is amended to allow 100 percent of qualified seismic retrofit costs, as defined by DBI, to be passed through to tenants.

However, because 40 to 60 percent of San Francisco apartments have rents that are at or close to the market rate (i.e., the maximum rent that may be charged), landlords have a limited ability to pass through additional costs to tenants. Under these constraints, landlords are less likely to submit a capital improvement petition to the Rent Board and will have to absorb a notable portion of costs themselves. As another financial impact, building owners may need to reduce rents and/or compensate tenants for lost parking and storage space during the course of construction.

Commercial tenants can expect to experience a greater impact than their residential counterparts. The seismic work will significantly disturb operations for two to four months, and many small businesses that occupy soft-story buildings lack the financial wherewithal to recover from this interruption and/or relocate to another space. However, studies suggest that while the retrofits may displace tenants, they are generally replaced by similar businesses. To the extent that changes do occur among commercial tenants, these are viewed as part of the normal pattern of land use change, and the retrofit activity may simply provide an opening for larger market dynamics to affect a neighborhood.

10.6 Impacts of Major Earthquake

This section highlights the potential socio-economic impacts of a major earthquake on San Francisco tenants, businesses, and building owners, absent a citywide retrofit policy. These findings draw on a literature review of the community impacts associated with Hurricane Katrina and the 1989 Loma Prieta and 1994 Northridge earthquakes.

10.6.1 Impacts on Building Owners

Multifamily housing is slow to recover following an earthquake. A 1994 study on residential rebuilding efforts after the Loma Prieta Earthquake found that one year after the earthquake, 90 percent of the multifamily units destroyed or rendered unserviceable were still out of service. Four years later, 50 percent of these units remained unrepaired or unreplaced (Comerio, Landis, and Rofe, 1994).

The federal government offers limited resources for rebuilding rental housing. The Federal Emergency Management Agency (FEMA) and Small Business Administration (SBA) offer grants and loans to homeowners for the rebuilding their properties following a disaster. In general, FEMA offers more financial assistance to homeowners than to renters, simply due to the added cost of reconstructing or repairing their homes. Homeowners also may qualify for additional months of rental assistance while repairing their property.[11]

For owners of rental properties, the SBA represents the primary source of financial assistance for rebuilding. The SBA offers Business Physical Disaster Loans with interest rates ranging from 4.0 to 8.0 percent, and a maximum term of 30 years, though applicants with credit available elsewhere have a maximum three-year term. Loans are limited to $2.0 million, and cannot exceed the verified uninsured disaster loss.

Following Hurricane Katrina, smaller building owners could also access forgivable loans through the Department of Housing and Urban Development's (HUD) Small Rental Repair Program. In contrast to the upfront grants available to homeowners for property reconstruction, the Program reimburses owners after repairs are completed and tenants are in place. A recent study found that due to the difficulty in accessing private financing for repairs, building owners have had difficulty taking advantage of the Small Rental Repair Program's reimbursements (Rose, Clark, and Duval-Diop, 2008).

In addition to assisting building owners, the federal government can also provide resources to developers of affordable multifamily rental housing in the form of Low Income Housing Tax Credits and Community Development Block Grant (CDBG) funds, as modeled by the Hurricane Katrina "Large Rental Program."

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 to service debt (Comerio, Landis, and Rofe, 1994). Owners have little incentive to rebuild, if construction costs cannot be recovered through rents. With units serving lower-income households, access to construction financing is even less feasible. In sum, if the building owner is carrying a large debt load relative to the building value, is making little or no profit from rental income, and the cost to repair is high, then incentives to re-construct the property as condominiums are greater.

When multifamily properties are demolished after an earthquake, the market favors reconstruction as condominiums, rather than apartments. Development economics generally find that condominiums generate greater financial returns to developers than do apartments, even in high-priced rental markets such as San Francisco. Demolished apartments are not subject to the City's Condominium Conversion Lottery and may be replaced as ownership units. Similarly, new apartments replacing demolished units are not subject to the City's Rent Stabilization Ordinance.

The current credit market will limit access to construction financing for any new residential development in the short-term. As noted earlier, lenders continue to apply tight underwriting criteria and more stringent financing terms for new construction of any kind in the current economic climate. Interviews with developers suggest that

[11] E-mail correspondence with Jo Ann Zwicky, Individual Assistance Program Specialist, DHS-FEMA Region IX. 1/7/09.

lenders are currently offering loans up to 50 percent of the building value, compared to 70 to 90 percent historically.

10.6.2 Impacts on Residents

Natural disasters have a particularly negative effect on lower-income households and other vulnerable populations, such as seniors and the disabled. Lower-income households typically have fewer resources to manage their losses, recover from economic and geographic displacement, and return to their homes. Furthermore, many lower-income residents live in multifamily buildings, which historically have been rebuilt at slower rates than single-family units, as discussed above.

A 2006 study of New Orleans following Hurricane Katrina suggests that lower-income areas have been slower to repopulate, due to a lack of transportation among poor households, fewer resources to repair damaged property, and the ongoing absence of employment prospects in the city's disrupted economy. The study also states that lower-income households may not be able to afford the higher rents in reconstructed buildings in New Orleans. As a result, the study expects major demographic and socioeconomic disparities in the city's repopulation (McCarthy et al., 2006).

Research on the impacts of the Loma Prieta earthquake in Santa Cruz County shows that seniors are similarly affected by natural disasters. The elderly are less mobile, and need to be near social services, grocery stores, pharmacies, shopping, entertainment, and existing community networks (Phillips, 1998). These factors, combined with the general loss of affordable housing, make it particularly difficult to find replacement housing for lower-income seniors, as well as disabled individuals, who lose their homes after a disaster.

Affordable housing stock is slow to recover following natural disasters. For example, following Hurricane Katrina, Federal and State allocations will only replace two out of five affordable rental units in State, and one out of three in New Orleans. Moreover, of the 24,600 units projected to receive assistance, only 11 percent are currently open for occupancy (Rose, Clark, and Duval-Diop, 2008).

The Loma Prieta Earthquake particularly impacted lower-income housing stock. The 1994 study of the Loma Prieta earthquake found that of the 6,300 San Francisco units destroyed or damaged after the earthquake, 75 percent were rental units, and 66 percent were rented by low- and moderate-income households (Comerio, Landis, and Rofe, 1994). The study also showed that Federal recovery assistance was less effective at meeting repair needs for multifamily buildings and affordable housing, in particular. While owners of multifamily buildings in strong San Francisco submarkets could rely on rental income to access rebuilding loans, owners of marginal properties had little cash flow to secure financing.

Evidence suggests that major earthquakes can have significant impacts on neighborhood transition. A study of the 1996 Northridge earthquake reported that an estimated 60,000 people migrated out of the San Fernando Valley as a result of the damage to homes and businesses (Petak and Elahi, 2000). The area had been suffering an economic decline due to contraction of the defense industry and falling home values. In the years following the disaster, approximately 20,000 new residents moved into the area. Most of the newcomers were younger and poorer than the previous population. These new residents had different spending habits and needs, greatly changing the retail fabric and overall social structure of neighborhoods.

In some Los Angeles neighborhoods, the Northridge earthquake had an even greater impact on neighborhood transition. In many areas that were once middle-income neighborhoods, the damage made structures uninhabitable and forced some to abandon their units. These neighborhoods subsequently became targets for looters, squatters, and street gangs, further degenerating the quality of the neighborhood. In the midst of an already weak housing market, it was not economically viable to reconstruct the housing stock, and low-income units were especially difficult to finance. Overall, this led to a spiraling decline in the affordable housing stock and an overall decline in property values (Petak and Elahi, 2000).

10.6.3 Impact on Businesses

Small businesses are more vulnerable than large firms following a natural disaster. Small businesses seldom carry insurance, and are rarely diversified in terms of products and services. They also lack the resources to address equipment and inventory damage, interruptions in utility and transportation lifelines. Small and locally-owned businesses are therefore less likely to recover from disasters compared to their chain competitors, whose profits are not dependent on a single store.

For small businesses located in older areas, structural damage can cause a number of problems that further delay and hamper recovery. Small businesses often lack the resources to address the damage that can occur in older buildings. Structural damage may also cause failure of older utility pipes, ducting, and sprinkler systems, which can cause flooding and interior damage. Similar damages to other nearby businesses and residences may reduce customer traffic, further compounding the economic hardship.

