Mitigating San Francisco's Soft-Story Building Problem

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ABSTRACT

San Francisco is in the process of doing something revolutionary: the City is heeding the warning of the moderate damage caused by the Loma Prieta earthquake, and may mandate strong rehabilitation measures for soft-story buildings to prevent catastrophe in future quakes. A study for the City, the Community Action Plan for Seismic Safety (CAPSS), recently estimated the consequences of several moderate to large Bay Area earthquakes on multi-unit, soft-story wood-frame dwellings. The project estimates that tens of thousands of residents of these buildings would be displaced from their homes, many for years, after a large earthquake, but retrofits would greatly reduce these impacts. Remarkably, it was building owner and tenant groups, not structural engineers, who actively led the discussion about whether mandatory mitigation makes sense. The project, with support from many community groups, calls for mandatory retrofit of the most vulnerable of these buildings.

THE CAPSS PROJECT

Overview of the project. The Community Action Plan for Seismic Safety (CAPSS) is a project of the San Francisco Department of Building Inspection. The purpose of the CAPSS project is to provide the San Francisco Department of Building Inspection with a plan of action or policy road map to reduce earthquake risks in existing buildings that are regulated by the Department, and also to develop repair and rebuilding guidelines that will expedite recovery after an earthquake.

The project is being carried out by the Applied Technology Council, the US's leading technology transfer organization dedicated to developing and promoting state-of-the-art, user-friendly engineering resources and applications to mitigate the effects of natural and other hazards on the built environment. CAPSS is a two-year project, which began in April of 2008 and will be completed in the summer of 2010. The CAPSS project originally began in 2001, and was suspended in early 2003. During this time, the project completed but did not publish an analysis of earthquake risk in San Francisco. The current effort builds on and enhances this existing work.

In February of 2009, the project released its first report titled *Here Today-Here Tomorrow: Earthquake Safety for Soft-Story Buildings* (ATC, 2009). The topics presented in this paper are discussed in more depth in that report and in its companion volume, *Documentation Appendices for Here Today-Here Tomorrow: Earthquake Safety for Soft-Story Buildings* (ATC, expected).

SAN FRANCISCO'S MULTI-UNIT WOOD-FRAME BUILDINGS

Description of typical San Francisco soft-story buildings. The term "soft-story" describes one level of a building that is significantly more flexible or weak than the stories above it and the floors or the foundation below it. In San Francisco's multi-unit, wood-frame buildings, weakness at the ground level stems from a lack of strong walls, both because of large openings in perimeter walls and because of few existing interior partition walls. During strong earthquake shaking, the ground level walls cannot support the stiff and heavy mass of the stories above them as they move back and forth. The ground-level walls can shift sideways until the building collapses, crushing the ground floor.

Figure 1 shows representative examples of what multi-unit, wood frame buildings that probably have soft-stories look like in San Francisco. These buildings have garage doors and/or large windows for commercial establishments at the ground floor. Large openings at the ground level are a strong indicator that a building might have a soft-story, but many characteristics affect a building's response to earthquake shaking, and only a building-specific analysis conducted by an engineer can determine if a particular building actually has a soft-story.

