

GENERAL GUIDELINES  
FOR THE ASSESSMENT AND REPAIR  
OF EARTHQUAKE DAMAGE  
IN RESIDENTIAL WOODFRAME BUILDINGS



Consortium of Universities for Research in Earthquake Engineering

**CUREE**, the Consortium of Universities for Research in Earthquake Engineering, is a non-profit organization incorporated in 1988 whose purpose is the advancement of earthquake engineering research, education, and implementation. There are 26 University Members of CUREE located in 18 states and approximately 300 individual professor members.

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CUREE provides a means to organize and conduct a large research project that mobilizes the capabilities of numerous universities, consulting engineering firms, and other sources of expertise. Examples of such projects include:

- Organization of the large, multidisciplinary conferences on the Northridge Earthquake for the National Earthquake Hazard Reduction Program federal agencies to bring together researchers and users of research;
- Participation in the SAC Joint Venture (CUREE being the "C"), which conducted a \$12 million project for the Federal Emergency Management Agency to resolve the vulnerabilities of welded steel frame earthquake-resistant buildings that surfaced in the 1994 Northridge Earthquake;
- Management of the CUREE-Caltech Woodframe Project, a \$7 million project funded by a grant administered by the California Office of Emergency Services, which included testing and analysis at over a dozen universities, compilation of earthquake damage statistics, development of building code recommendations, economic analyses of costs and benefits, and education and outreach to professionals and the general public;
- Establishment by CUREE under contract to the National Science Foundation of the consortium that manages the Network for Earthquake Engineering Simulation;
- Conducting research investigations in the USA jointly with Kajima Corporation researchers in Japan since the 1980s;
- Conducting the Assessment and Repair of Earthquake Damage Project, aimed at defining objective standards for application to buildings inspected in the post-earthquake context;



The goal of the Assessment and Repair of Earthquake Damage Project is to develop guidelines that provide a sound technical basis for use by engineers, contractors, owners, the insurance industry, building officials, and others in the post-earthquake context. Based on experimental and analytical research and a broad discussion of the issues involved, the guidelines produced by the project will facilitate improved consistency in the evaluation of building damage and the associated need for repairs.

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**CUREE**

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# Preface

This document has been prepared as part of the ongoing research project, *Assessment and Repair of Earthquake Damage in Woodframe Construction* administered by the Consortium of Universities for Research in Earthquake Engineering (CUREE) with major funding from the California Earthquake Authority (CEA). The primary objective of the project is to bring sound science and engineering to the important but infrequent undertaking of earthquake damage assessment and repair of typical single- and multi-family woodframe residential buildings in California.

The target audience of these *General Guidelines* is homeowners, contractors, insurance claims representatives, and other non-engineers involved in post-earthquake damage assessment of woodframe construction. A more detailed version intended for technical consultants engaged in post-earthquake damage assessment - *Engineering Guidelines for the Assessment and Repair of Earthquake Damage in Residential Woodframe Buildings*, CUREE Publication No. EDA-06 is in progress.

The content of this document is based upon the most current engineering research and best practices related to assessment and repair of earthquake damage in woodframe construction. It is hoped that the information provided herein will improve the consistency and quality of post-earthquake damage assessment and repair, thereby facilitating rapid recovery in those areas damaged by earthquakes.

Work on the project has been performed by academic institutions, commercial research laboratories, and practicing professionals under contract to CUREE. CUREE's project manager is Dr. John Osteraas. Technical guidance and oversight for the project is provided by the Advisory Group, membership of which consists of:

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Editorial review and assistance with the details of producing this document were provided by Darryl Wong, Reed Helgens, Nick Osteraas, Nadine Russell, Ed Thielen, Sarah Osteraas, and Kimberley Lawrence.

Given the ongoing nature of research work on this project, this document is subject to revision as additional information becomes available. The latest version of this document may be found at the CUREE website, [www.curee.org](http://www.curee.org). Comments, suggestions, and questions are welcomed and should be addressed to John Osteraas ([EDA.Editor@exponent.com](mailto:EDA.Editor@exponent.com)).

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# 1 Introduction

## 1.1 Summary

These *Guidelines* summarize the process and details of assessment and repair of common types of earthquake damage in typical residential woodframe buildings. The objectives are to provide owners, contractors, insurance claim representatives (adjusters), and others with a basic understanding of earthquake effects on buildings and guidance for:

- efficient and accurate identification of earthquake damage,
- selection of appropriate repairs for damage that can be reliably identified and appropriately repaired by qualified tradesmen without the assistance of a technical consultant,
- identification of those conditions for which the assistance of a technical consultant may be necessary for the accurate assessment and repair of damage,<sup>1</sup> and
- interaction with technical consultants.

A companion, in-depth technical document, *Engineering Guidelines for the Assessment and Repair of Earthquake Damage in Residential Woodframe Buildings*, CUREE Publication No. EDA-06 is in progress. The intended audience of that document is technical consultants such as engineers and architects who may become involved in post-earthquake damage assessment of woodframe buildings. A draft version of that document is available on the CUREE website.

These *Guidelines* have been motivated by inconsistencies in the earthquake damage assessment process in the aftermath of recent earthquakes in California. While some of the detail and references are California-centric, the general principles and methodology are generally applicable throughout the United States.

This document consists of ten sections:

**1 Introduction** – provides an overview of earthquakes and the various types of damage they cause and addresses general aspects of damage assessment, including a description of the stages of an assessment and inspection checklists.

**2 Earthquake Ground Motions and Damage Potential** – describes various quantitative and qualitative measures of earthquake ground shaking, and the general types of

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<sup>1</sup> Assistance of technical consultants is recommended where there are indications of conditions that could potentially affect the safety of a building's occupants or the performance of the building during future earthquakes, if unrepaired.

damage associated with various levels of ground shaking. Sources of maps of ground shaking data are identified.

**3 Geotechnical Aspects** – describes common types of soils, typical non-earthquake related conditions, typical types of earthquake related ground failure, and common repair techniques. Guidelines are provided for conducting an inspection and the circumstances indicating the need for technical consultant assistance.

**4 Foundations and Slabs-On-Grade** – describes common types of foundations, typical non-earthquake related conditions, typical types of earthquake related damage, and common repair techniques. Guidelines are provided for conducting an inspection, appropriate repair of common types of nonstructural earthquake damage, and the circumstances indicating the need for technical consultant assistance.

**5 Walls** – describes common types of wall construction, typical non-earthquake related conditions, typical types of earthquake related damage, and common repair techniques. Guidelines are provided for conducting an inspection, appropriate repair of common types of nonstructural earthquake damage, and the circumstances indicating the need for technical consultant assistance.

**6 Floors, Ceilings, and Roofs** – describes common types of construction, including finishes as well as concealed framing, typical non-earthquake related conditions, typical types of earthquake related damage, and common repair techniques. Guidelines are provided for conducting an inspection, appropriate repair of common types of nonstructural earthquake damage, and the circumstances indicating the need for technical consultant assistance.

**7 Fireplaces and Chimneys** – describes the most common types of fireplaces and chimneys, typical non-earthquake related conditions, typical types of earthquake related damage, and common repair techniques. Guidelines are provided for conducting an inspection, appropriate repair of common types of earthquake damage, and the circumstances indicating the need for technical consultant assistance.

**8 Mechanical, Electrical, and Plumbing Systems** – describes the most common types of mechanical, electrical, and plumbing systems and components, typical types of earthquake related damage, and common repair techniques. Guidelines are provided for conducting an inspection, appropriate repairs for common types of earthquake damage, and the circumstances indicating the need for technical consultant assistance.

**9 Working with Technical Consultants** – describes the various specialties of technical consultants that may be needed to assist with assessment and repair of earthquake damage, addresses interactions with technical consultants, including discussion of circumstances requiring a technical consultant, resources for locating engineers, expectations regarding qualifications, terms of the technical consultant engagement, and an outline for a comprehensive technical consultant's report.

**10 Glossary and Acronyms** – provides definitions of terminology used in this document.



## 1.2 Earthquake Basics

The fundamental manifestation of earthquakes is as ground shaking that can result in direct effects on people and the built environment by frightening people, disturbing building contents, and causing nonstructural and structural damage to buildings and other man-made improvements. Earthquakes can also trigger indirect effects on people and the built environment such as fires, ground failures (discussed in Section 3), tsunamis, and seiches.

Earthquakes occur when a geologic fault in the bedrock of the earth's crust ruptures suddenly and the sides of the fault slip with respect to each other over an area of a fault called the rupture surface. The rupture begins at a point on the fault plane called the hypocenter which is located miles beneath the ground surface; the epicenter is the point on the ground surface directly above the hypocenter. The rupture releases strain energy that has accumulated in the rock mass over time. The process is much like that of snapping fingers; before the snap, you push your fingers together and sideways. Because you are pushing them together, friction keeps them from moving apart; when you push sideways hard enough to overcome this friction, your fingers move suddenly, releasing energy in the form of sound waves that set the air vibrating and travel from your hand to your ear, where you hear the snap. A similar process occurs in an earthquake – over time stress accumulates in the Earth's crust along earthquake faults. The friction across the surfaces of a fault locks the fault and prevents movement as the stress accumulates. Eventually enough stress builds up to overcome the friction and the rock along the fault slips suddenly, releasing the stored energy. The energy is released in the form of seismic waves that radiate away from the fault rupture and travel through the earth's crust at very high speeds. When these seismic waves reach the ground surface they result in shaking of the ground surface; this shaking is what we perceive as an earthquake.

Faults are characterized by the direction of relative slip across the fault. In a strike-slip fault, the two sides of the fault move horizontally with respect to each other (envision two books placed flat on a table abutting each other and slide one book past the other – the surface between the two books would be the fault plane) as shown in Figure 1.1. During the 1906 San Francisco Earthquake, the ground surface was displaced (i.e., slipped) horizontally as much as 21 feet across the surface rupture of the San Andreas Fault, but in most earthquakes the amount of displacement is much less.

With dip-slip faults, opposite sides of the fault slip vertically with respect to each other. A thrust fault is a special category of dip-slip faults, in which one side of the fault is thrust over the other side of the fault due to compressive stresses that have built up across the fault. Thrust faulting is responsible for mountain building – following an earthquake; the ground on one side of the fault will be at a slightly higher elevation than before the earthquake. Over geologic time, the cumulative effect of thousands of such earthquakes is a mountain range. Faults that do not extend to the ground surface are known as blind faults. The 1994 Northridge Earthquake in the Los Angeles area occurred on a blind thrust fault, as illustrated in Figure 1.2. The ground above a blind thrust fault may bend instead of breaking, so that the surface manifestation of the fault over geologic time is only rolling hills rather than a surface rupture. Fault movement that contains significant components of both strike-slip and dip-slip movement are referred to as oblique faults.

The shaking of the ground surface during an earthquake is caused by the combined effect of the passage of several types of waves that cause the ground surface to oscillate or vibrate from side to side and up and down. The shaking may produce strong ground accelerations (to which humans are extremely sensitive), but, in the absence of ground failure, typically produces small ground deformations;<sup>2</sup> that is, the ground moves as a relatively rigid surface and does not significantly bend. Despite occasional accounts to the contrary, seismic waves at the ground surface are usually too subtle to be discernable to the naked eye. Absent ground failure, damage to buildings is caused by the rapid vibrations of the ground surface, not distortions of the ground surface.

## **1.2.1 Earthquake Damage**

The primary cause of damage during an earthquake is the effect of ground shaking on buildings and components. Earthquake damage can also be caused by earthquake-induced ground failure, earthquake-induced disturbance of bodies of water, and fires following the earthquake that are triggered by earthquake-induced damage to buildings and utilities. These indirect effects can cause damage that is locally much more severe than the direct effects of ground shaking. The following sections summarize how earthquakes cause damage.

### **1.2.1.1 Effects of Ground Shaking on Buildings**

The key to understanding earthquake damage is knowledge of the interaction between ground acceleration, building mass (or roughly speaking, the weight of the building), inertia, and flexibility (brittleness versus ductility). To get an intuitive feel for the effect of ground acceleration, let's take a ride on a bus in heavy traffic. Start off by standing in the aisle, facing forward without holding onto anything. As long as the bus is at rest, or traveling straight at a steady speed, this is easy to do. However, as the bus accelerates (or brakes), it is difficult to remain upright without grasping a bar or moving your feet. Here is what's happening: as the bus accelerates, you begin to tip backwards – your feet move with the bus but the rest of your body wants to remain at rest. This is the principle of inertia. The same thing happens when the bus brakes – your body wants to keep moving, but your feet are stuck to the floor, so you begin to tilt forward. Now imagine ten or fifteen rapid cycles of accelerator-brake/accelerator-brake ... and you have some “feel” for what a building goes through during an earthquake. Notice that you (hopefully) did not get damaged during this experiment because in response to the acceleration you were able to flex or grip a grab bar. Imagine what would have happened to a six-foot-tall pile of bricks next to you on the bus. The physics outlined above is illustrated in Figure 1.3.

To carry the analogy further, try traveling with two associates – one standing, one sitting, and one lying on the floor. Note the one standing has the most difficulty with acceleration while the one on the floor has no trouble whatsoever. This illustrates a second principle – that effect of earthquake forces is a function of height of the building above the ground, as well as the weight

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<sup>2</sup> A deformation is a change in shape or size of the material, such as when you hold a rubber eraser in your hands and bend it till you can see it visibly distort from its original flat configuration into a curved shape, or if you place a heavy weight on it and see it compress or squish to become thinner.

of the building.<sup>3</sup> The effect of earthquake forces will be greater on a taller structure than on a shorter structure or components built at-grade, such as floor slabs and pavement. To further illustrate the effect of mass and height, you could repeat the experiment wearing a heavy backpack. If it was difficult to remain upright before, the added weight of the backpack makes it virtually impossible to remain upright without gripping a hand hold.

One last point before we leave the bus. You may have noticed that the ride over some rough pavement was rather bumpy, which caused the bus and you to bounce up and down. These are vertical accelerations as opposed to the horizontal or lateral accelerations you experienced as the bus was accelerating, braking, or turning corners. Even though some of the vertical accelerations going over bumps are much greater than the lateral accelerations of stop-and-go driving, you have no difficulty standing. You are used to the constant vertical forces of gravity and a little additional force acting vertically is easy to resist. This illustrates another principle – vertical accelerations usually cause no damage in earthquakes because buildings, like people, can support more than their own weight in the vertical direction, but only a fraction of their own weight in a lateral direction.

Now, back to the world of buildings. The rapid movement back-and-forth and side-to-side of the ground surface creates inertial forces in buildings as the building attempts to “keep up” with the rapidly moving ground. These inertial forces tend to distort or rack the walls<sup>4</sup> of residential woodframe construction<sup>5</sup> out-of-square, as illustrated in Figure 1.4. In contrast to the walls, the horizontal elements (roof, floors, foundation, and pavements) each move relative to the ground as an essentially rigid unit. Thus, the horizontal elements experience relatively little distortion and consequently experience relatively low forces during earthquake ground shaking. The forces in the walls at the lowest level of the building are the greatest and decrease in the upper stories. Thus, for most woodframe residential buildings, earthquake damage is typically concentrated in the first-story walls, although there are notable exceptions where the weak link occurs elsewhere in the building. The response of a typical two-story woodframe building is shown schematically (and greatly exaggerated) in Figure 1.5. Typical lateral distortions range from a fraction of an inch per story in buildings with minor cosmetic damage to several inches per story in buildings with significant structural damage.

The forces generated by an earthquake in a building are roughly proportional to the mass (weight), height, and stiffness of the building. Thus, taller, heavier, and stiffer buildings, such as multi-story masonry buildings, are subject to greater forces during an earthquake than low, lightweight, and flexible buildings such as single-story woodframed houses. Consider two tract homes, adjacent and identical except that one has a lightweight wood shingle roof and the other has a heavy clay tile roof. The weight of the clay tiles is five to ten times that of the wood

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<sup>3</sup> For high-rise buildings, structural dynamics dominate.

<sup>4</sup> Walls in woodframe buildings are structurally referred to as shear walls because they resist the shearing or racking deformations generated by the inertial forces generated in the building by the earthquake.

<sup>5</sup> Woodframe or “two-by-four” construction is the most common type of residential structure in the United States, and it has walls and floors composed of closely spaced (usually 16 inches or 24 inches on center) lumber framing covered with various types of sheathing materials.

shingles, thus the home with the clay tile roof will experience higher inertia forces from the earthquake and, most likely, suffer more damage.<sup>6</sup>

Earthquake forces are sometimes compared to wind forces. They are similar in that both act to bend or move the building sideways. But there the analogy ends. The big differences are that the wind is a pressure that acts on surface area like a billboard or the side of a barn, while earthquakes act on the mass or weight of an object. Thus, a strong wind will tear a flag to shreds and leave a brick chimney unscathed while a strong earthquake will do just the opposite. The same analogy holds for the wood shingles and clay roof tile – high winds will tear off the shingles and leave the clay tile unscathed while a strong earthquake may dislodge the clay tile but leave the wood shingles unscathed. Secondly, strong wind tends to come from a predominant direction while earthquake ground motion changes direction rapidly, resulting in cyclic stresses in buildings that constantly reverse in direction. Lastly, a properly designed building is expected to resist strong winds (but not tornadoes) without damage but is expected to sustain some damage in a major earthquake.<sup>7</sup>

But forces are only the first half of the earthquake damage story – the flexibility and strength of the building is the other. Inertial forces cause stress in, and deformations of, the building. As long as the deformations and stresses generated do not exceed the capacity of the building materials and components, the building will shake to the consternation of its occupants and detriment of its contents, but will not sustain any damage. However, if the deformations and stresses are greater than the capacity of the building materials and components, earthquake damage in the form of cracking, permanent deformation (such as out-of-plumb walls), and even collapse can occur. Materials such as unreinforced masonry and plaster are brittle and very weak in tension and will crack at much lower deformations and stresses than wood or steel.

The locations in the building where the stresses and deformations first exceed the capacity of the structure are referred to as the weak links in the lateral load path through the structure. A sufficiently strong earthquake will find the weak links in a structure with perfect accuracy, just as water will invariably find any holes in its container. Knowledge of the typical location of weak links in various types of buildings in past earthquakes provides the road map for inspection of buildings following future earthquakes.

Figure 1.6 illustrates the main components of a typical woodframe house. To be effective, each part of the lateral force-resisting system of a building must be adequate and properly connected to the other parts in the system. For example, the connections from the roof diaphragm to the shear walls below must be strong enough to transfer the roof diaphragm force to the shear wall. At the base of the building, shear walls must be adequately connected to the foundation to be

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<sup>6</sup> For engineered buildings the weight of the different types of construction materials are taken into account in calculating earthquake forces and designing appropriate strength, but older houses were not engineered. In this example, with common prescriptive or rule-of-thumb construction that is allowed by the building code, the houses would have walls of similar strength but the one with the heavier roof would be exposed to stronger forces from the shaking.

<sup>7</sup> Modern building codes presume that in the infrequent very severe earthquake, a properly designed and constructed building will perform safely but will likely sustain some degree of damage: to design enough strength into a building to prevent damage during very severe shaking is generally considered to be too expensive for all but the most critical public facilities.

able to transfer building loads to the foundation. The foundation in turn must be large enough and strong enough to transfer the loads into the soil.

The load path can be thought of as a chain. It is only as strong as its weakest link. The roof and floor diaphragms and shear walls are two links in the chain, as shown in Figure 1.7. The connections between the roof, walls, floors, and foundation are additional links. These additional links serve as the connective points that complete the chain. The connections are just as important as the diaphragms and shear walls themselves. The seismic loads imparted to a building must successfully pass through all of these elements in order to reach the ground and effectively resist an earthquake's damaging forces. In other words, the load path or chain must be continuous and complete. There can be no missing links in the load path.

Structural weak links or vulnerabilities can significantly affect a building's response to ground shaking. Common vulnerabilities of woodframe residential buildings, which are discussed in Section 5, include:

- older buildings<sup>8</sup> that are not bolted to their foundations,
- older buildings with unbraced cripple walls between the foundation and first floor,
- split level houses,
- houses on steep hillsides,
- houses with open floor plans,
- buildings with large openings or large expanses of windows on one or more elevations, or
- buildings with soft/weak first floors and stiff/strong upper floors.

In summary, components of woodframe residential buildings that are most vulnerable to earthquake damage are the heavy, tall, stiff, and weak components, such as unreinforced masonry chimneys and narrow plaster walls in multi-story buildings. Typical modern woodframe houses are light, flexible, low-rise, and strong, if properly designed and built. Accordingly, serious structural damage in these buildings during earthquakes is uncommon, and collapse is extremely rare. This does not mean that woodframe houses are indestructible; rather that very intense shaking, ground failure, or the presence of significant structural defects are necessary to cause serious structural damage or collapse.

### **1.2.1.2 Ground Failure**

Ground failure is permanent deformation<sup>9</sup> of the ground surface triggered by the earthquake that includes the following phenomena, which are discussed in detail in Section 3:

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<sup>8</sup> Here "older" is short-hand for buildings that were built prior to the implementation of earthquake-resistant design features.

- surface fault rupture,
- liquefaction,
- earthquake-induced rockslides and landslides,
- earthquake-induced ground cracking, densification and settlement, and
- ridge-top shattering.

Ground failure may cause rupture of underground utilities and cracking or buckling of at-grade pavements and severe damage to above-grade improvements. As discussed in Section 3, surface fault rupture, liquefaction, and landslides generally occur in areas of known and mapped vulnerabilities. Densification and settlement generally occurs in areas of loose and dry native soils or certain types of fills. Ridge shattering may occur in certain topographic configurations in close proximity to the fault.

#### **1.2.1.3 Fire Following**

Firestorms ignited by damaged natural gas or electrical utilities can be a severe indirect effect of earthquakes. Fire following earthquake caused extensive damage in San Francisco in 1906, Tokyo and Yokohama in 1923 and Kobe in 1995. Modern urban earthquakes in California have caused numerous fire ignitions.<sup>10</sup> Favorable weather conditions and quick fire department response, prevented fires triggered by the 1989 Loma Prieta Earthquake and the 1994 Northridge Earthquake in 1994 from developing into large conflagrations.

#### **1.2.1.4 Disturbance of Bodies of Water**

Earthquakes can disturb various bodies of water, ranging from backyard swimming pools to the ocean, potentially causing considerable damage.

Tsunamis are the most notorious and deadly form of earthquake-induced disturbance of water. Tsunamis are waves caused by rapid vertical movement of the seafloor during subduction earthquakes that travel great distances across the ocean. Like earthquake waves on land, tsunami waves travel across the open ocean at great speed (500 miles per hour) and have maximum heights of only several feet. Thus, at the surface of the open ocean, a tsunami is of little consequence. As these waves approach shore and the depth of water decreases, the speed of the wave decreases but its height increases. In some areas, a tsunami can create a near vertical wall of water tens of feet in height that rushes far onto shore with catastrophic effects. Unlike normal coastal waves, a tsunami wave can be thousands of feet from front to back, like a an extreme tied or rapidly moving flood of water that keeps on coming for many seconds or minutes, rather than breaking and dissipating all at once. The largest tsunami on record was the Indian Ocean

<sup>9</sup> Permanent deformation means that the ground does not return to its original position after the earthquake shaking stops.

<sup>10</sup> According to a California Seismic Safety Commission report (SSC-02-03) approximately 60 fires were attributed to the Loma Prieta Earthquake and approximately 100 fires were attributed to the Northridge Earthquake. Over 100 fires were also started in the 1971 San Fernando Earthquake.

Tsunami of December 2004, which generated by a Magnitude 9 earthquake off the west coast of Sumatra and caused the deaths of an estimated 200,000 people.

Seiches are similar to tsunamis except that seiches are earthquake-induced waves in enclosed bodies of water such as lakes, reservoirs, and swimming pools. Seiches can occur in two ways. First, like a tsunami, a seiche can be created when a thrust fault causes a permanent vertical offset beneath a lake or reservoir. Second, a seiche may occur when the seismic waves traveling in the earth match the natural period of oscillation of the water in an enclosed body of water. With the latter mechanism, seiches can occur at great distances from the source of an earthquake. The 1964 Alaska Earthquake caused waves in lakes thousands of miles away in Louisiana and Arkansas. In that earthquake, another cause of a seich was demonstrated when a huge earthquake-induced landslide suddenly slid into a bay and caused a wave that extended over a thousand feet up the mountain on the other side of the bay

Strong earthquake shaking can also cause failure of earthen dams, leading to flooding of downstream areas.

## **1.3 Post-Earthquake Assessment Stages**

Three distinct types of post-earthquake assessments are commonly performed on buildings that have been subjected to strong ground motions:

- urban search and rescue assessments,
- safety assessments, and
- damage assessments – the focus of this document.

Urban search and rescue assessments focus on assessment of severely damaged buildings for purposes of location and extraction of potential trapped victims. Safety assessments focus on the safety of a building for continued occupancy, without regard to the extent of possible non-safety-related damage. Damage assessment focuses on determination of the nature, extent, and appropriate repair of all earthquake damage, whether safety-related or not. The focus of this document is damage assessment. By way of background, key aspects of urban search and rescue and safety assessment are summarized below.

### **1.3.1 Urban Search and Rescue Assessment**

Following a major earthquake in which occupied buildings are known to have collapsed, specially trained urban search and rescue teams will be dispatched to the most heavily damaged areas to search for and extract trapped victims. In the course of that effort, many buildings may be evaluated and searched, with the results of those efforts indicated by spray-painted markings on the building near the main entry. Such markings are relevant only in the context of search and rescue and should not be confused with safety assessment tagging, which evaluates the safety of the building for ongoing occupancy, as discussed in the next subsection.

### 1.3.2 Safety Assessment

Following a moderate to major earthquake, local or state building departments have the responsibility for conducting safety assessments where there is a concern over whether a building is still safe to occupy. To augment the relatively limited staff of these departments, some states such as California have well-organized systems whereby specially trained and pre-certified volunteer engineers, architects, and building inspectors are dispatched to the most seriously-affected areas to assist local governments in performing safety assessments of buildings. The result of that assessment is a green, yellow, or red “tag” or placard that is posted on the building to indicate its relative safety. Buildings posted with a red tag (UNSAFE) or yellow tag (RESTRICTED USE) have one or more recognized types of safety-related damage. Buildings posted green (INSPECTED) may have sustained damage, but are judged safe for continued lawful occupancy (i.e., not significantly more hazardous to the safety of the occupants than prior to the earthquake).

Generally, safety assessment evaluators are dispatched to the more heavily damaged neighborhoods to evaluate all buildings in the area within a week following the earthquake. Evaluations may vary in level of detail from only exterior observation to detailed walkthroughs. Buildings outside the more heavily damaged neighborhoods are generally evaluated only if the owner requests an assessment. If a building has not been evaluated and an owner/occupant has safety concerns, they should contact the local building department and request a safety assessment. The evaluator should explain any earthquake-related hazardous conditions found at the property to the owner or occupant. If a building has been posted red or yellow on the basis of a rapid assessment, the owner/occupant of a building may request a follow-up detailed safety assessment from the local building department to verify the appropriateness of, or revise, the original posting. For a building that retains a red tag (or a yellow tag for reasons other than a damaged chimney) following the detailed assessment, a technical consultant should be retained to perform an engineering safety assessment of the property. Strong aftershocks are common in the weeks following an earthquake. If an aftershock causes significant additional damage, reassessment of the building is recommended. More detailed information regarding safety assessment procedures and postings is available from the Applied Technology Council’s website: <http://www.atcouncil.org/pdfs/ATC202appendixA.pdf>.

Safety assessments do not address non-safety-related earthquake damage that may have occurred. Even if a building is deemed safe to occupy, it may have sustained damage that necessitates assessment, as discussed in the following section. By way of analogy, consider the car that has been in an accident. You (or your mechanic) may determine that all essential systems (brakes, steering, engine, etc.) in the car still work fine and it is safe to drive (the safety assessment), even if the trunk is jammed shut and bumpers and fenders are dented and need replacement. The extent and cost of repairs necessary to restore the full function and appearance of the car will be determined by a body shop (damage assessment).

### 1.3.3 Damage Assessment

One of the goals of these *Guidelines* is the efficient identification of earthquake-induced damage. Accordingly, emphasis is placed upon identification of common modes of earthquake-induced damage and distinguishing earthquake-induced damage from damage resulting from other



causes. This document specifically does not address issues of code compliance, construction defects, deterioration, obsolescence, seismic retrofits, voluntary upgrades, or other non-earthquake-induced conditions. The intent is not to minimize the significance of these items, but rather to maintain a manageable scope for this document and a well-defined and manageable scope of services for any technical consultants who are called upon to perform damage assessments.

In this document, earthquake-induced damage is defined as an adverse, non-trivial, physical change in the safety, serviceability, appearance, or repairability of a component or portion of a building caused by earthquake ground shaking or earthquake-induced permanent ground deformation. For the building structure, damage is considered *structurally significant* when it results in a non-trivial, adverse change in the ability of the building to sustain load or resist future earthquake shaking. *Nonstructural damage* (or *structurally insignificant* or *cosmetic damage*) is all other *damage* to the structure that does not meet the threshold of *structurally significant damage*. For building mechanical systems (such as the furnace and ductwork), only safety and serviceability are of concern since these systems have no structural function.

The appropriate level of effort for earthquake damage assessment will depend upon the seriousness of the damage. Every assessment should begin with a visual assessment by an owner, general contractor, or insurance claims representative using the criteria presented in this document. If this initial visual assessment identifies conditions that indicate the need for technical consultant assistance, the appropriate technical consultant(s), such as a structures specialist, should be retained for further assessment; otherwise, repairs may proceed with the methods presented in this document.<sup>11</sup> In some circumstances, invasive inspection may be recommended by the technical consultant to reliably determine the nature and extent of possible concealed earthquake damage. Aspects of the assessment process are more particularly described in the following paragraphs.

If the initial assessment is conducted by someone other than the owner/occupant, the inspector<sup>12</sup> should interview the property owner/occupant. The purpose of the interview is to obtain pertinent information regarding the condition of the property prior to the earthquake, experiences during the earthquake, disruption of and damage to contents, and observations regarding cracks, potential damage, or unusual conditions observed at the property (or adjacent property) following the earthquake. Appendix 1A presents a checklist to assist building occupants with recording what their experiences were during the earthquake and the observations that they made immediately following the earthquake.

Next, a visual inspection of all accessible areas of the property should be completed as detailed in subsequent sections. A thorough visual inspection of outdoor areas and the building exterior should be completed first. If it safe to enter the building, an visual inspection of interior conditions should be performed. Appendix 1B lists specific equipment that can facilitate the

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<sup>11</sup> Note however that even if technical consultant assistance is not indicated, depending upon the nature and scope of repair, building permits and other government agency approvals may be required by the local jurisdiction.

<sup>12</sup> In this document, the terms “inspector” and “inspection” are used in a generic sense to refer to the people and process associated with conducting post-earthquake damage assessment and should not be confused with the more specific terms “building inspector,” “special inspector,” “building inspection,” or “special inspection” associated with inspection of building construction for compliance with building code requirements.

inspection. Appendix 1C presents a checklist to provide guidance for a systematic visual inspection.

Clear color photographs or video are extremely useful for documenting conditions. Photographs should include overall views of the property and any observed earthquake-induced damage as well as any unusual conditions.

### **1.3.4 Attic and Crawlspace Inspections**

Earthquake-induced damage within attics or crawlspaces, in the absence of conspicuous visible external damage, is unlikely. In addition, there are hazards associated with entry into these areas. Accordingly, in the absence of external visible damage, entering attics and crawlspaces for post-earthquake inspections is not recommended. If an attic or crawlspace inspection is conducted, it should be performed by an individual qualified by training and experience. Appendices 1D and 1E provide checklists for inspections of crawlspaces and attics, respectively. Damage and abnormal conditions should be documented with photographs.

Due to safety concerns associated with entry into a confined space, inspection of these areas may require the presence of a second individual or assistance from the owner/occupant. Inspectors should be equipped with appropriate personal protective equipment and be knowledgeable of appropriate safety precautions. Safety precautions for attic and crawlspace inspections are presented in Appendix 1F.

### **1.3.5 Technical Consultant Assistance**

If damage patterns or obviously unsafe conditions indicating the need for technical consultant assessment (as described in detail in subsequent sections) are observed, a technical consultant should be retained to investigate. That investigation should include at the least a detailed visual inspection, measurements, and photographs, as described in the subsequent chapters. The technical consultant may recommend additional investigation, possibly including invasive inspection.

As discussed in Section 9, there are various specialties of technical consultants. The most common specialties involved in assessment and repair of earthquake damage in residential woodframe buildings are the structures specialist and the soils specialist. Structures specialists include Licensed Civil Engineers specializing in structural engineering, Licensed Structural Engineers (In California, Structural Engineers are Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Structural Engineer), and Licensed Architects with expertise in structures. Soils specialists include Civil Engineers specializing in soils or geotechnical engineering, Geotechnical Engineers (Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Geotechnical Engineer), and Engineering Geologists. See Section 9.3 for additional discussion.

In buildings constructed prior to 1980, where repairs will involve disturbing certain finishes or building materials that may contain asbestos or lead-based paint, the services of an appropriate, qualified, and licensed environmental consultant should be procured. This consultant may

recommend that testing and proper abatement be conducted. There are legal requirements for such evaluations and procedures when the work is being done by contractors, or if the amount of material being disturbed is larger than a few square feet. See Section 9.2.4 for additional information.

### **1.3.6 Invasive Inspection**

Invasive inspection (also known as “destructive testing”) is an investigative technique that can be used to inspect the condition of those parts and portions of a building that may be concealed from direct observation. Common types of invasive inspection include removal of carpeting and padding to inspect concrete floor slabs, extraction of core samples from concrete slabs and foundations, removal of wall finishes to inspect concealed framing, excavation of soil test pits, and drilling soil borings. Invasive inspection should be necessary only in those instances when the technical consultant is either unable to rule out or reasonably assume earthquake damage based on non-invasive means. Before pursuing invasive inspection, the benefits and costs of the undertaking should be understood and evaluated. There should be a clear understanding of the nature of the testing and associated costs, the nature and significance of information to be obtained, the nature and extent of damage to finishes associated with the invasive inspection, and responsibility for and standards for repair of that damage.

## **1.4 Earthquake Damage Repair Standards**

A second goal of these *Guidelines* is the appropriate repair of earthquake-induced damage. Accordingly, emphasis is placed upon repair of common patterns of earthquake-induced damage. This document specifically does not address repair of damage or deficiencies resulting from non-earthquake causes. The intent is not to minimize the significance of such items, but rather to maintain a manageable scope for this document and a well-defined and manageable scope of services for any technical consultants retained to conduct post-earthquake damage assessments. The guidance presented in this document is strictly limited to facilitating objective determination of earthquake damage and proper determination of appropriate repair (but not the cost of that repair) to restore the building to its pre-earthquake condition. Other considerations, such as requirements for building permits or other government agency approvals, application of particular insurance policy terms, or decisions regarding building replacement or remodeling in lieu of repair are outside the scope of this document.

There are varying types and degrees of repair that may be pursued following an earthquake, ranging from minor cosmetic repair that is deferred until the next cycle of repainting, to repair or replacement in kind, to retrofits or upgrades that bring the property up to code or improve the future performance of the building.

### **1.4.1 Like Kind and Quality Repair**

Like kind and quality repairs restore the function and appearance of the damaged component to that which existed before the earthquake using materials similar to those of the original construction. In those cases where the damage weakens the building, a structural repair will be

necessary. In all other cases, nonstructural repair is appropriate. Where one of the functions of an element is cosmetic, repairs should include work that is necessary to assure a reasonably uniform appearance after the repairs are completed. The repair methods described in these *Guidelines* are intended to restore the nonstructural function and appearance to that which existed prior to the earthquake. Technical consultants should be consulted where stabilization of soils or repair of structurally significant damage is necessary, or where repairs will disturb materials that potentially contain asbestos or lead-based paint.

In certain circumstances like kind and quality repairs may be impractical or undesirable due to changes in construction practices and technology. Common examples are replacement of older lath and plaster wall and ceiling finishes with modern drywall and replacement of masonry fireplaces and chimneys with prefabricated fireplaces and metal flues.

### **1.4.2 Code Mandated Retrofits**

In addition to normal changes in the building code over time, some jurisdictions have building code requirements that mandate varying degrees of retrofitting if certain damage thresholds are exceeded.<sup>13</sup> The local building department should be contacted to determine the existence of any applicable local requirements. Technical consultants should be asked to address specifically any building code upgrades that may be required to comply with applicable local building code requirements as part of the repair of earthquake damage.

### **1.4.3 Voluntary Upgrades**

In general, like kind and quality repair of earthquake damage will not prevent or limit recurrence of damage in future earthquakes or provide compliance with codes for new construction. A building repaired exactly to its pre-earthquake condition will, theoretically, sustain the exact same damage in a future repeat of the original earthquake and will sustain more severe damage in a stronger future earthquake. For older buildings with known seismic vulnerabilities, consideration of voluntary seismic upgrades to address potentially life-threatening vulnerabilities is strongly encouraged. Technical consultants may be asked to identify conditions (related or unrelated to actual earthquake damage) that they recommend be addressed to improve the life-safety performance of the building. If made, such recommendations should be clearly identified in the technical consultant's report as optional or voluntary upgrades to the building that will improve future performance of the building.

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<sup>13</sup> Currently, model building codes do not contain specific repair provisions, thus there are no relevant state or national standards. Rather, some jurisdictions in California have adopted specific local provisions.

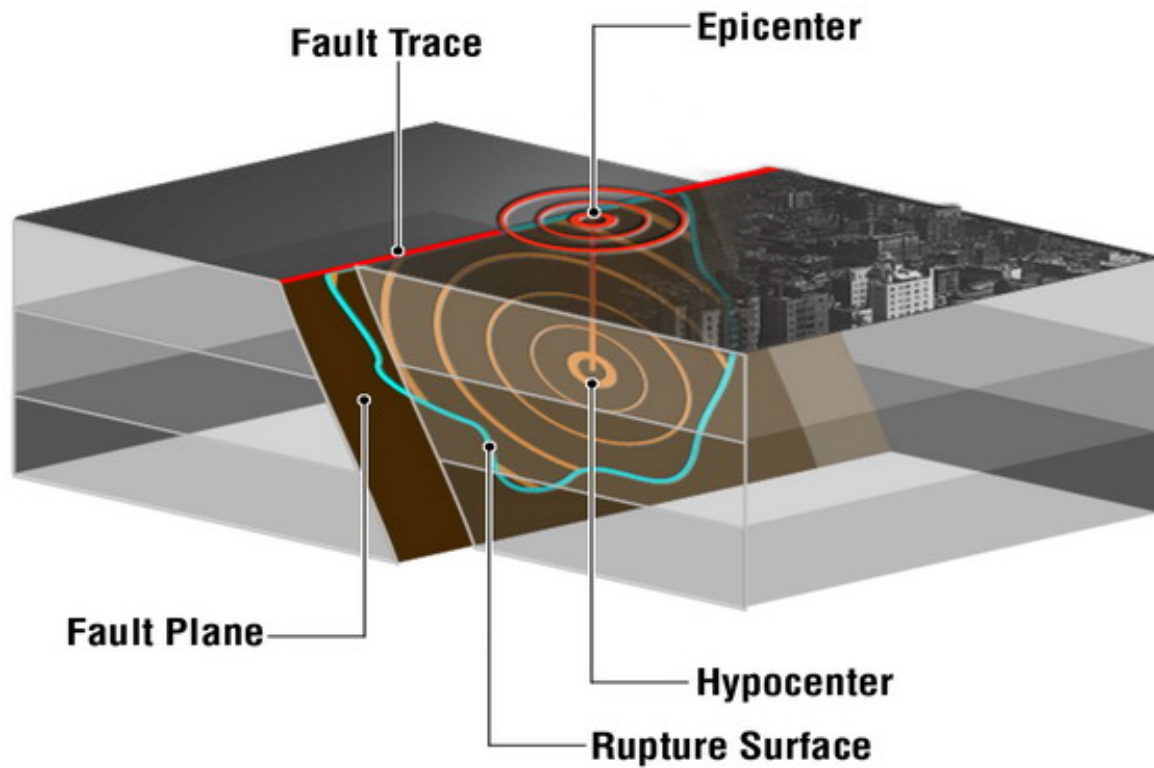


Figure 1.1. Strike-slip fault [Exponent].

