Engineering Guidelines and Community Actions to Reduce Earthquake Risks in San Francisco, California (ATC-52)

C. Rojahn
Applied Technology Council, Redwood City, California USA

L. Kornfield
Department of Building Inspection, San Francisco, California USA

L.D. Samant
Earthquake Hazard Reduction Policy Consultant, San Francisco, California USA

L.T. Tobin
Earthquake Hazard Reduction Policy Consultant, Mill Valley, California USA

SUMMARY:
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 policy road map and other technical resources to reduce earthquake risks in existing, privately-owned buildings that are regulated by the Department. The project was carried out by the Applied Technology Council (ATC), under contract to DBI, with broad input by community leaders, earth scientists, social scientists, economists, tenants, building owners, and engineers. Results from the CAPSS project are documented in a series of reports that address the following topics: (1) *Potential Earthquake Impacts* (ATC-52-1 Report); (2) *A Community Action Plan for Seismic Safety* (ATC-52-2 Report); (3) *Earthquake Safety for Soft-Story Buildings* (ATC-52-3 Report); and (4) *Post-Earthquake Repair and Retrofit Requirements* (ATC-52-4 Report). The project enjoyed the strong and highly visible political support of the former and current Mayors of San Francisco.

Keywords: buildings, earthquakes, resilience, impacts, policy

1. INTRODUCTION

Over the last decade, the San Francisco Department of Building Inspection (DBI) engaged community leaders, earth scientists, social scientists, economists, tenants, building owners, and engineers to conduct the Community Action Plan for Seismic Safety (CAPSS) project, a broadly based effort to develop earthquake mitigation approaches that make sense and reflect good public policy. The project development approach, which involved extensive community input and interaction, was selected on the premise that 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. Carried out by the Applied Technology Council (ATC), under contract to DBI, the CAPSS project provided 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 with repair and rebuilding guidelines that will expedite recovery after an earthquake.

The project enjoyed the strong political and highly visible support of the former and current Mayors of San Francisco. The CAPSS project participants also cooperated with and considered the efforts of other ongoing efforts intended to improve the City's earthquake resilience, including (1) efforts by the City's Planning Department to revise the Community Safety Element of the General Plan; (2) studies and recommendations by San Francisco Planning and Urban Research (SPUR) on earthquake resilience, emergency response and post-earthquake recovery; and (3) the City's *Resilient SF* initiative.

Early phases of the CAPSS project involved planning and conducting an initial earthquake impacts study, and later phases focused on the development of technical and policy guidance for addressing the City's most vulnerable buildings, and the development of guidance for evaluating and repairing earthquake damaged buildings. Key findings and results are provided in the remainder of this paper.

2. POTENTIAL EARTHQUAKE IMPACTS—AN OVERVIEW

At the outset of the CAPSS project, the ATC project team examined four possible earthquakes that could strike the City of San Francisco (Figure 1) and estimated the amount of damage and resulting ripple effects that each scenario earthquake could cause. The study only encompassed damage to privately-owned buildings and the impacts that flow from this. Damage to utilities, transportation networks, and public buildings were not studied but are likely to add substantial consequences to those described here. The study results are documented in the ATC-52-1 Report, *Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts* (ATC, 2010a).

The four scenario earthquakes were:

1. A moment-magnitude 6.9 earthquake on the Hayward fault in the East Bay. Of the four earthquakes studied, this event has the highest likelihood of occurring in the next 30 years.
2. A moment-magnitude 6.5 earthquake on the portion of the San Andreas fault closest to San Francisco.
3. A moment-magnitude 7.2 earthquake on the peninsula segment of the San Andreas fault closest to San Francisco. This earthquake would produce a level of shaking in many areas of the City that is similar to the level of shaking that the building code requires new structures be designed to resist without major structural failure.
4. A moment-magnitude 7.9 earthquake on the San Andreas fault, which is a repeat of the 1906 earthquake. This is the largest known earthquake to have occurred in northern California on the San Andreas fault.