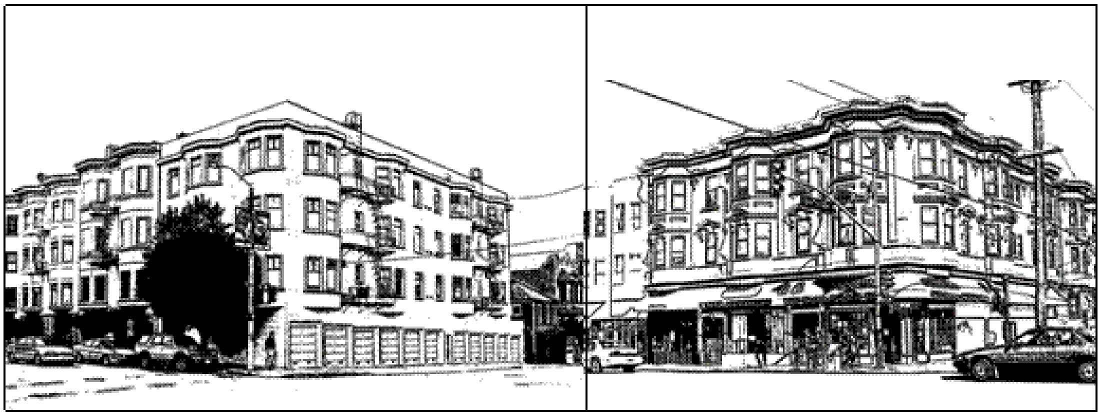

Figure 1. Multi-unit, wood-frame buildings that may have soft-stories

Survey of multi-unit, wood-frame buildings. In 2008, the San Francisco Department of Building Inspection conducted a sidewalk survey of wood frame buildings with three or more stories and five or more residential units. This survey was conducted by building inspectors and members of two professional organizations: the Earthquake Engineering Research Institute – Northern California Chapter and the Structural Engineers Association of Northern California. This survey provides information about important characteristics that contribute to vulnerability, such as the amount of openness in ground floor exterior walls and whether buildings are located on a corner or mid-block. It was restricted to building characteristics visible from the street. The Department survey identified approximately 4,400 wood frame buildings with three or more stories and five or more residential units built in San Francisco prior to a building code change in 1973 that largely eliminated soft-story conditions.

Subset of buildings analyzed. The CAPSS project decided to analyze a subset of these buildings, those with the largest ground floor openings, believed to be most vulnerable to damage. For the purposes of this project, significant ground floor openings were defined as openings (garage doors, windows, entry ways, or other openings) that span 80 percent or more of one side of a building, or 50 percent or more of two sides of a building. The Department's survey found approximately 2,800 buildings that have this level of openness. Examining this group in detail provides insights into the scope of damage that other similar buildings might experience in future earthquakes. This subset of buildings proved to be very vulnerable; given a chance to repeat this study, buildings with fewer openings would also be analyzed.

Uses and occupants of these buildings. A considerable percentage of San Francisco residents live in the 2,800 buildings analyzed by CAPSS. These buildings contain

29,000 residential units and an estimated 58,000 residents, or eight 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 these buildings.

Most of the people who live in multi-unit, wood frame buildings are renters. Assessor's data indicate that 90 percent of these buildings are used as rental apartments, with the remaining buildings classified as condominiums or other uses. In addition, all apartment buildings built before June 1979, which includes all of those of concern to CAPSS, are subject to San Francisco's Rent Stabilization Ordinance, commonly known as rent control. However, due to San Francisco's high rate of apartment turnover, many of these rent-controlled units are likely to be at or near market rate rent levels.

Close to 2,100 businesses operate in approximately 900 of the multi-unit, wood frame buildings analyzed by CAPSS. These businesses employ 6,900 people. Businesses housed in these buildings are concentrated in the retail, services, and food service industries. This reflects the 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. 84 percent of businesses in these buildings employ fewer than five people. The small size of businesses in these buildings suggests that many are independent, locally owned enterprises.

Many of these buildings are old: 65 percent were built before World War II. Some of them survived the 1906 earthquake, although this does not mean that they are "safe". A few dozen of these buildings are officially designated (locally or on the state or national registers) as historic. Many more are architecturally interesting and set the style and feel of their neighborhoods.

