SPUR SAN FRANCISCO PLANNING + URBAN RESEARCH ASSOCIATION

# THE DILEMMA OF EXISTING BUILDINGS:
## PRIVATE PROPERTY, PUBLIC RISK

## SPUR REPORT

Adopted by the SPUR Board of Directors

July 16, 2008

Released
February, 2009

The primary author of this report was David Bonowitz

www.spur.org

# THE DILEMMA OF EXISTING BUILDINGS: PRIVATE PROPERTY, PUBLIC RISK

San Francisco's earthquake resilience is limited by its existing building stock. Some of our buildings are simply unsafe. But a broader problem, fundamental to emergency planning, is that even our safe buildings are inadequate to support the response and recovery efforts we know will be needed. Mitigation should address that shortcoming; our policies and programs need to target the vulnerabilities that could turn a manageable emergency into a catastrophe.

Resilience – the ability to respond to an earthquake emergency and to recover without lasting disruption – can be measured by the speed and completeness with which essential functions, and eventually routine operations, are restored. SPUR has proposed resilience targets for City services, housing, transportation, and other key sectors of the built environment.[1] Hitting those targets will require usable buildings right away for evacuation centers, emergency shelters, hospitals, certain City departments, and the vast majority of private residences. Beyond the first 72 hours, recovery will depend on other structures too, like schools, offices, and retail. Earthquake resilience goes hand in hand with building performance.

This paper links resilience-critical functions with the types of structures that house them. By understanding which services are affected by vulnerable structure types, we can improve not only individual building performance but citywide resilience as well.

**Six policy recommendations for existing buildings**

1. Mandated retrofit of soft-story woodframe multi-family housing.
2. Mandated retrofit or redundancy for designated shelters.
3. A mitigation program for essential city services.
4. A mitigation program for critical non-ductile concrete buildings.
5. Mandated and triggered retrofit of gas lines and gas-fired equipment.
6. Assessment of the unreinforced masonry program.

## EXISTING BUILDINGS AND EARTHQUAKE RESILIENCE

San Francisco has more than 120,000 buildings,[2] at least 90 percent of which were erected before the adoption of modern building codes in the mid-1970s. Most of these buildings are safe even in large earthquakes, meaning they won't flat out collapse, break apart, or shed their heavy skins onto sidewalks.

But there will be damage. Many buildings, old and new, will see enough damage to make them unusable until they're repaired. For a Loma Prieta-sized earthquake close to the city, 30,000 buildings could be damaged beyond repair by shaking and fire.[3] Even if the true number is smaller, thousands of buildings will need substantial repairs before being reoccupied, and others will require inspection and lesser repairs.

Losing a quarter of our existing building stock in a foreseeable event, even temporarily, is not acceptable. But neither is the cost of eliminating all potential losses. For a large earthquake in our lifetime, then, some damage is inevitable. But how much is acceptable?

---

[1] SPUR Hazard Mitigation Task Force, "The Resilient City: Defining What San Francisco Needs from its Seismic Mitigation Policies," January 9, 2008 (draft).
[2] Applied Technology Council (ATC), "San Francisco's Earthquake Risk: Report on Potential Earthquake Impacts in San Francisco," March 1, 2005 (draft), Table 4.
[3] ATC, Table 15.

It depends on what we're trying to achieve. Would it be enough to eliminate the risk of life-threatening collapses? After all, the first goal of earthquake preparedness is to protect lives, and the Department of Building Inspection's Code Advisory Committee has already called for a program of phased mandatory retrofits for "collapse-hazard" buildings.[4]

But mere survival is not the only goal, especially from a citywide perspective. City policy must recognize responsibilities beyond basic safety and even beyond a simple reduction of damage.

SPUR advocates an earthquake preparedness policy that maximizes the City's resilience. Planning for resilience means preparing our structures, networks, and organizations so that expected losses are not disproportionate or catastrophic. With respect to existing buildings, it does not mean eliminating the possibility of damage or even the possibility of some collapse; rather, it means targeting the right damage, the critical damage, first.

So which buildings are critical to San Francisco's resilience? We know what services will be critical to earthquake response and recovery. We also know which structure types are most prone to collapse. What we need to know for assessing resilience is which structure types the critical services are in, and which of those buildings might be safe from collapse but are still not likely to be usable right away.

## WHY EXISTING BUILDINGS ARE CHALLENGING

For any given building, structural engineers have tools for reliably predicting damage and assessing safety. Unfortunately, those tools work best with individual buildings whose structural attributes are known. It's harder to draw reliable conclusions about any class of buildings such as shelters, schools, or residences. Two aspects of traditional engineering practice make this challenging.

First, existing buildings are relevant to resilience because of their *occupancy* – that is, because of the functions they house, whether residential, office, school, hospital, church, jail, warehouse and so on. But engineers classify and assess buildings not by occupancy but by structural materials (such as wood, masonry, concrete, or steel) and systems (such as frames and shear walls).

Some historic correlations are helpful here. For example, most single-family residential buildings are of conventional wood construction. But the patterns are not robust enough to be consistently useful. What's needed is an inventory that breaks out the structure types within each occupancy category.[5]

[4] Code Advisory Committee, Department of Building Inspection, City and County of San Francisco, "Policy Statement: San Franciscans have the right to occupy buildings that will not collapse in future earthquakes," November 16, 2005.

[5] The Department of Building Inspection's CAPSS study has made some nominal distinctions among residential and commercial occupancies (see ATC, Tables 8 through 11), but CAPSS deals only with private buildings and does not address hospitals, schools, fire stations, etc. By contrast, the City's draft Hazard Mitigation Plan lists public facilities but does so by occupancy only, ignoring the structure types and the variations in earthquake performance. Section 6.3 of the draft plan acknowledges the value of SPUR's approach, but Section 8 fails to prioritize such a study.

Second, existing buildings affect resilience to the degree they remain habitable or usable after the earthquake. Engineering assessments, however, rarely look at buildings this way, as they typically focus only on safety – that is, on whether occupants will be able to escape the building uninjured.[6] Using SPUR's terminology, these assessments determine whether a building is in Category E, but they make little or no distinction between Categories A through D. Consider the City's neighborhood recreation centers and department offices. Any engineering assessments done to date probably predict only whether these buildings might be evacuated safely and say little about whether they might remain in service to aid response and recovery. Some buildings can sustain damage but remain basically functional. A house that does that, for example, will not add to emergency shelter demands even if it needs costly repairs. On the other hand, a building might have very little structural damage but go out of service due to plumbing damage or broken windows, or even because the contents and furniture have toppled or been scattered across the floor.

**SPUR's Performance Categories: Safe does not always mean usable**

Earthquake safety is largely about whether a building can hold together *while* the ground is shaking. To assess resilience, it's just as important to know if the building will be usable once the shaking stops. SPUR considers both questions with its performance categories:

**Category A**: Safe and Operational

**Category B**: Safe and Usable during repair

**Category C**: Safe and Usable after repair

**Category D**: Safe but not repairable

**Category E**: Unsafe

So while resilience is a function of occupancy and usability, engineers tend to look more at structure type and safety. These disconnects point to the need for more complete building inventory data: We need to know which structures house which occupancies. Absent that data, can any broad observations be made? Though the relationship is fuzzy, it does stand to reason that post-earthquake usability correlates inversely with damage, and traditional building patterns do paint at least an impressionistic image of where our existing building stock might achieve or fall short of resilience goals.