Small retailers appear to be the most vulnerable to withstanding major earthquakes. In the case of the Northridge earthquake, businesses reported that for some time after the earthquake, residents changed their spending patterns, further 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 and Elahi, 2000).

A study of the 2001 Nisqually Earthquake in Washington State also highlighted the vulnerability of small retailers (Meszaros and Fiegener, 2002). Of the 13 industries surveyed, retail businesses reported not only 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 do most businesses.

*Even businesses that qualify for federal lending assistance eventually bear the full losses themselves (*Committee on Assessing the Costs of Natural Disasters, National Research Council, 1999). The SBA offers loans to businesses for the repair or replacement of real estate, inventories, machinery, equipment, and all other physical losses following a disaster. Business Physical Disaster Loans have interest rates ranging from 4.0 to 8.0 percent, and a maximum term of 30 years, though applicants with credit available elsewhere have a maximum three-year term. Loans are limited to $2.0 million, and cannot exceed the verified uninsured disaster loss. The SBA does not provide disaster grants.

While small businesses are generally more affected by natural disasters, the financial strength of some businesses will make some more resilient than others. A study of the Northridge Earthquake found that businesses in an unstable financial position before the earthquake suffered the same losses, but lacked the resources for a strong recovery (Tierney et al., 1997). The study also found that many business owners underestimated the financial risks associated with earthquakes and that most were unaware, unwilling, or unable to invest in earthquake preparedness.

10.6.4 Summary of Findings

Natural disasters have a disproportionate impact on multifamily housing, particularly rental units. Both Federal assistance programs and development economics favor the reconstruction of ownership units over apartments.

This loss of affordable rental housing, coupled with the lack of personal financial resources for recovery and relocation, makes lower-income households particularly vulnerable in a natural disaster. These findings do not necessarily contradict the demographic profile of residents discussed earlier. Because households in soft-story buildings may in fact have higher incomes than San Francisco as a whole, they may be able to rebound from a major earthquake more easily than lower-income households, despite potential damage to their buildings.

In terms of impacts on local businesses, small firms also have difficulty returning to operation following a major earthquake, due to a lack of financial resources. The retail industry is especially vulnerable to seismic events, due to its reliance on a steady customer base and a large investment in inventory. Given the overwhelming number of small businesses in soft-story buildings and in San Francisco as a whole, the city's economic recovery following an earthquake depends on a well-organized and prepared business community, and a seismically-sound commercial and mixed-use building stock.

10.7 Summary

10.7.1 Residential Profile

San Francisco has approximately 4,600 wood-frame buildings with three or more stories and five or more units, containing approximately 45,200 units or 13 percent of San Francisco's housing stock. Of these buildings, 2,900 have an open-wall condition, containing 29,200 residential units, or over 8 percent of all households in San Francisco.

The concentration of open-wall buildings varies significantly by neighborhood, suggesting that different areas of the city would be impacted more than others by an earthquake retrofit policy or seismic event. In particular, the Western Addition, Mission, Pacific Heights, Marina, and Richmond contain over 70 percent of the city's units in open-wall buildings.

The findings from a citywide demographic analysis of areas with a low, medium, and high concentration of open-wall units are largely driven by underlying neighborhood profiles. Households in high concentration areas generally are younger, have higher incomes, and are more likely to rent their homes. High concentration areas also have larger proportions of White residents and fewer African American, Asian American, and Hispanic residents. These patterns are consistent with demographic characteristics in neighborhoods such as the Marina, Pacific Heights, and North Beach, which have a large share of open-wall units.

Case studies of the Mission, the Western Addition, and the Richmond indicate that neighborhood-level demographics can vary from citywide trends. Most notably, within the Mission and Richmond Districts, areas with a high concentration of open-wall units have lower household incomes than the neighborhood as a whole. In addition, in both the Mission and Richmond Districts, areas with open-wall units have a larger share of racial minorities than do areas with no open-wall units.

Notwithstanding the citywide trends expressed here, it is important to note that lower-income households do in fact reside in soft-story buildings. As discussed in subsequent sections on this report, these households would be more economically vulnerable in the event of a major earthquake.

10.7.2 Business Profile

Approximately 31 percent of the 2,900 residential open-wall buildings in San Francisco are mixed-use buildings with a commercial use on the ground floor. These enterprises represent a small proportion of all businesses citywide; less than 3 percent of the city's firms operate in open-wall buildings, employing about 1 percent of all employees in San Francisco. The Western Addition, Mission, North Beach, and Pacific Heights neighborhoods contain a large share of these employers.

The data show that a large share of these firms are small retail shops, restaurants, and other personal and professional service businesses. In addition, almost 95 percent of open-wall businesses are small firms employing fewer than 10 people, suggesting that they are independent, locally-owned enterprises.

10.7.3 Impacts of Seismic Retrofit Policy

This study finds that the proposed seismic retrofits can be confined to the ground floor, and that construction will generally not lead to tenant displacement. In cases where a long-term tenant occupies the unit, and the Rent Stabilization Ordinance has kept rents below market-rate levels, landlords may raise rents to cover the retrofit costs. In fact, based on citywide average rents, the San Francisco Rent Stabilization Ordinance appears to provide a sufficient allowance for landlords to cover the cost of seismic retrofits. This finding assumes that the Ordinance is amended to allow 100 percent of qualified seismic retrofit costs, as defined by DBI, to be passed through to tenants.

However, because 40 to 60 percent of San Francisco apartments have rents that are at or close to the market rate (i.e., the maximum rent that may be charged), landlords have a limited ability to pass through additional costs to tenants. Under these constraints, landlords are less likely to submit a capital improvement petition to the Rent Board and will have to absorb a notable portion of costs themselves. As another financial impact, building owners may need to reduce rents and/or compensate tenants for lost parking and storage space during the course of construction.

Commercial tenants can expect to experience a greater impact than their residential counterparts. The seismic work will significantly disturb operations for two to four months, and many small businesses occupying soft-story buildings lack the financial wherewithal to recover from this interruption and/or to relocate to another space. However, studies suggest that while the retrofits may displace tenants, they are generally replaced by similar businesses. To the extent that changes do occur among commercial tenants, these are viewed as part of the normal pattern of land use change, and the retrofit activity may simply provide an opening for larger market dynamics to affect a neighborhood.

10.7.4 Impacts of Major Earthquake

Natural disasters have a disproportionate impact on multifamily housing, particularly rental units. Both Federal assistance programs and development economics favor the reconstruction of ownership units over apartments.

This loss of affordable rental housing, coupled with the lack of personal financial resources for recovery and relocation, makes lower-income households particularly vulnerable in a natural disaster. These findings do not necessarily contradict the demographic profile of residents discussed earlier. Because households in soft-story buildings may in fact have higher incomes than San Francisco as a whole, they may be able to rebound from a major earthquake more easily than lower-income households, despite potential damage to their buildings.

In terms of impacts on local businesses, small firms also have difficulty returning to operation following a major earthquake, due to a lack of financial resources. The retail industry is especially vulnerable to seismic events, due to its reliance on a steady customer base and a large investment in inventory. Given the overwhelming number of small businesses in soft-story buildings and in San Francisco as a whole, the city's economic recovery following an earthquake depends on a well-organized and prepared business community, and a seismically-sound commercial and mixed-use building stock.

APPENDIX 11: SOFT-STORY MITIGATION PROGRAMS IN OTHER COMMUNITIES

11.1 Overview

The CAPSS program has been asked to identify policy options to reduce the risk of wood-frame buildings with soft or weak first stories in San Francisco. As part of this process, the CAPSS team has researched the activities of other California communities relating to this high-vulnerability type of building. San Francisco can learn from the successes and failures of other communities.

This appendix describes mitigation programs and activities related to soft-story buildings for four California cities (See Table 11-1). Details of the soft-story programs of the City of Berkeley, City of Freemont, City of Santa Monica, and the City of Los Angeles are provided in Tables 11-2. 11-3, 11-4, and 11-5, respectively.