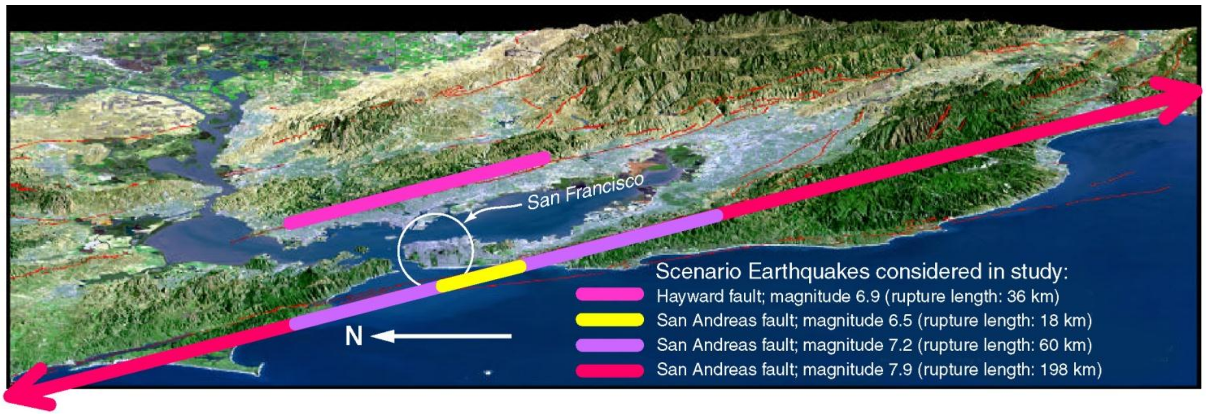

Figure 1. The location and length of fault rupture in the four CAPSS scenarios

2.1 Direct Damage to Buildings

The project team used the Hazards US (HAZUS®) methodology and software (FEMA/NIBS, 2002), which was extensively customized to represent the unique buildings and conditions in San Francisco, to estimate the amount and types of damage that could occur in the four possible scenario earthquakes. The details of the technical analysis are described in the ATC-52-1A Report, *Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts: Technical Documentation* (ATC, 2010b).

Table 1 shows the estimated cost of direct damage that could occur in the four possible earthquake scenarios due to shaking and ground failure (liquefaction), expressed in dollar losses by building use. These figures represent the costs to repair or replace buildings damaged in the scenarios and include damage to building structures and integral non-structural elements, such as partition walls, ceilings, and fixtures. The figures combine the costs of minor repairs with the costs incurred by buildings that need to be demolished and replaced from the ground up.

Table 1 Estimated Cost to Repair and Replace Buildings Damaged from Shaking and Ground Failure in Four Scenario Earthquakes, by Building Use

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

a. Estimates are in 2009 U.S. dollars.
b. Other Residences includes hotels, motels, nursing homes, and temporary lodging.
c. Other includes religious and educational buildings listed in San Francisco Assessor's Tax Roll.
d. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.

The following issues stand out as important findings:

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

2.2 Moment-Magnitude 7.2 Earthquake Scenario Impacts

The following summary of impacts of one possible earthquake, a moment-magnitude 7.2 earthquake on the San Andreas fault directly offshore from San Francisco, illustrates the types of consequences the City can expect following its next large earthquake. Such an earthquake could be considered expected because enough strain to produce an event of this size has built up on the San Andreas fault since 1906. If such an event occurs, the City should expect the following impacts, shown in Table 2.

Table 2 Estimated Damage States of Buildings Due to Shaking and Ground Failure in a Magnitude 7.2 Earthquake on the San Andreas Fault, by Building Use

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

a. Building functionality categorizations are derived from HAZUS® damage states. For more information, please see the ATC 52-1A Report (ATC, 2010b).
b. This level of damage can be referred to as "shelter in place".
c. Some of these buildings have collapsed. Others are standing but damaged beyond repair. None can be occupied.
d. The City is considering a program to require evaluation and possible retrofit of residential wood-frame buildings with 3 or more stories and 5 or more units. These buildings are a subset of this category. For more information about the performance of residential buildings, see Chapter 6 of the ATC-52-1 Report (ATC, 2010a).
e. Other Residences includes hotels, motels, nursing homes, and temporary lodging.
f. Other includes religious and educational buildings listed in the San Francisco Assessor's Tax Roll.
g. Numbers in table have been rounded, which can make totals differ from sum of columns or rows.

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

earthquake fires could add over $4 billion to these losses. Secondary economic losses, stemming from reduced business and household spending, would increase economic hardships.