The following table summarizes the current status of our building stock, indicating roughly where certain structure types and hazards can be expected to compromise SPUR's recovery targets. The darkened cells suggest where the most urgent mitigation measures are needed.

[6] Loss estimation tools such as HAZUS (used for the CAPSS study by Applied Technology Council) predict damage somewhat differently from basic safety assessments, but they still do not predict directly or reliably whether a building might remain in service.

**Estimated response and recovery feasibility by occupancy and structural vulnerability**

| Service / Occupancy | Vulnerable condition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | DBI-compliant Unreinforced Masonry | Soft-story wood frame | Non-ductile concrete frame | Unbraced cripple wall | Rigid wall – flexible diaphragm | Pre-Northridge steel systems | Steel or concrete frame w/ URM infill | Major falling hazards (chimneys, cladding) | Vulnerable gas lines and gas-fired equipment | Vulnerable nonstructural components |
| First responders | | | | | | | | | | |
| Medical services | | | | | | | | | | |
| Single-family residences | | | | | | | | | | |
| Multi-family residences | | | | | | | | | | |
| Emergency shelters | | | | | | | | | | |
| Essential City services | | | | | | | | | | |
| Schools | | | | | | | | | | |
| Social services | | | | | | | | | | |
| Retail | | | | | | | | | | |
| Businesses | | | | | | | | | | |

The vulnerability is prevalent for the occupancy and is likely to hamper response and recovery.

The vulnerability is unknown but could be prevalent enough to hamper response and recovery.

The vulnerability is common for the occupancy and could affect response and recovery.

The vulnerability is not typically associated with the occupancy or critical to its response and recovery.

**A few observations from the table about San Francisco's current building stock:**

- Despite the strong historic performance of typical wood frame houses in earthquakes, San Francisco's residential buildings are likely to affect resilience citywide because of the prevalence of soft-story multi-unit buildings and house-over-garage conditions. Unbraced cripple walls, though common in older houses throughout California, are relatively rare in San Francisco; instead, our high density and narrow lots have made two-story house-over-garage construction more prevalent.

- Neighborhood retailers and other businesses exist in nearly every structure type. As a sector, commercial occupancies can be affected by the broadest set of potential hazards and might therefore present the toughest challenge in terms of crafting simple, effective risk reduction policies.

- Non-ductile concrete frame buildings probably house every critical occupancy. A more complete and reliable inventory will significantly inform any risk reduction program for these structures.

- Nonstructural components include everything from ceilings and windows to boilers and plumbing. Their performance is notoriously unpredictable (due to a lack of building code provisions in the past and spotty construction quality more recently) and can affect the post-earthquake usability of almost every occupancy.

- In addition to vulnerable construction, geotechnical conditions such as the potential for landslide or liquefaction often affect performance. While these factors are important, they are not listed because the vulnerability is entirely based on location and is not related to the occupancy of the building.

## NEAR-TERM MITIGATION STRATEGIES FOR EXISTING BUILDINGS

Can building-by-building mitigation improve the resilience of a city of 120,000 structures? If it's targeted to the critical services and structure types, SPUR believes it can. Indeed, it's a tenet of California policy that proactive risk reduction and loss prevention make it easier to respond to and recover from potentially disastrous events.[7] The important thing for San Francisco is to find mitigation strategies that will be feasible on a citywide scale and to dovetail mitigation plans with response and recovery plans. In brief, effective resilience planning means if we're not prepared to mitigate, we must be prepared to respond and recover, and if we're not ready to respond and recover, we must take steps to mitigate.[8]

Every sector of our existing building stock poses some risks and presents some opportunities to improve resilience. Ranking sectors by importance is not easy; there is no formula to balance effectiveness, cost, fairness, and expedience, no computer program we can run to spit out a consensus mitigation plan. Setting priorities and achieving consensus also is complicated because the best strategies to increase resilience citywide might not be the ones that most serve individual citizens' self-interests. The City's responsibilities – and therefore its risks too – are broader and deeper.

In the end, mitigation programs are effective when they balance the needs and resources of all stakeholders. A mandatory program that no building owner can afford, or that causes enormous short-

[7] The Governor's Office of Emergency Services , "State of California Multi-Hazard Mitigation Plan," October 2007, section 1.1.
[8] OES, section 2.3.2.

term disruption to achieve a hypothetical long-term result, will accomplish little. On the other hand, programs designed for the convenience or benefit of individuals don't often get the job done for the community. Political leadership and community willingness must be in sync.

With this in mind, SPUR recognizes that our shortfall in resilience is a problem almost a century in the making. It will not be solved in a quick decade with a short list of programs. Still, the City needs to get started with policies and initiatives that make sense in the near term, as well as commitments to stay on the job for a generation to come. There are dozens of ways to reduce our risk and increase our resilience. They are all valuable, but they cannot all be done at once. Near-term strategies should address our biggest resilience gaps and set the stage for equally important programs to come later.

SPUR has prioritized six policy recommendations for near-term mitigation of existing building risks. Not surprisingly, our resilience-based approach and our simultaneous attention to both occupancy and structure type have led to somewhat different top priorities than those in the City's latest hazard mitigation plan.[9] While the City's draft priorities do include funding for an unspecified soft-story program, they cover mostly individual public facilities without an overarching set of citywide goals.

**SPUR's top policy recommendations:**

**1. Mandated retrofit of soft-story woodframe multi-family housing.**

Our current housing stock cannot provide the resilience we need. A documented history of poor performance and potentially disastrous effects on response and recovery make this a risk that deserves immediate attention. Not every residential building is a soft-story hazard, but soft-story conditions probably will determine whether our housing stock as a whole can meet a high resilience objective. The Department of Building Inspection's CAPSS study estimates that a major Bay Area earthquake could render 2000 or more of these buildings uninhabitable, leading to the loss of housing for 50,000 residents.[10]

These vulnerable buildings need to be identified and, as a class, they need to perform better. Because they are critical to our ability to find post-earthquake shelter in our own homes, they must remain not only repairable, but habitable. A mitigation program coordinated with citywide resilience goals would be consistent with existing City policy to facilitate "shelter-in-place" and post-earthquake damage assessment plans.[11]

SPUR recommends a program of mandated retrofits over a feasible compliance period as was done for unreinforced masonry buildings. Ample background work by the Department of Building Inspection and the readiness of policy-makers[12] will make a mandate feasible. A phased program

[9] City and County of San Francisco, Draft Hazard Mitigation Plan, posted September 5, 2008, section 8.
[10] Robert Selna, "S.F. 'soft-story' buildings at risk in quake," December 11, 2008. This article cites preliminary Community Action Plan for Seismic Safety data showing the City has 2800 buildings of three or more stories and five or more units in which the ground floor openings are substantial enough to indicate a soft-story condition.
[11] City and County of San Francisco, "All-Hazards Strategic Plan," 2008. Strategic Goal 15 calls for development of plans to shelter or evacuate at-risk populations. Strategic Goal 19 is explicit about passing legislation to strengthen soft-story buildings, in the context of a general call to develop resources for the post-earthquake safety assessment of buildings and the resumption of their occupancy.
[12] Soft-story mitigation is already explicitly noted in the City's 2008 "All-Hazards Strategic Plan" and in its draft Hazard Mitigation Plan. In July 2008, Mayor Gavin Newsom directed the Department of Building Inspection to develop a soft-story ordinance with incentives for voluntary retrofit (see Newsom, "Seismic Strengthening of Soft Story Buildings"). Those incentives were not approved, in part because voluntary work was not expected to be

administered by DBI should follow the model of the City's unreinforced masonry program. Whether an individual soft-story building needs to be retrofitted to Category C or B deserves further study by DBI through its CAPSS program. Exemptions and prioritization by building size, location, number of residential units, or other factors, with buildings housing low-income or otherwise socially vulnerable tenants meriting special interest, should be based on data already gathered by CAPSS. Further, the City should explore a full range of financial resources and incentives, including the potential for using bond funds left over from the Unreinforced Masonry Bond program, which distributed bond funds for the upgrade of unreinforced masonry buildings.