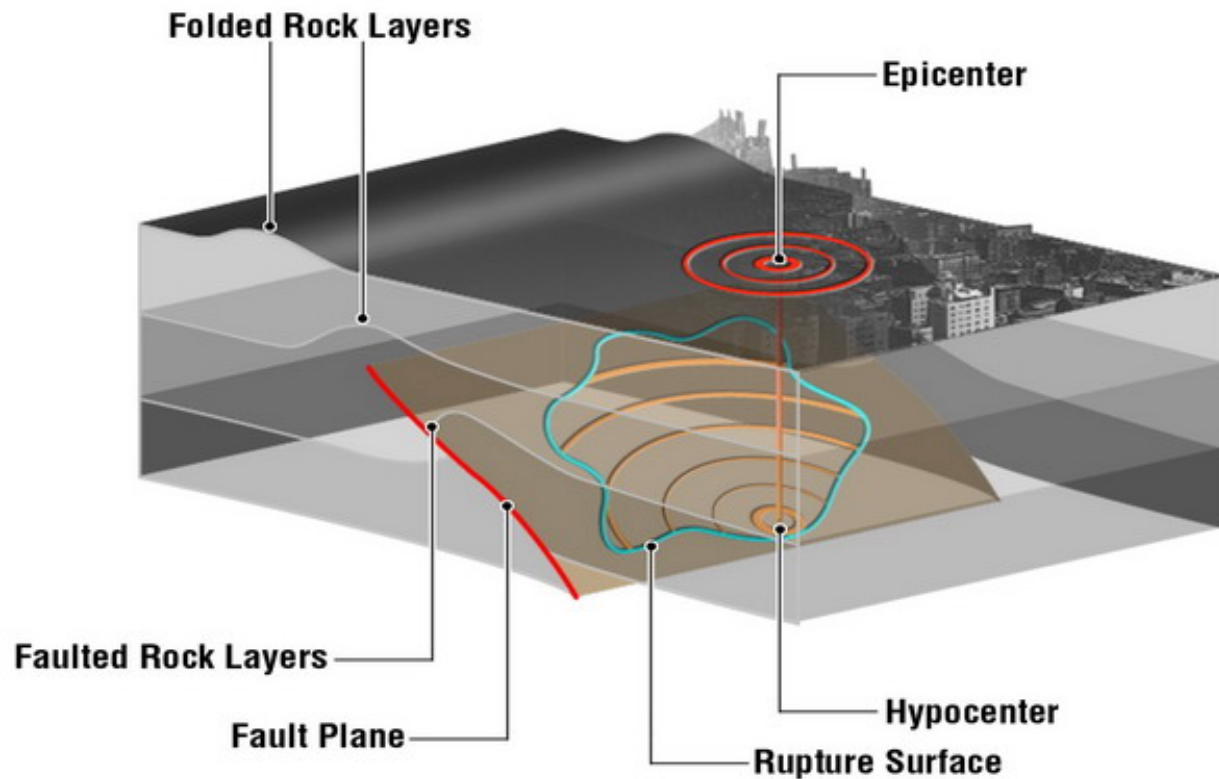


Figure 1.2. Blind thrust fault [Exponent].

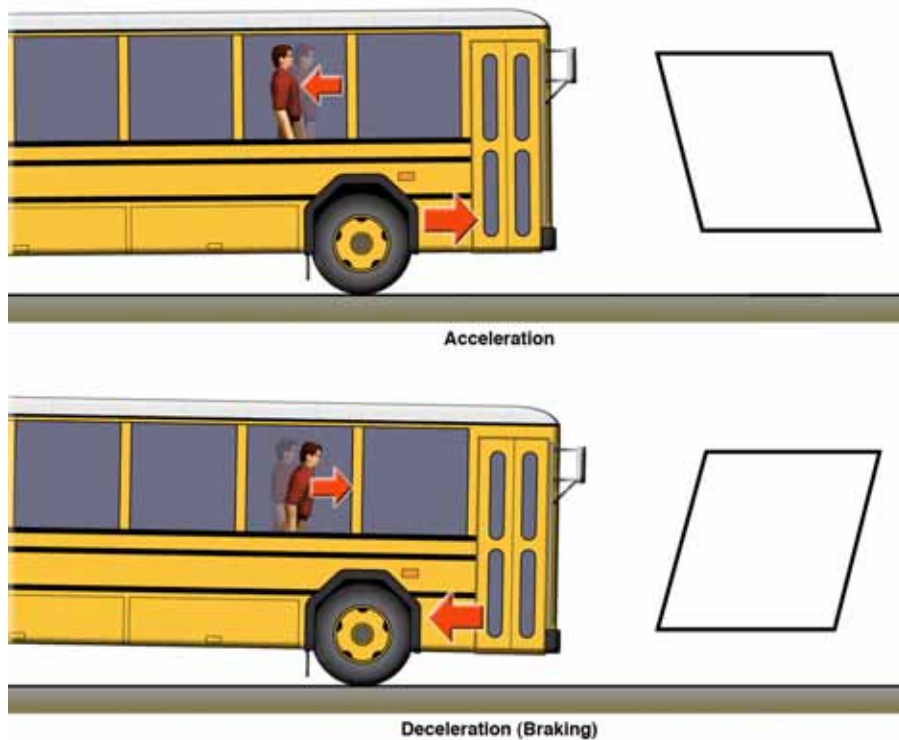


Figure 1.3. Effect of acceleration on vertical objects [Exponent].

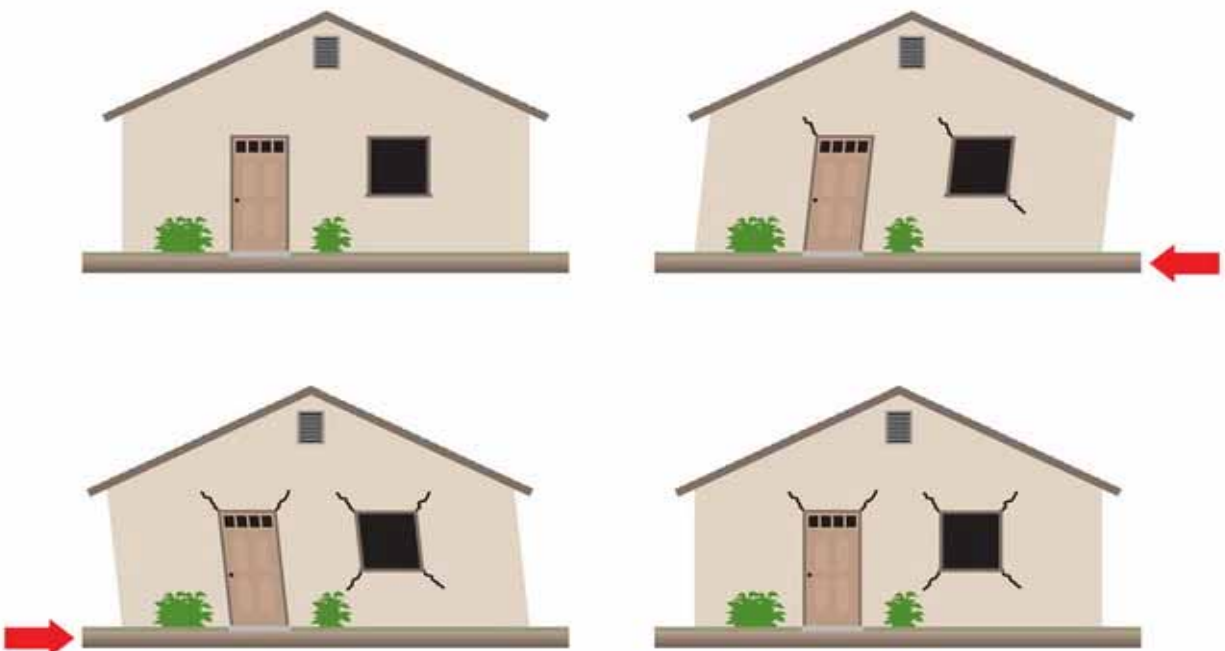


Figure 1.4. Illustration of racking distortion in walls caused by earthquake ground motions; amount of racking shown in this figure is greatly exaggerated for clarity – most buildings deform less than 1-inch laterally per story during a major earthquake [Exponent].

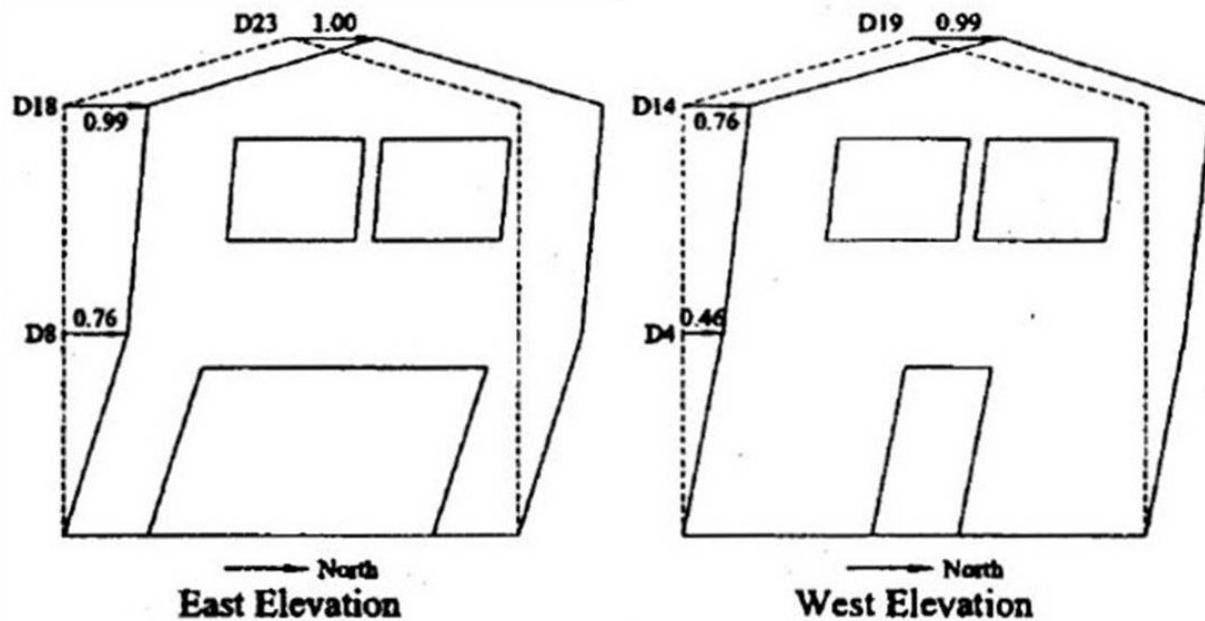


Figure 1.5. Lateral deformation patterns in a full-scale shake-table test of a two-story woodframe building. Horizontal deflections indicated are in inches [CUREE].

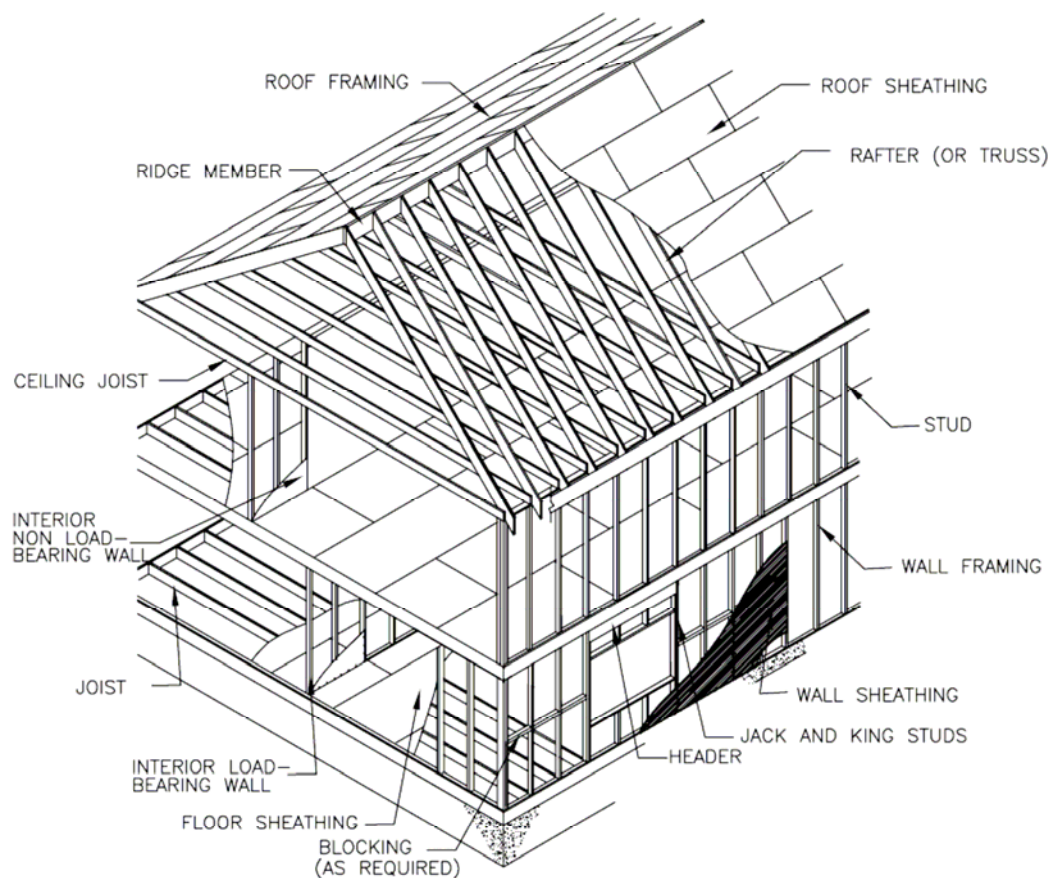


Figure 1.6. Elements of a typical woodframe house [HUD].

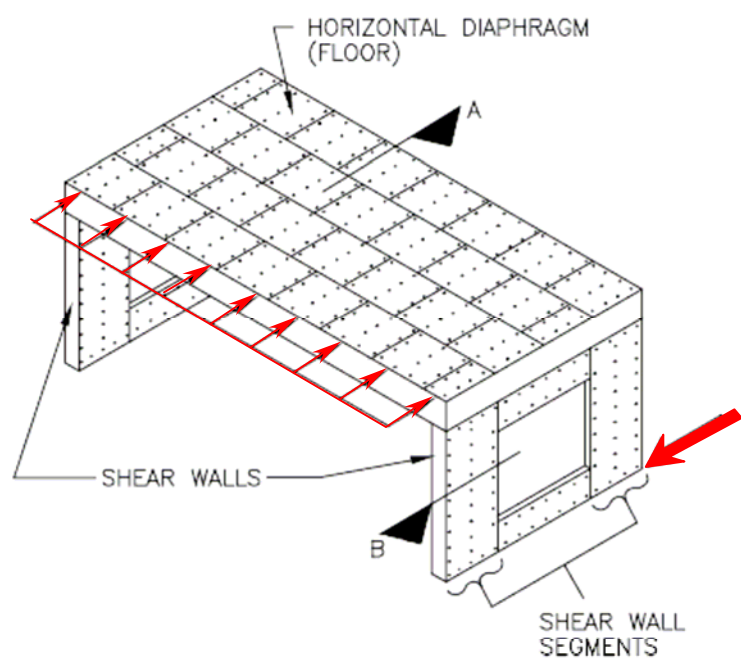


Figure 1.7. Schematic of the role of horizontal diaphragms (floors or roofs) and shearwalls in resisting earthquake loads [HUD].



# **Appendices Section 1**

## **1A Building Occupant Questionnaire**

Reduced scale images of the five-page CUREE Form EDA-F1 follow. For reproducing multiple copies, an electronic version of the form is available from the CUREE website.

## Building Occupant Questionnaire

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### A. GENERAL INFORMATION

1. **Property Address:** \_\_\_\_\_  
**Nearest Cross Street:** \_\_\_\_\_  
**City:** \_\_\_\_\_ **Zip Code:** \_\_\_\_\_  
**Occupant Name:** \_\_\_\_\_  
**Email:** \_\_\_\_\_ **Phone:** \_\_\_\_\_

### B. OBSERVATIONS

2. **Select the type of building or structure at this property: (✓ check one)**
- ☐ Single Family Home or Duplex  
☐ Apartment Building  
☐ Office Building/School  
☐ Mobile Home with Permanent Foundation  
☐ Other, please describe \_\_\_\_\_
3. **Were you at this property when the earthquake occurred?**
- ☐ Yes  
☐ No – Where were you? \_\_\_\_\_
4. **What was your situation during the earthquake? (✓ check one)**
- ☐ Inside  
☐ Outside  
☐ In stopped vehicle  
☐ In moving vehicle  
☐ Other, please describe \_\_\_\_\_
5. **If you were in a building with more than one level, what level were you on? (✓ check one)**
- ☐ Basement  
☐ First floor, main floor, or ground floor  
☐ Second floor  
☐ Third floor  
☐ Roof  
☐ Other, please describe \_\_\_\_\_

**Building Occupant Questionnaire**

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

**B. OBSERVATIONS (continued)**

6. Were you asleep during the earthquake? (✓ check one)

- ☐ No  
☐ Yes, slept through it  
☐ Yes, woke up

7. Did you feel the earthquake? (✓ check one)

- ☐ No  
☐ Yes

8. How would you best describe the ground shaking? (✓ check one)

- ☐ Not felt  
☐ Weak  
☐ Mild  
☐ Moderate  
☐ Strong  
☐ Violent

9. About how many seconds did the shaking last? \_\_\_\_\_

10. How would you best describe your reaction? (✓ check one)

- ☐ Don't remember  
☐ No reaction/Not felt  
☐ Very little reaction  
☐ Excitement  
☐ Somewhat frightened  
☐ Very frightened  
☐ Extremely frightened

11. How did you respond? (✓ check one)

- ☐ Don't remember  
☐ Took no action  
☐ Moved to doorway  
☐ Ducked and covered  
☐ Ran outside  
☐ Other, please describe: \_\_\_\_\_

**Building Occupant Questionnaire**

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

**B. OBSERVATIONS (continued)**

12. Was it difficult to stand or walk? (✓ check one)

- ☐ Did not try  
☐ No  
☐ Yes

13. Did you notice the swinging/swaying of doors or hanging objects? (✓ check one)

- ☐ Did not look  
☐ No  
☐ Yes, slight swinging  
☐ Yes, violent swinging

14. Did you notice creaking or other noises? (✓ check one)

- ☐ Did not pay attention  
☐ No  
☐ Yes, slight noise  
☐ Yes, loud noise

15. Did small objects (vases, books, statues, etc) objects rattle, topple over, or fall off shelves? (✓ check one)

- ☐ No Shelves  
☐ No  
☐ Rattled slightly  
☐ Rattled loudly  
☐ A few toppled or fell off  
☐ Many fell off  
☐ Nearly everything fell off

16. Did pictures on walls move or get knocked askew? (✓ check one)

- ☐ No pictures  
☐ No  
☐ Yes, but did not fall  
☐ Yes, and some fell

17. Did any furniture or appliances slide, tip over, or become displaced? (✓ check one)

- ☐ No furniture  
☐ No  
☐ Yes

**Building Occupant Questionnaire**

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

**B. OBSERVATIONS (continued)****18. Was heavy appliance (refrigerator or range) affected? (✓ check one)**

- ☐ No heavy appliance
- ☐ No
- ☐ Yes, some contents fell out
- ☐ Yes, shifted by inches
- ☐ Yes, shifted by a foot or more
- ☐ Yes, overturned

**19. Were freestanding walls or fences damaged? (✓ check all that apply)**

- ☐ No freestanding walls or fences at this property
- ☐ No
- ☐ Yes, some were cracked
- ☐ Yes, some partially fell
- ☐ Yes, some fell completely

**20. If you were at this property, did you immediately observe any damage to the building? (✓ check all that apply)**

- ☐ No damage
- ☐ Hairline cracks in walls
- ☐ A few large cracks in walls
- ☐ Many large cracks in walls
- ☐ Ceiling tiles or lighting fixtures fell
- ☐ Cracks in chimney
- ☐ One or several cracked windows
- ☐ Many windows cracked or some broken out
- ☐ Masonry fell from block or brick wall(s)
- ☐ Old chimney, major damage or fell down
- ☐ Modern chimney, major damage or fell down
- ☐ Outside wall(s) tilted over or collapsed completely
- ☐ Separation of porch, balcony, or other addition from building
- ☐ Building permanently shifted over foundation
- ☐ Water heater (damaged or toppling)

## Building Occupant Questionnaire

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### **B. OBSERVATIONS (continued)**

21. Do you know of any broken water mains in the area? (✓ check one)

☐ No

☐ Yes, please describe location \_\_\_\_\_

22. Do you know of any ground cracks or fissures in the area? (✓ check one)

☐ No

☐ Yes, please describe location \_\_\_\_\_

23. Any repairs made since the earthquake (✓ check one)

☐ No

☐ Yes, please describe location \_\_\_\_\_

24. Any other observations:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

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## **1B Useful Earthquake Damage Inspection Tools**

- Bright flashlight.
- Digital camera for documentation of observations.
- Accurate digital level, at least two feet long, but preferably, four feet long for checking the levelness of floors and the plumbness of walls and door and window openings.
- Hand held wallet-size crack gage for quickly measuring crack widths.
- Pocket mirror for checking for possible delamination along the bottom edge of stucco.
- Binoculars for inspection of chimneys, roofs, and upper portions of multi-story buildings.
- Step and/or extension ladders for accessing roofs.
- First aid kit.

### **Additional useful equipment for attic and crawlspace inspections**

- Personal protective equipment including a tight fitting dust mask/respirator, gloves, coveralls, and hat.
- Knee and elbow pads are desirable for accessing crawlspaces.
- Headlamp – essential for attic inspections.
- Dust-proof camera with neck strap.

## **1C General Earthquake Damage Inspection Checklist**

Reduced scale images of the eight-page CUREE Form EDA-F2 follow. For reproducing multiple copies, an electronic version of the form is available from the CUREE website.



## General Earthquake Damage Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### A. GENERAL INFORMATION

1. **Street Address of Property:** \_\_\_\_\_  
**City:** \_\_\_\_\_ **State:** \_\_\_\_\_ **Zip:** \_\_\_\_\_
2. **Property Owner's Name:** \_\_\_\_\_
3. **Date of inspection:** \_\_\_\_\_
4. **Inspector's Name:** \_\_\_\_\_

### B. BUILDING SITE INSPECTION

#### 5. Utility Service Safety:

**IMPORTANT**—Immediately following an earthquake, check the entire property, especially near appliances, for the smell of gas. If gas odor is detected, turn off the gas at the meter where it enters the house. Locate and repair leaks before turning gas back on. If the gas odor persists after the gas has been shut off, vacate the building and contact the gas utility company immediately.

**IMPORTANT**—Before entering a damaged, vacant building verify that gas is off. Check the gas meter for damage and position of main gas valve, either a manual valve or a seismically-activated gas shut-off valve. Do not enter the building if gas odor is detected.

- a. Odor of natural gas leakage? ☐ YES ☐ NO      b. Downed powerlines? ☐ YES ☐ NO

#### 6. Surrounding topography: (✓ check one)

- ☐ Flat  
☐ Gently sloping (easily walkable)  
☐ Steeply sloping (difficult or impossible to walk in some areas)

#### 7. Building pad: (✓ check one)

- ☐ Flat  
☐ Terraced or multilevel  
☐ Gently sloping (less than 4 foot ground surface elevation difference across house)  
☐ Steeply sloping (greater than 4 foot ground surface elevation difference across house)

#### 8. Geotechnical Issues: (if yes, provide description and photos)

- |   | YES                      | NO                       |
|---|--------------------------|--------------------------|
| a. New cracks in the ground?  | <input type="checkbox"/> | <input type="checkbox"/> |
| b. Signs of fresh cracking in or movement of hardscape?   | <input type="checkbox"/> | <input type="checkbox"/> |
| c. Signs of fresh cracking in or movement of retaining walls?                                     | <input type="checkbox"/> | <input type="checkbox"/> |
| d. Patterns of cracking that extend through the ground surface, hardscape, and improvements?      | <input type="checkbox"/> | <input type="checkbox"/> |
| e. Evidence of sand boils or other fresh-appearing deposits of sand or mud?                       | <input type="checkbox"/> | <input type="checkbox"/> |
| f. Unusual slumping, rising, or bulging of the ground surface?                                    | <input type="checkbox"/> | <input type="checkbox"/> |
| g. Evidence of rock falls or slope instability above site?  | <input type="checkbox"/> | <input type="checkbox"/> |
| h. Ground movement or wet areas indicating possible broken underground utility lines?             | <input type="checkbox"/> | <input type="checkbox"/> |
| i. Other phenomena (e.g., septic tanks surfacing, differential settlement, ground consolidation)? | <input type="checkbox"/> | <input type="checkbox"/> |

## General Earthquake Damage Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### B. BUILDING SITE INSPECTION (continued)

- |   | YES                      | NO                       |
|---|--------------------------|--------------------------|
| 9. Evidence of earthquake-induced permanent ground deformation in the immediate vicinity of the property? | <input type="checkbox"/> | <input type="checkbox"/> |

### C. GENERAL BUILDING INFORMATION

- |   |   |
|---|---|
| <p>10. Safety Assessment Tag: (✓ check one)    <input type="checkbox"/> None    <input type="checkbox"/> Green    <input type="checkbox"/> Yellow    <input type="checkbox"/> Red</p> <p style="padding-left: 40px;">(chimney only):    <input type="checkbox"/> Yellow    <input type="checkbox"/> Red</p> <p>11. a) Year of original construction (best estimate): _____</p> <p style="padding-left: 20px;">b) Total square footage (best estimate): _____</p> <p>12. Have any repairs, modifications, or demolition been performed since the earthquake?    YES    NO</p> <p style="padding-left: 20px;">If yes, describe _____</p> <p>13. Building configuration:</p> <p><input type="checkbox"/> a. Single story</p> <p><input type="checkbox"/> b. Combination one and two story</p> <p><input type="checkbox"/> c. Full two story</p> <p><input type="checkbox"/> d. Three story</p> <p><input type="checkbox"/> e. Split level</p> <p><input type="checkbox"/> f. Living space above garage</p> <p><input type="checkbox"/> g. Other, describe _____</p> <p>14. Exterior wall finish:</p> <p><input type="checkbox"/> a. Stucco</p> <p><input type="checkbox"/> b. Panel siding</p> <p><input type="checkbox"/> c. Lap siding</p> <p><input type="checkbox"/> d. Masonry veneer</p> <p><input type="checkbox"/> e. Other, describe _____</p> <p>15. Foundation configuration:</p> <p><input type="checkbox"/> a. Slab-on-grade</p> <p><input type="checkbox"/> b. Crawlspace without cripple walls</p> <p><input type="checkbox"/> c. Crawlspace with cripple walls</p> <p><input type="checkbox"/> d. Exposed piers or posts</p> <p><input type="checkbox"/> e. Partial basement</p> <p><input type="checkbox"/> f. Full basement</p> <p><input type="checkbox"/> g. Other, describe _____</p> | <p>16. Sill bolting:</p> <p><input type="checkbox"/> a. Structure bolted to foundation</p> <p><input type="checkbox"/> b. Structure not bolted to foundation</p> <p><input type="checkbox"/> c. Don't know</p> <p>17. Roof configuration:</p> <p><input type="checkbox"/> a. Gable</p> <p><input type="checkbox"/> b. Hip</p> <p><input type="checkbox"/> c. Flat or very low slope</p> <p><input type="checkbox"/> d. Shed</p> <p><input type="checkbox"/> e. Other, describe _____</p> <p>18. Roof covering:</p> <p><input type="checkbox"/> a. Asphalt shingles</p> <p><input type="checkbox"/> b. Wood shingle or shake</p> <p><input type="checkbox"/> c. Concrete or clay tile</p> <p><input type="checkbox"/> d. Metal shingles</p> <p><input type="checkbox"/> e. Membrane</p> <p><input type="checkbox"/> f. Other, describe _____</p> |
|---|---|

## General Earthquake Damage Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### D. EXTERIOR BUILDING INSPECTION

	YES	NO	N/A
<b>19. General: (if yes, provide description and photos)</b>			
a. Collapse, partial collapse, or building off foundation?	<input type="checkbox"/>	<input type="checkbox"/>	
b. Obvious lean in any story?	<input type="checkbox"/>	<input type="checkbox"/>	
<b>20. Exterior walls: (if yes, provide description and photos)</b>			
a. Fresh cracking at corners of door and window openings?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Fresh cracking at building corners?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Door or window openings racked out of square?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Broken glass in windows or doors?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. Wall leaning?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. Bulging or delamination of stucco?	<input type="checkbox"/>	<input type="checkbox"/>	
g. Pattern of cracking that extends from the ground surface, through foundation, and wall?	<input type="checkbox"/>	<input type="checkbox"/>	
h. Evidence of recent relative movement at mudsill line?	<input type="checkbox"/>	<input type="checkbox"/>	
i. At locations where the exterior stucco is continuous from the framing down over the foundation, is there cracking of stucco along the mudsill level accompanied by indications of permanent displacement (sliding) of the building relative to the foundation?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
j. Collapse, partial collapse, or separation of masonry veneer?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
k. Severe cracking, separations, or offsets at building irregularities?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>21. Foundation: (if yes, provide description and photos)</b>			
a. Fresh cracking of exposed perimeter foundation?	<input type="checkbox"/>	<input type="checkbox"/>	
b. Relative movement between slab and footing in "two-pour" slab-on-grade foundations?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## General Earthquake Damage Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### D. EXTERIOR BUILDING INSPECTION (continued)

	YES	NO	N/A
<b>22. Fireplace &amp; Chimney: (if yes, provide description and photos)</b>			
a. Present on external wall?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Present at internal location?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Collapse or partial collapse?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Visible damage or cracking?	<input type="checkbox"/>	<input type="checkbox"/>	
e. Visible tilting or separation from building?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. Shifted or loose clay flue tile segments and displaced joint mortar?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g. Deterioration of exposed mortar?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h. Does the top of the chimney rock when pushed?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
 <b>23. Roof: (if yes, provide description and photos)</b>			
a. Shifted or dislodged clay or concrete roof tile?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Impact damage to roof from falling chimneys?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Displaced rooftop HVAC units?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Significantly sagging roof ridgelines?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. Signs of movement between rafter tails and wall finishes at eaves?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. Buckled/dislodged flashing or tearing of roof membrane at chimneys, roof/wall intersections in split level buildings, additions, appendages, porches, or other building irregularities?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g. Tearing of roof membrane or deck waterproofing at re-entrant corners?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h. Toppling, shifting, or damage/leakage at refrigerant and electrical lines of rooftop mechanical equipment?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
i. Shifting of or damage to solar panels?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## General Earthquake Damage Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### D. EXTERIOR BUILDING INSPECTION (continued)

- |   | YES                      | NO                       | N/A                      |
|---|--------------------------|--------------------------|--------------------------|
| <b>24. Attached or abutting improvements: (if yes, provide description and photos)</b>  |                          |                          |                          |
| a. Collapse, partial collapse, or separation of attached porches, carports, patio covers, or awnings?   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| b. Evidence of recent settlement or displacement of exterior steps, patios, or walkways relative to the building?   | <input type="checkbox"/> | <input type="checkbox"/> |                          |
| c. Signs of movement between building floor or garage floor and exterior hardscape or retaining wall along the uphill side of homes on steeply sloping sites? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| d. Toppling, shifting, or damage/leakage at refrigerant and electrical lines of air conditioning condenser unit(s)?   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| <b>25. Independent exterior improvements: (if yes, provide description and photos)</b>  |                          |                          |                          |
| a. Damaged detached garage?   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| b. Damage to fences / privacy walls?  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| c. Damage to retaining walls?   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| d. Damage to pool & pool deck?  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| e. Evidence of leakage from irrigation supply lines?  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| f. Toppling, shifting, or damage/leakage at fuel connection of propane tanks?   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| g. Broken piping or shifting of pool or spa equipment?  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

### E. INTERIOR INSPECTION (including basement and attached garage, if present)

#### 26. General information

a. If interior access not possible, identify reason

- ☐ i. Red tag
- ☐ ii. Hazardous materials
- ☐ iii. Other hazardous condition, describe \_\_\_\_\_
- ☐ iv. Other, describe \_\_\_\_\_

b. Typical wall and ceiling finish

- ☐ i. Drywall
- ☐ ii. Plaster on gypsum lath
- ☐ iii. Plaster on wood lath
- ☐ iv. Other, describe \_\_\_\_\_

## General Earthquake Damage Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### **E. INTERIOR INSPECTION (continued)**

	YES	NO	N/A
<b>27. Walls: (if yes, provide description and photos)</b>			
a. Fresh cracking, buckling, spalling, or detachment of interior wall finish at corners of door and window openings?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Fresh cracking of wall finishes at wall corners or wall/ceiling intersections?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Door or window openings racked out of square?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Wall leaning?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. Pattern of cracking that extends from the floor slab through the wall?	<input type="checkbox"/>	<input type="checkbox"/>	
f. Movement or sliding of walls relative to the floor?	<input type="checkbox"/>	<input type="checkbox"/>	
g. Severe cracking, separations, or offsets at building irregularities?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h. Doors damaged, difficult to operate, or inoperable?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
i. Windows damaged, difficult to operate, or inoperable?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>28. Ceilings: (if yes, provide description and photos)</b>			
a. Collapse of ceiling finish?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Fresh cracking of ceiling finishes, especially at re-entrant corners; cracks along corner bead at stairwell openings; cracking or tearing of finishes at ceiling/wall juncture; or multiple "nail pops"?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Damage to ceiling finishes in vicinity of chimneys or fireplaces?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Separations or cracks in ceiling finishes at split-levels, re-entrant corners, additions, appendages, or other building discontinuities?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. Water damage or evidence of recent leakage from plumbing lines or roofing?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## General Earthquake Damage Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### E. INTERIOR INSPECTION (continued)

	YES	NO	N/A
<b>29. Floors: (if yes, provide description and photos)</b>			
a. Evidence of recent sloping, sagging, settlement or displacement of floors?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. In slab-on-grade locations, fresh cracking of floor slab or floor finishes?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Significant sagging or unusual bounciness of woodframed floors over crawlspace?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Separations or cracks in floor finishes at split-levels, re-entrant corners, additions, appendages, or other building discontinuities?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. Signs of movement between floor (including garage floor) and exterior hardscape or retaining wall along the uphill side of homes on steeply sloping sites?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. A pattern of fresh cracks, gaps, or joint separations in floor finishes?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g. Impact damage to floor finishes from falling contents?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>30. Fireplace: (if yes, provide description and photos)</b>			
a. Collapse, partial collapse, or separation of interior fireplace facing from, or movement relative to, the adjacent wall or firebox?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Differential movement between fireplace insert and firebox?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>31. Mechanical systems: (if yes, provide description and photos)</b>			
a. Displaced connection of appliance flues connected to chimneys?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Toppling, shifting, leakage from tank, leakage from water connections displaced flue connection or damage/leakage at gas line or electrical connection of water heater?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Shifting, damage/leakage at gas line, flue connection, electrical connection, refrigerant line, and condensate drain connection of furnace or air conditioning fan-coil unit?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Damage to gas line of gas stoves or gas fueled clothes dryers?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. Damage to toilets?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. Decreased or restricted water pressure at appliances, faucets, or toilets?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g. Toppling or shifting of free-standing wood stove and/or flue?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h. Toppling, shifting, damage/leakage at fuel connection of fuel oil tank?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## General Earthquake Damage Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### E. INTERIOR INSPECTION (continued)

- |   | YES                      | NO                       | N/A                      |
|---|--------------------------|--------------------------|--------------------------|
| <b>32. Architectural woodwork and special finishes:</b> (if yes, provide description and photos)                                |                          |                          |                          |
| a. Shifting of or damage to kitchen or bathroom cabinetry?  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| b. Impact damage to countertops from falling objects?   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| c. Cracking of ceramic tile in showers or tub/shower enclosures consistent with<br>earthquake damage to adjacent wall finishes? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

### F. CONTINGENT INSPECTIONS

- |   | YES                      | NO                       | N/A                      |
|---|--------------------------|--------------------------|--------------------------|
| <b>33. Crawlspace:</b> (if yes, attach CUREE Form EDA-F3) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| <b>34. Attic:</b> (if yes, attach CUREE Form EDA-F4)      | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

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## 1D Crawlspace Inspection Checklist

**Note:** In the absence of conspicuous visible external damage, earthquake-induced damage in crawlspaces is unlikely. In addition, there are hazards associated with entry into crawlspaces, especially those with tight access. Accordingly, in the absence of external visible damage, entering crawlspaces for post-earthquake inspection is not recommended. If a crawlspace inspection is conducted, it should be performed by an individual qualified by training and experience. Damage and abnormal conditions should be documented with photographs. Where description is called for on the following checklist, attach additional pages of notes and photographs keyed to appropriate checklist item (e.g., 8d).

Due to safety concerns associated with entry into a confined space, inspection of these areas may require the presence of a second individual. Inspectors should be equipped with appropriate personal protective equipment and be knowledgeable of appropriate safety precautions. Safety precautions for crawlspace inspections are provided in Appendix 1F.

Reduced scale images of the three-page CUREE Form EDA-F3 follow. For reproducing multiple copies, an electronic version of the form is available from the CUREE website.

## Crawlspace Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### A. GENERAL INFORMATION

1. Property address: \_\_\_\_\_  
 City: \_\_\_\_\_ State: \_\_\_\_\_ Zip: \_\_\_\_\_
2. Property Owner's Name: \_\_\_\_\_
3. Date of inspection: \_\_\_\_\_
4. Inspector's Name: \_\_\_\_\_

### B. OBSERVATIONS

#### 5. Extent of crawlspace (✓ check one)

- ☐ Full  
☐ Partial  
☐ Partitioned <sup>1</sup>  
☐ Portions inaccessible  
☐ Other, describe \_\_\_\_\_

<sup>1</sup> A partitioned crawlspace has two or more areas that are not interconnected and must be accessed from multiple entry locations.