3. DEVELOPMENT OF A COMMUNITY ACTION PLAN FOR SEISMIC SAFETY

The impact scenarios developed under the CAPSS project, as briefly described above, present what is likely to happen if San Francisco makes no changes to its preparations for earthquakes. Based on this information, the CAPSS project team worked with representatives of the City's communities to identify actions that could and should be taken to reduce the consequences of future major earthquakes. The identified actions are documented and explained in the ATC-52-2 Report, *Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, A Community Action Plan for Seismic Safety* (ATC, 2010c). This report recommends measures building owners and the City can take to reduce risk to privately owned buildings and identifies steps to protect important community resources that currently face high risk from future earthquakes—affordable housing, private schools, and medical clinics, to name a few. Reducing the negative consequences of future earthquakes is recognized as benefiting all San Franciscans: building owners, businesses, residential tenants, and the City government. Recognizing the challenges building owners face to finance seismic retrofits, the report recommends that the City take steps to assist and empower most building owners to make improvements on their own schedule, prior to enacting mandates.

This report recommends a three-step strategy to engage market forces to encourage structural retrofits, enact measures to reduce fire damage, and promote measures to reduce risk from falling hazards and non-structural elements. The strategy follows the following steps:

Step 1. Facilitate a market in which earthquake performance is valued;

Step 2. Nudge the market by requiring evaluation upon sale, or by a deadline; and

Step 3. Require retrofitting by a deadline.

By applying this three-step program in a phased manner, San Francisco would help buildings owners address their risk and take actions that benefit the broader community.

A major feature of the ATC-52-2 Report are seventeen recommended actions that San Francisco's City government leaders should take now to reduce the consequences of future earthquakes (Figure 2). These recommendations were developed with advice from an Advisory Committee of a diverse group of San Francisco residents. The Advisory Committee met over thirty times over two and a half years to guide the development of the recommendations.

On December 22, 2010, the Honorable Gavin Newsom, Mayor of San Francisco, issued Executive Order 10-02, Earthquake Safety Implementation Committee (ESIC), which directed the City Administrator to oversee the process of reaching out to interested parties around the City to build a broad coalition of supporters to implement the Community Action Plan for Seismic Safety (CAPSS) recommendations.

4. EARTHQUAKE SAFETY FOR SOFT-STORY BUILDINGS

Given the results of the potential impact studies for the 4 scenario earthquakes, Mayor Newsom directed CAPSS to first address soft-story residential structures, which are known to be amongst the most vulnerable (see Figure 3). The scope was limited to wood-frame structures with 3 stories or more and 5 or more residential units, built before May 1973. May 1973 was selected as the cut-off date because on May 21, 1973, 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, are believed to have adequate strength and stiffness at the ground level to resist earthquakes.

CAPSS Recommendations to Reduce the Consequences of Earthquakes

1. Require evaluation of all wood-frame residential buildings of three or more stories and five or more units, and retrofit of those that are vulnerable to earthquake damage.
2. Inform the public of risks and ways to reduce risk.
3. Adopt updated code standards for seismic evaluation and retrofit of all common buildings.
4. Require all buildings to be evaluated for seismic risk.
5. Require retrofits of vulnerable buildings.
6. Assist community service organizations to reach earthquake resilience.
7. Establish clear responsibility within City government for preparing for and reducing risk from earthquakes.
8. Adopt improved post-earthquake repair standards.
9. Offer incentives for retrofit of buildings.
10. Require gas shut-off valves on select buildings.
11. Track evaluations and retrofits in a database system.
12. Provide technical assistance for building retrofits.
13. Enact a façade ordinance.
14. Promote development and implementation of effective ideas on earthquake risk reduction.
15. Evaluate measures to reduce post-earthquake fires.
16. Address the hazards from damage to building systems, appliances, equipment and non-structural building elements.
17. Periodically assess progress and implementation of these recommendations.

Figure 2. Important CAPSS-recommended actions that San Francisco's City government leaders should take now to reduce the consequences of future earthquakes

Figure 3. Images of two multi-unit, wood-frame buildings that may have soft-stories

In calling for this work, the Mayor recognized that an effective program for the seismic evaluation and retrofit of vulnerable multi-unit, soft-story wood-frame residential buildings would enable San Francisco to retain significant amounts of housing after a major damaging earthquake, preserve architectural and cultural attributes, conserve energy and resources, and improve public safety.