**2. Mandated retrofit or redundancy for designated shelters.**

Until the housing stock is improved, we must be ready for the effects of significant housing losses. While the City has designated certain existing buildings to serve as shelters, it has not confirmed that those facilities will be sufficient or even usable after a damaging earthquake.[13]

The City must make this among its highest near-term priorities. Using SPUR's terminology, these facilities must be capable of at least Category B performance. The Department of Emergency Management, which designates shelter facilities, should be the lead agency for this work. Following assessment of the facilities currently designated, the Department should propose measures to address identified deficiencies by 2015.

**3. A mitigation program for essential City services.**

Essential post-earthquake services are those needed to implement a sufficient response and recovery plan. They include certain City department operations, as well as medical and social services. While the need for these services is acknowledged in the City's latest emergency planning documents, there does not appear to be a coordinated effort to identify and address critical vulnerabilities, even for city-owned or city-leased facilities.[14]

Of particular concern are medical and social services, which in San Francisco are provided in part by non-governmental organizations. If the City is relying on NGOs to make its emergency plan viable, it should allocate resources to help those organizations prepare. The Department of Emergency Management and the Department of Public Health should jointly engage the NGO community, coordinate the City's emergency plan with those NGOs' resources, and propose measures committing City resources to bridge the gaps those organizations – most of which are cash-poor – cannot fill on

---

effective, and in December 2008 the Mayor's Office noted its openness to mitigation programs that might include mandated retrofit of certain buildings (see Selna, "S.F. 'soft-story' buildings at risk in quake").

[13] While the City's Emergency Response Plan and All-Hazards Strategic Plan anticipate the need to provide post-earthquake shelters and to coordinate City departments to administer them, its draft Hazard Mitigation Plan does not list designated shelters as critical facilities (section 6.1.3). It does list San Francisco Unified School District buildings, the Civic Auditorium, and Moscone Center as critical, but it does not place any priority on measures to protect them (except to derive replacement values for asset management purposes). The City's branch libraries and recreation centers are listed as non-critical facilities.

[14] For example, the 2008 Emergency Response Plan relies on Department Operations Centers for coordinated provision of emergency functions including mass feeding, housing, public health, etc., and the All-Hazards Strategic Plan describes several related Strategic Goals. Yet the draft Hazard Mitigation Plan, while it lists over 50 "critical" City-owned government and care facilities, does not appear to prioritize risk reduction for any of them.

their own. Using SPUR's terminology, these facilities, if not backed-up by alternatives, must be capable of at least Category B performance.

A coordinated analysis of combined public and private capacity, overlain by estimates of service demands, is doable by 2010. The analysis will inform selection of mitigation strategies that should be implemented by 2015.

**4. A mitigation program for critical non-ductile concrete buildings.**

Mitigation starts with inventory. By 2010, DBI should know how many of these obsolete and dangerous buildings are in the City, where they are, what services they house, and what effects their expected performance will have on response and recovery. As critical City-owned buildings are identified, DBI and the Department of Public Works should take steps to require seismic evaluations. DBI should also consider changes to San Francisco Building Code Chapter 34 to trigger seismic evaluations of privately-owned concrete buildings. Together with a growing body of technical and cost data, we will then be in a position to move forward with a program that targets the unacceptable risks with the most appropriate and effective strategies.

**5. Mandated and triggered retrofit of gas lines and gas-fired equipment.**

Fire can turn a manageable earthquake emergency into catastrophe. Since broken gas lines often are involved in earthquake-related fires, the best solution is to prevent ruptures by bracing equipment (such as water heaters) and using flexible lines and connections. If the structure itself is a collapse hazard, or if the gas line passes through a damageable building wall, then a different solution is needed. An excess-flow gas-shutoff device can be installed upstream of the potential rupture location. But there's a problem: The damageable building is the owner's responsibility, but the line upstream of the meter belongs to the gas company.

SPUR's recommendation is for mandated retrofit, guided by a coordinated study. The Department of Building Inspection must determine which City buildings are at risk of collapse or rupture. PG&E must determine where individual ruptures will do the most damage and where excess-flow shutoffs will be effective (they do not work well on low-pressure lines), based on knowledge of its own distribution system. From the combined data, DBI should develop a retrofit mandate for selected existing buildings, to be implemented jointly by PG&E and building owners.

Meanwhile, the Department of Building Inspection and the Public Utilities Commission should work with PG&E, insurers, homeowners, and business associations to reach building owners and assist them in eliminating hazards voluntarily. DBI should consider requiring excess-flow shutoffs or seismic-triggered shutoffs on all new installations and should develop code provisions to trigger upgrades when properties are sold or altered.

**6. Assessment of the unreinforced masonry program.**

Retrofits of the City's unreinforced masonry buildings, mandated by a 1992 ordinance in compliance with a 1986 state law, are nearly complete. While unquestionably beneficial, these retrofits were minimal, intended only to prevent wholesale structural collapse. The effort of the past sixteen years will save lives, but it will not keep buildings usable during response and recovery, and unreinforced masonry buildings as a group remain a significant source of potential losses. Using SPUR's terminology, most of them have been improved only from Category E to Category C or D. The

Department of Building Inspection should now assess the completed program, draw lessons from it, and estimate the remaining risks in resilience terms.

Even with these recommendations implemented, it is important to remember that resilience is an attribute of organizations or communities, not of buildings. The capacity of a building to remain in service can be critical, but it is only part of what is called "continuity of operations". Just as important is the preparedness of the people and organizations a building houses and serves.

Finally, it's time for San Francisco to begin collecting and maintaining building data for use in resilience planning. We know the services that contribute to resilience, and we know the structural conditions that are prone to damage, but we don't know enough about which services are in which structures. A close look at our near-term recommendations will show that this unknown correlation is central to resilience planning. Basic structure type is information that can and should be tracked both to aid ongoing response planning and to confirm the viability of the City's emergency plan. For buildings and services already designated as critical, the Department of Emergency Management must know (and then account for) the structures in question. For other buildings, from houses to high-rises, DBI can collect valuable objective data – with no seismic assessment required – simply by requesting it in permit applications.

## MITIGATION STRATEGIES

Even where mitigation is necessary, it does not always have to involve an immediate mandate for structural retrofit. Effective risk reduction policies adopt and combine a variety of strategies:

**Inventory and planning-** Inventories and studies do not reduce risk. But they do make risk reduction programs viable by building consensus around objective data. Knowing what's at risk is always sound policy. From an inventory, the effort can progress to planning, then to implementation.