Table 11-1 Summary of Programs by Jurisdiction

Jurisdiction	Summary of Program
City of Berkeley	Requires an engineering study and informing tenants; retrofit not required.
City of Fremont	Requires an analysis and retrofit of buildings that do not meet the minimum standard; few buildings affected
City of Santa Monica	Requires an analysis and retrofit of buildings that do not meet the minimum standard; enforced for several years, but not supported in recent years
City of Los Angeles	Retrofit is not required

In addition, activities of a number of other communities are described: Oakland, San Jose, Burbank, San Leandro, and Campbell. These communities are taking or have taken some steps towards addressing the risk of soft-story buildings but did not have specific ordinances requiring retrofit of these buildings in place, at the time when this information was gathered and documented.

Table 11-2 City of Berkeley Soft-Story Program

Item	Information Provided by Jurisdiction
Jurisdiction	City of Berkeley, Building and Safety Division, Planning and Development Department
Nature of Ordinance	
Ordinance	Soft-Story Ordinance (Berkeley Municipal Code 19.39)
Date Enacted	October 2005
Approach	Berkeley's ordinance requires owners of buildings on the City's soft-story inventory to conduct engineering studies to identify structural retrofit solutions and their costs, in accordance with standards defined by the city. A notice and order is sent to owners of buildings on the City's Inventory of Potentially Hazardous Soft-Story Buildings. The notice and order provides six months to challenge the inclusion on the Inventory, before the notice becomes final. Once final, owners are required to post the building with a warning sign and notify tenants within 30 days. Within two years from the notice date, owners must file an engineer-prepared "Soft-Story Engineering Evaluation" report that compares the building with designated technical standards and defines a plan to fix any weakness. The report deadline is accelerated under certain events, including when title is transferred, the building is refinanced, or work of $75,000 or more is done. As notices become final, the ordinance requires recording notices of Inclusion on the Inventory with the County Recorder's Office. Retrofit is not required.
Scope	Residential buildings with five or more residential units with an apparent soft, weak and open front story
Priorities	Buildings with a wood ground floor are addressed first. The next phase will probably focus on high occupancy buildings with concrete podia at the ground floor.
Fees	Berkeley requires a review fee of $583.
Implementation Period	Owners have 6 months to contest inclusion in the soft-story inventory, before the notice becomes final. After notice becomes final, owners have 30 days to post a sign and notify tenants. Owners have two years to comply with the notice requirement for an analysis. Building owners can apply for time extensions.
Incentives	Once retrofitted, the owner enjoys a 15-year period during which additional requirements cannot be imposed. The City provides a report framework to guide report preparation and a roster of engineers who attended the City's training session. Retrofitting or a favorable analysis results in the building being removed from the list of soft-story buildings. Owners can forgo the cost of the review of the engineering report, if they choose to retrofit directly.
Penalties	There are sanctions or fees and fines for non-compliance and for the staff to bring buildings into compliance with the ordinance. So far, the program has relied on the voluntary compliance of owners.
Performance Objectives/ Technical Standards	Engineering reports compare buildings to Appendix Chapter A4 of the 2003 *International Existing Building Code* (IEBC). There is concern that the IEBC Appendix Chapter A4 requires work beyond addressing the soft, weak and open condition. The City might waive these requirements.

Table 11-2 City of Berkeley Soft-Story Program (continued)

Item	Information Provided by Jurisdiction
	Implementation
Number of Buildings, Types, Size	The city's survey identified 317 potential soft-story buildings with wood frames at the ground level. About 140 more buildings with concrete podia were also identified as having potential soft or weak open front conditions.
Progress	All wood-frame buildings identified in the survey have been noticed, most between March and September 2006. As of October 2008, engineering reports had been submitted for about 130 buildings. As of April 2008, about 10 buildings on the building inventory were found not to have soft-story weaknesses. A further 20 buildings were removed from the inventory because they have fewer than 5 residential units. Currently, about 33 buildings have been seismically retrofitted or have building permits to conduct retrofits. The Building Official reported on progress to Council in the winter of 2009 and planned, at that time, to recommend an ordinance mandating retrofit of buildings not meeting IEBC Appendix Chapter A4.
Cost	Engineering surveys have been in the range of $3,000 to $12,000 per building. Retrofit costs are not yet available. Staff will collect and analyze this information at some point.
Problems	The costs of retrofits are an allowable expense for building owners to pass through to tenants. However, most building owners may not actually be able to pass through these costs, due to having increased Net Operating Income, which is used as an offset to costs under Berkeley's rent control regulations.
Background	Berkeley's program emerged as the result of a long process involving the city's voters, discussions with building owners and community members, and review by the many boards that advise the city's lawmaking process. Initially, the city attempted to raise funds to assist in the structural strengthening of soft-story buildings through a ballot measure, but this was rejected by voters. Discussions followed to create legislation mandating that owners retrofit their buildings, but this was deemed too challenging as the community's initial step. This led to the city's current approach. The city is considering a more assertive approach.
	Administration
Number of staff for program, qualifications and duties	One staff member works on this program about half time. The building official uses normal procedures to check plans and inspect the work during construction.
Do you use consultants?	Engineering reports are reviewed by consultants: Bureau Veritas and Telesis Engineers.
Workload Metrics	The program is tracked by the key staff member, and information is stored in the city's central database in the Code Enforcement Module.
Any Lawsuits or Legal Opinions?	There have been no lawsuits. The City Attorney was involved during the program's development.
	Other Matters
Give Advice?	
Web Page	www.ci.berkeley.ca.us/ContentDisplay.aspx?id=622
Sources	Joan MacQuarrie, Building Official, personal communication. Dan Lambert, Senior Management Analyst, personal communication. www.ci.berkeley.ca.us/ContentDisplay.aspx?id=622.

Table 11-3 City of Fremont Soft-Story Program

Item	Information Provided by Jurisdiction
Jurisdiction	City of Fremont, Building and Safety Division, Community Development Department
Nature of Ordinance	
Ordinance	Fremont Municipal Code, Title VII (Building Regulations) Chapter 10 *Minimum Mandatory Earthquake Hazard Reduction Requirements and Standards for Existing Wood Frame Residential Buildings with Soft or Open-Front Walls*
Date enacted	May 1, 2007
Approach	Mandatory program requiring owners of apartment buildings with soft-story deficiencies to seismically retrofit. Building owners are required to complete a survey checklist to determine if the building meets minimum earthquake performance standards. If the building does not meet these standards, then building owners must retrofit according to a specified timetable.
Scope	Covers apartment buildings with soft-story deficiencies built before 1978. Condominiums and townhouses are not covered by the mandatory ordinance at this time.
Priorities	Apartment buildings with 10 or more units must seismically retrofit first. Apartment buildings with 10 or fewer units are also mandated to retrofit, with a longer deadline. Condominiums and townhouses have no mandates to retrofit.
Fees	Fees are rebated to owners, once the work associated with seismic retrofits is completed successfully.
Implementation Period	Building owners have 30 days to appeal, after receiving notice that they are covered by the ordinance. Buildings with more than 10 units must submit engineering plans within 24 months of notice and complete construction within 48 months. Buildings with 10 or fewer units must submit engineering plans within 36 months of notice and complete construction within 60 months. Building owners can apply for time extensions due to financial hardship.
Incentives	Plan check and building permit fees are returned for earthquake retrofits of soft-story apartment buildings, when the work is completed within the specified timetables.
Penalties	Apartment buildings not in compliance are deemed a public nuisance and could potentially be demolished.
Performance Objectives/Technical Standards	The ordinance, when adopted, was based on the 2001 version of the California Building Code. Buildings are required to resist a base shear of 75 percent of the code. The goal is to reduce the collapse hazard of buildings in the event of a major earthquake. The mandatory program only requires analysis and strengthening of the soft-story portion of the structure, the ground floor.
Implementation	
Number of Buildings, Types, Size	Fremont has identified fewer than 30 complexes or owners with apparent soft-story buildings, some with multiple buildings. This includes 19 apartment complexes with soft-story deficiencies. Two of these complexes were seismically retrofitted under a previous voluntary program. Seventeen complexes, some with multiple buildings and with an estimated 726 apartment units, have yet to be retrofitted. All buildings have wood-frame construction. Three condominium complexes with soft-story deficiencies have also been identified, but are not covered by the mandatory retrofit ordinance.