The CAPSS study of soft-story buildings had three primary components: (1) development of an inventory of wood-frame structures with 3 stories or more and 5 or more residential units, built before May 21, 1973; (2) an analysis of the seismic vulnerability of these buildings; and (3) development of recommendations to reduce their seismic vulnerability. The approach undertaken by the CAPSS project team and the findings and results of the study are described in detail in the ATC-52-3 Report. *Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings* (ATC, 2009a); and the companion ATC-52-3A Report. *Here Today—*

Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings: Documentation Appendices (ATC, 2009b).

4.1 Inventory Development and Seismic Vulnerability Analysis

The inventory was conducted through the analysis of a Housing Database maintained by the Housing Inspection Division of the San Francisco Department of Building Inspection (DBI), and a survey carried out with the assistance of volunteers from the Northern California Chapter of the Earthquake Engineering Research Institute and the Structural Engineers Association of Northern California. Based on the inventory effort, DBI determined that (1) there are approximately 4,400 wood-frame buildings built before May 21, 1973 in San Francisco with three or more stories and five or more residential units (Figure 4), and (2) most of these buildings may have a soft-story condition.

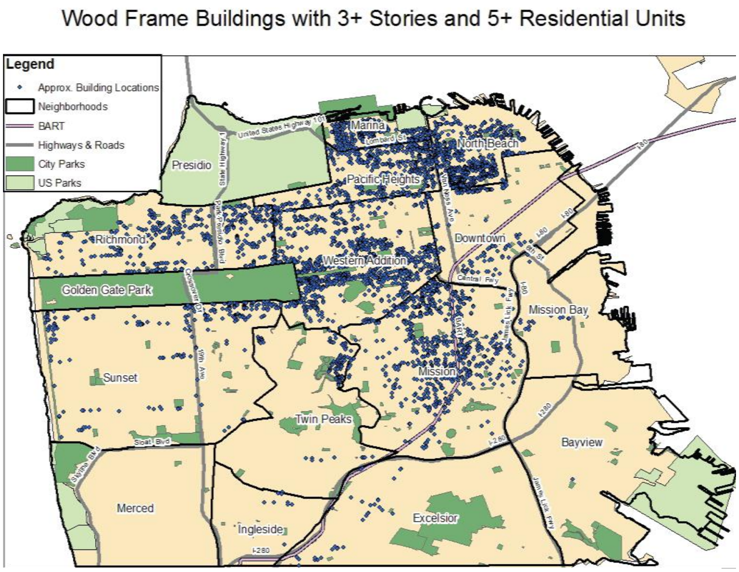

Figure 4. Locations of wood-frame buildings with three or more stories and five or more units.

The CAPSS project team 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. The team took a detailed look at roughly 2,800 buildings with 80 percent open area on one side, or at least 50 percent openings on two sides; these were considered to most likely exhibit soft-story conditions, although the other 1,600 wood-frame buildings in the same age and height category as well as a high number of 3-to-5 story pre-seismic-code commercial wood-frame buildings could also have weak-story problems. The team also developed the following key findings for the 2,800 buildings studied:

- As they now stand, 43 to 85 percent of the multi-unit, wood-frame buildings studied under the CAPSS project 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 severely damaged buildings that could not be occupied after an earthquake until they are either repaired or replaced.
- A quarter of these red-tagged buildings are expected to collapse, which threatens lives. This represents 300 to 850 multi-unit buildings, most of which contain rent-controlled apartments. Owners of such buildings might choose to rebuild them as condominium units, rather than rental apartment buildings, thus reducing the City's crucial rental housing stock.
- Nearly eight percent of the City's population, or about 58,000 people, live in these vulnerable soft-story 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.
- 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, eliminating $1.5 billion in damage after a magnitude 7.2 earthquake on the San Andreas fault.
- Estimates of the cost for seismic retrofits at the recommended level range from $160,000 to $130,000 per building (on the order of $10,000 to $15,000 per living unit) for direct construction costs. Retrofit construction would last for two to four months and could be generally limited to the ground floor level, meaning that residents of upper level apartments could stay in their homes.

4.2 Key Recommendations

A series of recommendations pertaining to earthquake safety for soft-story buildings was developed by the CAPSS project team based on the results of the above-described technical analysis and on discussions held in public meetings. Guidance and review were provided by the volunteer Advisory Committee of community members. Underlying the recommendations is the strong belief that establishing an earthquake safety policy for soft-story wood-frame residential buildings is a critical step toward making San Francisco a resilient city that will be able to resume normal life quickly after the next major earthquake strikes.

