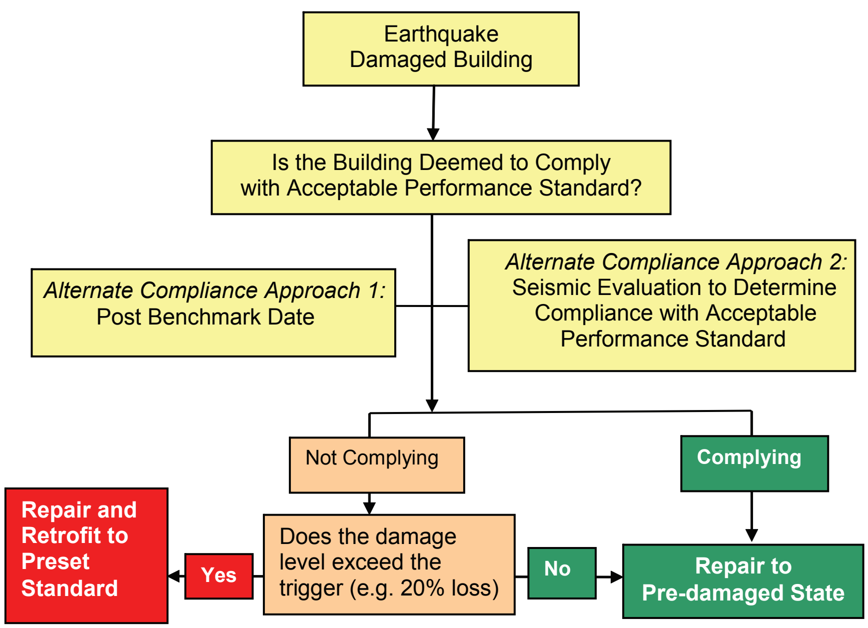
ATC 52-4

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

Post-Earthquake Repair and Retrofit Requirements



Applied Technology Council

Prepared for
San Francisco Department of Building Inspection
under the Community Action Plan for Seismic Safety (CAPSS) Project

Community Action Plan for Seismic Safety (CAPSS) Project

The Community Action Plan for Seismic Safety (CAPSS) project of the San Francisco Department of Building Inspection (DBI) was created to provide DBI and other City agencies and policymakers with a plan of action or policy road map to reduce earthquake risks in existing, privately-owned buildings that are regulated by the Department, and also to develop repair and rebuilding guidelines that will expedite recovery after an earthquake. Risk reduction activities will only be implemented and will only succeed if they make sense financially, culturally and politically, and are based on technically sound information. CAPSS engaged community leaders, earth scientists, social scientists, economists, tenants, building owners, and engineers to find out which mitigation approaches make sense in all of these ways and could, therefore, be good public policy.

The CAPSS project was carried out by the Applied Technology Council (ATC), a nonprofit organization founded to develop and promote state-of-the-art, user-friendly engineering resources and applications to mitigate the effects of natural and other hazards on the built environment. Early phases of the CAPSS project, which commenced in 2000, involved planning and conducting an initial earthquake impacts study. The final phase of work, which is described and documented in the report series, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco*, began in April of 2008 and was completed at the end of 2010.

This CAPSS Report, designated by the Applied Technology Council as the ATC-52-4 Report, recommends clarifications as to how owners should repair and strengthen their damaged buildings after an earthquake. Several other CAPSS reports are also available in the series, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco*:

- *Potential Earthquake Impacts* (ATC-52-1 Report), which focuses on estimating impacts to the City's privately owned buildings in future earthquakes, and the companion *Technical Documentation* volume (ATC-52-1A Report), which contains descriptions of the technical analyses that were conducted to produce the earthquake impacts;
- *A Community Action Plan for Seismic Safety* (ATC-52-2 Report), which recommends policies to reduce earthquake risk in privately owned buildings of all types; and
- *Earthquake Safety for Soft-Story Buildings* (ATC-52-3 Report), which describes the risk of one vulnerable building type and recommends policies to reduce that risk, and the companion *Documentation Appendices* volume (ATC-52-3A Report), which details the technical methods and data used to develop the policy recommendations and related analyses.

Many public and private organizations are working actively to improve the City's earthquake resilience. The CAPSS project participants cooperated with these organizations and considered these efforts while developing the materials in this report. Three ongoing projects outside of CAPSS but directly related to this effort are:

- *The Safety Element.* The City's Planning Department is currently revising the Safety Element of the General Plan, which lays out broad earthquake risk policies for the City.
- *The SPUR Resilient City Initiative*. San Francisco Planning and Urban Research (SPUR) published recommendations in February 2009 for how San Francisco can reduce impacts from major earthquakes. SPUR is currently developing recommendations on Emergency Response and Post-Earthquake Recovery.
- *Resilient SF.* San Francisco City government is leading a unique, internationally recognized, citywide initiative that encompasses the City's All Hazards Strategic Plan and seeks to use comprehensive advanced planning to accelerate post-disaster recovery. This work is coordinated by San Francisco's General Services Agency (GSA), the Department of Emergency Management (DEM) and Office of the Controller in collaboration with the Harvard Kennedy School of Government.

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Cover illustration: Flow chart of typical post-earthquake repair/retrofit process.

ATC-52-4

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

Post-Earthquake Repair and Retrofit Requirements

Prepared for the

DEPARTMENT OF BUILDING INSPECTION (DBI)
CITY AND COUNTY OF SAN FRANCISCO
under the Community Action Plan for Seismic Safety (CAPSS) Project

Prepared by the

APPLIED TECHNOLOGY COUNCIL (ATC)
201 Redwood Shores Parkway, Suite 240
Redwood City, California

PROJECT LEADERSHIP
Vivian L. Day, Chief Building Official, DBI Director
Laurence Kornfield, DBI Project Officer
Christopher Rojahn, ATC Project Principal
L. Thomas Tobin, ATC Co-Project Manager
Laura Samant, ATC Co-Project Manager

PROJECT CONSULTANTS
William T. Holmes, Lead
David Bonowitz
Bret Lizundia

PROJECT ENGINEERING PANEL
Roger Borcherdt
Patrick Buscovich*
Richard Eisner
Stephanie King
Jack Moehle
Chris Poland

*ATC Board Representative

2010

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DEPARTMENT OF BUILDING INSPECTION STAFF PARTICIPANTS

Pamela A. Levin, Deputy Director, Administrative Services
William Strawn, Communications Officer
Sylvia Thai, Administrative Support
Hanson Tom, Principal Engineer

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Katia Taipale
Michael Theriault
Stephen Tobriner
Dawn Trennert
Brook Turner
Fred Turner
Art VanBeek
Paul VanderMarck
Kay Vasilyeva
Rene Vignos
Kimberly Walsh
Paul Wermer
George Williams

PREFACE

The need for clear post-earthquake building repair and retrofit standards became evident in San Francisco in the aftermath of the 1989 Loma Prieta earthquake, following which many buildings sat damaged for months or longer. Owners, lenders, insurers, and governmental agencies wrestled with the many ways in which code provisions regarding building damage could be analyzed and interpreted.

This important part of San Francisco's Community Action Plan for Seismic Safety (CAPSS) provides a methodology for bringing clarity and consistency to the interpretation of code provisions regarding earthquake damage repair and retrofit, applying accepted guidelines and building on much previous work in the field. These proposals take a further giant step forward by proposing an important hazard mitigation policy, requiring the retrofit of buildings that suffer unexpected damage in small earthquakes, damage that indicates that the buildings would be unacceptably severely damaged in moderate and intense earthquakes.

The City and County of San Francisco and other jurisdictions will reap the benefits of the extensive community outreach, technical study, and creative problem solving that have led to these important CAPSS recommendations.

Laurence Kornfield (CAPSS Project Officer)
Deputy Director for Permit Services
Department of Building Inspection

EXECUTIVE SUMMARY

This report contains the conclusions and recommendations resulting from the effort to develop post-earthquake repair and retrofit requirements under the Community Action Plan for Seismic Safety Project (CAPSS) project of the Department of Building Inspection (DBI) of the City and County of San Francisco. The intent was not to change existing standards significantly, but to clarify post-earthquake repair and retrofit provisions primarily for the purpose of avoiding delays and disputes about whether a damaged building should be repaired or retrofitted. A secondary purpose was to enable implementation of a mitigation policy, based on damage patterns from actual ground motions.

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

This report makes a number of recommendations to improve San Francisco's post-earthquake repair provisions. The key recommendations in this report are the following:

- **The level of damage for which buildings should be required to be retrofitted should be clarified.** This report presents a new, clear method to determine which earthquake-damaged buildings should be required to be retrofitted after a damaging earthquake. The method is demonstrated on three example building types that represent more than 95% of all buildings in the City (ATC, 2010a*)*. The method currently in use for this purpose is challenging to calculate, produces inconsistent results, and will likely contribute to conflicts and delay in reconstruction after an earthquake.
- **Retrofit requirements should be rationalized.** This report recommends sensible retrofits that should be required for various types of damage in the three building types studied. The City's current policy would require some types of buildings to have a retrofit of the entire structure when only one component was damaged by the earthquake. Retrofit requirements following earthquakes should be consistent with retrofit requirements applicable to existing buildings before earthquakes.
- **Buildings that experience moderate damage during very low shaking should be required to be retrofitted.** All buildings should experience little to no damage in very low shaking. Those buildings that experience moderate damage in very low shaking have clear structural problems and should be improved

before a stronger earthquake strikes. Currently, the City only requires retrofit when damage is heavy and does not consider the level of shaking experienced in this determination.

San Francisco's post-earthquake repair provisions, similar to those found in the codes of other cities in high seismic zones, consist first of the definition of a group of buildings deemed to comply with the seismic performance standards of the code. For these buildings, seismic strengthening is never required, but damage must be repaired to pre-earthquake conditions. All other buildings, usually older buildings with older seismic designs (or no seismic design), are in a second group for which damage "triggers" are set that require not only repair of damage, but retrofit to improve seismic performance. The most commonly used damage trigger is the definition of a loss of strength in the lateral-force-resisting system above which retrofit is required. Currently in San Francisco, 20% or more loss of strength in any story in either horizontal direction will require retrofit. The calculation of loss of strength has proven problematic in past earthquakes, creating disputes between owners and building departments and causing delays in repairs, re-occupancy, and recovery.

This CAPSS effort included development of an overall strategy defining mitigation policy related to post-earthquake damage repair and a demonstration of implementation of that policy by developing specific post-earthquake repair provisions for three building types that are common in San Francisco.

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

Three building types were selected to demonstrate application of the proposed refinements and clarifications to post-earthquake repair provisions: (1) single-family and two-unit wood-frame residential buildings, (2) multi-unit wood-frame residential buildings, including, but not limited to soft-story wood-frame buildings, and (3) older concrete buildings, including those infilled with masonry.

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

For single-family and two-unit wood-frame residential buildings, primarily traditional single-family homes, the recommendations define damage to various elements specifically, not using percentage loss. The provisions typically require repair and retrofit only to the damaged element. For example, damage to a brick chimney requires work on the chimney but not to the rest of the house if it is not damaged. Similarly, damage to cripple walls in a typical crawl space only will require retrofit of the crawl space walls and will reference a preexisting standard,

Appendix A3 of the *International Existing Building Code* (ICC, 2009b). A document prepared for the California Earthquake Authority, *General Guidelines for the Assessment and Repair of Earthquake Damage in Residential Woodframe Buildings* (CUREE, 2007), which includes recommended repair techniques for essentially all elements of single-family dwellings, is also utilized to specify repair requirements in some cases. Disproportionate Damage triggers are included for certain damage patterns, such as significant permanent set (lateral sway) in any story.

The multi-unit wood-frame residential group includes the soft-story buildings that CAPSS has studied in other reports (ATC, 2009a,b). In addition, the Federal Emergency Management Agency (FEMA) has funded the Applied Technology Council (ATC) to develop a retrofit methodology for these buildings that will focus on optimizing overall building performance with retrofit work limited to the soft-story level (ATC-71-1 project (ATC, in preparation)). Assuming adoption of this methodology by the City of San Francisco as part of a voluntary or mandatory mitigation plan, buildings in this category damaged beyond the repair-only level will be required to comply with the ordinance. Requirements for other buildings in this category are more conventional, except triggers are based on visual damage patterns rather than percent strength loss. Disproportionate Damage triggers for several damage states are included.

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

Issues were identified that could not be resolved within the context of the CAPSS post-earthquake repair requirements developmental efforts, either because they were outside the primary purpose of this effort, or because time and resources were limited. These issues are discussed in Chapter 8. Recommendations are made to pursue development of building-specific, post-earthquake, repair standards for all common building types, but Chapter 8 outlines reasons why standards for unreinforced masonry buildings, steel braced-frame buildings, and steel moment-frame buildings should be the highest priority. In addition, it is recommended that the date currently used to define “complying buildings” in San Francisco (May 21, 1973 for all building types) be adjusted by building type to reflect the likelihood of acceptable performance. However, this represents a major change in policy by the City of San Francisco and should be studied in detail, including consideration of what dates should be used for each structural system, and economic consequences of the changes. It is also recommended that rules for mitigating site geologic hazards associated with damaged buildings also be developed.

Finally two issues completely beyond the scope of CAPSS, but nevertheless important, are identified: (1) verification of compliance with eligibility rules of the Stafford Act, and (2) clarification of rules regarding demolition of damaged buildings.

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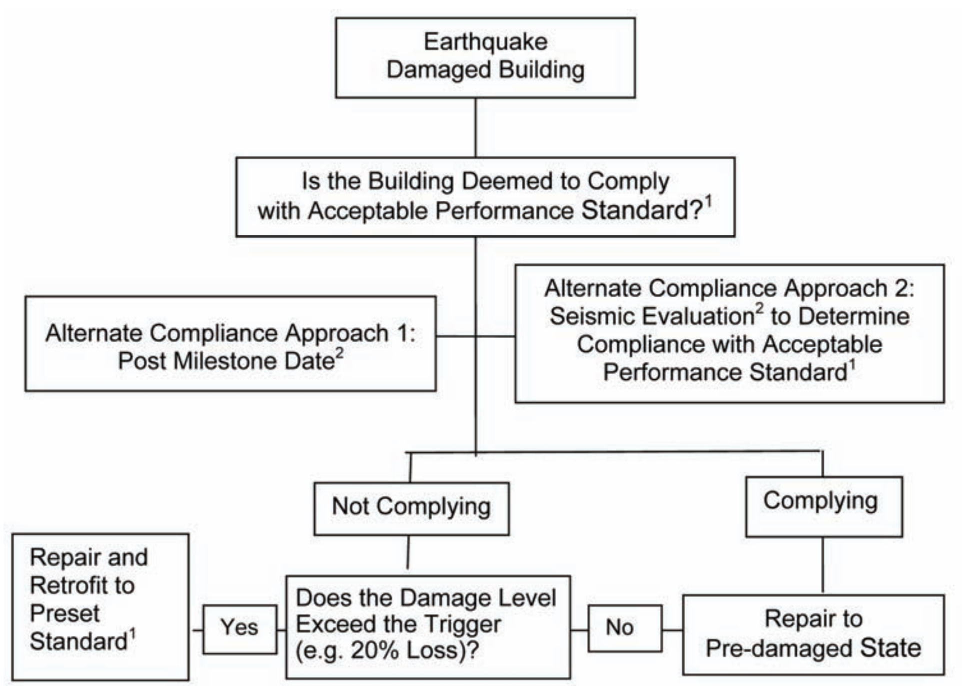
CHAPTER 1: INTRODUCTION

1.1 The Need for Formulation of Post-Earthquake Repair and Retrofit Provisions

Following a damaging earthquake, many buildings may be closed pending determination of safety and necessary repairs. A lack of clear repair standards and criteria for re-occupancy has often created controversy and extended the time that owners did not have full use of their buildings. Assuming that the earthquake itself is the ultimate test of seismic acceptability, many communities may take the opportunity in the post-earthquake period to require strengthening of buildings that are apparently seismically deficient due to their damage level. However, requiring too many buildings to be retrofitted to high standards might delay the economic recovery of the community. On the other hand, by not requiring retrofits or by allowing low standards for repair, strengthening, or both, could lead to equal or worse damage in subsequent earthquakes.

As shown in Figure 1-1, most code regulations used to date that control post-earthquake repair and/or retrofit (referred to in this report as "post-earthquake repair



Note 1. Acceptable Performance Standards may vary from jurisdiction to jurisdiction. The standard for evaluation may be different from the one used for retrofit.
Note 2. Jurisdictions may specify milestone dates for new buildings and retrofits and may use building-specific evaluation to determine state of compliance.

Figure 1-1 Flow chart of typical post-earthquake repair/retrofit process provisions") normally divide the building stock into *compliant* and *non-compliant buildings*. Compliant buildings are those judged to be adequately seismically resistant in their pre-damaged state and thus only need repair to their pre-earthquake condition. This code concept was created to avoid requiring retrofit of new or recently constructed buildings, but over the years acceptability has been extended to include all buildings thought to have seismic performance somewhat equivalent to new buildings, primarily judged by the provision of adequate life safety. The narrowest interpretation of compliance is full conformance with current code. More liberal interpretations include buildings in compliance with approved seismic life safety standards for existing buildings such as ASCE 31, *Seismic Evaluation of Existing Buildings* (ASCE, 2003), or the *International Existing Building Code* (ICC, 2009b). San Francisco defines this class of buildings to include all buildings constructed in compliance with the *San Francisco Building Code* (CCSF, 2010) after May 21, 1973—the date of a major change in the *San Francisco Building Code* (SFBC) following the San Fernando earthquake in 1971. Buildings fully retrofitted in accordance with the *San Francisco Building Code* (historically per SFBC Section 104f or in 2007 SFBC, Section 3403.5) after 1973 are also considered compliant. Typically, these buildings also are not subject to seismic retrofit triggers related to alterations or change in occupancy.

Buildings in the noncompliant class are not considered adequately seismically resistant and, if sufficiently damaged, must not only be repaired, but also must be retrofitted to a standard defined by code, often resisting 75% of the code forces for new buildings, or a similar standard developed specifically for retrofit (ICC, 2009a; ICC, 2009b). Code sections controlling post-earthquake repair and retrofit thus contain a trigger level of damage below which the building can be repaired to its original condition, but above which requires retrofit. Common damage triggers specify that the loss of lateral-load-carrying capacity due to the damage must not exceed a certain level, typically between 10% and 30%. The *San Francisco Building Code* has used a 20% loss of capacity for this trigger for about 20 years. The SFBC also has defined a retrofit standard (Section 3403.5) requiring design to 75% of code forces) and this standard is currently applicable when retrofit is required due to earthquake damage. An additional provision is that a building shown by analysis to satisfy the triggered retrofit criteria in its repaired state—that is, without additional retrofit—is considered compliant by evaluation, and is treated accordingly.

The importance of clear and enforceable post-earthquake repair provisions was recognized by the Structural Engineers Association of Northern California's (SEAONC) committee that assisted DBI in the formulation of the CAPSS project that led to CAPSS Phase 1: *Community Action Plan for Seismic Safety, City and County of San Francisco: Plan Description and Needed Services* (ATC, 2000). The understanding of this need came directly from experience in the 1989 Loma Prieta earthquake and the 1994 Northridge earthquake.

For example, in 1989, damage to the first story of several soft-story wood-frame apartment buildings in San Francisco triggered retrofit of the undamaged upper levels and after several emergency meetings of DBI and local engineers, an emergency regulation was put in place that limited repair and retrofit to the first level. In Oakland, retrofit triggers had recently been adopted that required several large marginally damaged downtown commercial buildings to be retrofitted. When the owners concluded such retrofit was not economically viable, the buildings were vacant for years, adding years to the general downtown malaise in that city.

After the Northridge earthquake in 1994, there were many disputes over the calculation of "lateral-load-carrying capacity," which is the parameter commonly used to determine when retrofit is necessary after an earthquake (and is the parameter currently in the SFBC for that purpose). The disputes were so ubiquitous that the Federal Emergency Management Agency (FEMA) funded the development of a standard methodology to calculate the lateral-load-carrying capacity of concrete and masonry wall buildings in their undamaged and damaged state (FEMA, 1999a,b).

In addition to avoiding confusion, disputes, and delays in repair or retrofit, development of more detailed post-earthquake repair standards provides an opportunity for implementation of public policy regarding mitigation of community seismic risk. Damage trigger levels can be set low for all buildings, or for targeted buildings, to require retrofits of more buildings after an earthquake. However, this mitigation requires increased costs for owners at a time that is perhaps otherwise demanding and may also delay full re-use of damaged buildings.

The CAPSS project presented a unique opportunity to obtain community, public policy, and engineering input for development of a rational post-earthquake repair and retrofit policy for the City and County of San Francisco.

1.2 Development of Post-Earthquake Repair and Retrofit Requirements

The CAPSS effort to develop post-earthquake retrofit and report requirements included three subtasks that have been addressed in this report, briefly described below.

- **Subtask 1: Develop a Strategy to Address the Repair and Retrofit of Earthquake-Damaged Buildings.** The charge for this subtask was that the strategy must consider life safety of citizens in the near term, the effect of retrofit requirements on re-occupancy time and recovery, and long-term mitigation goals. This strategy also needed to help direct the development of detailed post-earthquake repair/retrofit guidelines for various building types and uses, and consider a broad range of policy issues. The shaking in the next large earthquake generally will serve as a test that will expose the weakest buildings, or the weakest types of buildings with damage, even given the variation in earthquake ground motions in the region struck by an earthquake. If salvageable, should these buildings be repaired to their original vulnerable state? Should cost-effective improvements be included in the repairs? Should they be retrofitted to a pre-established level of safety? Should these rules be applied to all buildings or only the pre-selected vulnerable types? Should the rules vary depending on the level of ground shaking or level of damage? How should goals for the city's recovery, such as sheltering as many residents as possible in their own homes after an earthquake, influence repair and rebuilding standards? These are all policy questions that depend on the level of mitigation the City chooses to combine with repair.

  In order to select an appropriate philosophy, the City also needed to understand potential indirect ramifications, such as the availability of FEMA post-earthquake funding and societal motivation for owners to make certain decisions regarding their buildings. For this project, information required to develop the needed strategy was collected based on input from public meetings held during the project (including Advisory Committee meetings) with participants having socio-economic as well as engineering expertise.

- **Subtask 2: Place Building Types into Categories that will Define their Post-Earthquake Repair/Retrofit Requirements.** The efforts on this subtask recognized that all repair/retrofit regulations in the United States place buildings into categories to separate those that only need to be repaired from those that may be required to be retrofitted as well as being repaired. Recently constructed buildings that can meet or nearly meet current code requirements are generally required to be repaired only to original seismic capacity. On the other hand, older or clearly hazardous buildings are often required to be improved by retrofit when damaged above certain threshold values. An intermediate group is sometimes defined (for example, defined as able to meet about 75% of the strength required by new codes) that need only to be restored to their pre-earthquake condition. The application of this framework to San Francisco needed to be considered in this subtask.

  The second typical characteristic of repair/retrofit regulations that needed to be considered is the definition of a damage level, herein referred to as a "trigger," above which seismic retrofit is required in addition to repair of the damage. This trigger is currently measured as a percent loss of lateral-load-carrying capacity. The calculation of this loss is not straightforward and results are typically controversial. In addition, in order to define damage triggers more clearly so as to avoid disputes and delays in re-occupancy, post-earthquake repair and retrofit standards needed to be developed for narrow ranges of building types that will benefit from common policies and technical requirements. It was also recognized (1) that it may be advantageous to adopt different requirements for different building types; (2) that typical damage states for a given structural type can be described far more specifically than for the general building stock; and (3) that descriptions of building-specific damage states is expected to be a better parameter for retrofit triggers than the presently used percent loss of capacity.

- **Subtask 3: Development of Triggers and Guidelines for Both the Repair and Retrofit of Selected Building Types.** The charge for this subtask was to build upon the results of Subtasks 1 and 2.

  The first portion of this subtask was carried out in conjunction with, and parallel to, development of the policy decisions described in Subtask 1. A set of building types were selected for which individual repair/retrofit triggers and guidelines were outlined. The goal was to develop a clear format for such triggers and guidelines. Three building types were selected for detailed development.

  The residential wood building inventory developed for the loss estimation portion of the CAPSS project (see ATC, 2010a) was used to identify appropriate subsets expected to be particularly vulnerable, difficult to repair, economically burdened, or that simply occur in large numbers and therefore are expected to represent significant repair issues following a damaging event. Vulnerable building types of other materials that occur in large numbers (or otherwise represent significant repair issues) were also identified with the assistance of DBI and private engineers familiar with the building stock in San Francisco. In addition, building types for which significant post-earthquake evaluation and repair information is available were identified.

1.3 Organization of Report

Chapter 2 describes the development of an overall strategy for the development of post-earthquake repair and retrofit provisions for San Francisco.

Chapter 3 includes a description of significant structural building types in San Francisco and the reasons for selecting (1) single-family residential buildings, (2) multiple-unit wood-frame residential buildings, and (3) older concrete buildings as examples for development of building-specific post-earthquake repair provisions.

Recommendations pertaining to both the post-earthquake repair and retrofit of selected building types are introduced in Chapter 4, including a description of policies and implementation techniques common to all buildings. The development of post-earthquake repair provisions for the selected example building types is presented in Chapters 5, 6, and 7 for single-family residential buildings, multiple-unit wood-frame residential buildings, and older concrete buildings, respectively.

Chapter 8 contains recommendations for further study associated with post-earthquake repair provisions in San Francisco. During the completion of the overall effort to develop seismic repair and retrofit requirements, several issues have been identified that are beyond the scope of the current CAPSS program but that may be critical for an efficient DBI response to post-earthquake conditions.

CHAPTER 2: DEVELOPMENT OF AN OVERARCHING STRATEGY

2.1 Background

Initial activities to develop an overarching philosophy for post-earthquake reconstruction commenced during the last quarter of 2001 and the first quarter of 2002 (in an earlier stage of the project). These activities included interviews with FEMA and 17 other jurisdictions to obtain information to assist the City in understanding the potential indirect ramifications of various philosophy options. The interviews yielded information regarding written policy and requirements, and related information. California jurisdictions interviewed included: the City of Alameda, City of Anaheim, City of Berkeley, City of Emeryville, City of Menlo Park, City of Oakland, City of Sacramento, City of San Diego, City of San Jose, City of Santa Ana, City of Santa Barbara, City of Santa Cruz, City of Walnut Creek, County of Contra Costa, and County of San Mateo. Other interviewees included the cities of Portland, Oregon, and Seattle, Washington.

During the second quarter of 2002, the full project Advisory Committee and other stakeholders participated in a targeted workshop that provided useful policy direction. The results of interviews and the potential for building-type specific post-earthquake policies were discussed, but an overarching philosophy or repair strategy was not defined. However, the workshop highlighted the difficulty of defining a single such policy, and discussions at the workshop identified specific issues that would affect post-earthquake policies.

Following a several-year project hiatus during which there was no activity on the project, the issues identified in 2002 were re-introduced to the Advisory Committee in March, 2009. The project team then developed resolutions to the issues that, when considered together, would form the overall strategy needed to develop building-specific, post-earthquake, repair provisions. The resolutions to the issues were developed considering the following input:

- Discussions at the Advisory Committee meeting in March, 2009;
- National code changes in the area of post-earthquake repair requirements that were put in place since 2002;
- The growing interest in seismic deficiencies of soft-story wood-frame residential buildings, particularly in the San Francisco Bay Area;
- A national focus on *community resiliency*, as indicated by the vision contained in the *Strategic Plan for the National Earthquake Hazards Reduction Program, 2009-2013* (NEHRP, 2008), namely,

  > "A nation that is earthquake-resilient in public safety, economic strength, and national security";

- A local focus on the need for resiliency generated by a report on *The Resilient City* by the San Francisco Planning and Urban Research Association (SPUR, 2009); and
- A report to the City from the Structural Engineers Association of Northern California's SFBC Structural Damage Repair Study Group (SEAONC, 2008), on potential short-term improvements to the post-earthquake repair provisions.

2.2 Resolution of Issues

The issues associated with development of post-earthquake repair provisions are listed below, along with the resolutions for the CAPSS project.

Issue 1: What overarching strategy should be used for San Francisco's post-earthquake repair provisions?

Engineers, building officials, contractors, architects and owners are generally reluctant just to repair a building that appears to be exceptionally vulnerable in its "original conditions." In addition, assuming that the earthquake itself is the ultimate test of seismic acceptability, policy makers see an opportunity in the post-earthquake period to require strengthening of buildings that are apparently seismically deficient due to their high damage level relative to other buildings. These trends have created the code format of including a damage trigger to identify when repair is not allowed and retrofit is required. It is not clear how the triggers previously have been set with regard to public policy. Implementation of a "low" trigger that is likely to require many retrofits may delay the economic recovery of the community. Not requiring retrofitting, or allowing use of weak retrofit or repair requirements, could lead to equal or worse damage in the next earthquake.

Discussions in the earlier stages of the CAPSS project indicated difficulty in setting an overarching public policy (that might lead to either many or only a few retrofits) that appropriately applies to all buildings considering the various structural, occupancy, economic, and neighborhood characteristics. However, it became clear that the CAPSS program was recommending that a consistent path be followed to improve the seismic performance of all older buildings in San Francisco through triggers set for renovation as well as for damage and from voluntary and mandatory ordinances.

Recent SPUR initiatives identifying the importance of *resilience* add a new parameter to this public policy decision by emphasizing the importance of rapid reoccupancy of buildings, particularly residential buildings. In some cases, if a retrofit is triggered by damage, the building cannot be fully occupied until the retrofit is complete, potentially causing delays in neighborhood or city-wide recovery. However, as discussed above, there always must be a balance between rapid recovery in a given event and prudent preparation for the next event.

> ***Resolution:*** *The most general guidance to consider for developing post-earthquake repair provisions is to improve community resilience. However, more specific guidance leading to development of detailed policy and engineering criteria is created when the resolution of all the issues is considered together. This guidance should be used for developing post-earthquake repair provisions for the example buildings in this project. (See also Chapter 4 of this report.)*

Issue 2: Are different rules for different building types appropriate? Which ones are special and why?

Resilience issues are important when considering all buildings, but may apply to residential buildings differently from how they apply to commercial buildings. Buildings owned by, for example, public-service-oriented, non-profit organizations, schools, and hospitals, may also need special consideration.

> ***Resolution**: In San Francisco, different post-earthquake repair provisions should be developed for different building types and uses in order to reflect differing policy goals. For example, although retrofit triggers generally apply to retrofit of structures as a whole, retrofit of an entire single-family dwelling may seldom be appropriate or needed for safety, and may delay full re-occupancy and thus contribute to reduced community resilience.*

Issue 3: Does the percent loss trigger for retrofit need clarification?

Retrofit triggers generally have been described as percentage losses to the lateral system caused by damage. The lack of a standard method of calculating such losses, particularly in older buildings that may not have a well-defined lateral system, have caused disputes and delays in corrective action in past earthquakes. During the CAPSS project, a system was discussed that used more readily recognized damage states to establish retrofit triggers. Each structural type would have characteristic progressive damage states, and triggers could be identified in that way. This system would require identification of damage states for every significant non-complying building type. In addition, different triggers could be used for different levels of ground shaking. Recent advances in rapid mapping of ground shaking intensities after earthquakes will facilitate such consideration. An example of such a building-specific standard is shown below for a sample building type. The damage levels of Slight, Moderate, and Extensive would be described in terms of visual damage patterns rather than hard-line numbers describing loss of capacity.

Table 2-1 Illustration of the Concept of Retrofit Triggers Dependent on Ground Motion

Post-earthquake Reoccupancy Requirements: Sample Building			
	Damage levels		
Shaking Intensity	Slight	Moderate	Extensive
<0.2g	Repair	Strengthen	Strengthen
0.2-0.4g	Repair	Strengthen	Strengthen
>0.4g	Repair	Repair	Strengthen

If a single policy standard was to be used for all building types, it would only be necessary to identify and describe the damage levels of Slight, Moderate, Extensive (or some other defined level, as appropriate). If different policies for different buildings were desirable, a new table as well as damage descriptions would be necessary for each building judged as having seismic problems.

> ***Resolution**: When separate guidelines are developed for specific building types, the extent-of-damage measure used to trigger retrofit should be as clear and specific as possible. Calculation methods largely based on judgment should be avoided.*

Issue 4: Should the level of ground shaking be considered?

In general, the severity of earthquake damage will vary with the intensity of the shaking at the site. However, for any specific building, this trend may not be apparent due to the specific characteristics of the building or the shaking. Under traditional code retrofit triggering rules, a non-complying building suffering 20% loss of lateral load capacity (or however the local trigger is defined) in any ground motion requires retrofit in addition to repair. It therefore has been suggested that the damage level for triggering retrofit should be lower for low intensity shaking and higher for high intensity shaking.

> ***Resolution:*** *When separate guidelines are developed for specific building types, the intensity of ground motion of the site should be considered for the purpose of setting triggers for retrofit. The concept of Disproportionate Damage has been introduced (in this report) to respond to this issue.*

Issue 5: Should partial or delayed retrofit requirements be considered for some building types?

Considering the objective to contribute to resilience, policies should be considered that would require retrofit in a certain time period with continued occupancy, if a building can be judged safe for likely short-term repeat events, such as aftershocks. This type of policy has not been previously implemented and would require technical judgments concerning interim safety.

> ***Resolution:*** *If retrofit triggers are set at low levels of damage such that immediate re-occupancy (green tag*[1] *and some yellow tags*[2]*) is possible, delayed timelines for retrofit should be considered to facilitate community economic recovery.*

Issue 6: Should the definition of Complying Buildings in San Francisco (SFBC Section 104(f) or current Section 3403.5) be changed?

The *San Francisco Building Code* now "grandfathers" all buildings permitted after 1973, and all retrofits complying with the principles of 104(f) strengthening. National seismic evaluation standards do not accept all structural systems of this age. Should the SFBC change this long-standing policy and require not only repair, but retrofit for some of these older buildings? The California Health and Safety code (Section 19161) uses January 1, 1978 as a date to define potentially hazardous soft-story wood buildings. Early 104(f) retrofits are also suspect due to lack of consensus retrofit standards and techniques, and a repair to the original design code may be inappropriate for this case. On the other hand, UMBs (unreinforced masonry buildings, also known as URMs) retrofitted to the minimum requirements of the full San Francisco ordinance or to the lower Bolts-Plus standard, do not comply with 104(f) and high damage levels would theoretically require retrofit beyond the original work. For UMBs that do not meet full 104(f), a requirement to "re-retrofit" might violate state law that prevents requiring additional retrofitting for 15 years after an initial retrofit (Section 19166 of the Health and Safety Code), although both the

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[1] Green "INSPECTED posting placard, as prescribed, for example, in ATC-20-1 *Field Manual: Postearthquake Safety Evaluation of Buildings* (ATC, 2005).

[2] Yellow RESTRICTED USE posting placard , as prescribed, for example, in ATC-20-1 *Field Manual: Postearthquake Safety Evaluation of Buildings* (ATC, 2005).

initial retrofit and the "re-retrofit" must have certain characteristics for this exemption to be applicable.

> ***Resolution****: A change to the cut-off date for "complying buildings" in San Francisco could potentially affect hundreds, if not thousands, of buildings and put them at risk of triggering a retrofit to updated standards rather than merely repair. Significantly increasing the number of buildings that require retrofit after the next event may contribute to increased resilience for the following event at the cost of slower recovery for this one. Such a redefinition of "complying buildings" would also affect alteration and change-of-occupancy triggers, potentially slowing redevelopment and renovation in the City. Although the Milestone Table 3-1 of ASCE 31 (ASCE, 2003) provides guidance for more appropriate cut-off codes for most building types, it is not necessarily accurate for all building types in San Francisco and does not cover retrofitted buildings at all. However, additional study beyond this report is needed before an all-encompassing alternative definition can be recommended. Changes in this definition are not included for the example building types in Chapters 5, 6 and 7, and, in fact, are probably not appropriate for these particular building types. (See also the discussion in Chapter 8 of this report.)*

Issue 7: Should FEMA eligibility for reimbursement of repair costs for government buildings be considered?

In 2007, it was clear that the CAPSS recommendations pertaining to post-earthquake repair and retrofit requirements would not be available for some time and a volunteer committee was formed by the Structural Engineers Association of Northern California to study potential short-term improvements to the *San Francisco Building Code* earthquake damage repair standards. Much of the following information comes from their report, *Report and Recommendations of the SEAONC SFBC Structural Damage Repair Study Group* (SEAONC, 2008).

The question of FEMA "eligibility" is confined to repair of eligible buildings (government and certain private non-profit) and is further limited to only those cases where upgrade above the pre-disaster condition is proposed. FEMA Disaster Assistance Policy 9527.4 covers requirements for Construction Codes and Standards in its Appendix A.

FEMA's five-point criteria used to determine eligibility for local repair or replacement standards indicate that repair standards must:

1. apply to the type of repair or restoration required (standards may be different for new construction and repair work);
2. be appropriate to the pre-disaster use of the facility;
3. be found reasonable, in writing, and formally adopted and implemented, by the state or local government, on or before the disaster declaration date, or be a legal federal requirement applicable to the type of restoration;
4. apply uniformly to all similar types of facilities within the jurisdiction of the owner of the facility; and,
5. for any standard in effect at the time of a disaster, it must have been enforced during the time it was in effect.