Table 11-3 City of Fremont Soft-Story Program (continued)

Item	Information Provided by Jurisdiction
Progress	The city allows owners to appeal the identification of their buildings and inclusion in this program; however, none have appealed. Three, perhaps four, owners have submitted drawings to the City for review. None were under construction as of October 1, 2008.
Cost	When the ordinance was enacted, city staff estimated that it would cost building owners $2,500 to $3,500 per parking space at the ground level. A better estimate of the cost of engineering and construction might be received from design professionals working in the City. The estimated cost to the City in terms of lost permit fees was $22,000 to $40,000.
Problems	There were no particular “problems” with the program as of the time of this writing. Owners and their design engineers ask questions regarding the extent of required work.
Background	Fremont had a voluntary ordinance, enacted in 1999, to encourage building owners to strengthen multi-residential soft-story buildings. Owners of soft-story buildings were notified and the city adopted standards for seismic retrofits. Only two buildings, containing 96 rental units, performed seismic retrofits under this program.
Administration	
Number of staff for program, qualifications and duties	One structural engineer is responsible for monitoring the soft-story program and answering questions. This assignment takes less than 5 percent of his/her time. Plan review is conducted using the normal process for reviewing all permit requests and is done by the engineer assigned at the time of submittal.
Do you use consultants?	Consultants are not used.
Workload Metrics	
Any Lawsuits or Legal Opinions?	None
Other Matters	
Give Advice?	Plan check engineers do not give advice on retrofitting. Plans prepared for the owner are checked against code requirements, and deficiencies are noted on a list of comments. Plan checkers do not engage in design. Special inspection and construction observation by the engineer of record are required during construction. Retrofit solutions include steel frames, horizontal diaphragm braces to transfer loads to the back wall, and buttresses, if planning department set back requirements allow this solution.
Web site	http://www.fremont.gov/CityHall/Departments/BuildingSafety.htm http://www.fremont.gov/Construction/Ordinances/default.htm
Sources	Jack Chen, City of Fremont Building Department. http://www.fremont.gov/Construction/Ordinances/default.htm.

Table 11-4 City of Santa Monica Soft-Story Program

<table>
<tr><th>Item</th><th>Information Provided by Jurisdiction</th></tr>
<tr><td>Jurisdiction</td><td>City of Santa Monica, Planning and Community Development Department, Building and Safety Division</td></tr>
<tr><td colspan="2">Nature of Ordinance</td></tr>
<tr><td>Ordinance</td><td>Original ordinance number unknown.

Additional Ordinance: Ordinance 1945, adding Chapter 8.72 to the City’s Building Regulations, “Seismic Strengthening Provisions for Soft, Weak or Open Front Walls in Light, Wood framed Buildings”.</td></tr>
<tr><td>Date enacted</td><td>Original ordinance passed in mid-90’s after the 1994 Northridge earthquake.

Ordinance 1945 passed in June 1999</td></tr>
<tr><td>Approach</td><td>The city requires owners of wood-frame soft-story buildings to seismically retrofit within a given timetable.

The process began when the Building Officer sent a written notice to building owners that they are subject to this ordinance.

Building owners must have their building evaluated by a licensed civil or structural engineer and submit a report to the City. Buildings that do not meet the required standards must seismically retrofit. No additions, alterations, or remodels are allowed until seismic retrofit has occurred. Owners can seek permits to demolish their building instead of retrofitting.</td></tr>
<tr><td>Scope</td><td>The ordinance applies to all wood-frame buildings designed to a code in effect before December 12, 1995 that have soft, weak or open front line walls as defined in the building regulations.</td></tr>
<tr><td>Priorities</td><td>Buildings used as essential facilities must retrofit first. Buildings with more occupants must retrofit before buildings with fewer occupants.</td></tr>
<tr><td>Fees</td><td>Permit fees are waived for retrofits.</td></tr>
<tr><td>Implementation Period</td><td>Owners must submit an engineering report within four months of receiving notice from the city.

Buildings with soft-story deficiencies must retrofit within the following time periods after submitting an engineering report:
<table>
<tr><td>Type</td><td>Submit Plans</td><td>Begin Construction</td><td>Complete Construction</td></tr>
<tr><td>Essential facilities</td><td>60 days</td><td>150 days</td><td>1 year</td></tr>
<tr><td>More than 100 occupants</td><td>180 days</td><td>270 days</td><td>3 years</td></tr>
<tr><td>20 to 99 occupants</td><td>1.5 years</td><td>1 year, 8 months</td><td>3 years</td></tr>
<tr><td>Fewer than 20 occupants</td><td>2 years, 5 months</td><td>2 years, 8 months</td><td>4 years</td></tr>
</table></td></tr>
<tr><td>Incentives</td><td>Permit fees are waived for retrofits.

Owners are not required to compensate tenants, if temporary relocation is required. Tenants must be allowed to return to their units at rent-controlled rates.</td></tr>
<tr><td>Penalties</td><td>Information can be attached to building titles that they are potential soft-story buildings subject to this ordinance.</td></tr>
</table>

Table 11-4 City of Santa Monica Soft-Story Program (continued)

Item	Information Provided by Jurisdiction
Performance Objectives/ Technical Standards	Santa Monica developed its own technical standards (Chapter 8.72 of Santa Monica Municipal Code), based on work in Los Angeles. The goal of these standards is to substantially improve the performance of retrofitted buildings.
Implementation	
Number of Buildings, Types, Size	Approximately 2,100 buildings were identified as potential soft-story buildings by City staff during a field survey. These buildings were given notices to comply with the ordinance during or prior to March 1995. As of May 1997: • Seismic retrofits had been completed for over 1,000 buildings; • Owners of more than 200 buildings had submitted engineering reports that showed their buildings were not soft-story buildings; • Approximately 200 buildings had permits, current or expired, to conduct retrofits but had not received final inspection; • Owners of over 400 buildings had submitted engineering reports but had not yet requested permits for retrofits; and • Owners of more than 600 buildings had not responded to the City's notices.
Progress	Santa Monica's program has not been enforced since the late 1990's due to lack of resources and internal support by some key City staff. Recently, there have been staff changes within the city, and it is moving forward to enforce the ordinance. However, current city staff appear to be unaware of the progress that this program made a decade ago. The city has plans to hire a consultant to develop a new inventory of soft-story buildings and to review permits for retrofit status. Some elements of the original ordinance are likely to be altered, such as including an appeals process for building owners who believe that they should not be covered by the program.
Cost	No data on costs of seismic retrofits are available.
Problems	Santa Monica's soft-story ordinance has no real penalties for owners who do not comply. There may be institutional "memory loss" due to significant staff turnover. Current staff members seem unaware of the activities, reports and databases that were used to enforce this program.
Background	This ordinance was passed quickly after the Northridge earthquake. Santa Monica experienced significant damage in that event, which raised public concern about building safety. Santa Monica has required the retrofit of unreinforced masonry (URM) buildings, soft-story buildings, tilt-ups, non-ductile concrete buildings, and steel frame buildings. To date, only the URM and soft-story requirements have been enforced. Other types have not yet been inventoried. Owners of single-family homes are encouraged, but not required, to retrofit.
Administration	
Number of staff for program, qualifications and duties	Santa Monica had one staff member for approximately three years who was supposed to spend significant time on this program. However, this staff member was not able to spend as much time as hoped on this program due to a sizeable increase in the overall department workload. After this staff member left, the program apparently had no staff support.

Table 11-4 City of Santa Monica Soft-Story Program (continued)

Item	Information Provided by Jurisdiction
Do you use consultants?	A consultant will help the city resume this program.
Workload Metrics	
Any Lawsuits or Legal Opinions	
Other Matters	
Give Advice?	It is important to include penalties and enforcement mechanisms in an ordinance of this type.
Web site	http://www.qcode.us/codes/santamonica/ (Chapter 8.72)
Sources	Loretta Duvall, Mel Green and Associates, Torrance, CA (formerly Santa Monica Code Enforcement) Edwin Hacopian, Santa Monica Code Enforcement Timothy McCormick, Director of Building Services, County of Monterey (formerly Building Officer for the City of Santa Monica)

Table 11-5 City of Los Angeles Soft-Story Program

Item	Information Provided by Jurisdiction
Jurisdiction	City of Los Angeles, Department of Building and Safety
Nature of Ordinance	
Ordinance	Voluntary Earthquake Hazard Reduction in Existing Wood Frame Residential Buildings with Soft, Weak or Open Front Walls (Division 93, Article 1, Chapter IX of LA Municipal Code)
Date enacted	May 1998
Approach	The city developed technical standards for building owners who wish to voluntarily seismically retrofit their buildings.
Scope	The standards apply to apartment buildings, condominium buildings, hotels and other "congregate residences." It applies to wood-frame buildings with an open ground floor designed to codes prior to the 1995 code.
Priorities	None
Fees	No fee reductions
Implementation Period	None
Incentives	There may have been limited low-interest loans through the Housing Department, but no details are known.
Penalties	None
Performance Objectives/ Technical Standards	Their own standards are defined in the ordinance, developed with a task force of the Structural Engineers Association of Southern California (Chapter 93 of the Los Angeles Building Code). This was the first effort to define technical standards for retrofit of this type of building.