Following are the key CAPSS recommendations to provide earthquake safety for soft-story buildings:

1. *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.*
2. *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 averts 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 those neighborhoods.
3. *The City should immediately offer incentives to encourage voluntary retrofits.* The program 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 only soft-story wood-frame residential buildings.
4. *The Department of Building Inspection should form a working group to develop a detailed plan to implement the recommended program.*

The CAPSS study also points out that retrofitting benefits the entire City, its neighborhoods, building owners, and residential and business tenants. However, sharing the costs of retrofits among the beneficiaries—financial costs and inconveniences—raises policy issues of fundamental importance to the City. The ability to pay for retrofitting or endure disruption is not universal. Retrofitting costs would cause great hardship for some tenants and owners, especially those with limited income. The recommendations recognize this issue, provide insight into the costs and the beneficiaries, and outline a flexible program with financial incentives to facilitate retrofit and protect those with hardships. Finding an equitable balance between those who benefit and those who pay will challenge the City's decision makers. Ultimately, the cost of earthquakes is far greater than the cost of preparing.

5. POST-EARTHQUAKE REPAIR AND RETROFIT REQUIREMENTS

The culminating effort of the CAPSS project was the development of post-earthquake repair and retrofit requirements. The intent was to clarify current post-earthquake repair and retrofit code provisions primarily for the purpose of avoiding delays and disputes about whether a damaged building should be repaired or retrofitted. A secondary purpose was to enable implementation of a mitigation policy, based on damage patterns from actual ground motions.

After an earthquake, San Francisco codes currently allow some damaged buildings to simply be repaired to the way they were before the earthquake. Other damaged buildings are required to be retrofitted or improved as well as repaired, to make the building more robust in future earthquakes. This policy makes San Francisco safer and more resilient to earthquakes over time by strengthening those buildings that have been shown by an earthquake to have inadequate seismic resistance. Repair and retrofitting following moderate, less intense earthquakes make up an important strategy to improve San Francisco's resilience to more intense earthquakes.

The CAPSS findings, conclusions and recommendations pertaining to the repair and retrofit of earthquake-damaged buildings are provided in the ATC-52-4 Report, *Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Post-Earthquake Repair and Retrofit Requirements* (ATC, 2010d). The report describes the development of an overall strategy for the development of post-earthquake repair and retrofit provisions for San Francisco; describes related recommended policies and implementation techniques common to all building types; and provides post-earthquake repair provisions for three selected building types that represent more than 95% of all buildings in the City: (1) single-family and two-unit wood-frame residential buildings; (2) multi-unit wood-frame residential buildings, including, but not limited to soft-story wood-frame buildings; and (3) older concrete buildings, including those infilled with masonry. In addition, the ATC-52-4 Report contains recommendations for further study associated with post-earthquake repair provisions in San Francisco.

The overall strategy was defined by identifying several issues that are significant for post-earthquake repair provisions, and then resolving these issues with the help of the CAPSS Advisory Committee. These resolutions included the adoption of an overall goal of improving resilience for the City of San Francisco, consideration of the intensity of site ground motions for retrofit triggers, clarification of the traditional retrofit trigger that is based on a percentage loss of strength, and use of descriptive damage triggers defined specifically for various building types.

In order to consider the intensity of ground motion for post-earthquake retrofit triggers, as well as to introduce mitigation policy that uses real earthquake ground motions to identify seismically poor buildings, the concept of *Disproportionate Damage* triggers is introduced. New rules are proposed that will require retrofit of buildings that are damaged in such a way that their seismic deficiencies are demonstrated to be severe and potentially dangerous at low shaking levels ($Sa_{0.3} < 0.4g$, where $Sa_{0.3}$ is short-period spectral acceleration at a period of 0.3 seconds).

5.1 Repair and Retrofit Requirements for Single-Family and Two-Unit Residential Buildings

For single-family and two-unit wood-frame residential buildings, primarily traditional single-family homes, the recommendations define damage to various elements that is visibly evident, rather than using percentage loss. The provisions typically require repair and retrofit only to the damaged element. For example, damage to a brick chimney requires work on the chimney but not to the rest of the house if it is not damaged. Similarly, damage to cripple walls in a typical crawl space will require retrofit of only the crawl space walls and will reference a pre-existing standard, Appendix A3 of the *International Existing Building Code* (ICC, 2009). A document prepared for the California Earthquake Authority, *General Guidelines for the Assessment and Repair of Earthquake Damage in Residential Woodframe Buildings* (CUREE, 2007), which includes recommended repair techniques for essentially all elements of single-family dwellings, is also utilized to specify repair requirements in some cases. Disproportionate Damage triggers are included for certain damage patterns, such as significant permanent set (lateral sway) in any story.