Determination of compliance with the five-point criteria is legally complex and was considered beyond the scope of this study, although a general understanding of the issues was considered useful. Item 4 is particularly difficult to interpret. The FEMA response to a recent California Building Officials (CALBO) proposal indicates concerns whether "the ordinance, as currently drafted, applies to all voluntary work, including repairs, alterations and additions to damaged and undamaged buildings." Documents related to an appeal resulting from a recent earthquake near San Simeon, California, suggest a very broad interpretation by FEMA of "apply uniformly." Referring to a previous case of Royce Hall at the University of California, Los Angeles, (UCLA) as a precedent, the appeal document states, "The standard did not apply uniformly to all similar types of facilities in that it did not require seismic mitigation whenever the university committed its resources to the renovation of buildings generally and to the rehabilitation of buildings damaged by causes other than an earthquake." On the other hand, FEMA Disaster Assistance Policy 9527.4 has the following description of the fourth criterion:

> "4. Apply uniformly to all similar types of facilities within the jurisdiction of the owner of the facility.
>
> a. Code provisions must apply to all similar types and classifications of facilities regardless of the entity that owns the facility. This includes all facilities, private and public, eligible and ineligible for FEMA assistance, in the entire governmental jurisdiction or in a particular hazard zone within that jurisdiction.
>
> b. The phrase "similar types and classifications of facilities" refers to the type of use (e.g., hospitals, schools), or type of structural system (e.g., unreinforced masonry, steel-moment frame).
>
> c. In order for FEMA to find that a code and its thresholds are uniformly applied, the threshold provision(s) must generally be triggered by the repair or restoration of facilities damaged from any cause, regardless of type, as well as the renovation of buildings. Code upgrade thresholds that only apply to upgrade work as the result of earthquake-inflicted damage will be evaluated on a case-by-case basis to determine if they meet the five criteria including, specifically, criteria 3 and 5."

The last sentence of Item 4 c. (above) appears to allow triggers applicable only to earthquake damage in certain circumstances.

This issue is important because the SEAONC Study Group recommended that a unique trigger be used for damage from earthquake and wind. This recommendation was in response to reports that uniform application of a single trigger for all types of damage has in the past often produced unreasonable requirements leading to uneven enforcement and un-permitted repair. For example, a homeowner wanting to repair termite damage may trigger a seismic retrofit of their entire house, discouraging the repair work altogether or resulting in the work being done without a permit.

> ***Resolution:*** *It is beyond the scope of the CAPSS project to make a compliance determination or to propose legal interpretations of FEMA policies. CAPSS efforts to develop post-earthquake repair provisions that will reduce disputes and delays and promote resilience should, insofar as*

possible, be in accord with the common understanding of FEMA policies and their intent. (See also the discussion in Chapter 8 of this report.)

Issue 8: Can San Francisco modify the *California Building Code* (CBC) with respect to post-earthquake repair provisions?

When the CAPSS project started, the *California Building Code* (including the 2007 CBC) did not include post-earthquake damage retrofit triggers for privately owned buildings. The 2010 CBC has adopted triggers for all buildings and San Francisco theoretically is not permitted to be more lenient. The CBC includes triggers based on percent loss of strength, and CAPSS is recommending using predefined damage states for specific building types. Direct comparison to establish if the change is more or less stringent may be difficult. Enforcement procedures for these rules are also unclear.

> ***Resolution**: Local jurisdictions have authority to modify state code requirements in accordance with Health and Safety Code Section 17958. Local findings must be developed to substantiate that amendments meet such State requirements. In general, the recommendations of this report provide alternative methods of complying with the California Building Code(CBC) requirements, providing both clarification and detail of post-earthquake repair procedures. In addition to not considering local issues, the CBC will likely continue to use percent loss triggers without clarification, and, in addition, the triggers are subject to change each code cycle. As currently proposed, the 2012 International Building Code will change the retrofit trigger from 20% loss to 33% loss. It is unclear if the State of California will accept this relaxation and may choose to keep the trigger at 20%. A well thought out, rational and consistent policy in San Francisco would appear superior to State requirements and therefore may be found acceptable.*

CHAPTER 3: SELECTION OF EXAMPLE BUILDING TYPES

The selection of example building types for which post-earthquake repair and retrofit requirements would be developed (by the CAPSS project team) involved consideration of the following criteria/issues: importance of the building type to post-earthquake response and recovery, potential difficulties with evaluation of damage using traditional triggers, and available data describing typical damage states. All "non-complying" building types under the jurisdiction of the Department of Building Inspection were initially considered for potential selection, because only those building types are susceptible to mandated retrofit due to earthquake damage. Ultimately three example building types, comprising 95% of all buildings in the City of San Francisco, were selected.

3.1 Common Building Types in San Francisco

Predominant building types in the City of San Francisco were initially identified using results from the CAPSS earthquake impacts assessment, as documented in the companion report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts (ATC, 2010a).* The impacts assessment effort consisted primarily of a citywide loss estimate performed using the FEMA standardized earthquake loss estimation methodology, HAZUS (FEMA, 2002). More detailed inventory was developed for the most predominant structural type (wood frame), including single-family dwellings and multi-unit apartment and condominium buildings, particularly considering the presence of soft first stories created by garages or commercial spaces. Other input used to define the San Francisco building stock came from expert members of the CAPSS project team who developed the impact estimates and the CAPSS Advisory Committee.

Additional information concerning predominant building types in San Francisco was also available from the regional loss estimate performed for the Special Issue of EERI's *Earthquake Spectra:* "The 1906 San Francisco Earthquake: An Earthquake Engineering Retrospective 100 Years Later" (EERI, 2006). In addition, the CAPSS project team responsible for developing the post-earthquake repair and retrofit requirements (this report) provided input concerning the building inventory in San Francisco.

3.2 Selection of Example Building Types to be used for Development of Post-Earthquake Repair Provisions

The process for selecting example building types to be used for development and demonstration of recommended post-earthquake repair provisions involved the consideration of building type importance, availability of damage state descriptions, and other potential issues of concern. The data and information developed and evaluated during this process are documented in Table 3-1.

Table 3-1 Information Considered During the Selection of Example Non-Complying Building Types for Which Post-Earthquake Repair Provisions Would be Developed

Buildings Type	Formal Definition (Non-Compliance with SFBC[1] 3403.5 Assumed)	Importance	Sources for Damage State Information	Potential Issues
One- and Two-Family Residential Wood-Frame Buildings	Wood frame, 2-unit flats, and duplexes	Important for post-earthquake re-occupancy; large number of buildings.	CUREE EDA-02 (CUREE, 2007)	Multiple damage states? Repair requirements controversial in past.
Wood-Frame Residential Buildings with More Than Two Units	All wood-frame residential with long-term occupancy except medical or special needs occupancies. Soft-story and non-soft-story.	Important for post-earthquake re-occupancy; large number of units.	CUREE-Cal Tech Wood frame project reports[2]; NEESwood[3]; ATC-71-1 (ATC, in preparation)	Possible need to break out soft stories from remainder of inventory?
Subcategories of Residential Wood-Frame Buildings (buildings with soft stories, varying number of stories and units)	"Soft story" but needing some definition of the condition.	Important for post-earthquake re-occupancy; highly vulnerable	CUREE-Cal Tech Wood frame project reports [2]; NEESwood[3]; ATC-71-1 (ATC, in preparation)	Coordinate with ongoing ATC-71-1 Project (ATC, in preparation) as well as development of San Francisco Ordinance; need to define "soft story."
Older Concrete Buildings	Concrete buildings, including those with frames, walls and masonry infill	Some are highly vulnerable to collapse; high interest due to current research.	FEMA 306[4], PEER Grand Challenge Project[5]; Concrete Coalition (Comartin et al., 2008)	Multiple damage states; separate by different types?
Concrete Frame Buildings with Masonry Infill	Structural type not related to occupancy.	Unknown number, perhaps many multi-unit residential	UCSD NEESR Project[6], LA City Voluntary Ordinance[7]	Rationale for separation from other concrete buildings?
Steel Frame Buildings with Masonry Infill	Structural type not related to occupancy	25 pre 1906 (see EERI, 2006); probably more built between 1906-1933	UCSD NEESR Project[6]	Arguably, not much of a risk; possible environmental degradation of masonry, steel
Steel Moment-Frame Buildings	Moment frames with explicit seismic design and moment resisting connections.	Typically large commercial buildings containing many businesses; retrofit, if triggered, has important economic consequences.	SAC Joint Venture (FEMA, 2000b)	Damage to cladding; rules for older frames with bolted, riveted connections?
Steel Moment Frame Buildings	Compliant with 3403.5 but pre-1994 *Uniform Building Code* Emergency Provisions	A significant proportion of square footage may be in this category.	SAC Joint Venture (FEMA, 2000b)	Would require revision to venerable "grandfather" date in 1973.
Steel Braced Frame Buildings	Buildings with primary seismic systems consisting of steel braced frames	Excluding post-1973 retrofits, probably not a large number.	NIST follow-up studies to FEMA P695[8].	Little or no research on older braced frame detailing.

Table 3-1 Information Considered During the Selection of Example Non-Complying Building Types for Which Post-Earthquake Repair Provisions Would be Developed (continued)

Buildings Type	Formal Definition (Non-compliance with SFBC[1] 3403.5 assumed)	Importance	Sources for Damage State Information	Potential Issues
Steel Braced Frame Buildings	Compliant with 3403 but pre-1988 *Uniform Building Code* (including retrofits).	Need to address older braced frame non-ductile detailing, including thin walls and connections.	NIST follow-up studies to FEMA P695[8].	Limit to brace damage if no excess drift? If excess drift, retrofit all buildings? Would require revision to venerable "grandfather" date of 1973.
Unreinforced Masonry Buildings (UMBs)	Non compliant with UMB Ordinance	Bring existing noncompliance into focus and achieve mitigation	FEMA 306[4]	Appropriate upgrade for UMBs not clear. Use IEBC (ICC, 2009b), SF Ordinance, 3403.5?
Unreinforced Masonry Buildings (UMBs)	UMBs retrofit to "bolts-plus" (residential exception)	Performance expectation unclear—in theory, worse than full ordinance.	Nothing specifically available on bolts-plus	Appropriate upgrade for UMBs not clear. Use IEBC (ICC, 2009b), SF Ordinance, 3403.5?
Unreinforced Masonry Buildings (UMBs)	Full Ordinance	Damage expected in strong shaking; most will not comply with 3403.5; 15-year retrofit "Halo" will apply to some; controversy expected.	Little data available on expected performance of retrofitted UMBs.	Upgrade to 3403.5?
Unreinforced Masonry Buildings (UMBs)	Those that comply with 3403.5	Few in number; in theory, only repair will be required; expected performance of early versions of retrofit to 104f is unclear.	Braced frames with non-ductile detailing understood; little information on interaction with unreinforced masonry.	Would require revision to "grandfather" date in 1973; many retrofitted with braced frames expected to behave poorly.
"Compliant" Retrofits	Early application of 104f for retrofits; cut-off date uncertain (maybe 1988)	Many "early" retrofits may not perform well, particularly those done with braced frames with non-ductile detailing.	Braced frames with non-ductile detailing understood; little information on interaction with other systems; little information on the expected performance of other retrofit systems.	Use of "informal" allowable stresses for existing materials; big issue is to identify standard for upgrade of these buildings (if triggered); would require revision to venerable "grandfather" date of 1973.

Notes:

1. SFBC: *San Francisco Building Code*
2. CUREE-CalTech Wood Frame Project: reports available from www.curee.org
3. NEESwood: a Network for Earthquake Engineering Simulation (NEES) project to develop a Performance-Based Seismic Design Philosophy for Mid-Rise Woodframe Construction (http://nees.buffalo.edu/projects/NEESWood/)
4. FEMA 306: *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Basic Procedures Manual* (FEMA, 1999a)
5. PEER Grand Challenge Project: NEES Project of the Pacific Earthquake Engineering Research Center— Mitigation of Collapse Risk in Older Concrete Buildings
6. UCSD NEESR Project: NEES Project of the University of California, San Diego— Seismic Performance Assessment and Retrofit of Non-Ductile Concrete Frames with Infill Walls.
7. LA City Voluntary Ordinance: Chapter A5, *LA City Building Code*
8. NIST follow-up studies to FEMA P-695: (NIST, in preparation)

Based on discussions with the CAPSS project team, the CAPSS Advisory Committee, and San Francisco DBI, the following building types were selected as Example Building Types for development of post-earthquake repair provisions. The groups only include the non-complying portion of each category

3.2.1 Single-Family and Two-Family Dwellings

- **Description**: This group is primarily intended to represent single-family dwellings of wood construction. However, dwellings that also include a small apartment, duplexes, and two-unit flats are also included. The group is technically defined as "one- and two-unit dwellings of R-3 Occupancy." Apartments or condominiums with three or more units are not included in this group, but are covered in the example buildings in another category.
- **Reason selected:** Based on the findings of the CAPSS earthquake impacts study (ATC, 2010a), there are an estimated 130,000 of this general building type in San Francisco. In addition, it was estimated that only a small percentage were built after 1973, so most are non-complying and subject to damage-triggered retrofit after an earthquake under current *San Francisco Building Code* requirements. A significant damaging earthquake could create 30,000 to 40,000 of these buildings needing repair.

This building type is covered in detail in Chapter 5.

3.2.2 Other Wood Residential Buildings

- **Description**: This building type is intended to cover wood-frame residential buildings other than those covered in Paragraph 3.2.1. The technical definition is "Wood-frame buildings of R1 or R2 Occupancy."
- **Reason selected**: This building type, similar to the first group covering dwellings, is significant in terms of housing San Francisco residents. According to the CAPSS earthquake impacts report (ATC, 2010a), the city has about 19,000 multi-unit wood-frame residential buildings. These represent about 13 percent of all the city's residential buildings, but, due to their size, about 34 percent of the housing stock's replacement value. The ability for residents to stay in San Francisco, or at least return to their residences in San Francisco quickly after an earthquake, is important for the recovery effort and contributes to overall community resilience.

This building type is covered in detail in Chapter 6.

This broad class is of special interest because it contains the subset addressed in the CAPSS report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Earthquake Safety for Soft-Story Buildings* (ATC, 2009a) —about 4,400 pre-1973 buildings three stories or taller, with five or more residential units. Of these, about 2800 have significant, visible openings in the exterior walls at the ground floor and are therefore expected to have soft- or weak-story deficiencies. This group, plus an unknown additional percentage of the balance of the inventory comprise a target group for initial soft-story retrofit mandates and incentive programs. A repair/retrofit policy for the general class therefore needs to be coordinated with programs already existing or planned.

The current consensus definition of the structural or physical characteristics of the ground story that leads to a description of a "soft" or "weak" story is under study

(ATC, in preparation). Even so, the seismic performance of many buildings near the boundary of the eventual official definition of soft or weak story will likely be similar, so for purposes of post-earthquake repair provisions, no distinction is needed.

3.2.3 Older Concrete Buildings

- **Description**: These buildings consist of concrete framing, either a complete system of beams and columns or columns supporting slabs without gravity beams, as well as buildings supporting gravity loads primarily with concrete walls. Concrete frame buildings with unreinforced masonry infill walls are also included. Concrete buildings of all types that were designed and constructed in accordance with code provisions that did not contain ductile reinforcing requirements are generally considered potentially seismically vulnerable. Detailing requirements were placed into codes gradually, but the dividing line between design of "non-ductile" or "older" concrete buildings and seismically acceptable concrete buildings is often taken as the 1973 or 1976 *Uniform Building Code*. This timeline fits well with the current *San Francisco Building Code* definition of complying buildings as buildings permitted after 1973.

  Low-rise buildings built with concrete walls and wood or metal roofs are not included in the group.

- **Reason selected**: "Non-ductile" or older concrete structures have long been considered a building group that may represent our highest seismic life safety risk. Many of these buildings are large and have a high occupant load. Historically, particularly in other countries, many older concrete buildings have collapsed during earthquakes. In San Francisco, the collapse of a single, large concrete building could cause a high number of casualties, an order of magnitude higher than the total casualties experienced in any earthquake in the United States since 1906. Recognizing this potential vulnerability, considerable research has been devoted to understanding the seismic performance of this building type in the last decade. For example, a Network for Earthquake Engineering (NEES) Grand Challenge Grant was awarded by the National Science Foundation to the Pacific Earthquake Engineering Research (PEER) Center entitled "Mitigation of Collapse Risk in Older Concrete Buildings". Other federal agencies, including FEMA and the National Institute of Standards and Technology (NIST), also are funding applied research and development projects to improve understanding of seismic response of this building type. In addition, the Concrete Coalition (Comartin et al., 2008), a network of individuals, governments, institutions, and agencies with a shared interest in assessing the risk associated with dangerous non-ductile concrete buildings and developing strategies for fixing them, has recently organized efforts to develop an inventory of older concrete buildings in San Francisco.

  The CAPSS project team concluded that additional concentration on this building type in the form of development of post-earthquake repair provisions is therefore justified.

This building type in covered in detail in Chapter 7.

CHAPTER 4: APPLICATION OF OVERARCHING STRATEGY

This chapter discusses how San Francisco should apply the issues and recommended resolutions presented in Chapter 2. The details of application and implementation in a general sense are contained in this chapter and, for the specific building types, in Chapters 5, 6 and 7.

4.1 Recommended Process for Post-Earthquake Repair or Retrofit

The strategies and procedures recommended in this report are consistent with traditional policies used in San Francisco since about 1990, as described in Section 1.1. The cut-off date for complying buildings has been used since about 1970. However, it is recommended that the rules governing repair of earthquake damage be clarified to encourage pre-earthquake preparation by owners, to minimize post-earthquake disputes over appropriate action, and to avoid delays in re-occupancy and recovery.

Chapter 5, 6, and 7 detail rules for repair and retrofit for three specific building types, but all three assume the same overall process. An owner, or owner's engineer, architect, or contractor, starting the repair process, must determine if the building is classified by the *San Francisco Building Code* (SFBC) as "complying" or "noncomplying." If the building is complying, only repair to the original design is required and application is made for a building permit to make such repairs—often both engineering and contracting advice may be needed to design such repairs. If the building is noncomplying, the extent and type of damage must be compared to trigger levels specified in the code. If the damage is less than the trigger levels, repair to predamage levels is acceptable. If the damage level is greater than the trigger level, in addition to repair of damage, the building, or certain elements must be retrofitted.

The current SFBC Section 1604.11 (CCSF, 2010) defines a complying building by the date of its construction or retrofit:

> *An existing building or structure which has been brought into compliance with the lateral-force resistance requirements of the San Francisco Building Code in effect on or after May 21, 1973, shall be deemed to comply with [requirements for avoiding triggered retrofit].*

Noncomplying buildings with damage in excess of the trigger levels must be retrofitted. For these triggered retrofits, Section 1604.11 allows the use of design loads smaller than those required for new construction and, with Building Official approval, allows alternative criteria that provide equivalent performance. Of course, a building shown to satisfy these retrofit criteria in its repaired state – that is, without additional retrofit – would not have to undergo any retrofit. Such a building would be considered complying by evaluation.

The 2010 *California Building Code* (CBC) does not define compliance using the date of construction or permitting. Under the CBC, if the damage trigger is reached, a retrofit can be avoided only if the building complies with the specified standard by evaluation.

Currently, the basic damage trigger in both the SFBC and the CBC is a loss of 20% of lateral force-resisting capacity in either direction, in any story. The CBC refers to this damage level as Substantial Structural Damage. However, for the three example building types, this report proposes to create an alternative to the 20% loss trigger with more specific descriptions of damage, or with explicit calculation procedures that avoid poorly defined loss-of-strength calculations. It is assumed that the material in Chapters 5, 6, and 7 will be contained in Administrative Bulletins that will provide guidance to determine if the damage trigger has been reached. It is recommended that additional Administrative Bulletins be created to cover other potentially problematic building types, as discussed in Chapter 8 of this report.

For buildings whose compliance status is clearly controlled by a permit date, this status will normally be determined first, before considering damage-related retrofit triggers. However, if seismic evaluation is used to determine compliance, owners may choose to check damage triggers first. If the damage is less than the trigger level, only repair is necessary regardless of compliance status and an overall seismic evaluation can be avoided.

4.2 Recommended Application of Resolution of Specific Issues

Through discussion within the CAPSS project team, the CAPSS Advisory Committee, and DBI, it was decided that the intensity of ground motion should be considered in post-earthquake repair provisions (Chapter 2, Issue 4) and that delays in completion of triggered retrofits may be appropriate (Chapter 2, Issue 5), but no specific implementation methods were identified. The recommended implementation methods are described below:

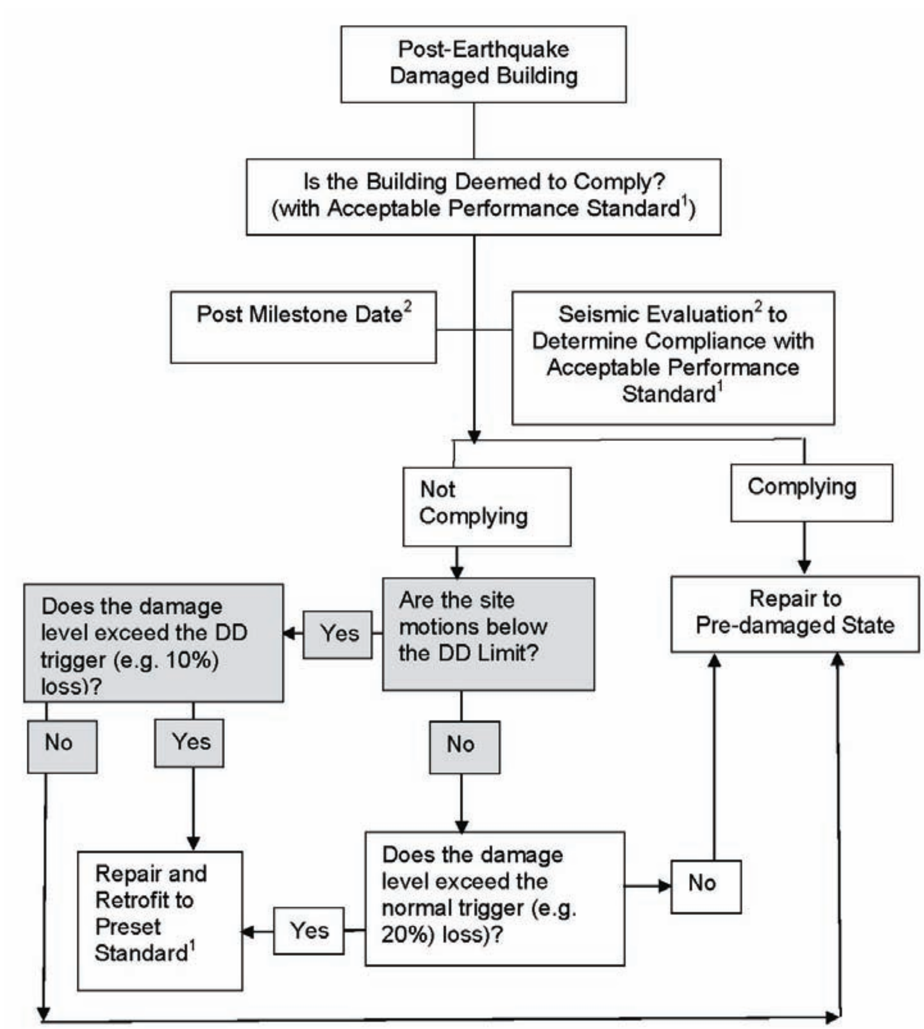
4.2.1 Consideration of Ground Motion and Disproportionate Damage

Table 2-1 illustrates the possibility of varying the retrofit damage trigger for three different intensities of ground motion. Incorporating several levels of ground motion, to be consistent and fair, requires a precise knowledge of the relationship between ground motion intensity and damage. While it may be justified to use damage that is disproportionate to the site ground motion as a means of identification of exceptionally seismically poor buildings, a complex matrix defining several such triggers, as suggested by Table 2-1, assumes precision of the identification of performance and ground motion beyond the current state of the art.

Therefore, it is recommended that a single condition of Disproportionate Damage be specified. For small ground motions, little or no damage should be expected in a broad range of both new and older buildings. Therefore moderate damage for these small motions, particularly to key lateral force-resisting elements, will be a reliable indicator that the building is seismically deficient and potentially dangerous. The new Disproportionate Damage triggers will supplement, but not replace, the existing Substantial Structural Damage trigger already in the CBC and the SFBC.

In national seismic hazard mapping, it is assumed that for short-period spectral accelerations (Sa at 0.2 seconds) of 0.25g or less, little or no structural damage should be expected in any buildings and the 0.25g ground-motion level is used to identify regions where no meaningful global building seismic design is required (buildings assigned to Seismic Design Category A, ASCE 7-05, Section 11-7, (ASCE, 2005). For defining Disproportionate Damage, it is recommended that "very low ground motions" be taken above this level, at a cut-off of short-period spectral acceleration less than or equal to 0.4g. However, since it is proposed to use ShakeMaps (USGS, 2003) as the ground motion mapping, the short-period spectral acceleration is taken at 0.3 seconds, to agree with that mapping system ($Sa_{0.3} \leq 0.4g$). Further, Disproportionate Damage should be defined as 10% loss of lateral capacity, or equivalent to half of the basic damage used as a trigger for all other ground motions, currently defined as 20% loss of lateral-load capacity.

See Figure 4-1 for a flow chart showing how the Disproportional Damage concept supplements the current code provisions based on Substantial Structural Damage.



Note 1. Acceptable Performance Standards may vary from jurisdiction to jurisdiction. The standard for evaluation may be different from the one used for retrofit.

Note 2. Jurisdictions may specify milestone dates for new buildings and retrofits and use building-specific evaluation to determine state of compliance.

Figure 4-1 Flow chart of post-earthquake repair process incorporating Disproportionate Damage (DD). DD steps shown shaded.

Therefore, it is recommended that the concept of Disproportionate Damage be incorporated into the SFBC defined conceptually as a 10% loss of lateral-load capacity in any story in any direction under site ground motions with short-period spectral acceleration of 0.4g or less ($Sa_{0.3} \leq 0.4g$). The site ground motions will be defined by USGS ShakeMaps (USGS, 2003) as developed by USGS one week after the event. However, an approved on-site instrument will override the USGS mapped value. See Appendix A for further discussion of the use of ShakeMaps for this purpose.

4.2.2 Delay in Completion of Triggered Retrofit

Traditional code provisions that require seismic retrofit in addition to repair do not specify a time limit for completion of the retrofit, nor do they provide guidance on re-occupancy of the building in the interim. Many building officials may interpret damage triggering a retrofit as equivalent to a red tag and not allow occupancy until the retrofit is completed. However, a 20% loss of lateral-load capacity is not directly related to building safety criteria as specified in the ATC-20 *Procedures for Postearthquake Safety Evaluation of Building* (ATC, 1989). To enhance the possibility of immediate re-occupancy and thus to contribute to overall community resilience, it is recommended that safety evaluation and tagging be explicitly separated from retrofit triggers. This is particularly important considering the recommendations for provisions covering Disproportionate Damage discussed above.

The safety tagging and subsequent safety detailed evaluations should therefore proceed independently from determination of whether damage has triggered a retrofit. It is recommended that DBI takes a position that a retrofit is immediately triggered, but that, considering the need for design, arrangement of financing, and general post-earthquake conditions, an extended period be given for completion of the work, to be determined as a policy decision. Different time frames may be appropriate for different situations. For example, a Disproportionate Damage trigger could be considered as justification of urgent action.

A given time period could be put into the SFBC, but the period appropriate for every event, every owner, and every building will differ. Therefore it is recommend that, when an Administrative Bulletin is completed for each Building Type, the time period should be determined by the Building Official, with input from the CAPSS Advisory Committee.

4.2.3 Consideration of Damage due to Structural Deterioration

Non-complying buildings in San Francisco are by definition nearly 40 years old, and many are considerably older. It is known that some of these buildings commonly suffer from structural deterioration, including damage to wood framing and sheathing, and rusting of reinforcing steel and structural steel members. The loss of strength due to this deterioration will contribute to damage levels, which indirectly will contribute towards a retrofit trigger. The loss of lateral strength from the deterioration itself should be considered, in addition to earthquake damage, when determining loss-of-strength compared to the as-built structure. The earthquake damage triggering section of the code should be clarified as to the combinations of deterioration and earthquake damage to be considered for retrofit triggers, as well as for repair requirements. This is mostly a common sense issue, but the code rules should neither allow earthquake repair to completely ignore deterioration nor require extensive destructive investigations to identify all deterioration.

4.3 Code Implementation of Recommendations

The 2010 *San Francisco Building Code* (CCSF, 2010) has already incorporated the 2010 CBC. Since the 2010 CBC contains revisions to Chapter 34 pertaining to the issues of this report, it is recommended that the following code changes be prepared for future incorporation into the SFBC.

Code implementation of the recommendations for improving post-earthquake repair provisions needs only the following steps:

- SFBC Section 3403.2.3.2.4 that specifies the 20% loss of lateral code capacity as the retrofit trigger need not be changed.
- The code should be clarified to require that all sources of damage to the lateral system present in a building undergoing a post-earthquake damage assessment shall be considered in calculations for loss of strength.
- New definitions and provisions must be introduced into the SFBC to add the requirement for retrofit in the case of Disproportionate Damage. Disproportionate Damage will be defined at 10% loss of lateral-force-resisting capacity in any story, in either direction, under site specific ground motion intensity with short-period spectral acceleration of 0.4g or less ($Sa_{0.3} \leq 0.4g$), as defined by ShakeMaps (USGS, 2003) published on the USGS website one week after the event.
- Specific interpretations of these code sections for each example building type will be contained in Administrative Bulletins. Recommended language for Administrative Bulletins is provided for each example building type considered in the CAPSS Project in Chapters 5, 6, and 7 of this report.
- Interpretations of these code sections for additional building types can be developed by others and issued as additional Administrative Bulletins. For example, if the completed methodology covering post-earthquake repair provisions for steel moment frames developed by the SAC Joint Venture (FEMA, 2000b) is deemed acceptable by DBI, it can be adopted as an interpretation and published as an Administrative Bulletin.

CHAPTER 5: SINGLE-FAMILY AND TWO-UNIT RESIDENTIAL BUILDINGS

5.1 Background

5.1.1 Buildings Included

This group represents one- and two-family dwellings of wood-frame construction, and includes duplexes and two-unit flats (R-3 occupancy type). Apartments or condominiums with three or more units are not included in this group, but are covered in the example building type in Chapter 6.

Structural sub-types in this group that are likely to have different performance characteristics are:

- Hillside dwellings that are much more transversely stiff on the uphill side because they are framed directly on footings. Downhill framing may be open (on posts), enclosed with a perimeter wall only, or enclosed with interior spaces stepped down the hill.
- Dwellings with soft or weak first stories. Generally these are houses built over garages, but soft stories also could be created due to the presence of large rooms and open exterior walls in the lowest floor.
- Dwellings with crawl space under the first floor, creating a laterally soft or weak base.
- Dwellings built directly on slab on grade.

5.1.2 Complying Buildings

- *Current definition*: In accordance with current San Francisco policy, buildings that meet the requirements of *San Francisco Building Code* (SFBC) Section 1604.11 are considered "complying," and earthquake damage need only to be repaired to comply with the original design code. As indicated elsewhere, new buildings permitted after May 21, 1973 and retrofits in accordance with Section 1604.11 (or its predecessor sections) permitted after that date are also deemed to comply.
- *Potential issues with use of 1973 as milestone date*: It is unclear when design/construction practice in San Francisco and/or DBI code enforcement practices minimized or eliminated the inclusion of significant seismic deficiencies in this building type, particularly the deficiencies that were at one time common in hillside houses, soft-story houses (houses over garages), or houses with crawl spaces (cripple walls). This information would be needed if the traditional milestone date is to be changed for this building type. If compliance is judged primarily by considering only life-safety aspects of equivalency to the code for new buildings, the 1973 date is probably acceptable

for this building type. However, it is possible that the year of 1978 may be used as a cut-off for the potential mandatory ordinance for weak-story wood apartment buildings. If that occurs, it is also logical to use that date for this building type. Use of this date would require several code changes and would also require coordination with triggers that require seismic upgrades as a result of renovation.

5.1.3 Typical Damage States

Almost all buildings in this group are non-engineered and therefore lack a specified lateral force-resisting system. Lateral forces in these structures are often resisted by exterior stucco walls or interior plaster or gypsum board partitions. The insurance industry has the most experience in assessing and repairing such damage as part of claims adjustment. Few other systematic studies of damage and acceptable repair techniques are available because many of the damage patterns do not threaten life safety and have required less attention by building departments. To resolve past controversy concerning which repairs are acceptable in different situations, the California Earthquake Authority sponsored development of repair guidelines for many of the typical damage states (CUREE, 2007). These repair guidelines are useful for the purpose of defining repair and/retrofit rules for this building group and certain recommendations are referenced in this chapter when applicable.

Based on damage noted in past earthquakes and documented in many publications, (CUREE, 2007; SSC, 1994; SCI, 2009), typical damage states for the building type have been identified as discussed below.

Site Damage

Liquefaction, landslide, or fault rupture at the site has caused damage to this building type in past earthquakes, but this issue is not unique to this building type and should be considered as a general issue for San Francisco to address in post-earthquake conditions.

Damage Independent of Specific Structural or Configuration Characteristics

- *Foundations*: If soil failure has not occurred, significant damage to foundations of these buildings is rare. Diagonal cracks may indicate differential settlement before or during the shaking. Vertical cracks often form in continuous footing due to light reinforcing and shrinkage. Ground shaking may cause a similar crack to form at locations predisposed to these conditions. In rare cases, ground shaking will cause a pre-existing crack to become larger. Small isolated foundations for posts in crawl spaces may tilt due to lateral movement of structure above, or pre-earthquake eccentricity of gravity load.

- *Connection to foundation*: Sill plates may be connected to the foundation material by anchor bolts or by nails driven into the bottom side of the sill and forced into place in wet concrete or mortar. Sliding of the entire structure relative to the foundation may be common if local construction practices in a given era installed plates with little or no connection at this interface.

- *Exterior walls of stucco, straight sheathing, or other semi-structural material:* Although seldom specifically designed as a lateral-force-resisting system, these walls often provide the stiffest and strongest resistance to lateral distortion. Stucco particularly, due to its stiffness and brittleness, will crack or become disconnected from the studs under lateral loading. Cracks will form first at the corners of window or door openings; these are the same location where cracks occur due to slight differential settlements or due to drying shrinkage of the stucco itself. Under larger lateral movements, diagonal or "X" cracks will form in solid panels. Wood walls of horizontal board sheathing or lightly nailed plywood will not show cracking damage but will allow lateral distortion of the structure between floors due to its flexibility. Damage in this case will be at the nails and between boards or panels.

- *Interior walls of plaster or gypsum-board sheathing:* Similar to exterior walls, interior walls of these materials can be stiff and brittle, but their overall stiffness may be reduced because they are supported by floor framing, rather than being continuous to a foundation as are exterior walls. These walls crack easily, particularly at corners where two walls connect. Large distortions will cause "X" cracking in solid panels.
- *Roofs*: Damage to roof framing is rare but can be caused by poor gravity framing layouts that are exacerbated by shaking. Roof tiles can become detached from base material and slide partially down roof slopes or even completely off the roof.
- C*himneys*: Masonry chimneys are extremely vulnerable to damage. The stiffness of a typical chimney is incompatible with the stiffness of the house structure, and there is often damage at the interface. More importantly, when built of unreinforced masonry, the portion of the chimney above the roof often collapses, sometimes into the house. Unreinforced chimneys also sometimes collapse from the fire box up or occasionally completely. Reinforced masonry or concrete chimneys usually stay intact but often pull away from the house structure. These chimneys often have steel ties at the attic or floor levels, which sometimes fail and are pulled out of the wood portion of the house. Even when damage is apparently limited to slight movement at the interface with the house or slight cracking of the masonry itself, the internal flue may be cracked or dislodged and should be inspected for fire safety.

Damage Dependent on Specific Structural or Configuration Characteristics

- *Irregular configuration or poorly connected wings*: The most significant configuration deficiencies occur in houses on hillside lots or houses with soft or weak stories, but those are categories themselves, as noted below. In houses that have misalignments of floor or roofs, ties across the stepped location are often missing. At such locations the two parts will often pull apart completely, or undergo differential movement that may compromise support of gravity framing. Such conditions could occur at joints between major portions of the structure or between the main structure and a smaller piece such as a porch, carport, or garage. The masses on either side of reentrant corners also may not be sufficiently tied together and may be damaged due to differential movement. Two-story spaces or stair openings in the diaphragm are sometimes located at corners, exacerbating this deficiency.
- *Hillside structures*: Houses on sloping lots may be built entirely at the uphill elevation and higher, or may be stepped down the slope. In either case the uphill portion of the structure will likely be directly connected to the foundations and the downhill portion supported on posts or walls of differing heights. In cases with little or no lateral support in the downhill portion of the house, complete collapse is possible, and on steep slopes, catastrophic slides down the slope have occurred. In less severe cases, for shaking perpendicular to the slope, the

structure will likely rotate around the uphill face, causing damage to the downhill walls or posts and also to connections to the uphill foundations. For shaking parallel to the slope, the direct uphill connections to the foundations will be significantly stiffer that downhill walls and will tend to attract most of the load, possibly pulling the framing off the foundation.

- *Soft or weak-story structures normally created by garage door openings in the lowest level*: Damage to these buildings is typical of damage to any soft- or weak-story structure. The soft- or weak-story will displace horizontally with the stories above acting more or less like a rigid box. This excess movement will cause local damage to walls and finishes, may leave the first floor out of plumb, or in extreme cases will cause sidesway collapse. The openings causing the weakness may only be on one face of the building creating a torsional response and amplified drifts near the perimeter of the buildings.
- *Crawl space framing*: In order to use wood framing for the first floor or to accommodate a slightly sloping site, houses often are built with an open space beneath the floor with a continuous concrete footing and/or wood-framed closure wall at the perimeter. The interior framing of the first floor is typically supported on wood posts and isolated footings. The short walls used in these conditions are called cripple walls or pony walls. In older houses, the cripple wall system is typically far weaker than the multiple walls making up the rooms of the house above, creating a weak story condition. Similar to the soft- or weak-story structures described above, excess displacement occurs at the crawl space level causing damage to finishes, potential permanent displacement, or sidesway collapse. The superstructure of these houses may not be excessively distorted during an earthquake and, in many cases, can be jacked up and put back in place. In addition to repairing damage to the upper finishes, a sufficiently strong crawl space level must be included in such repairs. In addition, utility lines often develop leaks from the crawl space movement causing damage, or in the case of gas lines, possibly fire. Retrofit of the cripple walls condition has proven relatively inexpensive and standard methods are available (ICC, 2010).