#### 6. Access location(s)

\_\_\_\_\_

#### 7. Framing between foundation and floor framing

- ☐ None (mudsill directly on concrete stem walls)  
☐ Perimeter stem wall with interior wood posts  
☐ Interior cripple walls  
☐ Partial perimeter cripple walls  
☐ Full perimeter cripple walls  
☐ Steel pipe columns and diagonal steel rod bracing  
 Retrofit ☐ Yes ☐ No ☐ Can't tell  
 If yes, ☐ Plywood ☐ Anchor bolts, straps, or plates  
☐ Other, describe \_\_\_\_\_

#### 8. Stem walls

- ☐ None  
☐ Perimeter  
☐ Interior  
☐ Concrete  
☐ Concrete Block  
☐ Brick  
☐ Other, describe \_\_\_\_\_

## Crawlspace Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### B. OBSERVATIONS (continued)

	YES	NO	N/A
<b>9. Framing: (if yes, provide description and photos)</b>			
• General pattern of tilting of posts, cripple walls	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Isolated tilting of posts, cripple walls	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Missing or loose posts	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Split sill plate	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Fractured, buckled, or loose diagonal braces	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Shifting or sliding of framing relative to foundation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Prior shimming or releveling	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Other abnormal conditions, describe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>10. Foundation: (if yes, provide description and photos)</b>			
• Visible cracks in stem walls, approximate number	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Cracks in stem walls greater than 1/8 inch wide, approximate number, locations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Nature and extent of prior repair, if any	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Indications of previous flooding or water intrusion	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Condition of masonry beneath fireplaces	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Other abnormal conditions, describe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>11. Plumbing: (if yes, provide description and photos)</b>			
• Evidence of active leakage	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Broken pipe or joint separations in sewer piping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>12. Forced air heating/cooling ductwork: (if yes, provide description and photos)</b>			
• Crushed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Separated joints	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Presence of asbestos insulation or joint taping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Damaged asbestos insulation or joint taping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Other abnormal conditions, describe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Crawlspace Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### C. CONCLUSIONS

13. ☐ No evidence of earthquake-induced damage observed in crawlspace.
14. ☐ Observed nonstructural or structurally insignificant conditions that may be earthquake induced and require repair, specify.
15. **Observed indications of potentially structurally significant earthquake damage that requires an inspection by a technical consultant, (✓ check all that apply):**
- ☐ Broken water, sewer, or gas line or wet areas indicating possible broken water or sewer lines
  - ☐ A pattern of cracks extending through the soil and foundation indicative of earthquake-induced permanent ground deformation
  - ☐ Signs of fresh cracks in concrete foundations wider than 1/8 inch or offset by more than 1/16 inch out-of-plane (the thickness of a nickel)
  - ☐ Fresh-appearing crack in footings or foundation stem walls wider than 1/8 inch or offset by more than 1/16 inch out-of-plane (the thickness of a nickel).
  - ☐ Extensive or large cracks (with signs of recent movement) in the foundation far in excess of what would be expected from normal shrinkage and settlement.
  - ☐ Fresh-appearing spalling in footings or foundation stem walls.
  - ☐ Racking of cripple walls, delamination of stucco
  - ☐ Shifting or tilting of support posts
  - ☐ Shifting of woodframing or mudsill relative to foundation; cracking of the mudsill
  - ☐ Damage to under floor portions of masonry fireplaces
16. ☐ Observed indications of conditions unrelated to earthquake that require further investigation, specify.

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## 1E Attic Inspection Checklist

**Note:** In the absence of conspicuous visible external damage, earthquake-induced damage in attics is unlikely. In addition, there are hazards associated with entry into attics, especially those with tight access. Accordingly, in the absence of external visible damage, entering attics for post-earthquake inspection is not recommended. If an attic inspection is conducted, it should be performed by an individual qualified by training and experience. Where description is called for on the following checklist, attach additional pages of notes and photographs keyed to appropriate checklist item (e.g., 8d).

Due to safety concerns associated with entry into a confined space, inspection of these areas may require the presence of a second individual. Inspectors should be equipped with appropriate personal protective equipment and be knowledgeable of appropriate safety precautions. Safety precautions for attic inspections are provided in Appendix 1F.

Reduced scale images of the two-page CUREE Form EDA-F4 follow. For reproducing multiple copies, an electronic version of the form is available from the CUREE website.

## Attic Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### A. GENERAL CONDITIONS

1. **Property address:** \_\_\_\_\_  
**City:** \_\_\_\_\_ **State:** \_\_\_\_\_ **Zip:** \_\_\_\_\_
2. **Property Owner's Name:** \_\_\_\_\_
3. **Date of inspection:** \_\_\_\_\_
4. **Inspector's Name:** \_\_\_\_\_

### B. OBSERVATIONS

#### 5. Extent of attic (✓ check one)

- ☐ Full  
☐ Partial  
☐ Partitioned <sup>1</sup>  
☐ Portions inaccessible  
☐ Other, describe \_\_\_\_\_

<sup>1</sup> A partitioned attic has two or more areas that are not interconnected and must be accessed from multiple entry locations.

#### 6. Access location(s)

\_\_\_\_\_

#### 7. Attic framing

- ☐ Conventional field framed  
☐ Metal plate connected trusses  
☐ Other, describe \_\_\_\_\_

#### 8. Roof sheathing

- ☐ Spaced board sheathing  
☐ Board sheathing  
☐ Plywood or oriented strand board (OSB) sheathing  
☐ Plywood or OSB sheathing over spaced sheathing

#### 9. Framing: (if yes, provide description and photos)

	YES	NO	N/A
• Damage to top and bottom connections of diagonal braces between ridge board and ceiling framing or failing of braces	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Separation of framing at ridge board	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Fresh fractures in framing members	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Attic Inspection Checklist

Where description is indicated, attach additional pages of notes and photographs keyed to appropriate checklist item.

### B. OBSERVATIONS (continued)

10.	Chimney(s): (if yes, provide description and photos)	YES	NO	N/A
	• Masonry			
	• Visible cracks or offsets	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	• Damage to framing adjacent to chimney	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	• Damage to framing where metal tie straps from masonry to framing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	• Metal Flue			
	• Open or offset joints	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11.	Plumbing: (if yes, provide description and photos)	YES	NO	N/A
	• Broken pipe or joint separations in sewer vent piping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12.	Forced air heating / cooling ductwork: (if yes, provide description and photos)	YES	NO	N/A
	• Crushed ductwork	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	• Separated joints in ductwork or appliance flues	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	• Presence of asbestos insulation or joint taping on ductwork or appliance flues	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	• Damage to asbestos insulation or joint taping on ductwork or appliance flues	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	• Shifted or disconnected furnaces or fan coil units	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	• Other abnormal conditions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### C. CONCLUSIONS

13. Conclusions: (✓ check all that apply)
- ☐ No evidence of earthquake-induced damage observed in attic.
- ☐ Observed nonstructural or structurally insignificant conditions that may be earthquake induced and require repair, specify.
- ☐ Observed indications of potentially structurally significant earthquake damage that requires an inspection by a technical consultant:
- ☐ Impact damage to roof framing from fallen chimney
  - ☐ Framing damage adjacent to the chimney
  - ☐ Buckling or fracture of diagonal braces supporting the ridge board or damage to end connections
  - ☐ Separation between roof framing and an adjacent wall
  - ☐ Fresh separations of framed connections
- ☐ Observed indications of conditions unrelated to earthquake that require further investigation, specify.

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## **1F Attic and Crawlspace Inspection Safety**

- Never enter an attic or crawlspace without informing another individual of your entry and the approximate time you intend to be in the attic or crawlspace.
- Always use appropriate personal protective equipment. Gloves, tight-fitting disposable facemask, and coveralls are the minimum. Kneepads and elbow pads are desirable accessories for crawlspace inspections.
- Be aware of potential biological hazards including human or animal waste, pesticides, rodents, reptiles, or insects.
- Beware of and avoid electrical wiring that is loose or exposed.
- Beware of and avoid exposed nails.
- Do not enter crawlspaces, or portions thereof, contaminated with sewage.
- Safe maneuvering in attic spaces requires both hands to be unencumbered. Use a headlamp for lighting. Carry a compact camera on a neck strap or secured in a pocket.
- When moving in an attic, always maintain three points of contact (both feet and one hand or one foot and two hands). Verify that there is solid support before stepping. Step only on 2x or heavier framing – avoid stepping on 1x ties and braces. Never step on insulation or gypsum wallboard.



## 2 Earthquake Ground Motions and Damage Potential

### 2.1 Introduction

The focus of this section is on description of ground shaking and the typical patterns of damage commonly observed for varying levels of ground shaking. Damage to buildings and contents during an earthquake is a function of the level of ground shaking and the ability of the buildings and contents to resist that shaking. The principal objectives of this chapter are to summarize the various measures of ground shaking intensity that are readily accessible and to briefly summarize the relationship between the intensity of ground shaking, building vulnerabilities, and the potential for damage. In general, greater intensity of shaking increases the likelihood of damage that necessitates the assistance of a technical consultant. Buildings with known vulnerabilities are more likely to sustain serious damage than typical buildings and should be inspected by a technical consultant.

The U.S. Geological Survey (USGS) and other organizations monitor earthquake activity throughout the United States using a variety of methods, including instruments that measure and record the ground shaking. In California the USGS and the California Geological Survey network of strong motion instrumentation<sup>14</sup> is especially extensive. The data obtained from strong motion instruments can be used to characterize the earthquake ground shaking intensity and are typically available online within minutes following a California earthquake. The publicly available information can be used to develop preliminary estimates of potential damage resulting from ground shaking. Links to relevant sites are provided in the appendices to this section.

### 2.2 Limitations

This section presents a very brief introduction to the topic of earthquake ground motions and their effect on buildings and soil. See Section 2 of *Engineering Guidelines for the Assessment and Repair of Earthquake Damage in Residential Woodframe Construction*, CUREE Report No. EDA-06 for more detail regarding the use of earthquake ground motions for engineering analysis.

### 2.3 Measuring Earthquakes

Earthquakes, like hurricanes or tornadoes, are complex natural phenomena subject to great variability in their characteristics and effect on the built environment. Over the years, many parameters have been developed to better quantify the characteristics and effects of earthquakes.

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<sup>14</sup> Strong motion instruments, or accelerographs, are similar to the sensitive seismographs used by seismologists to detect and measure earthquakes thousands of miles away, except that the strong motion instrument is designed to accurately record nearby severe ground shaking.

Those most relevant to the assessment of damage to woodframe residential buildings are discussed in the following subsections.

### 2.3.1 Earthquake Magnitude

The magnitude<sup>15</sup> of an earthquake is essentially a measure of the size of the earthquake in terms of the total amount of energy released at the rupture surface, reported as a single decimal number, such as 6.7. The size of an earthquake, in general, is related to the surface area of the fault rupture and the amount of displacement over that rupture surface. In terms of the analogy previously given of two books laid back to back on a table and shoved sideways to suddenly lurch, the rupture area is the contact area between the spines of the books, and the displacement would be the distance one book slides vis-avis the other. Ruptures with small displacements over small areas result in imperceptible ground shaking lasting mere seconds, while ruptures with larger displacements over hundreds of square miles of a fault can cause ground shaking that is felt over thousands of square miles and lasting upwards of a minute, as illustrated in Figure 2.1.<sup>16</sup> So, one logical measure of earthquakes is the size of and displacement across the rupture surface – the fundamental basis of the magnitude scale commonly used nowadays. Since fault displacement is strongly correlated with the area of the rupture surface, the total energy released by an earthquake is roughly proportional to the surface area of the fault rupture.

On the magnitude scale, a unit increase in magnitude (e.g., from 6.0 to 7.0) corresponds to approximately a 32-fold increase in energy release. A two unit increase (e.g., from 6.0 to 8.0) corresponds to a 1,000-fold increase in energy release! Greater energy release generally means longer duration shaking over a larger area. The largest earthquake ever recorded was a Magnitude 9.5 earthquake in Chile on May 18, 1960, while the largest earthquake ever recorded in the United States was the Alaska Earthquake on March 27, 1964, with Magnitude 9.2. In comparison, the Northern California Loma Prieta Earthquake (also known as the World Series Earthquake) of October 17, 1989 had a Magnitude 6.9 while the Southern California Northridge Earthquake of January 17, 1994 had a Magnitude 6.7. While the smallest of these earthquakes in magnitude, the Northridge Earthquake caused the greatest economic damage due to its location in a heavily urbanized region. The USGS maintains an extensive database of the magnitude and epicenters of past earthquakes, which is easily accessible on the internet as described in Appendix 2A.

A rough correlation between magnitude and maximum earthquake severity is shown in Table 2-1. Unfortunately, beyond these rough correlations, the magnitude of an earthquake is not terribly helpful for damage assessment purposes. Ground shaking is a complex phenomenon,

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<sup>15</sup> There are several definitions of magnitude such as the Richter magnitude, moment magnitude, body-wave magnitude, among others; the Richter magnitude scale developed by Charles Richter is the most widely known and is based on the record of an earthquake from a standardized seismograph, corrected for distance. Values typically reported by the USGS for modern earthquakes are based on the moment magnitude scale, which is based on the area of the rupture and its displacement, as described above, along with the rigidity of the rock. The differences between the various magnitude scales are subtle and not of any major significance outside the world of seismology.

<sup>16</sup> The adverse effects of the earthquake are concentrated over a much smaller area than the area over which the earthquake is felt, and the majority of the energy released by an earthquake is also concentrated over a much shorter time period than the full duration of the shaking.

based on many factors that include the size and type of rupture, the distance of the site from the rupture, direction of rupture propagation relative to the direction to the site, the regional geology and topography, and the local soil conditions. At a particular site, the ground motion may be strong or weak, long or short, and jerky or rolling.

**Table 2-1. Earthquake magnitude versus earthquake severity**

Magnitude	Duration of Shaking (sec)	Typical Modified Mercalli Intensity in Areas of Strongest Shaking	Typical Earthquake Effects in Areas of Strongest Shaking
Less than 3.0	--	III	Generally not felt but recorded
3.0 – 4.0	--	IV – V	Often felt but rarely causes damage
4.0 – 5.0	2	VI – VII	At most slight damage to well-designed buildings and can cause major damage to poorly constructed buildings over small regions
5.0 – 6.0	6	VII – VIII	Can result in damage in areas up to about 60 miles across
6.0 – 7.0	18	IX – XX	Major earthquake and can cause serious damage over larger areas
8.0 or greater	34 (Magnitude 8.0)	IX – XX	Significant earthquake and can cause serious damage in areas several hundred miles across

### 2.3.2 Intensity of Ground Shaking

While the magnitude of an earthquake provides a general sense of its relative size and potential for damage, magnitude alone does not provide sufficient information to assess the character of ground shaking at a particular site. Thus, it is necessary to look to other more descriptive measures of earthquake ground shaking to capture the geographic variations in ground shaking associated with an earthquake. Intensity is the term generally used to qualitatively characterize the local level of ground shaking, i.e., the damage potential of the ground shaking at a particular location. Earthquake intensity varies from place to place depending on various site-specific and earthquake characteristics. For example, the most intense shaking experienced during earthquakes generally occurs near the epicenter, and decreases with distance away from the fault, a phenomenon known as attenuation. However, all sites located equidistant from the epicenter of an earthquake do not typically experience the same intensity of ground shaking because of individual site characteristics or propagation characteristics of the seismic waves.

By way of analogy, consider a collection of model boats floating on a small pond into which a rock is tossed. The boats are equivalent to our buildings. The magnitude is equivalent to the size of the rock – the larger the rock, the bigger the splash, the larger the energy released at the source, and the higher the waves. Boats close to the point of impact of the rock are likely to be swamped, if the rock is of sufficient size. Boats farther from the point of impact are less likely to be swamped although they may experience a wild ride. With increasing distance, the effect of the waves decreases to little ripples. To understand the effect of our rock on a particular boat, we need to know the size of the waves at the location of the boat and how seaworthy our boat is.

Likewise for earthquakes, to understand the effect at a particular site, we need to know the intensity of ground motion as well as the seismic vulnerability of our building.

Magnitude and distance from the fault rupture are the most important determinants of intensity – larger magnitudes correspond to ground shaking of greater strength and longer duration for a given site at a given distance from the fault rupture. The strength of ground shaking generally decreases rapidly with distance from the rupture plane. In California, on average, the strong shaking near the fault becomes half as strong at a distance of about 8 miles, a quarter as strong at a distance of 17 miles, an eighth as strong at a distance of 30 miles, and a sixteenth as strong at a distance of 50 miles. The rate of this decrease is strongly influenced by regional geology, being much more rapid along the West Coast than east of the Rocky Mountains. In other words, for the same magnitude event, an earthquake in the eastern US will affect a much larger area than an earthquake in California. For example, the San Francisco Earthquake of 1906 (Magnitude 7.8) was felt 350 miles away in the middle of Nevada, whereas the New Madrid Earthquake of December 1811 (Magnitude 8.0) in the Mississippi Valley is reported to have rung church bells in Boston, Massachusetts, 1,000 miles away.

In addition to the magnitude of the earthquake and distance of a site from the rupture plane, the intensity of shaking in a given region also depends heavily on the local topographic and soil conditions, termed site effects. Deep, soft soils may amplify bedrock motions, causing stronger shaking at the surface than an area equidistant from the epicenter but underlain by firm ground or bedrock. Thus, an area underlain by deep, soft soil deposits may often experience more severe damage than the surrounding areas. Examples of this type of amplification occurred during the 1989 Loma Prieta Earthquake. While the epicenter was 60 miles distant and most of the Bay Area escaped serious damage, ground motions in portions of Oakland and in the Marina district of San Francisco underlain by soft soils were more than 10 times stronger than at neighboring sites on rock.

To characterize the overall effect of all of the foregoing influences on the local damage potential of an earthquake, various intensity scales have been developed which, as discussed below, provide a combined measure of ground motion and building vulnerability. While each earthquake has a single magnitude, the intensity of ground shaking for that earthquake varies throughout the area affected by the earthquake. Thus, ground shaking intensity data are typically presented as maps illustrating the variation of intensity throughout the affected area.

### **2.3.3 Modified Mercalli Intensity Scale**

The Modified Mercalli Intensity (MMI) scale has been the most widely used intensity scale in the United States since the 1930s. The scale is based on the observed local effects of ground motions on people, building contents, buildings, and the environment. The scale ranges from I to XII, as shown in a condensed version presented in Table 2-2, with I being imperceptible and XII being total destruction of the built environment.<sup>17</sup>

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<sup>17</sup> Note that total destruction of a city of buildings constructed in accord with modern earthquake regulations has never been occurred; this description was originally developed in the context of Nineteenth Century cities of buildings constructed of unreinforced stone and brick masonry.

Each level of intensity is characterized by certain effects (i.e., many small objects overturned and fallen) that are commonly observed at that intensity level. The same effect may occur less frequently or less strongly at lower intensity levels and occur more frequently and more strongly at higher intensity levels. For example, at MMI VI, overturned furniture occurs in many instances; at MMI V and below, occurrences of overturned furniture are rare; whereas, at MMI VII and above, occurrence of overturned and possibly damaged furniture is common. Humans are much more sensitive to ground shaking than contents or buildings; humans typically begin to feel the shaking at MMI III. In areas where the intensity of shaking is below MMI V, damage to buildings or contents is extremely unlikely. At MMI V, some damage to contents but no damage to buildings would be expected. Minor damage to some buildings occurs at intensity VI. Progressively more building and contents damage occurs at MMI VII through IX. MMI X through XII are generally associated with ground failure and very severe damage to buildings and contents. By observing the local effects of the earthquake in any affected area, the MMI of that area can be determined by finding the description in Table 2-2 that most accurately describes the overall local effect of the earthquake.<sup>18</sup>

Historically, for significant earthquakes, the USGS has compiled earthquake intensity data in the form of MMI maps for the region in which the earthquake was felt. The intensities are plotted on a map, and contour lines of equal intensity are drawn that divide the area into zones of similar intensity of shaking to create an isoseismal map. An example of the isoseismal map for the 1994 Northridge Earthquake is presented in Figure 2.3. As a point of reference, during the Northridge Earthquake (Moment Magnitude = 6.7), MMI IX corresponds to the three most heavily damaged regions, covering a total of about 11 square miles that included approximately 12,400 dwelling units. MMI VIII was observed over an area of about 275 square miles that included approximately 206,700 dwelling units. MMI VII was observed over an area of about 821 square miles that included approximately 328,800 dwelling units.

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<sup>18</sup> Intensity is a location-specific measure of the earthquake ground shaking; significant variability may exist in the seismic performance of buildings assigned to the same intensity depending on the particular characteristics of the buildings as discussed later in this section.

**Table 2-2. Abridged modified Mercalli intensity scale**

MMI	Abridged Description
I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stack, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

### 2.3.4 Community Internet Intensity

The Community Internet Intensity (CII) map was developed to rapidly estimate the MMI of an earthquake using the internet. In this process, internet responses to an online questionnaire based on the MMI scale are compiled from citizens in earthquake-affected (or “felt”) regions. The responses are summarized in the form of a map, which shows the assigned MMI level for each ZIP code. Although the CII methodology can assimilate response information quickly, it may not be possible to receive enough quick responses from highly damaged regions in the case of a large earthquake. An example of the CII map for the 1994 Northridge Earthquake is presented in Figure 2.4. CII questionnaires and maps may be found on the USGS website as discussed in Appendix 2A.

### 2.3.5 Instrumental Intensity

Ground shaking of earthquakes in urban areas of California and some other states is recorded by seismic instruments at hundreds of locations throughout the area affected by the earthquake. Much of that data is transmitted in real time and available for processing within minutes after a major earthquake. One of the products of this data processing is ShakeMap, an automated surrogate of the MMI map that presents the variation in intensity of ground shaking based on

interpolated data from available instruments and a model of the topography and geology of the area. The intensities derived in this process are termed Instrumental Intensities and are correlated with MMI; the Instrumental Intensity values are reported using regular Arabic numerals as opposed to the MMI values, which are reported using Roman numerals. Figure 2.5 presents the ShakeMap of the Northridge Earthquake, which may be compared with the MMI and CII maps presented in Figure 2.3 and Figure 2.4, respectively.

The major advantage of ShakeMap over a traditionally-developed MMI map is the timeliness of the information – a ShakeMap is generally available in minutes following a significant earthquake. In addition, it is objectively based on the readings of strong motion instruments rather than the personal accounts of individuals. The major shortcoming of ShakeMap is that it is based on an approximate correlation with the MMI scale, but does not include field observations of damage. Thus, for any particular location, the intensities of shaking indicated by ShakeMap may not agree with the intensity based on effects observed in the field. Furthermore, significant uncertainty may be associated with the underlying data values. ShakeMaps can be found on the USGS website as discussed in Appendix 2A.

### **2.3.6 Instrumental Records**

To collect detailed numerical data, various agencies install sensitive automated recording instruments (accelerographs) in known seismic areas to collect detailed records of earthquake ground motion when it occurs. Accelerograms are the records of the ground acceleration (typically recorded on three axes – north/south, east/west, and up/down) at the location of the instrument during the earthquake. In addition to their use in the production of ShakeMap described above, accelerograms are used by specialized consultants to perform numerical analysis of ground response (for ground failure) and building response to earthquake ground shaking.

### **2.3.7 Ground Motion Parameters**

Instead of a complete accelerogram, various simplified parameters are commonly used to describe the more important aspects of the ground motion. A myriad of parameters have been developed in an attempt to efficiently characterize the ground motion recorded by the accelerogram. These parameters, termed ground motion parameters, generally represent the amplitude, frequency content and/or duration characteristics of earthquake ground motions. The most direct measures of amplitude are the peak values of ground acceleration, velocity, and displacement.<sup>19</sup> The peak value of acceleration is known as peak ground acceleration (PGA). Similarly, the peak values of velocity and displacement are commonly referred to as peak ground velocity (PGV) and peak ground displacement (PGD), respectively. With few exceptions, these peak values will be in one of the two horizontal directions. Because horizontal ground motions cause the vast majority of damage, there is little practical interest in vertical ground motion parameters.

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<sup>19</sup> In the analogy of our model boats on the pond, the maximum wave that passes by a particular boat would be the peak wave, but that peak value does not describe all the other waves that passed by the boat. Thus, the peak is a useful parameter, but not fully descriptive of the severity of motion.

### **2.3.8 Ground Surface Strains**

The passage of seismic waves, which cause ground vibrations we call earthquakes, cause rapid ground movements but small ground deformations. Despite occasional accounts to the contrary, seismic waves at the ground surface are usually too subtle to be discernable to the naked eye – the length of the waves is generally on the order of thousands of feet while the amplitude (height) of the waves is typically on the order of a few inches. This is unlike our analogy with the model boats on the pond, where the waves noticeably distort the water's surface. As a practical matter, the ground does not bend, twist, or stretch over the length of typical woodframe residential buildings. The land under the building can be visualized as shaking back and forth and somewhat up and down in various directions during the earthquake as a relatively rigid plate. In all but the most severe shaking, distortions of the ground surface are too small to damage improvements on the scale of woodframe residential buildings.

## **2.4 Damage Potential**

The MMI scale provides a general, qualitative description of the level of damage associated with the intensity of shaking in an area, but does not provide specific information about the level of expected damage for residential woodframe buildings. Several relationships between expected damage (based on observed historical performance and expert judgment) to woodframe houses and ground shaking intensity have been developed. Damage is expressed in terms of a damage factor, which is the ratio of the repair cost to the replacement cost of the building. In addition, qualitative descriptions of the damage estimates are also provided (i.e., light, moderate, and heavy).

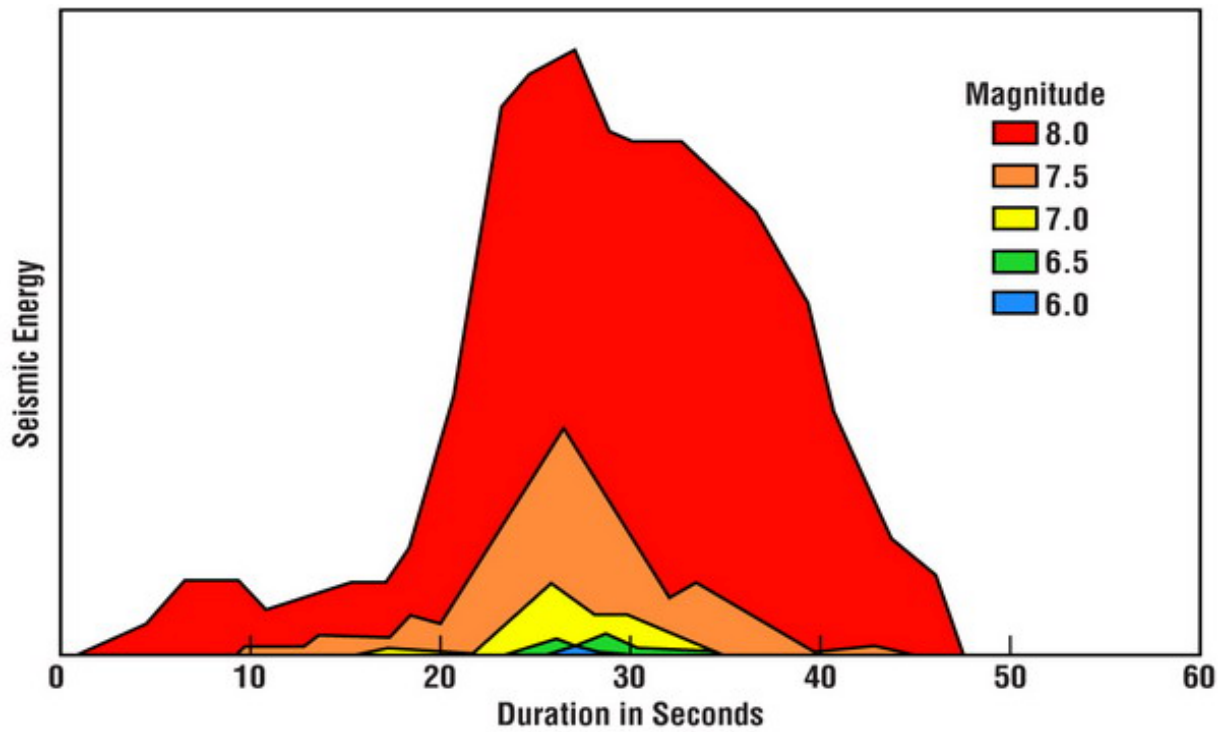
It must be noted that these damage estimates represent the expected average for the entire population of similar buildings, and are not directly applicable to any specific building. Buildings with vulnerable configurations (e.g., split level houses) will likely sustain damage greater than the average while buildings with less vulnerable configurations (e.g., single-story slab-on-grade houses with many walls) will likely sustain damage less than the average. General damage estimates do not include the effect of earthquake-induced ground failure.

Comparison with other building types (e.g., reinforced masonry) indicates that low-rise woodframe buildings are relatively resilient to earthquake ground shaking. Generally, no damage is expected for an average woodframe building where the MMI is less than VI; while, heavy damage (cost of repair greater than 30% of the replacement value) is expected only at MMI XII.

Common structural vulnerabilities that increase damage potential include lack of bolting of the sill plate to the foundation, weak-story or soft-story configurations, walls with extensive openings, walls with high height-to-width ratios, building height of three stories or more, split level configurations, cut-fill building pads, hillside lots, stepped cripple walls, improperly braced chimneys, heavy tile roofing, and non-standard configurations in plan or height. Some of these characteristics are more common in older houses, but some pertain to new construction as well. Conversely, conditions associated with better than average seismic performance include slab-on-grade or concrete stem wall foundations, single-story height, rectangular floor plans with



numerous partitions, stucco clad and/or reinforced plaster clad walls with few and small openings, light-weight roofing.



(After Hartzell and Heaton, 1988) Oregon Department of Geology and Mineral Industries

Figure 2.1. Illustration of comparative “size” of earthquakes [USGS].

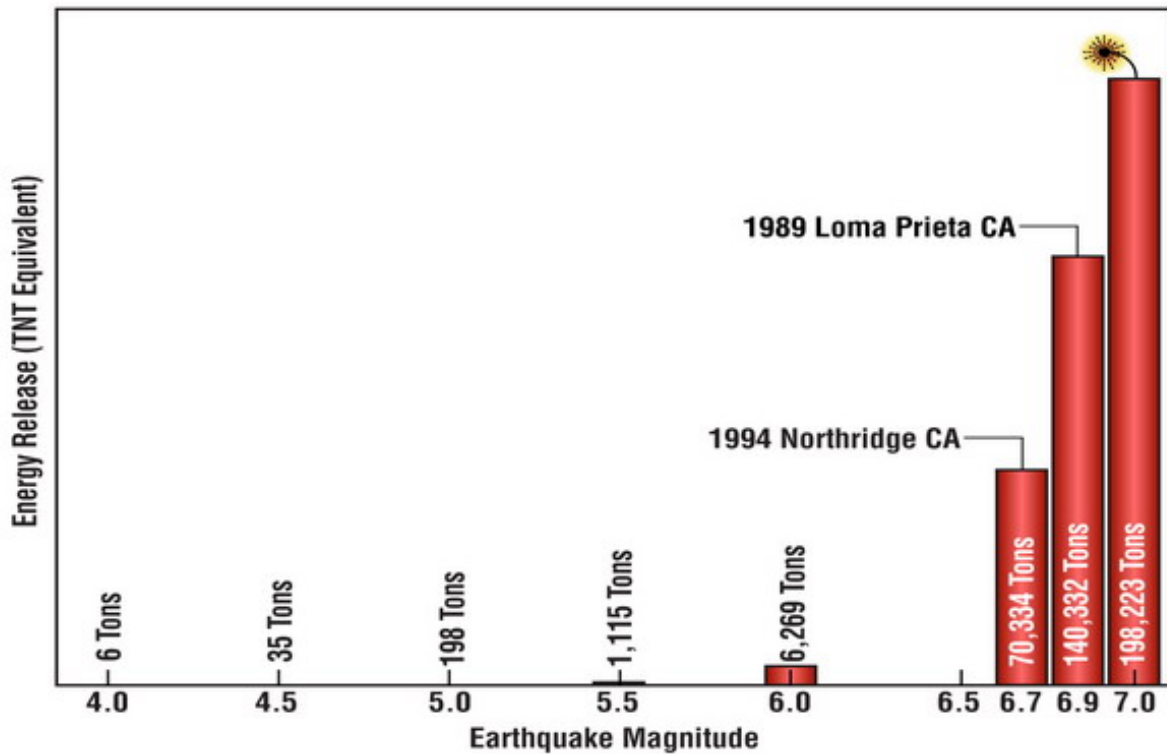
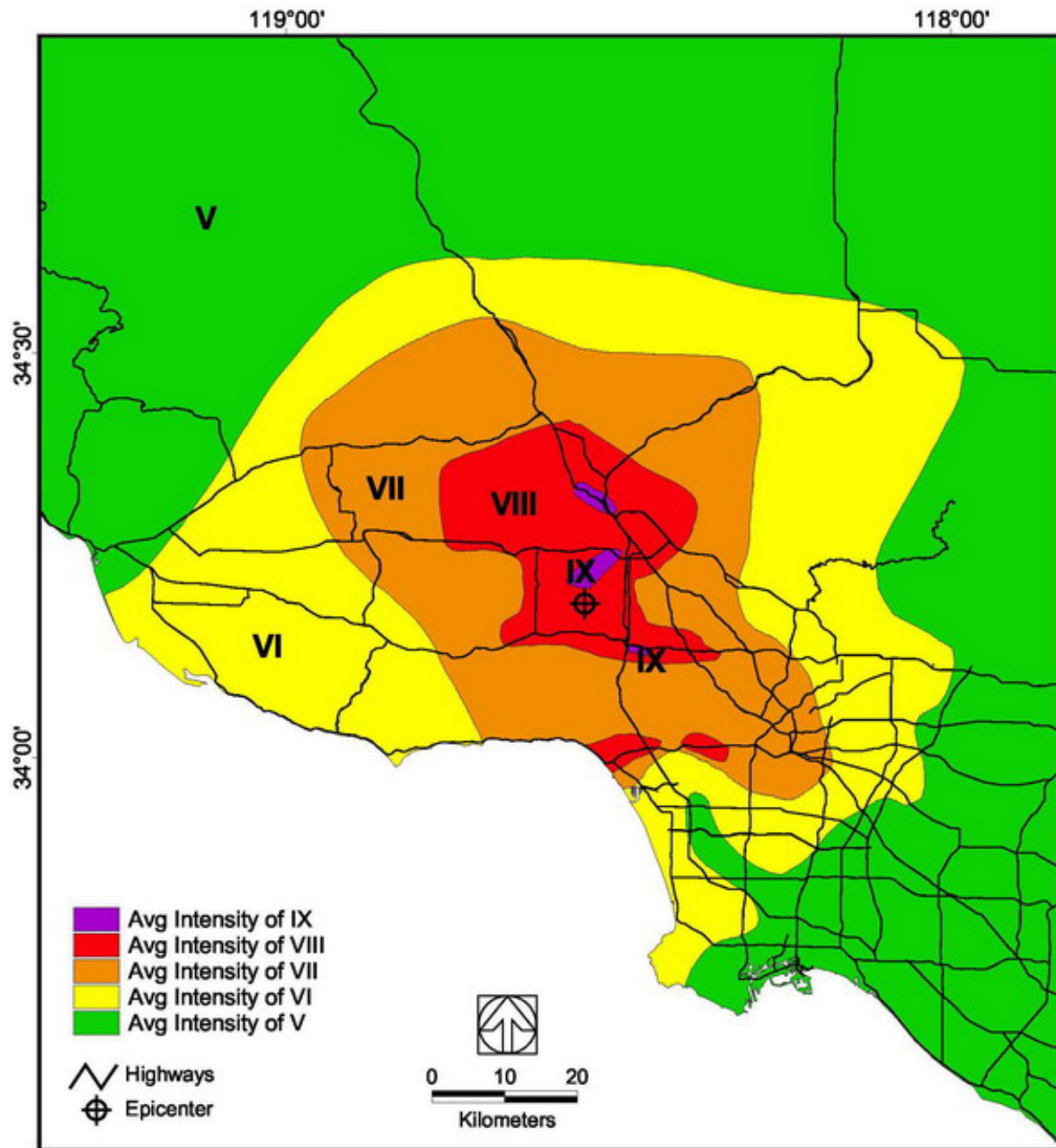


Figure 2.2. Illustration of total energy release as a function of earthquake magnitude [Exponent].



Dewey, J.W., Reagor, B.G., Dengler, L., and Moley, K. (1995). Intensity distribution and isoseismal maps for the Northridge, California earthquake of January 17, 1994. U.S. Geological Survey, Open-File Report 95-92.

Figure 2.3. Isoseismal map of MMI for the Northridge Earthquake of January 17, 1994 [USGS].