THE RISK OF DOING NOTHING

Likely damage in future earthquakes. Expected damage to these buildings was calculated for four scenario earthquakes. For insights, it is helpful to focus on the damage that would occur from one of these scenarios, a magnitude 7.2 earthquake on the San Andreas Fault. This size earthquake would produce shaking in many parts of the City that would be similar to the "design level" shaking that San Francisco's building code requires engineers to consider when designing new buildings. In a magnitude 7.2 quake, this subset of 2,800 buildings would experience the following damage (the range represents the uncertainty of the results):

- 43 to 85 percent of buildings—from 1,200 to 2,400 multi-unit buildings—would be red-tagged, as defined in ATC-20-1 (2005); each building's safety tag has been predicted from its estimated damage state probability distribution. This means that residents could not use them until they were repaired or replaced, which could take years. For this structure type, most of the buildings that do not collapse should be repairable, although repairs may be expensive. These red-tagged buildings contain from 12,000 to 25,000 residential units.

- A quarter of these red-tagged buildings would collapse, from 300 to 850 buildings with approximately 3,000 to 9,000 residential units. Collapses threaten lives. They also mean that San Francisco permanently loses these buildings, their architectural character, and the rent-controlled apartments in them.
- Over $4 billion dollars in damage to building structures and their contents would be incurred.

Consequences of this damage to San Francisco. The estimated damage to multi-unit, wood frame soft-story buildings in each of the scenarios examined would have severe consequences for the City. The discussion below examines only the impacts of damage to the 2,800 buildings studied by this project.

Many City residents would be displaced from their homes. Without retrofit, perhaps as few as ten percent of these buildings are expected to receive green tags in the M7.2 scenario, meaning that they could be continuously occupied. Some, but not all, yellow-tagged buildings can also be continuously occupied. In the least damaging scenario studied (a M6.5 earthquake on the San Andreas Fault), over 13,000 residents of this building type would need post-earthquake shelter, many for years. Residents would face dislocation, expense, separation from neighborhood services, and possible difficulty in accessing schools and jobs due to this relocation.

The City's rental stock would be slow to recover. 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 in the Bay Area were still out of service. Four years later, 50 percent of these units had not been repaired or replaced (Comerio, et al., 1994).

The City could lose many rental units permanently, especially those covered by rent control. When multifamily properties are demolished after an earthquake, the market favors those properties being reconstructed 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. Even if owners choose to rebuild apartments, new apartments replacing demolished units are not subject to the City's Rent Stabilization Ordinance, meaning they will have no rent control.

Building owners would bear most of the financial losses to these buildings, a figure estimated at $3.2 billion to $4.4 billion for the four scenario earthquakes studied. Discussions with building owners suggest that few owners of multi-unit apartment buildings currently carry earthquake insurance. Insurance for this type of building is expensive and does not provide comprehensive coverage.

THE CONSEQUENCES OF RETROFITTING

Retrofit schemes analyzed. Wood frame soft-story buildings can be retrofitted to improve their performance in earthquakes. Retrofitting these buildings generally involves installing shear walls, steel frames or steel cantilevered columns, typically only at the soft-story. However, not all retrofits are the same. The CAPSS project selected four representative buildings with large ground floor openings to evaluate the benefits and costs of retrofitting. For each building, three different retrofit designs were developed, ranging from a basic retrofit to a retrofit requiring more extensive work. Details about the representative buildings studied and the various retrofit schemes are available in the Documentation Appendices (ATC, expected) and in a companion paper in the present proceedings (Porter and Cobeen, 2009). The three retrofits were intended to achieve three different levels of performance when exposed to strong shaking:

- **Retrofit Scheme 1.** This is a minimal retrofit approach intended to reduce harm to those who live and work in or frequent the building. Collapse would be prevented, and occupants should be able to escape the building safely, but the building might not be repairable or fit for occupancy after an earthquake. Rent-controlled apartments could be permanently lost.
- **Retrofit Scheme 2.** This is a moderate retrofit level that is intended to avoid demolition. It would still allow significant damage, and the occupants could become homeless after a major earthquake and need to seek other lodging for the years it could take to repair the building. Repaired rental units would remain under rent control restrictions, and neighborhood character would be protected.
- **Retrofit Scheme 3.** This scheme is similar to Retrofit 2, except that it uses different structural steel members. It is intended to allow the residents to remain in their units after a major earthquake. A building retrofitted to this standard would be damaged after a major earthquake, but would be expected to withstand strong aftershocks. There might be significant damage to nonstructural building elements, utility services might not function, and some areas of the building might be off limits.