5.2 Repair and Retrofit Requirements for Multi-Unit Wood-Frame Residential Buildings

The multi-unit wood-frame residential group includes the soft-story buildings, with three or more stories and five or more residential units, described above. A retrofit methodology for these buildings, now under development by ATC, with funding from the Federal Emergency Management Agency, will focus on optimizing overall building performance with retrofit work limited to the soft-story level (FEMA, in preparation). Assuming adoption of this methodology by the City of San Francisco as part of a voluntary or mandatory mitigation plan, buildings in this category damaged beyond the repair-only level will be required to comply with the ordinance. Requirements for other buildings in this category are more conventional, except triggers are based on visual damage patterns rather than percent strength loss. Disproportionate Damage triggers for several damage states are included.

5.3 Repair and Retrofit Requirements for Older Concrete Buildings

The proposed provisions for older concrete buildings, which include concrete frames infilled with masonry, depend significantly on a study funded by FEMA and conducted by the Applied Technology Council following the 1994 Northridge earthquake, resulting in the publication of the FEMA 306, 307, and 308 reports (FEMA, 1999a,b,c). That study was intended to clarify the extent of loss of strength in concrete and masonry wall components when damaged. The FEMA-funded study was needed because engineers could not agree on strength loss in damaged concrete buildings when making percent loss calculations, leading to delays in repair, retrofit, or both. Clear descriptions of various damage states are given and a methodology is defined for performing strength loss calculations in the FEMA documents. Due to the wide availability of this guidance, the percent loss trigger is maintained for this building type. Additional guidance is proposed in the ATC-52-4 Report covering concrete frame components, for both lateral-force-resisting frame and gravity-resisting components. Disproportionate Damage triggers for several damage states are included.

ACKNOWLEDGEMENTS
The authors respectfully acknowledge David Bonowitz, Kelly Cobeen, William Holmes, Bret Lizundia, Keith Porter, Charles Scawthorn, Hope Seligson, and the numerous other ATC consultants who assisted in the preparation of these documents and the underlying data. Grateful acknowledgement is also extended to the broad range of volunteers who participated in the CAPSS Advisory Committee activities.

REFERENCES

ATC. (2009a). Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings, ATC-52-3 Report, Applied Technology Council, Redwood City, Calif.

ATC. (2009b). Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings: Documentation Appendices, ATC-52-3A Report, Applied Technology Council, Redwood City, California.

ATC. (2010a). Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts, ATC-52-1 Report, Applied Technology Council, Redwood City, California.

ATC. (2010b). Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts, Technical Documentation, ATC-52-1A Report, Applied Technology Council, Redwood City, California.

ATC. (2010c). Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Community Action Plan for Seismic Safety, ATC-52-2 Report, Applied Technology Council, Redwood City, California.

ATC. (2010d). Here Today—Here Tomorrow, The Road to Earthquake Resilience in San Francisco, Post-Earthquake Repair and Retrofit Requirements, ATC-52-4 Report, Applied Technology Council, Redwood City, California.

CUREE. (2007). General Guidelines for the Assessment and Repair of Earthquake Damage in Residential Woodframe Buildings, Consortium of Universities for Research in Earthquake Engineering, Richmond, California.

FEMA. (1999a). Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Basic Procedures Manual, FEMA 306 Report, prepared by the Applied Technology Council for the Federal Emergency Management Agency, Washington, DC.

FEMA. (1999b). Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Technical Resources, FEMA 307 Report, prepared by the Applied Technology Council for the Federal Emergency Management Agency, Washington, DC.

FEMA. (1999c). The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings, FEMA 308 Report, prepared by the Applied Technology Council for the Federal Emergency Management Agency, Wash., DC.

FEMA. (in preparation), Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings With Weak First Stories, FEMA P-807 Report, prepared by the Applied Technology Council for the Federal Emergency Management Agency, Washington, DC.

FEMA/NIBS. (2002). Loss Estimation Methodology, HAZUS®-99 Service Release 2 (SR2) Technical Manual. prepared by the National Institute of Building Sciences for the Federal Emergency Management Agency, Washington, D.C.

ICC. (2009). International Existing Building Code, International Code Council, Washington, DC.