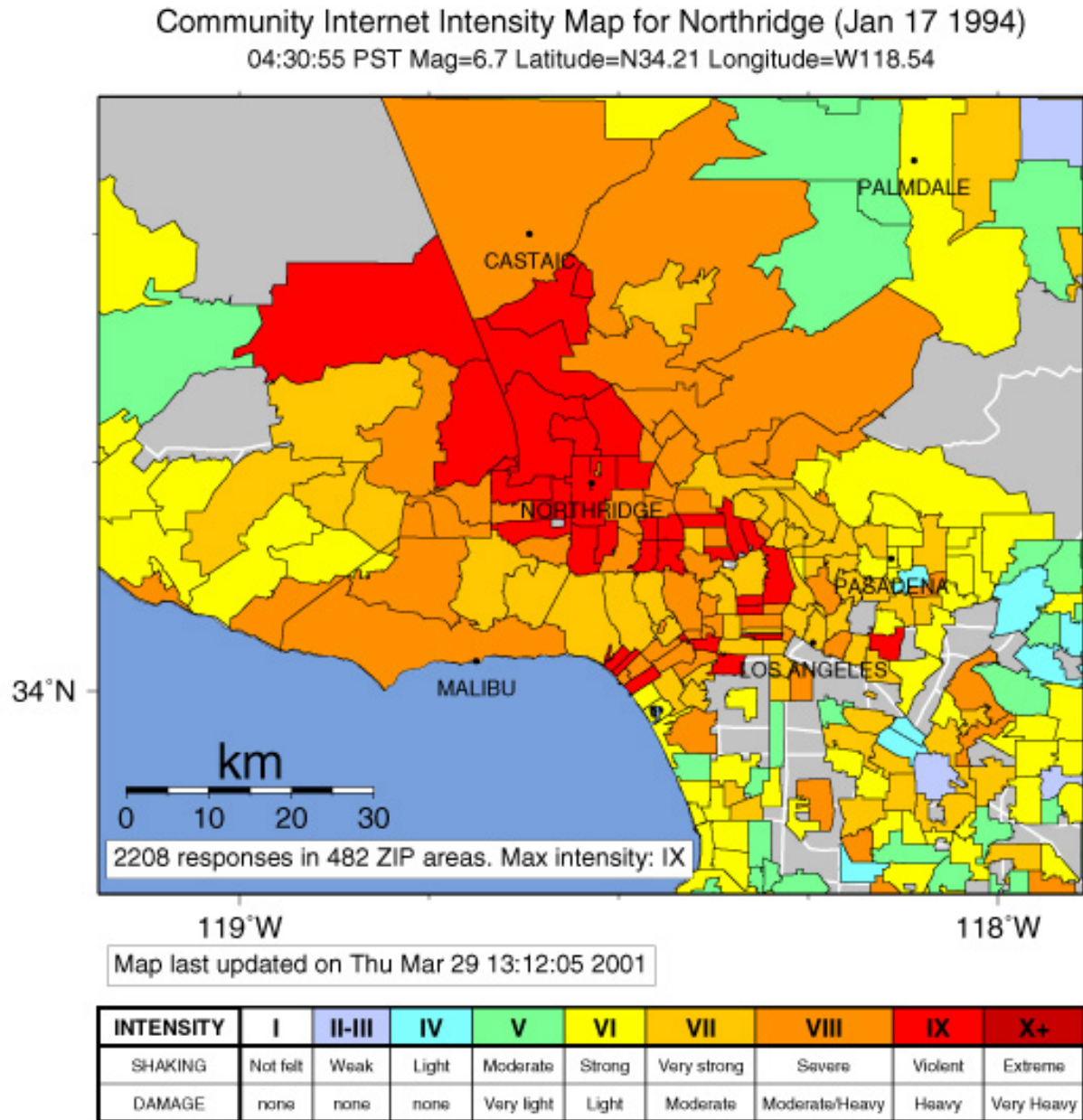
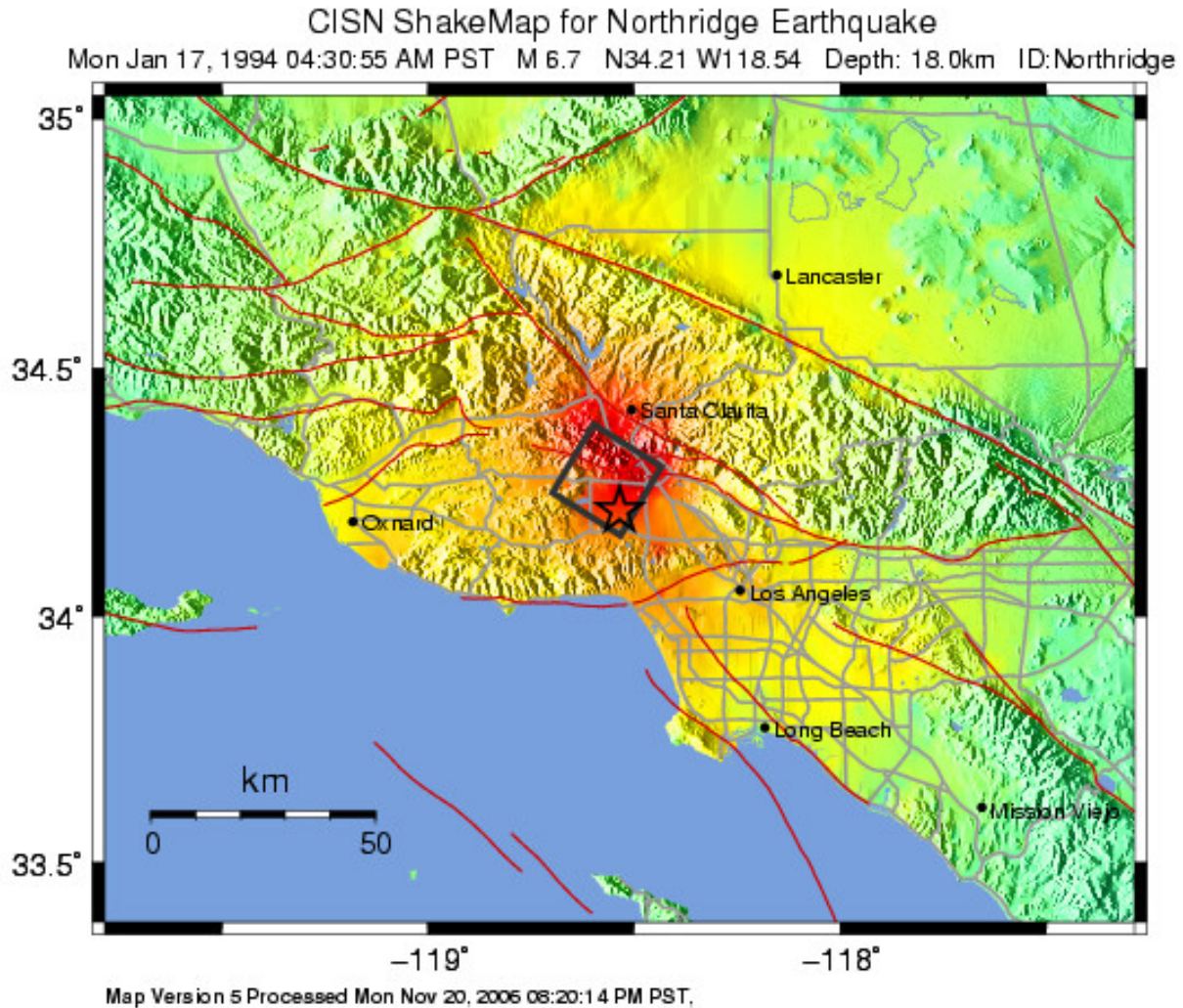


Figure 2.4. CII map for the 1994 Northridge Earthquake; on the website, positioning the mouse over an area will result in display of the underlying data [USGS].





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 2.5. ShakeMap showing the instrumental intensities for the 1994 Northridge Earthquake [USGS].



## Appendices Section 2

### 2A Sources of Earthquake Information and Data

*Note: The website addresses presented below were current as of the date of publication of this document. Due to the dynamic nature of the web, the addresses as well as content of referenced websites may be expected to change with time. Also note that the appearance of some websites may differ based on web browser used.*

The USGS Earthquake Hazards Program website, <http://earthquake.usgs.gov/recenteqsUS/>, (Figure 2B.1) serves as a primary source of earthquake event information and data for the United States. The link “ShakeMaps” on the left side of the webpage directs the user to another page that links to “ShakeMaps” for the states of California, Washington, and Utah. Selecting any of these states on the US map on the webpage lead the user to “ShakeMaps” for the individual states. For California, there are two separate links: one that leads to Northern California, and the other to Southern California. The user can directly access the California “ShakeMaps” by accessing the USGS website <http://quake.wr.usgs.gov/recent/shaking.html> (Figure 2B.2). The remainder of this discussion uses an event in Northern California to illustrate the use of the USGS website.

On selecting the “N.Calif.” link located above the map shown on the left in Figure 2B.2, the user is directed to a webpage<sup>20</sup> (Figure 2B.3.) that lists the most recent event for Northern California. The webpage provides the date, time, magnitude, and location for the most recent event, for events with a magnitude greater than 3.5. The information is typically available within about 10 minutes of the event occurrence. The information is updated as the USGS receives more data, the user is advised to access (and refresh) these webpages when the evaluation is to be carried out and not rely on previously downloaded information, especially in the first few days following the event. Selecting the “Most Recent Event” link directs the user to information and data for the specific event.<sup>21</sup> The remainder of this discussion uses the December 22, 2003, Magnitude 6.5, San Simeon Earthquake event for illustrative purposes.

The first webpage that the user is directed to on selecting the “Most Recent Event” link is an instrumental intensity map, the “ShakeMap,” for the particular event (Figure 2B.4). The various earthquake intensities are represented by different colors on the map, and a table at the bottom of the map provides a numeric relationship between the intensity and color on the map. Selecting the “Peak Ground Acceleration” link or the “Peak Ground Velocity” link located above the shaking intensity map directs the user to contour maps for the peak ground acceleration (Figure 2B.2), and peak ground velocity (Figure 2B.6), respectively.

The CII Maps can be accessed by selecting the “Did You Feel It” link above the right hand side map shown in Figure 2B.2. Selection of the link directs the user to a USGS website,<sup>22</sup> which

<sup>20</sup> <http://quake.wr.usgs.gov/research/strongmotion/effects/shake/>

<sup>21</sup> <http://quake.wr.usgs.gov/research/strongmotion/effects/shake/40148755/intensity.html>

<sup>22</sup> <http://pasadena.wr.usgs.gov/shake/ca/>

provides links to the CII Map for the most recent event as well as an archive of other events (Figure 2B.6). Selecting a particular earthquake event, or the most recent event from Figure 2B.6, results in the user being directed to a separate webpage that shows the CII Map for the selected event. For example, Figure 2B.7 shows the felt intensity map for the San Simeon Earthquake. Selecting the “Statistics” link above the map directs the user to another webpage that provides tabulated results per ZIP code for the number of reports from the particular ZIP code and the intensity ascribed to the particular ZIP code based on the reports.

The USGS also maintains a searchable database of historical earthquakes at [http://neic.usgs.gov/neis/epic/epic\\_circ.html](http://neic.usgs.gov/neis/epic/epic_circ.html) that can be searched to find earthquakes of any size that have occurred within any specified distance of a particular location during any desired window of time. The latitude and longitude of the desired location can be obtained from online geocoding programs such as:

- <http://www.maporama.com>
- <http://www.terraserer-usa.com/>
- <http://www.batchgeocode.com/lookup/>
- <http://stevemorse.org/jcal/latlon.php>
- <http://www.melissadata.com/lookups/geocoder.asp>



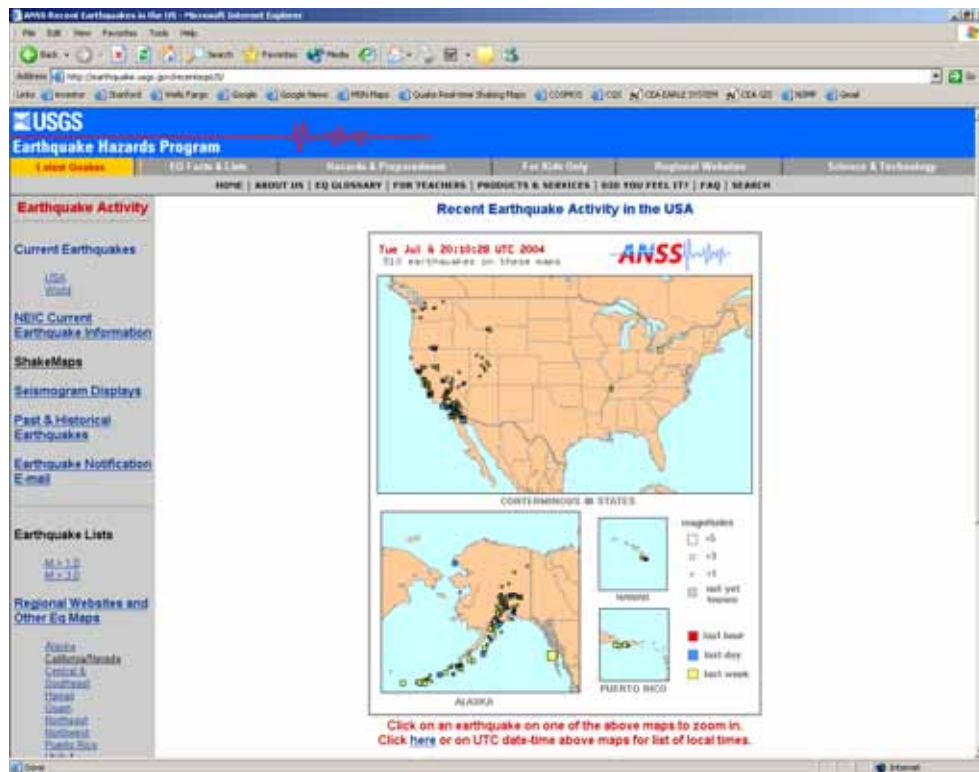


Figure 2B.1. USGS Earthquake Hazards Program website showing recent earthquake activity.

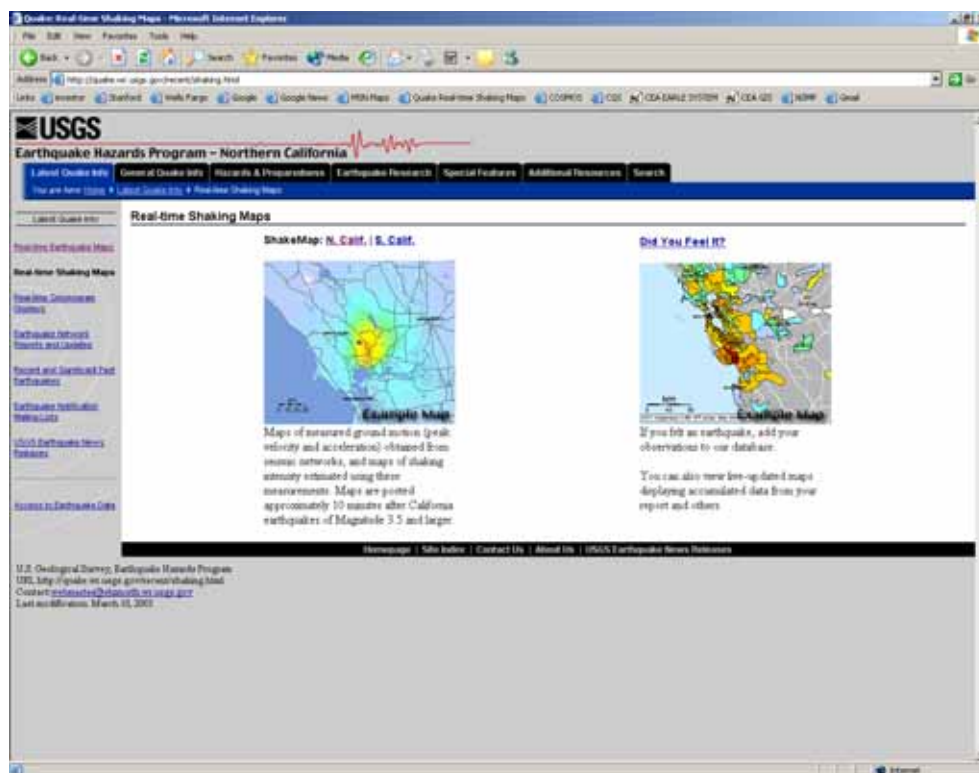


Figure 2B.2. USGS Earthquake Hazards Program website showing ShakeMaps for California.



Figure 2B.3. USGS Earthquake Hazards Program website listing recent earthquake events for Northern California.

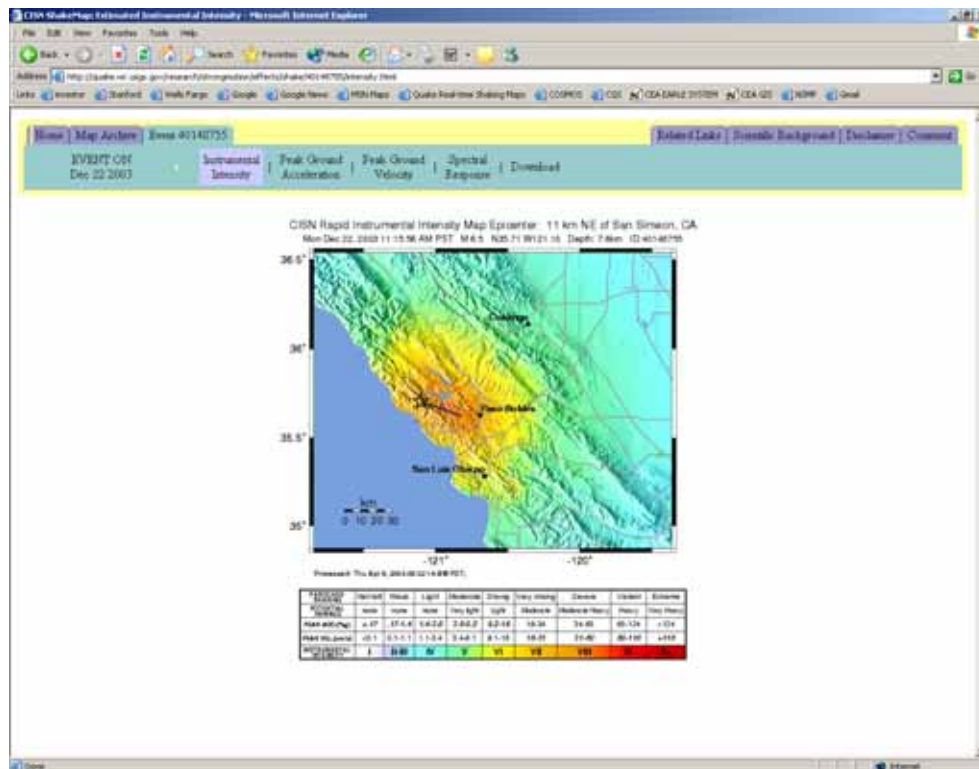


Figure 2B.4. USGS Earthquake Hazards Program website showing ShakeMap (instrumental intensity map).

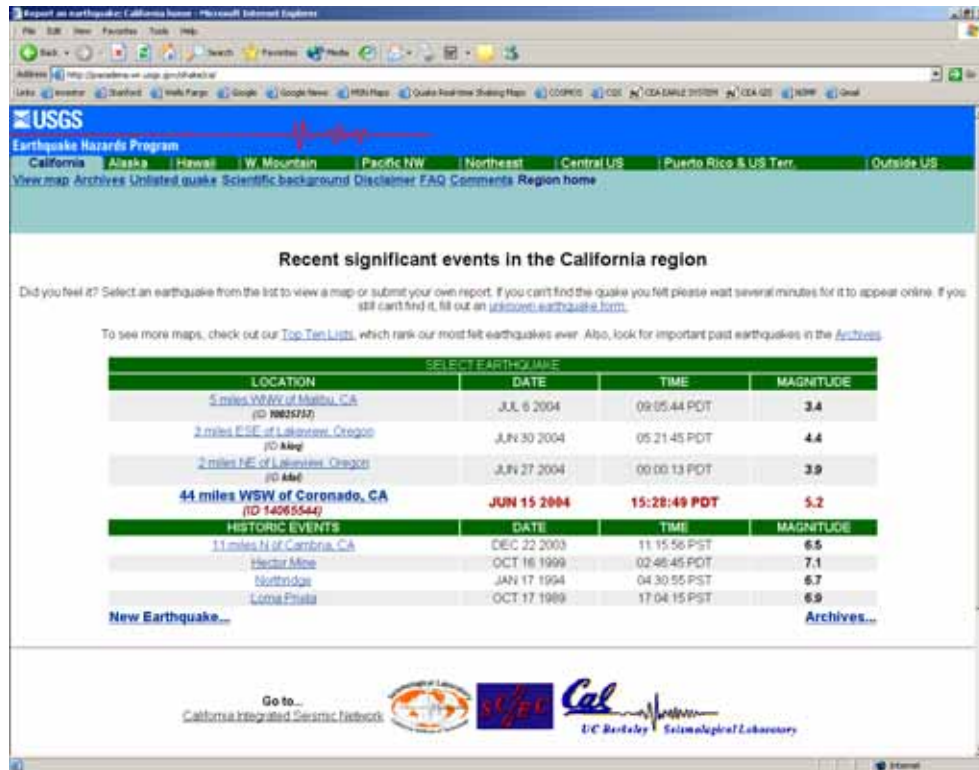


Figure 2B.5. USGS Summary of recent events in the California region.

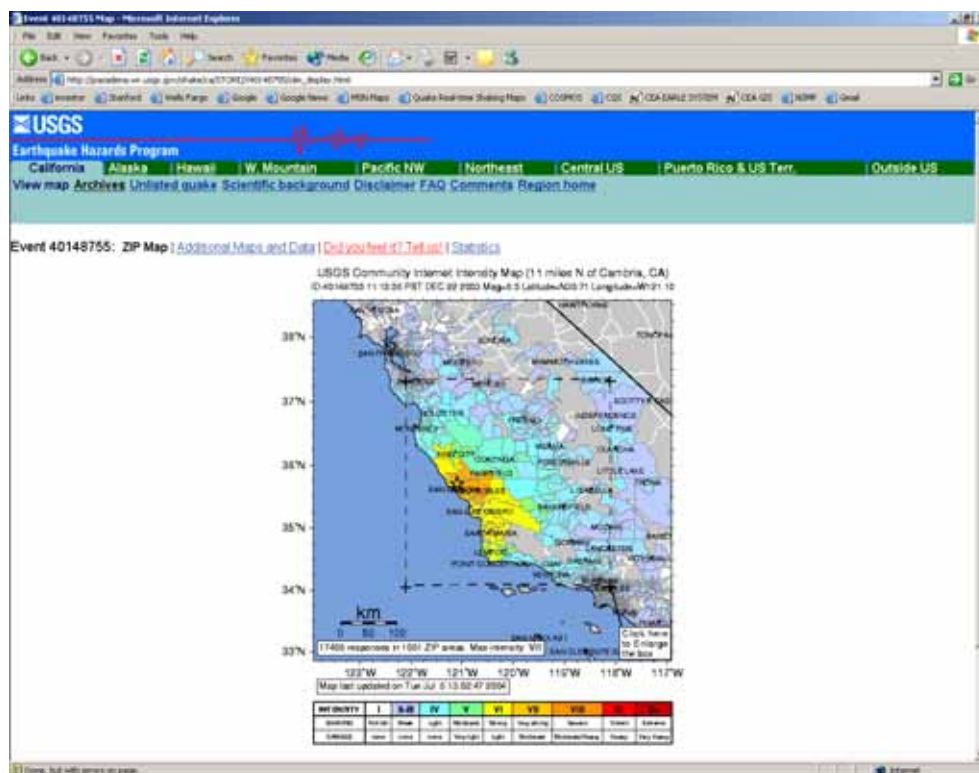


Figure 2B.6. USGS CII Map for Paso Robles Earthquake of December 23, 2003.

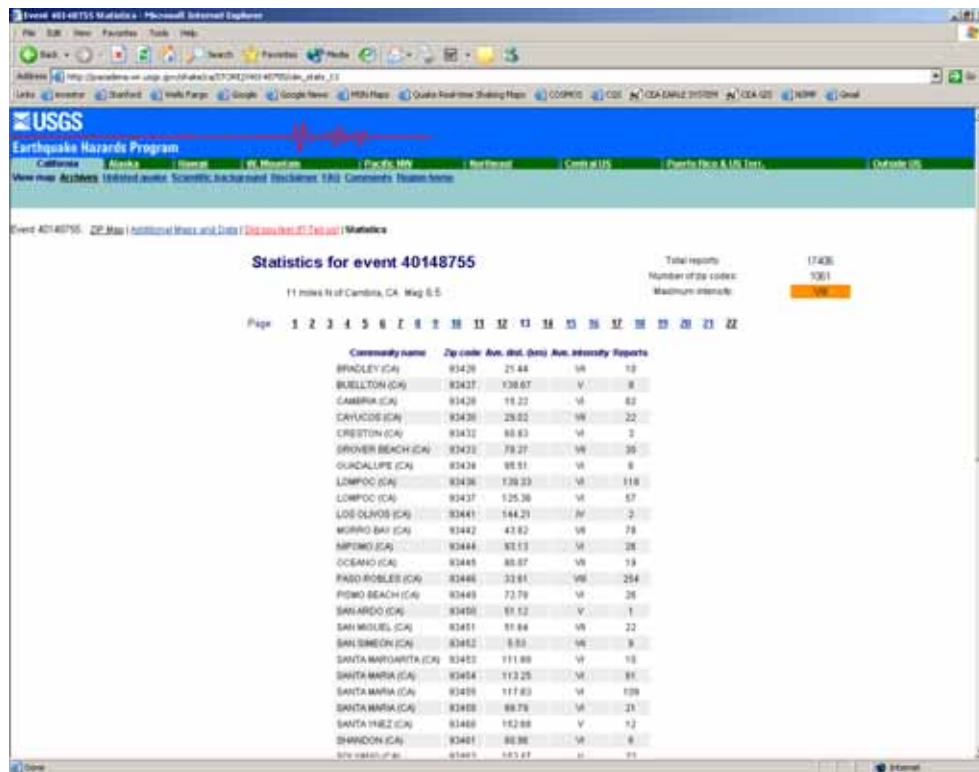


Figure 2B.7. USGS statistics for event.

## 3 Geotechnical Aspects

### 3.1 Quick Guide

#### 3.1.1 What to Look For

See Section 3.6 for a detailed discussion of assessment guidelines and methods.

- Signs of earthquake-induced permanent ground deformation in the exposed ground surface:
  - Fresh-appearing deposits of sand, commonly referred to as “sand boils” or “sand volcanoes”
  - Straight or jagged cracks, either parallel to a slope or behind the top of slopes or retaining walls
  - Unusual slumping, rising, or bulging of the ground surface
  - Evidence of landslides or rock falls
  - Ground movement or wet areas indicating broken underground utility lines (water, gas, sewer)
- Signs of fresh cracking (see Section 4 for guidance on determining whether a fracture is recent) in or movement of:
  - At-grade hardscape (paved areas) such as driveways, street pavement, public and private walkways, public curb and gutter, patios and pool decks
  - Retaining walls
  - Exposed surfaces of concrete floor slabs, footings, or stem walls
  - Above-grade finishes, such as stucco, drywall, masonry block walls, in a pattern consistent with ground failure or occurring in an unusual pattern (i.e., damage unusually concentrated in portions of the building)
- Patterns of cracking that extend across the ground surface and into adjacent hardscape and other improvements.

### 3.1.2 Where to Look

See Section 3.6 for a detailed discussion of assessment guidelines and methods.

- Examine the exposed ground surface, including sloped as well as terraced portions and hardscape (driveways, walkways, patios, pool decks) of the subject property.
- Examine above-grade improvements including exposed building floor slabs, foundations, building walls, retaining walls, masonry walls, and fences.
- Examine the exposed ground surface and hardscape (sidewalks, curb, gutter, and street pavement) of surrounding public property and adjacent properties (if possible), including upslope and downslope areas if applicable.

### 3.1.3 When to Call a Technical Consultant

If any of the following damage patterns are observed, a soils specialist<sup>23</sup> should be retained to perform an inspection of the property. See Section 3.6.1 for a detailed discussion of the circumstances indicating the need for consultant assistance.

- Indication of landslide, liquefaction, fault rupture, differential settlement, or other permanent ground deformation.
- Any fresh-appearing cracks in the ground surface, hardscape, or swimming pool shell or separations of construction joints wider than 1/4 inch.
- Any indications of recent widening of existing cracks in hardscape or swimming pool shell or separations of construction joints of more than 1/4 inch.
- Any fresh-appearing out-of-levelness in exterior improvements, such as driveways, street pavement, public and private walkways, public curb and gutter, patios and pool decks.
- Any fresh-appearing cracks in concrete foundation elements wider than 1/8 inch or offset by more than 1/16 inch out-of-plane (the thickness of a nickel).
- Any indications of additional widening of existing cracks in concrete foundation elements of more than 1/8 inch or additional offset of more than 1/16 inch out-of-plane.

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<sup>23</sup> Soils specialists are Civil Engineers specializing in soils or geotechnical engineering. California and some other states have additional designations, including Geotechnical Engineers (Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Geotechnical Engineer), and Engineering Geologists. See Section 9.3 for additional discussion.

- Collapse, rotation, or sliding of retaining walls.
- Indications of damage to underground utility lines in the vicinity of the property, such as seepage onto the ground surface indicative of broken water lines, and/or odors that may be indicative of broken sanitary sewer or gas lines.

### **3.1.4 Repair Guidelines**

If the soils specialist determines that earthquake-induced permanent ground deformation has occurred, they will recommend the nature and extent of remedial work, if any, required to stabilize the ground and/or improvements at the property. See Section 3.7 for a discussion of repair methodologies.

## **3.2 Summary**

Many buildings in California experience some amount of earth movement during their service life, which is caused by a variety of common geotechnical processes, including settlement, expansive soil movement, slope creep, landslides, and retaining wall movement. In addition to their strong shaking, earthquakes can also cause permanent ground deformation that may result in damage to buildings and surrounding improvements. The main mechanisms by which earthquakes induce permanent ground deformation include surface fault rupture, liquefaction, landslides, ridge-top fissuring and shattering, seismic compression (soil densification), and retaining wall failure. Earthquake-induced permanent ground deformation generally occurs in limited areas with specific vulnerabilities, such as loose saturated soils adjacent to bays and rivers, steep terrain, or along the fault.

Damage caused by non-earthquake earth movements may appear similar to earthquake-induced permanent ground deformations (i.e., horizontal or vertical permanent ground deformation). While inspecting a property after an earthquake, it is important to distinguish between long-term earth movements that occurred prior to the earthquake and those that occurred due to the earthquake. Many long-term soil conditions are relatively benign and do not require remedial work, while certain earthquake effects can cause damage to buried utilities or create slope instabilities. For example, ground settlements and/or heave caused by expansive soil need to be differentiated from ground settlements associated with liquefaction or seismic compression. Similarly, investigations of sloping sites must distinguish between long-term slope creep or retaining wall deformations and instabilities from earthquake-induced slope or retaining wall movements.

When looking for indications of earthquake-induced permanent ground deformation, the best course of action is to inspect the deformation-sensitive elements throughout the property. These include hardscape such as driveways and sidewalks, utility lines, swimming pools, foundations and building finishes such as stucco. In addition to a thorough inspection of the subject property, it is also important to examine the neighboring areas for similar indications of earthquake-induced permanent ground deformation in the curbs, street pavements, and other similar features.



If indicators of earthquake-induced permanent ground deformation have been identified on the property, or if there is concern about the stability of the site, a soils specialist should be contacted to assess the damage and develop an appropriate repair and/or mitigation plan, if necessary. This assessment may involve subsurface investigation and laboratory testing to complete the necessary analysis. Appropriate repairs may address damage to soil, rock, or improvements at the site necessary to restore pre-earthquake stability, or include upgrades to meet current code standards and/or mitigate the potential for similar damage in future earthquakes.

### **3.3 Limitations**

This section of the *Guidelines* addresses only geotechnical conditions and earth retaining walls commonly associated with conventional residential woodframe development. Assessment of unusual geotechnical or geological conditions or other types of engineered retaining structures foundation systems should be conducted by a suitably qualified soils specialist.

### **3.4 Description of Geotechnical Aspects**

All buildings and other improvements rely upon the strength and stability of the underlying soil and rock for satisfactory performance. Building foundations (see Section 4 for further discussion of building foundations) distribute the weight of the building to the underlying ground (i.e., fill, soil, and/or rock). Foundations will prevent damaging levels of differential movement or settlement, if properly designed and constructed for building loads and actual site ground conditions. Movement or deformation of these underlying materials beyond the amounts assumed in design may damage the supported buildings and improvements. Unfortunately, some buildings in California, especially houses, are constructed on sites where the ground is subject to long-term movements, which can result in varying degrees of distress to improvements constructed on the site.

A common condition in hilly or mountainous areas is the terraced building pad constructed with “cut-fill” grading, where earth excavated from the higher part of the lot (the “cut”) is placed as fill on the lower part of the lot as illustrated in Figure 3.5. The location on the ground surface where the undisturbed native soil transitions to the fill material is referred to the “cut-fill line” or “cut-fill boundary.” Such sites may experience problems with long-term differential settlement as well as increased levels of damage during earthquakes because the fill soils at the site may be less dense than the native soil or rock in the cut areas. Furthermore, to create level building pads, such sites often employ earth retaining structures as discussed three paragraphs hence.

All buildings experience some amount of earth movement during their life, which is caused by a variety of long-term geotechnical processes. Long-term earth movements are discussed in Section 3.5 and include settlement, shrink/swell of expansive soils, slope creep, and landslides.

Soil and rock are also widely used as construction materials – structural fill material placed under controlled conditions to terrace hillsides, build roads, and create level building pads upon which to build houses. While most fills are quite stable, some have experienced varying degrees of poor performance over time, ranging from minor differential settlements to large-scale



landslides. In general the quality of structural fills has improved in recent decades, although many residential areas are constructed on fills of varying degrees of quality. Some areas, such as portions of San Francisco, have been constructed on landfill placed many years ago prior to the advent of modern engineering knowledge and quality control.

To accommodate abrupt changes in grade, retaining walls are constructed. Retaining walls are subject to sustained, long-term horizontal (or lateral) pressure from the soil behind the wall and short-term horizontal forces from earthquake ground shaking. The walls must be designed to resist the lateral pressures without excessive deformation or failure. In addition, retaining walls must have an adequate foundation to transfer their loads into the supporting soil beneath the wall without exceeding the strength of the foundation soil. Adequate drainage behind retaining walls helps to reduce hydrostatic pressures and increase stability of the retained soil.

## **3.5 Long-Term Sources of Earth Movement**

Both native soils and engineered fills in many areas of California are unstable to some degree, resulting in a number of long-term geotechnical processes that damage buildings and improvements, as discussed in the following subsections.

### **3.5.1 Settlement**

Settlement is downward vertical movement of the ground surface resulting from densification of soft or loose soils. Settlement may occur in soft natural ground but more commonly occurs in earth fills or as a result of inadequate compaction of the fill during construction. Damage to buildings and improvements occurs when one portion experiences greater settlement than the rest of the building or improvement, a condition referred to as *differential* settlement. This occurs when fill thickness or material properties, such as density or degree of compaction, vary across the property.

### **3.5.2 Expansive Soil Movement**

Shrinking or swelling of expansive soil occurs when the water content of the soil is reduced (drying) or increased (wetting). Certain clays are particularly sensitive to water content changes. Cycles of shrinking and swelling may occur in soil layers near the ground surface that are subjected to evaporation, transpiration, rainfall, or rising or falling groundwater table (Figure 3.1 to Figure 3.4). The water content variation can be seasonal (e.g., summer to winter) or can follow a long-term trend (e.g., from changes in landscaping and vegetation or installation of pavements that change surface drainage patterns) or can be more transient, such as from irrigation or utility line leaks. A good indication that expansive soils are present at a site is desiccation cracking (a web-like network of cracks as shown in Figure 3.6) in the soil surface during dry seasons of the year.

### **3.5.3 Slope Deformation (Creep)**

Slope deformation may sometimes occur due to soil creep – the slow down-slope movement of fill, soil, or rock, usually confined to areas along a slope face or near the top of slope (Figure 3.7). Some creep takes place in almost all steep earth and rock slopes. The rate of creep is dependent of factors such as material type, slope inclination, and water content fluctuations within the slope. Slope creep occurs within shallow soil/rock materials, and hence damage is generally confined to areas along a slope face or near the top of the slope.

### **3.5.4 Slope Instability (Landslide)**

Slope instability (i.e., landslide or rockslide) refers to the relatively rapid movement of a mass of soil or rock down a slope. Landslides can occur in natural slopes, manmade cut slopes, or manmade fill slopes. Landslides can be triggered by changes in slope geometry (i.e., excavation near slope toe), loading of the top of slope, and increased water pressure within the slope. Historically, periods of heavy rain in California have triggered numerous landslides.

### **3.5.5 Retaining Wall Deformation or Instability**

The quality of residential retaining walls ranges from modern, well-engineered walls designed for long-term performance to poor quality walls constructed without benefit of basic engineering. Those retaining walls that are not adequately designed or constructed to resist long-term lateral forces from the retained soil may tilt outward, bend, slide, or crack over time. Many retaining wall failures are due to the buildup of water pressure behind the wall due to inadequate drainage or excessive water infiltration behind the wall. Walls constructed of wood will also deteriorate over time. Significant movement of retaining walls will result in soil deformation and ground cracking behind the walls. Note that some movement should be anticipated for all retaining walls over time. However, significant movement due to earthquake or lateral earth pressures should be evaluated by a soils specialist.

## **3.6 Earthquake-Induced Permanent Ground Deformation**

For the purpose of this document, earthquake-induced permanent ground deformation is defined as any permanent ground deformation caused by earthquake ground shaking or fault rupture that results in damage to improvements.<sup>24</sup> Larger soil failures affect broad areas, damaging buildings, pavements, and buried utilities. However, the area which experiences soil failure due to an earthquake is typically a very small percentage of the entire area affected by the earthquake. While often dramatic, earthquake-induced permanent ground deformation only occurs in limited areas with specific vulnerabilities, such as loose saturated soils adjacent to bays and streams, steep terrain, or along the fault. Following are the various modes of earthquake-induced permanent ground deformation.

<sup>24</sup> The type and depth of soil underlying a site can significantly amplify bedrock motions resulting in stronger ground shaking at sites underlain by deep, soft soils relative to sites underlain by shallow, stiff soil or bedrock. This transient site response aspect of soils is outside the scope of this section but is discussed briefly in Section 2.

### 3.6.1 Surface Fault Rupture

Earthquakes result from relative displacement (i.e., slip) of blocks of rock on opposite sides of the fault surface deep within the earth's crust. Surface fault rupture occurs when these displacements reach the surface of the ground (Figure 3.8 to Figure 3.12).

If ground rupture is confined to a relatively narrow zone, then the total offset will appear as a linear feature that makes the rupture easier to identify. Any buildings, pavements, or utility lines crossing the fault will be destroyed (Figure 3.8 and Figure 3.9). Sometimes fault rupture occurs along multiple branch traces and/or movement is distributed across wider zones, hundreds of feet wide. In this case, the total offset is distributed across a larger area making it difficult to identify the exact location of ground rupture (Figure 3.12).

Faults are generally well-defined and documented; however, several recent earthquakes have occurred on faults that were not previously known or were thought to have been inactive. Maps of seismic hazard and known faults are available, either in paper form or online for some geographic regions.<sup>25</sup> Maps of the location of epicenter, causative fault, and the surface trace of the fault rupture are also available after a significant earthquake. Following major earthquakes, detailed maps of the trace of surface fault rupture are typically prepared by the USGS or state geologic surveys. As with other maps of earthquake-induced permanent ground deformation, fault trace maps take some time to assemble and will not be immediately available.

### 3.6.2 Liquefaction

Strong shaking in loose, water-saturated sandy soils can cause the soils to liquefy, a phenomenon similar to quicksand, caused by a build up of water pressure as the loose soil begins to densify. When liquefaction occurs, the strength of the soil decreases, and the water-soil mixture temporarily behaves as a liquid rather than a solid and is able to flow. If the pressurized soil-water mixture finds a conduit to the surface, it will vent to the surface and form sand deposits on the ground surface referred to as "sand boils" (Figure 3.13 to Figure 3.15). Other phenomena that are associated with liquefaction include ground settlement and cracking in level ground and lateral movement in sloping ground (flow failure and lateral spreading). The loss of strength associated with liquefaction can result in loss of bearing capacity of the soils underlying a building, which can cause the building to settle and tilt, or an increase in buoyancy of in-ground structures such as buried tanks, which can cause them to float to the surface.