5.2 Recommendations

5.2.1 Process

It is recommended that the basic process governing post-earthquake repair standards described in Section 4.1 be maintained. However, the damage triggers described in this chapter should be deemed to comply with the 20% loss-of-strength provision.

5.2.2 Complying Buildings

As per the resolution of Issue 6 in Chapter 2, and the discussion in Section 5.1.2, it is recommended to maintain the current definition of Complying Building as those buildings permitted after May 21, 1973.

5.2.3 Damage Triggers Requiring Partial or Complete Retrofit

The most significant characteristic of damage patterns in this building group is that damage is often confined to a single component (e.g., chimney, porch) or level (e.g., crawl space, garage level). Considering the guiding principle of enabling rapid re-occupancy to improve resilience, damage to a somewhat isolated component or level should not require global retrofit that would include construction and disruption in relatively undamaged areas. This concept is implemented in Table 5-1, which lists damage types and extent and required repair or retrofit.

The damage triggers are defined by visual classification of severity rather than calculation of loss of lateral force capacity which would be particularly problematic for this building group due to the non-engineered construction and the need for homeowners to retain professional engineers for the calculations.

5.2.4 Disproportionate Damage Triggers

In accordance with the overall strategies described in Chapter 4, when obvious and significant seismic weakness are identified by damage at very small shaking levels (Disproportionate Damage), those deficiencies should be mitigated. This concept is implemented for certain damage types in Table 5-1.

Table 5-1 Damage Triggers for Repair/Retrofit of Single-Family Dwellings and Two-Unit Duplexes/Flats

Component/Condition	Minimum Triggering Damage	Ground Motion[1]	Minimum Retrofit[2]
Stone or masonry veneer, incidental unreinforced masonry (URM) wall (non-chimney)	Appearance similar to “Heavy Damage” as described in Section 7.5 of FEMA 306[4], or failure of anchorage to backing in over 20% of the wall area.	Any	Remove and replace.
	Appearance similar to “Moderate Damage” as described in Section 7.5 of FEMA 306, or visible failure of anchorage to backing anywhere.	0.4g or less	
URM foundation piers or continuous footings with crawl space	“Moderate Damage” as described in Section 7.5 of FEMA 306. Visible relative movement of supported joist or beams on support of 1″ or more. Permanent movement that results in inadequate bearing of supported member.	Any	Retrofit crawl space to Section 3403.6 of SFBC[4].
Cracks in continuous footings without visible related soil failure or movement	Cracks less than 0.25″ width.	Any	No retrofit required. Repair to original strength in accordance with Section 4A.3 of CUREE EDA-2[4].
	Cracks greater than 0.25″ width or offset.	Any	No retrofit required. Obtain engineering for repair.
Cracks in continuous footings with visible related soil failure or movement	Cracks and visible related soil failure or movement.	Any	Obtain engineering instructions for mitigation of soil movement and repair of footing. Mitigate soil issue as recommended by engineer.
Cripple wall or post-and-beam crawl space. If height of cripple wall varies by more than 4 feet, see “hillside structure”	Permanent set of 2″ anywhere, or visible general relative movement of supported joist or beams on support of 1″ or more. Permanent movement that results in inadequate bearing of most supported members.	Any	Retrofit crawl space in accordance with IEBC Chapter A3[4].
	Permanent set 1″ anywhere or visible relative movement of most supported joists or beams on support.	0.4g or less	

Table 5-1 Damage Triggers for Repair/Retrofit of Single-Family Dwellings and Two-Unit Duplexes/Flats (continued)

Component/Condition	Minimum Triggering Damage	Ground Motion[1]	Minimum Retrofit[2]
Anchorage of floor/wall framing to foundations	Permanent movement of 1″ anywhere	Any	Retrofit crawl space in accordance with IEBC Chapter A3.
Hillside structures (supports from foundations to first floor vary in height by more than 4 feet.)	Permanent set of 2″ or 2% drift, whichever is greater, at downhill support. Failure of connections in downhill supports, if post and beam braced frame, or moment frame. Separation of uphill framing from foundation support or indication of relative movement (during shaking) parallel to slope of 1″ or more.	Any	Retrofit from the foundation level to a level with a full-plate diaphragm for Section 3403.6 of SFBC, specifically including the torsion created by the various height walls or other supports.
	Permanent set 1″ or 1% drift, whichever is greater, at the downhill support. Signs of movement that could lead to failure of the downhill supports. Visible relative movement of the uphill support parallel to the slope.	0.4g or less	
Weak Story: Any story less than 60% of the strength of the story above in either direction.[3]	Permanent set of 2″ or more or indication of any movement (during shaking) in the story of 4″ or more anywhere in the plan.	Any	Retrofit soft story in accordance with soft story ordinance. Retrofit any stories below to at least same strength[3].
	Permanent set of 1″ or more or indication of any movement (during shaking) in this story of 2″ or more.	0.4g or less	
Stories other than Weak Stories	Permanent set of 2″ or more anywhere in the plan. Permanent set of 1″ anywhere if torsional displacement is noted. Indications of excessive response such as severe cracking of brittle walls, nail fracture or pullout in wood, multiple jammed doors and broken windows.	Any	Retrofit from damaged story to foundations in accordance with Section 3403.6 of SFBC. Repair of walls not part of the designated lateral-force-resisting system can be in accordance with Section 5.8 of CUREE EDA-2.
Connection between two parts of a structure including wings, split levels, porches, and beam to post connections	Permanent separation or sliding at joint of 1″ or more. Permanent movement that results in inadequate bearing of supported member.	Any	Repair shall include structural separation with independent gravity support for each structure or a seismic tie that will transfer 20% of the weight of the lighter portion across the joint.

Table 5-1 Damage Triggers for Repair/Retrofit of Single-Family Dwellings and Two-Unit Duplexes/Flats (continued)

Component/Condition	Minimum Triggering Damage	Ground Motion[1]	Minimum Retrofit[2]
Unreinforced masonry chimneys	Damage patterns, as described in Chapter 7 of CUREE EDA-2, that require replacement of any chimney bricks or flue tiles or replacement of substantial extent of mortar.	Any	Minimum retrofit/replacement according to Appendix 7A of Chapter 7 of CUREE EDA-2.
Any chimney	Earthquake caused separation of chimney from the surrounding or adjacent wood framing and clear movement from a hand pushed “rock test” as described in Section 7.7.3 of CUREE EDA-2.	Greater than 0.4g	Repair/replace attic ties if present. If no tie to wood framing is evident, provide new engineered tie or replace chimney according to Appendix 7A of CUREE EDA-2.
		0.4g or less	Replace chimney in accordance with Section B of Appendix 7A of CUREE EDA-2.
Ceiling plaster	Falling or delaminated ceiling plaster greater than 10% of area of any room.	Any	Determine extent of delamination or deteriorated plaster and replace.
Ceiling material	Cracks in ceiling material indicating permanent movement, or local crushing of ceiling material at crack.	Any	If cracks are caused by movement of joists at their supports, provide tie across area of slippage. Otherwise, repair.
Roof tiles	Damage to multiple tiles, unanchored or slipped tiles.	Any	Determine extent of missing or deteriorated anchorage and replace.
Roof framing	Obvious lateral sliding of roof joists at supports or splitting of roof framing members.	Any	Obtain engineering opinion of cause and recommended repair.

Notes:

1. Sa at 0.3 seconds as shown on event ShakeMap as updated one week after the event.
2. Damage less than Minimum Triggering Extent shall be repaired to original strength/condition by methods acceptable to DBI.
3. This might be changed to story shear ratio as considered in the ATC-71-1 project (ATC, in preparation). Strength ratio (60%) may also be revised.
4. References:
   FEMA 306: *Evaluation of Earthquake Damaged Concrete and Masonry Buildings*, (FEMA 1998a);
   CUREE EDA-2: *General Guidelines for the Assessment and Repair of Earthquake Damage in Residential Wood frame Buildings*: (CUREE, 2007) ;
   IEBC Chapter A3: Proposed 2012 *International Existing Building Code, Appendix A*, (include SEAOC improvements to 2009 IEBC) (ICC, 2010);
   SFBC: *San Francisco Building Code*, 2010 Edition. (CCSF, 2010).

5.3 Implementation Recommendations

5.3.1 Recommended Building Code Amendment

As discussed above and in Chapter 4, the 2010 CBC and SFBC already trigger retrofit for cases of Substantial Structural Damage. The concept of Disproportionate Damage, however, is not yet in the building codes, so a local code amendment will be needed. This section proposes language for the necessary code change with reference to the 2010 CBC. Justification of the amendment as required by California Health and Safety Code sections 17958.5 and 18941.5 and other applicable regulations is left to the City.

For reference, here is the definition of Substantial Structural Damage already in 2010 CBC Section 3402:

> **SUBSTANTIAL STRUCTURAL DAMAGE.** A condition where:
>
> 1. In any story, the vertical elements of the lateral-force-resisting system have suffered damage such that the lateral-load-carrying capacity of the structure in either horizontal direction has been reduced by more than 20 percent from its pre-damage condition; or
>
> 2. The capacity of any vertical gravity load-carrying component, or any group of such components, that supports more than 30 percent of the total area of the structure's floor(s) and roof(s) has been reduced more than 20 percent from its pre-damage condition and the remaining capacity of such affected elements, with respect to all dead and live loads, is less than 75 percent of that required by this code for new buildings of similar structure, purpose and location.

The following new definition should be added to SFBC Section 3402 (proposed text is underlined):

> **DISPROPORTIONATE DAMAGE.** A condition of earthquake-related damage where:
>
> 1. The 0.3-second spectral acceleration at the building site as estimated by the United States Geological Survey for the earthquake in question is not more than 0.40 g; and
>
> 2. In any story, the vertical elements of the lateral force-resisting system have suffered damage such that the lateral load-carrying capacity of the structure in any horizontal direction has been reduced by more than 10 percent from its pre-damage condition.

The SFBC should modify CBC Section 3405.4 as follows (proposed new text is underlined):

> **3405.4 Less than substantial structural damage.**
>
> **3405.4.1 Disproportionate Damage.** Buildings with Disproportionate Damage shall be subject to the requirements of Section 3405.2 for earthquake evaluation and rehabilitation as if they had substantial structural damage to vertical elements of the lateral-force-resisting system.
>
> **3405.4.2. Other damage.** For damage less than substantial structural damage that is not Disproportionate Damage, repairs shall be allowed that restore the building to its pre-damage state using materials and strengths that existed prior to the damage. New structural members and connections used for this repair shall comply with the detailing provisions of this code for new buildings of similar structure, purpose and location.

5.3.2 Recommended Wording for Administrative Bulletin

This section recommends text for a San Francisco Department of Building Inspection Administrative Bulletin to implement the recommendations in Table 5-1 for single-family dwellings and two-unit flats and duplexes. The purpose of the Administrative Bulletin is to interpret the existing CBC and SFBC provision regarding Substantial Structural Damage and the proposed SFBC provision for Disproportionate Damage.

In the text that follows, italicized parenthetical remarks are notes to DBI staff for use in preparing a draft Bulletin for approval by the Building Inspection Commission.

TITLE: Seismic Retrofit Triggers, Scope, and Criteria for Single-Family Dwellings and Two-Unit Flats and Duplexes Triggered by Earthquake Damage

PURPOSE: The purpose of this Bulletin is to establish Department policy for interpreting damage definitions in the San Francisco Building Code and for setting the scope and criteria of triggered retrofits.

REFERENCES:

2010 *California Building Code* (CBC) Sections 3402 and 3405.

2010 *California Historical Building Code* (CHBC), CCR Title 24 Part 8.

2010 *San Francisco Building Code* (SFBC) Sections 3402 and 3405 (CCSF, 2010).

2012 *International Existing Building Code* (IEBC) *Appendix* Chapter A4 (or 2009 IEBC Appendix Chapter A4 with National Council of Structural Engineers Associations (NCSEA)/Structural Engineers Association of California (SEAOC) amendments).

ASCE/SEI Standard 31-03, *Seismic Evaluation of Existing Buildings* (ASCE, 2003).

ASCE/SEI Standard 41-06, *Seismic Rehabilitation of Existing Buildings*, with Supplement 1 (ASCE, 2007).

CAPSS Report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Post-Earthquake Repair and Retrofit Requirements* (ATC-52-4 Report).

FEMA 306: *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Basic Procedures Manual*, (FEMA, 1999a).

CUREE EDA-2: *General Guidelines for the Assessment and Repair of Earthquake Damage in Residential Wood frame Buildings*, (CUREE, 2007).

Administrative Bulletin for Single-Family and Two-Unit Residential Buildings Page 1

DISCUSSION:

CBC Section 3405.2 triggers seismic evaluation, and possibly retrofit, when earthquake damage reaches the level of "substantial structural damage to vertical elements of the lateral-force-resisting system." Substantial structural damage is defined in Section 3402 as, in essence, a capacity loss of 20 percent. But the code gives no rules for identifying a 20-percent loss or even for calculating capacity loss in general, so implementation of these provisions relies on interpretation by the Department. This Bulletin presents the Department's interpretation of a 20-percent lateral capacity loss in terms based on visual indicators of critical damage modes, as well as describing other situations where retrofit or partial retrofit is required. *(This Administrative Bulletin is written as a strict interpretation of substantial and disproportionate damage. Cut-off dates delineating complying buildings or evaluation methods to show "compliance" are not included. However the DBI may want to broaden the scope to include approved methods—or dates—for classifying a building as complying as well as indicating that such buildings only need be repaired. An Administrative Bulletin with such a scope could be a stand-alone document for dealing with earthquake damage for the given building type.)*

(Provisional, pending SFBC adoption of provisions for Disproportionate Damage.) Further, SFBC Section 3405.4 triggers seismic evaluation, and possibly retrofit, when earthquake damage reaches the level of "Disproportionate Damage," defined in Section 3402 as, in essence, a lateral capacity loss of 10 percent. This Bulletin presents the Department's interpretation of a 10-percent capacity loss in terms based on visual indicators of critical damage modes.

APPLICABILITY:

Buildings that satisfy all of the following criteria are eligible for the interpretations and provisions of this Bulletin. Other buildings, if not eligible for interpretations of similar Bulletins, are subject to the code provisions as interpreted by the Department on a case-by-case basis.

The provisions of this Bulletin shall apply to all eligible buildings, except that at the discretion of the Department, measurements of capacity loss, based on analysis, testing, or other objective data, may be allowed.

A. The building's structure includes at least one story in which the seismic force-resisting system is a wood light-frame system in at least one direction. This Bulletin applies only to the stories and directions with wood light-frame systems.

B. The building has wood floor and roof diaphragms.

C. The building is assigned to Occupancy Category I or II and contains, at most, one residential unit in occupancy group R-3. At the discretion of the Department, buildings with one or two residential units may be deemed eligible to be considered under the Administrative Bulletin for multi-unit residential buildings if they are structurally and architecturally similar to that group.

SUBSTANTIAL STRUCTURAL DAMAGE:

Substantial Structural Damage to the vertical elements of the lateral-force-resisting system shall be deemed to exist when any of the damage patterns described in Table 1 is observed in an eligible building.

(Provisional, pending SFBC adoption of provisions for Disproportionate Damage.)

DISPROPORTIONATE DAMAGE:

Disproportionate Damage shall be deemed to exist when any of the damage patterns described in Table 2 is observed in an eligible building where the 0.3-second spectral acceleration at the site estimated by the U. S. Geological Survey in the ShakeMap approved by the DBI is not more than 0.40g.

EVALUATION OR RETROFIT SCOPE FOR BUILDINGS WITH SUBSTANTIAL STRUCTURAL DAMAGE:

For buildings with Substantial Structural Damage, evaluation and retrofit (where required) shall proceed in accordance with those criteria shown in Table 1.

(Provisional, pending SFBC adoption of provisions for Disproportionate Damage.)

EVALUATION OR RETROFIT SCOPE FOR BUILDINGS WITH DISPROPORTIONATE DAMAGE:

For buildings with Disproportionate Damage, evaluation and retrofit (where required) shall proceed in accordance with those criteria shown in Table 2.

EVALUATION OR RETROFIT ENGINEERING CRITERIA:

Where evaluation or retrofit is triggered by earthquake damage at any level, the engineering criteria shall be permitted to use earthquake loads that are 75 percent of those prescribed by the SFBC for new construction, in accordance with CBC Section 3405.2. Any of the following alternative codes, standards, or guidelines may be used as alternative criteria for qualifying buildings:

A. ASCE 31-03, *Seismic Evaluation of Existing Buildings*, at the Life Safety performance level.

B. ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, with a structural performance objective of Life Safety in a BSE-1 hazard.

C. 2012 *International Existing Building Code* (IEBC) Appendix Chapter A4 (or 2009 IEBC Appendix Chapter A4 with NCSEA/SEAOC amendments).

D. 2010 *California Building Code* Section 3415-3420.

E. 2010 *California Historical Building Code* (California Title 24 Part 8).

F. *(Provisional, pending completion of ATC-71-1)* ATC-71-1 Report, *Simplified Interim Guidelines for Seismic Retrofit of Weak-Story Wood-Frame Buildings* (ATC, in preparation).

Table 1 Substantial Structural Damage Triggers for Repair/Retrofit of Single-Family Dwellings and Two-Unit Duplexes/Flats

Component/Condition	Substantial Damage Trigger	Minimum Retrofit[1]
Stone or masonry veneer, incidental URM wall (non-chimney).	Appearance similar to “Heavy Damage” as described in Section 7.5 of FEMA 306[3], or failure of anchorage to backing in over 20% of the wall area.	Remove and replace.
URM foundation piers or continuous footings with crawl space.	“Moderate Damage” as described in Section 7.5 of FEMA 306. Visible relative movement of supported joist or beams on support of 1″ or more. Permanent movement that results in inadequate bearing of supported member.	Retrofit crawl space to Section 3403.6 of SFBC[3].
Cracks in continuous footings without visible related soil failure or movement.	Cracks less than 0.25″ width.	No retrofit required. Repair to original strength in accordance with Section 4A.3 of CUREE EDA-2[3].
	Cracks greater than 0.25″ width or offset.	No retrofit required. Obtain engineering for repair.
Cracks in continuous footings with visible related soil failure or movement.	Cracks and visible related soil failure or movement.	Obtain engineering instructions for mitigation of soil movement and repair of footing. Mitigate soil issue as recommended by engineer.
Cripple wall or post-and-beam crawl space. If height of cripple wall varies by more than 4 feet, see “hillside structure”.	Permanent set of 2″ anywhere, or visible general relative movement of supported joist or beams on support of 1″ or more. Permanent movement that results in inadequate bearing of most supported members.	Retrofit crawl space in accordance with IEBC Chapter A3[3].
Anchorage of floor/wall framing to foundations	Permanent movement of 1″ anywhere.	Retrofit crawl space in accordance with IEBC Chapter A3.
Hillside structures (supports from foundations to first floor vary in height by more than 4 feet.)	Permanent set of 2″ or 2% drift, whichever is greater, at downhill support. Failure of connections in downhill supports if post and beam braced frame, or moment frame. Separation of uphill framing from foundation support or indication of relative movement (during shaking) parallel to slope of 1″ or more.	Retrofit from the foundation level to a level with a full-plate diaphragm for Section 3403.6 of SFBC[3], specifically including the torsion created by the various height walls or other supports.
Weak Story: Any story less than 80% of the strength of the story above in either direction.[2]	Permanent set of 2″ or more or indication of any movement in the story of 4″ or more (during shaking) anywhere in the plan.	Retrofit soft story in accordance with soft story ordinance. Retrofit any stories below to at least same strength.[3]
Stories other than weak stories.	Permanent set of 2″ or more anywhere in the plan. Permanent set of 1″ anywhere if torsional displacement is noted. Indications of excessive response such as severe cracking of brittle walls nail fracture or pullout in wood, multiple jammed doors and/or broken windows.	Retrofit from damaged story to foundations in accordance with Section 3403.6 of SFBC. Repair of walls not part of the designated lateral-force-resisting system can be in accordance with Section 5.8 of CUREE EDA-2.

Table 1 Substantial Structural Damage Triggers for Repair/Retrofit of Single-Family Dwellings and Two-Unit Duplexes/Flats (continued)

Component/Condition	Substantial Damage Trigger	Minimum Retrofit[1]
Connection between two parts of a structure including wings, split levels, porches, and beam to post connections.	Permanent separation or sliding at joint of 1″ or more. Permanent movement that results in inadequate bearing of supported member.	Repair shall include structural separation with independent gravity support for each structure or a seismic tie that will transfer 20% of the weight of the lighter portion across the joint.
Unreinforced masonry chimneys.	Damage patterns, as described in Chapter 7 of CUREE EDA-2, that require replacement of any chimney bricks or flue tiles or substantial extent of mortar.	Minimum retrofit/replacement according to Appendix 7A of Chapter 7 of CUREE EDA-2.
Any chimney.	Earthquake caused separation of chimney from the surrounding or adjacent wood framing and clear movement from a hand pushed “rock test” as described in Section 7.7.3 of CUREE EDA-2.	Repair/replace attic ties if present. If no tie-to-wood framing is evident, provide new engineered tie or replace chimney according to Appendix 7A of CUREE.
Ceiling plaster.	Falling or delaminated ceiling plaster greater than 10% of area of any room.	Determine extent of delamination or deteriorated plaster and replace.
Ceiling material.	Cracks in ceiling material indicating permanent movement or local crushing of ceiling material at crack.	If cracks are caused by movement of joists at their supports, provide tie across area of slippage. Otherwise repair.
Roof tiles.	Damage to anchorage of roof tiles, unanchored or slipped tiles.	Determine extent of missing or deteriorated anchorage and replace.

Notes:

1. Damage less than Minimum Triggering Extent shall be repaired to original strength/condition by methods acceptable to DBI.
2. This might be changed to story shear ratio as considered in the ATC-71-1 project (ATC, in preparation), when completed.
3. References:
   FEMA 306: *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Basic Procedures Manual* (FEMA 1999a);
   CUREE EDA-2: *General Guidelines for the Assessment and Repair of Earthquake Damage in Residential Wood frame Buildings* (CUREE, 2007);
   IEBC Chapter A3: Proposed 2012 *International Existing Building Code, Appendix A*, (include SEAOC improvements to 2009 IEBC) (ICC, 2010);
   SFBC: *San Francisco Building Code*, 2010 Edition. (CCSF, 2010)

Table 2 Disproportionate Damage Triggers for Repair/Retrofit of Single-Family Dwellings and Two-Unit Duplexes/Flats

Component/Condition	Disproportionate Damage Trigger	Minimum Retrofit[1]
Stone or masonry veneer, incidental URM wall (non-chimney).	Appearance similar to "Heavy Damage" as described in Section 7.5 of FEMA 306[3], or visible failure of anchorage to backing anywhere.	Remove and replace.
Cripple wall or post-and-beam crawl space. If height of cripple wall varies by more than 4 feet, see "hillside structure".	Permanent set of 1″ anywhere, or visible relative movement of most supported joists or beams on support.	Retrofit crawl space in accordance with IEBC Chapter A3.[3]
Hillside structures (supports from foundations to first floor vary in height by more than 4 feet.)	Permanent set of 1″ or 1% drift, whichever is greater, at the downhill support. Signs of movement that could lead to failure of the downhill supports. Visible relative movement of the uphill support parallel to the slope.	Retrofit from the foundation level to a level with a full-plate diaphragm for Section 3403.6 of SFBC[3], specifically including the torsion created by the various height walls or other supports.
Unreinforced masonry chimneys.	Earthquake caused horizontal cracking at roof line or at top of fire box.	Minimum retrofit/replacement according to Appendix 7A of Chapter 7 of CUREE EDA-2.
Any chimney.	Earthquake caused separation of chimney from the surrounding or adjacent wood framing and clear movement from a hand pushed "rock test" as described in Section 7.7.3 of CUREE EDA-2.	Replace chimney in accordance with Section B of Appendix 7A of CUREE EDA-2.

Notes:

1. Damage less than Minimum Triggering Extent shall be repaired to original strength/condition by methods acceptable to DBI.
2. This might be changed to story shear ratio as considered in the ATC-71-1 project (ATC, in preparation), when completed.
3. References:

FEMA 306: *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Basic Procedures Manual* (FEMA 1999a);
CUREE EDA-2: *General Guidelines for the Assessment and Repair of Earthquake Damage in Residential Wood frame Buildings* (CUREE, 2007);
IEBC Chapter A3: Proposed 2012 *International Existing Building Code, Appendix A*, (include SEAOC improvements to 2009 IEBC) (ICC, 2010);
SFBC: *San Francisco Building Code*, 2010 Edition. (CCSF, 2010)

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CHAPTER 6: MULTI-UNIT WOOD-FRAME RESIDENTIAL BUILDINGS

6.1 Background

6.1.1 Buildings Included

This group, like the smaller buildings addressed in Chapter 5, represents a common combination of structure type and occupancy. Generally it includes all wood-frame buildings (categorized as "wood light frame" type W1 or W1A by the engineering standards ASCE 31 *Seismic Evaluation of Existing Buildings* [ASCE, 2003], and ASCE 41, *Seismic Rehabilitation of Existing Buildings* [ASCE, 2007]), whose occupancy includes more than two units in residential groups R-1 (for example, hotels), R-2 (for example, apartment houses), R3.1 (for example, group homes) or R-4 (assisted living and rehabilitation facilities).

Questions about which buildings are included (or not) can be anticipated by a review of the group's structural and occupancy characteristics:

- *Wood-framing systems*: The designed or *de facto* seismic-force-resisting system can include any shear wall or pier assemblies combining wood structural panels, gypsum board, plaster, or stucco. Light-frame systems with metal studs are not specifically included.
- *Floor and roof diaphragms*: Only buildings with wood diaphragms are included. Wood diaphragms with cementitious fill (sometimes used for fire resistance over a parking level) are included; structural concrete diaphragms are not.
- *Combined structural systems or materials*: Many buildings in this class have first story walls of concrete or concrete masonry units (CMU), generally for increased fire resistance within a parking level or to provide soil retention on a sloped site. Newer (roughly post-1970) buildings might have a full concrete podium with the multi-story wood-framed structure above. The wood upper stories of these vertical combinations (assuming they meet the criteria for wood framing systems) are included in the group. Buildings that combine wood with steel, CMU, or concrete lateral elements within a single story, however, are not included.
- *Retrofit combinations*: A qualifying wood-frame lateral system may be original or part of a retrofit. A building with a first-story retrofit using lateral elements of steel, concrete, or CMU is included, but as with other vertical combinations, any rules derived for wood-frame structures would apply only to the stories with wood-frame lateral systems.

- *Foundations*: Only buildings with continuous foundations are included. A continuous foundation of unreinforced masonry (as might be found in the oldest members of the group), while included, will probably introduce some complexities in setting repair or retrofit scope and criteria.
- *Height*: All building heights are included, though multi-unit buildings would generally be expected to be more than one story.
- *Regularity*: Regular and irregular buildings are included. Nevertheless, the proposed repair/retrofit provisions are not intended to address rare situations such as split-level diaphragms. In San Francisco, many multi-unit buildings, while not representing classic "hillside" construction, are on sloped sites and present non-uniform first-story heights. These buildings are included to the extent that the relevant evaluation and retrofit criteria can accommodate them; that is, if the cited criteria (for example, ATC guidelines, ASCE standards) can accommodate these buildings, then they are eligible for the code interpretations described here.
- *Nonstructural masonry*: Buildings with masonry chimneys, hollow clay tile partitions, brick veneer, or similar elements are included, but the proposed repair/retrofit provisions are not specifically intended to address those elements.
- *Occupancy and Occupancy Category*: The proposed provisions are intended for typical multi-unit buildings whose primary occupancy is residential. Only Occupancy Category II buildings are included (for example, no large schools, hospitals or emergency response facilities). Many included buildings will contain mixed uses or will have areas designated as business, mercantile, utility (parking), or other occupancies, especially at the ground level. While all occupancies within the Residential group are included, future resilience goals might distinguish some of the buildings in this group from others. Structurally, all the buildings in the group may be treated similarly. But considering response or recovery, the City might want to deal separately with uses presenting special risks, perhaps including small schools, daycare, assisted living, hotels, assembly spaces, or businesses storing small quantities of hazardous materials. The provisions proposed in this report do not yet make such distinctions.
- *Ownership type*: All ownership types (e.g., rentals, condominiums) are included. Nevertheless, complete implementation of any repair/retrofit policy might have to account for variations in laws or regulations regarding tax assessment, rent control, disclosures upon sale, and subsidized or Section 8 housing.
- *Historic status*: Buildings exempt from retrofit triggers due to historic designation are included in principle. Whether or not a particular retrofit trigger will apply to them, however, will depend on designations and interpretations not yet made. See Chapter 8 of this report for further discussion.
- *Number of units*: While the general class is described as "multi-unit," buildings with any number of units (even one or two) are included in principle if the building is otherwise similar to a typical member of the class. For example, a two-story Victorian corner building with first-floor retail might have only one or two residential units in the upper story but is

otherwise more like a three-story apartment building than it is like a typical San Francisco house or duplex.

6.1.2. Complying Buildings

As discussed in Chapter 2 (Issue 6), San Francisco currently exempts from retrofit all buildings erected or "brought into compliance" after May 21, 1973. For the most part, the multi-unit wood-frame buildings of greatest concern to San Francisco all pre-date 1973, and the post-1973 buildings are relatively rare. Therefore, a change to the compliance date is not expected to have a significant effect on the number of retrofits triggered within this building group. However, if San Francisco retains this exemption, it might affect some buildings:

- Buildings retrofitted to standards in place after the 1989 Loma Prieta earthquake would be exempt from any new retrofit trigger. Potentially, this could exempt retrofitted systems now known to be obsolete or inadequate, from further retrofitting after future earthquakes. These could include braced frames with thin-walled steel tubes and light-frame shear walls that pre-date 1997 code changes made in response to the Northridge earthquake.
- New San Francisco incentives for voluntary retrofit of soft-story buildings (DBI, 2010) continue to use the 1973 date. Similarly, Proposition A, a proposed bond measure on the city's November 2010 ballot, defines eligible soft story buildings as those "constructed on or before 1974." However, California Health and Safety Code Section 19161, which authorizes the adoption of targeted soft-story retrofit programs, generally considers buildings constructed before January 1, 1978 to be potentially deficient. If San Francisco maintains its 1973 cut-off date, some buildings deemed to comply by the city could be said to be out of compliance with state standards. If San Francisco adopts the 1978 cut-off date, some buildings that were previously complying will become non-complying.
- ASCE 31 (ASCE, 2003), listed below as an appropriate option for evaluation criteria, cites the 1976 *Uniform Building Code* (ICBO, 1976) as the benchmark code for W1 structures (house-like buildings) and the 1997 *Uniform Building Code* as the benchmark code for W1A structures (typical apartment buildings). If the post-1973 exemption is maintained, the triggered work will be out of full compliance with the current national standard (which itself is subject to revision). If San Francisco adopts the 1978 date noted above, it will be closer to the current national standard.

6.1.3 Typical Damage Patterns

Wood-frame buildings of different eras and with different construction details will be prone to different damage patterns. For example, the oldest wood-frame buildings in San Francisco are likely balloon-framed (as opposed to platform-framed) and therefore present different load paths in the connections between floor joists and wall studs. Similarly, light wells, sloped sites, bay windows, brick veneer, minimal building separations, tuckunder parking or other common San Francisco conditions will affect the particulars of a building's earthquake performance.

Such details, even while they should be considered and understood by a post-earthquake inspector, probably are not necessary for a generic policy or code provision. Further, because wood-frame buildings are generally flexible, they will always be prone to structurally insignificant opening of joints and cracking of brittle finishes. These nominal patterns also should be understood but need not affect a repair/retrofit policy. Instead, this report recommends focusing on the broad damage modes most critical to overall performance. To facilitate coordination with the CBC and SFBC definitions of triggering damage levels, it is useful to divide the critical damage modes into those that primarily affect the seismic-force-resisting system and those that primarily affect the gravity-load-carrying system.

The critical damage modes affecting the seismic-force-resisting system are:

- Sheathing delamination, visually indicated by loose stucco or plaster, nail pull-through at wood or gypsum board panels, or permanent wall or pier in-plane racking.
- Panel mechanisms, visually indicated by full or near-full diagonal shear cracking, full or near-full horizontal flexural cracking of plaster or stucco, or loss of nailing connections from the sheathing to the top plate or sole plate.
- Load path failure, visually indicated by hold-down pullout or stud fracture, sliding of the sole plate at the floor line, sliding of the sill plate at the top of the footing, failure of diaphragm-to-wall connections at the rim joist or blocking, or collector or chord failure. This mode is intended to capture damage at the connections and interfaces between main elements of the seismic-force-resisting system.
- P-delta instability, visually indicated by permanent story drift or by jammed doors and windows repairable only by structural repair (not by reframing openings).
- Torsional instability, visually indicated by measurable or obvious permanent torsional deformation, stiffness loss at a substantial number of perimeter elements or wall lines, or strength loss not balanced between wall lines on opposite sides of the building.

The critical damage modes affecting the gravity-load-carrying system are:

- Loss of bearing capacity, visually indicated by subsidence or differential settlement of the foundation.
- Member failure, visually indicated by crushing, fracture, or shortening of posts, wall studs, or other components, or by column, post, or pier damage due to deformation incompatibility.
- Load path failure, visually indicated by damage to shear connections between floor framing and columns or walls, or by substantial reduction of seat bearing. Again, this mode is intended to capture damage at the connections and interfaces between main structural elements.
- P-delta instability, visually indicated by permanent story drift, or by jammed doors and windows repairable only by structural repair.

6.2 Recommendations

6.2.1 Complying Buildings

As discussed in Section 6.1.2, the 1973 date San Francisco currently uses to note automatic compliance differs from other precedents and standards. Because most of the buildings in this group (in San Francisco, at least) were built well before 1973, however, the date is not expected to have much effect on the outcome of repair/

retrofit requirements. Therefore, while this report generally recommends the use of different benchmark codes and dates for different structure types, it does not make a strong recommendation to change the 1973 date for multi-unit wood-frame residential buildings.

For the sub-group of soft-story buildings, as noted above, the California Health and Safety Code broadly rates buildings constructed before 1978 as "potentially hazardous." With respect to soft-story building programs, San Francisco might want to adopt this 1978 benchmark date, but the reasons would be about consistency with statewide legislation, not about technical differences in building performance.

A building that does not comply by date can instead comply by evaluation. Acceptability of the pre-damage building by any of the applicable alternative evaluation or retrofit criteria discussed in Section 6.2.3 would qualify the building as complying.

6.2.2 Damage Trigger Definitions

As discussed in Chapter 4, the CBC and SFBC both already require retrofit of non-complying buildings when the Substantial Structural Damage level is met. This report proposes an additional trigger intended to find Disproportionate Damage in relatively small earthquakes. Both triggers are generically defined in terms of capacity loss, with the understanding that such definitions are inherently difficult to apply. If these damage thresholds could be defined in alternative terms based on the visual indicators of critical damage modes, that would improve the consistency and efficiency of post-earthquake assessments and of repair/retrofit determinations.

This section proposes such alternative terms for multi-unit wood-frame residential buildings. The alternative terms, which interpret and enhance the existing definitions of Substantial Structural Damage and Disproportionate Damage with component-specific rules, are presented in Table 6-1.

As noted in Section 6.1.1, all sheathing types over wood framing are included in this group of buildings. Many buildings, intentionally or not, present combinations of sheathing materials and detailing that complicates response to earthquake shaking. Where materials with different structural characteristics—stucco and plywood, for example—both resist earthquake effects in the same direction and story, assessing the observable damage requires analysis or judgment to supplement the rules in Table 6-1. In general, where well-detailed wood structural panels are sufficient to control the structure's capacity, observable damage to stiffer but relatively weak and brittle finishes (stucco and plaster) may be ignored. By contrast, where wood elements are archaic (horizontal board siding, for example) or clearly inadequate as a complete system, the stucco sheathing should be treated as *de facto* seismic-force-resisting elements. This is what Table 6-1 means where it refers to wall segments or piers contributing significant strength or stiffness.

In most cases, engineering judgment applied to careful damage observations should be sufficient to distinguish the significant system elements. In all cases, however, the code official retains the right to call for additional investigation or analysis by the permit applicant. There are no consensus guidelines for quantifying damage to combinations of sheathing types on wood framing. However, the ATC-71-1 project (ATC, in preparation) has developed guidelines for combining material strengths and stiffnesses that could be useful in this regard, by helping to establish the relative contributions of various wall segments and piers.

Table 6-1 Retrofit Triggers and Criteria for Critical Damage Patterns in Multi-Unit Wood-Frame Residential Buildings

Component and Damage Pattern	Minimum Triggering Damage	Ground Motion[1]	Evaluation/Retrofit Scope and Criteria[2]
Wood-frame shear panels (wall segments or piers) and sheathing. Any of the following damage patterns, separately or in combination, indicating sheathing delamination or panel mechanism: • Stucco or plaster loose at more than one wall stud. • Nail pull-through at wood or gypsum board sheathing at more than one wall stud. • Visible permanent in-plane racking. • Diagonal shear cracking across half or more of a plaster or stucco panel. • Horizontal flexural cracking across half or more of a plaster or stucco panel. • Loss of nailing connection from sheathing to top plate or sole plate.	Substantial Structural Damage:[3] In any story, in any direction, the total length of wall segments and piers with any of the listed damage patterns is 20 percent or more of the total length of wall segments and piers in that story and direction.	Any	Triggered scope: Full building, both directions, lateral system only, wind and seismic load cases, per 2010 CBC Section 3405.2.1 and 3405.2.3. Seismic criteria: “75 percent” reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]
	Disproportionate Damage:[3] In any story, along any wall line, the total length of wall segments and piers with any of the listed damage patterns is 20 percent or more of the total length of wall segments and piers along that wall line in that story.	$Sa_{0.3} \leq$ 0.4g	Triggered scope: Full building, both directions, seismic system only, seismic load cases only. Seismic criteria: “75 percent” reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]
Connections and load path elements. Any of the following damage patterns, separately or in combination, indicating lateral load path failure: • Hold-down pullout or stud fracture at hold-down. • Sliding of sole plate at floor line. • Sliding of sill plate at top of footing.	Substantial Structural Damage: Any.	Any	Triggered scope: Full building, both directions, lateral system only, wind and seismic load cases, per 2010 CBC Section 3405.2.1 and 3405.2.3. Seismic criteria: “75 percent” reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]
	Disproportionate Damage: Any.	$Sa_{0.3} \leq$ 0.4g	Triggered scope: Full building, both directions, seismic system only, seismic load cases only. Seismic criteria: “75 percent” reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]

Notes:

1. Where the Ground Motion is shown as “Any,” the trigger, scope, and criteria shown are intended to reflect the intent of the 2010 CBC for cases of Substantial Structural Damage. Where the Ground Motion is limited, the trigger, scope, and criteria shown are intended to reflect the supplemental Disproportionate Damage trigger proposed in this report. $Sa_{0.3}$ indicates the event-specific mapped spectral acceleration at 0.3 seconds as shown on the event’s ShakeMap one week after the event.