All retrofits examined by the CAPSS project limited construction work to the ground floor. For most buildings, it should be possible to achieve the performance described above without extending work into the upper floors. The retrofits do not, however, mitigate against liquefaction damage. While the retrofits would increase the safety of buildings that experience liquefaction, it cannot be assumed that the buildings could be occupied or repaired should liquefaction occur. This level of performance would require costly upgrades to foundations.

Damage avoided by retrofits. The CAPSS project examined how earthquake damage would lessen in four scenario earthquakes if all 2,800 multi-unit, wood frame buildings with three or more stories, five or more residential units, and large ground floor openings were retrofitted to each of the three retrofit schemes. A look at the impacts of retrofitting in one of these scenarios, a magnitude 7.2 earthquake on the San Andreas Fault, provides insights. Key points that emerge include:

- Retrofitting would greatly reduce collapses in a magnitude 7.2 earthquake on the San Andreas. If all 2,800 buildings were retrofitted using scheme 3, collapses would be reduced to less than one percent of buildings, from an estimated 11 to 31 percent without retrofits. Retrofit schemes 1 and 2 would also reduce collapses significantly.
- The number of buildings that receive red tags would also be significantly reduced, although many buildings would still be heavily damaged. Retrofitting all 2,800 buildings reduces red tags to 6 to 36 percent of buildings, depending on the level of retrofit, down from an estimated 43 to 85 percent red-tagged with no retrofit.
- Retrofits reduce the direct loss to these buildings by up to $1.5 billion. This figure includes the cost of repairing or replacing the buildings and their contents. Many buildings would still require costly repairs after retrofit.

Figure 2 illustrates how post-earthquake safety tagging would change if buildings were retrofit to various levels.

The loss estimates for this project do not consider the risk of post-earthquake fire. However, damaged buildings are a major cause of fire ignitions. Retrofitting buildings reduces their damage and, thus, reduces the number of expected ignitions.

Costs of retrofitting. Retrofitting clearly reduces damage and collapses, but that increased performance comes at a cost. The CAPSS project took a detailed look at the direct construction costs of each retrofit scheme for four representative San Francisco buildings. Although the actual costs of retrofitting any specific building would vary depending on the unique circumstances of each project, the cost estimates produced for these retrofits provide guidance about the overall range that should be expected and the differences in cost associated with achieving different performance levels.

Table 1 presents cost estimates in 2008 dollars for direct construction costs based on an analysis of retrofits for four representative multi-unit, wood frame soft-story buildings. These estimates include direct construction costs and permit fees. They do not include architectural or engineering design fees, costs of relocating any conflicting utilities, or costs associated with other circumstances described below.

Engineering fees would vary, but would represent at least 10 percent of construction costs.