Maps of potential liquefaction hazard zones are available for selected regions of California that identify the liquefaction hazard.<sup>26</sup> Site-specific data from these maps is often disclosed as part of real estate transactions in California. Following major earthquakes, maps delineating areas of documented liquefaction are typically prepared by the USGS or state geologic surveys. As with other maps of earthquake-induced permanent ground deformation, liquefaction maps take some time to assemble and will not be immediately available.

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<sup>25</sup> Fault maps of California and Nevada are available online through the USGS at <http://quake.wr.usgs.gov/info/faultmaps>. Maps of seismic hazard are available at [http://earthquake.usgs.gov/research/hazmaps/products\\_data](http://earthquake.usgs.gov/research/hazmaps/products_data).

<sup>26</sup> <http://www.conservation.ca.gov/cgs/shzp/>

### 3.6.3 Seismic Compression (Soil Densification)

While liquefaction occurs only in soil below the water table, soil above the ground water table may also sustain permanent deformation during an earthquake. Some dry soils that experiences strong shaking may decrease in volume, resulting in ground surface settlements and potential lateral movements near slopes (Figure 3.16 to Figure 3.19). This process is termed seismic compression, and is especially prevalent in loose sands but has also been observed in certain types of engineered fills. The process is similar to what happens to the loose contents of a box of cereal during the vibration of shipment, thus the label “contents may have settled during shipment.” The magnitude of seismic compression is directly related to the thickness of the susceptible material; hence, seismic compression may be more apparent in deeper fills.<sup>27</sup>

If the soils are not uniform across a certain area (i.e., some areas are fill while other areas are native or some areas have been more densely compacted than other areas), the ground surface may compress more in the areas of looser soils or thicker fills. This type of settlement imposes a differential elevation across the building (and is thus called differential settlement) which can cause significant distress to the building and can also damage or break underground utilities such as pipes.

### 3.6.4 Earthquake-Induced Slope Instability (Landslide)

Inertial forces introduced during strong earthquake shaking can cause slopes to experience downslope movement (Figure 3.20 to Figure 3.23). This movement can occur in slopes consisting of fill, soil, or rock and may range in size from a few feet across to spanning hundreds of acres. Buildings located near the moving part of the slope can be taken down with it, and those beneath the slope can be pushed aside or covered with the debris. Less dramatic movement is also possible. Depending on the level of shaking, geometry and soil conditions, the slope response can include toe bulging at the bottom of the slope, cracking near the crest and some downhill movement of mass near the crest. Homes located very close to the toe of an unstable slope can be damaged by the lateral forces imposed by the bulging mass near the toe. Near the crest, the foundation of a home can be pulled apart or distorted by cracks near the crest of the slope. Depending on many factors such as geometry, soil and rock conditions, drainage conditions, groundwater regime, if left unrepaired, it is possible that, minor earthquake-induced ground cracking on or behind a slope or minor earthquake-induced slope movement could lead to the slope being more susceptible to rain-induced landsliding.

Maps of landslide hazard zones are available for selected regions of California that identify the earthquake-induced landslide hazards.<sup>28</sup> Site-specific data from these maps is often disclosed as part of real estate transactions in California. Following major earthquakes, maps delineating documented landslide areas are typically prepared by the USGS or state geologic surveys. As with other maps of earthquake-induced permanent ground deformation, landslide maps take some time to assemble and will not be immediately available.

<sup>27</sup> Based on Northridge Earthquake experience, significant seismic compression was observed in relatively modern, well-compacted fills in the range of 100-ft thick and in older, poorly compacted fills in the range of 50-ft thick.

<sup>28</sup> <http://www.conservation.ca.gov/cgs/shzp/>

### **3.6.5 Ridge-Top Shattering**

Ridge-top shattering is a result of focusing of earthquake shaking at the crest of a slope due to local topographic effects. This effect is commonly most pronounced at the top of narrow ridges. The ground surface may resemble plowed ground or be disrupted into chunks or blocks of soil. The indications of ridge-top shattering are similar to the indications of landslides in steep terrain.

### **3.6.6 Retaining Wall Deformation or Instability**

During an earthquake, ground shaking can generate lateral forces in the soil behind retaining walls that combine with the sustained, long-term pressures on the wall, resulting in sliding, rotation, bending, or settlement of the wall and/or damage to structural elements of the wall (Figure 3.24 and Figure 3.25). In those cases where a retaining wall supports a building, movement of the wall can also cause damage in the supported building. The seismic performance of retaining walls depends on the soil properties, water drainage features, structural properties of the wall, and the level of strong shaking during the earthquake. Cantilever and gravity retaining walls may move by sliding and/or tilting (Figure 3.26). Reinforced soil slopes/walls deform in a ductile manner without formation of a distinct failure surface and may produce minor settlement of the backfill, face bulging or spalling, and minor cracking in the backfill.

## **3.7 Assessment Guidelines and Methodologies**

Earthquake-induced permanent ground deformation can range from dramatic destruction of buildings to more subtle cracking or differential settlement. While assessment of the dramatic damage is straightforward, assessment of more subtle damage is more challenging, given the similarities between the effects of earthquake-induced permanent ground deformation and long-term non-earthquake effects on buildings. The objective of this section is to provide assessment guidance sufficient to permit an individual lacking geotechnical expertise to perform geotechnical triage or sorting – to distinguish between those sites that merit further investigation by a soils specialist from those sites with no evidence of earthquake-induced permanent ground deformation. Guidelines presented below are conservative, that is, they should reliably identify sites with significant earthquake-induced permanent ground deformation with few exceptions, but the process will likely result in some “false positives” (i.e., cases where the guidance provided in this document indicates the need for further investigation by a soils specialist, but that specialist’s investigation finds no earthquake-induced permanent ground deformation at the site in question).

If all sites were pristine and stable in the absence of earthquakes, identification of earthquake-induced permanent ground deformation after an earthquake would be straightforward. In reality, many buildings in California exhibit varying degrees of distress from long-term, non-seismic ground deformation that may have gone unnoticed but appear similar to the effects of earthquake-induced permanent ground deformation.

Care must be exercised in the assessment of earthquake-induced ground deformation, as misinterpreting normal and benign shrinkage cracks in expansive soil as the head scarp of an

earthquake-induced landslide can translate into tens or hundreds of thousands of dollars of unnecessary repairs. If a property is located on level ground, care should be exercised to distinguish ground settlements and/or heave that occurred prior to the earthquake from ground settlements associated with liquefaction or seismic compression. Likewise, if a property is located on sloping ground, it is important to distinguish long-term slope instability (landslides), creep or retaining wall movements from ground deformations associated with earthquake-induced landslides or seismic compression.

### 3.7.1 Site Inspection

While the following discussion focuses on inspection of the site surrounding a building and the common indicators of earthquake-induced permanent ground deformation to be found there, observations from inspection of the building (as discussed in subsequent sections) should also be considered in the course of assessing potential earthquake-induced permanent ground deformation at the site.

An initial inspection for possible earthquake-induced permanent ground deformation should be conducted as soon as possible after a major earthquake. At this point, any potential earthquake-induced cracks in the ground and hardscape will be “fresh” and therefore readily distinguishable from cracks due to other causes that may have pre-existed the earthquake. The initial inspection should include examination of those elements most likely to exhibit damage from ground movement (Figure 3.27). These include hardscape, utility lines, swimming pools, exposed building floor slabs and foundations, and building finishes as discussed in more detail below:

1. **Hardscape (Driveway, Patios, Sidewalks, etc.):** Fresh cracks in hardscape or the significant widening of pre-existing cracks or construction joints are good indicators of earthquake-induced permanent ground deformation (Figure 3.28 to Figure 3.35). Also, fresh out-of-levelness in driveways, patios, decks, and other hardscape not consistent with the normal construction practices (e.g., patios adjacent to buildings are usually sloped away from the building for drainage) (Figure 3.36) or evidence of movement of exterior improvements relative to the building (Figure 3.37 through Figure 3.39) are indicators of possible earthquake-induced permanent ground deformation. Features such as paint or debris within cracks, previous patching of cracks, and previous releveling of wood decks are indicators of a pre-existing condition, possibly associated with non-earthquake geotechnical processes (e.g., consolidation or slope creep, Figure 3.40 and Figure 3.41). See Section 4.7.2 for guidance on determining whether a fracture is recent.
2. **Utility Lines:** Damage to underground utility lines on the property, such as water service lines, sanitary sewer lines, and gas lines, are indicators of possible earthquake-induced permanent ground deformation (Figure 3.10, Figure 3.42, and Figure 3.43).<sup>29</sup> The condition of these lines, and serviceability of the lines (i.e., recent clogging of sewer lines) relative to their

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<sup>29</sup> Although uncommon, underground utilities can also be damaged by transient earthquake ground movements, without any accompanying permanent ground deformations.

condition prior to the earthquake are also important, and can be indicative of earthquake-induced damage.

3. **Swimming Pool:** Swimming pools can be an effective means by which to assess recent changes in the levelness of at-grade improvements. Typically, swimming pool waterline tile are installed reasonably level (good workmanship is  $\pm 1/4$  inch for waterline tile)<sup>30</sup> and significant deviations from level may be indications of earth movement, earthquake-induced or otherwise (Figure 3.44). Chemical residues, if present on the waterline tile, can indicate the pre-earthquake water surface location. The degree to which these residues form a non-level surface may indicate whether swimming pool movement occurred prior to or as a result of the earthquake. Fresh-appearing out-of-levelness of the pool coping not consistent with construction tolerances and fresh-appearing cracking of the pool shell are indicators of possible earthquake-induced permanent ground deformation.
4. **Foundations:** Typical residential foundation types are discussed in Section 4. Indicators of earthquake-induced permanent ground deformation related to foundation performance include the following:
  - a. fresh cracking or the significant widening of pre-existing cracks in concrete stem walls or footings (Figure 3.45 to Figure 3.48),
  - b. soil deformations adjacent to foundations (e.g., bulging or tension cracks), and
  - c. out-of-levelness consistent with conspicuous earthquake damage to adjacent wall finishes (Figure 3.34, Figure 3.49 to Figure 3.52). The presence of patched cracks, debris within cracks, and evidence of previous releveling (Figure 3.53) are indicators of long-term, re-occurring ground movement unrelated to earthquake shaking. Careful attention to detail is necessary to distinguish the effects of long-term foundation movement from movement associated with earthquake-induced permanent ground deformation.

It should be noted that Indicators a and c (i.e., some cracking and unlevelness of floors) are present in virtually every foundation. Accordingly, care must be exercised to distinguish possible earthquake-induced permanent ground deformation damage from pre-earthquake conditions. In some cases, the distinction may not be clear, particularly if reconnaissance is performed many months or years following the earthquake.

5. **Building Finish:** Finish elements that should be inspected and documented include wall finishes (as discussed in Section 5) and masonry block walls or fences – elements that tend to be vulnerable to shaking-induced damage. Hence, the presence of damage to such elements is not necessarily indicative

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<sup>30</sup> Workmanship Guidelines and Practices for Residential In Ground Swimming Pools and Spas, 2004 Edition, National Spa and Pool Institute, Alexandria, VA.

of earthquake-induced permanent ground deformation. To assess the possible contribution of earthquake-induced permanent ground deformation to damage in these elements, a pattern of cracking such as vertical cracks coincident with ground cracks, or parallel diagonal cracks (often referred to as *en echelon* cracks) consistent with settlement should be present that is consistent with an earthquake-induced ground deformation mode (Figure 3.34, Figure 3.45, Figure 3.46, and Figure 3.49 to Figure 3.51).

In addition to a thorough inspection of an individual property, for some geotechnical conditions, it is also helpful to examine the neighboring areas for similar indications of earthquake-induced permanent ground deformation. Typically, this inspection can be performed by walking the area within several blocks of the property. Indicators of earthquake-induced permanent ground deformation that are identified in the area surrounding the site can provide insight into the types of earth movement that may have affected the property of interest. Such indicators include:

- Offsets or patterns of cracking in sidewalks, curbs, street pavements, and other similar features (Figure 3.28 through Figure 3.30 and Figure 3.31 through Figure 3.33).
- Surface fault rupture (Figure 3.8 to Figure 3.12).
- Sand boils from liquefaction (Figure 3.13 to Figure 3.15).
- Slope deformation or instability (Figure 3.20, Figure 3.21, and Figure 3.23).
- Seismic compression of deep fills – distress should follow the cut/fill line and occur predominantly in fill.
- Ridge-top shattering.
- Indications of damage to underground utility lines (Figure 3.10, Figure 3.42, and Figure 3.43).

### **3.7.2 Technical Consultant Assistance**

If the initial inspection reveals any of the following indications of earthquake-induced permanent ground deformation, a soils specialist should be retained to perform a further inspection:

- Indication of slope deformation or failure, liquefaction, fault rupture, differential settlement or other earthquake-induced permanent ground deformation described above.
- Any fresh-appearing cracks in the ground surface, hardscape, or swimming pool shell or any separations of construction joints wider than 1/4 inch.
- Any fresh-appearing out-of-levelness in exterior improvements, such as patios, pool decks, or pool coping.



- Any fresh-appearing cracks in concrete foundation elements wider than 1/8 inch or offset by more than 1/16 inch out-of-plane (the thickness of a nickel).
- Rotation, sliding, structural damage, or collapse of retaining walls.
- Damage to underground utilities on the property, such as water lines, sanitary sewer lines, and gas lines.

The initial scope of services from the soils specialist should consist of review of publicly available documents regarding site geology and earthquake effects as well as detailed visual inspection and documentation (site reconnaissance) of the property and surrounding areas. If earthquake effects cannot be reasonably confirmed or eliminated by the soils specialist based on their research and observations, further investigation such as test pits, soil borings, laboratory testing of soil samples, and video inspection or testing of buried utility lines may be required.

The assistance of a soils specialist may also be necessary if the passage of time has obscured potential surface manifestations earthquake-induced permanent ground deformation.

Section 3.2 of CUREE Publication No. EDA-06 provides more detailed guidance regarding the scope of soils specialist investigations.

### **3.8 Repair Methodologies**

If their assessment of site conditions confirms the existence of earthquake-induced permanent ground deformation, the soils specialist can provide recommendations for dealing with that deformation. Recommendations for a particular site are entirely dependent upon the nature and extent of the earthquake-induced permanent ground deformation.

In many cases of earthquake-induced permanent ground deformation the ground surface will be slightly distorted from its original condition, but the stability and capacity of the soil to support the building are unaffected. Thus, there is no damage in the soil to repair. However, there may be damage to improvements that requires repair, as discussed in other sections of these *Guidelines*.

Where the soil has been destabilized by the earthquake, such as a landslide, repairs will typically involve either stabilization of the landslide or construction of a retaining structure to support the ground beneath the building. For severe damage, such as a large landslide or surface fault rupture, an engineered repair is possible but abandonment of the site may be the only practical or legal alternative, given applicable building and zoning regulations.

Developing recommendations to stabilize the ground or address severe ground failure will typically require a clear understanding of subsurface soil conditions. Developing this understanding may include subsurface exploration (borings or test pits) and laboratory testing to assist the soils specialist in estimating the necessary material parameters to perform the required analyses, including an analysis of the potential for future earthquake-induced permanent ground deformation.

Section 3 of CUREE Publication No. EDA-06 provides more detailed guidance regarding repair alternatives and guidance regarding subsurface investigations.

### **3.8.1 Permits, Upgrades, and Retrofits**

Depending upon the nature and scope of damage and proposed repair, building permits and other government agency approvals may be required by the local jurisdiction. In addition to normal changes in the building code over time, some jurisdictions have building code requirements that mandate upgrading portions or all of the building, if certain damage thresholds are exceeded. In addition, in areas of ground surface fault rupture or severe earthquake-induced permanent ground deformation, local or state regulations may impose significant restrictions or requirements on repair or reconstruction. Therefore, it is important to check with the local building department to determine the existence of any applicable requirements.

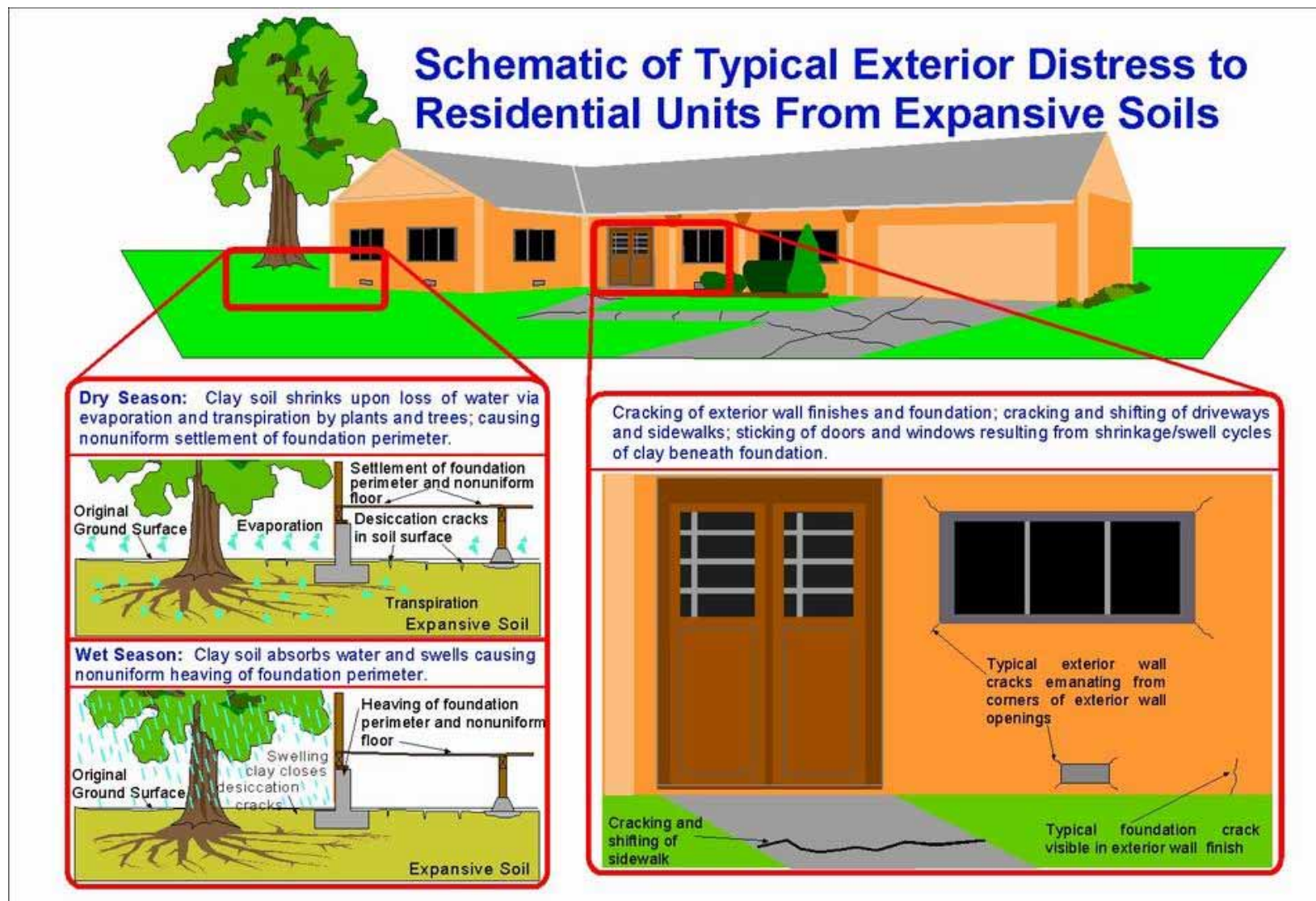


Figure 3.1. Schematic of typical long-term, non-earthquake distress caused by expansive soil to the exterior of a residential building with a perimeter concrete foundation [Exponent].

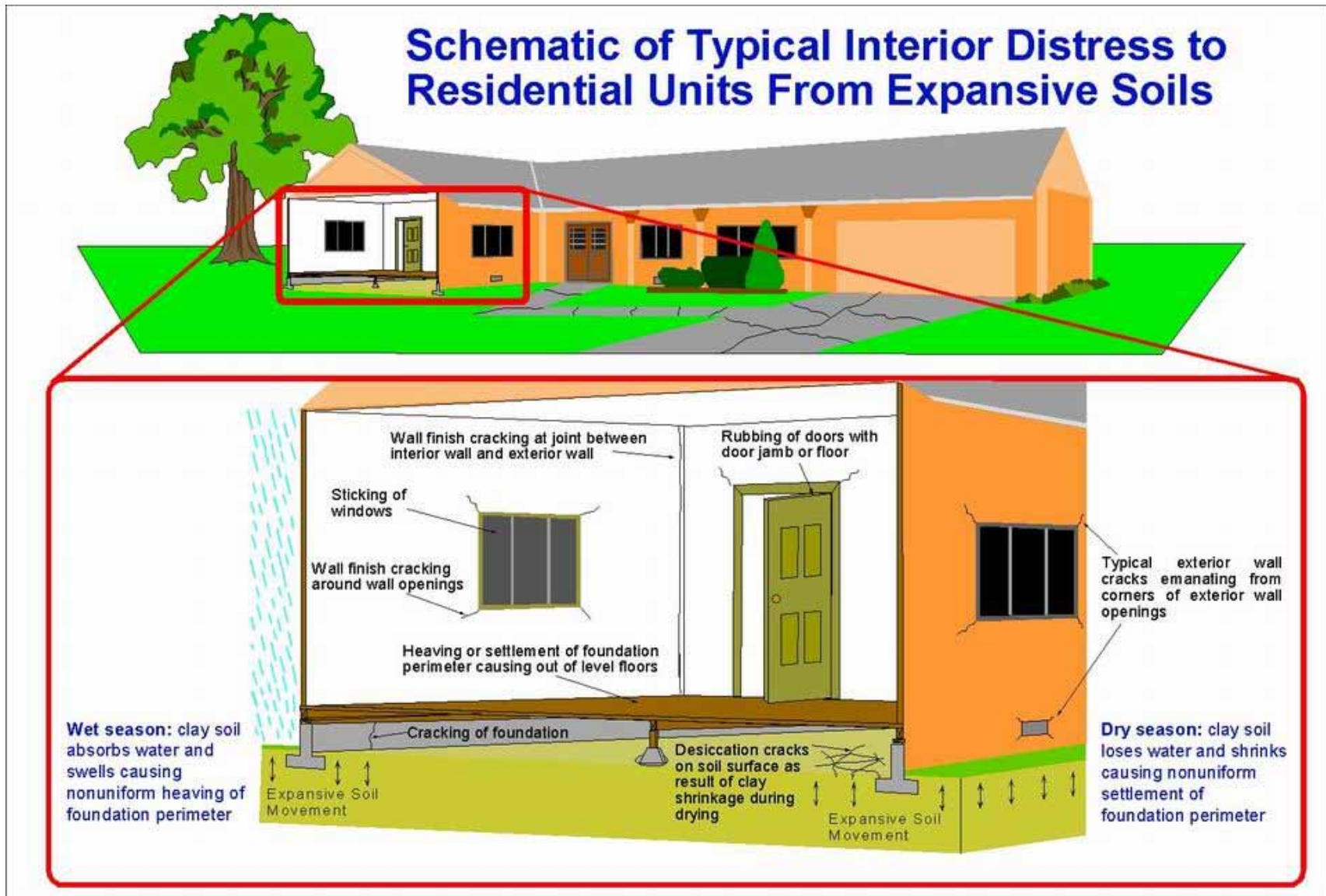


Figure 3.2. Schematic of typical long-term, non-earthquake distress caused by expansive soil to the interior of a residential building with a perimeter concrete foundation [Exponent].



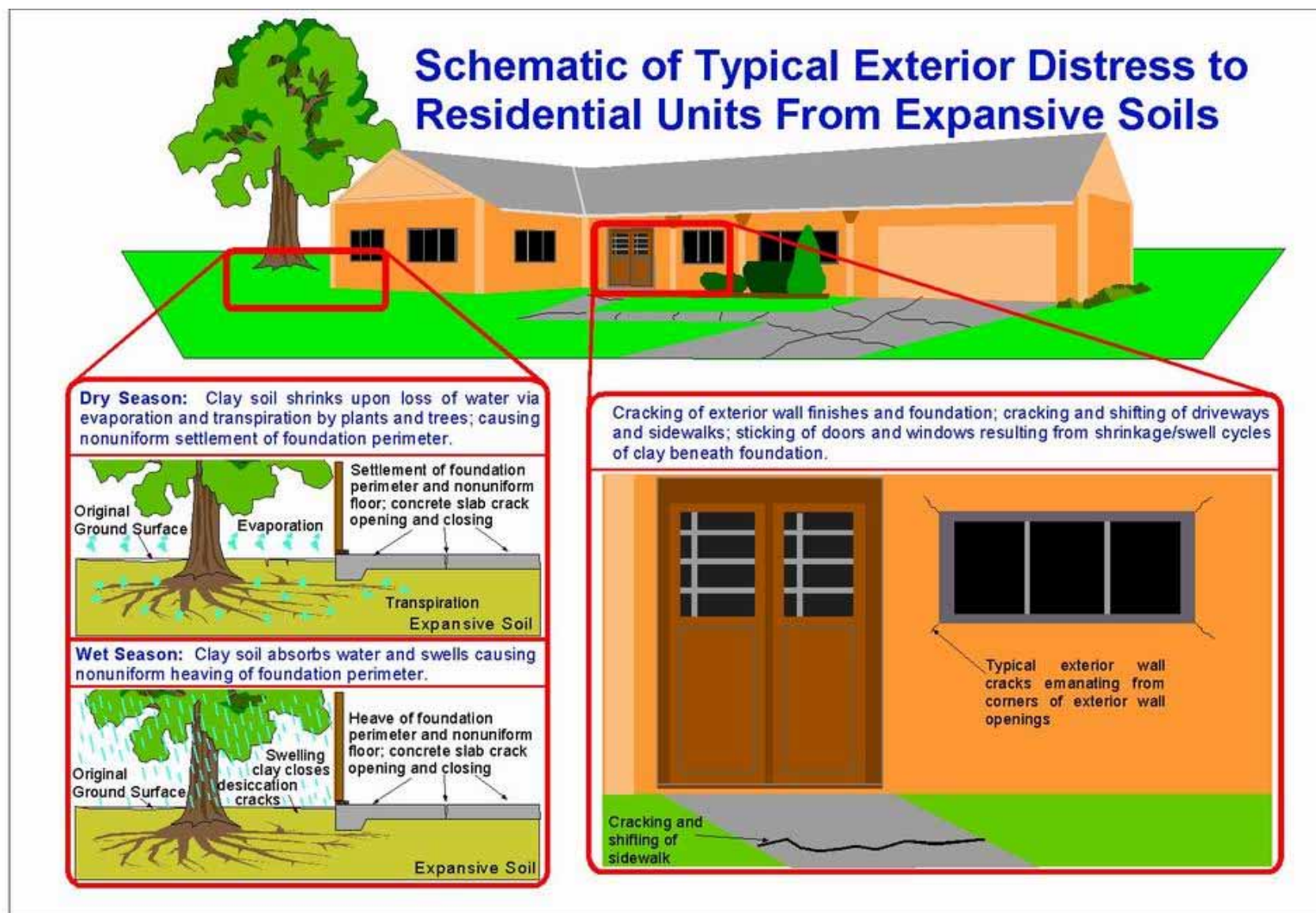


Figure 3.3. Schematic of typical long-term, non-earthquake distress caused by expansive soil to the exterior of a residential building with perimeter footings and slab-on-grade floor [Exponent].

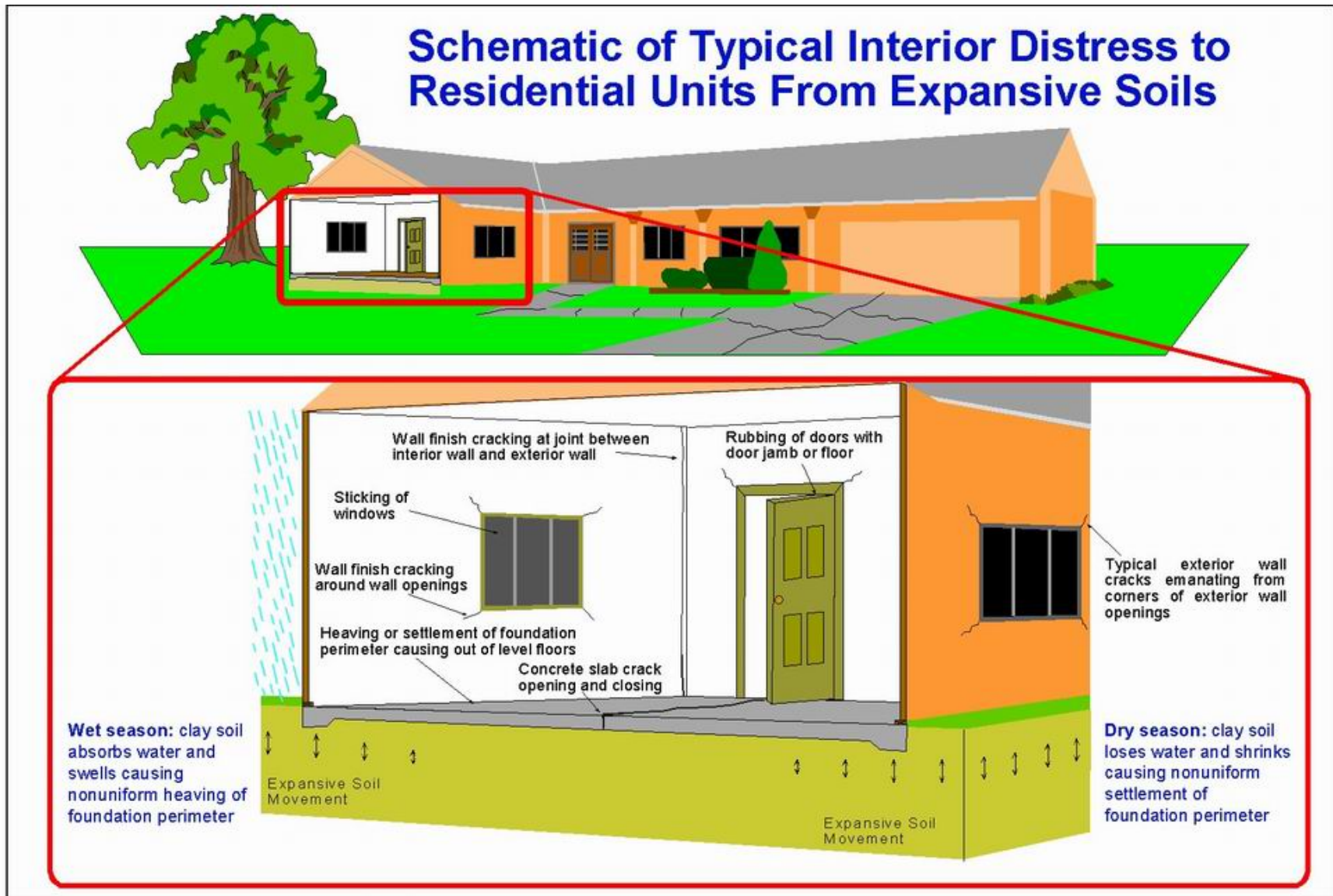


Figure 3.4. Schematic of typical long-term, non-earthquake distress caused by expansive soil to the interior of a residential building with perimeter footings and slab-on-grade floor [Exponent].



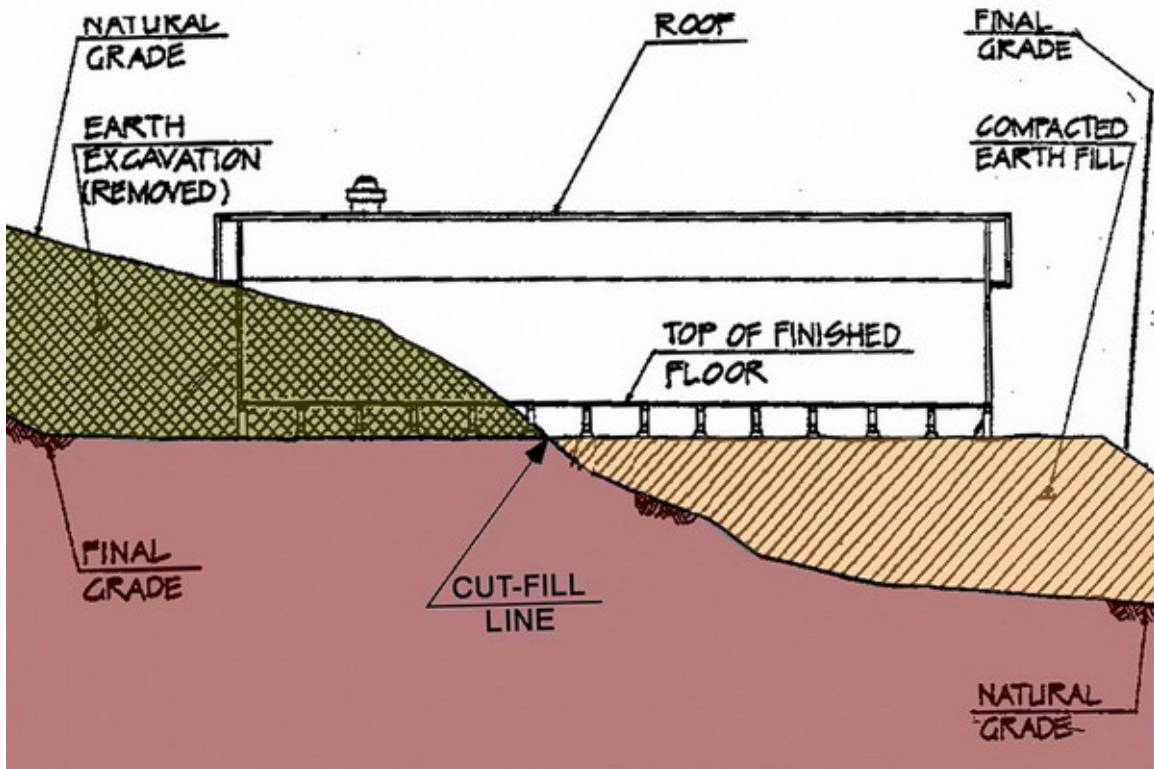


Figure 3.5. Schematic cross-section of a cut-fill building pad [Exponent].



Figure 3.6. Desiccation cracking of expansive soil within a crawlspace, a long-term, non-earthquake condition [Exponent].

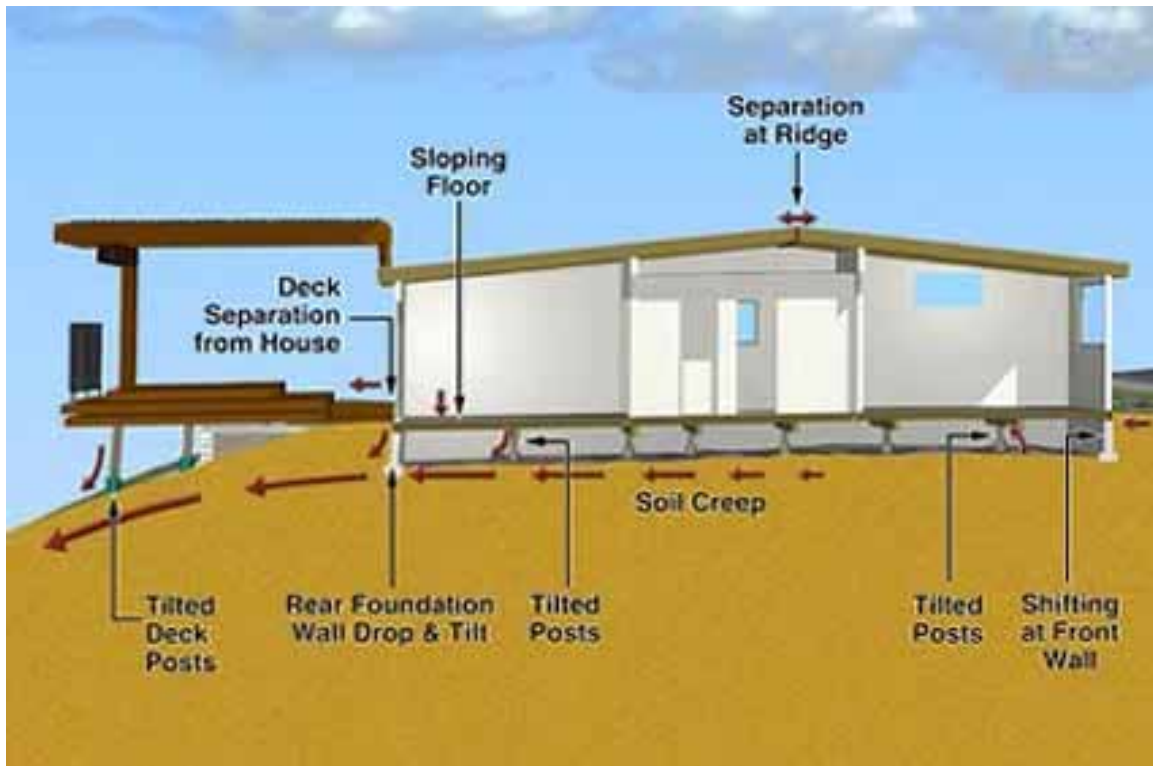


Figure 3.7. Schematic of damage to residence resulting from long-term, non-earthquake soil creep [Exponent].



Figure 3.8. Surface fault rupture from the 1971 San Fernando Earthquake and associated damage to pavement and buildings in the Sylmar area [NISEE].





Figure 3.9. House damaged by surface fault rupture from the 1971 San Fernando Earthquake [ATC, Castle].



Figure 3.10. Waterline break along fault rupture from the 1972 Managua, Nicaragua Earthquake [NISEE].



Figure 3.11. Surface faulting midway between El Centro and Holtville from the 1940 El Centro, California Earthquake [NISEE].



Figure 3.12. Sidewalk displaced by distributed faulting from the 1972 Managua, Nicaragua Earthquake [NISEE].





Figure 3.13. Sand boil due to liquefaction of old, poorly compacted, water-saturated fill during the 1989 Loma Prieta Earthquake [NISEE].



Figure 3.14. Tennis court damage with ejection of wet sand from soil liquefaction (site is adjacent to a river) during the 1989 Loma Prieta Earthquake [NISEE].



Figure 3.15. Sand boils at Kawaihae Harbor from the 2006 Hawaii Earthquakes [UHM].