Table 6-1 Retrofit Triggers and Criteria for Critical Damage Patterns in Multi-Unit Wood-Frame Residential Buildings (continued)

Component and Damage Pattern	Minimum Triggering Damage	Ground Motion[1]	Evaluation/Retrofit Scope and Criteria[2]
Connections and load path elements. Any of the following damage patterns, separately or in combination, indicating lateral load path failure: • Failure of diaphragm-to-wall connections at rim joist or blocking. • Collector or chord failure.	Substantial Structural Damage: Moot. No retrofit triggered.	Any	None.
	Disproportionate Damage: At any floor level, the damage affects the load path to more than one pier or wall segment, or affects the load path to the only pier or wall segment along a wall line.	$Sa_{0.3} \le$ 0.4g	Triggered scope: Components similar to or performing the same function as the damaged component, throughout the building, both directions, seismic load cases only. Seismic criteria: "75 percent" reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]
Gravity load-carrying members, connections, and load path elements. Any of the following damage patterns, separately or in combination, indicating member failure, load path failure, or loss of bearing capacity: • Floor framing-to-column/wall shear connection damage. • Loss or substantial reduction of seat bearing. • Crushing, fracture, or shortening of posts, wall studs, or other components. • Column, post, or pier damage due to deformation incompatibility. • Subsidence or differential settlement of foundation.	Substantial Structural Damage: The damaged components as a group support more than 30 percent of the total area of the structure's floor(s) and roof(s), and the remaining capacity of any damaged component with respect to all dead and live loads is less than 75 percent of that required for new buildings of similar structure, purpose, and location.	Any	Triggered scope: Full building, both directions, lateral system only, wind and seismic load cases, per 2010 CBC Section 3405.2.1 and 3405.2.3, as referenced by Section 3405.3.1. Seismic criteria: "75 percent" reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]
	Disproportionate Damage: The damaged components as a group support more than 10 percent of the total area of the structure's floor(s) and roof(s), and the remaining capacity of any damaged component with respect to all dead and live loads is less than 75 percent of that required for new buildings of similar structure, purpose, and location.	$Sa_{0.3} \le$ 0.4g	Triggered scope: Full building, both directions, seismic system only, seismic load cases only. Seismic criteria: "75 percent" reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]

Notes (continued):

2. All damaged members, connections, and load path elements, even where no retrofit or evaluation criteria are specified, should be repaired to their pre-damage condition per 2010 CBC Section 3405.4.
3. For assessment of wood-frame shear panels, only wall segments or piers contributing significant strength or stiffness to each wall line of the pre-damage structure need be considered. Large openings do not count toward the total length of wall segments and piers.
4. Recommended alternatives (see Section 6.2.3 of this report):
   ASCE 31, *Seismic Evaluation of Existing Buildings,* Life Safety
   ASCE 41, *Seismic Rehabilitation of Existing Buildings,* Life Safety in BSE-1
   2009 *International Existing Building Code*, *Appendix* Chapter A4 with NCSEA/SEAOC amendments (or approved 2012 *International Existing Building Code*, Chapter A4)
   ATC-71-1, *Simplified Interim Guidelines for Seismic Retrofit of Weak-Story Wood-Frame Buildings* (ATC, in preparation)

Table 6-1 Retrofit Triggers and Criteria for Critical Damage Patterns in Multi-Unit Wood-Frame Residential Buildings (continued)

Component and Damage Pattern	Minimum Triggering Damage	Ground Motion[1]	Evaluation/Retrofit Scope and Criteria[2]
Permanent lateral deformation indicating increased P-delta instability.	Substantial Structural Damage: 2 percent or more permanent story drift in any story.	Any	Triggered scope: Full building, both directions, lateral system only, wind and seismic load cases, per 2010 CBC Section 3405.2.1 and 3405.2.3, as referenced by Section 3405.3.1. Seismic criteria: "75 percent" reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]
	Disproportionate Damage: Any of the following: 1 percent or more permanent story drift in any story. Jammed doors or windows repairable only by structural repair (not by reframing openings).	$Sa_{0.3} \leq$ 0.4g	Triggered scope: Full building, both directions, seismic system only, seismic load cases only. Seismic criteria: "75 percent" reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]
Damage indicating torsional instability.	Substantial Structural Damage: Significant stiffness loss on more than one perimeter wall line. Significant strength loss not balanced between wall lines on opposite sides of building.	Any	Triggered scope: Full building, both directions, lateral system only, wind and seismic load cases, per 2010 CBC Section 3405.2.1 and 3405.2.3, as referenced by Section 3405.3.1. Seismic criteria: "75 percent" reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]
	Disproportionate Damage: Significant stiffness loss on more than one perimeter wall line. Significant strength loss not balanced between wall lines on opposite sides of building. Any visually obvious permanent torsional deformation.	$Sa_{0.3} \leq$ 0.4g	Triggered scope: Full building, both directions, seismic system only, seismic load cases only. Seismic criteria: "75 percent" reduced forces, per 2010 CBC Section 3405.2.1 and 3405.2.3, or approved alternatives as applicable.[4]

Notes (continued):

4. Recommended alternatives (continued) (see Section 6.2.3 of this report):
   2010 *California Building Code* Section 3415-3420
   2010 *California Historical Building Code* (California Title 24 Part 8)

6.2.3 Triggered Scope and Criteria

A code provision that triggers evaluation or retrofit is only partly about defining the trigger. A complete provision also defines the scope of triggered work and the criteria for executing that work. These are also shown, in abbreviated form, in the rightmost column of Table 6-1. Here, for Occupancy Category II buildings, the scope and criteria already provided in 2010 CBC and SFBC Section 3405 are useful as starting points. These are appropriate for retrofit triggered by Substantial Structural Damage, but could be modified as follows for retrofit triggered by Disproportionate Damage.

Elements considered: While retrofit triggers sometimes consider individual elements, wall lines, stories, and loading directions, work triggered by Section 3405 generally applies to the whole structure—that is, all stories in both directions. (Exceptions apply where approved alternative criteria allow partial retrofit. For example, see the alternative criteria for soft-story buildings, discussed below.) This comprehensive approach is appropriate for work triggered by Substantial Structural Damage. For work triggered by Disproportionate Damage, San Francisco could limit the retrofit to the damaged direction and/or to the stories at or below the damage. Partial retrofit, it could be argued, is less costly and disruptive, so a partial retrofit policy would have greater acceptance and higher rates of compliance. In the present case, however, Disproportionate Damage is already expected to be very rare, and relaxed evaluation criteria are already expected to reduce the amount of triggered work. Also, as noted below, criteria for soft-story buildings—buildings of most concern in this group—already allow partial retrofit. Therefore, Table 6-1 generally maintains the comprehensive approach even for work triggered by Disproportionate Damage. An exception is made for Disproportionate Damage to certain load path elements whose damage is independent of the overall seismic-force-resisting system.

Gravity system elements: For both Substantial Structural Damage and Disproportionate Damage cases, the building's gravity load-carrying components are exempt from upgrade triggered by earthquake effects, except to the extent that those components also are part of the building's seismic-force-resisting system. In fact, earthquake damage to gravity-carrying components is generally a sign of a deficient seismic force-resisting system, so if that damage exceeds a triggering level, it is the seismic system that should be upgraded, as contemplated by CBC Section 3405.3.1 and as reflected in the discussion of damage patterns above and in Table 6-1.

Nonstructural components: While building codes are not explicit on this point, conventional practice is to ignore nonstructural components when implementing triggered seismic retrofits. This report supports that practice and recommends limiting the triggered work in both Substantial Structural Damage and Disproportionate Damage cases to the (intended or *de facto*) seismic-force-resisting elements. There may be cases where nonstructural components (brick veneer, for example) can compromise the performance objective, but in the context of triggered retrofit these may be reasonably ignored. If such components are damaged, they will still have to be repaired (and a voluntary upgrade will often be just as cost-effective); no triggered upgrade is necessary.

Load types: Under CBC Section 3405, Substantial Structural Damage triggers evaluation (and possibly retrofit) for both wind and seismic loads. For Disproportionate Damage, which is unique to San Francisco and intended specifically to address earthquake risk, this report recommends that only seismic loads be considered.

Engineering criteria: CBC Section 3405 allows "75 percent" reduced seismic loads for work triggered by Substantial Structural Damage. (This is the same allowance historically provided by SFBC Section 1604.11 and 104(f).) Reduced loads are also appropriate for work triggered by Disproportionate Damage. In addition, the following alternative evaluation and design criteria are also appropriate for work triggered by either Substantial Structural Damage or Disproportionate Damage:

- 2009 IEBC criteria, as allowed by the 2009 IBC and the 2010 CBC and SFBC. (The IBC section number is 3401.5. The CBC and SFBC section number will depend on California code modifications; it is expected to be Section 3401.8, to be clarified by published errata.) The 2009 IEBC offers several options deemed equivalent to the "75 percent" reduced seismic loads:
  - *Life Safety provisions of ASCE 31*. (Note that ASCE 31 requires a "Tier 2" full-building evaluation for type W1 and W1A structures taller than two stories in areas of high seismicity such as San Francisco.)
  - *Life Safety provisions of ASCE 41*, considering the Life Safety/BSE-1 earthquake hazard level.
  - *IEBC Appendix Chapter A4, for buildings with soft, weak, or open-front walls*. Since Chapter A4 limits the retrofit work to the soft story, it applies only when the triggering damage is limited to that story. In addition, note that Chapter A4 will be substantially revised and improved for the 2012 edition. Where Chapter A4 is cited, either the 2012 edition or the 2009 edition with the NCSEA/SEAOC-proposed modifications should be used. Oakland's soft story ordinance and San Francisco DBI's voluntary retrofit incentives (DBI, 2010) already do this.
- CBC Sections 3415-3420, intended for state-owned buildings, allow the use of ASCE 41 with a hazard level reduced with the same intent as the 75 percent factor in Section 3405. Section 3415.1.1 allows local jurisdictions to use Sections 3415-3420, though adoption in their entirety might be necessary to take advantage of them. Absent full adoption, the building official should be able to authorize customized criteria based on Sections 3415 to 3420 on a case-by-case basis.
- Criteria developed by ATC (in preparation) for a San Francisco mandatory soft-story retrofit should be applicable, pending confirmation that the final ordinance requirements are sufficiently similar to the Life Safety/BSE-1 performance objective or to the results of a "75 percent of code" retrofit.
- In general, a jurisdiction must allow the owner of an eligible historic building to use alternative engineering criteria provided in the *California Historical Building Code* (CBSC, 2007. See Title 24 Part 8, Section 8-102.1.). In general, the CHBC criteria are consistent with the safety-based performance objectives of the criteria listed above, but the intentional flexibility of the CHBC makes full equivalence unpredictable. If San Francisco seeks higher performance or tighter requirements when retrofit is triggered, it could disallow the CHBC for certain subsets of buildings it designates as "distinct hazards." See Section 8.7 of this report for further discussion.

6.2.4 Coordination with Existing Programs

- San Francisco has addressed or is in the process of addressing soft-story multi-unit wood-frame residential buildings through various programs. DBI (2010) specifies criteria and procedures to qualify for incentives for voluntary retrofit. A program for mandatory evaluation and retrofit of certain buildings is currently in development. As the city adopts the provisions recommended here for triggered retrofit, coordination with existing voluntary and mandatory programs is recommended. In most cases, special coordination provisions should not be needed, as the triggered scope and criteria are expected to mesh with those of the voluntary and mandatory programs. Regarding compliance schedules, the more restrictive of the triggered and mandatory provisions would apply.

6.3 Implementation Recommendations

6.3.1 Recommended Building Code Amendment

As noted in Section 5.3.1, certain amendments must be made to the SFBC to formalize the concept of Disproportionate Damage. The recommendations of Section 5.3.1 also apply to Chapter 6.

6.3.2 Recommended Wording for Administrative Bulletin

This section recommends text for a San Francisco Department of Building Inspection Administrative Bulletin to implement the recommendations in Table 6-1 for multi-unit wood-frame residential buildings. The purpose of the Administrative Bulletin is to interpret the existing CBC and SFBC provision regarding Substantial Structural Damage and the proposed SFBC provision (see Section 6.3.1 above) for Disproportionate Damage.

In the text that follows, italicized parenthetical remarks are notes to DBI staff for use in preparing a draft Bulletin for approval by the Building Inspection Commission.

TITLE: Seismic Retrofit Triggers, Scope, and Criteria for Retrofits of Multi-Unit Wood-Frame Residential Buildings Triggered by Earthquake Damage

PURPOSE: The purpose of this Bulletin is to establish Department policy for interpreting damage definitions in the San Francisco Building Code and for setting the scope and criteria of triggered retrofits.

REFERENCE:

2010 *California Building Code* (CBC) Sections 3402 and 3405.

2010 *California Historical Building Code* (CHBC), CCR Title 24 Part 8.

2010 *San Francisco Building Code* (SFBC) Sections 3402 and 3405.

2012 *International Existing Building Code* (IEBC) *Appendix* Chapter A4 (or 2009 IEBC Appendix Chapter A4 with NCSEA/SEAOC amendments).

ASCE/SEI Standard 31-03, *Seismic Evaluation of Existing* Buildings.

ASCE/SEI Standard 41-06, Seismic Rehabilitation of Existing *Buildings*, with Supplement 1.

ATC-71-1 Report, *Simplified Interim Guidelines for Seismic Retrofit of Weak-Story Wood-Frame Buildings* (ATC, in preparation).

CAPSS Report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Post-Earthquake Repair and Retrofit Requirements* (ATC-52-4 Report).

DISCUSSION:

CBC Section 3405.2 triggers seismic evaluation, and possibly retrofit, when earthquake damage reaches the level of "substantial structural damage to vertical elements of the lateral-force-resisting system." Substantial structural damage is defined in Section 3402 as, in essence, a capacity loss of 20 percent. But the code gives no rules for identifying a 20-percent loss or even for how to calculate capacity loss in general, so implementation of these provisions relies on interpretation by the Department. This Bulletin presents the Department's interpretation of a 20-percent lateral capacity loss in terms based on visual indicators of critical damage modes. *(This Administrative Bulletin is written as a strict interpretation of substantial and disproportionate damage. Cut-off dates delineating complying buildings or evaluation methods to show "compliance" are not included. However the DBI may want to broaden the scope to include approved methods—or dates—for classifying a buildings as complying as well as indicating that such buildings only need be repaired. An Administrative Bulletin with such a scope could be a stand-alone document for dealing with earthquake damage for the given building type.)*

(Provisional, pending SFBC adoption of provisions for Disproportionate Damage.) Further, SFBC Section 3405.4 triggers seismic evaluation, and possibly retrofit, when earthquake damage reaches the level of "disproportionate damage," defined in Section 3402 as, in essence, a lateral capacity loss of 10 percent. This Bulletin presents the Department's interpretation of a 10-percent capacity loss in terms based on visual indicators of critical damage modes.

APPLICABILITY:

Buildings that satisfy the following criteria are eligible for the interpretations and provisions of this Bulletin. Other buildings, if not eligible for interpretations of similar Bulletins, are subject to the code provisions as interpreted by the Department on a case-by-case basis. The provisions of this Bulletin shall apply to all eligible buildings, except that at the discretion of the Department, measurements of capacity loss based on analysis, testing, or other objective data may be allowed.

A. The building's structure includes at least one story in which the seismic-force-resisting system is a wood light-frame system in at least one direction. This Bulletin applies only to the stories and directions with wood light-frame systems.

B. The building has wood floor and roof diaphragms.

C. The building has a continuous foundation.

D. The building is assigned to Occupancy Category I or II and contains more than two residential units in occupancy group R-1, R-2, R-3.1, or R-4. At the discretion of the Department, buildings with one or two residential units may be deemed eligible if they are structurally and architecturally similar to typical multi-unit residential buildings.

SUBSTANTIAL STRUCTURAL DAMAGE:

Substantial Structural Damage to the vertical elements of the lateral-force-resisting system shall be deemed to exist when any of the following damage patterns is observed in an eligible building:

A. In any story, in any direction, the total length of wall segments and piers with any of the following damage patterns, separately or in combination, is 20 percent or more of the total length of wall segments and piers in that story and direction. Only wall segments or piers contributing significant strength or stiffness to each wall line of the pre-damage structure need be considered. Large openings do not count toward the total length of wall segments and piers.

- Stucco or plaster loose at more than one wall stud.
- Nail pull-through at wood or gypsum-board sheathing at more than one wall stud.
- Visible permanent in-plane racking.
- Diagonal shear cracking across half or more of a plaster or stucco panel.
- Horizontal flexural cracking across half or more of a plaster or stucco panel.
- Loss of nailing connection from sheathing to top plate or sole plate.

B. Any of the following damage patterns to connections and load path elements, separately or in combination:

- Hold-down pullout or stud fracture at hold-down.
- Sliding of sole plate at floor line.
- Sliding of sill plate at top of footing.

C. Gravity-load-carrying members, connections, and load path elements with any of the following damage patterns, separately or in combination, as a group support more than 30 percent of the total area of the structure's floor(s) and roof(s), and the remaining capacity of any damaged component with respect to all dead and live loads is less than 75 percent of that required for new buildings of similar structure, purpose, and location.

- Damage of the shear connection between floor framing and column wall.
- Loss or substantial reduction of seat bearing.
- Crushing, fracture, or shortening of posts, or wall studs.
- Column, post, or pier damage due to deformation incompatibility.
- Subsidence or differential settlement of foundation.

D. Permanent story drift of 2 percent or more in any story.

E. Either of the following damage patterns:

- Significant stiffness loss on more than one perimeter wall line.
- Significant strength loss not balanced between wall lines on opposite sides of building.

(Provisional, pending SFBC adoption of provisions for Disproportionate Damage.)

DISPROPORTIONATE DAMAGE:

Disproportionate Damage to the vertical elements of the lateral-force-resisting system shall be deemed to exist when any of the following damage patterns is observed in an eligible building at which the 0.3-second spectral acceleration estimated by the U. S. Geological Survey ShakeMap, as approved by DBI, is not more than 0.40g.

A. In any story, in any direction, the total length of wall segments and piers with any of the following damage patterns, separately or in combination, is 20 percent or more of the total length of wall segments and piers along that wall line in that story. Only wall segments or piers contributing significant strength or stiffness to each wall line of the pre-damage structure need be considered. Large openings do not count toward the total length of wall segments and piers.

- Stucco or plaster loose at more than one wall stud.
- Nail pull-through at wood or gypsum-board sheathing at more than one wall stud.
- Visible permanent in-plane racking.
- Diagonal shear cracking across half or more of a plaster or stucco panel.
- Horizontal flexural cracking across half or more of a plaster or stucco panel.
- Loss of nailing connection from sheathing to top plate or sole plate.

B. Any of the following damage patterns to connections and load path elements, separately or in combination:

- Hold-down pullout or stud fracture at hold-down.
- Sliding of sole plate at floor line.
- Sliding of sill plate at top of footing.

C. Gravity load-carrying members, connections, and load path elements with any of the following damage patterns, separately or in combination, as a group support more than 10 percent of the total area of the structure's floor(s) and roof(s), and the remaining capacity of any damaged component with respect to all dead and live loads is less than 75 percent of that required for new buildings of similar structure, purpose, and location.

- Damage to shear connection between floor framing and to column or wall.

- Loss or substantial reduction of seat bearing.
- Crushing, fracture, or shortening of posts, or wall studs.
- Column, post, or pier damage due to deformation incompatibility.
- Subsidence or differential settlement of foundation.

D. Permanent story drift of 1 percent or more in any story, or a pattern of jammed doors or windows repairable only by structural repair (not by reframing openings).

E. Any of the following damage patterns:

- Significant stiffness loss on more than one perimeter wall line.
- Significant strength loss not balanced between wall lines on opposite sides of building.
- Any visual obvious permanent deformation.

F. Any of the following damage patterns, separately or in combination, such that at any floor level, the damage affects the load path to more than one pier or wall segment, or affects the load path to the only pier or wall segment along a wall line.

- Failure of diaphragm-to-wall connections at rim joist or blocking.
- Collector or chord failure.

EVALUATION OR RETROFIT SCOPE FOR BUILDINGS WITH SUBSTANTIAL STRUCTURAL DAMAGE:

For buildings with Substantial Structural Damage, evaluation and retrofit (where required) shall proceed in accordance with CBC Section 3405.2, subject to the following interpretations as to scope of work:

A. Evaluation or retrofit shall consider the entire structure, i.e., all stories and all directions, regardless of where in the structure the triggering damage occurred. Exception: Buildings and damage patterns eligible for partial retrofit under one of the alternative criteria documents.

B. Gravity-load-carrying components need not be considered except to the extent that they are also part of the building's seismic-force-resisting system.

C. Nonstructural components need not be considered.

D. Load cases that include either wind or earthquake effects shall be considered.

(Provisional, pending SFBC adoption of provisions for Disproportionate Damage.)

EVALUATION OR RETROFIT SCOPE FOR BUILDINGS WITH DISPROPORTIONATE DAMAGE:

For buildings with Disproportionate Damage, evaluation and retrofit (where required) shall proceed in accordance with SFBC Section 3405.4.1, subject to the following interpretations as to scope of work:

A. Evaluation or retrofit shall consider the entire structure, i.e. all stories and all directions, regardless of where in the structure the triggering damage occurred. Exception: Buildings and damage patterns eligible for partial retrofit under one of the alternative criteria documents.

   Exception: Where the triggering damage is limited to connections or load path elements and does not affect wood-frame wall segments, piers, or other "vertical elements of the lateral-force-resisting system," the evaluation or retrofit scope may be limited to components throughout the building in all directions similar to or performing the same function as the components with triggering damage.

B. Gravity-load-carrying components need not be considered except to the extent that they are also part of the building's seismic-force-resisting system.

C. Nonstructural components need not be considered.

D. Only load cases that include earthquake effects need be considered.

EVALUATION OR RETROFIT ENGINEERING CRITERIA:

Where evaluation or retrofit is triggered by earthquake damage at any level, the engineering criteria shall be permitted to use earthquake loads that are 75 percent of those prescribed by the SFBC for new construction, in accordance with CBC Section 3405.2. Any of the following alternative codes, standards, or guidelines may be used as alternative criteria for qualifying buildings:

A. ASCE 31-03, *Seismic Evaluation of Existing Buildings*, at the Life Safety performance level.

B. ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, with a structural performance objective of Life Safety in a BSE-1 hazard.

C. 2012 *International Existing Building Code* (IEBC) Appendix Chapter A4 (or 2009 IEBC Appendix Chapter A4 with NCSEA/SEAOC amendments).

D. 2010 *California Building Code* Section 3415-3420.

E. 2010 *California Historical Building Code* (California Title 24 Part 8).

F. *(Provisional, pending completion of ATC-71-1)* ATC-71-1 Report, *Simplified Interim Guidelines for Seismic Retrofit of Weak-Story Wood-Frame Buildings* (ATC, in preparation).

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CHAPTER 7: OLDER CONCRETE BUILDINGS

7.1 Characteristics of Building Type

7.1.1 Description of Building Type

Scope of Included Building Types

This group covers three general concrete building types: concrete moment-frame, concrete shear-wall, and concrete frames with infill masonry. In the FEMA Model Building Type designations used in publications such as ASCE 31-03 (ASCE, 2003), these are identified as Types C1, C2, and C3, respectively. Only buildings with concrete floor systems are included; concrete buildings with wood floors (Types C2A and C3A) are not included. Also not included are tilt-ups (Type PC1), precast frames (Type PC2), or lift slab construction. The following summaries briefly describe each of the three covered types; most of the material is taken or edited from FEMA 547, *Techniques for the Seismic Rehabilitation of Existing Buildings* (FEMA, 2006). For a more detailed description of the types (including illustrations) and their seismic response characteristics, see FEMA 547 itself.

Concrete Moment-Frame Buildings

These buildings consist of concrete framing, either a complete system of beams and columns or columns supporting slabs without gravity beams. Lateral forces are resisted by cast-in-place moment frames that develop stiffness through intended or unintended rigid connections of the column and beams or slabs. The lateral-force-resisting frames could consist of the entire column and beam system in both directions, or the frames could be placed in selected bays in one or both directions. An important characteristic is that no significant concrete or masonry walls are present, or that they are adequately separated from the main structure to prevent interaction. Some buildings of this type have frames specifically designed for lateral loads, but also have interacting walls apparently unaccounted for in the design. These buildings could be classified in the moment-frame building type, noting the potentially interacting walls, or they could be put in the concrete shear-wall building type.

Older concrete buildings may include frame configurations that were not designed for lateral load, but if no walls or braces are present, the frames become the effective lateral-force-resisting system and should be included in this building category. Frames classified by code as ductile or semi-ductile beginning in the late 1960s and early 1970s are far more constrained in configuration due to prescriptive rules governing girder configuration, strong column and weak beam layout, and limitations on joint shear. Buildings of this type that have integral masonry walls on the perimeter should be placed in the concrete frames with infill masonry building type. Floors may be a variety of cast-in-place or precast concrete systems.

Concrete Shear-Wall Buildings

Reinforced concrete walls in a building will act as shear walls whether designed for that purpose or not. Therefore, cast-in-place concrete buildings that contain any significant amount of concrete wall will fall into this category. However, there are two distinctly different types of concrete wall buildings: those that contain an essentially complete beam/slab and column gravity system, and those that use bearing walls to support gravity load and have only incidental beam and column framing.

Buildings Using Bearing Walls To Support Gravity Load

In this type of building, all walls usually act as both bearing and shear walls. The structural type is often used in mid- and low-rise hotels and motels. This system is also used in many residential apartment/condominium type buildings.

In order for this framing system to be efficient, a regular and repeating pattern of concrete walls are required to provide support points for the floor framing. In addition, since it is difficult and expensive to make significant changes in the plan during the life of the building, planning flexibility is not normally an important characteristic of the building occupancy. The occupancy type that most often fits these characteristics are residential buildings, including dormitories, apartments, motels, and hotels. These buildings will often be configured with reinforced concrete bearing walls between rooms that also act as shear walls in the transverse direction, and reinforced concrete walls on the interior corridors acting primarily as shear walls in the longitudinal direction. Sometimes, the longitudinal lateral-force-resisting system includes the exterior wall system, although this wall is normally made as open as possible.

It is seldom possible to plan a building layout that provides complete gravity support with walls only and often local areas are supported with isolated columns and sometimes with beams and girders, but story heights in these buildings are usually small, and added depth in the floor framing system for girders is difficult to obtain. The extent of such beam and column framing may suggest a structural system of frames with walls, but structures should have an essentially complete gravity frame system to be considered a frame with walls. If significant plan area is supported solely by walls, the structures are normally classified as bearing wall.

Buildings Using Frames To Support Gravity Load

Other concrete buildings use columns and beams to support gravity loads rather than bearing walls. Although it is typically assumed that the gravity framing is not part of the lateral force-resisting system, the framing could add stiffness to the building, particularly near the top of taller buildings. This building type is very common and has been used in a wide variety of occupancies and in all sizes.

In buildings with incidental concrete walls and a substantial beam-column gravity frame system, this building type merges with the concrete moment-frame building type.

Gravity frame systems in this building type include cast-in-place concrete beam and slab, one-way joists, two-way waffles, and two-way or flat slabs.

In earlier concrete buildings of this type, the walls were often intended for fire protection of vertical shafts, or as exterior closure walls. Later buildings often were designed with a shear-wall lateral-force-resisting system, but they are now often found deficient due to low global strength, a highly torsional plan layout, or detailing that leads to premature shear failure.

In buildings designed with shear walls, the walls are either strategically placed around the plan, or at the perimeter. Shear-wall systems placed around the entire perimeter almost always contain windows and other perimeter openings and are often called punched shear walls. On the other hand, older buildings will have concrete walls somewhat arbitrarily placed in plan.

Concrete Frames with Infill Masonry Shear Walls

Buildings in the infill family are normally older buildings that consist of an essentially complete gravity frame assembly of concrete columns and floor framing systems. The floors can consist of a variety of concrete systems including flat plates, two-way slabs, and beam and slab. Exterior walls, and possibly some interior walls, may be constructed of unreinforced masonry, tightly infilling the space between columns horizontally and between floor structural elements vertically, such that the infill interacts with the frame to form a lateral-force-resisting element. Exterior wall infills may also include lightly reinforced concrete, often 6″ to 8″ thick and poorly reinforced. Windows and doors may be present in the infill walls. The buildings that fall into this category could have exposed clay brick masonry, terra cotta, or exposed concrete on the exterior.

The archetypical infill building has solid clay brick at the exterior with one wythe of brick running continuously past the plane of the column and beam, and two or more wythes infilled within the plane of the column and beam. The exterior wythe of clay brick forms the finish of the building although patterns of terra cotta, stone, or precast concrete may be embedded into the brick. However, there can be many variations to this pattern, depending on the number and arrangement of finished planes on the exterior of the building. For example, the full width of the infill wall may be located within the plane of the column and beam with a pilaster built out and around the column and a horizontal band of brick or other material covering the beam; the beam may also be slightly offset from the centerline of the column to accommodate the pattern of exterior finishes.

Hollow-clay-tile masonry may also be used as an exterior infill material. Although this material often has a very high compression strength, the net section of material available to form the compression strut within the frame will normally contribute a lateral strength of only a small percentage of the building weight. The material being brittle and the wall being highly voided, these walls may also lose complete compressive strength quite suddenly. Therefore, walls of hollow-clay-tile infill will probably not contribute a significant portion of required lateral resistance except when walls are arranged as infill on both the exterior and interior of the building.

More recent buildings may have unreinforced concrete block masonry configured as an exterior infill wall, with a variety of finish materials attached to the outside face of the concrete block. Similar to hollow clay tile walls, these walls may exhibit moderate-to-low compressive strength and brittle behavior that marginalizes their usefulness as lateral force-resisting elements. In addition, hollow-concrete-block exterior walls often will not be installed tight to the surrounding framing, eliminating infill compression strut behavior.

7.1.2 Complying Buildings

Definition of Complying Buildings

In accordance with current San Francisco policy, buildings that meet the requirements of *San Francisco Building Code* (SFBC) Section 1604.11 are considered “complying,” and earthquake damage need only to be repaired to comply with the original design code. 2007 SFBC Section 1604.11.1 defines the milestone date as “the San Francisco Building Code in effect on or after May 21, 1973.” On May 21, 1973 and June 25, 1973, the Board of Supervisors passed a series of amendments to the 1972 SFBC. The next edition of the SFBC was the 1975 version.

Potential Issues with Use of 1973 as the Milestone Date for Older Concrete Buildings

The 1973 SFBC milestone date is used for all building types, even though code provisions evolve differently for different structural systems. ASCE 31-03 (ASCE, 2003), on the other hand, has varying milestone dates or “benchmark years” for different structural systems, and uses the 1976 *Uniform Building Code* (UBC) for both concrete moment-frame and concrete shear-wall buildings. There is no UBC benchmark year for concrete frames with URM infill. It is important to understand the context for changes in code provisions for concrete buildings before and after the SFBC milestone date. A short summary follows.

Uniform Building Code

The first *Uniform Building Code* is the 1927 edition. Earthquake requirements were contained in an appendix. There were two categories for lateral forces. When the allowable gravity bearing pressure on the footings was 4000 psf or more, the allowable stress design (ASD) base shear was $V = 0.075W$ where W was the dead load plus live load. For weaker soils with allowable footing pressures of less than 4000 psf and for pile supported structures, $V = 0.10W$. Shear stresses in concrete walls were limited to 4% of the compressive strength of the concrete. There were no concrete detailing provisions.

In the 1935 UBC, the western states were mapped into three earthquake zones, with coastal California placed in the highest zone. For footing pressures over 2000 psf, the ASD base shear was $V = 0.08W$ where W was the dead load plus half the live load; and buildings founded on weaker soils below 2000 psf, V=$0.16W$. Shear stresses in concrete walls were limited to 5% of the compressive strength of the concrete. Earthquake provisions remained unchanged until the 1949 UBC.

In the 1949 UBC, the base shear equation was modified and depended on the number of stories, with lower loads for more stories. For a one-story building, $V = 0.133W$, where W was the dead load plus the live load. Detailing provisions now included minimum thicknesses for shear walls and minimum reinforcing ratios. The base shear used for design depended on the type of structural system and the period of the building fundamental mode. These provisions continued up to the 1961 UBC, except for a change in the 1958 edition in the definition of W to only include half the live load.

In the 1961 UBC, the base shear equation was modified; the concepts of vertical-load-carrying space frames, moment-resisting space frames, shear walls, and box systems were defined; and detailing provisions were modified. For a typical shear-wall building without a complete vertical-load-carrying space frame (a “box system”), the base shear remained at $V = 0.133W$. Minimum concrete wall-to-diaphragm anchorage forces were added, and prescriptive details for reinforcing bar layers were added. An explicit note was added that all concrete or masonry elements within the structure that resist seismic forces were to meet the reinforced concrete detailing requirements.

In the 1967 UBC, significant changes were made to detailing provisions for concrete buildings. The concept of a ductile moment-resisting space frame was introduced. This included stirrups in beam ends and plastic hinge zones at $d/4$ (d = effective depth of reinforcing bars), $16d_b$ (d_b = bar diameter) or 12" and special transverse reinforcing in columns at a maximum spacing of 4". Detailing provisions were introduced for concrete shear walls, including boundary elements that had to carry dead, live and earthquake forces and the requirement to anchor horizontal reinforcing to the boundary elements. For a typical shear-wall building, the ASD base shear of $V = 0.133W$ was doubled unless a moment-resisting space frame was provided. Provisions in the 1970 UBC were unchanged.

In the 1973 UBC, some additional requirements were added for concrete moment-frame buildings, including deformation compatibility requirements for the gravity-load-carrying members not designed as part of the lateral system.

In the 1976 UBC, the base shear equation was revised. For a typical shear-wall building without a complete vertical-load-carrying frame, the allowable stress design base shear rose to $V = 0.186W$.

In the 1985 UBC, both the concrete frame and shear-wall provisions were significantly revised. Changes include eliminating the force increase without a space frame, but adding capacity reduction factors for shear-critical behavior; development lengths for seismic loading, equations for calculating shear capacity in walls and diaphragms, and requirements on members that are not part of the defined lateral-force-resisting system.

San Francisco Building Code

The first SFBC to have earthquake provisions was the 1948 version. For a one-story building, $V = 0.08W$, where W was the dead load plus live load. Forces were increased for buildings on poor soil and decreased if the building was bearing on rock. There were values for design of parts of structures, torsion checks, overturning checks, and requirements related to height. Provisions in the 1952 SFBC were unchanged.

In the SFBC approved on April 6, 1956, base shear was a maximum of $V = 0.075W$, where W was the dead load plus half the live load. An increase of 25% was required for buildings "on marshy or filled ground, whether carried on piles or not, unless the footings under the columns are so interconnected as to prevent horizontal displacement."

In the SFBC with an effective date of May 6, 1962 (with amendments up to and including August 30, 1962), requirements were similar to the 1961 UBC.

The SFBC with an effective date of March 20, 1969; the amendments through July 1, 1970; the 1972 SFBC with amendments through 1973; and the 1975 SFBC with amendments through 1982 were all similar to the 1967 UBC, with some adjustment in design values for elements in moment frames.

In the 1984 SFBC, the requirements of 1979 UBC were adopted with the force increase that had occurred in the 1976 UBC. Thus, for a typical shear-wall building without a complete vertical-load-carrying frame, the allowable stress design base shear rose to $V = 0.186W$.

Subsequent versions of the SFBC have generally followed the UBC requirements.

Recommended Milestone Date for Older Concrete Buildings

A key conclusion from the above summary is that there were no significant code changes impacting concrete buildings in San Francisco until the 1969 SFBC when ductile detailing provisions became required and then with the 1984 SFBC when the base shear increased by 40% (for typical shear-wall buildings).

The use of 1973 as the milestone date thus means that the early ductile detailing provisions are required, but the force increase that occurred much later is not required. Consistent with the expected performance goals for typical triggered retrofits, this is believed to be reasonable, and a change in the milestone date is not deemed necessary for older concrete buildings.

7.1.3 Concrete Building Stock in San Francisco

The Concrete Coalition—a network of individuals, governments, institutions, and agencies with shared interest in assessing the risk associated with dangerous non-ductile concrete buildings and developing strategies for fixing them (Comartin et al., 2008)—has made a number of efforts to investigate the building stock in San Francisco and to help quantify the number of concrete buildings in the City and develop an inventory. Efforts have included review of assessor records, Sanborn maps, sample field verifications, and in early 2010, a more extensive walkthrough of the downtown business district. To conservatively account for the possibility of delayed implement-tation of building code changes, the Coalition has used 1980 as a milestone date.

Prior to the 2010 walkthrough, Kadysiewski (2009) reported that the "final estimated count of pre-1980 concrete buildings existing today is approximately 3,000…. The total number of concrete buildings of all ages is estimated at 3,700." By comparison, "it is estimated that there are a total of 130,000 buildings of all types in San Francisco today, of which 115,000 were built before 1980." More recent work done as part of the CAPSS project places the total number of buildings in San Francisco at approximately 160,000.