Table 11-5 City of Los Angeles Soft-Story Program (continued)

Jurisdiction	City of Los Angeles, Department of Building and Safety
Implementation	
Number of Buildings, Types, Size	The City has no inventory of potential soft-story buildings. According to information developed under the CUREE-Caltech Wood-Frame Project, there are an estimated 20,000 wood-frame apartment or condominium buildings in the LA area with “tuck under” parking at the ground level.
Progress	As of June 2006, owners of 106 wood-frame soft-story buildings had conducted voluntary retrofits that met the city’s standard, or were in the process of doing so.
Cost	No data.
Problems	
Background	After the 1994 Northridge earthquake, the city developed technical standards for retrofits of: • wood-frame buildings with weak cripple walls and unbolted sill plates; • hillside buildings; • reinforced concrete and reinforced masonry wall buildings with flexible diaphragms; and • reinforced concrete buildings and concrete frame buildings with masonry infills.
Administration	
Number of staff for program, qualifications and duties	Retrofit plans are checked through normal procedures.
Do you use consultants?	
Workload Metrics	
Any Lawsuits or Legal Opinions	
Other Matters	
Give Advice?	
Web site	
Sources	Andrew Adelman, General Manager, Department of Building and Safety, Personal communication and written materials Victor Cuevas, staff, LA Department of Building and Safety

11.2 Activities of Additional Communities

11.2.1 City of Oakland

Oakland has no ordinances requiring soft-story retrofits.

The City of Oakland is currently developing an inventory of its soft-story buildings. The inventory focuses on buildings with five or more units, from two to seven stories. Some buildings with concrete podia are included. The inventory effort was scheduled to be completed by the end of 2008.

The Association of Bay Area Governments (ABAG) is organizing the inventory process, supported by a FEMA grant. The Structural Engineers Association of Northern California (SEAONC) and the Northern California Chapter of the Earthquake Engineering Research Institute (EERI-NC) are providing volunteers to assist in surveying nearly 4,000 parcels.

Source: Jeanne Perkins, consultant to ABAG

11.2.2 City of San Jose

San Jose has no ordinances requiring soft-story retrofits.

The City completed an inventory of apartment buildings with apparent soft-stories, prepared maps with locations identified, and conducted an outreach program including education and training for owners.

The city staff recommended preparation of a program to require retrofit with priority given to 460 addresses (some with multiple buildings and units) that were considered to be of poor construction and located on poor soil. The program was to be modeled after the City's program for unreinforced masonry (URM) buildings. The City would waive permit fees, provide some engineering services, and a special "opt in" district would be created for owners wishing to borrow funds. The URM program created a special district in about 1992, when interest rates were high and money tight. However, the economy improved, and owners preferred to rely on traditional sources for funds; the potential use of the district funds was abandoned in about 1995.

The City Attorney opposed releasing the inventory information and moving ahead with a program, and the City Manager was concerned with the political implications of a program. The effort was dropped, but the City developed some helpful information for apartment owners and others.

Between 1998 and 2000, the City of San Jose created several publications about soft-story buildings:

- *The Apartment Owner's Guide to Seismic Safety*: *A Handbook for Owners to Identify Seismic Hazards in Low Rise Apartment Buildings* was prepared by Vukazich, Department of Civil Engineering, San Jose State University, San Jose, California;
- *Practical Solutions for Improving the Seismic Performance of Buildings with Tuck-under Parking*, a publication of pre-engineered typical solutions, was prepared by Rutherford and Chekene; and
- Two other technical reports analyzing costs and technical approaches to retrofit soft-story buildings;

Sources:

- http://www.sjsu.edu/cdm/projects/inventory.html
- quake.abag.ca.gov/mitigation/PR-Soft-Story-11-17.pdf
- http://www.sanjoseca.gov/emergencyServices/brochures.asp
- Francis Edwards, San Jose State University, former director of Emergency Services for San Jose.

11.2.3 City of Burbank

Burbank has no ordinances requiring soft-story retrofits.

Burbank held public hearing in Spring 2008 on a concept proposal to address the risk of soft-story buildings. These proposals were put on hold due to stiff opposition.

11.2.4 City of San Leandro

San Leandro has no ordinances requiring soft-story retrofits.

The City's Building Department has conducted a preliminary "draft" inventory of about 330 multi-family residential, commercial/office, and mixed-use buildings containing approximately 4,000 units. All buildings with two or more stories were surveyed. City staff met with the Apartment Owners Association and the Chamber of Commerce while conducting this inventory. City staff are now working to further validate which buildings have soft-story conditions by conducting an in-house survey for each building based on the screening form provided in FEMA 154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, Second Edition* (FEMA, 2002). City Council will be approached soon to discuss the appropriate policy for reducing risk in these buildings

Sources:

- William Shock, Chief Building Official
- http://www.quake06.org/quake06/best_practices/IMSSB.html

11.2.5 City of Campbell

Campbell has no ordinances requiring soft-story retrofits.

The City worked with a consultant to develop an inventory of soft-story buildings in the city. All building owners were mailed a copy of San Jose's *The Apartment Owner's Guide to Seismic Safety*.

Consultants developed the inventory of soft-story buildings in the City of Campbell (Disaster Mitigation Collaborative, a non-profit based at San Jose State).

Source*:* http://www.sjsu.edu/cdm/projects/inventory.html

APPENDIX 12: INCENTIVES TO ENCOURAGE SEISMIC RETROFITS

12.1 Introduction

The purpose of this appendix is to provide San Francisco's decision makers with a range of incentives that could be offered to encourage seismic retrofits. Some of these incentives will make sense for San Francisco; others will not. Some of the ideas mentioned here have more details than others. Many are not fully fleshed out. Undoubtedly there are additional incentives that could be offered, which are not described here.

12.2 Background

A significant earthquake could destroy more than a quarter of the building stock in San Francisco. This level of damage would injure thousands, cripple the city's economy, cause a housing crisis, devastate tourism, and irrevocably change the character and affordability of the city. Some argue that the damage could reach a "tipping point," causing recovery challenges that would persist for years. These are compelling reasons to consider earthquake losses to privately-owned buildings as a community issue, more than simply a collection of many private losses experienced by building owners and their tenants. If avoiding these consequences is a community priority, then it could make sense for the community to invest in encouraging private building owners to seismically retrofit.

Over time, San Francisco could work to reduce its vulnerability by seismically upgrading the weakest buildings. Designing a program to improve the earthquake performance of buildings involves many variables and elements:

- *Scope:* Which buildings should be addressed?
- *Priorities:* Should any particular building type, use or occupancy be addressed before other buildings?
- *Approach:* What is the proper degree of government intervention? Should building retrofits be required or encouraged?
- *Implementation Period:* How many years is the City willing to wait until the building stock is strengthened?
- *Incentives:* To what degree should the City encourage compliance with a program, given that there are benefits to retrofitting that accrue to the general public and not just to owners?
- *Performance Objectives:* How much damage is acceptable in privately-owned buildings after an earthquake, and are there different levels of acceptable damage for buildings with different uses?

This appendix provides options for one of these elements: incentives to encourage building owners to seismically retrofit their buildings. These options have been collected from efforts in other communities, previous efforts in San Francisco, and ideas that have not yet been tried in any community. Not all of these ideas will be appropriate for San Francisco.