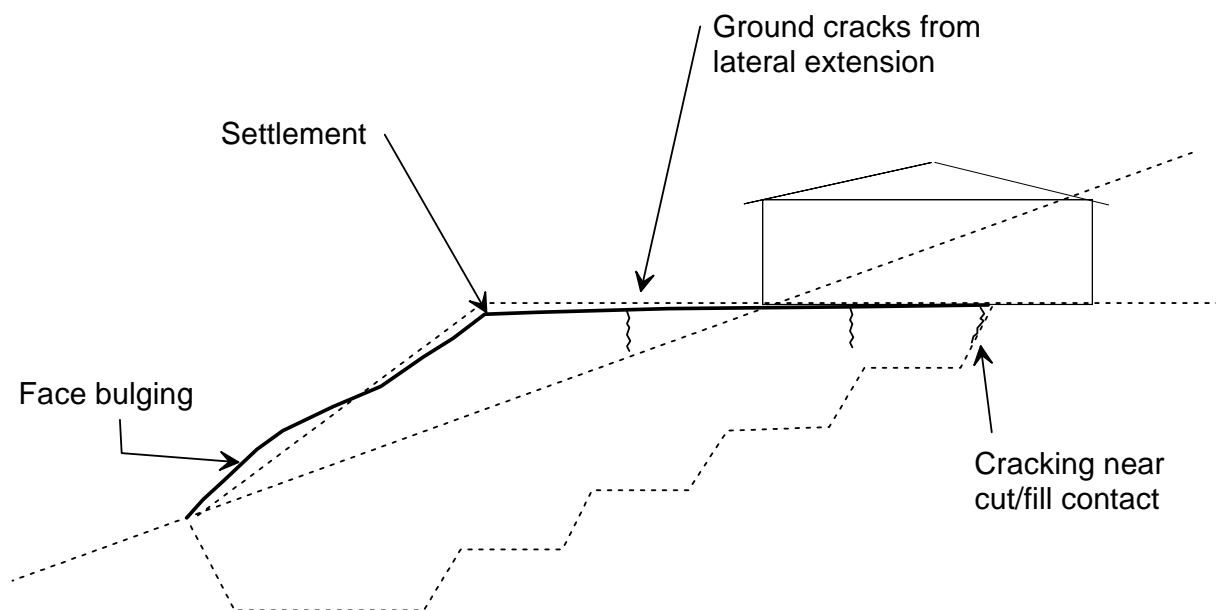


Figure 3.16. Schematic showing possible earthquake damage to a fill slope [Stewart].





Figure 3.17. Building damaged by movements in hillside fill during the 1994 Northridge Earthquake; damage to the residence is shown in Figure 3.18 [NISEE].



Figure 3.18. Evidence of lateral ground movement, near back of building shown in Figure 3.17 [NISEE].



Figure 3.19. Minor settlement caused by densification of loose sandy fill at Embarcadero, Pier 1 in San Francisco during the 1989 Loma Prieta Earthquake; the building is pile-supported [NISEE].



Figure 3.20. House displaced by large blocks of soil uplifted at toe of L Street landslide, Anchorage district, during the 1964 Anchorage, Alaska Earthquake [USGS].



Figure 3.21. Rockfalls from the 1971 San Fernando Earthquake [NISEE].





Figure 3.22. Rockfall from 2003 San Simeon Earthquake (top); similar rockfall occurred downslope and impacted house; impact marks on slope and house indicated by arrows (bottom) [Exponent].





Figure 3.23. Rockfall on a road cut at northern end of North Kohala from 2006 Hawaii Earthquakes [UHM].



Figure 3.24. Retaining wall damage during the 2003 San Simeon Earthquake; granular backfill spilling from new crack in retaining wall [Exponent].



Figure 3.25. Collapse of un-mortared and unreinforced stone retaining wall in Honokaa, Hawaii during the 2006 Hawaii Earthquakes [UHM].

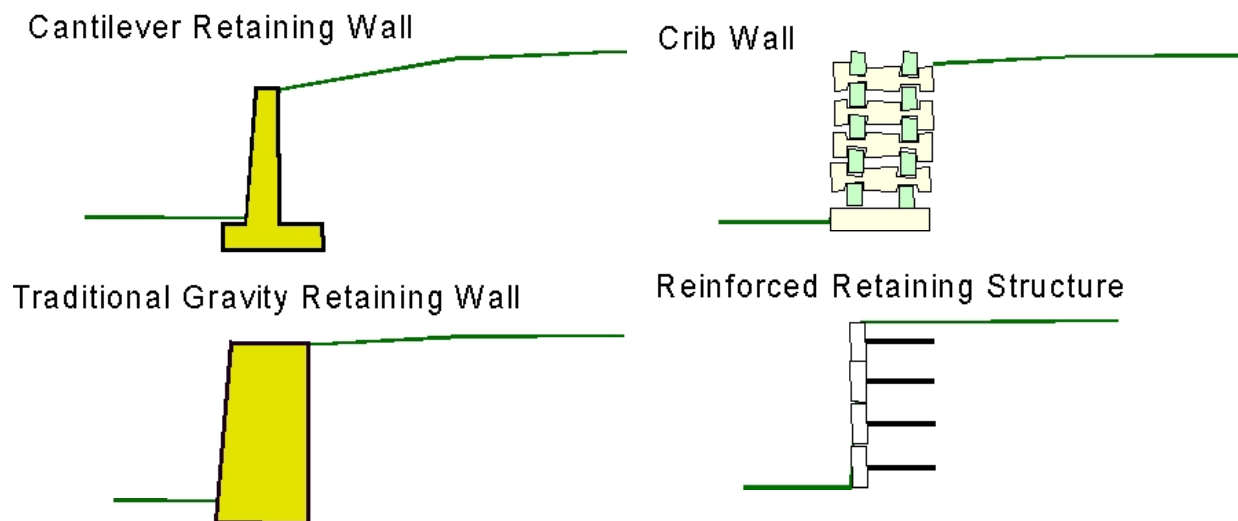


Figure 3.26. Examples of different types of retaining walls utilized in residential construction [Exponent].

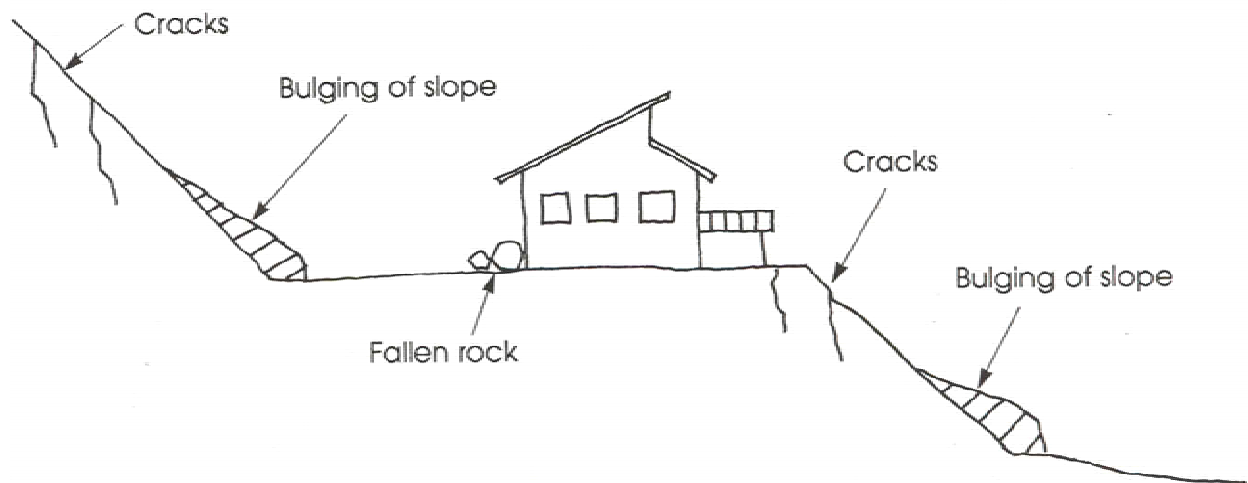


Figure 3.27. Schematic illustration of evidence of possible seismically-induced ground failure [ATC].



Figure 3.28. Asphalt pavement cracking along SR 46 as a result of a deep rotational slope failure in fill during the 2003 San Simeon Earthquake [EERI].





Figure 3.29. Street and house damaged by several inches of landslide displacement during the 1971 San Fernando Earthquake; displacement is readily visible as street crack in photograph [ATC, Youd].



Figure 3.30. Pavement patching and damage to adjacent sidewalk in City of San Fernando following the 1971 San Fernando Earthquake [NISEE].



Figure 3.31. Offset sidewalk from the 1971 San Fernando Earthquake [NISEE].



Figure 3.32. Damaged street, gutter, and curb from the 1971 San Fernando Earthquake [NISEE].





Figure 3.33. Buckling of driveway reportedly due to liquefaction during the 1989 Loma Prieta Earthquake [NISEE].



Figure 3.34. Projection of liquefaction-induced ground cracking through a building in the city of Chimbote during the 1970 Peru Earthquake [NISEE].



Figure 3.35. Driveway cracking following the 2003 San Simeon Earthquake; arrows indicate pavement cracking (top and bottom left), ground cracking (bottom), and offset in curb (bottom right) [Exponent].





Figure 3.36. Driveway cracking and differential settlement following the 1989 Loma Prieta Earthquake [NISEE].



Figure 3.37. A 2-inch separation opened at the construction joint between the garage slab and driveway slab following the 1957 Daly City Earthquake [NISEE].





Figure 3.38. Concrete porch and steps offset from original position by earthquake-induced permanent ground deformation as evidenced by exposed foundation concrete [Exponent].



Figure 3.39. Dropping of entry walkway supported on poorly compacted backfill during the Northridge Earthquake [Exponent].

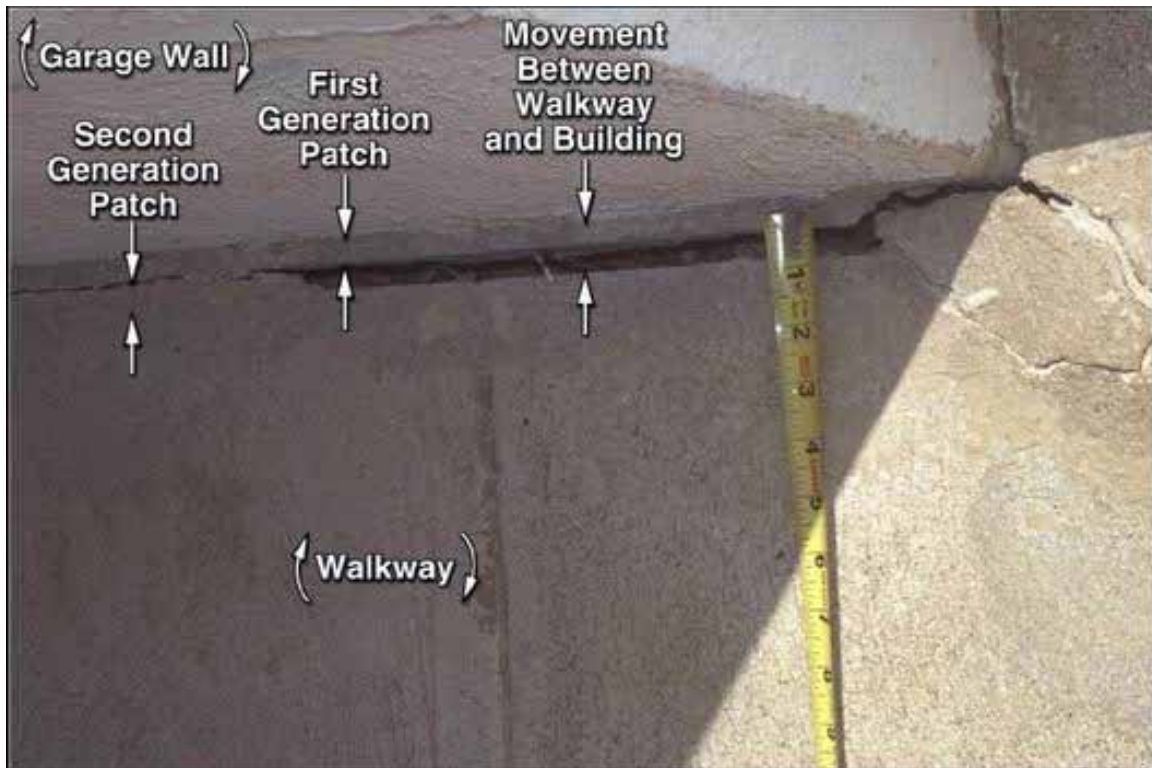


Figure 3.40. Different vintages of grout between a sidewalk and residence near a top of slope indicate a history of lateral movement as a result of slope creep rather than earthquake damage [Exponent].



Figure 3.41. Grout within driveway slab-on-grade crack indicates long-term problem with expansive soil beneath driveway rather than earthquake damage [Exponent].





Figure 3.42. Utility pipe ruptured by lateral spreading on Balboa Boulevard from the 1994 Northridge Earthquake [NISEE].



Figure 3.43. Pipe failures and resulting pavement distress and settlement from the 1971 San Fernando Earthquake [NISEE].

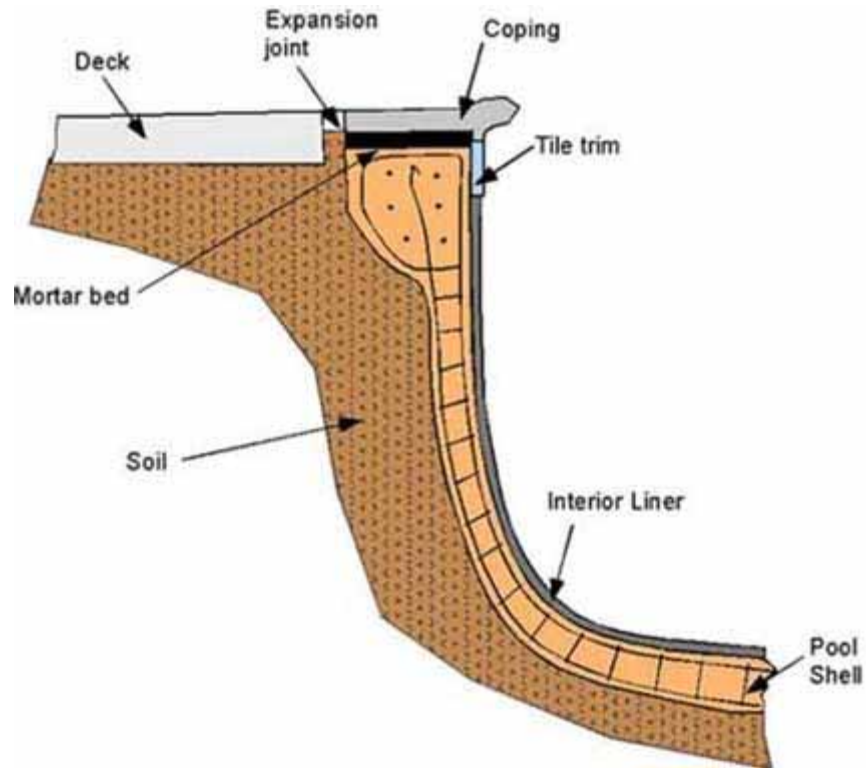


Figure 3.44. Schematic cross-section of typical in-ground swimming pool [Exponent].



Figure 3.45. Damage from lateral spreading to house foundation in Wakami, Japan during the 1983 Nihonkai-Chubu Earthquake [NISEE].





Figure 3.46. Foundation slab and wall of this house in the Balboa Boulevard area was damaged by small settlement and ground cracking that is evident in the lawn (arrow) during the 1994 Northridge Earthquake [USGS].



Figure 3.47. Foundation and ground cracking following the 2003 San Simeon Earthquake; bottom shows the out-of-plane offset present across foundation crack shown in top photograph [Exponent].



Figure 3.48. Foundation and ground cracking following the 2003 San Simeon Earthquake [Exponent].



Figure 3.49. One-story masonry house in a main housing development in the town of Caucete, damaged due to differential settlement caused by liquefaction during the 1977 Caucete, San Juan, Argentina Earthquake; damage to the interior slab is shown in Figure 3.50 [NISEE].





Figure 3.50. Damaged concrete slab-on-grade floor of the house shown in Figure 3.49; sandy mud ejected by liquefaction covers part of the floor [NISEE].



Figure 3.51. Damage to a residence in Oceano, California from lateral spreading following the 2003 San Simeon Earthquake [USGS].





Figure 3.52. Damage to a slab-on-grade from liquefaction at Los Angeles County Juvenile Hall, Sylmar, California during the 1971 San Fernando Earthquake [Meehan].



Figure 3.53. Releveling of foundation indicates prior settlement and possibly on-going deformation mode rather than earthquake damage [Exponent].



## **4 Foundations and Slabs-On-Grade**

### **4.1 Quick Guide**

#### **4.1.1 What to Look For**

- Signs of fresh cracking in, or displacement of, concrete foundations and floor slabs (see Section 4.7.2 for guidance on determining whether a fracture is recent).
- Signs of recent sloping, sagging, settlement, or displacement of floors, patios, decks, etc.

#### **4.1.2 Where to Look**

- The exposed surfaces of concrete footings or stem walls, to the extent that they are visible from outside the house or from inside an attached garage.
- The edge of the concrete floor slab, to the extent that it is visible from outside the house or from inside an attached garage.
- Exposed floor slabs, such as in closets, utility rooms, or attached garages.
- Slab-on-grade floors finished with brittle materials (ceramic tile, slate, marble, brick pavers).
- Slab-on-grade floors finished with semi-brittle materials (sheet vinyl, vinyl floor tile, adhered wood flooring).

#### **4.1.3 When to Call a Technical Consultant**

If any of the following damage patterns are observed, a structures specialist<sup>31</sup> should be retained to perform a further foundation inspection:

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<sup>31</sup> In California, structures specialists include Licensed Civil Engineers specializing in structural engineering, Licensed Structural Engineers (Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Structural Engineer), and Licensed Architects with expertise in structures. See Section 9.3 for additional discussion.

- Extensive or large cracks (with signs of recent movement) in the foundation far in excess of what would be expected from normal shrinkage and settlement (see Section 4.5).
- Any fresh-appearing crack in footings, foundation stem walls, or exposed floor slabs wider than 1/8 inch or offset by more than 1/16 inch out-of-plane (the thickness of a nickel) that had not been noticed before the earthquake.
- Any fresh-appearing spalling in footings, foundation stem walls, or exposed floor slabs that had not been noticed before the earthquake.
- Perceptible<sup>32</sup> slope in a floor or slab-on-grade (other than intentional slopes for drainage) that had not been noticed before the earthquake.
- Any sign of lateral or vertical displacement of the foundation, including fresh smooth planar soil surfaces adjacent to a slab or footing and fresh separation greater than 1/8 inch between the slab or footing and the adjacent ground (not to be confused with gaps created by shrinkage of expansive soil).

If the building was constructed prior to 1980 and repair work will involve disturbance of certain types of floor finishes that may contain asbestos or lead-based paint, a suitably qualified and licensed environmental consultant should be retained to test for the presence of regulated hazardous materials and, if necessary, recommend appropriate abatement and waste disposal measures. See Section 9.2.4 for additional information.

#### **4.1.4 Repair Guidelines**

Structurally insignificant earthquake damage can be addressed as described in Section 4.8 and as shown in Table 4-1.

## **4.2 Summary**

Foundations are those elements between the soil and the woodframing that support the weight of the house. Most residential buildings in California are built on shallow foundations that extend less than about two feet into the near-surface soils. Shallow foundations are typically used either in conjunction with slab-on-grade floors, or to support timber floor framing over a crawlspace.<sup>33</sup>

Concrete slabs-on-grade<sup>34</sup> are used in virtually all residential construction for walkways, patios, driveways, garage floors, basement floors, rat slabs in crawlspaces, and, in milder climates, they

<sup>32</sup> Generally, floor slopes shallower than about one inch in twenty feet are not perceptible. Greater slopes (i.e., steeper than about 1/8 inch in two feet) can be discerned by careful observation.

<sup>33</sup> Buildings with crawlspaces can be identified from the exterior by the presence of screened or louvered vents on the building exterior below the elevation of the first floor.

<sup>34</sup> Slabs-on-grade are concrete slabs that are cast directly on the ground and are supported by the underlying soil, as opposed to elevated structural slabs such as those used for floors in multistory parking garages and office buildings. Some building codes and references use the term slab-on-ground, which is generally considered to be synonymous with the term slab-on-grade.

are often used for the at-grade floor of the house. With the exception of certain post-tensioned slabs, slabs-on-grade are not considered part of the building foundation. Even though concrete is often used as a structural material, the purpose of a house slab-on-grade is generally not to carry structural loads but to provide a durable barrier between the soil and the inhabited space and a serviceable subfloor surface.<sup>35</sup>

Concrete shrinks slightly as it cures, and virtually all concrete develops cracks ranging in width from imperceptible hairlines to significant and visible cracks of 1/8 inch or more. Shrinkage cracking of concrete members is a normal and expected condition. In addition, settlement, heave, and/or creep of the supporting soils can cause shrinkage cracks to widen and additional cracks to form over time. These causes are independent of, and occur in the absence of, earthquakes.

Post-earthquake damage assessments must distinguish between pre-existing cracking and cracking caused by the earthquake. In addition, for earthquake-induced damage, distinction should be made between that resulting from permanent ground deformation and other possible mechanisms. Even in severe ground shaking, the stresses from shaking induced in residential foundations and slabs-on-grade are typically small compared to the concrete strength or the causes described above. Consequently, most earthquake-related damage to foundations and slabs-on-grade is a result of permanent earthquake-induced ground deformation and/or the effects of earthquake shaking on elements that had been undermined or otherwise weakened by prior earth movement. There is some evidence that slabs-on-grade that span cut and fill transitions on a hillside site may be particularly susceptible to shaking-induced cracking, even in the absence of differential permanent ground displacement. Otherwise, there is scant field evidence of shaking-induced cracking of concrete foundations and slabs-on-grade in the absence of permanent ground deformation. However, in areas of intense ground shaking, relative transient movement across cold joints,<sup>36</sup> control joints,<sup>37</sup> or pre-existing cracks has been documented, resulting in damage to brittle finishes spanning those joints or cracks.<sup>38</sup> Previously unnoticed cracks are often “discovered” after major earthquakes due to a heightened awareness and careful inspection specifically for cracks.

Post-earthquake inspection of residential concrete foundations and slabs-on-grade consists of visual inspection of exposed concrete surfaces, including the exposed foundation/floor slab at the building perimeter and any brittle or semi-brittle floor surfaces applied directly to a slab-on-grade. Because ordinary cracks in residential concrete are extremely common, attention to detail is necessary to distinguish between pre-existing cracks and earthquake-induced cracks. Key indicators of earthquake-induced cracking are the freshness of the crack surfaces, associated settlement, and a consistent pattern of cracking in adjacent finishes. When apparently fresh

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<sup>35</sup> In some circumstances, slabs-on-grade may serve a secondary structural purpose such as restraining the tops or bottoms of retaining walls.

<sup>36</sup> Cold joints are the intersections between two vintages of concrete, where fresh concrete was cast against hardened concrete without preparation of the existing concrete surface, resulting in little or no bond across the interface. See Figure 4.7 for example.

<sup>37</sup> Control joints are tooled grooves, saw-cuts, or inserts cast into the slab to create predefined planes of weakness that force straight cracks to form in prescribed locations, rather than the relatively random, jagged pattern that would form otherwise. The grooves extending across a sidewalk at regular intervals is an example of control joints.

<sup>38</sup> Research to quantify transient ground surface strains is underway with results due to be published mid-2010.

cracks are found, it is necessary to determine whether the cracking is minor and repairable with standard methods (as outlined in Section 4.8) or whether the cracking indicates possible structural damage that requires evaluation by a structures specialist. In general, apparently fresh cracks wider than 1/8 inch or offset by more than 1/16 inch out-of-plane<sup>39</sup> merit a more detailed investigation by a structures specialist.

Cracks in residential concrete foundations and slabs-on-grade are commonplace. Other than as an indicator of possible permanent ground deformation (either long-term or earthquake-induced), cracks in residential concrete are generally not a structural safety concern. Accordingly, repair generally consists of repair or replacement of brittle finishes spanning the crack after the crack in the concrete is sealed against potential moisture intrusion or insect pest entry, or left as-is. Structural repair of foundations and slab-on-grade cracking is generally not required to restore or maintain pre-earthquake capacity or function. Where structural repair of earthquake-induced cracking is required, epoxy injection with proper procedures, quality control, and quality assurance is an effective method of repair. Instances of more severe damage necessitate evaluation by a structures specialist and possibly the use of other repair techniques.

### 4.3 Limitations

These *Guidelines* address only conventional, cast-in-place concrete foundations, although aspects of the discussion may be applicable to other foundation systems. Damage to other types of foundation systems, such as concrete block, brick, or stone should be assessed by a structures specialist.

### 4.4 Description of Residential Concrete Foundation Types

Foundations are those elements between the soil and the woodframing that support the weight of the house. The vast majority of house foundations are constructed of concrete, although treated wood foundations (treated poles and All Weather Wood Foundation) are also occasionally used for new construction. Historically, foundations have also been constructed of redwood, adobe, brick masonry, concrete block masonry, and stone rubble.

The following types of concrete foundation elements, used in various combinations, are found in typical California houses:

- Thickened slab edges around the perimeter of concrete slab-on-grade floors (Figure 4.1).
- Continuous strip footings around the perimeter of a slab-on-grade (Figure 4.2 and Figure 4.8).

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<sup>39</sup> “Out-of-plane offset” means that the original surface is offset across the crack – in a slab for example, the surface on one side of the crack would be higher than the surface on the other side of the crack as shown in Figure 4.20.

- Continuous strip footings under woodframe stud walls (cripple walls) that support the first floor framing over a crawlspace (Figure 4.3).
- Continuous stem walls from the soil to the underside of the first floor framing over a crawlspace (Figure 4.4).
- Isolated pads or pedestals (sometimes pre-cast) supporting wood posts that support the first floor framing over a crawlspace (Figure 4.5).
- Drilled piers-and-grade beams supporting wood floor framing over a crawlspace (this type of foundation is often visually indistinguishable from a stem wall foundation, although structurally it functions much differently) (Figure 4.6).
- Post-tensioned slabs-on-grade are an engineered variant of a slab with thickened edges. Steel cables embedded in the concrete are highly tensioned to strengthen the slab and minimize cracking. A post-tensioned slab is not easily distinguished from a conventional slab-on-grade.

With the exceptions of the pier-and-grade-beam foundation and post-tensioned slabs, concrete foundation elements have historically had very little, if any, steel reinforcing. In recent years, modest reinforcing of residential foundations has become more common in California.

Concrete residential foundations serve several functions, both structural and nonstructural. Structurally, foundations distribute the superstructure loads to the underlying soil. Nonstructural functions include providing a durable link between the ground and timber framing, and providing a barrier against water and pest infiltration. Slab-on-grade floors provide a hard, flat, and durable floor surface.

Shallow foundations are dependent upon the strength, stiffness, and long-term stability of the underlying soils for satisfactory performance. Shallow foundations transfer and distribute superstructure loads to the soil to prevent settlement of the building into the soil, just as snowshoes allow a person to walk on top of the snow by distributing the person's weight over a sufficiently wide area.

## **4.5 Non-Earthquake Sources of Residential Foundation Cracking and Damage**

The hardness, durability, and high compressive strength of concrete make it a nearly ideal foundation, floor slab, and pavement construction material, while its fundamental shortcomings of low tensile strength and shrinkage during curing and drying lead to cracking. Thus, virtually all concrete members have cracks of one sort or another. The causes of cracking in residential concrete slabs-on-grade and foundations are numerous, but the most common are restrained shrinkage and thermal movements, and long-term differential movement of the supporting soil.

Foundations and slabs-on-grade are particularly susceptible to cracking due to shrinkage. Exposure to the sun and wind during curing will accelerate drying shrinkage of slabs-on-grade.

Common methods of controlling concrete shrinkage, or disguising its consequences, are typically not used in the construction of residential foundations and interior slabs-on-grade. The most common method of concealing the visible effects of shrinkage and thermal cracking is to provide control joints. Control joints are ubiquitous in exterior slabs-on-grade (sidewalks, driveways, patios, etc.), although often ineffective because they are too shallow or too widely spaced. Control joints have not been widely used in residential foundations or interior slab-on-grade floors; however, because of the desire for a smooth surface for floor coverings and because shrinkage cracking is inconsequential and will ultimately be hidden from view. In some localities, the creation of concealed control joints using “zip strips” is becoming more common, especially for larger floor slabs, to better control the location of shrinkage cracks.

The other common method for controlling, but not preventing, shrinkage cracks involves additional steel reinforcing. A nominal amount of welded wire steel mesh is often, but sometimes ineffectively,<sup>40</sup> used in slabs as shown in Figure 4.7 and Figure 4.8. The intended purpose is to spread the inevitable shrinkage cracking evenly throughout the slab.

Another method of crack control is pre-stressing the slab with highly tensioned cable tendons. This approach is often effective where the maximum dimension is 30 to 40 feet. However, cracks will often develop when the maximum dimension is greater than about 50 feet.

The rate of concrete shrinkage is time dependent, occurring most rapidly in freshly placed concrete and decreasing with time. Accordingly, shrinkage cracks essentially become dormant after a few years. However, where concrete is subjected to large temperature fluctuations or seasonal soil movements, shrinkage cracks may continue to move and widen over time.

Residential foundations and slabs-on-grade rely on support from stable soil. The soil below a foundation may shift or distort due to many causes including non-uniform compaction, densification, consolidation, downhill creep, moisture-related shrink/swell (in expansive soils), or frost heave (in cold climates). When these soil movements result in differential settlement, heave, or elongation, stresses will develop in the foundation. These stresses will cause shrinkage cracks to widen and may cause new cracks to form. Because of the stiffness and low tensile strength of plain<sup>41</sup> or lightly reinforced concrete, relatively minor differential soil movement will induce cracking. Cracks caused by differential settlement will eventually become dormant, as the soil and foundation approach a stable equilibrium. As discussed in Section 3, seasonal soil moisture fluctuations may cause cracks in concrete floor slabs to cyclically open and close as the soil shrinks and swells. Cracks caused by creep or shrink/swell will remain active unless the underlying soil movement is arrested or the foundation is underpinned. Long-term or seasonal soil movement tends to shift slabs and foundations in addition to cracking them. Out-of-level slabs, out-of-plane offsets across cracks, and cracks of varying width often indicate that something more than concrete shrinkage is at work.

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<sup>40</sup> To be effective, steel reinforcing must be embedded completely within the concrete, preferably in the middle one third of the slab thickness. It is not uncommon to find welded wire steel mesh only partially embedded on the bottom of a slab-on-grade.

<sup>41</sup> “Plain concrete” is concrete placed with little or no reinforcement such as steel reinforcing bars, welded wire fabric, or prestressing cable tendons.



Shrinkage cracks develop at planes of weakness or emanate from openings or reentrant (inside) corners. In slabs, shrinkage cracks typically emanate from reentrant corners, at locations where plumbing pipes or heating ducts extend through the slab, from the corners of fireplaces, and diagonally across corners restrained by foundations. In the absence of these causes of stress concentration, shrinkage cracks develop in random locations, usually taking the shortest path across the slab, subdividing a large slab into smaller sections. Most of these cracks are well-spaced, of uniform width, and with no vertical offset across the crack. In addition, where slabs-on-grade are cast abutting a wall footing, as around the edge of a garage slab, the cold joint between the slab and the stem wall will often open as the slab shrinks away from the wall.

In footings and stem walls, shrinkage cracks develop at openings for access, vents, plumbing, ductwork, at corners, at “steps” (changes in elevation of the top of the stem wall) (Figure 4.9), at anchor bolts (Figure 4.10), and at recesses in the stem wall provided for floor beam supports (Figure 4.11). Otherwise, cracks develop at essentially random locations along the length of the footing or stem wall, subdividing it into shorter lengths. Without aggravating soil conditions, the cracks are generally near vertical, of uniform width or slightly wider toward the top of the stem wall, and with no offset across the crack.

Other non-earthquake causes of and contributors to concrete foundation and slab damage include:

- Corrosion of reinforcing steel as shown in Figure 4.12 or anchor bolts (especially in marine environments or where deicing salts are used).
- Tree roots, vines, or other vegetation as shown in Figure 4.13.
- Vehicle traffic loads, especially where the underlying soil has been eroded or softened, for example by a sprinkler system, as shown in Figure 4.14.
- Changes in site drainage conditions or vegetation coverage and irrigation, including paving of areas adjacent to the foundation or slab that were previously vegetated.
- Extensive burrowing of gophers or other rodents.

## **4.6 Earthquake-Induced Foundation Damage**

Concrete slabs-on-grade and residential foundations have performed extremely well in past earthquakes at sites that did not sustain earthquake-induced permanent ground deformation. Following an earthquake, however, foundations and slabs may be scrutinized for the first time and under that scrutiny, numerous cracks are observed for the first time. Given the correlation between the earthquake and the fact that the first observation of cracks occurs right after the earthquake, it is easy to jump to the conclusion that the cracks were caused by the earthquake and perhaps represent serious structural damage. In reality, while earthquake-induced cracking of slabs and foundations can occur under certain circumstances, it is not common. Cracking of structural significance is even more uncommon. Actual earthquake-induced damage to

residential foundations and slabs-on-grade is almost invariably associated with permanent ground deformation of some sort,<sup>42</sup> and/or conspicuous visible damage to the superstructure.

As most residential foundations rely on the strength and stability of the supporting soils for satisfactory performance, ground failure or permanent ground deformation (as distinct from the transitory deformation of soils and buildings that occurs while they are shaking during an earthquake) generally causes foundation damage as well. Mechanisms by which earthquakes can induce permanent ground deformation and damage buildings and their foundations are discussed in Section 3 and will not be repeated in this section.

The most common effects of earthquake-induced permanent ground deformation on residential foundations are large displacements and rupture foundation elements, which are visually obvious. In many instances, the foundations and the supported buildings are damaged beyond repair. In some cases, earthquake-related soil or fill settlement, which might be as little as two or three inches at the edge of a filled slope, can cause damage to supported buildings. As discussed in Section 3, if there are indications of earthquake-induced permanent ground deformations at a site, a soils specialist should be retained to investigate. Building damage patterns that indicate possible earthquake-induced permanent ground deformation include:

- Fresh-appearing vertical or diagonal cracks in foundations or concrete floor slabs or visible differential foundation movement.
- Fresh-appearing (i.e., inconsistent with the quality of construction, general level of maintenance, and normal aging) sloping, sagging, or settlement of floors, patios, decks, etc.
- Sloping, sagging, or settlement of floors, patios, decks, etc., consistent with conspicuous earthquake damage to adjacent woodframed walls.

Permanent ground deformation is not always necessary for earthquake-related foundation damage. Other vulnerable foundation conditions and their potential earthquake damage patterns are discussed in the following paragraphs. These patterns are generally of no structural significance if displacements are small, although cosmetic repair may be necessary.

The most common occurrence is minor relative movement across the horizontal construction joint between the footing and the slab-on-grade in two-pour systems (Figure 4.7). When the plastic vapor barrier and/or sand fill are extended over the top of the footing as shown in Figure 4.15, the strength of the connection between slab and foundation is reduced. While the result of this movement is spalling and cracking of stucco or concrete patching material around the perimeter of the foundation as shown in Figure 4.16, or cracking of brittle floor finishes at interior steps or floor level changes as shown in Figure 4.17, there are, as a practical matter, no consequences beyond the need for cosmetic repair. Significant earthquake-induced sliding of the slab relative to the foundation will show as a consistent pattern of slab-footing offset and will

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<sup>42</sup> One possible exception to this general statement is for slabs and foundations that span a cut/fill contact at a site. There have been field observations of slab and foundation cracking along the cut/fill line without measurable permanent deformation of the fill.

likely be accompanied by spalling of concrete at anchor bolts, substantial damage to the house walls, and damage to utility lines that penetrate the floor slab.

Similar movement can occur in two-pour systems where the slab-on-grade is cast against, rather than on top of the foundation, as frequently occurs in garages and less commonly within living spaces (Figure 4.18). The movement is manifested by a development or widening of a narrow gap between the footing and slab-on-grade. If the house slab has this detail, any related movement will be visible only upon removal of carpets along the edge of the rooms. As a practical matter, the only consequence of this movement is the opening of a possible path of entry for insect pests.

Application of brittle floor finishes (ceramic tile, slate, marble, other stone work, and brick-pavers) over concrete slabs-on-grade is common. Generally, such finishes are bonded directly to cracked slabs. Such installations are sensitive to even minor differential movement across the cracks in the slab. Due to temperature effects and minor soil movements, over time the finish materials will develop hairline cracks that follow the cracks in the slab, a phenomenon known as “telegraphing.” Telegraphing of cracks can also occur in areas of intense ground shaking as shown in Figure 4.19. Close inspection often reveals a wider crack in the slab than in the finish materials. The difference in width between the two cracks indicates the width of the slab crack at the time the finish was installed, a condition that allows distinction between finish cracking caused by telegraphing of an existing crack and fresh cracking of the underlying concrete slab.

One special geotechnical condition that has been reported as possibly associated with earthquake-induced damage to slab-on-grade foundations is the existence of a cut and fill transition beneath the slab.

Finally, intense earthquake shaking may cause movement across cracks that had formed prior to the earthquake, due to various non-earthquake causes discussed above. Such movement might be substantial enough to make pre-existing cracks or slopes noticeable. If the earthquake contribution changes the scope of repair necessary to correct the condition, that exacerbation would be properly classified as earthquake damage. However, unless the earthquake contribution widens the crack beyond 1/8 inch or creates an out-of-plane offset greater than 1/16 inch, exacerbation should be considered structurally insignificant.

## **4.7 Assessment Guidelines and Methodologies**

Initial assessment of concrete foundation elements consists primarily of visual examination of the patterns and details of visible cracks. This initial assessment should be accomplished by a visual inspection of the perimeter of the buildings and inspection of any visible areas of foundation within a garage. If the inspection reveals possible earthquake-induced foundation damage, a technical consultant should be retained for an assessment.

Before focusing on the concrete itself, however, it is helpful to understand relevant features of the site. A generally hilly area indicates that a level lot was probably graded by cutting and/or filling the original terrain. The cut-fill boundary is a likely place to find slab and foundation damage.

It is also necessary to identify relevant details of the foundation construction. If the house has a raised foundation, are there wood cripple walls over concrete footings (Figure 4.3), or is the crawlspace enclosed by full-height concrete stem walls (Figure 4.4)? Is the interior of the house supported in the same way as the perimeter, or are there individual wood posts on concrete (or masonry) piers (Figure 4.5)? In addition to the raised portion, does the house also have a more recent slab-on-grade addition?

In a slab-on-grade house, is there evidence of a two-pour system (Figure 4.7 and Figure 4.15 through Figure 4.18)? Can the location of the horizontal cold joint between the slab and the footing be distinguished, or is it obscured by finishes or adjacent construction?

In the course of an overall visual inspection of the house, those portions of the foundation and slabs-on-grade readily visible should be examined for signs of fresh cracking or recent differential movement. Readily visible locations include:

- Exposed slabs, such as in closets, utility rooms, or attached garages.
- Slab-on-grade floors finished with brittle materials (ceramic tile, slate, marble, or brick pavers).
- Slab-on-grade floors finished with semi-brittle materials (sheet vinyl, vinyl floor tile, and adhered wood flooring).
- The edge of the concrete slab, to the extent that it is visible from outside the house or from inside an attached garage.
- The outside surfaces of concrete footings or stem walls, to the extent that they are visible from outside the house or from inside an attached garage.