7.1.4 Typical Damage States

The following discussion on typical damage states has been drawn from several documents, most notably those developed under the FEMA-sponsored ATC-43 project, which was initiated following the 1994 Northridge earthquake to develop more rational procedures for understanding and quantifying the damage to earthquake-damaged concrete and masonry wall buildings. It resulted in the FEMA 306, 307 and 308 report series (FEMA, 1999a, b, c). FEMA 306, *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Basic Procedures Manual* (FEMA, 1999a), provides evaluation procedures for damaged concrete wall, masonry wall, steel and concrete frame with masonry infill, and unreinforced masonry wall buildings. It did not cover concrete moment-frame buildings. FEMA 307, *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Technical Resources* (FEMA, 1999b), provides the research basis for the methodology. FEMA 308, *The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings* (FEMA, 1999c), describes a potential policy framework for using the FEMA 306 results in determining whether damage to a building could be accepted with structural repairs, whether restoration to the pre-event condition was needed, or whether upgrade would be required to both repair the damage and provide additional capacity beyond the original pre-event capacity.

The FEMA 306 method is displacement-based and requires development of a global force-displacement or "pushover" curve for the structure, both in the pre-event (undamaged) and the damaged condition. The method emphasizes determining the components (piers, spandrels, joints) in the wall system and the governing behavior modes that the components have experienced. Detailed guides are provided for common components and behavior modes. The guides categorize the damage states (Insignificant, Slight, Moderate, Heavy and Extreme) and provide reduction factors for reducing the strength and stiffness of the component at each level of damage. A performance objective is then selected so that a target demand can be established for both the pre-event and damaged conditions.

A key finding of FEMA 306 is that indications of damage, such as cracking and spalling, are only meaningful in light of the mode of component behavior. For example, FEMA 306 notes that "A one-eighth-inch crack in a wall panel on the verge of brittle shear failure is a very serious condition. The same size crack in a flexurally-controlled panel may be insignificant with regard to future seismic performance" (FEMA, 1999a). For concrete shear-wall and infill-frame buildings, the FEMA 306 classifications for components, behavior modes, and damage states are used in this report.

Concrete Wall Damage/Behavior Modes

FEMA 306 organizes wall behavior modes into three categories of ductility: high, intermediate, and limited. See FEMA 306 for details.

- *High Ductility*: Adequately designed reinforced concrete walls of various configurations can respond to earthquake shaking in a ductile manner. Ductile wall response usually results from flexural behavior, which requires that the wall components be designed to avoid failures in shear, buckling of longitudinal bars, loss of concrete strength, lap splice slip, and out-of-plane wall buckling. Modes include:
    - Ductile flexural response;
    - Foundation rocking of individual wall piers; and
    - Global foundation rocking of wall.
- *Intermediate Ductility*: The earthquake response in the following behavior modes is initially governed by flexure, but after some number of cycles, reaching some level of earthquake displacements, a response mode other than flexure predominates. At this point, the component suffers strength degradation.
    - Flexure then diagonal tension;
    - Flexure then web crushing;
    - Flexure then sliding shear;
    - Flexure then boundary-zone compression;
    - Flexure then lap-splice slip; and
    - Flexure then out-of-plane wall buckling.

- *Limited or No Ductility*: The following brittle failure modes preempt any flexural yielding of the wall component. They are force-controlled rather than displacement-controlled modes, as defined in FEMA 356, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (FEMA, 2000a).
    - Preemptive diagonal tension;
    - Preemptive diagonal compression (web crushing);
    - Preemptive sliding shear;
    - Preemptive boundary-zone compression; and
    - Preemptive lap-splice slip.

The recent February 27, 2010 magnitude-8.8 earthquake in Chile provided a significant test of modern concrete shear-wall buildings, and there was widely varying damage. Though the buildings have some significant design differences from U.S. buildings, they also have many similarities. It was observed that many of the Chilean buildings have relatively thin walls and small rebar sizes, yet they often may have relatively large ratios of wall area to floor area. Research over time will lead to a better understanding of why some buildings were heavily damaged and others were not, even when detailing seemed similar and they were close to one another. At this point, we can say that many of the above failure modes were observed, and that many of the damaged buildings lacked ductile detailing in the shear walls. This led to numerous examples of boundary zone compression, as well as diagonal tension cracking, and out-of-plane wall buckling.

Besides damage to wall components and to gravity-load-carrying elements discussed in the section on concrete moment-frame buildings, there can be damage to concrete floor systems in shear-wall buildings. The parallel layouts of supporting walls and the need to minimize story heights normally leads to the use of one-way uniform-depth concrete floor systems. Cast-in-place and precast systems, both conventionally reinforced and prestressed, have been employed. The precast systems are often built up of narrow planks, which may not provide an adequate diaphragm unless a cast-in-place topping is provided. In addition, the precast systems may be placed with only a very narrow bearing area on the supporting walls, which may be inadequate to provide vertical support during seismic movements. The adequacy of the shear connection between slab and walls is also often an issue for both cast-in-place and precast systems. Either of these deficiencies could lead to collapse of a bay.

Concrete Infill Wall Damage/Behavior Modes

FEMA 306 separated behavior modes for infilled frames into configurations where the infill was a solid panel fully infilling the frame and those with partial infill and then further categorized modes by ductility capacity. A summary of modes follows. See FEMA 306 for more detail.

- Solid infill panel damage/behavior modes:
    - High ductility: bed joint sliding;
    - Moderate ductility: diagonal cracking and corner compression crushing of the infill against the frame; and
    - Low ductility: out-of-plane failure of the infill.

- Infilled concrete frame damage/behavior modes:
    - High ductility: flexural yielding of frame;
    - Moderate to low ductility: lap-splice slip and column tension yielding; and
    - Low ductility: shear failure or joint failure of the frame.

Concrete Frame Damage/Behavior Modes

FEMA 306 does not cover concrete frames. The following list of potential damage and behavior modes for the concrete moment frames is taken in part from ATC-14, *Evaluating the Seismic Resistance of Existing Buildings* (ATC, 1987), and ATC-20, *Procedures for Postearthquake Safety Evaluation of Buildings* (ATC, 1989*)*:

- Column shear failure due to inadequate confinement, inadequate shear strength, or short column effects;
- Column compression failure;
- Column lap-splice failure;
- Column-beam joint failure, particularly at exterior locations where there is a lack of confinement on one or more faces;
- Beam shear failure due to inadequate confinement or shear strength;
- Beam failure due to lack of adequate longitudinal beam bar continuity through the column;
- Story mechanism formation due to a strong beam and weak column layout;
- Transfer girder failure due to plan offsets in column location;
- Panel zone torsion due to offsets and eccentricities in between girders and columns in exterior frames;
- Excessive residual drift due to inadequate strength and stiffness;
- Excessive torsional response due to eccentric frame layouts;
- Punching shear failure in older building with only slabs as the beam element of the frame; and
- Post-tensioning damage.

Foundation Damage

Concrete buildings have a wide variety of foundation types, which are largely dependent on site constraints and soil conditions. More severe damage states include pile cap failures due to lack of top reinforcing for negative moments, pile failures due to lack of ductile detailing, excessive settlement, and shear failures in grade beams. Foundation damage, however, is generally not a common behavior mode in concrete buildings, and it is usually difficult to see and document. Foundation damage can lead to superstructure damage in some cases. For this report, specific foundation damage provisions are not identified; rather foundation damage and soil movement are viewed in the context of the damage resulting in the superstructure.

7.2 Recommendations

7.2.1 Use of FEMA 306 and FEMA 308

Damage repair and upgrade recommendations for concrete shear-wall and infill buildings are based on the FEMA 306 procedures, with additional requirements. These additional requirements include triggers for specific component damage and conditions that primarily relate to damage to the gravity-load-carrying system, which was not directly addressed in FEMA 306. These requirements also incorporate the Disproportionate Damage concept discussed in Chapter 4. FEMA 306 covered only concrete wall and masonry infill wall buildings; it did not cover concrete moment frames. Damage repair and upgrade provisions for concrete moment-frame buildings are based on specific component damage and conditions.

FEMA 306 was selected for use in evaluating the concrete shear-wall and concrete infill-frame buildings because it represents the most comprehensive and rational basis for evaluating the damage to these building types. It focused carefully on understanding the underlying meaning of observed and expected cracking and behavior, rather than simply emphasizing the size of cracks as many other methods had done.

The method can be relatively involved, so the amount of effort to categorize the wall components, determine their governing behavior modes, and assemble the global pushover curve should not be underestimated. Quantitative analysis is required by the FEMA 306 methodology; simply matching observed crack patterns with diaphragms included in FEMA 306 is insufficient and inappropriate.

Once demand and capacity results are obtained through the FEMA 306 process, the ATC-43 project envisioned using the FEMA 308 framework to determine whether the damage can be accepted or whether restoration or upgrade is required. The FEMA 308 framework addresses key issues, including the relative severity of the damaging ground motion, the acceptability of the performance characteristics both before and after the damaging event, and the change in the characteristics as a result of the damaging event. FEMA 308 defined parameters and illustrated a potential framework, but it did not provide specific numeric values for those parameters. The CAPSS project team adopted the FEMA 308 framework and developed specific numeric values for use in the framework. A significant simplification was made so that the triggering value would not depend on the demand-capacity ratio of the building, since the notion of varying the trigger value on the basis of capacity is not contained in either the current SFBC or future national model codes in preparation.

7.2.2 Overview of Recommended Post-Earthquake Repair Requirements for Older Concrete Buildings

Concrete Shear-Wall and Infill-Frame Buildings

The Figure 7-1 flowchart illustrates the post-earthquake repair requirements for damaged concrete shear-wall and infill-frame buildings. It is similar to the figure in Chapter 4, except that it includes the concept of a FEMA 306 quantitative evaluation for concrete wall and infill buildings and also the concept that when lateral capacity losses are small (less than 5%), and there is no significant damage to the gravity-load-carrying system, then restoration is not required. Cosmetic repairs, which are mainly to satisfy aesthetic or waterproofing considerations, would be permitted.

The process begins with a determination of whether the damaged building has sufficient pre-earthquake capacity to satisfy Section 3403.5, which leads to the 1973 SFBC milestone requirements of SFBC Section 1604.11.1. If this is the case, then the building need not be upgraded, regardless of the level of damage. Restoration of pre-earthquake capacity can be undertaken, or a full FEMA 306 evaluation (labeled "optional FEMA 306 evaluation" in Figure 7-1) can be done for concrete shear-wall and infill buildings in an attempt to justify only cosmetic repairs if the capacity loss is below 5%.

If the building does not meet the SFBC Section 1604.11.1 requirements, then the full FEMA 306 evaluation is triggered, and cosmetic repair, restoration, and upgrade requirements are as shown in Figure 7-1. This is labeled "mandatory FEMA 306 evaluation" in the figure.

In addition, any of the deficiencies noted in Table 7-1 must also be addressed. These are primarily related to gravity-load-carrying damage, load-path failures, or significant damage in individual components. The Disproportionate Damage concept is used in selected component/damage combinations such that in smaller events, lower levels of damage serve as a trigger. The current SFBC Section 3403.2.3.2.4 concept is retained so that damage to gravity-load-carrying members supporting more than 30% of a roof or an individual floor leads not only to addressing the damaged component but a lateral upgrade as well.

Concrete Moment-Frame Buildings

The process for concrete moment-frame buildings is simpler and directly follows the general process outlined in Chapter 4. The Section 3403.5 check is made to establish overall compliance of the pre-earthquake condition with the 1973 milestone date requirements. Then the specific checks in Table 7-1 are made. Complying buildings need to be restored to the original capacity. Cosmetic repair is not permitted. Non-complying buildings need to provide upgrades as required for components in Table 7-1.

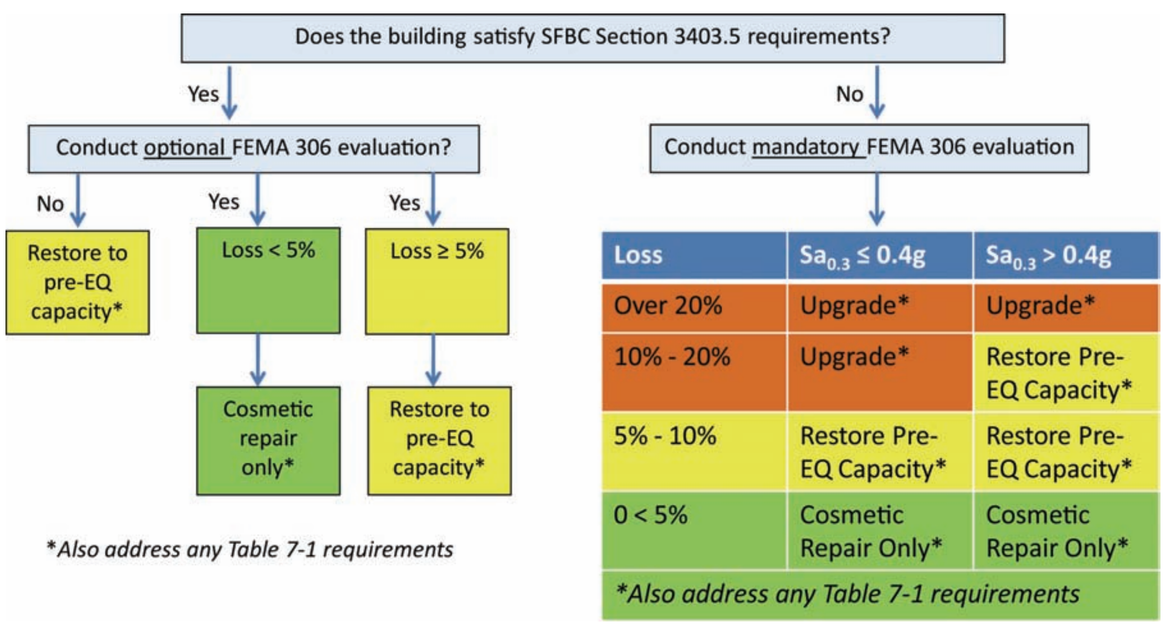

Figure 7-1 Flowchart for the post-earthquake repair of concrete shear-wall and infill-frame buildings.

Table 7-1 Triggers for Specific Components or Conditions in Older Concrete Buildings

Component/Condition	Minimum Triggering Damage	Ground Motion[1]	Minimum Retrofit[2]
Shear cracks in gravity load-carrying columns or bearing walls supporting less than 30% of the area of a roof or an individual floor.	Preemptive diagonal tension crack meeting the “Moderate” or worse criteria of the RC2H component in Section 5.5 of FEMA 306 or any component with “Extreme” damage per Section 5.5 of FEMA 306.	Any	Replace component.
	Preemptive diagonal tension crack meeting “Moderate” criteria of the RC2H component in Section 5.5 of FEMA 306 except inclined crack widths are between 1/16″ and 1/8″.	$Sa_{0.3} \leq 0.4g$	
Shear cracks in gravity-load-carrying columns or bearing walls supporting 30% or more of the area of a roof or an individual floor.	Preemptive diagonal tension crack meeting the “Moderate” or worse criteria of the RC2H component in Section 5.5 of FEMA 306 or any component with “Extreme” damage per Section 5.5 of FEMA 306.	Any	Replace component and upgrade lateral system to SFBC 3405.3.
	Preemptive diagonal tension crack meeting “Moderate” criteria of the RC2H component in Section 5.5 of FEMA 306 except inclined crack widths are between 1/16″ and 1/8″.	$Sa_{0.3} \leq 0.4g$	
Beam-column joint shear at joints with at least one exterior face in columns supporting less than 30% of the area of a roof or individual floor.	Cracking representative of joint shear at the beam-column joint with cracks at least 1/8″ wide or offset along the crack at least 1/16″.	Any	Replace component.
Beam-column joint shear at joints with at least one exterior face in columns supporting more than 30% of the area of a roof or individual floor.	Cracking representative of joint shear at the beam-column joint with cracks at least 1/8″ wide or offset along the crack at least 1/16″.	Any	Replace component and upgrade lateral system to SFBC 3405.3.
Punching shear damage at slab around columns without intersecting beams in columns supporting less than 30% of the area of a roof or individual floor.	Evidence representative of potential punching shear such as fresh circular cracking in the slab around a column with or without vertical offset at the crack.	Any	Replace component.
Punching shear damage at slab around columns without intersecting beams in columns supporting more than 30% of the area of a roof or individual floor.	Evidence representative of potential punching shear such as fresh circular cracking in the slab around a column with or without vertical offset at the crack.	Any	Replace component and upgrade lateral system to SFBC 3405.3.
Leaning story (excessive drift) in a concrete moment-frame building.	Permanent set of 1% of the story height or more resulting from earthquake damage.	Any	Upgrade lateral system to SFBC 3405.3.
	Permanent set of 0.5% of the story height or more resulting from earthquake damage.	$Sa_{0.3} \leq 0.4g$	
Separation of floor-to-wall connections.	Permanent separation or sliding at joint of 1″ or more. Permanent movement that results in inadequate bearing of supported member.	Any	Upgrade connection using forces from SFBC 3405.3.

Table 7-1 Triggers for Specific Components or Conditions in Older Concrete Buildings (continued)

Component/Condition	Minimum Triggering Damage	Ground Motion[1]	Minimum Retrofit[2]
Delamination of more than 30% of cast-in-place topping from precast floor or roof framing where topping serves as the diaphragm.	Permanent separation of topping from precast members.	Any.	Replace damaged topping slab and tie new slab to underlying precast members using SFBC 3405.3 forces and current detailing.
Fractured bars at diaphragm chords or collectors.	Permanent separation or sliding at joint of 1″ or more. Permanent movement that results in inadequate bearing of supported member.	Any.	Replace damaged bars and tie or splice new components to surrounding structural elements using SFBC 3405.3 forces and current detailing.

Notes:

1. *Sa* at 0.3 seconds as shown on event ShakeMap as updated one week after the event.
2. Damage less than Minimum Triggering Damage extent shall be repaired to original strength/condition by methods acceptable to DBI.

7.2.3 Evaluation and Requirements for Concrete Shear-Wall and Infill-Frame Buildings

The detailed evaluation for shear-wall and infill-frame buildings shall be conducted in accordance with FEMA 306 as follows.

FEMA 306 Parameter Determination

Perform the FEMA 306 evaluation process for the pre-event structure and the damaged structure.

- The evaluation shall use the nonlinear static procedures as defined in FEMA 306 to determine the capacity for pre-event and damaged conditions. FEMA 306 was developed at the time that FEMA 273, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA, 1997), was also in development, prior to the publication of FEMA 356. Additional research and development effort was incorporated into FEMA 356 and then into ASCE/SEI 41-06 (ASCE, 2007). The comparable, more current equations in ASCE 41 should be implemented in performing a FEMA 306 evaluation, rather than using the FEMA 273 equivalents.
- The demand shall be determined in accordance with ASCE/SEI 41-06.
- In order to perform a FEMA 306 evaluation a performance objective must be selected that links a performance level with an earthquake hazard level. The performance objective shall be to take the Life Safety Structural Performance Level of ASCE 41, together with 75% of the spectral demand associated with the current code value at the building site. This hazard level is identical to that in SFBC Section 3403.5 and 1604.11.3. Note that this is simply the value used in the evaluation.

Simplified FEMA 308 Parameter Determination

A simplified version of the FEMA 308 approach to determining threshold triggers based on loss is adopted. It is similar to the procedure shown in Figure 7-1. Thus, the FEMA 308 parameters are determined as follows. See FEMA 308 for further definition of the terms.

- Determine performance capacity and loss indices:
  - Determine the Pre-event Performance Index: $P = d_c / d_d$
  - Determine the Damaged Performance Index: $P' = d'_c / d'_d$
  - Determine the Loss: $L = 1 - (P'/P)$
- FEMA 308 Table 3-1 parameters for determining whether existing damage is acceptable and <u>need not</u> trigger restoration or upgrade are as follows:
  - $L_{r(min)}$:
    - 5% if damaging event has $Sa_{0.3} \leq 0.4g$
    - 5% if damaging event has $Sa_{0.3} > 0.4g$
  - $L_{r(max)}$: Same as $L_{r(min)}$ since L_r does not vary
    - 5% if damaging event has $Sa_{0.3} \leq 0.4g$
    - 5% if damaging event has $Sa_{0.3} > 0.4g$
  - P'_{min}: Not required since L_r does not vary
  - P'_{max}: 1.0
- FEMA 308 Table 3-2 parameters for determining whether existing damage triggers upgrade are as follows:
  - $L_{u(min)}$:
    - 10% if damaging event has $Sa_{0.3} \leq 0.4g$
    - 20% if damaging event has $Sa_{0.3} > 0.4g$
  - $L_{u(max}$: Same as $L_{u(min)}$ since L_u does not vary
    - 10% if damaging event has $Sa_{0.3} \leq 0.4g$
    - 20% if damaging event has $Sa_{0.3} > 0.4g$
  - P_{min}: Not required since L_u does not vary
  - P_{max}: 1.0

Upgrade Triggers due to Specific Component Damage or Conditions

In addition to the triggers for upgrade per the general FEMA 306/308 methods described above, damage to any of the specific components or other conditions noted in Table 7-1 shall trigger upgrade to the requirements noted in the table.

7.2.4 Evaluation and Requirements for Concrete Moment-Frame Buildings

The detailed evaluation for concrete moment-frame buildings shall be conducted to determine if any of the specific component damage or condition triggers in Table 7-1 are present.

For concrete moment-frame buildings with some interacting walls, in addition to the Table 7-1 checks, the requirements given above for concrete shear-wall buildings are also applied. When a FEMA 306 determination of loss of capacity is performed, the moment-frame capacity is not included in development of the force-displacement pushover curve.

7.3 Implementation Recommendations

7.3.1 Recommended Building Code Amendment

As noted in Section 5.3.1, certain amendments must be made to the SFBC to formalize the concept of Disproportionate Damage. The recommendations of Section 5.3.1 also apply to Chapter 7.

7.3.2 Recommended Wording for Administrative Bulletin

This section recommends text for a San Francisco Department of Building Inspection Administrative Bulletin to implement the recommendations in Section 7.2 for older concrete buildings. The purpose of the Administrative Bulletin is to interpret the existing *California Building Code* (CBC) and SFBC provision regarding Substantial Structural Damage and the proposed SFBC provision for Disproportionate Damage.

In the text that follows, italicized parenthetical remarks are notes to DBI staff for use in preparing a draft Bulletin for approval by the Building Inspection Commission.

TITLE: Seismic Retrofit Triggers, Scope, and Criteria for Retrofits of Older Concrete Buildings Triggered by Earthquake Damage

PURPOSE: The purpose of this Bulletin is to establish Department policy for interpreting damage definitions in the San Francisco Building Code and for setting the scope and criteria of triggered retrofits.

REFERENCE: 2010 *California Building Code* (CBC) Sections 3402 and 3405.

2010 *California Historical Building Code* (CHBC), CCR Title 24 Part 8.

2010 *San Francisco Building Code* (SFBC) Sections 3402 and 3405.

ASCE/SEI Standard 31-03, *Seismic Evaluation of Existing Buildings* (ASCE, 2003).

ASCE/SEI Standard 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007).

CAPSS Report, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Post-Earthquake Repair and Retrofit Requirements* (ATC-52-4 Report).

FEMA 273: *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA, 1997).

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FEMA 306: *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Basic Procedures Manual* (FEMA, 1999a).

FEMA 308: *The Repair of Earthquake-Damaged Concrete and Masonry Wall Buildings* (FEMA, 1999c).

FEMA 356: *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (FEMA, 2000a).

DISCUSSION:

CBC Section 3405.2 triggers seismic evaluation, and possibly retrofit, when earthquake damage reaches the level of "Substantial Structural Damage to vertical elements of the lateral-force-resisting system." Substantial Structural Damage is defined in Section 3402 as, in essence, a capacity loss of 20 percent. But the code gives no rules for identifying a 20-percent loss or even for how to calculate capacity loss in general, so implementation of these provisions relies on interpretation by the Department. This Bulletin presents the Department's interpretation of a 20-percent lateral capacity loss for older concrete buildings.

(Provisional, pending SFBC adoption of provisions for Disproportionate Damage.) Further, SFBC Section 3405.4 triggers seismic evaluation, and possibly retrofit, when earthquake damage reaches the level of "Disproportionate Damage," defined in Section 3402 as, in essence, a lateral capacity loss of 10 percent. This Bulletin presents the Department's interpretation of a 10-percent capacity loss.

APPLICABILITY:

Buildings that satisfy all of the following criteria are eligible for the interpretations and provisions of this Bulletin. Other buildings, if not eligible for interpretations of similar Bulletins, are subject to the code provisions as interpreted by the Department on a case-by-case basis. The provisions of this Bulletin shall apply to all eligible buildings, except that at the discretion of the Department, measurements of capacity loss based on analysis, testing, or other objective data may be allowed.

A. The building contains cast-in-place concrete bearing walls or cast-in-place concrete frames.

B. The building contains at least one floor diaphragm made of cast-in-place concrete.

DEFINITIONS:

- **SUBSTANTIAL STRUCTURAL DAMAGE:** Substantial Structural Damage to elements of the lateral-force-resisting system shall be deemed to exist when the results of a FEMA 306 loss estimate exceed 20% for a concrete shear-wall or infill-frame building or when any of the damage patterns described in Table 1 is observed in an eligible building.

  (Provisional, pending SFBC adoption of provisions for Disproportionate Damage.)

- **DISPROPORTIONATE DAMAGE:** Disproportionate Damage shall be deemed to exist when the results of a FEMA 306 loss estimate exceed 10% or any of the damage patterns described in Table 1 is observed in an eligible building where the 0.3-second spectral acceleration at the site estimated by the U.S. Geological Survey in the ShakeMap approved by the DBI is not more than 0.40g.
- **COSMETIC REPAIR:** Repairs that improve the visual appearance of damage to a component. These repairs may also restore the nonstructural properties of the component, such as weather protection. Any structural benefit is negligible.
- **CONCRETE SHEAR WALL:** A concrete wall which resists lateral forces applied parallel to the plane of the wall.
- **CONCRETE MOMENT FRAME:** A building frame system in which seismic shear forces are resisted by shear and flexure in members and joints of the frame, including slab-column moment frames.
- **CONCRETE INFILL FRAME:** A concrete moment frame with panel(s) of masonry placed within the frame members that participate in resisting lateral forces.

EVALUATION PROCEDURE AND RETROFIT SCOPE:

Concrete Shear-Wall and Infill-Frame Buildings

Overview

The flowchart in Figure 1 illustrates the post-earthquake repair requirements for damaged concrete shear-wall and infill-frame buildings.

The process begins with a determination of whether the damaged building has sufficient pre-earthquake capacity to satisfy SFBC Section 3403.5, which references the 1973 SFBC milestone requirements of SFBC Section 1604.11.1. If this is the case, then the building need not be upgraded, regardless of the level of damage. Restoration of pre-earthquake capacity can be undertaken, or a full FEMA 306 evaluation (labeled "optional FEMA 306 evaluation" in the figure) can be done for concrete shear-wall and infill buildings in an attempt to justify only cosmetic repairs if the capacity loss is below 5 percent.

If the building does not meet the SFBC Section 1604.11.1 requirements, then the full FEMA 306 evaluation is triggered, and cosmetic repair, restoration, and upgrade requirements are as shown in the figure. This is labeled "mandatory FEMA 306 evaluation" in the figure.

In addition, any of the deficiencies noted in Table 1 must also be addressed. These are primarily related to gravity-load-carrying damage, load path failures, or significant damage in individual components.

Table 1 Triggers for Specific Components or Conditions in Older Concrete Buildings

Component/Condition	Minimum Triggering Damage	Ground Motion[1]	Minimum Retrofit[2]
Shear cracks in gravity load-carrying columns or bearing walls supporting less than 30% of the area of a roof or an individual floor.	Preemptive diagonal tension crack meeting the “Moderate” or worse criteria of the RC2H component in Section 5.5 of FEMA 306 or any component with “Extreme” damage per Section 5.5 of FEMA 306.	Any	Replace component.
	Preemptive diagonal tension crack meeting “Moderate” criteria of the RC2H component in Section 5.5 of FEMA 306 except inclined crack widths are between 1/16″ and 1/8″.	$Sa_{0.3} \leq$ 0.4g	
Shear cracks in gravity-load-carrying columns or bearing walls supporting 30% or more of the area of a roof or an individual floor.	Preemptive diagonal tension crack meeting the “Moderate” or worse criteria of the RC2H component in Section 5.5 of FEMA 306 or any component with “Extreme” damage per Section 5.5 of FEMA 306.	Any	Replace component and upgrade lateral system to SFBC 3405.3.
	Preemptive diagonal tension crack meeting “Moderate” criteria of the RC2H component in Section 5.5 of FEMA 306 except inclined crack widths are between 1/16″ and 1/8″.	$Sa_{0.3} \leq$ 0.4g	
Beam-column joint shear at joints with at least one exterior face in columns supporting less than 30% of the area of a roof or individual floor.	Cracking representative of joint shear at the beam-column joint with cracks at least 1/8″ wide or offset along the crack at least 1/16″.	Any	Replace component.
Beam-column joint shear at joints with at least one exterior face in columns supporting more than 30% of the area of a roof or individual floor.	Cracking representative of joint shear at the beam-column joint with cracks at least 1/8″ wide or offset along the crack at least 1/16″.	Any	Replace component and upgrade lateral system to SFBC 3405.3.
Punching shear damage at slab around columns without intersecting beams in columns supporting less than 30% of the area of a roof or individual floor.	Evidence representative of potential punching shear such as fresh circular cracking in the slab around a column with or without vertical offset at the crack.	Any	Replace component.
Punching shear damage at slab around columns without intersecting beams in columns supporting more than 30% of the area of a roof or individual floor.	Evidence representative of potential punching shear such as fresh circular cracking in the slab around a column with or without vertical offset at the crack.	Any	Replace component and upgrade lateral system to SFBC 3405.3.
Leaning story (excessive drift) in a concrete moment-frame building.	Permanent set of 1% of the story height or more resulting from earthquake damage.	Any	Upgrade lateral system to SFBC 3405.3.
	Permanent set of 0.5% of the story height or more resulting from earthquake damage.	$Sa_{0.3} \leq$ 0.4g	
Separation of floor-to-wall connections.	Permanent separation or sliding at joint of 1″ or more. Permanent movement that results in inadequate bearing of supported member.	Any	Upgrade connection using forces from SFBC 3405.3.
Delamination of more than 30% of cast-in-place topping from precast floor or roof framing where topping serves as the diaphragm.	Permanent separation of topping from precast members.	Any	Replace damaged topping slab and tie new slab to underlying precast members using SFBC 3405.3 forces and current detailing.
Fractured bars at diaphragm chords or collectors.	Permanent separation or sliding at joint of 1″ or more. Permanent movement that results in inadequate bearing of supported member.	Any	Replace damaged bars and tie or splice new components to surrounding structural elements using SFBC 3405.3 forces and current detailing.

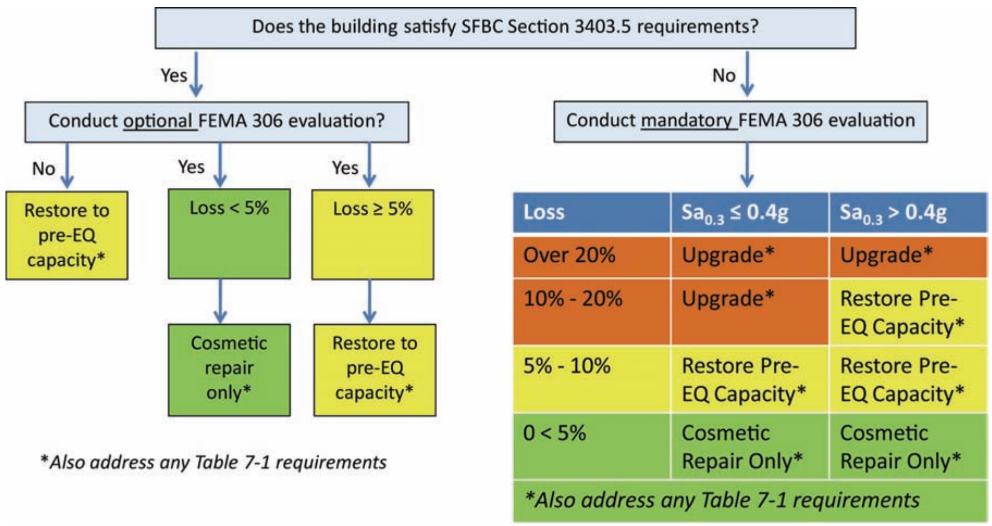

Figure 1 *Flowchart for the post-earthquake repair of concrete shear-wall and infill-frame buildings.*

FEMA 306 Parameter Determination

Perform the FEMA 306 evaluation process for the pre-event structure and the damaged structure.

- The evaluation shall use the nonlinear static procedures as defined in FEMA 306 to determine the capacity for pre-event and damaged conditions. FEMA 306 was developed at the time that FEMA 273 was also in development, prior to the publication of FEMA 356. Additional research and development effort was incorporated into FEMA 356 and then into ASCE/SEI 41-06. The comparable, more current equations in ASCE/SEI 41-06 shall be implemented in performing a FEMA 306 evaluation, rather than using the FEMA 273 equivalents.
- The demand shall be determined in accordance with ASCE/SEI 41-06.
- The performance objective shall be to take the Life Safety Structural Performance Level of ASCE/SEI 41-06, together with 75% of the spectral demand associated with the current code value at the building site.

Simplified FEMA 308 Parameter Determination

A simplified version of the FEMA 308 approach to determining threshold triggers based on loss is adopted. It is similar to procedure shown in Figure 1. Thus, the FEMA 308 parameters are determined as follows. See FEMA 308 for further definition of the terms.

- Determine performance capacity and loss indices:
    - Determine the Pre-event Performance Index: $P = d_c / d_d$
    - Determine the Damaged Performance Index: $P' = d'_c / d'_d$
    - Determine the Loss: $L = 1 - (P'/P)$

- FEMA 308 Table 3-1 parameters for determining whether existing damage is acceptable and need not trigger restoration or upgrade are as follows:
  - $L_{r(min)}$:
    - 5% if damaging event has $Sa_{0.3} \leq 0.4g$
    - 5% if damaging event has $Sa_{0.3} > 0.4g$
  - $L_{r(max)}$: Same as $L_{r(min)}$ since L_r does not vary
    - 5% if damaging event has $Sa_{0.3} \leq 0.4g$
    - 5% if damaging event has $Sa_{0.3} > 0.4g$
  - P'_{min}: Not required since L_r does not vary
  - P'_{max}: 1.0
- FEMA 308 Table 3-2 parameters for determining whether existing damage triggers upgrade are as follows:
  - $L_{u(min)}$:
    - 10% if damaging event has $Sa_{0.3} \leq 0.4g$
    - 20% if damaging event has $Sa_{0.3} > 0.4g$
  - $L_{u(max}$: Same as $L_{u(min)}$ since L_u does not vary
    - 10% if damaging event has $Sa_{0.3} \leq 0.4g$
    - 20% if damaging event has $Sa_{0.3} > 0.4g$
  - P_{min}: Not required since L_u does not vary
  - P_{max}: 1.0

Upgrade Triggers due to Specific Component Damage or Conditions

In addition to the triggers for upgrade per the general FEMA 306/308 methods described above, damage to any of the specific components or other conditions noted in Table 1 shall trigger upgrade to the requirements noted in the table.

Concrete Moment-Frame Buildings

The process for concrete moment-frame buildings is as follows. The Section 3403.5 check is made to establish overall compliance of the pre-earthquake condition with the 1973 milestone date requirements. Then the specific checks in Table 1 are made. Complying buildings need to restore the original capacity. Cosmetic repair is not permitted. Non-complying buildings need to provide upgrades as required for components in Table 1.

For concrete frame buildings with some interacting walls, in addition to the Table 1 checks, the requirements given above for concrete wall buildings are also applied. When a FEMA 306 determination of loss of capacity is performed, the moment-frame capacity is not included in development of the force-displacement pushover curve.

EVALUATION OR RETROFIT ENGINEERING CRITERIA:

Where evaluation or retrofit is triggered by earthquake damage at any level, the engineering criteria shall be permitted to use earthquake loads that are 75 percent of those prescribed by the SFBC for new construction, in accordance with CBC Section 3405.2. Any of the following alternative codes, standards, or guidelines may be used as alternative criteria for qualifying buildings:

A. ASCE 31-03, *Seismic Evaluation of Existing Buildings*, at the Life Safety performance level.

B. ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, with a structural performance objective of Life Safety in a BSE-1 hazard.

C. 2010 *California Building Code* Section 3415-3420.

D. 2010 *California Historical Building Code* (California Title 24 Part 8).

CHAPTER 8: RECOMMENDED FURTHER ACTIONS REGARDING POST-EARTHQUAKE REPAIR PROVISIONS

During the course of this study, several important issues were identified that could not be resolved within the scope of the CAPSS project. This chapter discusses these issues and recommends further action by DBI, development work in a CAPSS-type project, or assistance by the Structural Engineers Association of Northern California (SEAONC).

8.1 Development of Post-Earthquake Repair Guidelines for Building Types Not Covered by This Report

Although it is recommended that DBI develop post-earthquake repair guidelines for all significant building types in San Francisco, several specific types, not covered in this document, are considered high priority as discussed below.

8.1.1 Unreinforced Masonry Buildings (UMBs)

In most jurisdictions, these buildings are known as URMs (UnReinforced Masonry buildings), but to be consistent with DBI usage, they are termed UMBs (Unreinforced Masonry Buildings) here. Due to a mandatory retrofit ordinance passed in San Francisco in 1992, there are several classes of UMBs in San Francisco, as described below. Since some retrofits have been completed within the last 15 years, the state law prohibiting enforcement of re-retrofit for a 15-year period (Health and Safety Code Section 19166) may apply.