12.3 Incentives

Incentives for seismic retrofits could be offered to encourage voluntary retrofits or to ease the impact of mandated seismic upgrades. For example, the City could develop a policy to require owners of vulnerable buildings to upgrade to a minimal standard that would save lives, and could also incentivize them to retrofit to a higher standard that would ensure that buildings could be occupied and would be repairable after earthquakes, thereby preserving post-earthquake housing and improving resilience.

The most effective approach might be to offer multiple incentives, because no single incentive or combination of incentives will serve the interests of every building owner. The decision of a building owner to seismically retrofit is complex and occurs within a context of many competing needs. Building owners vary significantly, ranging from a city resident who owns one apartment building that he or she lives in to a corporation, and these diverse owners have varying knowledge, resources and motivation. A variety of incentives would allow owners to assemble unique combinations to satisfy their particular needs.

Building retrofit incentives can be divided into the following categories:

- *Financial incentives:* grants, rebates, credits, loans, loan interest reductions, deferred loans, donated and reduced-rate labor, insurance premium savings, fee waivers;
- *Policy incentives:* expedited processing of permit applications and loan applications, waiver of property restrictions;
- *Technical assistance incentives:* advice on retrofitting, standard details, help with garnering incentives, assistance with contracting questions; and
- *Information incentives:* information and materials.

Examples from each of these categories are discussed below.

12.4 Options for Incentives to Encourage Seismic Retrofits

12.4.1 Financial Incentives

Financial incentives reduce the costs of seismic retrofits for owners. It could make sense for communities to offer financial incentives because, while many of the benefits of retrofits go directly to building owners, there are also larger societal benefits, such as safety for tenants and preserved affordable housing and neighborhood character.

The California Constitution (Article XVI, Section 6) prohibits gifts of public funds for private purposes. However, seismic retrofits of privately-owned buildings have been supported by programs such as loans, grants to low income residents and non-profit organizations, and tax rebates, in recognition of their public benefits. Whether or not the City could subsidize private owners who retrofit their buildings, voluntarily or because of a mandate, should be considered by the City Attorney. Conflicting opinions have been voiced, but there seems to be flexibility in interpreting the law when the public will benefit in ways such as improved public safety.

Grants, Credits and Rebates

San Francisco could provide grants or rebates to pay for a portion of qualified expenditures on building evaluation, design drawings and/or construction.

Communities have used redevelopment funds and Community Development Block Grant (CDBG) funds to provide grants to cover costs associated with retrofitting vulnerable buildings. CDBG funds could only be used for low- and moderate-income homeowners. Small Business Administration Certified Development Corporation CDC/504 loans might be available for small businesses.

The following communities provided grants or rebates for their unreinforced masonry building (URM) retrofit programs (EERI, 1998, p 39):

- Inglewood, California: City reimbursed up to $3,000 of cost of engineering studies and 100 percent of plan check fees, permits and taxes using redevelopment money;
- San Jose, California: City provided redevelopment fund grants for engineering design work;
- Sonoma, California: City reimbursed owners for a portion of engineering fees;
- Tustin, California: City used CDBG grants of up to $2,000 to cover engineering costs; and
- West Hollywood, California: City used CDBG grants of up to $7,100 per building and housing rehabilitation program of $10,000 per building.

Property Tax

Existing state tax law (Section 74.5 California Revenue and Taxation Code) provides that the cost of an earthquake retrofit should not increase the property assessment used to determine the amount of property taxes. However, it could be challenging for building owners to secure this benefit, because they must submit specific information to their County Assessor's Office prior to conducting retrofit work. Due to lack of state support, many Assessor's Offices around the state do not have forms for this purpose, and their staff are not trained to process this benefit.

At this time, it is not known whether and how San Francisco manages this issue. In a few jurisdictions, city officials have worked with the County Assessor's Office to facilitate this process for building owners. San Francisco could make sure that this benefit is truly available to building owners and could advertise and explain it to homeowners, so that they follow proper procedures.

Further incentives involving property tax are possible, such as deferred or reduced property taxes for building owners who have seismically retrofitted. Currently, we are unaware of other communities that have offered this type of incentive for seismic upgrades.

Real Estate Transfer Tax Rebate

San Francisco currently has a real estate transfer tax of 0.68 percent of the purchase price for properties sold for under $1 million and 0.75 percent for properties sold for over $1 million. In November 2008, San Francisco voters approved a measure

(Measure N, "Changing Real Property Transfer Tax Rates") to rebate one-third of San Francisco's transfer tax to properties for conducting seismic upgrades or installing active solar systems, as well as doubling the transfer tax for properties sold for $5 million or more. At the time of writing, it is not clear how the transfer tax rebate program will be implemented.

The City of Berkeley rebates up to one-third of its transfer tax amount (1.5 percent of purchase price) for qualified earthquake retrofit on homes. This program, along with Berkeley's other retrofit incentives, has led to an estimated 45 percent of the private residences in Berkeley being made more seismically resistant. Over $6 million in transfer taxes have been rebated. In recent years, Berkeley has required retrofits to meet specified standards to qualify for a transfer tax rate. This was done because some retrofits were found to be ineffective at reducing a building's seismic risk.

In 2007, the City of Oakland followed in Berkeley's footsteps and developed a program to offer a rebate of up to one-third of its property transfer tax (1.5 percent of purchase price), if those funds are used for qualified seismic retrofit programs.

Fee Rebates

The City collects fees associated with property taxes and charges for certain services. It could compensate owners who conduct qualified seismic safety upgrades by reducing relevant fees.

Reducing fees reduces existing City government resources. If there is no existing fee with a nexus to earthquake emergency management, then a new emergency management fee could be established, and then reduced, to compensate owners who spend their own money to reduce emergency response burdens on the City.

Loans

The City could assist building owners to pay for seismic retrofits by:

- offering loans with rates lower than commercial rates;
- providing loan guarantees;
- reducing or "buying down" loan interest rates; or
- making market-rate loans available to those who might not otherwise qualify for them.

The City could provide these loan services or assist building owners to get loans from other sources. Loans could be repaid through assessment liens paid along with property taxes. Loan payments could be deferred for a period of time, or until the sale of the property for hardship cases.

To reduce or "buy down" loan interest rates, the City, a contractor or another organization wishing to encourage retrofit could subsidize loans by "buying down" with cash the interest rate on a loan to a level below prevailing market rates. For example, a 3-2-1 buy down would reduce the interest by 3 percent the first year, 2 percent the second year and 1 percent the third year and would revert to market rate for the fourth and subsequent years. A 3 percent buy down of a $100,000 loan for one year would cost about $3,000.

In 1992, San Franciscans passed a bond measure to offer loans for mandated retrofits to unreinforced masonry buildings. Most of the funds were intended for market rate loans (7.5 percent rate), and a portion of the funds was for low-interest loans (2.5

percent rate) for qualified buildings housing low-income tenants. Very few building owners took advantage of the market rate loans, but the low-interest loans provided a useful source of financing for some affordable housing upgrades. To date, slightly over 15 percent of the $350 million has been used for loans; about 13 percent was used for low-interest loans and 2 percent used for market rate loans. Some building owners have stated that they chose not to seek these loans, because there were complex conditions attached to the loans and it was easier and more cost-effective to deal with commercial lenders.

In general, many building owners prefer conventional loans from commercial lenders to loans offered by a government entity. Commercial second mortgages are not common and when offered, generally have high interest rates. Note that if borrowers default on mortgages, government liens often are paid before loans from other financial institutions. This reduces the equity that covers the private loans and could affect existing mortgages or make new or refinanced mortgages unattractive, because mortgage lenders generally do not offer “second place” loans, and if they do, then the interest rates will reflect the risk.

The City could fund loan programs for seismic retrofits in a variety of ways, including, but not limited to, those listed below:

- The remaining funds authorized for unreinforced masonry building loans could be repurposed to provide loans to other building types through a ballot measure.
- The City could raise funds for loans to property owners by creating a special city-wide tax district that collects funds from the property owners who voluntarily opt-in to use it as a financing mechanism for seismic safety upgrades. Those that opt-in would pay for the cost of their own loan, plus fees necessary to administer the program. Payment could be via property tax assessment over a set period.
- CDBG funds could be used for retrofit loans on homes owned by persons with low or moderate incomes.
- City funds or bond proceeds could be used to fund a retrofit loan loss guarantee fund or to purchase insurance on retrofit loans, to reduce risk of default and the interest rate. A City department could create a revolving fund for this purpose. Guidance from the City Attorney would be needed in order to do this.
- Financing for seismic retrofits might be available to eligible non-profit organizations through programs including the Association of Bay Area Governments (ABAG) Authority for Non-Profit Corporations.