Outside the house, the edge of slab and face of concrete footings or stem walls may be bare concrete, painted concrete, finished with a skim coat of stucco, or finished with stucco or other finishes continuous from the wall above.

#### **4.7.1 Technical Consultant Assessment**

If any of the following damage patterns are observed, a structures specialist should be retained to perform a foundation inspection. In the absence of these conditions, earthquake damage to the foundation or slabs-on-grade is unlikely, and further investigation is generally not warranted.

- Fresh-appearing cracks wider than 1/8 inch or offset by more than 1/16 inch out-of-plane (Figure 4.20) that are in exposed visible areas and had never been noticed before the earthquake.
- Extensive or large cracks (with signs of recent movement) in the foundation far in excess of what would be expected from normal shrinkage and settlement (see Section 4.5).

- Perceptible slopes in floors, slabs-on-grade (other than drainage slopes), or swimming pools that have never been noticed before the earthquake.
- Vertical or horizontal out-of-plane offsets exceeding 1/16 inch (the thickness of a nickel) across any earthquake-caused or earthquake-exacerbated cracks.
- Indication of earthquake-induced permanent ground deformation as discussed in Section 3.

The structures specialist's assessment should include detailed visual inspection, measurement, and sometimes mapping of cracks. If the need is indicated by the initial structures specialist's assessment, the structures specialist may recommend selective pulling of carpets (for buildings with carpeting over slab-on-grade floors) as outlined in Appendix 9A, as well as a geotechnical investigation or invasive investigation of the foundation and/or slab-on-grade floor.

Invasive inspection should be necessary only in those instances when the structures specialist is unable to rule out, or reasonably assume, earthquake damage based on non-invasive means. Potential invasive structural investigation work is outlined in Appendix 9A. Geotechnical investigation as outlined in CUREE Publication EDA-06 may be required in some instances to fully understand damage patterns observed in foundations and/or slabs-on-grade.

If the building was constructed prior to 1980 and repair work will involve disturbance (demolition, removal, grinding, sanding, etc.) of any of the following types of floor finishes, a suitably qualified environmental consultant should be retained,

- vinyl tile and/or mastic,
- Backing or underside of sheet vinyl, or
- Enamel paint on concrete floors.

As discussed in Section 9.2.4, the consultant should test for the presence of regulated hazardous materials and, if the results of the tests are positive, recommend appropriate abatement and waste disposal measures.

#### **4.7.2 Establishing the Cause of Cracks**

The most reliable indicator of an earthquake contribution to an observed foundation crack is the presence of corresponding earthquake damage to adjacent slabs, soil, or superstructure. If corresponding damage is not present, in some cases it is possible to determine whether the cracks are of recent origin or a long-term condition by visual examination of the crack surfaces. Visible indicators are most reliable in the weeks immediately following the earthquake and become less so as time passes; cracks weather, repairs are made, and other events intervene to obscure fresh damage.

Characteristics of cracks that provide clues to their age include:

- Sharpness of the crack edge: Fresh cracks exhibit sharp edges free of weathering, rounding, or erosion. Note that cracks in protected locations, such as within a crawlspace or beneath a floor covering will not “weather” and may look sharp and fresh for many years. Figure 4.21 shows a fresh crack in Portland cement concrete, while Figure 4.22 shows an older crack with worn and rounded edges.
- Relative color of crack surfaces and exposed surface of the element: A fresh crack surface concrete will typically be a different shade than the exposed, weathered surface as shown in Figure 4.23.
- Condition of crack surfaces: Fresh cracks exhibit clean fracture surface. Older cracks may exhibit contamination with paint (Figure 4.24), oil, grease, floor covering adhesive (Figure 4.25 and Figure 4.26), sawdust, drywall joint compound (Figure 4.27), or other foreign matter that may have accumulated since the crack initially developed.
- Grout, caulk, or other patching or repair material in the crack as shown in Figure 4.28 through Figure 4.30
- Leveling material adjacent to or spanning the crack as shown in Figure 4.31.
- Dirt, dust, debris, or vegetation in the crack as shown in Figure 4.32 through Figure 4.34.
- Where slabs are covered with an adhered floor finish, setting mortar or adhesive may extend into the crack (Figure 4.36), or the bottom side of finish material that spanned a pre-existing crack may show an impression of the crack in the pattern of adhesive trowel marks or setting mortar as shown in Figure 4.36.
- Condition of carpet tack strips that cross the crack. Tack strips installed over old dormant cracks will span the crack without damage. Cracks that formed or widened since the tack strip was installed might break tack strips or pull the tack strip loose. Determining the age of breaks in tack strips is often difficult. Double tack strips or offset tack strips paralleling cracks indicate cracks were present when the tack strips were installed.
- Recent differential movement between adjacent elements is generally manifested by exposure of unpainted surfaces, torn caulk or expansion joint material, staining or debris remnants, gaps between trim and the abutting surface, and other discontinuities.
- Examination of the interface where two vintages of concrete meet can indicate the relative age of cracks. Recent cracks will extend through both vintages of concrete, while older cracks will be present only in the older vintage of concrete as shown in Figure 4.37.

- If the pattern of a stain or efflorescence<sup>43</sup> is markedly different on two sides of a crack, then the crack was present before the stain developed as shown in Figure 4.38.
- Typical shrinkage crack patterns for concrete slabs-on-grade were described previously. In addition, concealed control joints (formed with “zip strips”) as shown in Figure 4.39 and construction joints associated with additions or modifications look like very straight shrinkage cracks. A very straight shrinkage crack can also indicate where slab reinforcing was not properly lapped or was intentionally separated.

## 4.8 Repair Methodologies

The appropriate repair of foundations and slabs-on-grade must consider the nature, extent, cause, and significance of the damage. Where earthquake damage results from permanent ground deformation, stabilization of the site may need to be addressed as one component of the overall repair plan. Where the damage represents a loss of structural capacity a structural repair will be necessary. In all other cases, a nonstructural repair is appropriate.

Table 4-1 summarizes appropriate repair methods for those earthquake damage patterns that can be addressed without structures specialist assistance. If the cause of an observed damage pattern cannot be determined, or if the damage is outside the description given in the table, a structures specialist should be retained to address the issue. The repair methods listed in the table are further discussed in the following sections. The methods in the table address the concrete structural elements only; repair of any associated damage to nonstructural finishes should be done in accord with normal practices of the relevant trades.

**Note:** The repair methods presented in this chapter presume that the building materials are free of regulated levels of hazardous materials. If testing as recommended in Section 9.2.4 indicates the presence of regulated levels of asbestos or lead, the abatement and waste disposal recommendations of the environmental consultant should be incorporated into the overall scope of repair.

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<sup>43</sup> Efflorescence is a white powder that forms on the surface of concrete or masonry when dissolved salts are deposited as water seeping through the concrete evaporates.



**Table 4-1. Repair methods not requiring technical consultant assistance for nominal earthquake damage to concrete foundations and slabs-on-grade**

Structural Element	Earthquake Damage Pattern	Recommended Repair Method*
Slab-on-grade	Pre-existing shrinkage crack that has widened due to the earthquake, less than 1/8-inch wide, no offset, no slope or settlement	No structural repair warranted
	Pre-existing shrinkage crack that has widened due to the earthquake, less than 1/8-inch wide, no offset, no slope, or settlement. Evidence of pre- or post-earthquake water or insect pest intrusion	Seal cracks
	Crack that has been caused or widened by the earthquake, up to 1/4-inch wide, offset up to 1/16 inch, no perceptible slope	Epoxy injection, if aesthetically acceptable, otherwise remove and replace
	Earthquake damage to stucco finish along horizontal cold joint between bottom of slab and top of footing (e.g., Figure 4.7), no apparent footing damage, no evidence of sliding more than 1/8 inch	No structural repair of concrete warranted (see Section 5 for stucco repair recommendations)
	Opening of construction joint between edge of slab and adjacent wall footing caused by the earthquake (typical garage detail)	Seal gap
Footing or stem wall	Pre-existing shrinkage crack that has widened due to the earthquake, less than 1/8-inch wide, no offset, no slope or settlement	No structural repair warranted
	Crack that has been caused or widened by the earthquake, up to 1/4-inch wide, offset up to 1/16 inch, no perceptible slope, settlement, or rotation	Epoxy injection

\* Repair methods presented in this table presume that the building materials are free of regulated levels of hazardous materials. If testing as recommended in Section 9.2.4 indicates the presence of regulated levels of asbestos or lead, the abatement and waste disposal recommendations of the environmental consultant should be incorporated into the overall scope of repair.

#### 4.8.1 No Structural Repair Warranted

For many cracks in residential concrete, whether or not they are earthquake-related, the appropriate structural repair is to do nothing. These cracks are typically the result of shrinkage and have no practical effect on the function of the element. In the normal course of construction and maintenance of buildings, shrinkage cracks are ignored or cosmetically patched. Isolated cracks less than 1/8-inch wide with less than 1/16 inch out-of-plane offset are structurally insignificant and may be left unrepaired. Nonstructural repair of the crack may be appropriate for cosmetic reasons or to prevent moisture and pest intrusion. For cosmetic considerations of exposed concrete, see Section 4.8.6.

## **4.8.2 Seal Cracks or Gap**

Larger cracks or gaps may provide an additional path of entry for insect pests or moisture and sealing of those cracks or cold joints may be desirable in some circumstances. Where no out-of-plane offset is present, cracks and gaps may be sealed by routing the crack and filling the space with an elastomeric joint sealant. Cracks and gaps may also be sealed with any of a number of commercially available cement-based patching materials, many of which have a latex additive to increase bond strength. For cosmetic considerations of exposed concrete, see Section 4.8.6.

## **4.8.3 Apply Leveling Compound**

Where a vertical offset occurs across a crack in a floor slab, a leveling compound may be used to restore flatness as needed for installation of flooring. Floor covering installers routinely do minor leveling of slab surfaces to provide a smooth substrate beneath the floor finish.

## **4.8.4 Epoxy Injection**

Epoxy injection consists of the injection, under controlled pressure, of epoxy resins formulated for structural repair of concrete, into cracks in concrete elements. Epoxy injection is a widely used method for concrete crack repair because it solves several problems: it seals the crack against water and insect pest entry, it protects any reinforcing steel crossing the crack from corrosion, and it provides tensile and flexural strength comparable to or exceeding that of the uncracked concrete element. Cracks ranging in width from 0.002 inch to 1/4 inch may be satisfactorily repaired with epoxy injection.<sup>44</sup> For cosmetic considerations of exposed concrete, see Section 4.8.6.

Epoxy injection is a specialized trade that utilizes specialized and often proprietary materials and methods. As such, specific materials, equipment, and procedures may vary by region or contractor. Quality assurance procedures are an essential aspect of epoxy injection repair work. In addition, some jurisdictions require an engineering report in support of epoxy repairs. For application to plain or lightly reinforced residential concrete, this requirement is typically waived, but regulations vary by jurisdiction. Recommendations regarding epoxy injection of residential concrete are presented in Appendix 4A.

## **4.8.5 Removal and Replacement**

As discussed below, appearance is a consideration for some concrete repairs. Aesthetically acceptable repair of cracks in architecturally exposed concrete (driveways, walkways, patios, and pool decks) is generally impractical, although there are methods available for that purpose. Generally, however, for architecturally exposed residential concrete slabs-on-grade (walks, patios, etc.), removal of the damaged area and replacement in-kind is usually the most practical solution.

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<sup>44</sup> Cracks wider than 1/4 inch can be reliably repaired at the direction of an engineer, using special procedures referenced in Appendix 4A.

#### **4.8.6 Cosmetic Considerations**

Repair should also include cosmetic work that is necessary to assure a reasonably uniform appearance after the repairs are completed. Cosmetic considerations for foundations (stem walls and footings) include:

- Unless the foundation is an exposed, visible element in the building, cosmetic matching is not necessary.
- If the foundation in the area of the repair is a visible element and the repair will detract from a reasonably uniform appearance, consideration of cosmetic matching should be included in the repair.

Cosmetic considerations for slabs-on-grade include:

- Unless the slab-on-grade is an exposed, visible element in the building, cosmetic matching is not necessary.
- If the slab-on-grade in the area of the repair is a visible element, repair should include consideration of cosmetic appearance, consistent with the condition function, and appearance of the existing concrete surface.

#### **4.8.7 Technical Consultant Repair Recommendations**

For damage patterns not addressed in the table above, or at sites with soil problems, the technical consultant(s) should be asked to recommend repairs. Repairs that might be recommended by a technical consultant in addition to those presented in Table 4-1 include:

- Grinding and leveling where a vertical offset across a crack in a slab-on-grade is greater than 1/16 inch.
- Epoxy or cementitious grout repair (possibly with prepacking with sand or aggregate) of cracks wider than 1/4 inch.
- Partial replacement of the slab, footing, or stem wall might be appropriate for sections with concentrations of damage, or wide cracks with large offsets. Damaged or offset material is removed by saw cutting or jack hammering to create a gap at least two feet wide. New steel reinforcing is doweled into the edges of the existing concrete to insure that the new and old concrete will be properly tied together. New concrete is then placed.

- External reinforcement consisting of leaving a cracked or damaged section of concrete (generally stem walls) in place and attaching external reinforcement that restores the flexural and tensile capacity of the element. For conventional residential foundations, external reinforcement is appropriate when epoxy injection is not feasible. Typical external reinforcement approaches include:
  - Steel plates bolted into intact concrete on both sides of the damaged area.
  - Reinforced concrete grade beams constructed adjacent to the damaged area and doweled into intact concrete on both sides of the damaged area.
  - Fiberglass or carbon fiber composites that are bonded to the surface of the element and span across the crack.
- External post-tensioning consists of installing high strength threaded steel rods along the inside face of a stem wall and prestressing the rods to provide a state of nominal compression in the stem wall. This method effectively strengthens or reinforces the stem wall and is effective in areas subject to slope creep or highly expansive clay. Otherwise, it is an excessively conservative method for residential foundation repair.
- Complete replacement of a slab or foundation is appropriate only when the foundation has been damaged beyond repair due to earthquake-induced permanent ground deformation, is grossly deficient relative to prevailing standards, or was already in poor condition prior to the earthquake.

#### **4.8.8 Releveling**

Earthquake-induced soil movement can cause differential settlement of the foundation, leaving the building in a noticeable out-of-level condition. Once the soil beneath the building is stabilized, there are several alternatives to relevel<sup>45</sup> the building that may be recommended by the structures specialist, preferably with advice from a soils specialist:

- Releveling woodframe floors over a raised foundation: woodframe superstructures over a crawlspace are relatively straightforward to relevel on the existing foundation. Nuts on the mudsill anchor bolts are removed, the building is jacked level, the anchor bolts are extended using coupling nuts and reconnected, and the void beneath the mudsill is filled with grout. Wood support posts are shimmed or replaced with adjustable steel support posts. An experienced contractor can accomplish releveling with little disruption or damage to the building interior, but some allowance should be made for associated cosmetic refinishing.

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<sup>45</sup> No building is perfectly level. The objective of releveling is to return a building to its pre-earthquake condition. Care must be taken not to make the building more level than it was prior to the earthquake. Over releveling will likely cause significant cosmetic damage and may cause structural damage.

- Releveling woodframe buildings on slabs-on-grade: a woodframe house on a slab-on-grade can also be relevelled on the existing foundation, although all work must take place within the first-story living space and results in considerable disruption. Following releveling of the woodframe building, the slab surface may be leveled with a leveling compound.
- Lift or compaction grouting, a type of pressure grouting that lifts the building and lifts and stabilizes the soil immediately beneath the foundation, is an alternative for releveling of buildings with slab-on-grade floors. Stiff, cementitious grout is injected into the soil beneath the slab through injection pipes around the building perimeter and distributed within the building interior. Grout is injected sequentially, gradually bringing the slab, foundation, and superstructure back up to level.
- Underpinning consists of installing concrete shafts or steel pipe piles into the ground beneath the foundation to support the building on deeper, more stable soil. Underpinning may be the recommended repair to address unstable soil conditions identified as part of the geotechnical investigation. In the absence of unstable soils however, underpinning is not recommended for repair of earthquake-induced foundation damage.

#### **4.8.9 Permits, Upgrades, and Retrofits**

Depending upon the nature and scope of damage and proposed repair, building permits and other government agency approvals may be required by the local jurisdiction. In addition to normal changes in the building code over time, some jurisdictions have building code requirements that mandate upgrading portions or all of the building, if certain damage thresholds are exceeded. Check with the local building department to determine the existence of any applicable local requirements.

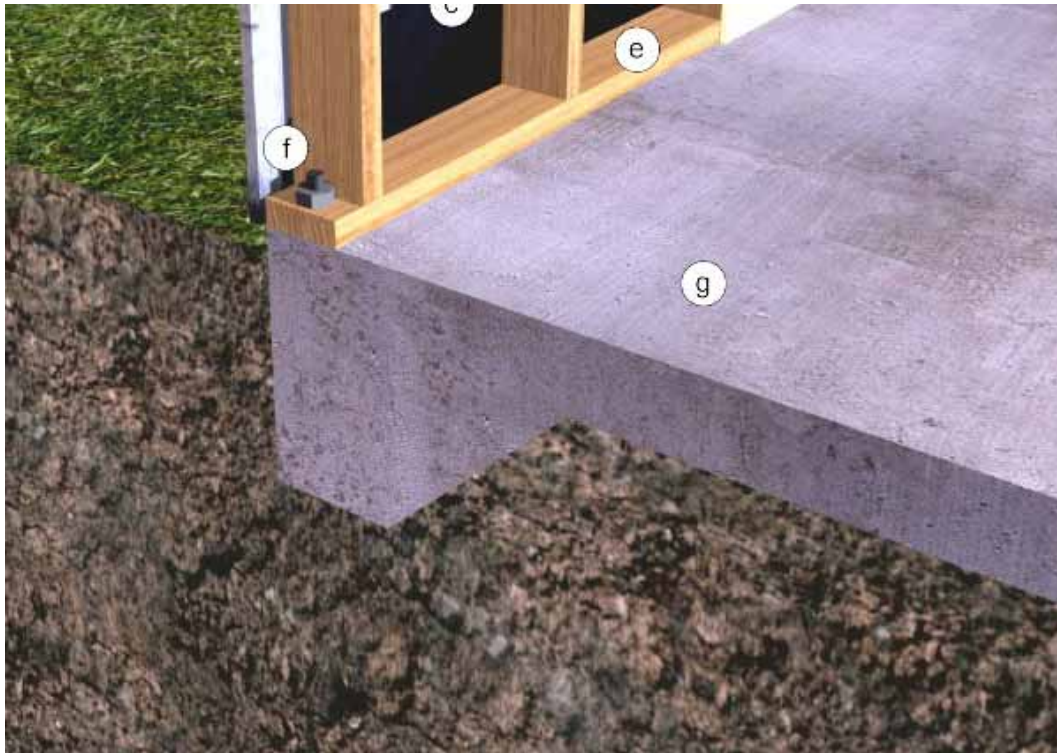


Figure 4.1. Continuous footing at perimeter of a slab-on-grade – single-pour system [Exponent].

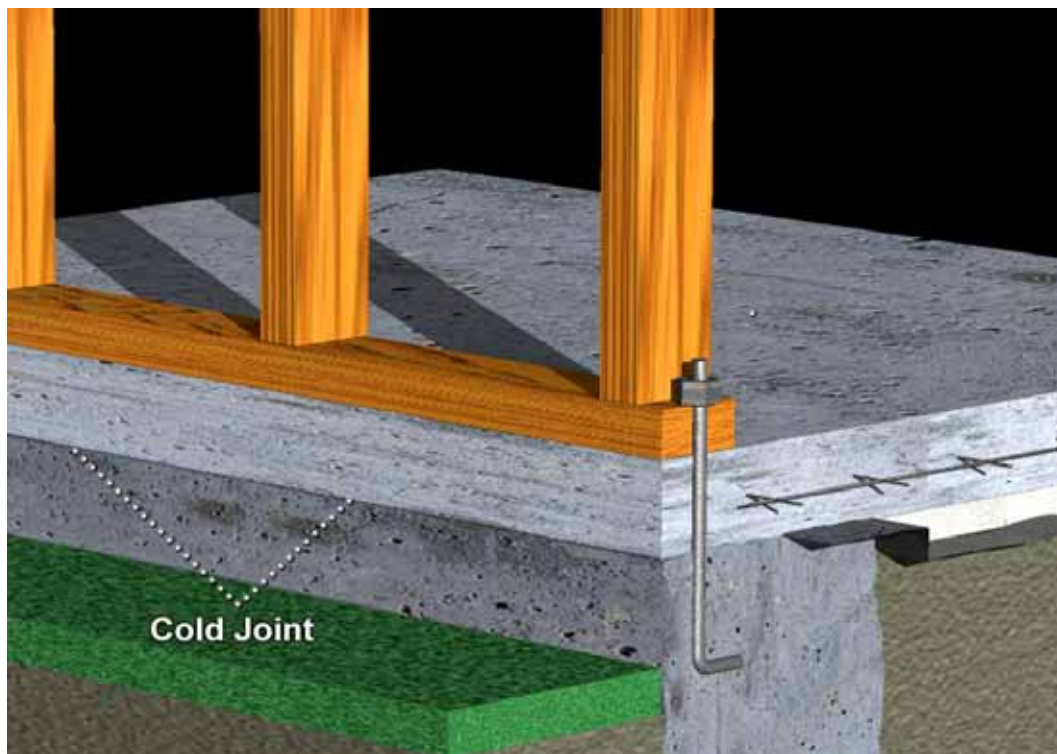


Figure 4.2. Continuous footing at perimeter of a slab-on-grade – two-pour system with cold joint between slab and footing [Exponent].

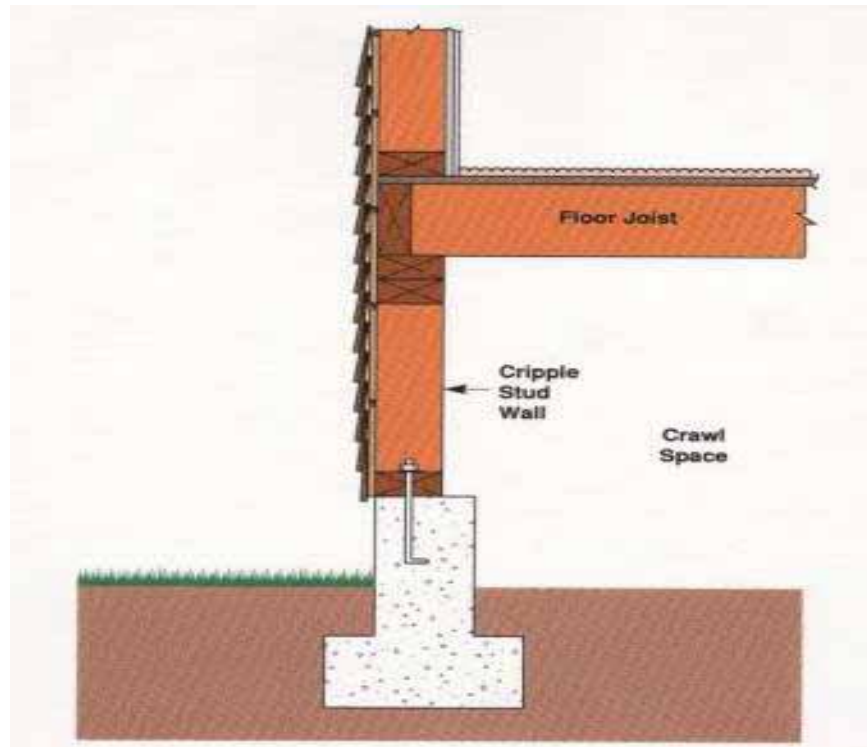


Figure 4.3. Continuous footing supporting woodframed cripple wall [Exponent].

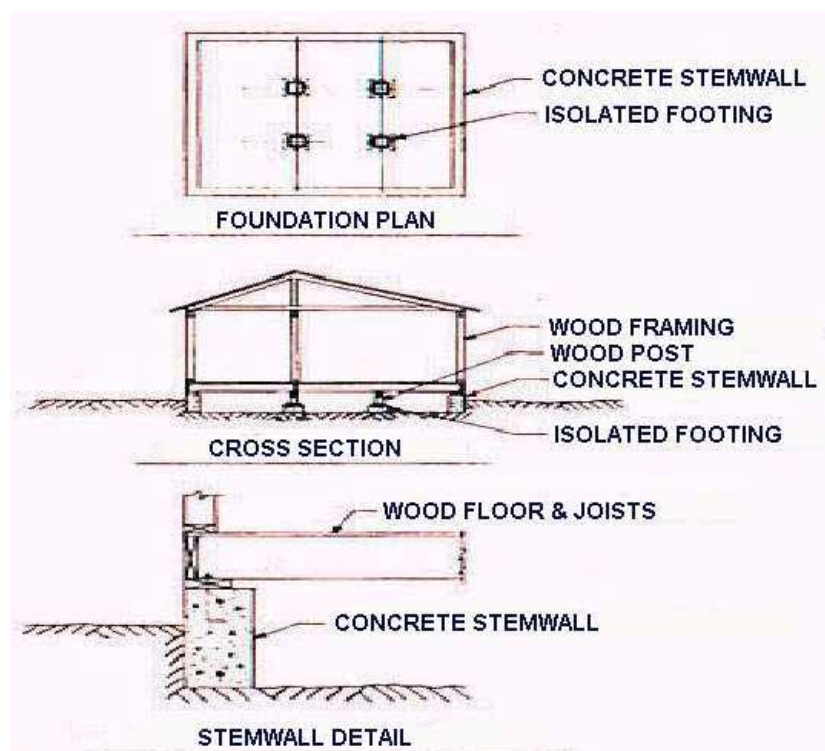


Figure 4.4. Stem wall supporting first floor woodframing.





Figure 4.5. Undamaged isolated footings supporting wood posts of first floor woodframing [Exponent].

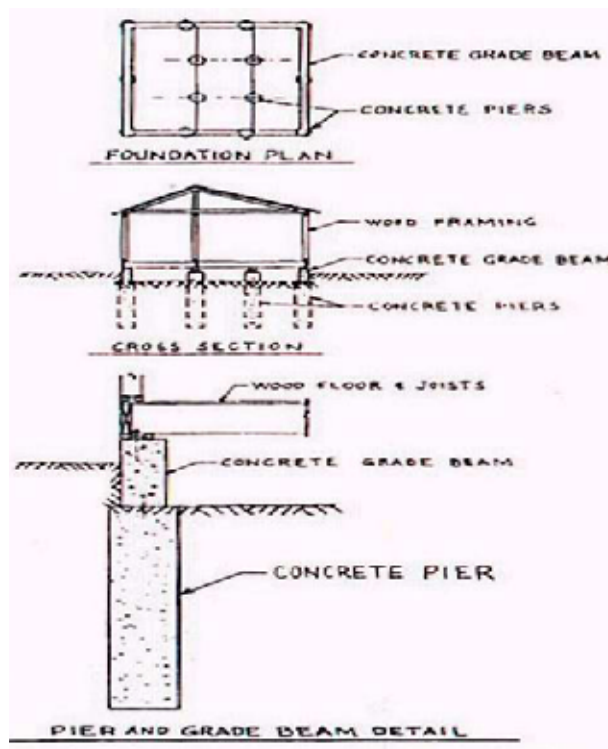


Figure 4.6. Drilled pier-and-grade-beam foundation supporting first floor woodframing.

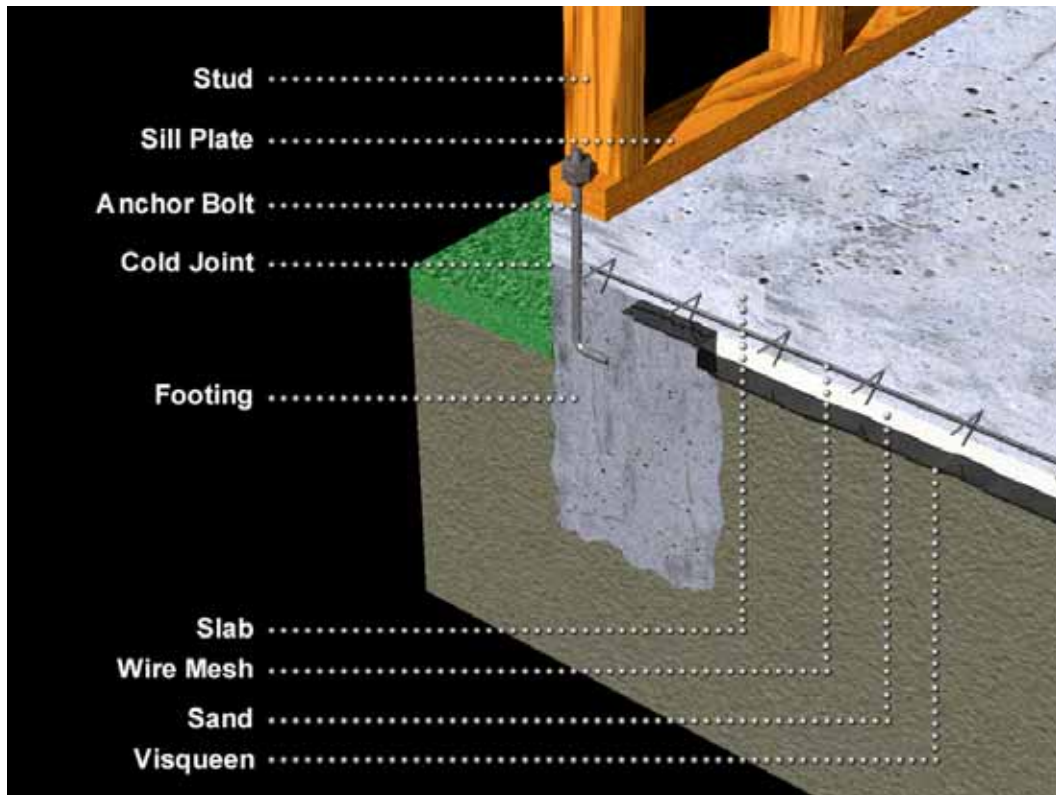


Figure 4.7. Slab-on-grade with independent perimeter footing and horizontal construction joint [Exponent].

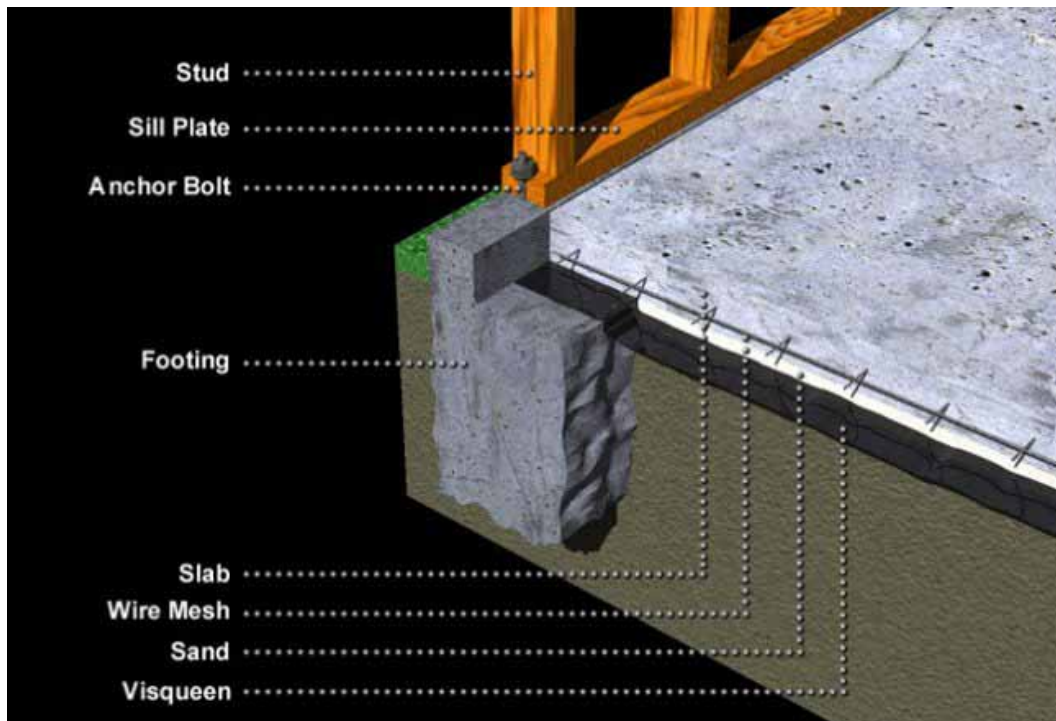


Figure 4.8. Slab-on-grade with independent perimeter footing and vertical construction joint [Exponent].



Figure 4.9. Concrete shrinkage crack emanating from reentrant corner at a step in a perimeter stem wall [Exponent].



Figure 4.10. Shrinkage crack in a concrete stem wall emanating from an anchor bolt [Exponent].





Figure 4.11. Shrinkage crack in a concrete stem wall emanating from a beam pocket [Exponent].



Figure 4.12. Core extracted from concrete stem wall showing cracking caused by swelling pressure generated by corroding reinforcing steel [Exponent].



Figure 4.13. Uplift and cracking of concrete sidewalk caused by tree roots [Exponent].



Figure 4.14. Cracking due to vehicle loads on a concrete driveway over soft soil [Exponent].





Figure 4.15. Earthquake-induced relative movement at slab/footing interface in two-pour slab-on-grade construction due to sand covering the footing during construction [Exponent].



Figure 4.16. Earthquake-induced differential movement and spalling at cold joint between stem wall and slab in two-pour construction [Exponent].



Figure 4.17. Earthquake-induced cracking of ceramic tile spanning the cold joint between the floor slab and the stem wall in a two-pour system [Exponent].



Figure 4.18. Opening of cold joint between floor slab and perimeter footing [Exponent].





Figure 4.19. Earthquake-induced cracking of ceramic tile on a slab-on-grade [Exponent].



Figure 4.20. Illustration of out-of-plane offset in a concrete slab-on-grade [Exponent].



Figure 4.21. Fresh crack in concrete exhibiting sharp edges, crack faces free of contamination and gap clear of debris [Exponent].

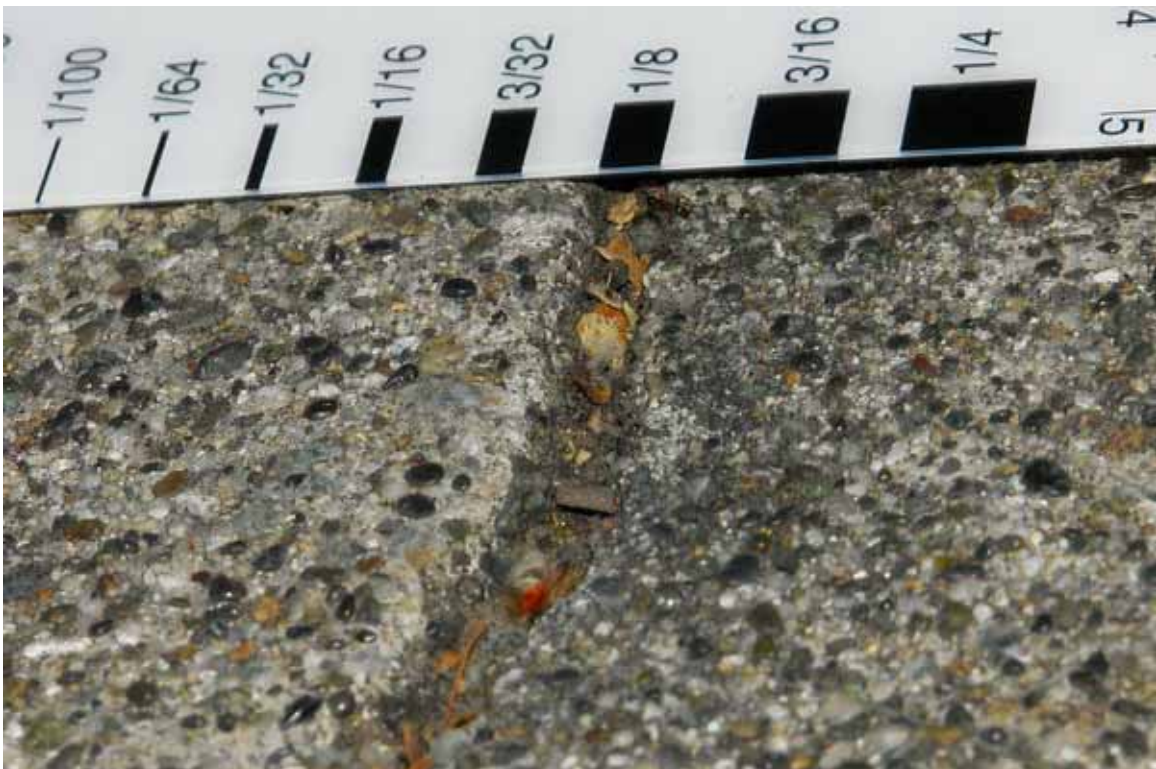


Figure 4.22. Older crack in concrete exhibiting worn and rounded edges [Exponent].





Figure 4.23. Fresh crack in concrete exhibiting lighter color on crack face relative to weathered surface [Exponent].



Figure 4.24. Older crack in concrete exhibiting worn and rounded edges contaminated with paint [Exponent].



Figure 4.25. Older crack in concrete floor slab contaminated with carpet pad adhesive [Exponent].



Figure 4.26. Parquet flooring adhesive filling crack in concrete slab [Exponent].





Figure 4.27. Dabs of drywall joint compound within shrinkage crack in concrete slab-on-grade floor [Exponent].



Figure 4.28. Older crack in foundation stem wall exhibiting prior patching and painting [Exponent].



Figure 4.29. Mortar within garage slab-on-grade crack indicates previous patching of crack (not earthquake damage) [Exponent].



Figure 4.30. Crack in concrete slab-on-grade floor that exhibits two prior generations of patching as well as opening since last patching (not earthquake damage) [Exponent].





Figure 4.31. White leveling compound spread across existing crack at time of carpet installation [Exponent].



Figure 4.32. Debris (sawdust) from original construction in foundation crack observed shortly following the 2003 San Simeon Earthquake (not earthquake damage) [Exponent].



Figure 4.33. Dirt and efflorescence indicates age of foundation wall crack is not recent (not earthquake damage) [Exponent].



Figure 4.34. Debris and vegetation in older crack (not earthquake damage) [Exponent].





Figure 4.35. Grout completely filling slab-on-grade crack (indicated by pen) indicates that slab crack was present at the time of the tile installation and has not experienced movement since tile installation (not earthquake damage) [Exponent].



Figure 4.36. Setting mortar that had flowed into an existing slab crack that remained bonded to the backside of a ceramic tile when the tile was removed, a clear indication that the concrete slab was cracked when the tile was installed [Exponent].



Figure 4.37. Termination of crack in older concrete (upper left) where it abuts newer concrete (lower right) indicates that crack existed prior to the installation of the newer concrete [Exponent].