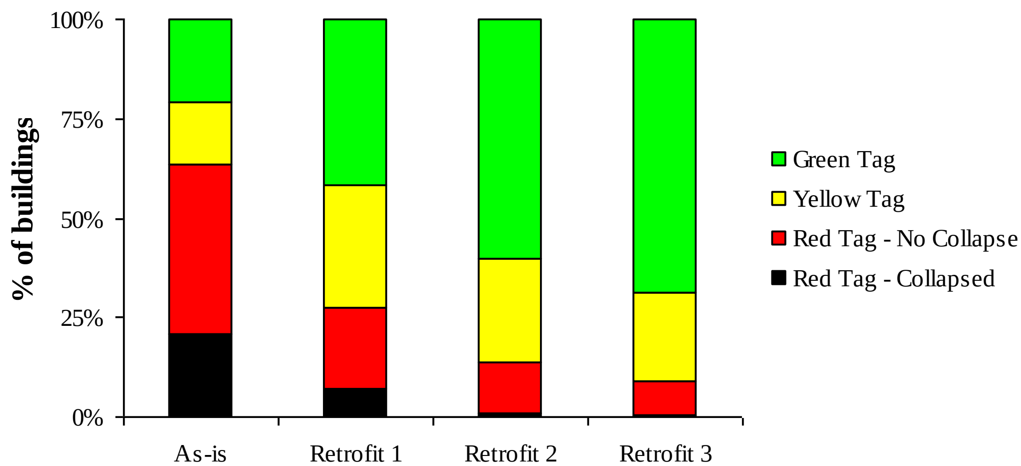

Figure 2. Approximate distribution of predicted safety inspection tags with and without three retrofit schemes in a M7.2 scenario earthquake on the San Andreas Fault.

Table 1. Direct construction costs estimated for four representative multi-unit, wood frame soft-story buildings for each retrofit scheme.

	Per Building ($)		Per Residential Unit ($)		Per Square Foot ($)	
	Average	Range	Average	Range	Average	Range
Retrofit Scheme 1	65,000	49,000 to 79,000	11,000	9,000 to 13,000	6.60	3.00 to 9.40
Retrofit Scheme 2	105,000	59,000 to 132,000	17,000	15,000 to 20,000	10.00	5.70 to 12.10
Retrofit Scheme 3	93,000	58,000 to 114,000	16,000	13,000 to 19,000	9.00	4.60 to 11.10

Although retrofit scheme 3, which provides the better performance, is less expensive than retrofit scheme 2, in general it costs more to get better performance. Retrofit 2 uses steel moment frames and plywood shear walls. Retrofit 3 uses steel cantilevered columns and plywood shear walls. Cantilevered columns generally are less expensive to construct than are moment frames, but are not always appropriate to use. Many structural engineers prefer frames to cantilevered columns. This analysis shows that a range in performance is available at a range of costs.

These costs do not include the costs of other work that might be triggered by this construction. In particular, buildings with commercial use are subject to Title 24, which implements the Americans with Disabilities Act (ADA). These requirements cannot be waived for seismic safety projects. If the Title 24 threshold is triggered, the overall costs of construction rise considerably, and a number of changes might be required that impact the businesses in the affected space. For example, a restaurant with a small bathroom might be required to upgrade the bathroom to a larger size, which would reduce the amount of floor space available for customer seating.

Construction costs could be higher for many other reasons, as well. Buildings with ground floor commercial spaces may be able to keep those tenants in place by carrying out construction during off-hours, but this increases costs. Owners of historic or architecturally important buildings could see their construction costs rise by an estimated 20 to 50 percent due to efforts to maintain the architectural integrity of the building. Buildings with occupied commercial or residential spaces at the ground floor could see costs rise if significant demolition and replacement of interior finishes are required. In some cases, other fire and life safety upgrades relating to issues such as egress, parapets, and façade materials could be triggered. None of these issues are included in the cost estimates shown in Table 1.

Building owners would bear most of the costs of seismic retrofit construction. The San Francisco Rent Stabilization Ordinance governs owners' ability to pass seismic retrofit costs on to residential tenants. The Ordinance allows landlords to pass through the full cost of any seismic retrofit that is 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. An analysis comparing the monthly debt service required to cover the costs of a seismic retrofit found that it was well within the permitted capital improvement pass-through to tenants who pay the average monthly rent for an example property. However, when rents in a building are already at market rates, a landlord who attempts to pass through seismic retrofit costs risks losing tenants. Currently, an estimated 40 to 60 percent of San Francisco apartments have rents at or close to market rate. Also, landlords with long-term tenants paying rents well below market rates would not be able to pass all of their costs on to those tenants.