Permit Fee Waivers

The City could waive or reduce fees charged for building permits, plan checking, planning review and/or variance applications or other permits required for seismic retrofit work.

The City considered but did not pass legislation to waive such fees for voluntary retrofits in the Fall of 2008. Waiving these fees would reduce City revenues.

Pass Through of Retrofit Costs to Tenants

Building owners who seismically retrofit their buildings could be allowed to pass through the costs of these retrofits to renters in rent-controlled units.

For the City's unreinforced masonry building program, building owners were allowed to pass through 100 percent of seismic retrofit costs to rent-controlled tenants over a 15-year period, with a maximum increase of 10 percent of the base rent in any one year. This was coupled with a daily stipend for temporary relocation and other protections for tenants. Some, but not all, building owners took advantage of this benefit. Presumably, many buildings had turnover in their tenants, allowing them to rent units at market rate and negating the need to seek pass-throughs for retrofit expenses.

In 2002, the City passed a law allowing 100 percent pass-through of any code mandated seismic or energy upgrades. When this work is voluntary, however, only 50 percent of costs can be passed through to tenants. The City could alter this to allow 100 percent of expenses for voluntary seismic retrofits to be passed through.

Tax Reductions for Historic Properties

There are two existing incentive programs that could be used to reduce taxes for historic properties that conduct seismic upgrades: the state Mills Act and the creation of a federal historic district.

The Mills Act (California Government Code, Article 12, Sections 50280 - 50290, California Revenue and Taxation Code, Article 1.9, Sections 439 - 439.4) gives local governments the authority to enter into contracts with owners who restore and maintain historic properties. In exchange, the property owners could get significant property tax savings (approximately 50%). Only buildings that are listed on the National Register or are located in a National Register District can qualify for this incentive. The process to apply for this program is expensive and cumbersome. The City limits its annual loss to a maximum of $1 million per year due to the Mills Act.

Creating a National Register Historic District could provide a federal income tax credit for qualifying work on contributing historic properties within the district.

The City of St. Helena used both of these tools to assist owners of unreinforced masonry buildings to seismically retrofit. Creating a federal historic district was a successful incentive, giving owners a 20 percent federal tax credit. Many building owners found the Mills Act less appealing because of its cumbersome process.

Insurance Incentives

Most, but not all, earthquake insurance for single-family homes and renters in California is offered through the California Earthquake Authority (CEA), a publicly managed, largely privately funded organization. CEA policies are offered through participating private insurance companies. The CEA was started in 1996, after the southern California Northridge earthquake, which caused major losses to insurance companies and restricted their willingness to offer earthquake policies. CEA policies reflect the risk of earthquake damage and have higher premiums, higher deductible limits, and more limited content and living expenses coverage than policies prior to Northridge. Private insurance companies offer earthquake insurance on commercial properties, such as multi-unit residential properties.

The ability of property insurers to offer incentives is limited by market competition, federal tax law, state regulation and the nature of insurance working best when covering large numbers of predictable losses and dispersed over time and location. Risks that are infrequent, unpredictable and concentrated in time and space by a single event are hard to cover by actuarially based reserves.

Currently, the CEA offers a 5 percent rate credit to those who retrofit their homes. This discount is offered for wood-frame construction dwellings built before 1979, if the frame is tied to the foundation, has cripple walls braced with plywood or its equivalent, and if the water heater is secured to the building frame. The retrofit discount is not available for houses built on concrete-slab foundations, and insurance is not offered by the CEA for multi-unit residential housing.

Other possible incentives associated with earthquake insurance are possible but not currently available. These include further discounts on premiums for homeowners who have retrofitted, lower deductibles and coinsurance percentages, and increased availability of coverage.

Action by the CEA, non-participating insurance companies, and the Insurance Commissioner would be needed in order to enact these incentives. Insurance premiums are regulated by the Department of Insurance to assure that rates charged are fair, actuarially justified and that reserves are sufficient to pay losses. Because insurance companies compete for market share, they could use retrofit-based reduced premiums to attract more policies. However, this is a double-edged sword: increased customers result in increased exposure to losses concentrated in the area affected by earthquakes.

Insurance agents could be enlisted in efforts to explain the risk of earthquake damage to residential and commercial policyholders. Property insurance policies exclude damage due to earthquake shaking, but they do cover fire losses. Because of the direct link between earthquake and fire in San Francisco, there might be an incentive to insurance companies to encourage retrofitting measures that also reduce the risk of fires following earthquakes.

Insurance companies that provide owners with liability coverage should have an interest in retrofitting. See incentive 4.5.

FEMA Grants

Grants from FEMA are not an incentive *per se*, but because they could be used in a variety of ways to help fund incentive programs, they are briefly mentioned here.

FEMA offers a variety of grants to state and local agencies to reduce the risk from hazards. Hazard Mitigation Grants (Section 404 of the Federal Stafford Act) provide matching grants from a fund established from a percentage of post-disaster repair grants (Section 406 of the Federal Stafford Act). The amount available under Section 404 depends on the magnitude of Section 406 grants to the state following disasters declared by the President and the percentages established at the time. These grants could be used in communities not affected by the declared disaster (e.g., San Francisco could apply for grant funds after an earthquake in Los Angeles).

FEMA also provides grants from the Pre-Disaster Mitigation Program to state and local governments. The amount appropriated by Congress varies each fiscal year. San Francisco could apply for grants to fund some of the costs of administering mitigation programs and providing incentives.

Federal, State or Private Sector Incentives

There are a number of frequently mentioned potential financial incentives that would require action by federal or state level government or private sector institutions. It is not within the power of the City to offer these incentives. They are mentioned here for completeness.

These include:

- Preferable mortgage rates for earthquake resistant structures, provided by lending institutions such as Fannie Mae or private banks;
- Income tax credits and/or homeowner deductions for the costs of seismic retrofits, or accelerated depreciation rates for retrofit improvements. The value of deductions varies with taxpayer's adjusted gross income, while tax credits provide a specific tax reduction to all taxpayers;
- Removal of financial disincentives for retrofitting, by removing programs that subsidize post-disaster losses through casualty tax deductions of disaster losses, and disaster assistance that subsidizes losses of owners who chose not to retrofit. This policy could have unintended implications on recovery and be perceived as callous; and
- Companies that provide building materials could offer a discount or rebate on materials used for retrofitting deficient properties. There would have to be compensating factors such as increased volume or market share due to favorable publicity.

12.4.2 Policy Incentives

There are many incentives that are not directly financial that could be powerful motivators to encourage seismic retrofit, such as allowing owners to make changes to a building that they would not otherwise be allowed to make, if they seismically upgrade their building. For example, Palo Alto granted density bonuses and waived parking set aside fees to encourage seismic strengthening. All of these policy incentives have social. if not financial, "costs,", because there are politically sound reasons for each aspect of how changes in buildings are currently regulated. Many of the ideas mentioned below might not be acceptable in San Francisco. However, City leaders might decide that seismic safety and preservation of affordable housing and neighborhood character after an earthquake are community priorities that outweigh some other needs.

Exemptions for Nonconforming Conditions

Many older buildings have nonconforming conditions that do not meet current code requirements, such as construction directly on the lot line, inadequate setbacks, or inadequate parking. If upgrade projects trigger changes to nonconforming conditions, such as when buildings are altered or enlarged, then the City could offer some exemptions to these requirements, if owners seismically retrofit.

Non-Permitted Work

Many buildings in San Francisco have made additions or alterations without permits and might avoid seeking permits for seismic retrofit in order to avoid detection and the associated cost of either removing the improvement or having it regularized. The City could establish a program to facilitate approvals, except for illegal developments that are unsafe.

Zoning Incentives

City land use policies and zoning ordinances could provide important value in return for retrofitting. The City could exempt homes that retrofit from selected zoning restrictions, such as allowing concessions regarding encroachment into set backs, increased floor/area ratios, height limits, density bonuses, and on site parking requirements. These concessions would be more powerful, if owners who elect not to use them could sell them to others or transfer them to another location within the City (Transfer of Development Rights).