- *Unretrofitted UMBs not covered by the mandatory ordinance*: This group includes residential UMBs with less than 5 units, including single family dwellings. Although small, these buildings are likely to be severely damaged in strong ground motion and clear repair/retrofit provisions will be needed for them.
- *Unretrofitted UMBs covered by the mandatory ordinance*: These buildings are essentially out of compliance with current regulation. It is recommended that San Francisco formulate a policy with immediate repair/retrofit requirements if damaged. It is further recommended that the concept of Disproportionate Damage be applied to these buildings.
- *UMBs retrofitted to the special regulations developed for qualifying buildings (commonly known as "bolts plus")*: These buildings were allowed to be retrofitted to a lesser standard than the ordinance applied to all other UMBs. That is, the regulations required less retrofit work, less cost, and less disruption to satisfy community concerns, including the then-current policy of maintaining low-cost housing that is a common occupancy type for these buildings. It is recommended that this policy be re-examined for the purpose of identifying post-earthquake repair standards. Currently, if triggered by over 20-percent loss of lateral strength, the *San Francisco Building Code* (SFBC) would default to the

generalized regulations (those not covered by a building-specific Administrative Bulletin as recommended in Chapter 5, 6, and 7) for these buildings that will require retrofit to the requirements of Section 3403.5, or 75% of current code.

- *UMBs retrofitted to the full ordinance*: Buildings retrofitted strictly in accordance with the provisions of the ordinance did not meet Section 3403.5 (then 104f) at the time of retrofit and certainly do not now. Therefore these buildings are not considered automatically "complying," and, if triggered by over 20% loss of lateral strength, the SFBC would default to the generalized regulations (those not covered by a building-specific Administrative Bulletin as recommended in Chapter 5, 6, and 7) that will require retrofit to the requirements of Section 3403.5, or 75% of current code. Current rules of application of Section 3403.5 to UMBs are unclear and this lack of clarity will cause delays and disputes. It is recommended that repair/retrofit guidelines be developed specifically for this building type.
- *UMBs retrofitted to Section 104f*: Technically, under current rules, these buildings will be classified "complying" and therefore will only require repair, regardless of damage level. It is recommended that this policy be re-examined, and if appropriate, that a special repair/retrofit guideline be developed for this building type.

8.1.2 Buildings with a Lateral-Force-Resisting System of Braced Frames (Either Used in the Original Construction or in a Retrofit)

There are many braced frame buildings in San Francisco, particularly retrofits done in the 1970s and 1980s. Many of these use thin-wall tubes that are susceptible to fracture as brace elements and/or are designed without other detailing configurations that prevent brittle failures. It is expected that many such frames will be damaged in strong ground shaking. Under current rules, most of these buildings will be classified "complying" and only will require repair to the standard under which they were designed. Merely replacing a buckled or fractured brace will be relatively fast and inexpensive, but updating the detailing requirements, including the brace itself and the gusset plates, may not be. Further, there are currently no rules in place to determine the "loss of lateral strength" for braces or connections in various damage states, potentially causing disputes and delays in re-occupancy.

It is recommended that a post-earthquake repair standard be developed specifically for this building type, both for buildings considered "complying" and "non-complying" under current SFBC. As discussed in Section 8.2, updating the definition of "complying" (which determines whether repair or retrofit is required for significant damage) should be considered for this building type.

8.1.3 Steel Moment-Frame Buildings

In the 1994 Northridge earthquake, many steel moment-frame buildings were damaged with brittle fractures of the beam-column joint. In response, FEMA funded a significant investigation into the causes of the damage, how the damage could be repaired, and how the damage could be prevented in new buildings. The investigation was carried out by the SAC Joint Venture (a partnership of the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering) and resulted in many publications, including FEMA 352, *Recommended Post-Earthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings* (FEMA, 2000b). It is recommended that this document be studied and considered for adoption as a post-earthquake repair Administrative Bulletin by DBI. Such an adoption would change the definition of "complying" for this building type as discussed in Section 8.2.

8.2 Potential Revisions to the Definition of Complying Building Currently Used in the SFBC (All Buildings Permitted after May 21, 1973)

As discussed elsewhere in this report, buildings permitted for new construction (or retrofit under Section 104f) after May 21, 1973 are "deemed to comply" with the SFBC and only require repair to the pre-earthquake condition after an earthquake, regardless of damage level.

This date (May 21, 1973) was originally placed in the SFBC to ensure acceptability of buildings designed to the 1973 *Uniform Building Code* (UBC). A significant increase in design forces was planned for the 1976 UBC and there was concern that all buildings designed prior to 1976 would be considered deficient, and possibly hazardous. The 1973 design force level was also considered adequate for retrofit and was used for that purpose for some time, although the retrofit force level was eventually changed to 75% of the current code. (The 1973 UBC was approximately equal to 75% of the 1976 UBC for most structural periods.)

However, since the adoption of the 1973 UBC, many changes have occurred in building codes besides the 1976 change in design force, including the improvements in detailing for braced frames and moment frames discussed in Sections 8.1.2 and 8.1.3. In addition, the art of seismic retrofitting was not mature in the 1970s and early 1980s, and many of these retrofits would not meet modern standards, and some may be hazardous. It is concluded that there are buildings in San Francisco currently "deemed to comply" that can be expected to fall far short of expected performance, and if significantly damaged in an earthquake, should be retrofitted rather than merely repaired.

There are several options to improve the definition of complying buildings in the SFBC. The *International Existing Building Code* allows compliance with the national standard for seismic evaluation, ASCE 31 (ASCE, 2003), as an option to be classified as "complying" and therefore allow repair, rather than retrofit, regardless of damage level. To avoid the need for engineering evaluation of every building, San Francisco could adopt *Table 3-1 Benchmark Buildings* of ASCE 31 (see Table 8-1) that gives a code year considered acceptable for each building type. Or, to consider San Francisco's unique design and construction practices over the years, particularly retrofitting techniques, San Francisco could develop its own table of milestone years for each building type that was built new or retrofitted.

It is recommended that DBI study post-1973 building types in San Francisco to identify those that may have unacceptable vulnerabilities, for the purpose of updating the current definition of complying buildings. If significantly damaged in an earthquake, these buildings should not be only repaired, but retrofitted to acceptable standards. In addition, such a re-definition would require reconsideration of the rules for retrofit triggers associated with building renovation under the SFBC.

Table 8-1 Table 3-1 From ASCE 31 (ASCE, 2003) Showing Suggested Benchmark Years at or Beyond Which Code Designed Buildings are Likely to be Found Acceptable

Building Type[1,2]	Model Building Seismic Design Provisions					FEMA 178[ls]	FEMA 310[ls,io]	CBC[io]
	NBC[ls]	SBC[ls]	UBC[ls]	IBC[ls]	NEHRP[ls]			
Wood-Frame, Wood Shear Panels (Type W1 & W2)	1993	1994	1976	2000	1985	*	1998	1973
Wood-Frame, Wood Shear Panels (Type W1A)	*	*	1997	2000	1997	*	1998	1973
Steel Moment-Resisting Frame (Type S1 & S1A)	*	*	1994[4]	2000	**	*	1998	1995
Steel-Braced Frame (Type S2 & S2A)	1993	1994	1988	2000	1991	1992	1998	1973
Light Metal Frame (Type S3)	*	*	*	2000	*	1992	1998	1973
Steel Frame with Concrete Shear Walls (Type S4)	1993	1994	1976	2000	1985	1992	1998	1973
Reinforced Concrete Moment-Resisting Frame (Type C1)[3]	1993	1994	1976	2000	1985	*	1998	1973
Reinforced Concrete Shear Walls (Type C2 & C2A)	1993	1994	1976	2000	1985	*	1998	1973
Steel Frame with URM Infill (Type S5 & S5A)	*	*	*	2000	*	*	1998	*
Concrete Frame with URM Infill (Type C3 and C3A)	*	*	*	2000	*	*	1998	*
Tilt-Up Concrete (Type PC1 & PC1A)	*	*	1997	2000	*	*	1998	*
Precast Concrete Frame (Type PC2 & PC2A)	*	*	*	2000	*	1992	1998	1973
Reinforced Masonry (Type RM1)	*	*	1997	2000	*	*	1998	*
Reinforced Masonry (Type RM2)	1993	1994	1976	2000	1985	*	1998	*
Unreinforced Masonry (Type URM)[5]	*	*	1991[6]	2000	*	1992	*	*
Unreinforced Masonry (Type URMA)	*	*	*	2000	*	*	1998	*

[1] Building Type" refers to one of the Common Building Types defined in Table 2-2 (of ASCE 31).
[2] Buildings on hillside sites shall not be considered Benchmark Buildings.
[3] Flat Slab Buildings shall not be considered Benchmark Buildings.
[4] Steel Moment-Resisting Frames shall comply with the 1994 UBC Emergency Provisions, published September/October 1994, or subsequent requirements.
[5] URM buildings evaluated using the ABK Methodology (ABK, 1984) may be considered benchmark buildings.
[6] Refers to the GSREB or its predecessor, the *Uniform Code of Building Conservation* (UCBC).

[ls] Only buildings designed and constructed or evaluated in accordance with these documents and being evaluated to the Life Safety (LS) Performance Level may be considered Benchmark Buildings.
[io] Buildings designed and constructed or evaluated in accordance with these documents and being evaluated to either the Life Safety or Immediate Occupancy (IO) Performance Level may be considered Benchmark Buildings.

* No benchmark year; buildings shall be evaluated using this standard.
** Local provisions shall be compared with the UBC.

NBC = *National Building Code* (BOCA, 1993). (Note: see ASCE 31 for details on ref. citations)
SBC = *Standard Building* Code (SBCC. 1994).
UBC = *Uniform Building Code* (ICBO, 1997)
GSREB = *Guidelines for Seismic Retrofit of Existing Buildings* (ICBO, 2001).
IBC = *international Building Code* (ICC, 2000).
NEHRP = FEMA 368 and 369, *NEHRP Recommended Provisions* for *the Development of Seismic Regulations for New Buildings* (BSSC, 2000)
FEMA 178 *(See* BSSC, 1992a)
FEMA 310 *(See* FEMA, 1998)
CBC = *California Building Code, California Code* of *Regulations, Title 24* (CBSC, 1995).

8.3 Post-Earthquake Reimbursement Under the Robert T. Stafford Disaster Relief and Emergency Assistance Act

San Francisco's eligibility for reimbursement under this act is dependent on the nature of upgrade and repair triggers for all sources of damage to buildings, including earthquake, wind, and fire. Eligibility is confined to repair only of designated buildings (government and certain non-profit) and is further limited to those cases where upgrade above the pre-disaster condition is required. This issue was discussed in detail in the *Report and Recommendations of the SEAONC SFBC Structural Damage Repair Study Group* dated April 3, 2008 (SEAONC, 2008). The recommendations of this report have not been implemented, but the conclusion regarding this issue was that determination of compliance with FEMA's five-point criteria for eligibility (included in FEMA Disaster Assistance Policy 9527.4) was legally complex and difficult to achieve pre-disaster. However, apparent deviations from the five-point criteria occur in the current SFBC (exclusion for Homeless Shelters), in the SEAONC recommendations (different repair/retrofit standards for different causes of damage), and in this document (different repair/retrofit standards for different building types and special standards for seismic damage).

It is recommended that the City of San Francisco investigate eligibility under the Stafford Act considering current and future proposed post-earthquake repair standards.

8.4 Site Geologic Hazards

Such hazards include landslide, liquefaction, lateral spreading, differential settlement, and surface fault rupture. It is presumed that damage to a structure from these causes would be included when determining damage levels that trigger retrofit. It is not clear when mitigation of these site hazards will be required after a damaging earthquake. For example, if retrofit of a structure is triggered, to what extent are site geologic hazards required to be mitigated? In some cases, such as massive landslide or lateral spreading, it will be impossible to mitigate the hazard within an owner's property. It is recommended that guidelines be developed to cover the most commonly expected circumstances to avoid delays and disputes in the post-earthquake environment.

8.5 Implementation of Post-Earthquake Repair Guidelines

Post-earthquake repair guidelines can only be enforced by DBI at the time of post-earthquake inspection or application of a building permit for repair. In the post-earthquake environment, repairs may be undertaken without a permit. It is important that engineers, architects, and contractors are aware of damage repair guidelines, especially if several Administrative Bulletins are developed and adopted. The adoption of Disproportionate Damage triggers may be especially difficult to enforce due to the relatively minor damage that could trigger a full retrofit.

It is recommended that after guidelines proposed in Chapters 5, 6, 7 or 8 of this report are adopted that DBI develops educational material including booklets and seminars for earthquake inspectors, professional associations, and the public. Users of the DBI Building Occupancy Resumption Program (BORP) particularly should be made aware of these post-earthquake guidelines; specific mention of the Administrative Bulletins should be put in the BORP Guidelines for Engineers. Training of post-earthquake safety inspectors (ATC-20 training) should emphasize that damage levels that may trigger repair or retrofit, including those for Disproportionate Damage, are separate from criteria for safe occupancy.

8.6 Clarification of Rules for Permitting Demolition of Buildings

Although rules and standards for permitting demolition of buildings are not completely controlled by DBI, it should be recognized by the City of San Francisco that following a damaging earthquake, many owners, for many reasons, may wish to demolish and replace their buildings rather than to proceed with repair and/or retrofit. Such replacement on a large scale will have significant consequences on the availability of short-term housing and on the availability of affordable housing in the long-term as well as on the character of neighborhoods. Policies to minimize undesirable long-term effects from demolition and replacement should be developed before an earthquake, rather than in a post-earthquake environment. This is especially critical for buildings that may be historic resources.

8.7 Application to Historic Buildings

There are several state regulations that appear to put limits on wholesale inclusion of historic buildings into a post-earthquake retrofit program triggered by damage. However, it is the recommendation of this study that buildings exempt from retrofit triggers due to historic designation be included in the program in principle. In practice, historic buildings are exempt from triggered retrofits (CBSC, 2007. See Title 24 Part 8, Sections 8-102.1.5 and 8-102.1.6.), but San Francisco could possibly override this exemption by classifying certain buildings as “distinct hazards.” It is not clear whether a “distinct hazard” must be designated in advance of an earthquake for a general class of buildings or whether such a finding could be made for individual buildings based on the level of damage. In any case, such a designation might be consistent with the spirit of the *California Historical Building Code* (CHBC), though perhaps not with the letter of its current provisions. Thus, application of any proposed repair/retrofit provisions will depend on interpretations yet to be made.

In general, a jurisdiction must allow the owner of an eligible historic building to use alternative engineering criteria provided in the *California Historical Building Code* (CBSC, 2007. See Title 24 Part 8, Section 8-102.1.). In general, the CHBC criteria are consistent with the safety-based performance objectives of the criteria listed above, but the intentional flexibility of the CHBC makes full equivalence unpredictable. If San Francisco seeks higher performance or tighter requirements when retrofit is triggered, it could disallow the CHBC for certain subsets of buildings it designates as “distinct hazards.”

Specifically, the CHBC does not directly address appropriate repair or retrofit of a historic building after it has been damaged in an earthquake. As with other issues discussed in this chapter, it is recommended that the City of San Francisco develops a post-earthquake response to damaged historic buildings that is clearer than the CHBC. The pertinent sections of the CHBC are quoted below:

> **8-102.1.5 Unsafe buildings or properties.** When a qualified historical building or property is determined to be unsafe as defined in the regular code, the requirements of the CHBC are applicable to the work necessary to correct the unsafe conditions. Work to remediate the buildings or properties need only address the correction of the unsafe conditions, and it shall not be required to bring the entire qualified historical building or property into

compliance with regular code.

8-102.1.6 Additional work. Qualified historical buildings or properties shall not be subject to additional work required by the regular code, regulation or ordinance beyond that required to complete the work undertaken. Certain exceptions for accessibility and for distinct hazards exist by mandate and may require specific action, within the parameters of the CHBC.

DISTINCT HAZARD. Any clear and evident condition that exists as an immediate danger to the safety of the occupants or public right of way. Conditions that do not meet the requirements of current regular codes and ordinances do not, of themselves, constitute a distinct hazard. Section 8-104.3, *State Historical Building Code* appeals, remains applicable.

8.8 Consideration of Code Revisions Recommended by SEAONC

It is recommended that when DBI prepares the primary code changes needed to implement the recommendations of this report, prior recommendations made by SEAONC (SEAONC, 2008) also be considered. The most important issue addressed by this previous report is the separation of damage triggers for fire and wood deterioration from seismic triggers. This separation will allow owners of smaller wood buildings to repair non-seismic related damage (e.g., termite or rot damage) without triggering seismic retrofit of the whole building.

APPENDIX A: USE OF SHAKEMAP TO SET GROUND MOTIONS FOR DISPROPORTIONATE DAMAGE TRIGGERS

A.1 Introduction

ShakeMap[1] is a product of the U.S. Geological Survey (USGS) and portrays within minutes the extent of shaking during earthquake throughout the world. ShakeMaps are automatically generated for both small and large earthquakes in the San Francisco Bay Area.

The ShakeMap dataset of event-specific ground motion was recommended for use for post-earthquake repair/retrofit decisions early in the development of this document. However, reviews of draft versions of this document generated a large number of comments concerning the feasibility and appropriateness of using ShakeMaps for this purpose. This appendix addresses these concerns, mostly using publicly available information from the Internet. In addition, USGS has been contacted directly concerning the specific use recommended by this document, and has given several suggestions on how the use of mapping data could be implemented. Appendix B contains copies of the USGS-prepared resources discussed in Appendix A.

A.2 Review Comments

A major concern from reviewers was whether the maps were sufficiently accurate to incorporate in building code regulations. The mapping of ground-motion parameters in ShakeMap is a combination of instrumental data and data from ground-motion prediction equations[2]. In instrument-rich jurisdictions such as San Francisco (see Figure A-1), the maps are primarily based on instrumental data and infilled with calculated data. The ground motion is assigned to a grid spaced at approximately 1 km and interpolated in between. There are refinements to the initial map over the first few days due to the addition of instrumental data not automatically transmitted to USGS, but starting about one week after the event the maps are relatively stable. A site specific instrument should over-ride the ShakeMap value, but if the instrument is in the USGS system, its recorded value will be reflected on the map anyway.

A second concern was how the effects of site-soil conditions are considered during the development of ShakeMaps. For instrumental readings the conditions at the site are directly measured. For infill calculations, standard soil amplification factors are

[1]ShakeMap—A Tool for Earthquake Response, USGS Fact Sheet FS-087-03, 4 pp, September, 2003.

[2] ShakeMap Scientific Background, 6 pp, http://earthquakes.usgs.gov/earthquakes/shakemap/background.php

applied (Borcherdt's method[3], similar to the code) based on two maps, the Chris Wills' geology map of California[4] and an additional GIS (geographical information system) layer of sediment and fill for the Bay Area.[5]

The last major subject for comment was implementation and dispute resolution. As indicated above, a site-specific instrumental measurement (if approved by DBI before the event) will take precedence over the map values. Ground-motion values will be available to the address (coordinate) level of resolution (using ShakeCast[6]), so reading of maps is not an issue. It is reasonable to assume that if the *San Francisco Building Code* (SFBC) specifies that a credible product produced by the USGS at a certain date after the event will be used to identify site ground motions for the purpose of determining Disproportionate Damage triggers, the regulation will be found legal and enforceable. Similar (although less accurate) maps are used to set ground-motion parameters for design of new buildings without issue. Various specific implementation methods can be derived using other USGS products (ShakeCast) either by extracting ground-motion data at a given coordinate location, or by maps drawn on a block-by-block level to minimize disputes caused by varying values on large lots or neighboring lots.

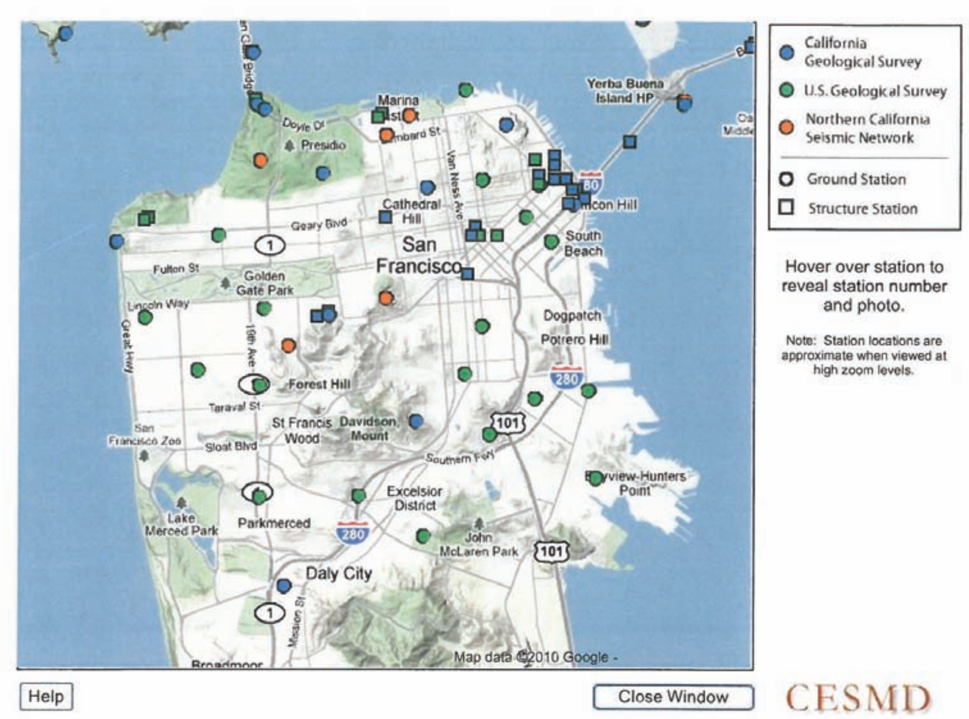

Figure A-1 Strong-motion stations in the City and County of San Francisco, Northern California http://www.strongmotioncenter.org/LoaderNC.html

[3] Borcherdt, R.D., 1994, "Estimates of Site-Dependent Response Spectra for Design (Methodology and Justification)," *Earthquake Spectra*, Vol. 10, pp 617-653.

[4] Wills, C., et al., 2000, "A Site Condition Map for California Based on Geology and Shear – Wave Velocity, *Bull. Seismol. Soc Am*, Vol 90, pp 187-208.

[5] Kuo-Wan Lin, USGS, personal communication, 2 pp, August 27, 2010.

[6] USGS ShakeCast, USGS Fact Sheet 2007-3086, 6 pp, October, 2007.

A.3 Methods of Implementation

The use of the ShakeMap technology for triggering Disproportionate Damage is greatly enhanced by the availability of ShakeCast from the USGS (Lin and Wald, 2008). ShakeCast is a fully automated system for delivering specific ShakeMap products to users and for triggering pre-established post-earthquake protocols. For example, the California Department of Transportation (Caltrans) has deployed the prototype ShakeCast system to estimate instantly the damage level of more than 11,000 bridges and overpasses due to the shaking levels established by ShakeMap. Although, DBI may not need the full capabilities of ShakeCast, ShakeCast Lite, another USGS application, automatically enables address level (coordinate) retrieval of ground-motion values from the ShakeMap background database, properly scaled between the 1-km grid points.

Using the full ShakeCast capability, it will be possible for DBI to develop a local application to automatically draw a block-oriented application boundary of Disproportionate Damage (the $Sa_{0.3}$ contour of 0.4g).

The USGS is continually placing new instruments in the field and accepting input from private instruments into the ShakeMap system. Netquakes[7,8,9] is a USGS program that is placing seismographs into private buildings that will instantly transmit site ground-motion data into the ShakeMap system via the Internet. USGS is looking for volunteer building locations, but gives priority to buildings in target areas. However, the program and the technology is an indication that many more instruments will be available for the ShakeMap system in the future, many probably from privately installed instruments.

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[7] Netquakes, Description, 1 p.

http://earthquakes.usgs.gov/monitoring/netquakes/

[8] Netquakes, Frequently Asked Questions, 3 pp.

http://earthquake.usgs.gov/monitoring/netquakes/faq.php

[9] Netquakes: View Data: Northern California, 1 p. accessible from the netquakes web page.

APPENDIX B: U.S. GEOLOGICAL SURVEY (USGS) SHAKEMAP, SHAKECAST, AND NETQUAKE RESOURCES

USGS
science for a changing world

UNDERSTANDING EARTHQUAKE HAZARDS IN URBAN AREAS

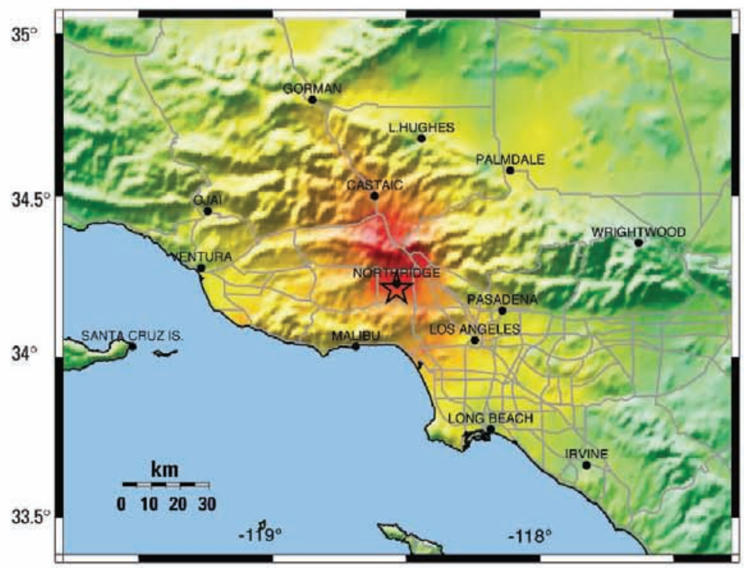
ANSS ShakeMap— A Tool for Earthquake Response

Immediately following an earthquake, emergency managers must make quick response decisions using limited information. Automatically and rapidly generated computer maps of the intensity of ground shaking (ShakeMaps) are now available for California within about 10 minutes of an earthquake. This quick, accurate, and important information can aid in making the most effective use of emergency-response resources.

What is ShakeMap?

ShakeMap is a tool used to portray the extent of potentially damaging shaking following an earthquake. It can be found on the Internet at *http://earthquake.usgs.gov/shakemap/* and is automatically generated for both small and large earthquakes in areas where it is available. It can be used for emergency response, loss estimation, and public information. ShakeMap was first developed for earthquakes in southern California as part of the TriNet Project, a joint effort by the U.S. Geological Survey (USGS), California Institute of Technology (Caltech), and the California Geological Survey (CGS).

Following the Northridge earthquake in 1994, older analog instruments were replaced with a state-of-the-art seismic network with digital communications in real time. Deployment was completed in 2002. This network enables seismic data to be used in new and innovative ways. A product of the new network, ShakeMap, was made possible by advances in telecommunications and computer-processing speed, and research aimed at understanding the relation between recorded ground motions and damage intensities. ShakeMaps show the distribution of ground shaking in the region, information critical for emergency-management decision-making. It is the distribution of intensity (local severity of shaking), rather than the magnitude (the total energy released by the earthquake), that provides useful information about areas prone to damage. Having this information in real time will result in lives saved and reductions in property damage.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

If only they had been available. . . *ShakeMaps did not exist in 1994 when the magnitude 6.7 Northridge, Calif., earthquake occurred. Had a ShakeMap been available for that earthquake, it could have been used to rapidly guide emergency-response teams to areas that potentially had the greatest need. The above ShakeMap is made with data recorded from the Northridge earthquake. It shows that the greatest shaking occurred to the north of the epicenter and in other isolated areas, a pattern that could not have been anticipated with only magnitude and location information for the earthquake.*

Why ShakeMap is Necessary

After a damaging earthquake, emergency managers must quickly find answers to important questions: Where is the most serious damage?

U.S. Department of the Interior
U.S. Geological Survey

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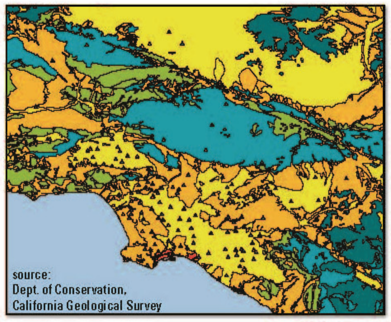
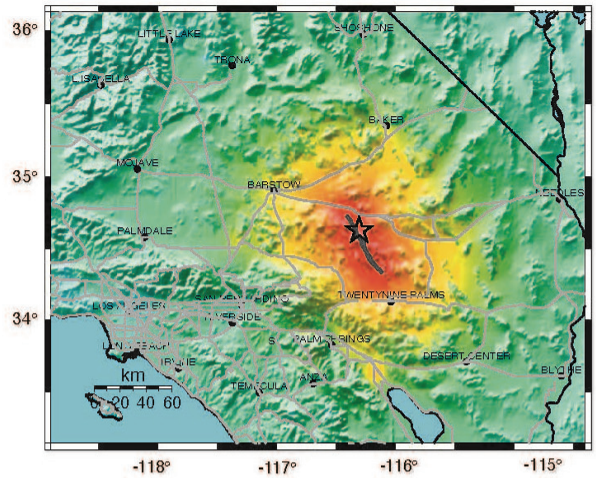
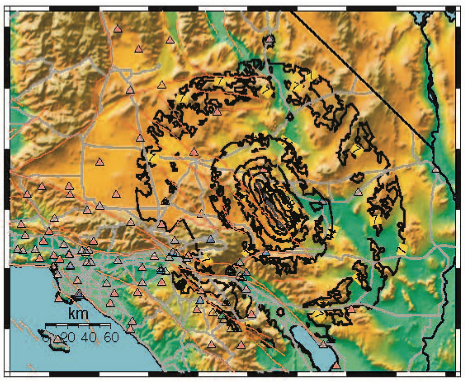
Making ShakeMap



1 *The shaking level is recorded at hundreds of seismic stations (triangles). In the areas between stations, shaking levels are estimated on the basis of knowledge of how seismic energy travels and of the local geology. Relatively weak soils that transmit seismic energy more easily are shown in orange, yellow, and red. Stronger units are shown in green and blue.*



3 *Ground motions are converted to color-coded seismic intensity to show potential damage and perceived shaking level at all locations. Additional maps provide information on specific frequencies of shaking waves, that can be used to anticipate the response of different types of buildings to the ground motion. These are useful for estimating which areas are most likely to have damaged buildings and utility and transportation lifelines. All the maps are refined and updated as more data become available.*



2 *Example from the 1999 Hector Mine, Calif., earthquake. Ground-motion amplitudes are contoured to indicate where recorded motions were strongest. Here, topography is color coded (browns and yellows indicate higher elevation, blues and greens indicate lower elevation).*

Where is less damage? What resources must be mobilized and in what quantities? Government response organizations typically answer these questions after a preliminary survey of the damaged area. Private-sector organizations conduct their own investigations but also wait for government reports regarding damage. This reconnaissance requires hours and sometimes days to complete. As a result, decisions regarding search and rescue, medical emergency response, care and shelter for the injured and displaced persons, and other critical response needs must often be made while information is still incomplete.

In the past, rapidly available information on an earthquake included the magnitude, location, and some assessment of the probability of damaging aftershocks. Even though useful, this information was not sufficient to support rapid post-earthquake emergency-management decision-making. Because an earthquake happens over a fault surface, not at a single point, the location of the earthquake (the epicenter) tells us only where the earthquake started, not necessarily where the shaking was the greatest. For a large earthquake, damage can sometimes occur hundreds of miles from the epicenter. Other factors, such as rupture direction and local geology, influence the amount of shaking in a particular area.

Although emergency responders identified many areas of heavy damage soon after both the 1994 Northridge and the 1989 Loma Prieta earthquakes in California, additional regions of severe damage were only belatedly discovered. A ShakeMap displays the distribution of ground shaking within minutes after an earthquake so that emergency services may be deployed to those locations.

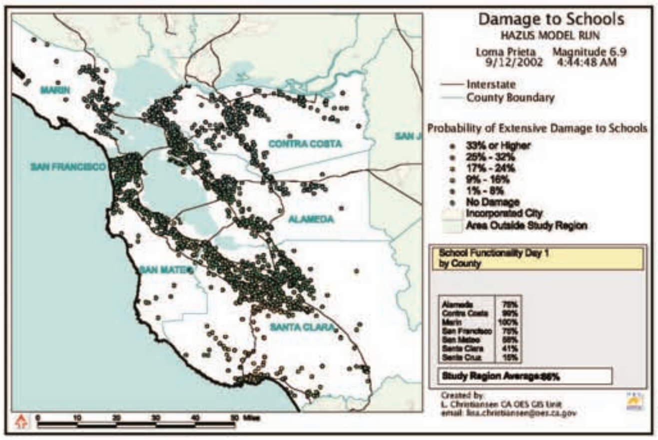
Putting ShakeMap to Use

ShakeMap's rapid portrayal of shaking distribution following an earthquake provides opportunities to enhance post-disaster response by integrating other useful technologies including geographic information systems (GIS) and the Federal Emergency Management Agency's (FEMA) loss-estimation software (HAZUS). City, county, and State agencies can obtain ShakeMap "shapefiles" for use as overlays with GIS, providing a more detailed understanding of potential damage to local infrastructure and facilitating a more effective response. HAZUS estimates economic (damage and dollar losses) and societal impacts (number of casualties, displaced families, shelter needs) of earthquakes. The California Office of Emergency Services uses ShakeMap rather than magnitude and location to calculate HAZUS loss estimates, thus generating estimates based on actual measured ground shaking.

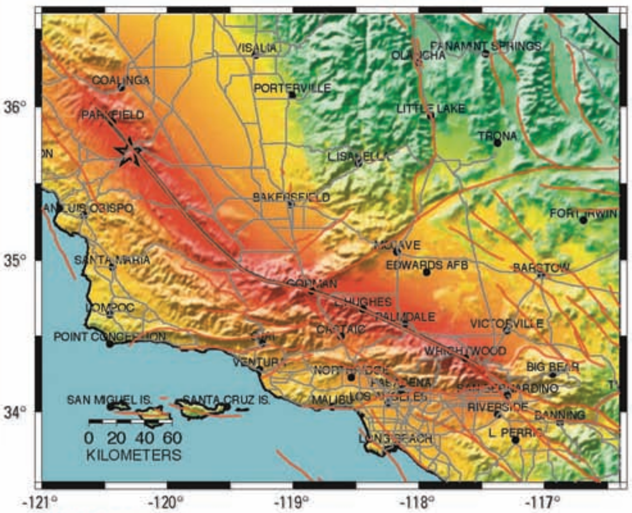
Response and recovery efforts by utilities and private companies benefit from quick knowledge of where facilities are likely to be damaged, and which employees may be unavailable due to the location of their homes or commuting routes with respect to damaged areas.

Using ShakeMap, the California Department of Transportation (Caltrans) will evaluate traffic flow and prioritize inspection of the nearly 25,000 bridges and overpasses statewide, and earthquake engineers will prioritize building-safety inspections, an otherwise potentially overwhelming task. The public will also have access to the information needed to understand their situation, or to gauge the severity of the shaking in communities where relatives reside.

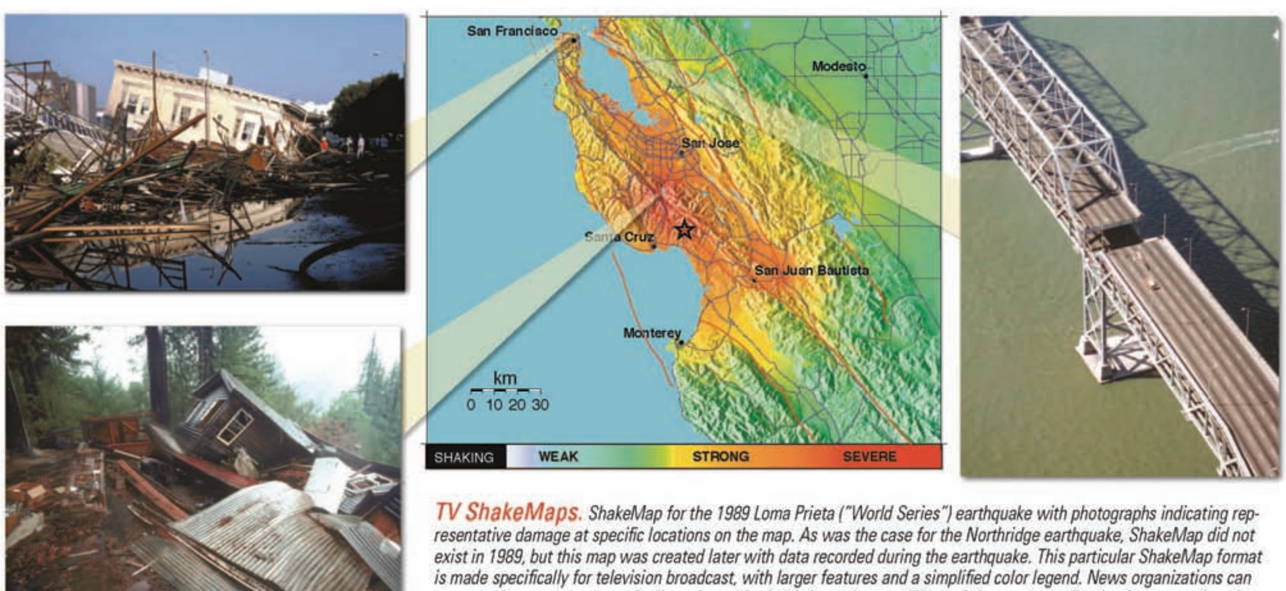
ShakeMaps are organized in a database and made available on the World Wide Web. The maps are interactive—selection of an individual station on the map displays detailed information, including the station name, geographic coordinates, and the local peak ground-motion values. The Web site provides access not only to maps of the most recent earthquakes but also to maps of significant events in the past and shaking expected for candidate earthquake ruptures in the future—so called "scenario" earthquakes.