**Mandated retrofit-** Generally enacted by legislation, mandated programs require work on specified buildings regardless of an owner's intent. Mandates tend to address otherwise intractable conditions with long records of poor performance and sizable remaining inventories still at risk, especially where the mitigation would have a broad public benefit. Examples of mandated retrofit programs include the improvements to California hospitals (SB 1953) and programs for unreinforced masonry buildings in accord with California's 1986 URM Law (SB 547).

**Voluntary retrofit-** Where mandates are not viable, a policy of voluntary retrofit can be effective. Driven only by owners' knowledge and risk sensitivity, with minimal outside requirements, voluntary work can range from bracing a water heater to a complete structural upgrade. In booming economies, owners retrofit to limit business disruptions. In slower times, they have other priorities. Institutional owners do voluntary work to fulfill management responsibilities to their constituents. Voluntary work also can be encouraged by education and by incentives such as fee or assessment waivers or grandfathering with respect to future mandates.

**Triggered retrofit-** Seismic improvements can be required, or triggered, by the scope of repairs, additions, alterations, changes of occupancy, or even changes in ownership. San Francisco has upgrade triggers in Chapter 34 of its Building Code. The work often is driven by business decisions to otherwise improve a property, so triggers can be effective if they apply when new funds are available. On the downside, an owner's intended project might be scaled down or skipped completely in order to *avoid* triggering additional seismic requirements.

**Insurance and risk transfer-** If an unacceptable risk cannot be actually removed, its financial component can sometimes be transferred through insurance or reinsurance. This strategy works best when expected losses are otherwise repairable, and when quick recovery or continuity of operations is not needed.

**Redundancy-** Backup, or redundant, facilities don't reduce damage, but they can shorten the time needed to recover normal operations. Redundancy planning can save retrofit costs and avoid the service disruptions that sometimes come with retrofitting. The strategy also makes sense when the vulnerable facility is deficient in other ways as well, so that rebuilding makes more sense than retrofit. It is not an effective strategy where relocation cost and delay will interfere with critical post-earthquake operations.

**Occupancy resumption planning-** When other risk reduction strategies are not feasible, or while they are being implemented, a plan to speed up re-occupancy (often as part of a broader continuity of operations plan) can at least aid recovery when the building remains habitable, even if it does not reduce damage or actual risk. The City's All-Hazards Strategic Plan calls for enhancement of an existing program called BORP, but its draft Hazard Mitigation Plan does not prioritize the application of BORP to city-owned or city-leased facilities.

## PAYING FOR MITIGATION

No discussion of programs and policies is complete without considering costs. Who should pay for retrofits the City determines are essential to its broad-based response and recovery plan? If individual buildings are improved, why should the whole community pay for the work? On the other hand, why should a relative few property owners have to improve their buildings if the improvements are clearly motivated by citywide needs – or in some cases, by the needs of other individuals or groups?

In general, whoever "owns the risk" should pay to have it reduced. But whose risk is in question here if the issue is resilience? SPUR's recommendations are for City policies that benefit the City as a whole. Decisions to improve safety or insure against losses in any given building are, and should be, functions of the enlightened self-interests of individual owners and tenants. When SPUR calls for retrofit of, say, a vulnerable apartment building, it's not to reduce specific losses but to help limit the shelter demand and keep the housing stock stable. So while an individual owner might have the most direct benefit from a retrofit, the City reduces its risk too, and should therefore bear some portion of the costs in their broadest sense. At the same time, whoever benefits most from the City remaining productive, solvent, beautiful, functional – whoever benefits from San Francisco being *San Francisco* – must support the common wealth that in turn enriches them.

The menu of mitigation strategies comes with a menu of payment options. As with most public works projects, major seismic retrofits are usually funded by bonds. Federal and state grants are also available on a competitive basis from the Department of Homeland Security, through California's Office of Emergency Services. Mandated retrofits of private buildings are typically unfunded, and the affected owners must rely on loans, institutional bonds, or self-funding. If funding cannot be found, unintended consequences result: churches and hospitals are among the institutions that have closed their doors, unable to pay for mandated seismic improvements.

Whether public funds could be granted to improve private buildings for the common good is a fair question that resilience advocates will have to address (though Oakland has already established such a program). Loans and incentives have ample precedent, but also inconsistent results. San Francisco made low interest loans available to owners of unreinforced masonry buildings in a program that went largely unused. With mixed success, some jurisdictions have offered incentives for voluntary retrofit in the form of waivers on permit fees, transfer taxes, assessments, etc. Certainly the funding mechanism must be suited to the stakeholders and the properties involved, and no single mechanism will work in all cases. A socio-economic study of how to fund effective earthquake risk reduction, though outside the scope of these recommendations, is a task SPUR looks forward to taking on.

Two things we do know from past mitigation programs in San Francisco and elsewhere. First, for a policy to achieve its goal, it must be designed so the funders can rationally expect a benefit from their investments. Second, after the earthquake damage is done, even the most rational wish they had spent more to prepare.

# THE REMAINING RISK: A SECTOR-BY-SECTOR REVIEW

SPUR's top near-term recommendations focus on the most severe disconnects between current conditions and recommended resilience goals, considering costs, benefits, and political viability. The near-term recommendations, SPUR expects, can be implemented by 2015. At that point, or as new information becomes available, additional mitigation efforts can and should begin. Some ideas for those longer-term mitigation programs are given in the following sector-by-sector review of our expected resilience gaps.

Meanwhile, there's no reason why private individuals and organizations should wait for a City policy to prod them to action. SPUR's recommendations address citywide resilience through public policy, but personal policy can be effective too. House by house, school by school, business by business, the same principles can be applied to reduce risk and help build the resilient city.

## EMERGENCY OPERATIONS AND FIRST RESPONDERS

In 2006 the City's Department of Public Works cited between 172 and 200 facilities "critical" to earthquake response and recovery and another 300 deemed "important".[15] The City's latest Hazard Mitigation Plan currently lists 277 "critical facilities," of which 145 are owned by the San Francisco Unified School District; leased facilities do not appear to be included.[16] While the list thus appears to be in flux, it no doubt would include the relatively new Emergency Communications Center and Emergency Operations Center, police and fire stations, and buildings that support city departments executing response and recovery tasks. While the various planning documents make no performance predictions, they do acknowledge that certain public and private buildings will require immediate post-earthquake inspections and that the corps of trained inspectors will need to be enlarged.[17]

New police and fire stations are designed to be functional immediately following an earthquake. Older facilities might have been designed to the higher criteria of their day, but even those designs are likely obsolete. The good news is that most of the City's twelve police stations and 53 fire stations have been retrofitted. According to Fire Department and DPW data, all but one of the City's fire stations have been retrofitted since a 1992 bond measure, though in some cases the work might have addressed only the critical roll-up doors.[18] Beyond the structural performance, the SSFD acknowledged in 2006 that it still lacked a plan to have stations inspected for reoccupancy after an earthquake and that some stations still had no emergency generators or on-site supplies to support an extended response phase.[19]

Among the police facilities, the department's Southern Station remains a concern. Along with the department's administrative headquarters and jail facilities for 800 inmates,[20] Southern Station occupies

[15] City and County of San Francisco, "Earthquake Response Plan Enhancement," September 22, 2006 (Administrative draft, version 1.0), section 7.10.1 and section 6.6.1.
[16] City and County of San Francisco, Draft Hazard Mitigation Plan, posted September 5, 2008, section 6.1.3.
[17] City and County of San Francisco, "Earthquake Response Plan Enhancement," section 6.6.1, and "All-Hazards Strategic Plan," section 3.1.5.
[18] M. Bello et al., "San Francisco Bay Area fire stations – Seismic risk assessment," 2006, and Earthquake Engineering Research Institute – Northern California Chapter, "Bay Area Best Practices in Earthquake Risk Reduction," April 2006.
[19] James M. Vannucchi, "Preparation for Major Earthquake of the San Francisco Fire Department – Then & Now," April 18, 2006, page 7.
[20] City and County of San Francisco, "Earthquake Response Plan Enhancement," section 4.4.5.

parts of the Hall of Justice, a facility found seismically deficient in several separate reports produced since the Loma Prieta earthquake.[21]

Of the City department offices needed for initial response and recovery, City Hall is a high-profile retrofit using base isolation technology. The main library is a 1996 base-isolated structure in the Civic Center that can also be expected to perform especially well. The City's 2006 plan, however, identified Moscone Center or Bill Graham Auditorium as locations for an alternate seat of government.[22] Whether these or the other "critical" facilities will be immediately usable is less well known.