Palo Alto modified its zoning laws to encourage owners of unreinforced masonry buildings to retrofit. The zoning laws were modified to permit expansion of the floor area of downtown buildings included in the program, if the owner performed seismic upgrades. These buildings were also exempted from on-site parking requirements and fees for off-site parking.

Condominium Conversion

Converting multi-unit residential properties to condominiums buildings is a lengthy, complex process generally intended to limit the number of conversions. This process, which is driven by the difference in market value between rental and individually-owned units, could be used to trigger mandatory seismic retrofit, or could be eased as an incentive to those who retrofit voluntarily.

Exempt or Defer Triggered Work

Owners that choose to voluntarily seismically retrofit their buildings might trigger other required work, such as:

- Americans with Disabilities Act upgrades;
- Fire resistance upgrades and sprinklers;
- Title 24 energy analysis and upgrades; or
- Neighborhood notification.

The City could exempt owners from some triggered requirements. Note that owners cannot be exempted from triggered ADA upgrades, which can be costly. This is a federal requirement, and the courts have determined that seismic strengthening projects should not be exempted from this requirement.

Expedite Permits and Reviews

The City could provide over the counter permits without delay whenever possible. All permit reviews for seismic retrofits could be expedited. Planning Department review for most projects with seismic retrofits could be bypassed.

Discretionary Zoning Permits

The City could pass an ordinance linking discretionary zoning permits for building occupancy to seismic upgrades, if a building is designated potentially hazardous.

Rebuilding Restrictions

Currently, a rent-controlled apartment building that is demolished after an earthquake could be replaced by a building having a greater return on investment than apartments, such as condominiums. It can also be rebuilt maintaining non-conforming conditions of the previous building, such as proximity to the lot line and parking capacity. This potential could be viewed as a disincentive to seismically upgrade the city's worst buildings. Post-earthquake rebuilding policies could be changed to restrict this.

Transfer of Development Rights (TDR)

The City could allow owners to transfer unused development rights to another site. This incentive might be especially valuable for owners of historic properties. The value of the development rights to be transferred should be comparable to the cost of a seismic retrofit.

12.4.3 Technical Assistance Incentives

Many, maybe most, owners have never hired an engineer, sought permits or engaged a contractor and find the process daunting. Technical assistance incentives help building owners to navigate the complex engineering issues associated with building retrofits. City-offered technical review and advice would improve the chances that building owners would carry out effective retrofit projects.

Training Construction Professionals

The City could provide training to engineers and contractors in all stages of the retrofit process: building evaluation, retrofit design, and construction. A list with the names of those who complete the training successfully would be made available to building owners. However, training would not guarantee that those on the list are properly licensed and insured, or that they engage in good business practices.

Training could be provided free (FEMA grants could cover the cost), at a subsidized cost, or at-cost to prospective inspectors, civil engineers, architects, contractors and owners interested in developing a retrofit specialty. Training could be offered through existing organizations and training programs. A program name and logo could be copyrighted and trained individuals could be allowed to use it in advertising and business documents. The City's awareness literature could promote use of trained individuals.

The City of Berkeley provided training for civil engineers in preparation for its soft-story building program, and ABAG has provided training to contractors for retrofitting cripple walls.

Information for Building Owners

The City could provide publications or other materials about how to work with engineers and contractors for evaluations, design and contracting. These could include information that will help them to ask relevant questions and to evaluate proposed costs and activities.

Standard Plan Sets

The City could provide standard details and drawings to simplify and expedite approval of retrofit work. Buildings that are retrofitted according to the standard plan could receive expedited permit review and bypass engineering analysis. It might not be wise to eliminate engineering judgment on many buildings, and standardized solutions might not be possible for many buildings because of unique features.

Standard plan sets and details work best for single-family homes in standard configurations. They are probably not feasible for larger, complex, multi-family buildings. Standard plan sets exist for some configurations of single-family homes common in the East Bay, developed by the California Building Officials, but these are not applicable to typical San Francisco homes.

Independent Advice and Evaluations

Technical advice could be provided through intermediaries with no financial interest in the outcome. The Department of Building Inspection could inspect properties before approving construction drawings and critique plans. Partner organizations—private non-profits and professional associations—could provide technical advice through the auspices of the Department of Building Inspection. This type of program could be funded by a FEMA grant.

Assistance Navigating City Program

Owners of multi-unit buildings have a variety of characteristics. Some live in their buildings, some live out of state; some have cash available, others might have all of their assets in the property with little monthly income. Many owners have never hired an engineer or architect for a major project and have never engaged a contractor. The process of retrofitting would be daunting for many. The City could provide assistance on project financing and how to secure incentives. An ombudsman could be designated for all retrofit activities, guiding building owners though requirements, incentives, and financing options.

Tool Lending Library

The city could lend tools to building owners, so that they could do some retrofit work without purchasing or renting specialized tools. This could be a significant incentive to handy owners of small buildings or single-family homes, but of little importance when a contractor is needed to do specialized and difficult work.

Building Owner Training Programs

Building owners could be trained in:

- the City's retrofit program;
- the types of damage expected when buildings are retrofitted to different standards (performance objectives);
- how to select engineers to evaluate buildings and design retrofits, and contractors to conduct the work; and,
- how to do simple retrofit work themselves.

This could be integrated into an ongoing community-training program, such as the Fire Department's Community Emergency Response Team program.

12.4.4 Information Incentives

Many building owners and users do not know how their buildings will perform in an earthquake. Being better informed about risk can enable people to make informed choices about the level of risk they are willing to accept. Information can drive market-based decisions about seismic retrofitting. Owners choose to strengthen their buildings to protect their investments; tenants choose to occupy safer buildings; and retrofitted building could be more valuable when sold.

Real Estate Transfer Disclosures

Existing state real estate disclosure laws require building owners to disclose any known seismic deficiencies when a building is sold. Sellers are not required to evaluate the vulnerability of their building or to strengthen any known weaknesses.

The effectiveness of disclosure is compromised when owners often check the "do not know" option rather than speculating on deficiencies. Real estate earthquake vulnerability disclosure requirements could be amended to require an engineering evaluation of a building when sold. Existing state statutes would need to be amended to require this.

Possibly the City could note information about a building's seismic status as part of its tax assessor/official record. This could include a "certificate of retrofit" or documentation of whether the building is on a list of potentially vulnerable buildings.

Tenant Notification

Building owners can be mandated to notify tenants if their buildings are deemed to be potentially hazardous in earthquakes.

The City would need to identify hazardous or potentially hazardous buildings before such a program could occur. For some types of hazardous buildings (e.g., URM buildings), this is a relatively straightforward process. For others (e.g., older concrete buildings), this is challenging and could identify many buildings as potentially hazardous that actually pose little risk.

Building Ratings

Proposals to evaluate and rate the earthquake performance of buildings are discussed frequently. The objective would be to create an evaluation system that would be meaningful and that would be replicated closely by a variety of inspectors or engineers. The ratings would reflect the risk of earthquake loss, and the objective would be to influence market value, insurance premiums, and lending rates. Meaningful and replicable analysis methods are not yet available.

Placards

Owners of unreinforced masonry buildings are required to post signs warning occupants of the building's earthquake vulnerability. The objective is to give those who enter a chance to make an informed decision, and to warn those who might rent or purchase the building of its condition. These signs tend not to discourage persons from entering for limited periods but might have an impact on market or rental values. Owners of buildings found to have a weak first story could be required to post a notice and then be allowed to remove it upon completion of retrofit work.

Standard of Care

Owners have a responsibility to maintain their properties in a safe condition. Following earthquakes, those who are harmed might believe that the owner is responsible for damages. Although no case law on this matter was uncovered during this CAPSS effort, if a claim goes to court, the test will be determined by the standard-of-care, that is, whether the owner took reasonable steps appropriate to the location and time to provide an appropriately safe building. By establishing criteria for identifying vulnerable buildings, clear retrofit standards and compliance deadlines, the City could affect how the standard-of-care would be interpreted and applied. Those who comply are more likely to be found as having acted reasonably than those who have not. Clarifying liability in this fashion might encourage those who are concerned about liability and might encourage liability insurers to exert pressure on owners to retrofit.

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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.

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

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