Likelihood of Damage to Schools. *Scenerio map for an earthquake similar to the 1989 magnitude 6.9 Loma Prieta, Calif., earthquake, prepared using a geographic information system (GIS). This map was made by using ShakeMap input for Hazards U.S. (HAZUS) loss-estimation software. Probable damage to schools is just one of many HAZUS maps produced to help evaluate and respond rapidly following a damaging earthquake. The Federal Emergency Management Agency (FEMA), statewide agencies, and local municipalities also use HAZUS to plan their response to earthquake disasters. Figure courtesy of L. Christensen, California Governor's Office of Emergency Services (OES).*



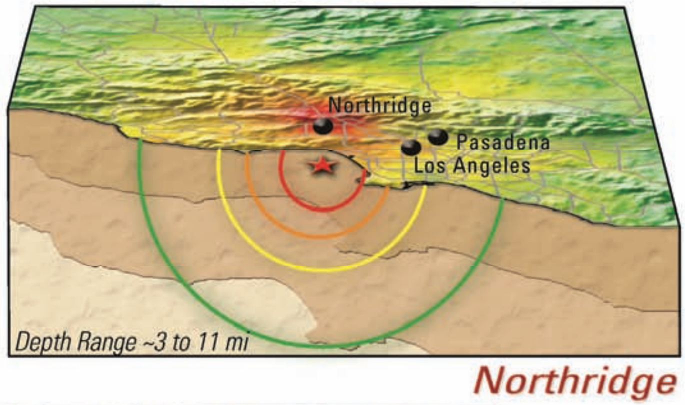
1857 Scenario. *"Scenario" ShakeMap for a hypothetical repeat of the magnitude 7.8, 1857 Fort Tejon earthquake in southern California. Strong, potentially damaging shaking occurred as far as 200 miles from the epicenter (star) over a significant portion of the State. The most severe shaking occurred near a portion of the San Andreas fault that ruptured (black trace). Color scale is the same as that of the Northridge ShakeMap.*

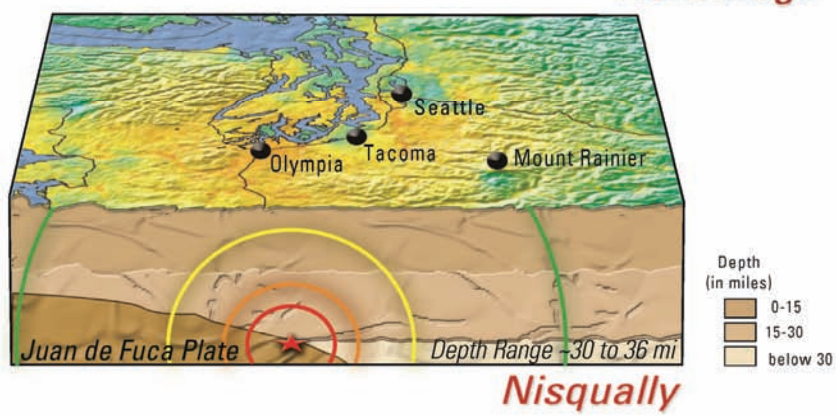


TV ShakeMaps. *ShakeMap for the 1989 Loma Prieta ("World Series") earthquake with photographs indicating representative damage at specific locations on the map. As was the case for the Northridge earthquake, ShakeMap did not exist in 1989, but this map was created later with data recorded during the earthquake. This particular ShakeMap format is made specifically for television broadcast, with larger features and a simplified color legend. News organizations can now get these maps automatically and provide vital information to millions of viewers immediately after an earthquake.*

Northridge (M 6.7) versus Nisqually (M 6.8)

Comparison of ShakeMaps generated for the magnitude 6.7, 1994 Northridge, Calif., and the magnitude 6.8, 2001 Nisqually, Wash., earthquakes. Though similar in ***magnitude****, the difference in earthquake focal* ***depth*** *resulted in substantially different levels of shaking and damage and, therefore, necessitated very different levels of emergency response. Such differences are not obvious from the magnitude and epicenter information alone but are readily discernable from these displays.*





Despite the similar magnitudes, the shaking intensity of the Northridge earthquake reached IX (very strong) close to the epicenter (note the red shading near Northridge), but only reached VII for the deeper Nisqually event (note the lack of red shading).

Modified Mercalli Intensity Scale

Intensity describes the effects of ground shaking on people, buildings, and natural features. It varies from place to place within the affected region, depending on the location of the observer with respect to the earthquake epicenter. In general, the intensity decreases as one moves away from the fault, but other factors such as rupture direction and local geology also influence the amount of shaking. Roman numerals are commonly used to describe intensities to distinguish them from magnitudes. The Modified Mercalli Intensity Scale is currently used in the United States and ranges from I to X.

Magnitude Scale

Magnitude is a number representing the total amount of energy released by the earthquake source. It is based on the amplitude of the earthquake waves recorded on instruments that have a common calibration. The magnitude of an earthquake is thus represented by a single, instrumentally determined value.

The Future of ShakeMaps

Current work will soon enable users to have automatic delivery of a wide range of ShakeMap products with a variety of types of telemetry, including wireless devices. Coupling automatic ShakeMap delivery with instant analysis of the user's facilities will allow immediate impact assessments, enabling rapid response decisions to be made more easily and confidently.

Efforts are now underway to expand the use of ShakeMaps to other seismically active areas of the United States under the auspices of the U.S. Geological Survey's Advanced National Seismic System (ANSS, *http://earthquake.usgs.gov/*). In addition to California, ShakeMaps are now being produced in other seismically active urban areas, including Seattle and Salt Lake City. With expanded seismic instrumentation, it will eventually be possible for any seismic network to generate ground-shaking maps for its region and make them rapidly available on the Internet and through the media. An investment in high-quality instrumentation and ongoing support can result in a system that will promote more efficient emergency response, help reduce losses, and save lives after an earthquake. The work of U.S. Geological Survey scientists within ANSS is only part of the ongoing USGS effort to safeguard lives and property from future earthquakes.

For More Information Contact:

Earthquake Hazards Program
U.S. Geological Survey
Golden, CO 80401

ShakeMaps are at:
http://earthquake.usgs.gov/shakemap/

Partners: Cooperating Regional Networks under the Advanced National Seismic System (ANSS), including the California Integrated Seismic Network (CISN), the University of Utah Seismographic Stations (UUSS), and the Pacific Northwest Seismic Network (PNSN).

Written by David Wald, Lisa Wald, Bruce Worden, and Jim Goltz

Graphics and layout design by Lisa Wald and Eleanor M. Omdahl

This Fact Sheet is available online at http://pubs.usgs.gov/fs/fs-087-03/

USGS SHAKEMAP SCIENTIFIC BACKGROUND

Source: http://earthquake.usgs.gov/earthquakes/shakemap/background.php

ShakeMap Scientific Background

Introduction

A ShakeMap is a representation of ground shaking produced by an earthquake. The information it presents is different from the earthquake magnitude and epicenter that are released after an earthquake because ShakeMap focuses on the ground shaking produced by the earthquake, rather than the parameters describing the earthquake source. So, while an earthquake has one magnitude and one epicenter, it produces a range of ground shaking levels at sites throughout the region depending on distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the Earth's crust.

Part of the strategy for generating rapid-response ground motion maps is to determine the best format for reliable presentation of the maps given the diverse audience, which includes scientists, businesses, emergency response agencies, media, and the general public. In an effort to simplify and maximize the flow of information to the public, we have developed a means of generating not only peak ground acceleration and velocity maps, but also an instrumentally-derived, estimated Modified Mercalli Intensity map. This map makes it easier to relate the recorded ground motions to the expected felt and damage distribution. The Instrumental Intensity map is based on a combined regression of recorded peak acceleration and velocity amplitudes. (see Intensity Maps)

Even with the current seismic station distribution in Calfornia, data gaps are common, particularly for events outside the densely-instrumented metropolitan regions surrounding Los Angeles and San Francisco. In order to stabilize contouring and minimize the misrepresentation of the ground motion pattern due to data gaps, we augment the data with predicted values in areas without data. Given the epicenter and magnitude (and for larger earthquakes, fault geometry if avaliable), peak motion amplitudes in spare regions are estimated from the ground motion prediction equations.

The instrumental intensity map shows station symbols as open triangles in order to see the underlying intensity value. The legend bar at the bottom explains the colors (and see Intensity Maps below). **For the intensity map as with other maps, station locations are the best indicator of where the map is most accurate: Near seismic stations the shaking is well constrained by data; far from such stations, the shaking is estimated using standard seismological inferences and interpolation.**

Note: ShakeMaps are generated automatically following moderate and large earthquakes. These are preliminary ground shaking maps, normally posted within several minutes of the earthquake origin time. The acceleration and velocity values are raw and are at least initially, NOT checked by humans. Further, since ground motions and intensities typically can vary significantly over small distances, these maps are only APPROXIMATE. At small scales, they should be considered unreliable. Finally, the input data is raw and unchecked, and may contain errors. (See Disclaimer)

Maps - General Information

- The **Red star** usually located near the center of the map is the epicenter.
- **Small unfilled circles**, shown on some maps, are points where strong motion values were estimated and used to fill gaps in the station distribution.
- The **colored triangles** indicate reporting stations. In California, for example:

  Red triangles are stations from the Caltech/USGS digital telemetered network.

  Blue triangles represent California Geological Survey (CGS) and California Strong Motion Instrumentation Program (CSMIP) dial-up stations.

  Yellow triangles represent stations from the ANZA Regional Network.

  Green triangles represent National Strong Motion Project (NSMP) dial-up stations or, on historical maps, non-digital stations from which strong motion records were digitized.
- On the Intensity maps, station symbols are open, allowing the underlying intensity color to show thru. On the other maps station symbols (circles, triangles) are color coded according to the data type mentioned above.

When viewing the peak ground motion maps using a Javascript-enabled browser, additional information about the earthquake epicenter and recording seismic stations can be viewed. A brief summary line is displayed when the mouse pointer is over the epicenter symbol or a station symbol. If the symbol is clicked, a small window with a table of information will be opened. By selecting the epicenter, the earthquake information includes the event date, time, location coordinates in degrees latitude and longitude, and hypocentral depth in kilometers; selecting a seismic station jumps to that stations entry in the table. This window can be moved to a preferred location, and clicking on the tab bar to see another map will close the current information window.

The station information includes the station code and name, the agency that manages the station, the station location coordinates in degrees latitude and longitude, and the peak acceleration, velocity, and spectral acceleration for each component of ground motion (when available). Spectral acceleration maps are only made for larger earthquakes (normally, magntidue greater than 5.5). When the peak ground motion maps are made, the value from the peak **horizontal** component of ground motion is used as the value for the station. This value is highlighted in bold in the station information.

Components from many stations are defined by three letter codes. The last letter indicates the orientation (Z = vertical, N = horizontal north, E = horizontal east). The first two letters indicate the instrument class:

Code	Description
VL	low gain channels on the analog network
VH	high gain channels on the analog network
AS	FBA's on the analog network
HL	FBA's on the digital network
HN	FBA's on the digital network
BH	broadband data streams
HH	broadband data streams

FBA's (force balance accelerometers) are designed to record extremely large ground motions and can accurately record waves from very large earthquakes. However, ground motions from small and moderate earthquakes are often too small to trigger these instruments or rise above instrument noise. On the other hand, Broadband seismic sensors can record extremely small ground motions and accurately record waves from earthquakes that range from very small up to moderately large. A number of stations have both FBA and broadband sensors. For ShakeMap, the network tends to emphasize FBA recordings for large ground motions and broadband recordings for small ground motions.

Occassionally, station channels will be flagged due to problems with the station or possibly anomalous peak values. In this case, the popup window of station information will indicate the flagging with the following codes:

Code	Description
M	Manually flagged
T	Outlier
G	Glitch (clipped or below noise)
I	Incomplete time series
N	Not in list of known stations

Map Types

Peak Acceleration Maps

Peak horizontal acceleration at each station is contoured in units of percent-g (where g = acceleration due to the force of gravity = 981 cm/s/s). The peak values of the vertical components are not used in the construction of the maps because they are, on average, lower than the horizontal amplitudes and ground motion prediciton equations used to fill in data gaps between stations are based on peak horizontal amplitudes. The contour interval varies greatly and is based on the maximum recorded value over the network for each event.

For moderate to large events, the pattern of peak ground acceleration is typically quite complicated, with extreme variability over distances of a few km. This is attributed to the small scale geological differences near the sites that can significantly change the high-frequency acceleration amplitude and waveform character. Although distance to the causative fault clearly dominates the pattern, there are often exceptions, due to local focussing and amplification. This makes interpolation of ground motions at one site to a nearby neighbor somewhat risky. Peak acceleration pattern usually reflects what is felt from low levels of shaking up to to moderate levels of damage.

Peak Velocity Maps

Peak velocity values are contoured for the maximum horizontal velocity (in cm/sec) at each station. As with the acceleration maps, the vertical component amplitudes are disregarded for consistency with the regression relationships used to estimate values in gaps in the station distribution. Typically, for moderate to large events, the pattern of peak ground velocity reflects the pattern of the earthquake faulting geometry, with largest amplitudes in the near-source region, and in the direction of rupture (directivity). Differences between rock and soil sites are apparent, but the overall pattern is normally simpler than the peak acceleration pattern. Severe damage, and damage to flexible structures is best related to ground velocity. For reference, the largest recorded ground velocity from the 1994 Northridge (Magnitude 6.7) earthquake made at the Rinaldi Receiving station, reached 183 cm/sec.

Spectral Response Maps

Following earthquakes larger than magnitude 5.5, spectral response maps are made. Response spectra portray the response of a damped, single-degree-of-freedom oscillator to the recorded ground motions. This data representation is useful for engineers determining how a structure will react to ground motions. The response is calculated for a range of periods. Within that range, the Uniform Building Code (UBC) refers to particular reference periods that help define the shape of the "design spectra" that reflects the building code.

ShakeMap spectral response maps are made for the response at three UBC reference periods: 0.3, 1.0, and 3.0 seconds. For each station, the value used is the peak horizontal value of 5% critically damped pseudo-acceleration.

Rapid Instrumental Intensity Maps

As an effort to simplify and maximize the flow of information to the public, we have developed a means of generating estimated Modified Mercalli Intensity maps based on instrumental ground motion recordings (Wald et al., 1999). These "Instrumental Intensities" are based on a combined regression of peak acceleration and velocity amplitudes vs. observed intensity for eight significant California earthquakes (1971 San Fernando, 1979 Imperial Valley, 1986 North Palm Springs, 1987 Whittier, 1989 Loma Preita, 1991 Sierra Madre, 1992 Landers, and 1994 Northridge).

From the comparison with observed intensity maps, we find that a regression based on peak velocity for intensity > VII and on peak acceleration for intensity < VII is most suitable. This is consistent with the notion that low intensities are determined by felt accounts (sensitive to acceleration). Moderate damage, at intensity VI-VII, typically occurs in rigid structures (masonry walls, chimneys, etc.) which also are sensitive to high-frequency (acceleration) ground motions. As damage levels increase, damage also occurs in flexible structures, for which damage is proportional to the ground velocity, not acceleration. By relating recorded ground motions to Modified Mercalli intensities, we can now estimate shaking intensities within a few minutes of the event based on the recorded peak motions made at seismic stations.

A descriptive table of Modified Mercalli Intensity is available from ABAG (Association of Bay Area Governments). A table of intensity descriptions with the corresponding peak ground acceleration (PGA) and peak ground velocity (PGV) values used in the ShakeMaps is given below. ShakeMap uses PGA to estimate intensities lower than V, it linearly combines PGA & PGV for intensities greater than V and less than VII, and it uses PGV for intensities greater than VII (See Wald et al., 1999b, for more details).

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Global Earthquake ShakeMaps

For regions around the world were there are insufficient near-real time strong motion seismic stations to generate an adequate, strong-ground-motion data-controlled ShakeMap, we can still provide a very useful estimate of the shaking distribution using the ShakeMap software.

Initially, a point source approximation (hypocenter and magnitude) is used to constrain region-specific empirical ground motion estimation. Site amplification is approximated from a relationship developed between topographic gradient and shear-wave velocity. Additional constraints for these predictive maps come primarily from three important sources, the availability of which varies depending on the region in which the earthquake occurred, as well as a function of time after the earthquake occurrence. These constraints include: (1) additional earthquake source information, particularly fault rupture dimensions, (2) observed macroseismic intensities (including via the USGS �Did You Feel It?� system, and (3) observed strong ground motions, where and when available.

When intensity data are used directly, the peak ground motion parameters are inferred from the macroseismic observations using the equations of Wald et al, (1999a). This is the opposite approach normally used in ShakeMaps where numerous seismic recording are available, and from them the intensities are then inferred.

Input data for global ShakeMaps are depicted with circles for intensity reports and triangles for strong motion data. Intensities are further separated by color: **Blue** circles indicate data collected via the USGS "Did You Feel It?" Community Internet Intensity Map system and **Yellow** circles indicate traditional Modifed Mercalli Intensity assignments. For the intensity maps, circles are open, allowing the underlying intensity color to show thru. On the other maps observation location symbols (circles, triangles) are color coded according to the data type mentioned above.

Shakemap Atlas

An atlas of maps of peak ground motions and intensity "ShakeMaps" has been developed for approximately 1,000 recent and historical global earthquakes (Allen and others, 2008). These maps are produced using established ShakeMap methodology (Wald and others, 1999c, 2005) and constraints from macroseismic intensity data, instrumental ground motions, regional topographically-based site amplifications (Wald and Allen, 2007), and published earthquake rupture models. The Atlas of ShakeMaps provides a consistent and quantitative description of the distribution of shaking intensity for recent global earthquakes (January 1973 – September 2007 for Version 1.0). We anticipate that the Atlas will be regularly updated with more data constraints for historical events and the addition of future significant events as time progresses.

The Atlas was developed specifically for calibrating global earthquake loss estimation methodologies to be used in the USGS Prompt Assessment of Global Earthquakes for Response (PAGER) Project. PAGER will employ these loss models to rapidly estimate the impact of global earthquakes as part of the USGS National Earthquake Information Center's earthquake response protocol. Though developed primarily for PAGER, we anticipate many other uses for the historical ShakeMap Atlas, including disaster response planning, capacity building and outreach programs, in addition to calibration of other global loss methodology approaches.

The primary sources for instrumental data are:

- Pacific Earthquake Engineering Research Center's Next Generation Attenuation (NGA) database
- Consortium of Organizations for Strong-Motion Observation Systems (COSMOS)
- European Strong-Motion Database (ESD)
- Kyoshin Network (K-NET), Japan

Macroseismic intensity observations are gathered from several online sources, including:

- National Geophysical Data Center, National Oceanic and Atmospheric Administration (NOAA)
- Centro Regional de Sismología para América del Sur (CERESIS)
- Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy

Community Internet Intensity Maps data obtained from the USGS Did You Feel It? (DYFI?) system (Wald and others, 1999a; Atkinson and Wald, 2007) are a valuable ground-shaking constraint and are used for U.S. events since 1999 and for global events since 2003. Additional intensity data were gathered or digitized from numerous earthquake reconnaissance reports and peer reviewed publications, or through the generous contribution from colleagues around the world.

An important, consolidated source for finite fault models is provided by Martin Mai of the Swiss Seismological Service, Zurich. Other fault rupture dimensions were digitized from observations of surface displacement, finite-fault source inversions and slip distribution determined from teleseismic observations, or more recently, from InSAR observations. Less well-constrained faults have been estimated from earthquake aftershock distributions.

The ShakeMap Atlas aims to provide the best estimate of the shaking distribution for historical earthquakes. One important feature of the Atlas is that data constraints are not limited to those data produced by the National Earthquake Information Center, and we will openly accept data contributions that help to improve the representation of the shaking distribution for any of the events. References to all data sources in the Atlas of ShakeMaps (as of August 2008) are provided in Allen and others (2008). Please contact Trevor Allen or David Wald with any comments or data contributions.

Release Notes

Below we indicate the default values and predictive equations used in constructing the Atlas of ShakeMaps. Variations in ground-motion prediction equations (GMPEs) and other configurations may change on an event-by-event basis. Please see the event info.xml on individual ShakeMap download pages or Allen and others (2008) for more information.

Version 1
Date Range: January 1973 – September 2007
Active crust GMPE: Boore and others (1997)
Subduction zone GMPE (intraslab and interface): Youngs and others (1997)
Stable continent GMPE: Atkinson and Boore (2006)
Seismic site-conditions: Wald and Allen (2007) <http://earthquake.usgs.gov/vs30/>
Peak ground motion to macroseismic intensity conversions: Wald and others (1999b)

References

See website, **http://earthquake.usgs.gov/earthquakes/shakemap/background.php** for list of references.

Scenario Earthquakes

Earthquake Scenarios describe the expected ground motions and effects of specific hypothetical large earthquakes. In planning and coordinating emergency response, utilities, emergency responders, and other agencies are best served by conducting training exercises based on realistic earthquake situations, ones that they are most likely to face. Scenario earthquakes can fill this role; they can be generated for any potential hypothetical future or past historic earthquake by the following steps.

First, assume a particular fault or fault segment will rupture over a certain length relying on consensus-based information about the potential behavior of the fault. For historic events, the actual rupture dimensions may be constrained based on existing observations or models. Second, estimate ground motions at all locations in a chosen region surrounding the causative fault.

These earthquake scenarios are not earthquake predictions. That is, no one knows in advance when or how large a future earthquake will be. However, if we make assumptions about the size and location of a hypothetical future earthquake, we *can* make a reasonable prediction of the *effects* of the assumed earthquake, particularly the way in which the ground will shake. This knowledge of the potential shaking effects is the main benefit of the earthquake scenario for planning and preparedness purposes.

In California, the California Geological Survey (CGS) and the U.S. Geological Survey (USGS) have evaluated the probabilistic hazard from active faults in the state as part of the Probabilistic Seismic Hazard Assessment For The State of California described by Peterson et al. (1996) and the National Seismic Hazard Mapping Project described by Frankel et al. (1996). From these maps it is possible to prioritize the best scenario earthquakes to be used in planning exercises by considering the most likely candidate earthquake fault first, followed by the next likely, and so on. Such an analysis is easily accomplished by hazard deaggregation, in which the contributions of individual earthquakes to the total seismic hazard their probability of occurrence and the severity of the ground motions are ranked in order. U sing the individual components ("deaggregations") of these hazard maps, a user can properly select the appropriate scenarios given their location, regional extent, and specific planning requirements. Currently, the ShakeMap scenario events come directly out of the CGS catalog of fault source parameters that make up the statewide probabilistic seismic hazard assessment.

Details of the choice of scenarios for the northern California Bay Region can be found here.

Users interested in specific scenarios for planning purposes are encouraged to make such a request by filling out a ShakeMap Comment Form.

Estimating Ground Motions for Scenario Earthquake ShakeMaps

At present, ground motions are estimated using an *empirical attenuation relationship*, which is a predictive relationship that allows the estimation of the peak ground motions at a given distance and for an assumed magnitude. Thus, ground motions are estimated for a given magnitude earthquake, and at a particular distance from the assumed fault, in a manner consistent with recordings of past earthquakes under similar conditions. For ShakeMap, we use the relationship of Boore et al. (1997) for peak and spectral acceleration, and we use Joyner and Boore's (1988) relationship for peak velocity. We use these predictive relationships to estimate peak ground motions on rock sites, and then correct the amplitude at that location based on the site soil conditions as we do in the general ShakeMap interpolation scheme. Site conditions come directly from the Statewide Site Conditions Map for California (Wills et al., 2000) and we correct for site amplification with the amplitude and frequency-dependent factors determined by Borcherdt (1994).

Attributes and Limitations of Current Maps

Our approach is simple and approximate. We account for fault finiteness by measuring the distance to the surface projection of the fault location (Joyner and Boore's distance definition), but we do not consider the direction of rupture nor do we modify the peak motions by a directivity term. With this approach, the location of the earthquake epicenter does not have any effect on the resulting ground motions; only the location and dimensions of the fault matter. If we were to add directivity to the calculations, than different choices of epicentral location would result in significantly different motions for the same magnitude earthquake and fault segment. Rather, our approach here is to show the average effect since it is difficult to show results for every possible epicentral location.

Our empirical predictive approach also only gives average peak ground motions values so it does not account for all the expected variability in motions, other than the aforementioned site amplification variations. Actual ground motions show significant variability for a given distance, magnitude, and site condition and, hence, the scenario ground motions are more uniform than would be expected for an actual earthquake. The true variations are partially attributable to 2D and 3D wave propagation, path effects (such as basin edge amplification and focusing), differences in motions among earthquakes of the same magnitude, and complex site effects not accounted for by our method.

Uses

Earthquake scenarios are used heavily in emergency response planning. Primary users for response planning include city, county, state and federal government agencies (e.g., the California Office of Emergency Services, FEMA, the Army Corp of Engineers), emergency response planners and managers for utilities, businesses, and other large organizations. Scenarios are also used for loss-estimation by utilities, governments, and industry.

Scenarios are of fundamental interest to the community and scientific audiences interested in the nature of the ground shaking likely experienced in past earthquakes as well as the possible effects due to rupture on known faults in the future.

In addition, more detailed and careful analysis of the ground motion time histories (seismograms) produced by such scenario earthquakes is highly beneficial for earthquake engineering considerations. Engineers require site-specific ground motions for detailed structural response analysis of existing structures and future structures designed around specified performance levels. In the future, with these scenarios we will also provide synthetic time histories of strong ground motions that include rupture directivity effects.

Future Scientific Advances

While current earthquake modeling techniques are sufficient for providing useful motion time histories and scenario ShakeMaps based on empirical means (e.g., ground motion attenuation relations), substantial improvement will require developing cost-effective numerical tools for proper theoretical inclusion of known complex ground motion effects. These efforts are underway and must continue in order to obtain site, basin and deeper crustal structure, to characterize and test 3D earth models (including attenuation and nonlinearity), and to improve numerical wave propagation methods to obtain useful, site-specific, ground motion time histories.

References

See website, **http://earthquake.usgs.gov/earthquakes/shakemap/background.php** for list of references.

USGS SITE CORRECTIONS IN SHAKEMAP FOR SAN FRANCISCO

The following information on site corrections in ShakeMap for San Francisco was provided to the CAPSS project team by Kuo-Wan Lin of the U.S. Geological Survey. The text has been edited for clarity and consistency with other parts of the appendix:

1. **Applied V_s30 (shear-wave velocity over 30 meters depth) value**. To determine the applied V_s30 value used for a given location on the ShakeMap, it is necessary to digest the information included in the ShakeMap product "grid.xml." One simple way to do this is to use the program ShakeCast (see following pages). By clicking inside the mapped area (or entering an address) in ShakeCast Lite, one can extract the representative ground motion measures of the grid in which the geographic location falls. The entry SVEL represents the V_s30 estimates. In full ShakeCast, if a facility covers multiple grids then the maximum value will be used.
2. **V_s30 equivalent NEHRP site class and amplification factor**. Listed below is the actual site correction lookup table used inside ShakeMap based on Borcherdt's (1994) method (Borcherdt, 1994, *Earthquake Spectra*, Vol. 10, No. 4, pages 617-653). Each V_s30 estimate can be translated to an equivalent NEHRP site class. The final site amplification factor is applied based on the peak ground acceleration (PGA) value and the frequency of the computed ground motion measure. PGA and spectral acceleration, PSA0.3 sec, use one category, and peak ground velocity (PGV), PSA1.0, and PSA3.0, the other.

Short Period (0.1-0.4 sec) site correction factors for PGA used in ShakeMap

Site Class (Vmax m/s) /PGA (g)	0.1	0.2	0.3	0.4
E (163)	1.65	1.43	1.15	0.93
DE (298)	1.34	1.23	1.09	0.96
D (301)	1.24	1,17	1.06	0.97
CD (382)	1.15	1.10	1.04	0.98
C (464)	1.00	1.00	1.00	1.00
BC (686)	0.98	0.99	0.99	1.00
B ( )				

Mid Period (0.4-2.0 sec) site correction factors for PGV used in ShakeMap

Site Class (Vmax m/s) /PGA (g)	0.1	0.2	0.3	0.4
E (163)	2.55	2.37	2.14	1.91
DE (298)	1.72	1.65	1.56	1.46
D (301)	1.71	1.64	1.55	1.45
CD (382)	1.49	1.44	1.38	1.32
C (464)	1.29	1.26	1.23	1.19
BC (686)	1.00	1.00	1.00	1.00
B ( )	0.97	0.97	0.97	0.98

3. **Site correction data source**. The site correction data layer for Northern California ShakeMap is based on surface geology map/data and is from two sources, the Chris Wills geology map of California

(http://pubs.usgs.gov/ot/2009/1298/pdf/usgs_of2009-1298_wills.pdf, table 1) and an additional GIS layer of sediment and fill for the Bay Area.

4. **Grid sampling, grid resolution, and strong motion input data**. Currently ShakeMap for the Bay Area is produced at a grid spacing of 0.016667 degrees, or roughly 1km on each side. The site correction data layer has been sampled to match the computation resolution. Maps showing the locations of available strong-motion stations that can be used as ShakeMap inputs can be obtained from the USGS strong-motion data center. Not all station data will be available immediately after an earthquake. A high resolution ShakeMap for the Bay Area or just San Francisco, in addition to the regular ShakeMap, may be an option to provide street-level data sampling.

USGS ShakeCast

Automating, Simplifying, and Improving the Use of ShakeMap for Post-Earthquake Decisionmaking and Response

ShakeCast is a freely available, post-earthquake situational awareness application that automatically retrieves earthquake shaking data from ShakeMap, compares intensity measures against users' facilities, and generates potential damage assessment notifications, facility damage maps, and other Web-based products for emergency managers and responders.

What is ShakeCast?

ShakeCast, short for *ShakeMap Broadcast*, is a fully automated system for delivering specific ShakeMap products to critical users and for triggering established post-earthquake response protocols. ShakeMap is a well-established tool used to portray the extent of potentially damaging shaking following an earthquake. ShakeMap is automatically generated for small and large earthquakes in areas where it is available and can be found on the Internet at *http://earthquake.usgs.gov/shakemap/*. It was developed and is used primarily for emergency response, loss estimation, and public information. However, for an informed response to a serious earthquake, critical users must go beyond just looking at ShakeMap, and understand the likely extent and severity of impact on the facilities for which they are responsible. To this end the U.S. Geological Survey (USGS) has developed ShakeCast.

ShakeCast allows utilities, transportation agencies, businesses, and other large organizations to control and optimize the earthquake information they receive. With ShakeCast, they can automatically determine the shaking value at *their* facilities, set thresholds for notification of damage states for each facility, and then automatically notify (by pager, cell phone, or email) specified operators and inspectors within their organizations who are responsible for those particular facilities so they can set priorities for response.

Collapse of the Interstate-5/State Highway-14 interchange showing damage north of Los Angeles caused by the 1994 magnitude 6.7 Northridge, California, earthquake. Thousands of State and County bridges were shaken at varying intensity levels during this earthquake; many required inspections.

Example Uses and Users: The California Department of Transportation (Caltrans)

Caltrans has deployed the prototype ShakeCast system (Version 1.0). Following a major earthquake, Caltrans faces an array of decisionmaking challenges. Perhaps no other agency has a comparable earthquake exposure in the State of California. Caltrans has more than 11,000 bridges and overpasses under its responsibility in California; having an instantaneous snapshot of the likely damage to each will allow Caltrans to set priorities for traffic rerouting, closures, and inspections following a damaging earthquake. One of several critical tasks facing Caltrans after an earthquake is to rapidly assess the condition of all bridges and roadway corridors in the State highway system. Timely response is important to ensure public safety, aid routing of emergency vehicle traffic, and (re-) establish critical lifeline routes.

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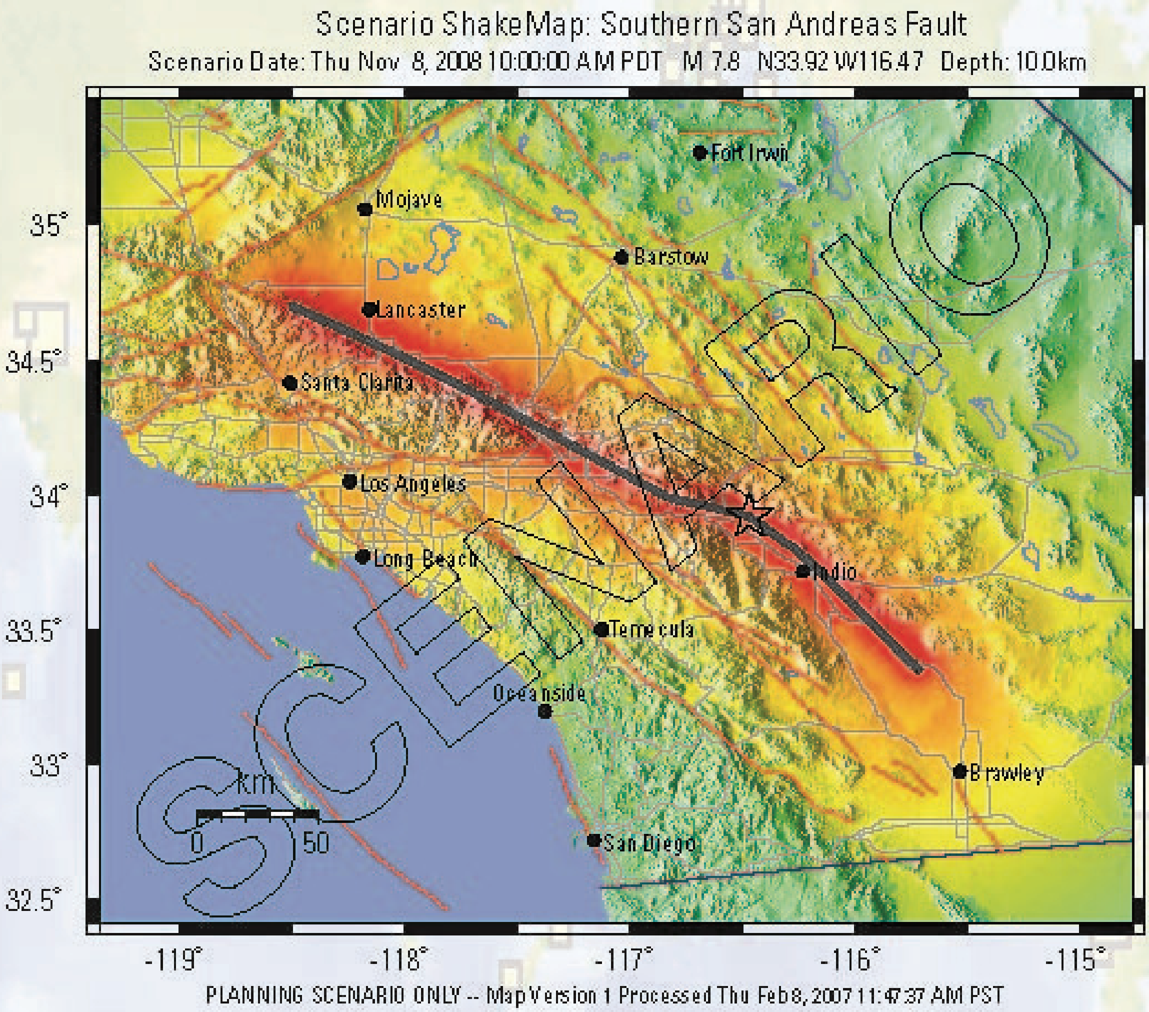
In addition to real-time notification, ShakeCast also can generate and deliver scenario earthquakes for facility response plans (figs. 1 and 2). This application includes routine testing of the system, earthquake scenario exercises, and evaluating performance and response under potential earthquake conditions. ShakeMap is now used routinely to generate earthquake scenarios for many regions; ShakeCast will further allow planning exercises to be performed using the same notification tools that will be available and in place for responding to a real earthquake.

ShakeCast Technology

Individuals, companies, utilities, and agencies could develop their own strategies and tools for using ShakeMap given their



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. ShakeMap intensity map for a magnitude 7.8 Scenario Earthquake on the southern San Andreas fault. Red lines delineate faults and light grey lines show highways.

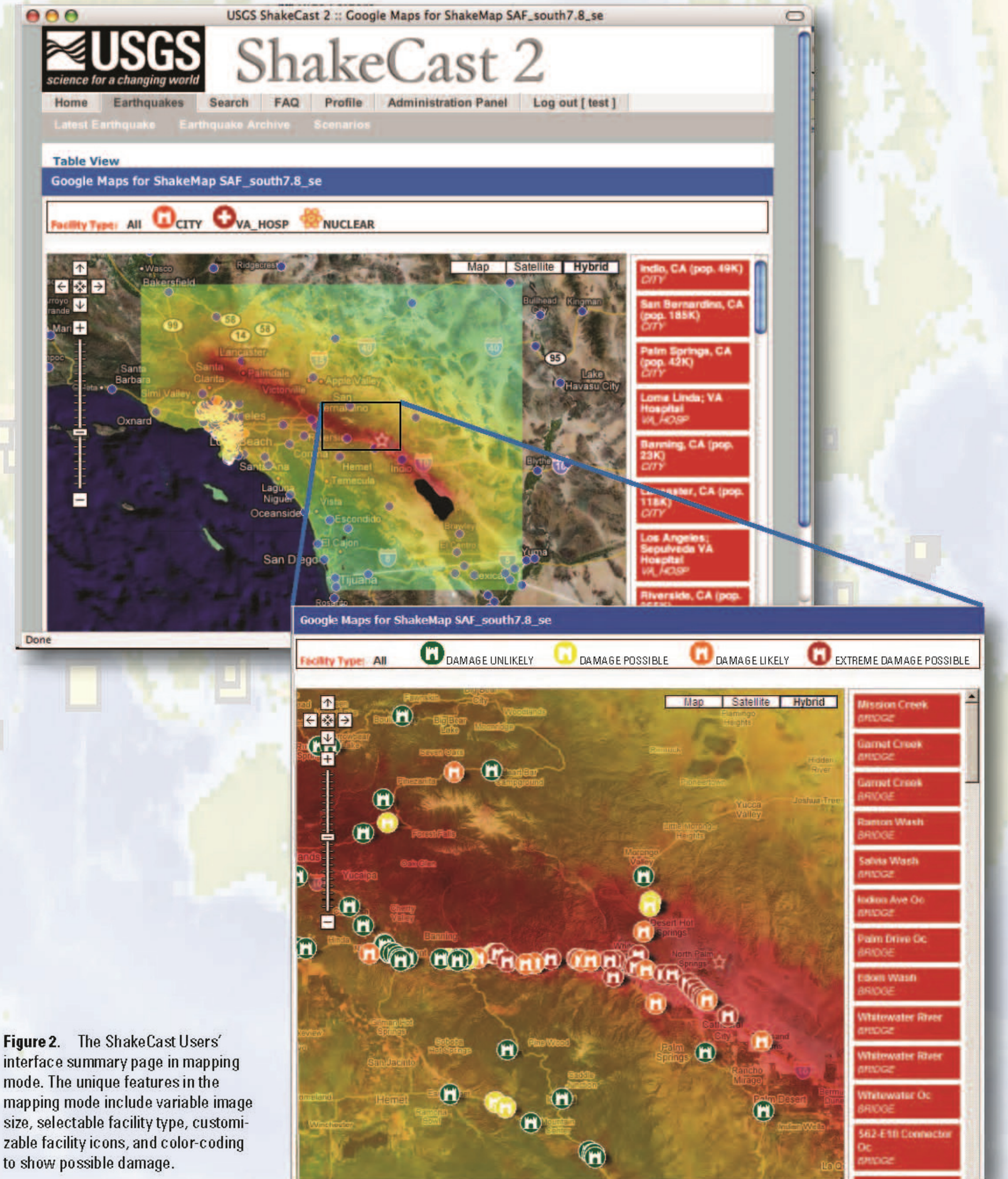


Figure 2. The ShakeCast Users' interface summary page in mapping mode. The unique features in the mapping mode include variable image size, selectable facility type, customizable facility icons, and color-coding to show possible damage.