**Recommended Mitigation:**

- Inventory DPW's critical facility list, tracking structure type, nonstructural components, and retrofit status.
- Provide retrofit, replacement, or redundancy to ensure that response-critical facilities will be both safe and reliably functional. (This is one of SPUR's top near-term recommendations.)
- Implement building occupancy resumption plans.

## HOSPITALS AND ANCILLARY MEDICAL FACILITIES

The City counts thirteen hospitals within city limits,[23] though the number of distinct buildings is higher.[24] All acute care hospitals in California are required by 1994 legislation to be seismically safe by 2013 and ready for post-earthquake operations by 2030. Several of San Francisco's facilities, notably San Francisco General Hospital, the region's only Level I Trauma Center, still require substantial retrofit.[25] In November 2008, San Francisco voters approved, with an 84% majority, $887 million in general obligation bonds to build a replacement facility on the SFGH campus. San Francisco's other public facility, Laguna Honda Hospital and Rehabilitation Center, is in the process of being replaced and upgraded.

In addition to SFGH and Laguna Honda, eighteen neighborhood clinics and health centers (fourteen of which offer primary care services) participate in the Community Health Network of San Francisco.[26] Design of new clinics is regulated by California's Office of Statewide Healthcare Planning and Development, but existing clinics, like existing government office buildings, were generally not designed to provide immediate post-earthquake service. Clinics and Health Centers, though likely to be critical to San Francisco's earthquake response, also are not subject to the upgrade requirements of acute-care hospitals. For example, some of the neighborhood satellite clinics are in retrofitted unreinforced masonry buildings. While parapet braces and wall anchors should prevent fatal collapses and falling hazards, they

---

[21] Jaxon Van Derbeken, "S.F. Hall of Justice – a 'shameful' danger," *San Francisco Chronicle*, October 24, 2005.
[22] City and County of San Francisco, "Earthquake Response Plan Enhancement," section 2.2.1.
[23] Ibid., section 4.4.4.
[24] For purposes of earthquake preparedness, a count of separate buildings is more meaningful. A building count can identify more specific risks and can also reveal useful redundancies. The Office of Statewide Health Planning and Development (OSHPD) tracks a different number of facilities because it distinguishes individual campuses and some individual buildings.
[25] In November 2007, the California Legislature allowed OSHPD to use HAZUS software (the same software used for the City's CAPSS study) to reclassify some of the hospitals required to meet the 2013 deadline. To some, this suggested that the qualifying facilities pose less risk than initially believed, but that is not generally the case. First, the primary purpose of the reclassification was merely to determine which facilities might be allowed a deadline extension to 2030. Second, any reclassification would merely remove a facility from the list of "collapse hazards." Post-earthquake usability would still be doubtful. Third, the reclassification applies primarily to facilities in the Central Valley. Hospitals in San Francisco will probably not be reclassified.
[26] See the Community Health Network website at http://www.dph.sf.ca.us/chn/HlthCtrs/MapHlthCtr.htm.

hardly assure that these facilities will remain in service. To the extent that the City relies on the Community Health Network to supplement its hospitals in an emergency, it should be tracking and improving their facilities as well.

**Recommended Mitigation:**

- Develop a mitigation program for essential city services, starting with a detailed analysis of medical and social service resources. (This is one of SPUR's top near-term recommendations.)
- Track OSHPD compliance of both the City-owned and privately-owned acute care facilities.
- Complete the mandated retrofit or replacement of San Francisco General Hospital, and implement a near-term contingency plan for Level I Trauma Center services.
- Inventory the neighborhood clinics and health centers, tracking structure type, nonstructural components, and retrofit status.
- Retrofit, replace, or provide redundancy for privately-owned response-critical facilities to ensure both safe and usable performance.
- Encourage privately-owned facilities to implement building occupancy resumption plans.

## HOUSING

Probably the greatest determinant of successful earthquake response, and of San Francisco's resilience generally, will be the performance of its housing stock. Well over eighty percent of the city's existing buildings are for residential occupancy, and certain vulnerable critical structure types number in the thousands.

As detailed in the City's CAPSS study and its earthquake response plan, the potential losses are staggering. If the projections are realized, responders will be overwhelmed, and recovery will be late, slow, and costly. The City's own planning documents acknowledge this. But if the performance overall can be improved so all but a relative few can find safe shelter in their own homes, then response can focus properly on the helpless and indigent, and recovery – which starts with the re-occupancy of damaged homes, schools, and workplaces – can begin straight away.

While the CAPSS study has developed substantial data on the City's housing stock, it has not made the distinctions necessary to identify particularly vulnerable occupants, such as the disabled or disadvantaged. "Social vulnerability" maps of San Francisco have been produced, but they have not yet been linked to structural data. Anecdotally, however, it is known that unreinforced masonry buildings (most of which have been nominally retrofitted in compliance with DBI requirements) account for a disproportionate share of single room occupancy and transitional housing in the Tenderloin and South of Market.

Unreinforced masonry buildings account for some of the vulnerable housing stock – about 800 buildings when the City's ordinance was developed in 1990.[27] Again, even those buildings with required parapet bracing and wall anchors are likely to see damage, and many will not be immediately habitable after a large earthquake.

Hillside houses and non-ductile concrete frame structures represent two more small but hazardous slices of the housing pie. These vary greatly in style and structural adequacy, but the worst of them, unlike, say, the worst cripple wall houses on flat sites, are likely killers. The City has no inventory of its hillside

[27] Recht Hausrath & Associates, *Seismic Retrofitting Alternatives for San Francisco's Unreinforced Masonry Buildings: Socioeconomic and Land Use Implications of Alternative Requirements*, October 1990, page 28.

houses or its NDC frames, though CAPSS has estimated that there are about 1900 NDC frames with brick infill panels.[28]

Two of the most common residential building types suffer from the same basic structural flaw: too much open space on the ground floor. One of these is the house-over-garage, or HOG, typically a two-story single-family residence with a one-car garage taking a good part of the first floor. San Francisco has tens of thousands of these throughout the west half of the city, most within three miles of the off-shore San Andreas fault. Aside from brick chimneys and unbraced water heaters, the chief seismic deficiency in this house type is the openness of the front wall line with its wide garage door. As a class this simple building type is not thoroughly studied, and it might be as adequate as most houses of conventional wood framing. But if one is wracked, thousands are wracked, and if one catches fire, thousands could burn.