Most residential tenants would bear little disruption due to seismic retrofits. Construction for retrofits of multi-unit, wood frame soft-story buildings can generally be limited to the ground floor, which is typically used for parking, storage or commercial space. However, commercial tenants in the ground floor of these buildings can expect to experience a greater impact from retrofits than their residential counterparts. The seismic work would be likely to disturb operations significantly for a period of two to four months. Many small businesses lack the financial wherewithal to recover from closing, relocation or heavy disruption for a few months.

Benefits of retrofitting. The costs of retrofitting are short-term and readily apparent. Most of the benefits of retrofitting, which are realized as avoided losses, are not evident until after an earthquake strikes. Retrofitting multi-unit, wood frame soft-story buildings directly saves building owners money by avoiding damage, reducing the cost of post-earthquake repairs and avoiding business interruption (loss of rent). The estimated savings due to retrofit varies depending on the intensity of the earthquake and on the level to which a building has been retrofitted. In the four scenario earthquakes examined by the CAPSS project, building owners as a whole save between $400 million and $1.5 billion, depending on the level of retrofit, in reduced damage to building structure and contents. The costs of all retrofits citywide would total about $260 million, to achieve a performance that would allow most residents to remain in their damaged but safe homes after an earthquake.

From the perspective of an individual owner, resources invested in retrofit result in significant savings after an earthquake. Table 2 shows the average loss that would be avoided if the building was retrofitted and then shaken by a magnitude 7.2 earthquake on the San Andreas Fault, per residential unit.

Table 2. Average loss avoided through retrofit per residential unit in a magnitude 7.2 earthquake on the San Andreas Fault.

	Average per unit $ loss avoided to structure and contents
Retrofit scheme 1	24,000
Retrofit scheme 2	41,000
Retrofit scheme 3	52,000

There are many other benefits to owners, residents, businesses, neighborhoods and the City as a whole that come from retrofitting. These relate to the reduced costs and impacts that can be expected from less damage. All aspects of San Francisco will benefit from a faster recovery, with residents back in their homes and small, neighborhood-serving businesses back in operation. The City will benefit by keeping older buildings in place that contribute to community charm and character.

THE RECOMMENDED PROGRAM

Process to develop recommendations. The CAPSS project held eight Advisory Committee meetings open to the public to discuss this work. These meetings were attended by representatives of tenants, landlords, various City neighborhoods, urban planners, historic preservationists, contractors, emergency managers, business groups, attorneys, labor representatives, and technical specialists. In addition, one well-attended day-long workshop was held to develop the project's detailed policy recommendations. At this workshop, the diverse group of gathered stakeholders agreed that the City needed a mandatory retrofit policy to address the risk of these buildings. Drafts of the project's recommendations were available for public review and discussed in public City meetings, such as Building Inspection Commission meetings. High profile local media coverage assisted the project's policy dialogue.

Overview of recommended program. The project recommended the following program to the City:

- 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.
- 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 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 there would be some damage and utilities might not function.
- The City should immediately offer incentives to encourage voluntary retrofits. The program recommended by CAPSS 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.
- All seismically deficient buildings covered by this program should be retrofitted within four years of the date on which their owners are notified to comply by the City. Buildings whose damage would most seriously impact the community should be required to retrofit first.
- The Department of Building Inspection should form a working group to develop a detailed plan to implement the recommended program.

Current status of recommendations. The CAPSS project submitted a report with the findings described in this paper to the City in February of 2009. The City's Mayor publicly supported these recommendations and representatives from the Mayor's Office met with the project's Advisory Committee to discuss how to move forward on this issue. At the time this paper was written, the City was still in the preliminary stages of responding this recommendation. Since the report was released, the City, as the country and state plunged into a deepening recession, entered a challenging time of budget cuts and staff reductions. This may delay the City's response to the project's recommendations, but City leaders have recognized reducing the risk of its soft-story buildings as a critical issue for the well-being of San Francisco. The City is moving forward with incentives for voluntary retrofits, including waiving some fees and expediting plan review. An initiative may appear before City voters in the next year that repurposes some unused bond funds to provide low-interest loans for these retrofits.

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