Example Uses and Users: Los Angeles Unified School District (LAUSD)

LAUSD is using Shakecast to help improve earthquake monitoring and emergency response in southern California, where it is responsible for over 700,000 K-12 students, 100,000 employees, 13,500 buildings, and 1,100 schools and offices. Students and schools are spread across 704 square miles. Under an agreement with the City of Los Angeles, LAUSD buildings are integral to the emergency operations of the city, because school facilities will serve as emergency shelters to be managed by the Red Cross. Hence, knowing which structures are most likely damaged is critical for response and recovery, for example, in designating emergency shelters.

unique facilities and communication paths. However, such efforts are costly and complex. Rather, the USGS is facilitating this process with ShakeCast, building a more general-use tool for the most critical user needs. The ShakeCast software is customizable for facilities, fragilities, and notifications, and we anticipate additional adaptations will be made since the open-source code is provided. Such innovations then can be provided in the tool kit included with updates of the ShakeCast system.

Information Technology (IT) security is a primary concern for users requiring automatic electronic delivery of information. By taking advantage of standard Internet protocols, ShakeCast users avoid most typical corporate and Government concerns and firewall limitations. By using Really Simply Syndication (RSS) and interval polling, users initiate all communications with the USGS Web servers that host ShakeMap, and retrieve selected products as a request rather than a "push." This RSS approach allows users to update software automatically under conditions of their own choosing.

ShakeCast software is built upon open-source tools, providing standard, freely available software for all users, encouraging user improvements, and simplifying interfacing with existing users' response tools. ShakeCast uses the Apache Web server and PHP (Hypertext Preprocessor) for dynamic Web content, MySQL for facility and notification databases, and is wrapped in Practical Extraction and Report Language (PERL) scripting. Exchange files are in Extensible Markup Language (XML) for standardized interfacing with Web, geographic information system (GIS), spreadsheets, databases, and other applications.

Where Can ShakeCast be Used?

ShakeMap is now produced for all earthquakes around the globe of magnitude 5.5 or larger. Globally, these ShakeMaps are primarily predictive and thus lack the resolution and certainty of shaking estimates for maps made in regions of dense seismic instrumentation for which it was principally developed. Regions in the United States that have ShakeMap operating with reasonable (but variable) seismic station coverage include major parts of California, Washington, Oregon, Nevada, Utah, Hawaii, and Alaska. Other regions are improving station coverage. Hence, since ShakeMaps are produced for any region of the world, ShakeCast can be deployed for any exposure of facilities worldwide, again with more uncertainty in the results in regions not specifically listed above.

We use the term "facilities" loosely; at the USGS National Earthquake Information Center (NEIC) in Golden, Colorado, we assign cities as "facilities" and run ShakeCast to determine shaking levels at cities within the United States and around the globe any time a ShakeMap is produced. The list of cities, their populations, and the intensity estimated at each city becomes a Hypertext Markup Language (HTML) email notification that proves useful for NEIC analysts and for other response purposes. Ultimately, these city-based notifications will be integrated as an option in the USGS Earthquake Notification Service (ENS), but this option does not reduce the need for critical users to put their own inventories into an in-house ShakeCast system.

ShakeCast Availability and Installation

ShakeCast is available in two levels, full and "Lite." We describe in detail the full ShakeCast system that allows users to estimate impact to numerous facilities, each potentially with different vulnerabilities and notification recipients. We expect this system to be deployed by critical users in an earthquake-hardened, operational environment. We have also made available ShakeCast Lite, a subset of the system that allows users to automatically receive ShakeMap products on their laptop or desktop computers, and launch predefined applications using those maps or data. For example, many users employ ShakeCast Lite to automatically open a Web browser showing the latest ShakeMap in their region, launch Google Earth® with the ShakeMap KML file, download ShakeMap grid files, and initiate loss-estimation applications, or deliver ShakeMap GIS files to their corporate GIS department for further analyses. ShakeCast Lite is simple to install and use.

An overview of ShakeCast from the users' perspective is provided in figure 3. Organizations using ShakeMap/ShakeCast first download and install the ShakeCast (Version 2) software package on a hardened in-house computer system. The software is installed with an interactive installation script. Facility, vulnerability, and notification data are input using import tools and simple, comma separated (CSV) users' files. ShakeCast comes preconfigured, but custom configuration is simplified by ShakeCast tools and the Web interface. The Web interface allows an administrator to access all functions of the local ShakeCast system, and end users are able to manage their own personal information and notification preferences.

Initial setup involves the following steps: (1) populating a database of facility locations and types; (2) assigning fragilities using specific ShakeMap parameters (for example, intensity, peak or spectral acceleration) and the corresponding likely "green," "yellow," and "red" damage states ("damage unlikely," "damage possible," and "damage likely" thresholds, for example); (3) specifying who receives notifications by listing addresses of facility managers and response personnel (email, cell phone); and (4) selecting under which circumstances the alerts are sent (for example, damage "possible" at specific facilities). In addition, the user can customize the content of the summary report that is delivered internally; for example, a list of facilities based on their likely damage state, and organizational specific links and images.

Example user and earthquake data, tutorials, and documentation are provided with the installation package.

Ongoing ShakeCast Development

Ongoing software development of ShakeCast continues, and much of it is motivated by users' experiences and recommendations. ShakeCast, Release Version 2.1, is expected to include the following enhancements:

- Additional predefined facility structure types and vulnerability functions. Currently (2007) 36 structure types are available from the Federal Emergency Management Agency's Hazards US loss modeling software (HAZUS-MH).
- Additional vulnerability types, including pipeline, liquefaction, and landslide failure potential. In addition to maps, 2-D profiles will provide pipeline cross-sectional views.
- Ability to select a specific structure and seismic instrument data over interpolated shaking values from ShakeMap.

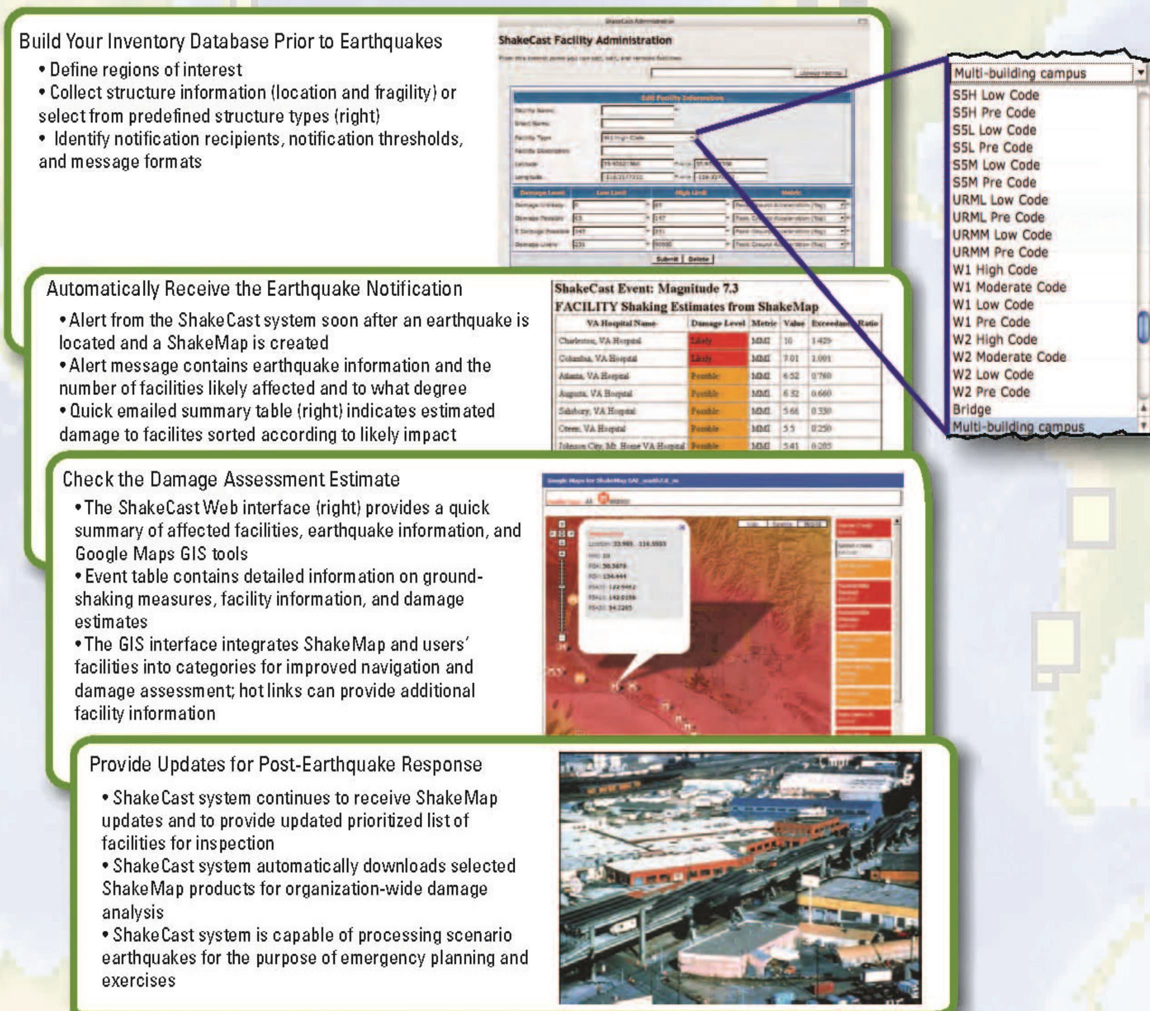


Figure 3. ShakeCast overview from the users' perspective.

Collapsed section of the Cypress viaduct of Interstate 880 in Oakland following the magnitude 6.9 earthquake in 1989 in Loma Prieta, California.

- Expanded GIS support for common data exchange formats and application programming interfaces (APIs) (currently supports data export via user-defined templates).
- Support for UNIX, Mac, and LINUX operating systems (currently runs on Microsoft Windows).
- Compute and visualize uncertainties in ground shaking and damage likelihood.
- Improved re-notification logic, allowing flexibility in conditions for re-alerting (for example, if damage state changes for one or more facilities).

Optional, automatic updates of the software will be provided by the RSS feed from USGS Web servers.

Sources of Additional Information

On the Web:

ShakeMap:
http://earthquake.usgs.gov/shakemap/
ShakeCast Software:
http://earthquake.usgs.gov/shakecast/

Contacts:

Kuo-Wan Lin, USGS, Golden, CO, *klin@usgs.gov*, (303) 273-8563
David Wald, USGS, Golden, CO, *wald@usgs.gov*, (303) 273-8441

Acknowledgments

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USGS NETQUAKE DESCRIPTION

NetQuakes

The USGS is trying to achieve a denser and more uniform spacing of seismographs in select urban areas to provide better measurements of ground motion during earthquakes. These measurements improve our ability to make rapid post-earthquake assessments of expected damage and contribute to the continuing development of engineering standards for construction.

To accomplish this, we developed a new type of digital seismograph that communicates its data to the USGS via the internet. The seismographs connect to a local network via WiFi and use existing broadband connections to transmit data after an earthquake. The instruments are designed to be installed in private homes, businesses, public buildings and schools with an existing broadband connection to the internet.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government

View Data

The most recent triggered activity at each seismograph is available online.

Volunteers Needed

We are looking for people who are willing to host these "NetQuakes" seismographs. The NetQuakes seismographs access the internet via a wireless router connected to your existing broadband internet connection. The seismograph transmits data only after earthquakes greater than magnitude 3 and otherwise do not consume significant bandwidth.

To host a NetQuakes instrument, you must provide:

- An out-of-the-way location in a 1-2 story building (no significant basement) with less than ~4000 sq feet in plan; building must have a concrete slab foundation in some location (for example, a garage) to which the NetQuakes box can be bolted. Buildings within a half mile of significant business districts and those near urban or suburban faults (such as the Hayward fault in the East Bay) are highly desirable.
- A local network with a permanent broadband connection to the internet. If you don't have WiFi, we will install a WiFi router.
- AC power to the seismograph.

Occasional minor servicing of the instrument, such as battery replacement.

Sign Up

Over the next several years we hope deploy many more of these seismographs in several urban areas. We are collecting names and addresses of people who are willing to host one of these seismographs so that as they become available, we will be able to place them in the most effective locations.

Northern California

If you live northern California (especially in the San Francisco Bay area), you can sign up if the location of your home or business is eligible.

Southern California

If you live southern California (especially near dense population centers), you can sign up if the location of your home or business is eligible.

Pacific NW

If you live in the Pacific NW (especially in the Seattle area), you can sign up if the location of your home or business is eligible.

USGS NETQUAKE FREQUENTLY ASKED QUESTIONS

General

Why do seismologists need to deploy more seismographs?

Records of earthquake ground motion close to large earthquakes are used by the engineers to develop methods to construct buildings that do not collapse during earthquakes. These recordings can also be used to understand why engineered structures (buildings, bridges, overpasses, pipelines) fail during earthquakes if the instrument is located close to the structure. These recordings are quite rare, particularly in dense urban areas. Unfortunately, the San Francisco Bay area is home to several large faults, but this situation is ideal for recording strong shaking near engineered structures.

Signing Up

Can renters host a NetQuakes seismograph?

Yes, as long as the owner of the property does not object to the small hole we must drill to secure the baseplate of the seismograph. The owner of the property will have to sign the Permit Agreement.

Will the USGS pay me to host a NetQuakes seismograph?

No. We are looking for volunteers.

Are there any forms to sign?

You will be asked to sign an agreement that describes your responsibilities and those of the USGS. You can view it here.

My house is just inside one of the polygons. Are you sure I'm ineligible to host a seismograph?

The polygons are only for guidance, so please submit an application.

I wasn't selected to host a NetQuakes site, but I still want to host an seismograph. Will there be future opportunities?

We appreciate your willingness to host a seismograph and regret that we don't have sufficient funding to install seismographs at the locations of all applicants. We hope to install more seismographs next year, and we will keep your application on file.

Installation

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government

How big is a NetQuakes seismograph and what does it look like?

The seismograph has dimensions of approximately width=5.5", height=6.5", and length=11.5".

How much power does the NetQuakes seismograph use?

Approximately 3 watts. At typical residential electricity rates of $0.12/kWh, this costs ~$0.26/month

Where do you prefer to install the NetQuakes seismograph?

The seismograph is a sensitive instrument and therefore should be located where there is as little ambient noise as possible. Garages or basements with concrete slabs are ideal. Locations next to pool pumps or air conditioners are undesireable because the earthquake signal will be contaminated by this noise. If the seismograph is located where there is frequent foot or vehicle traffic, it may trigger repeatedly on non-earthquake signals.

What is involved in installing the seismograph?

The technician and you will agree on a mutually acceptable location to site the instrument. The technician will install the WiFi router, drill a 1/2" hole in the concrete floor, orient the baseplate of the seismograph to point north, bolt the baseplate to the floor, and confirm that the seismograph is both functional and has Internet connectivity. If using wireless, the seismograph will need to be located within about 120 feet of the wireless router.

How long will it take for the technician to install the instrument?

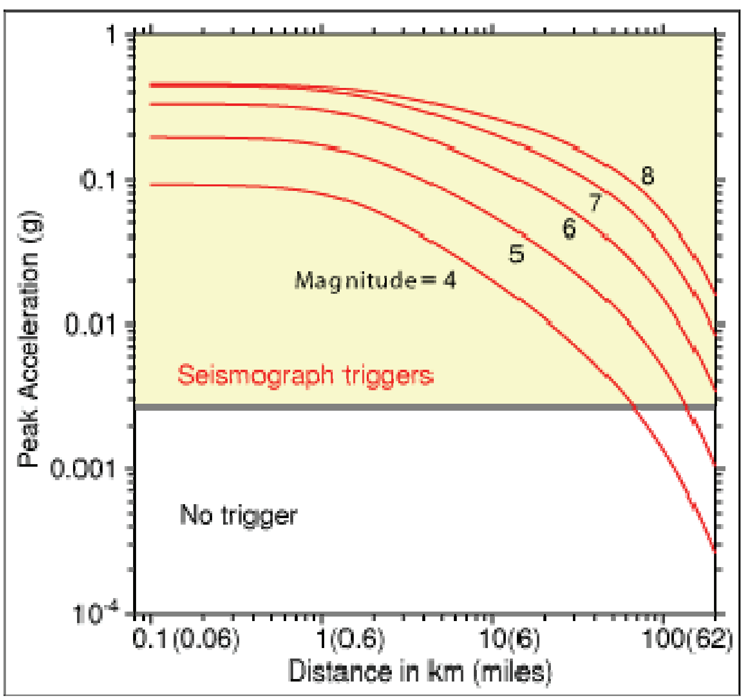
We estimate 2 hours.

Why do you need to bolt the seismograph to the floor?

We want the seismograph to faithfully record strong shaking. If the seismograph slides across the floor or bounces off the ground, then the data are useless. Should we permanently remove the seismograph, we will remove the bolt and fill the small hole.

Triggering

How big does an earthquake need to be to trigger the seismograph?



The seismograph will trigger if the acceleration is greater than 0.25% of the earth's gravity on the horizontal sensors. The plot below shows that the seismograph should trigger for earthquakes of magnitude (M)>4 if within 60 km (37 miles) and M>5 at twice that distance. It is common for the seismograph to trigger on quakes as small as magnitude 3 within distances of a few 10's of km.

For more background on how seismic energy attenuates, visit the "Next Generation of Ground-Motion Attenuation Models" Project.

Will I create an "earthquake" if I accidentally bump the seismograph or if it triggers when I move my car in and out of the garage?

The instrument will trigger if the acceleration is greater than 0.25% of the earth's gravity. It will transmit the data to the USGS, but unless there is a real earthquake at the same time, the data will be ignored but still visible to you on the Web site.

Data & Transmission

Where can I see the data recorded by my NetQuakes seismograph?

Images of the previous 30 days of triggered accelerograms from your instrument are available under View Data on this web site.

What will the USGS do with the earthquake data from the NetQuakes seismograph?

Real-time software will automatically incorporate the data for computing ShakeMaps, improving earthquake locations and magnitudes, and determining the fault orientation. If the magnitude is greater than about 5, we will also use the seismograms to calculate the amount of fault displacement that occurred during the earthquake. The earthquake data will be quickly archived at public datacenters for use by seismologists and engineers. Noise triggers will be discarded.

How does the NetQuakes seismograph access the Internet?

Most hosts will probably prefer that the NetQuakes seismograph connect to the Internet using wireless networking to a WiFI home router using 802.11b or 802.11g, but it does support connection via an Ethernet cable. To minimize the time USGS technicians spend installing the NetQuakes seismograph, we prefer to provide you with a WiFi router that we know works with the NetQuakes seismograph. You will be given the security key so you can use the router. If we can configure the NetQuakes seismograph to successfully connect to the Internet using your wireless router, we will be happy to use your equipment. If using wireless, the seismograph will need to be located within about 120 feet of the wireless router.

Can the USGS access my home computer?

No. Your computer is behind your LAN's firewall and therefore the USGS cannot access your LAN. If we install a WiFi router, we will provide you with administrator passwords on the WiFi router so that you can confirm that the firewall settings of the router are secure.

How long does it take for the NetQuakes seismograph to transmit an earthquake record to the USGS?

About 1 minute.

What happens to the seismic data if the power goes out during an earthquake?

The seismograph will run on internal batteries for about 36 hours. When the battery voltage drops below the required level, the seismograph goes into sleep mode. When it senses the availability of A/C power, it will restart, send data files to the USGS if there is Internet connectivity, and synchronize timing.

What happens if my Internet connection is unavailable?

It will keep trying to connect forever.

Service & Maintenance

How do I know that the NetQuakes seismograph is working?

You can trigger the instrument by gently bumping the instrument so that it triggers. The tiny yellow LED labeled “event” will light for ~1-2 minutes indicating that data are being recorded. Then, the blue LED labeled “link” will light briefly indicating that communications have been established with one of the servers and the data are being uploaded. In a few minutes an image of the accelerograms from your instrument will appear on this web site. If the instrument is malfunctioning, the USGS will notify you about replacing it.

How does the USGS know that the seismograph is functioning properly?

At the beginning of each day, the seismograph will call our servers and send the previous day's computer log. This is a record of each action the seismograph has taken. Once a day, the sensor and record electronics are tested with a calibration signal. At regular intervals, usually once an hour, a short state-of-health message is sent with information about the internal batteries, memory usage, temperature, etc.

What kind of skills do I need to service a NetQuakes seismograph?

A hexdriver (provided) is all that is needed to remove the screws securing the seismograph lid and the seismograph from the baseplate. Servicing will be limited to changing the battery approximately every 3 years, or swapping the entire seismograph if the USGS detects that is malfunctioning. Instructions will also be enclosed with anything we send you, as will business-reply packaging to return the old batteries or seismograph to us free of charge.

I am moving. What do I do with the NetQuakes seismograph?

Please contact us and we will arrange to remove the seismograph. If the new owner desires to keep it operating, please ask them to contact us to make new WiFi and other arrangements.

I am changing Internet Service Providers. Will that require changing anything in the NetQuakes seismograph?

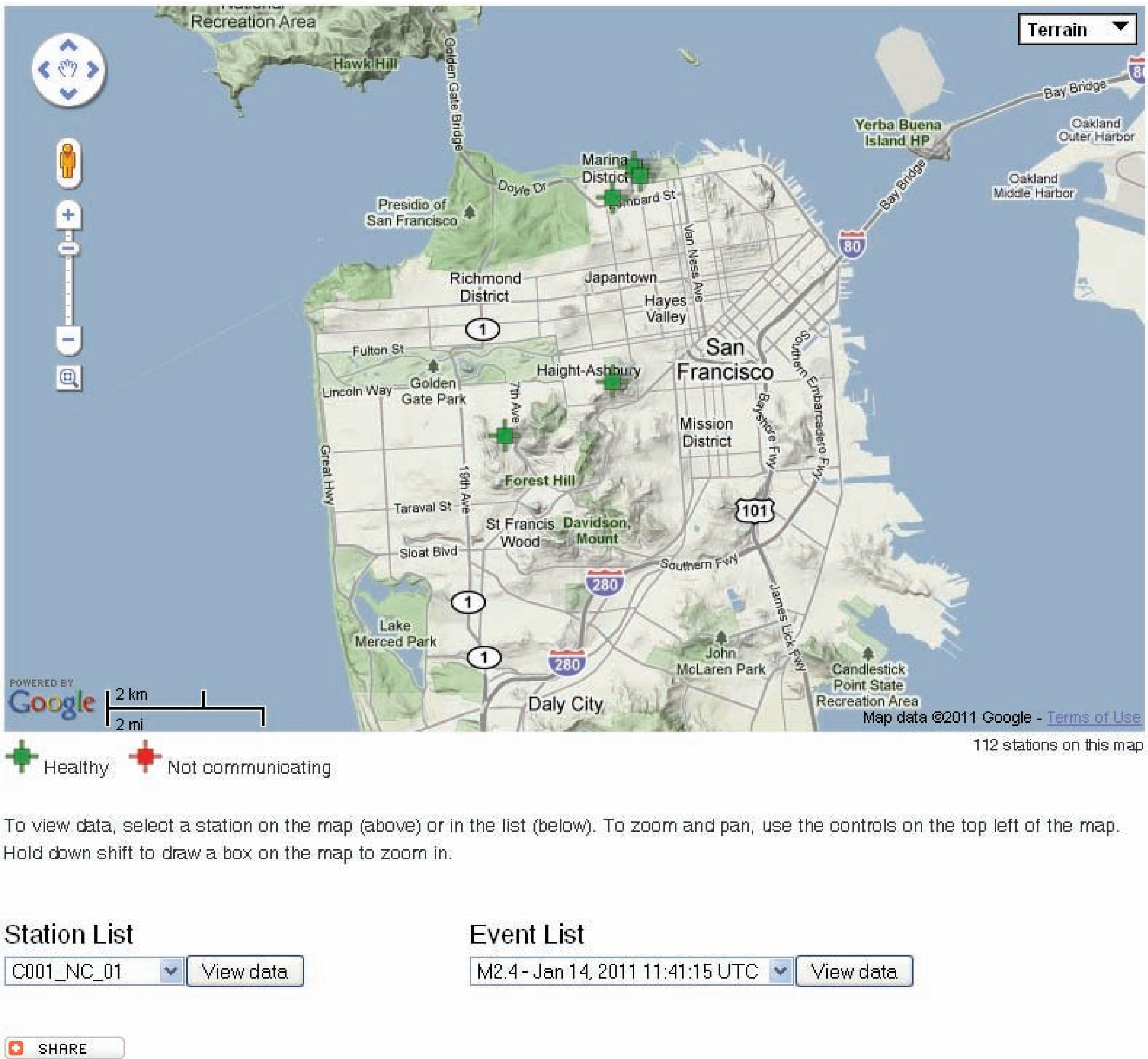
No.

USGS NETQUAKE VIEW FINDER

NetQuakes: Map of Instruments

Northern California

The USGS is trying to achieve a denser and more uniform spacing of seismographs in select urban areas. To accomplish this, we developed a new type of digital seismograph that transmits data to USGS via the internet after an earthquake. The instruments are designed to be installed in private homes, businesses, public buildings and schools. Learn more about how you can help.



References to non-U.S. Department of the Interior (DOI) products do not constitute an endorsement by the DOI. By viewing the Google Maps API on this web site the user agrees to these Terms of Service set forth by Google.

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PROJECT PARTICIPANTS

The Applied Technology Council (ATC) gratefully acknowledges the ATC consultants, who served as the principal authors of this report, the significant contributions of the volunteer Community Action Plan for Seismic Safety (CAPSS) Advisory Committee, participants in the CAPSS Advisory Committee meetings, and the advisory Project Engineering Panel. ATC also gratefully acknowledges the leadership and support provided by San Francisco Department of Building Inspection personnel and the Building Inspection Commission. Individuals who served in these various capacities are identified below.

SAN FRANCISCO DEPARTMENT OF BUILDING INSPECTION (DBI)

Vivian L. Day, Chief Building Official, DBI Director

Laurence Kornfield, Chief Building Inspector and DBI Project Officer

Pamela A. Levin, Deputy Director, Administrative Services

William Strawn, Communications Officer

Sylvia Thai, Administrative Support

Hanson Tom, Principal Engineer

SAN FRANCISCO BUILDING INSPECTION COMMISSION

Mel Murphy, President

Kevin B. Clinch (as of January 2009)

Reuben Hechanova

Frank Lee

Robin Levitt (until December 2009)

Warren Mar (as of January 2010)

Criss Romero

Vahid Sattary (until January 2009)

Debra Walker

ATC MANAGEMENT

Christopher Rojahn, Executive Director (ATC Project Principal), 201 Redwood Shores Parkway, Suite 240, Redwood City, California 94065

L. Thomas Tobin, Consultant (ATC Co-Project Manager), Tobin & Associates, 444 Miller Avenue, Mill Valley, California 94941

Laura Samant (ATC Co-Project Manager), San Francisco, California

ATC PROJECT ENGINEERING PANEL

Roger D. Borcherdt, U. S. Geological Survey, 345 Middlefield Road, MS 977, Menlo Park, California 94025

Patrick Buscovich (ATC Board Representative), Patrick Buscovich and Associates, 235 Montgomery Street, Suite 823, San Francisco, California 94104

Richard K. Eisner, Consultant, Oakland, California 94610

Stephanie A. King, Weidlinger Associates, 399 W. El Camino Real, Suite 200, Mountain View, California 94040

Jack P. Moehle, University of California, Berkeley, 325 Davis Hall, MC 1792, Berkeley, California 94720

Chris D. Poland, Degenkolb Engineers, 235 Montgomery Street, Suite 500, San Francisco, California 94104

ATC CONSULTANTS

David Bonowitz, Structural Engineer, 605A Baker Street, San Francisco, California 94117

William Holmes (Lead Consultant), Rutherford & Chekene, 55 Second Street, Suite 600, San Francisco, California 94105

Bret Lizundia, Rutherford & Chekene, 55 Second Street, Suite 600, San Francisco, California 94105

ATC PROJECT COORDINATION AND PUBLICATION SERVICES

Bernadette Hadnagy, ATC Operations Manager, 201 Redwood Shores Parkway, Suite 240, Redwood City, California 94065

Peter Mork, ATC Information Technology Manager, 201 Redwood Shores Parkway, Suite 240, Redwood City, California 94065

CAPSS VOLUNTEER ADVISORY COMMITTEE AND MEETING ATTENDEES

Mary Lou Zoback (Advisory Committee Co-Chair), Risk Management Associates

John Paxton (Advisory Committee Co-Chair), Real Estate Consultant

Glen Altenberg

Robert Anderson, California Seismic Safety Commission/California Earthquake Authority

Thomas Anderson, Anderson Niswander Construction, Inc.

Steve Appiano, Saunders Construction

Alexandra Bevk, SF Heritage

Jack Boatwright, U.S. Geological Survey, Menlo Park

Bruce Bonacker, SF Heritage

Amy Brown, Office of City Administrator

Mainini Cabute, City of San Jose

Tim Carrico, Property owner/manager

Arrietta Chakos, Consultant

Cynthia Chono, Department of Public Works

Susan Christenson, Department of Emergency Management

Randy Collins, FTF Engineering

Anthony Demascole, Structural Engineer
Sarah Dennis, Planning Department
Rick Dichoco, Tenderloin Neighborhood Development Group
Regina Dick-Endrizi, Office of Small Business
Jason Elliot, Mayor’s Office
Arthur Fellows, Stafford King Weise Architects
J. Edgar Fennie, Fennie+Mehl Architects
Chris Fogle
Natalie Fogle, Architecture + Art
Katie Freeman, Hagerty Consulting
Sig Freeman, Wiss, Janney, Elstner Associates
Lisa Fricke, San Francisco Apartment Association
Kurt Fuchs, Office of the Controller
Jack Gold, SF Heritage
Marjorie Greene, Earthquake Engineering Research Institute
Joe Grubb
David Halsing, URS
Craig Hamburg, Real Estate Professional
Michael Hamman, San Francisco Chapter of the National Association of the Remodeling Industry
Stephen Harris, Simpson Gumpertz & Heger
Reuben Hechanova , Building Inspection Commission
Ephraim Hirsch, Structural Engineer
David Hoska, Lingruen Associates
Danielle Hutchings, Association of Bay Area Governments
Garrett Ingoglia, Hagerty Consulting
Jonas Ionin, Planning Department representative
Carla Johnson, Mayors Office on Disability
Laurie Johnson, Consultant
Paul Johnson, Northroad Builders
Sarah Karlinsky, San Francisco Planning and Urban Research
Jed Lane
Ed Lee, City Administrator’s Office
Kent Leung, Department of Public Works
Robin Levitt, Building Inspection Commission
Reinhard Ludke, Creegan + D’Angelo
Joan MacQuarrie, City of Berkeley
Mike Mahoney, Federal Emergency Management Agency
Dave Massen, Renter
David Mar, Tipping Mar
Jorge Martinez, Fireman’s Fund Insurance
David McCormick, Simpson Gumpertz & Heger
William Mitchell, SF Fire Department

Dick Morten
Mel Murphy, Building Inspection Commission
Chris Nance, California Earthquake Authority
Janan New, San Francisco Apartment Association
Sherry Niswander, Anderson Niswander Construction, Inc.
Bob Noelke, Small Property Owner
Luke O'Brien, SF Citizens for Responsible Growth
Brendan O'Leary, SF Fire Department
Erevan O'Neill, One Design
Shane O'Reilly, San Francisco Coalition for Responsible Growth
Peter Reitz, Small Property Owners of SF Institute
George Orbelian, Project Kaisei
Ken Paige, Paige Glass
Jeanne Perkins, Consultant to Association of Bay Area Governments
Lee Phillips, Code Advisory Committee, Disability representative
Chris Poland, Degenkolb Engineers
Bill Quan
Tom Quan
Sharyl Rabinovici, University of California, Berkeley
Evan Reis, Certus Consulting
Badie Rowshandel, California Geological Survey/California Earthquake Authority
Daniel Shapiro, SOHA Engineers
Heidi Sieck, Office of City Administrator
Armand Silva, Professor of Civil Engineering, University of Rhode Island, emeritus
Skip Soskin, Building Owners and Managers Association
Kate Stillwell, Structural Engineer
Brian Strong, City Administrator's Office
Fuad Sweiss, Department of Public Works
Katia Taipale, City Administrator's Office
Michael Theriault, SF Building and Construction Trades Council
Stephen Tobriner, Professor of Architecture, University of California, Berkeley, emeritus
Dawn Trennert, Middle Polk Neighborhood Association
Brook Turner
Fred Turner, California Seismic Safety Commission
Art VanBeek, Tenderloin Neighborhood Development Corporation
Paul VanderMarck, Risk Management Solutions
Kay Vasilyeva, City Administrator's Office
Rene Vignos, Forrell/Elsesser
Debra Walker, Building Inspection Commission
Kimberly Walsh, Department of Emergency Management
Paul Wermer, San Francisco Neighborhood Network
George Williams, San Francisco Housing Action Coalition

APPLIED TECHNOLOGY COUNCIL: AN OVERVIEW

The Applied Technology Council (ATC) is a nonprofit corporation founded to protect life and property through the advancement of science and engineering technology. With a focus on seismic engineering, and a growing involvement in wind and coastal engineering, ATC's mission is to develop state-of-the-art, user-friendly resources and engineering applications to mitigate the effects of natural and other hazards on the built environment.

ATC fulfills a unique role in funded information transfer by developing nonproprietary consensus opinions on structural engineering issues. ATC also identifies and encourages needed research and disseminates its technological developments through guidelines and manuals, seminars, workshops, forums, and electronic media, including its web site (www.ATCouncil.org) and other emerging technologies.

Key Publications

Since its inception in the early 1970s, the Applied Technology Council has developed numerous, highly respected, award-winning, technical reports that have dramatically influenced structural engineering practice. Of the more than 100 major publications offered by ATC and its Joint Venture partners, the following have had exceptional influence on earthquake engineering practice:

ATC-3-06, *Tentative Provisions for the Development of Seismic Regulations for Buildings*, funded by the National Science Foundation (NSF) and the National Bureau of Standards and completed in 1978, provides the technical basis for seismic provisions in the current *International Building Code* and other model U. S. seismic codes.

ATC-14, *Evaluating the Seismic Resistance of Existing Buildings*, funded by NSF and completed in 1987, provides the technical basis for the current American Society of Civil Engineers (ASCE) Standard 31, *Seismic Evaluation of Existing Buildings* (the national standard for seismic evaluation of buildings).

ATC-20, *Procedures for Postearthquake Safety Evaluation of Buildings*, funded by the California Office of Emergency Services and the California Office of Statewide Health Planning and Development, is the *de facto* national standard for determining if buildings can be safely occupied after damaging earthquakes. The document has been used to evaluate tens of thousands of buildings since its introduction two weeks before the 1989 Loma Prieta earthquake in Northern California.

ATC-40, *Seismic Evaluation and Retrofit of Concrete Buildings,* funded by the California Seismic Safety Commission and completed in 1996, won the Western States Seismic Policy Council' s "Overall Excellence and New Technology Award" in 1997.

FEMA 273, *NEHRP Guidelines for the Seismic Rehabilitation of Existing Buildings,* funded by the Federal Emergency Management Agency (FEMA) and completed in 1997 under the ATC-33 Project*,* provides the technical basis for the current American Society of Civil Engineers (ASCE) Standard 41, *Seismic Rehabilitation of Existing Buildings* (the national standard for seismic rehabilitation of buildings).

FEMA 306, *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual*, **FEMA 307,** *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Technical Resources*, and **FEMA 308**, *The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings*, funded by FEMA and completed in 1998 under the ATC-43 Project, provide nationally applicable consensus guidelines for the evaluation and repair of concrete and masonry wall buildings damaged by earthquakes.

FEMA 352, *Recommended Post-earthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings,* funded by FEMA and developed by the SAC Joint Venture, a partnership of the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering, provides nationally applicable consensus guidelines for the evaluation and repair of welded steel moment frame buildings damaged by earthquakes.

FEMA P646, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis*, funded by FEMA and completed in 2008 under the ATC-64 Project, provides state-of-the-art guidance for designing, locating and sizing structures to resist the effects of tsunamis and thereby provide safe evacuation refuge in affected coastal areas.

Organization

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

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