The other hazardous wood structure type is the soft-story apartment building, of which the City has perhaps 3000, housing about 60,000 people.[29] These buildings represent an array of obstacles to response and recovery. First, they perform poorly and are prone to collapse, as six did in the Marina district in Loma Prieta.[30] Second, they provide housing for an enormous number of people, almost all middle-income renters. The CAPSS study is estimating that as many as 80 percent of these vulnerable structures will be uninhabitable after a major earthquake.[31] Third, when they do collapse or lean, they block streets and hamper response. Fourth, those that front onto shopping corridors house first-floor retail occupancies characteristic of San Francisco, whose loss will affect neighborhood resilience.

Neither CAPSS nor DBI has counted the retrofits of residential buildings. Anecdotally, we know that some voluntary retrofits were motivated by nearby Marina district damage in Loma Prieta. Major renovations or condo conversions might have involved code-triggered seismic improvements. But these are rare exceptions. It is safe to say that very little of San Francisco's most vulnerable housing stock has been seismically improved since its original construction.

Finally, as suggested above, our woodframe housing stock is vulnerable not only to structural damage but to fires caused by ruptured gas lines. Gas lines break either because gas-fired equipment slides or tips over or because the building is damaged where the line passes through a wall. Clearly, a collapsing HOG or soft-story building threatens to snap the gas line. More commonly, earthquake-related fires have started because unbraced water heaters topple. All new and replaced water heaters are required to be braced. Many old tanks have been voluntarily retrofitted as well. But many remain vulnerable. In the cheek-by-jowl houses in the west half of the city, how many need to fall over and ignite before the fire department is unable to respond?

Equipment bracing, installation of flexible lines, and mitigation of collapse-risk structures can effectively eliminate this risk. But if the problem is the release of gas from a ruptured line, a simple device that detects excess flow and shuts it off might be just as effective. In 2005, the state completed a legislatively-mandated study of shutoff devices and found it unnecessary to require them in new residential buildings.[32]

---

[28] ATC, Table 4.

[29] Robert Selna, "S.F. 'soft-story' buildings at risk in quake," December 11, 2008. This article cites preliminary CAPSS data showing the City has 2800 buildings of three or more stories and five or more units in which the ground floor openings are substantial enough to indicate a soft-story condition.

[30] Stephen K. Harris and John A. Egan, "Effects of Ground Conditions on the Damage to Four-Story Corner Apartment Buildings," page F181.

[31] Robert Selna, "S.F. 'soft-story' buildings at risk in quake," December 11, 2008, citing preliminary CAPSS findings.

[32] Kim Strange, "Information Bulletin 2005-02 (SHL)", March 21, 2005.

Of course, new buildings with newly installed appliances do not pose nearly the same risk as unbraced water heaters in vulnerable structures. San Francisco should follow the example set by Contra Costa County (and several of its cities), which requires excess flow gas shutoff devices in all new construction and triggers installation of shutoffs in certain existing buildings undergoing alteration.[33] In addition to triggered mitigation, the City should work with PG&E to encourage voluntary installation of excess flow shutoff devices as well.

Earthquake risk reduction for residential buildings is fraught with tradeoffs between public interests and private rights, especially in San Francisco where housing comes at a premium. There is no question that extensive housing losses will affect the City's resilience, its economic vitality, and its very character – to say nothing of the safety of some of our most vulnerable neighbors. But compared with fire stations or hospitals, it remains difficult to demonstrate this abiding public interest when mitigation will so significantly affect individual building owners and could displace tenants. Still SPUR advocates the following as principal strategies that deserve careful and immediate consideration.

**Recommended Mitigation:**

- Continue DBI efforts to inventory soft story multi-family residential buildings, working toward a mandatory strengthening ordinance modeled on San Francisco's unreinforced masonry requirements. (This is one of SPUR's top near-term recommendations.)
- Develop code provisions to trigger water heater bracing and installation of excess flow gas shutoff devices upon sale of the building or issuance of permits for alteration or addition. Encourage voluntary bracing and shutoff installation as well. (This is one of SPUR's top near-term recommendations.)
- Inventory non-ductile concrete structures, with and without masonry infill panels. (This is one of SPUR's top near-term recommendations.)
- For City-owned housing, provide retrofit, replacement, or redundancy to ensure that response- and recovery-critical facilities will be both safe and reliably functional.
- For City-owned housing, implement building occupancy resumption plans.
- For facilities run by NGOs, provide financial incentives (fee waivers, planning and design grants, in-kind services, transferable rights, tax credits and deductions, etc.) for earmarked donations to retrofit or replacement projects.
- For NGO-run facilities, fund or provide building occupancy resumption plans.
- Fund development of prescriptive plan sets for typical soft story multi-family residential buildings and house-over-garage single-family residences.
- Encourage brick chimney bracing or removal.
- Revise rent control and pass-through regulations so that voluntary retrofit is less costly to owners than demolition and reconstruction. Update, extend, and encourage assessment exclusions similar to those provided by California Revenue and Taxation Code section 74.5.
- Extend new and existing inventories to study correlations between housing stock and socially vulnerable populations.

### Emergency shelters

The City's 2006 plan estimates, "Approximately 50,000 people will seek shelter at sites run by the [City] and by private nonprofit organizations, churches, and other organizations."[34] The City maintains a

[33] Contra Costa County Board of Supervisors, "Ordinance No. 2000-11: Gas Shut-off Devices," 2000.
[34] City and County of San Francisco, "Earthquake Response Plan Enhancement," section 6.3.1.

database of potential shelter facilities with capacity for 55,000 people, but it acknowledges expected shortages in supplies, trained personnel, and bed space, because designated shelter buildings might be damaged and unusable.[35] While the plan discusses non-compliant disabled access at many of these facilities, it says little about their seismic safety or post-earthquake usability, acknowledging only that each facility should be inspected before it is staffed and opened 72 hours after the shaking.

In addition to providing shelter for people displaced from damaged homes, designated shelter facilities might also be pressed into service as bulk distribution and feeding sites, personnel staging areas, general disaster assistance offices, etc.

Potential shelters in San Francisco include four schools designated by the American Red Cross[36] and probably several community centers (with auditoriums or gyms), or facilities managed by the City's "nonprofit partners." This again points to the disconnect between emergency priorities and building regulation. Unless they were designed for the nominally higher criteria used for new public assembly spaces or were designated as emergency shelters *at the time of their original design*, community centers, soup kitchens, and other potential shelter sites can not be expected to perform any better than typical housing or commercial buildings of similar construction.

Several churches in San Francisco have been in the news in recent years for their struggles to fund retrofits, but the problem goes beyond historic unreinforced brick buildings. Recent studies of community- and faith-based organizations are finding facilities unlikely to support post-earthquake operations, let alone emergency-related surges in demand. Seismic assessments of City-owned recreation and cultural centers after the Loma Prieta earthquake found many that failed a "life safety" assessment.

Two new efforts might nominally improve our preparedness with respect to emergency shelters. In January 2008, the Bay Area Super Urban Area Security Initiative (SUASI), in which the City participates, issued a Request for Proposals to create a database of 325 potential shelter sites in the 10-county SUASI region. However, SUASI focuses primarily on terrorism and largely presumes that shelters themselves will not be affected by the events in question. In February 2008, San Francisco voters approved $185 million in bond funds for improvements to neighborhood parks and recreation facilities. Campaign literature promised to "rebuild unstable recreation centers for earthquake safety," and the City's 1992 seismic assessments played a part in selecting the facilities, but most of the projects involve play areas and small restroom buildings, and it is unlikely that this work will improve any major buildings to serve as high-capacity shelters.

**Recommended Mitigation:**

- Coordinate with SUASI efforts to inventory all designated shelters, and extend the SUASI database to consider earthquake effects.
- Apply incremental and triggered retrofits to improve potential shelter facilities for earthquake resistance when they are altered, renovated, or repaired.
- For City-owned facilities, provide retrofit, replacement, or redundancy to ensure that response- and recovery-critical facilities will be both safe and reliably functional. Coordinate with projects that renovate cultural or recreational facilities. (This is one of SPUR's top near-term recommendations.)

[35] Ibid., section 6.3.2.
[36] See the website of the San Francisco Unified School District, http://portal.sfusd.edu/template/default.cfm?page=emergency.attachment.t

- For facilities run by community-based organizations, provide financial incentives (fee waivers, planning and design grants, in-kind services, transferable rights, tax credits and deductions, etc.) for earmarked donations to retrofit or replacement projects.
- For CBO-run facilities, fund or provide building occupancy resumption plans.

## ESSENTIAL CITY SERVICES

Other potentially critical facilities house the offices of City departments. Despite the City's reliance on them, it is highly likely they were designed only for performance as routine office buildings and have obsolesced along with the rest of the existing building stock. The City's 2006 earthquake plan indicates that 191 City-owned facilities were targeted for retrofit after the Loma Prieta earthquake and that less than half of those projects were complete by 2002.[37] The 2008 draft Hazard Mitigation Plan does not prioritize retrofit of any department offices.[38]

**Recommended Mitigation:**

- Develop a mitigation program for essential city services, starting with a detailed analysis of medical and social service resources. Track City-owned facilities with respect to post-earthquake need, structure type, nonstructural components, and retrofit status. (This is one of SPUR's top near-term recommendations.)
- Provide retrofit, replacement, or redundancy to ensure that response-critical facilities will be both safe and reliably functional.
- Implement building occupancy resumption plans.

## SCHOOLS

Despite seventy-five years of Field Act-compliant school construction, even some school facilities are vulnerable. A 2002 study by the Division of the State Architect, which regulates new school construction, found that 75% of the non-woodframe K-12 school buildings throughout the state provide unreliable or questionable seismic safety – to say nothing of their post-earthquake usability.[39] In 2006, voters used Proposition 1D to earmark $200 million for the seismic retrofit of these buildings,[40] but San Francisco does not appear to have taken advantage of these resources.[41] Meanwhile, ABAG's regional hazard mitigation plan, in which San Francisco participates, cautions that designation as a potential emergency shelter "does not mean that the school has had a hazard or structural evaluation to ensure" its suitability.[42]

**Recommended Mitigation:**

- Coordinate with DSA to confirm and extend its 2002 study, with emphasis on non-ductile concrete structures.
- Coordinate with mitigation strategies for designated emergency shelters.

---

[37] City and County of San Francisco, "Earthquake Response Plan Enhancement," section 4.4.5.
[38] City and County of San Francisco, Draft Hazard Mitigation Plan, posted September 5, 2008, Table 8-2.
[39] Department of General Services, "Seismic Safety Inventory of California Public Schools," November 15, 2002.
[40] OES, section 5.5.4.1.
[41] Robert Selna, "S.F. to check 12 schools' seismic safety," August 24, 2008.
[42] Association of Bay Area Governments, "Taming Natural Disasters: Multi-Jurisdictional Local Government Hazard Mitigation Plan for the San Francisco Bay Area," March 17, 2005, page 27.

- Provide retrofit, replacement, or redundancy to ensure that response-critical facilities will be both safe and repairable.
- Implement building occupancy resumption plans.

## SOCIAL SERVICES FACILITIES

The City's response and initial recovery will rely not only on government services but on community-based and faith-based organizations that routinely house, feed, care for, and otherwise assist the City's most vulnerable residents, including at-risk youth, the indigent elderly, the disabled, the homeless, and the substance-addicted. Yet their facilities are no better prepared to survive earthquakes – and in many cases are more vulnerable –than typical housing, retail, or office facilities.

**Recommended Mitigation:**

- Develop a mitigation program for essential city services, starting with a detailed analysis of medical and social service resources. (This is one of SPUR's top near-term recommendations.)
- Develop a retrofit program for critical non-ductile concrete buildings, starting with inventory of pre-1980 concrete structures of all occupancies. (This is one of SPUR's top near-term recommendations.)
- For facilities run by community-based organizations, provide financial incentives (fee waivers, planning and design grants, in-kind services, transferable rights, tax credits and deductions, etc.) for earmarked donations to retrofit or replacement projects. Update, extend, and encourage assessment exclusions similar to those provided by California Revenue and Taxation Code section 74.5.
- For CBO-run facilities, fund or provide building occupancy resumption plans.

## COMMERCIAL BUILDINGS

Commercial occupancies contribute to resilience as outlets for goods and services in the days after an earthquake, as providers of jobs to support recovery, and as generators of revenue for the City over the long term.

Compared with residential buildings, quite a few commercial buildings have been retrofitted. San Francisco, like most California jurisdictions, requires seismic improvements only when a building is subject to major renovation or a change of occupancy. Commercial buildings change occupancy more frequently (for example, from warehouse to office to retail over the course of a generation), and many of San Francisco's buildings were adapted to new uses or new tenants during the boom of the late-1990s. Dozens of high-profile downtown buildings, including corporate headquarters, banks, hotels, theaters, department stores, etc., have been retrofitted since Loma Prieta. Along with these major renovations and seismic retrofits come improvements in fire suppression and life safety systems, which should aid post-earthquake response as well.

Still, most of these voluntary improvements were designed to ensure safety, not to keep the buildings in service after the earthquake. And for every retrofit there are untold numbers of similar structures still obsolescing.

Vulnerable structure types commonly used for older commercial buildings include unreinforced masonry, non-ductile concrete frames (with or without masonry infill), precast tilt-up walls, precast (and sometimes post-tensioned) parking structures, and to a lesser degree, welded steel moment frames and braced frames of the types whose flaws were exposed by the Northridge earthquake.

As discussed above, the city's 1250 or so commercial unreinforced masonry buildings have largely been improved as required by ordinance, but only to the extent that they will probably not kill anyone. Otherwise, because of the structural variation and because no reliable inventories exist, it is difficult to make an assessment of the commercial building stock beyond the estimates produced by the CAPSS study.

**Recommended Mitigation:**

- For commercial buildings, the emphasis should be on collapse prevention to limit response demands and on damage control to limit job loss and speed recovery.
- Develop a retrofit program for critical non-ductile concrete buildings, starting with inventory of pre-1980 concrete structures of all occupancies.
- Continue to encourage building occupancy resumption programs with outreach to small businesses.
- Develop incentives for recovery-critical non-structural risk reduction, such as bracing of HVAC, power, water, and sewer components.

## REFERENCES

Association of Bay Area Governments (ABAG), "Taming Natural Disasters: Multi-Jurisdictional Local Government Hazard Mitigation Plan for the San Francisco Bay Area," March 17, 2005.

Applied Technology Council (ATC), "San Francisco's Earthquake Risk: Report on Potential Earthquake Impacts in San Francisco," prepared for the San Francisco Department of Building Inspection, Community Action Plan for Seismic Safety (CAPSS), March 1, 2005 (draft).

Bello, M. et al., "San Francisco Bay Area fire stations – Seismic risk assessment," in *Managing Risk in Earthquake Country* (Proceedings of the 100th Anniversary Earthquake Conference, April 18-22, 2006, San Francisco.

City and County of San Francisco, "All-Hazards Strategic Plan," 2008. Available at http://www.sfgov.org/site/uploadedfiles/oes/StrategicPlan2008.pdf.

City and County of San Francisco, "Earthquake Response Plan Enhancement," September 22, 2006 (Administrative draft, version 1.0). Available at http://www.sfgov.org/site/oes_index.asp?id=27514.

City and County of San Francisco, "Emergency Operations Plan, Part I: Basic Plan," January 2005.

City and County of San Francisco, "Emergency Response Plan: An element of the CCSF Emergency Management Program," April 2008. Available at http://www.sfgov.org/site/oes_index.asp?id=27514.

City and County of San Francisco, "Draft Hazard Mitigation Plan," prepared by URS Corporation, undated, posted September 5, 2008 at http://www.sfgov.org/site/oes_index.asp.

Code Advisory Committee, Department of Building Inspection, City and County of San Francisco, "Policy Statement: San Franciscans have the right to occupy buildings that will not collapse in future earthquakes," November 16, 2005.

Contra Costa County Board of Supervisors, "Ordinance No. 2000-11: Gas Shut-off Devices," 2000.

Department of General Services, "Seismic Safety Inventory of California Public Schools," November 15, 2002.

Earthquake Engineering Research Institute – Northern California Chapter, "Bay Area Best Practices in Earthquake Risk Reduction." Unpublished html document, April 2006.

Governor's Office of Emergency Services (OES), "State of California Multi-Hazard Mitigation Plan," October 2007.

Harris, Stephen K. and Egan, John A., "Effects of Ground Conditions on the Damage to Four-Story Corner Apartment Buildings," in *The Loma Prieta, California, Earthquake of October 17, 1989—Marina District* (U.S. Geological Survey Professional Paper 1551-F), Thomas D. O'Rourke, editor, United States Government Printing Office, Washington, 1992.

Newsom, Gavin, "Seismic Strengthening of Soft Story Buildings" (Executive Directive 08-07), Office of the Mayor, City and County of San Francisco, July 7, 2008. Available at http://www.sfgov.org/site/dbi_page.asp?id=84080.

Recht Hausrath & Associates, Seismic Retrofitting Alternatives for San Francisco's Unreinforced Masonry Buildings: Socioeconomic and Land Use Implications of Alternative Requirements, Prepared for the San Francisco Department of City Planning, October 1990.

Selna, Robert, "S.F. to check 12 schools' seismic safety," San Francisco Chronicle (www.sfgate.com), August 24, 2008.

Selna, Robert, "S.F. 'soft-story' buildings at risk in quake," San Francisco Chronicle (www.sfgate.com), December 11, 2008.

SPUR Hazard Mitigation Task Force, "The Resilient City: Defining What San Francisco Needs from its Seismic Mitigation Policies," March 1st, 2009 (www.spur.org)

Strange, Kim, "Information Bulletin 2005-02 (SHL)", Department of Housing and Community Development, Division of Codes and Standards, March 21, 2005.

Van Derbeken, Jaxon, "S.F. Hall of Justice – a 'shameful' danger," *San Francisco Chronicle*, October 24, 2005.

Vannucchi, James M., "Preparation for Major Earthquake of the San Francisco Fire Department – Then & Now," United States Senate, Subcommittee on Disaster Prevention and Prediction, Senate Committee on Commerce, Science and Transportation, April 18, 2006.

# SEISMICALLY VULNERABLE STRUCTURES:

## AN ENGINEER'S ROGUES GALLERY

The science of earthquake-resistant design is only about 50 years old, and as a young discipline, it still grows in spurts after each damaging event. Just as unreinforced brick buildings were recognized as widespread hazards in the 1930s, certain newer building types, including structures of all sizes and materials, are now known to be vulnerable.


**Unreinforced masonry bearing wall.** These brick and mortar buildings have been killing people in California earthquakes since the Gold Rush. Often called "URM," unreinforced masonry was outlawed after the 1933 Long Beach earthquake, but thousands of older buildings remained. The most common hazard involves unbraced parapets falling onto sidewalks and peeling the upper walls away from the roof. San Francisco adopted a parapet ordinance in 1969, but parapets are not the whole problem. In 1986, state legislation required jurisdictions in high seismic zones to adopt mitigation measures. San Francisco's URM ordinance was adopted after the Loma Prieta earthquake.

**Soft-story woodframe.** An abundance of wall openings in the first story, typically for garage bays or storefront windows, makes these buildings vulnerable to collapse as the flexible first story sways sideways. This class includes post-World War II apartment buildings with "tuckunder" parking as well as older buildings with garage doors instead of open stalls. Many of San Francisco's soft story buildings are further complicated by hillside conditions and by extensive openings along more than one side.

**House over garage.** This is the smaller, single-family version of the soft story problem. Outside San Francisco, the HOG is often a ranch house with a two-car garage. Here, we have a handful of older prototypes numbering in the tens of thousands, block after block throughout the Richmond and Sunset Districts. On a 25-foot lot there is usually enough wall area, even with a garage opening and a wide main entrance, to accommodate a decent retrofit sufficient to stiffen the structure, preventing collapse and, more important, maintaining habitability.

**Non-ductile concrete frame.** Ductility is the property that allows a structure to bend without breaking. In concrete, it's achieved by careful design of the embedded steel reinforcing bars – a lesson learned from the collapse of several relatively new concrete buildings in the 1971 San Fernando earthquake. Most pre-1980 concrete structures are therefore suspect, but it's unclear how many should be considered potential killers. Unlike URM or soft story buildings, NDC structures are hard to spot from the sidewalk, and their evaluation and retrofit can require relatively sophisticated engineering.

**Tilt-up.** Relatively cheap and fast to build, tilt-ups remain the structural system of choice for one-story warehouses, strip malls, and light industrial facilities. The chief deficiency in pre-1995 tilt-ups is the connection between the rigid walls and the flexible roof. When that connection fails, the concrete wall panel falls away from the building, and the roof collapses. Similar buildings with reinforced concrete block walls often have the same vulnerability.

**Cripple wall.** The cripple wall is the short wood stud wall around a house's crawl space. With no stiff plaster finishes or room partitions in the crawl space, the perimeter cripple walls are inadequate to support the swaying house above. Like a soft story, the cripple walls lean, then fall over. Though rarely life-threatening, a cripple wall collapse displaces a family and destroys its chief economic asset. Cripple walls are easily and effectively retrofitted by adding plywood sheathing inside the crawl space.

**Nonstructural components.** Any part of a building that's heavy, brittle, or loosely attached, even if it carries no structural loads, is vulnerable to earthquake damage. The heavy parts – chimneys, brick veneer, concrete cladding panels – can be life threatening. The gas lines and gas-fired equipment can start fires. The rest – light fixtures, plumbing and sprinkler lines, HVAC equipment, shelving, and so on – can take a building out of service, disrupting operations and delaying recovery.