Figure 4.38. Pattern of efflorescence around crack in stem wall indicates that crack is not of recent origin [Exponent].



Figure 4.39. Linear shrinkage crack in concrete floor slab at location of a concealed control joint created by a “zip strip” [Exponent].

## Appendix Section 4

### 4A Recommendations for Crack Repair by Epoxy Injection in Residential Concrete

The following recommendations are offered to ensure effective structural repair of cracks in residential foundations and slabs-on-grade. These recommendations do *not* constitute a construction specification or instructions to a contractor. They are general guidelines for use in arranging, pricing, and monitoring the work.

#### 4A.1 General Recommendations

1. Work should be performed by a California licensed contractor specializing in epoxy injection. The status of a California contractor's license may be verified with the Contractors State License Board at: <http://www.cslb.ca.gov/consumers/index.html>.
2. All work must comply with applicable building codes and regulations, including interpretations and guidelines of the local building department. In some cases, a deputy building inspector or an approved special inspector may be required to provide continuous inspection of the epoxy injection work.
3. The key objective of the work is to adequately fill all identified cracks with a structural epoxy resin that is adequately bonded to the concrete crack surfaces. To achieve this objective, the contractor is expected to exercise judgment regarding material selection and procedures, based on prior experience.
4. Surfaces adjacent to the crack or other areas of application shall be cleaned of dirt, dust, oil, efflorescence, paint, or other foreign material detrimental to establishing a bond of the sealing material prior to epoxy injection.
5. Cracks must be clean prior to injection. Remove loose debris in the crack with 100 psi compressed air using a needle tip nozzle. Clean older cracks with silt or clay in them with high pressure water, or, if tightly packed, a combination of high-pressure water and compressed air. Allow crack surfaces to dry, if water is used for cleaning or if the concrete is in a wet environment. If debris remains in the crack, inject with Grade 1 material, followed with a more viscous grade depending on the width of the crack and the extent of capping.
6. Injection ports should be located either on the crack surface or in a drilled hole intersecting the crack. Ports should be spaced at a distance along the crack not less than the thickness of the slab, stem wall, or footing.



7. Following completion of injection and curing of epoxy, remove surface seal and any installed ports that protrude from the surface of the concrete using heat and a razor scraper or grinding.
8. Clean and remove all spills, leaks, and stains.

## **4A.2 Crack Width Criteria**

The following guidelines are subject to review and approval by the building official and the design engineer, if any.

1. Cracks narrower than 1/32 inch wide need not be injected.
2. Where cracks can be adequately sealed on all edges with a combination of an epoxy paste cap on exposed surfaces and firm soil or an epoxy-soil cap on concealed surfaces, cracks up to and including 1/4 inch wide should be injected with adhesive conforming to the requirements of ASTM C881, Type IV, Grade 1.
3. Where cracks cannot be adequately sealed on all edges, cracks should be injected with adhesive conforming to the requirements of ASTM C881, Type IV and of an appropriate grade. In the absence of contractor's experience, the following guidelines are offered:
  - a. Grade 1 for cracks up to 0.060 inch (1/16 inch) wide.
  - b. Grade 2 for crack widths of 0.060 inch up to 0.120 inch (1/16 to 1/8 inch) wide.
  - c. Grade 3 for crack widths of 0.120 inch up through 0.250 inch (1/8 to 1/4 inch) wide.

Where cracks vary in width over their length or depth, use of multiple viscosities of epoxies may be required. Viscosity is temperature dependent, and the above recommendations may need to be modified for temperatures significantly different from 70°F.

4. As part of an engineered repair, cracks up to 1/2 inch wide may be injected with a low exotherm adhesive conforming to the requirements of ASTM C881, Type IV.
5. As part of an engineered repair, cracks wider than 1/4 inch may be prepacked with coarse sand or pea gravel aggregate and injected with an adhesive conforming to the requirements of ASTM C881, Type IV, Grade 1.

## **4A.3 Footings or Stem Walls**

1. For footings or stem walls surrounding a crawlspace, access as much of one side as possible and as much of the other side as practical (accounting for

- possible obstruction by plantings, hardscape, property line limits, etc.). On the backside, seal the crack down to firm soil; on the front side (the exposed side from which the grout is injected), excavate to bottom of footing. Do not excavate beneath the footing. Clean crack, install ports, seal, and inject crack with appropriate grade material.
2. For footings or thickened edges surrounding slab-on-grade floors, only one-sided access is practical. Expose the concrete to the bottom of the footing. Do not excavate beneath the footing. Clean crack, install ports, seal, and inject crack with appropriate grade material.
  3. For either one-sided or two-sided access, injection should begin at the lowest port and proceed upward to the top of the stem wall or footing.

#### **4A.4 Slabs-on-Grade**

1. For slabs-on-grade, cracks should be cleaned, ports or 1/4 inch wide masking tape placed at a spacing no more than the slab thickness, the exposed surface sealed, and the masking tape (if used) removed.
2. Begin injection at one end of the crack and proceed port to port along the length of the crack. If there is a noticeable difference in elevation from one end of the crack to the other, start at the lowest elevation and proceed upslope. Two methods are effective for injecting cracks where the backside is not accessible:
  - 2A. Alternative A: Inject Grade 1 material and allow it to seep into the soil bedding or backfill and jell (about 1.5 hours). Reinject crack with Grade 1. Repeat process until crack is completely filled.
  - 2B. Alternative B: Inject crack with appropriate grade material.

#### **4A.5 Quality Assurance/Quality Control**

In the course of the injection work, the contractor should follow the quality control guidelines of Sections 2.1 and 2.2 of ICRI Guideline No. 03734,<sup>46</sup> as appropriate for the job. The most common problem with epoxy injection, especially where access is available on only one side, is epoxy seeping out before it jells. In addition to concurrent quality control referenced above, quality assurance testing for this condition consists of grinding or chipping away the epoxy seal (near the top of the stem wall, anywhere along the length of a slab-on-grade crack) to visually inspect the injected crack. If the crack is filled to the top surface, loss of epoxy fill due to seepage has not occurred. If loss of epoxy due to seepage has occurred, reinjection of the crack with epoxy is required.

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<sup>46</sup> “Guide for Verifying Field Performance of Epoxy Injection of Concrete Cracks,” Concrete Repair Manual, Second Edition, Vol. 2, ICRI Guideline No. 03734, International Concrete Repair Institute, Sterling, VA [www.icri.org](http://www.icri.org).

Where the repair is deemed structural by the structures specialist or building official, the effectiveness of the injection process should be evaluated in accord with the procedures of Section 2.3 of ICRI Guideline No. 03734 by random coring, at the rate of two cores for the first 100 lineal feet of crack injected and one core for every additional 100 lineal feet of crack injected. Local jurisdictions may require a higher sampling rate. Three alternatives are available:

1. Small diameter (about 3/4 inch) core angled at 45 degrees to the concrete surface and located so as to intersect the crack plane at roughly the mid-thickness of the element. Visually examine the core for complete filling of the crack. Apply a sharp hammer blow to the side of the core to verify integrity of the repair.
2. Two-inch diameter core (or a 4-inch diameter core if the crack does not extend roughly perpendicular relative to the concrete surface) perpendicular to the concrete surface through the crack. Visually examine the core for adequate filling of the crack. Per ICRI Guideline No. 03734, fill is considered adequate if 90% of the crack is filled with adhesive, as viewed from the exposed length of the crack on the sides of the core. Apply a sharp hammer blow to the side of the core to verify integrity of the repair.
3. Four-inch diameter core perpendicular to concrete surface through the crack. Visually examine the core for complete, filling of the crack. Per ICRI Guideline No. 03734, fill is considered adequate if 90% of the crack is filled with adhesive, as viewed from the exposed length of the crack on the sides of the core. Submit the core to a testing laboratory for a splitting tensile test.

Evaluation of the results is the same for all three testing alternatives. Fracture of the core through the parent concrete away from the repair indicates satisfactory performance. The presence of shiny or glassy areas on a face of hard cured epoxy adhesive exposed by the test fracture indicates that the glassy or shiny area cured while exposed to air and there is no effective bond because the crack was not adequately filled with epoxy adhesive. If inadequate fill is found, the crack should be reinjected and retested.

Test core holes shall be filled using a two-component epoxy grout mix, applied by hand trowel, thoroughly rodded, and tamped in place. For exposed concrete surfaces in plain view, the surface finish shall match the color and texture of the adjacent surface.

# 5 Walls

## 5.1 Quick Guide

### 5.1.1 What to Look For

- Fresh cracking (see Section 5.7.4), buckling, or detachment of exterior stucco or brick veneer.
- Fresh cracking, buckling, or detachment of the interior plaster or drywall.
- Signs of walls wracked out-of-square (jammed doors, jammed or broken windows).
- Walls tilted out of plumb (either full-height walls or cripple walls).
- Signs of movement or sliding of interior partitions relative to the floor.

### 5.1.2 Where to Look

- At the corners of door and window openings.
- At building corners on the exterior near the base of the wall.
- Along the plate line on the exterior, where the woodframing meets the concrete foundation.
- If a weep screed<sup>47</sup> is present along the bottom edge of the stucco, check for detachment by a hand pull at intervals around the building perimeter.
- At the elevation of the second floor rim joist in two-story houses.
- At the typical elevation (8 feet above the floor) of wall top plates in taller walls, such as gable end walls adjacent to cathedral ceilings.
- At doors and windows, check for squareness and plumbness of opening.
- Check for signs of sliding at the base of interior walls at door openings, archways, and the ends of walls.

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<sup>47</sup> Weep screed: a metal flashing at the foundation plate line on exterior stucco walls that allows trapped water to drain to the exterior of the building. Common on houses constructed since about 1970.

### 5.1.3 When to Call a Technical Consultant

If any of the following damage patterns are observed, a structures specialist<sup>48</sup> should be retained to perform an inspection of the house:

- The walls are wracked visibly out of plumb, or doors and/or windows have been rendered inoperable by the earthquake due to their openings being wracked out-of-square (excluding patio doors and closet doors that have come off their tracks or doors and/or windows rendered inoperable due to hardware failure or impact damage).
- The stucco has developed cracks wider than 1/16 inch (the thickness of a nickel) and more than about 3-feet long or across the full width of a wall section between door or window openings.
- Loose, bulging, or buckled stucco and/or fresh cracking along the sill plate line, as well as evidence indicating possible relative movement between framing and foundation.
- Stucco cracks are greater than 1/8-inch wide or spalling that has exposed wire mesh reinforcing.
- Evidence of detachment or delamination of stucco from the framing (as determined by visual observation or feel of looseness).
- Gypsum wallboard or lath is bulging, loose, or has detached from the framing.
- Nails have pulled through the edges of gypsum wallboard or there is a pattern of numerous nail pops.
- Interior finish cracks are wider than 1/16 inch or occur at locations away from panel joints or the corners of door or window openings.
- The house is taller than one story and has one or more open exterior wall lines<sup>49</sup> in the first story with visible damage.
- Fresh water damage to interior wall finishes due to rain or plumbing leakage within walls or ceilings.

If the building was constructed prior to 1980 and repair work will involve disturbance of certain types of floor finishes that may contain asbestos or lead-based paint, a suitably qualified and licensed environmental consultant should be retained to test for the presence of regulated

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<sup>48</sup> Structures specialists include Licensed Civil Engineers specializing in structural engineering, Licensed Structural Engineers (Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Structural Engineer), and Licensed Architects with expertise in structures. See Section 9.3 for additional discussion.

<sup>49</sup> An “open wall line” is a length of wall from corner to corner that does not have at least two solid wall panels 32-inches wide or wider along its length or, for longer walls, a wall that does not have at least one solid wall panel 32-inches wide or wider for every 25 feet of wall length.

hazardous materials and, if necessary, recommend appropriate abatement and waste disposal measures. See Section 9.2.4 for additional information.

### **5.1.4 Repair Guidelines**

Minor earthquake damage can be addressed as described in Section 5.8 and as shown in Table 5-1.

## **5.2 Summary**

Wall surface materials or sheathing<sup>50</sup> are among the first components of a woodframe house to sustain damage in an earthquake. The severity of damage can range from very minor cosmetic cracking, which is common and widespread, to serious structural damage, which is uncommon outside areas of intense ground shaking. Absent conspicuous visible damage, earthquake-induced damage to the underlying framing is highly unlikely. Because wall surface materials often have the structural role of laterally bracing the structure, careful inspection for indicators of possible structurally significant damage is essential. If indicators of possible structurally significant damage are found, a structures specialist should be retained to inspect the house. If indicators of potential structurally significant damage are not found, damage to wall surfaces should be considered cosmetic and repaired in accord with the guidelines presented below in Section 5.8.

Cracking of wall surface materials due to non-earthquake causes is extremely common, especially in stucco. It is important to distinguish between earthquake-induced cracking and pre-existing cracking due to other factors.

In many situations, wall repair consists of patching and repainting the wall surface material. More severe damage may require installation of additional fasteners between the wall sheathing and the framing, localized removal and replacement of sheathing, removal and replacement of sheathing over the length of one or more walls, or installation of code required upgrades to the lateral load resisting system of the building. Repairs other than those described in Section 5.8 should be done in accord with recommendations of a structures specialist's report.

## **5.3 Limitations**

This document addresses only walls of conventional woodframe construction covered on at least one side with stucco, lath and plaster, or drywall. It also applies to conventional wall elements with wood board sheathing, plywood, or OSB beneath the finishes. It does not apply, however, to the following:

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<sup>50</sup> The terms “wall surface material” and “wall sheathing” are used in this document to identify the materials covering the wood stud wall framing. Stucco, plaster, and drywall are the most common materials used.



- Unconventional buildings characterized by unusual wall configurations, open plans with few room partitions, open exterior wall lines with little or no length of solid wall, or buildings containing steel frames.
- Walls of brick, concrete block, or stone masonry (except for veneer over woodframing).
- Adobe or log construction.
- Exterior wall finish materials other than conventional Portland cement stucco (such as exterior insulation and finish systems; wood, aluminum, or vinyl siding; wood, or cement-asbestos shingles).

## 5.4 Description of Typical Wall Construction

The overwhelming majority of California houses have walls of conventional wood stud framing consisting of 2×4 vertical studs (which actually measure 1-1/2 inch by 3-1/2 inch in modern construction) spaced at 16 inches with structural sheathing or a nonstructural finish applied to each face, as illustrated in Figure 5.1 and Figure 5.2. The framing typically includes diagonal bracing (let-in wood bracing or steel straps) or blocking (cut-in bracing) beneath the sheathing. Newer houses, especially two-story houses, can be expected to have plywood or OSB sheathing beneath a finish of stucco, siding, or stone veneer. Where present, plywood or OSB provides the structural bracing to resist lateral loads and the stucco and drywall/plaster serve only as nonstructural finishes. Accordingly, repairs to the finishes may be nonstructural. However, it should generally be assumed that all wall surface materials serve a structural function until determined otherwise by a structures specialist.

Typical exterior sheathing materials include stucco and panel siding (plywood or hardboard). Horizontal lap siding (wood, hardboard, or cement-board) is used as a weather barrier, but it is not effective as structural sheathing. Some houses have decorative areas of brick or stone masonry veneer. Less common (at least in California) exterior finish materials include cedar shingles, vinyl or aluminum siding, wood board and batten siding, and full brick or stone masonry veneer. In most cases, building paper is installed behind the exterior finish as a second line of defense against rainwater entry into the wall cavity.

Conventional stucco is typically a 7/8-inch thick layer of Portland cement plaster reinforced with wire mesh that is sprayed or troweled onto the wall in three layers and cures to a hard, durable finish, as illustrated in Figure 5.3. The three layers are termed scratch, brown and finish or color coat. Stucco may be applied to open framing or over wood sheathing. Where applied to open framing, regularly spaced line wire is stretched across the framing to provide temporary support for the building paper during the application of the scratch coat of stucco. Wire mesh nailed or stapled to the wall framing or sheathing provides both reinforcement of the cement plaster and attachment of the stucco to the building.

Typical interior finishes are plaster in older homes and drywall in newer homes. Plaster in most houses built since the mid-1930s is applied over gypsum lath nailed to the studs (also called buttonboard); although in older houses (through the early twentieth century) wood lath was used.

Ceramic or stone tile commonly found in bathtub and shower surrounds is typically applied over a lath and mortar base in older homes while various panel substrates are used in newer construction. Decorative plywood, hardboard, or solid wood paneling are used occasionally and are generally applied over drywall or plaster.

Walls serve several functions. As aesthetic elements, most walls are finished or decorated. As nonstructural elements, exterior walls protect the living space from the elements, and interior walls subdivide the living space. As structural elements, some walls support the weight of the roof or upper stories (bearing walls), and most walls serve to resist lateral forces from wind and earthquake (lateral system walls).

In addition to cosmetic effects, damage to a wall can affect its structural strength, stiffness, or stability and can also compromise its function as a weather-resisting building enclosure or as an architectural partition. As relatively stiff and brittle materials, drywall, plaster, and stucco are the wall components most susceptible to distress, even from causes other than earthquakes. By contrast, the underlying woodframing is quite flexible and is unlikely to sustain serious damage in the absence of significant conspicuous damage to wall finish materials. Accordingly, this chapter focuses on the brittle sheathing and finish materials.

The surface material of a wall is subject to stresses from gravity loads, long-term or seasonal foundation movement, temperature fluctuations, stucco shrinkage, and wind or earthquake loads. In an uninterrupted wall line, most stresses distribute uniformly through the sheathing. Door and window openings, however, create stress concentrations at their corners from which cracks originate. Doors and windows are also sensitive indicators of differential movements and can aid in evaluating damage.

## **5.5 Non-Earthquake Sources of Wall Damage**

Walls are subject to multiple types and sources of damage and distress during their service life, much of which goes unnoticed or is routinely repaired. This section describes conditions commonly found in stucco, plaster, and drywall and in doors and windows in the absence of earthquakes.

As discussed in Section 3, differential foundation movement is a common cause of wall cracks and operational problems in doors and windows. Due to their brittle nature, wall finish materials are sensitive to minor foundation movements, either settlement or heave. Soils in many areas of California are expansive, which results in swelling or shrinking with changes in soil moisture that can be related to seasonal rainfall, irrigation, plumbing leaks, improper drainage, or simple changes in drainage patterns. This soil movement causes distortion and cracking, generally in the form of diagonal cracks extending from the corners of door and window openings, and misalignment of doors and windows. These effects are often seasonal and cyclical, e.g., doors and windows may bind during one season but operate freely during other seasons. Fill settlement and creep of hillside soils have similar effects but do not exhibit cyclic seasonal variations. A common characteristic of cracking related to differential foundation movement is a unidirectional pattern of diagonal cracks in wall finishes, especially around openings (i.e., diagonal cracks only at one pair of diagonally opposite corners around a window) as illustrated

in Figure 5.4. The upper end of the crack will point toward the portion of the building that is down relative to that portion in the direction of the bottom end of the crack. The cracking will also be concentrated above the areas of greatest differential foundation movement.

### 5.5.1 Stucco

- Drying shrinkage – Like concrete, stucco shrinks slightly as it dries, and invariably cracks to some degree. The degree of visible shrinkage cracking is largely dependent upon workmanship, the amount of water in the stucco mix, and the amount of time the first two layers are allowed to cure and dry prior to application of the finish layer. The thin finish layer, often called the “color coat,” is typically pigmented with color so that painting is not required. There are four typical patterns of shrinkage cracks:
  - Diagonal cracks extending from the corners of door and window openings as shown in Figure 5.5. Where openings are close together, cracks will tend to extend from the corner of one opening to the next, rather than extending diagonally.
  - Semi-random, semi-orthogonal pattern (i.e., a grid work) of cracks in portions of walls without openings as shown in Figure 5.6. This pattern can often be seen when the thin finish coat is sandblasted during the course of a cosmetic renovation.
  - Roughly linear vertical cracks regularly spaced at about 16 inch intervals along the wall corresponding to the underlying studs as shown in Figure 5.7. This pattern is due to uneven application of the stucco: thick between the studs, but thin (and therefore prone to cracking) where the studs provided a rigid backing during application.
  - Cracking is a pattern of thousands of very fine, interconnected cracks that develops on the surface of the stucco and which is most commonly visible on unpainted, smooth finished stucco, as shown in Figure 5.8.
- Thermal expansion and contraction – Stucco also expands and contracts slightly with changes in temperature, which causes additional cracking and causes patched cracks to reappear. For this reason, it is common to see more cracking in stucco located on south and west facing walls than in north and east facing walls.
- Seasonal shrinking and swelling – Stucco in houses constructed with shallow foundations placed upon expansive soils may be subjected to stresses due to differential distortion due to seasonal shrinking and swelling of the foundation soils. These seasonal movements may cause preexisting cracks to open and close and repaired cracks to reopen.

- Sill line cracking – For houses built in California prior to the early 1970s it was common practice to extend the stucco seamlessly down over the concrete foundation to the ground surface. Due to a variety of factors, a horizontal crack often develops in the stucco along the line between the woodframe superstructure and the concrete foundation – the sill line. In newer houses, a sheet metal weep screed eliminates this crack because the stucco is not continuous over the wood-concrete interface.
- Construction joints and control joints are intentional discontinuities or planes of weakness built into the stucco, either as a result of additions to the building or attempts to control cracking. Well-defined linear cracks result. Sometimes, inattention to crack control will lead to a crack where a control or construction joint should have been installed. Control joints are uncommon in residential stucco.
- Framing movement – Woodframing members used in residential construction are often “green” (wet), especially in California. If stucco is applied to the woodframing before it reaches a dry state, stresses will develop and cracks and/or bulges may develop in the stucco. Because wood shrinkage and warping is most pronounced in larger members, cracks are most likely in such locations as headers over wide doors and windows and beams that support walls in the story above.
- Construction sequence effects – Stucco manufacturers recommend that upper stories should be built and heavy roof tiles should be loaded into place before the stucco is applied to the first-story walls. Otherwise, the additional strains caused by the weight of the upper stories and roof can crack the brittle first-story stucco.
- Improper installation of wire lath – Proper embedment of continuous wire lath reinforces the stucco and is essential for satisfactory performance. If the wire lath is not properly furred out from the substrate or if adjacent pieces of lath are not properly lapped, excessive cracking will develop.

### **5.5.2 Plaster**

- Seasonal shrinking and swelling – Plaster in houses constructed with shallow foundations placed upon expansive soils may be subjected to stresses due to differential distortion due to seasonal shrinking and swelling of the foundation soils. These seasonal movements may cause preexisting cracks to open and close and repaired cracks to reopen.
- Framing movement – Woodframing members used in residential construction are often green (wet), especially in California. If plaster is applied to the woodframing before it reaches a dry state, stresses will develop resulting in cracks and/or bulges developing in the plaster. Because wood shrinkage and warping is most pronounced in larger members, cracks are most likely in such

locations as headers over wide doors and windows and beams that support walls in the story above.

- Construction joints and control joints are intentional discontinuities or planes of weakness built into the plaster, either as a result of additions to the building or attempts to control cracking. Well-defined linear cracks result. Sometimes, inattention to crack control will lead to a crack where a control or construction joint should have been installed.

### 5.5.3 Drywall

- Seasonal shrinking and swelling – Drywall in houses constructed with shallow foundations placed upon expansive soils may be subjected to stresses due to differential distortion due to seasonal shrinking and swelling of the foundation soils. These seasonal movements may cause preexisting cracks to open and close and repaired cracks to reopen.
- Framing movement – Woodframing members used in residential construction are often “green” (wet), especially in California. If drywall is applied to the woodframing before it reaches a dry state, stresses will develop and cracks and/or bulges may develop in the drywall. Corner bead cracks and separation often occur at the bottom of large beams or headers as a result of shrinkage of the beam relative to the non-shrinking drywall. Cracking due to framing movement and shrinkage is most common:
  - Around window headers.
  - At drywall returns or jambs at windows.
  - At large headers over wide door and window openings.
  - At large beams or posts.
  - In stairwells.
  - At the juncture between interior partitions and ceilings attached to the bottom of prefabricated wood trusses.
  - At the apex of cathedral ceilings.
- Gaps – Minor gaps are common where drywall abuts exposed framing, such as exposed wood beams.<sup>51</sup> The source of the gaps is a combination of construction imperfections and shrinkage of the exposed framing members.

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<sup>51</sup> At exposed large beams, twisting, splits, and checks running along the length of the beam are a natural phenomenon of the drying process of the beam and are generally not an indication of a structural problem and are not the result of the earthquake.

- Nail pops – If woodframing dries and shrinks after drywall installation, or if the drywall nails or screws are not drawn tight, the fastener head will, in time, cause a circular crack and/or a slight bump in the finish over the fastener as shown in Figure 6.7. Nail pops generally occur in random locations (unless one part of the house was subject to the poor workmanship of a single drywaller during construction).

#### **5.5.4 Ceramic and Stone Tile**

- Cracking of isolated tile at reentrant corners, and cuts for plumbing are common.
- Cracking of grout lines at wall corners and at the juncture with tubs, shower pans, and floors is common due to minor shrinkage and thermal movements.
- Deterioration and decay of underlying framing from water leakage is common in walls and floors around showers and bath tubs.

#### **5.5.5 Doors and Windows**

Doors and windows require close alignment for proper operation. In addition to differential foundation movement discussed previously, poor construction quality, framing shrinkage, wood swelling, thermal expansion, and loose or deteriorated hardware can contribute to operability problems with doors and windows.

#### **5.5.6 Wood Trim**

Gaps, separations, and openings in the joints of wood trim can result from poor workmanship, cracking of paint that once concealed a gap, or shrinkage of wood trim itself. It can also result from differential foundation movement or shrinkage of the woodframing.

### **5.6 Earthquake-Induced Wall Damage**

Stucco, plaster, and drywall are among the first components of a woodframe house to sustain damage in an earthquake. The severity of damage can range from very minor cosmetic cracking, which is common and widespread, to extensive cracking and delamination of the wall sheathing materials. Earthquakes generate lateral (sideways) forces in buildings that cause walls to rack back and forth (i.e., be distorted out-of-square as the upper story or roof moves horizontally relative to the ground) as illustrated in Figure 1.4 and Figure 1.5. Those forces can also cause walls to slide if not securely attached to the foundation. In the vast majority of cases, damage is confined to the wall finishes and sheathing, and damage to the underlying framing is uncommon. Wall surfaces can also be locally damaged by impact from contents, mechanical equipment, or collapsing fences or chimneys.



A key characteristic of earthquake-induced wall cracking is a symmetric pattern of diagonal cracks in wall finishes with similar diagonal cracks radiating from all four corners of window openings as illustrated in Figure 5.10. Cracking will typically be present in similar locations on both faces of a wall and, for most multi-story residential buildings, larger and more concentrated in the lowest story as shown in Figure 5.11.

A key indicator of the severity of damage to walls is the degree of residual racking in the wall. Little or no residual racking indicates, in most cases, an absence of structurally significant damage. Residual racking that results in broken window glass or impairs the operation of doors or windows indicates the possibility of structural damage and the need for evaluation by a structures specialist.

### **5.6.1 Stucco**

Diagonal cracks at door, window, and vent openings are the first stucco cracks to form (assuming an absence of shrinkage cracks) in an earthquake. The extent of this cracking may be indistinguishable from normal temperature and shrinkage cracking. With stronger ground shaking, the diagonal cracks widen, spalling of stucco along cracks may occur (Figure 5.12), and “X” cracks (Figure 5.13) may form in stucco panels between window openings. Figure 5.14 illustrates the relationship between cracking and racking of a laboratory specimen of a woodframed wall sheathed with stucco and drywall. If the shaking is strong enough, the stucco attachments can be damaged, and the stucco panels can detach from the woodframing in sheets. This failure mode, called delamination, is most likely in long stiff wall lines with few openings or in solid segments of walls between full height openings such as doors, as shown in Figure 5.15. It generally begins as detachment from the sill plate along the base of the wall. Walls where the stucco mesh was not fastened to the sill plate are especially vulnerable to this mode of failure.

The building paper beneath the stucco finish is more flexible and less brittle than stucco. Post-earthquake inspections of garages, crawlspaces, and other areas where the backside of the stucco wall is exposed have shown that the stucco can crack without affecting the building paper or the woodframing. Therefore, if the stucco itself is repairable and the repair is confined to treatment of the individual cracks, hidden damage to the building paper or studs is extremely unlikely, and removal of stucco for inspection is generally not necessary.

Stucco that extends down over the concrete foundation is susceptible to cracking along the sill plate line, as shown in Figure 5.16. Fresh cracking that is continuous around the building with signs of relative movement between the superstructure and the foundation is cause for assessment by a structures specialist. Inspectors should look along the sill plate and at wall ends for consistent offsets exceeding 1/4 inch that would indicate sliding of the wall line on its foundation. In multi-story houses, especially those built over crawlspaces, buckling of the stucco will occasionally occur just above the sill plate line as shown in Figure 5.20.

### **5.6.2 Drywall**

The first earthquake-related cracks to form in drywall usually occur at the corners of door, window, and vent openings; along taped joints near those openings; and at locations of previously patched cracks. As the strength of shaking increases, these cracks will extend in length and width, and cracks may form along corner beads, interior wall corner joints, wall-to-ceiling joints, and/or along tape joints between drywall sheets (Figure 5.17). Nail pops may form along the edges of a wall, especially near the ceiling. With stronger shaking, the diagonal cracks widen, and “X” cracks can form, particularly at panels between windows. In severe shaking, it is possible for drywall to detach from the framing.

### **5.6.3 Gypsum Lath and Plaster**

Plaster is like weak stucco, while gypsum lath is panelized, similar to drywall. Earthquake damage patterns in a lath and plaster system are thus combinations of those typical of stucco and drywall. The first earthquake damage to appear usually includes diagonal cracks at the corners of door and window openings. With more intense shaking, the plaster will generally crack and spall along the lath panel joints, often in a stair step pattern as shown in Figure 5.18. In severe shaking, detachment of the lath from the framing is possible.

Wood lath found in older houses is not panelized like gypsum lath. Typical damage patterns in plaster over wood lath are closer to those of weak stucco than those in panelized gypsum lath.

### **5.6.4 Ceramic and Stone Tile**

Earthquake damage patterns in ceramic and stone tile wall finishes are similar to those of other wall finishes as shown in Figure 5.19. Diagonal cracking of tile or stair step cracking of grout lines at reentrant corners around wall openings (if present) and cracking of grout lines at wall corners and wall/floor intersections are most common.

### **5.6.5 Doors and Windows**

Earthquake damage to doors and windows occurs when their openings are racked out-of-square. Thus, the performance of doors and windows depends on the lateral resistance and overall performance of the building. Damage to doors and windows is typically accompanied by distress to the adjacent walls. Without typical cracking in adjacent wall elements, no damage to the doors or windows would be expected. In strong shaking, misalignment of door/window hardware or minor permanent racking of the openings could occur. Severe shaking can cause permanent racking of the openings, broken window glass, damage to hardware, and damage to the actual door or window unit rendering it inoperable.

Doors and hinged windows (especially casement windows) are sensitive to permanent racking of their openings and can serve as good indicators of any permanent racking of the wall. A consistent pattern of impaired operation of doors and/or hinged windows, accompanied by damage to the adjacent or aligned walls, may be indicative of earthquake-induced racking of the building and warrants evaluation by a structures specialist.

## 5.7 Assessment Guidelines and Methodology

Initial inspection of wall elements consists primarily of visual examination of the patterns and details of visible cracks. In addition, manual inspection is necessary to confirm that sheathing materials (stucco, plaster, and drywall) remain tightly attached to the wood stud framing. The operation of doors and windows should also be checked, looking for damage consistent with observed wall cracks. The following paragraphs describe many detailed observations that must be made. However, the most important aspect of the visual examination is assembling the pattern of damage from those details. For example:

- are there diagonal cracks radiating from all four corners of all window openings in both the interior and exterior wall finishes of a wall?
- is there conspicuous cracking of the wall finishes at the corners of visibly out-of-square openings?
- in multi-story buildings, is the cracking more severe on the lowest story?

### 5.7.1 Exterior

A thorough exterior inspection should include examination of all elevations of the building. Areas of cracking should be documented and photographed. If no cracking is observed, this also should be documented and photographed. Absent obvious signs of previous patching or paint within a crack, it is sometimes difficult to distinguish minor earthquake-related stucco cracks from non-earthquake cracks. If the plaster or drywall finishes on the interior face of the wall also exhibit a pattern of earthquake-induced cracking, it is reasonable to conclude that the earthquake caused much of the observed exterior stucco cracking. If the interior finishes are undamaged, earthquake shaking is likely not the predominant cause of the stucco cracking, even if it might have exacerbated pre-existing cracks enough to make them visible.

All exposed wall surfaces should be carefully observed through close visual inspection where safely accessible (a pair of binoculars allows inspection of the upper portions of multi-story houses without ladder work). Check for the following damage patterns and document their location and severity:

- Racking/leaning of the building.
- Window or door openings racked out-of-square.
- Separation between different portions of buildings, such as where roofs or floors are discontinuous (e.g., in a split-level house), or where the main house attaches to a garage, addition, porch, or other building wing.
- Cracking, particularly adjacent to wall openings, at reentrant corners, along the sill line (Figure 5.20), and around the exterior of the fireplace/chimney.
- Bulging or buckling of the stucco or wall finishes as shown in Figure 5.21.

- Detachment of the stucco from the framing, using visual and manual inspection where the studs are exposed (e.g., inside the garage as shown in Figure 5.22) and along exposed edges of the wall surface materials or sheathing (e.g., along the sill line and at door openings). A mirror is useful for examining the bottom edge of the stucco. Hand pressure or hand pull along the bottom edge of the stucco may also be used to feel for any detachment from stud framing.

To the extent possible, assess the age of any observed damage patterns that are not obviously earthquake-related.

If all of the following conditions are true, then any earthquake damage may be judged structurally insignificant and may be repaired as discussed in the following subsection.

- The building is plumb.<sup>52</sup>
- Stucco has not become detached from framing.
- All fresh cracks are located at corners of openings or wall discontinuities and are no more than 1/16-inch wide, and there is no spalling of stucco that exposes the wire mesh reinforcing.

If any of the following conditions exist, an evaluation should be performed by a structures specialist:

- The walls are racked visibly out of plumb, or doors and/or windows have been rendered inoperable by the earthquake due to their openings being racked out-of-square (excluding patio doors and closet doors that have come off their tracks or doors and/or window rendered inoperable due to hardware failure or impact damage).
- The stucco has developed cracks wider than 1/16 inch (the thickness of a nickel) and more than about 3-feet long or across the full width of a wall section between door or window openings.
- There is loose, bulging, or buckled stucco and/or fresh cracking along the sill plate line and evidence indicating possible relative movement between framing and foundation.
- Any cracks are greater than 1/8-inch wide or spalling has occurred that has exposed wire mesh reinforcing.

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<sup>52</sup> Neither structures nor components of structures are built perfectly plumb. Construction tolerances for wall plumbness range from 1/4 inch over an 8- or 10-foot wall height to 3/8 inch over a height of 32 inches. Distinguishing between an out-of-plumb condition associated with earthquake damage to surrounding wall finish materials and normal construction imperfections is essential to proper evaluation of potential earthquake damage. Lack of plumbness in the absence of other earthquake damage is generally indicative of construction imperfection and does not generally warrant engineering assessment or repair.

- There is evidence of detachment or delamination of stucco from the framing (as determined by manual inspection).
- The house is taller than one story and has one or more open exterior wall lines in the first story with visible damage.
- The building has been yellow-tagged for reasons other than a damaged chimney.
- The building has been red-tagged.
- The building configuration, location, or damage state fall under criteria adopted by the local building department that require an assessment by a structures specialist.

### **5.7.2 Interior**

The inspection should include a thorough interior inspection involving a room-by-room examination of wall and ceiling finishes. Areas of cracking should be documented and photographed. If no cracking is observed, this also should be documented and photographed. Absent obvious signs of previous patching or paint within a crack, it is sometimes difficult to distinguish minor earthquake-related plaster and drywall damage from non-earthquake cracks.

All exposed wall surfaces should be carefully observed, with manual inspection (hand pressure to feel for any sheathing detachment from stud framing) where safely accessible. Careful observation and attention to detail are essential. Wallpaper, paneling, and veneer can hide much of the minor cracking typical of both pre-earthquake and earthquake-related causes. Structurally significant damage can tear wallpaper and buckle or detach paneling. Still, where these finishes are present, the inspector should not rely on visual inspection alone, but should feel for loose paneling or bulging plaster beneath the wallpaper, especially at the corners of door and window openings. Check for the following damage patterns, and document their location and severity:

- Cracks or bulges in wall and ceiling finishes – If wall surfaces are finished with wallpaper, feel along the corners of openings for any bulges or tears in the underlying wall finish.
- Fresh separations between the wall and the floor (Figure 5.23) or between the wall and the ceiling.
- Differential movement or separation around the fireplace.
- Interior wall surface cracks aligned with cracks in the perimeter foundation or exterior stucco.
- Damage from falling or shifting contents or mechanical equipment.

- Window or door damage, including general condition and wear, squareness of opening, smoothness of operation, and evidence of pre-earthquake condition.
- Plumbness of doorjambs – Use a digital level to check plumbness and levelness of doorframes. If out of plumb, note direction of tilt and check for a pattern of tilts and associated cracking of surrounding wall finishes throughout the house.

If both of the following conditions are true, then any earthquake damage may be judged structurally insignificant and may be repaired as discussed in the following subsection:

- Where finish cracking is present, there is no pattern of racking of walls or wall openings of more than  $\pm 0.2$  degrees ( $\pm 3/8$  inch over 8 feet) from plumb.
- All interior finish cracks are no wider than 1/16 inch and are located in areas of expected earthquake damage (corners of openings, wall discontinuities, and drywall joints, and so on).

If any of the following conditions exist, assessment by a structures specialist should be performed:

- The walls are racked visibly out of plumb, or doors and/or windows have been rendered inoperable by the earthquake due to their openings being racked out-of-square (excluding patio doors and closet doors that have come off their tracks or doors and/or window rendered inoperable due to hardware failure or impact damage).
- Gypsum wallboard or lath is bulging, loose, or has detached from the framing.
- Interior finish cracks are wider than 1/16 inch or occur at locations away from panel joints or the corners of door or window openings.
- The house is taller than one story and has one or more open exterior wall lines in the first story with visible damage.

### **5.7.3 Technical Consultant Assessment**

Assessment by a structures specialist should include detailed visual inspection of interior and exterior wall finishes, manual testing or probing, and measurement (and sometimes mapping) of cracks, as outlined in Appendix 9B. Based on findings of that non-invasive assessment, the structures specialist may recommend invasive inspection. Invasive inspection may be necessary in those instances when the structures specialist is unable to rule out or reasonably assume the existence of concealed earthquake damage based on their non-invasive assessment. Potential invasive inspection work is outlined in Appendix 9B.



If the building was constructed prior to 1980 and repair work will involve disturbance (demolition, removal, grinding, sanding, etc.) of any of the following types of wall finishes, a suitably qualified environmental consultant should be retained,

- Wall materials that may contain asbestos include:
  - Gypsum joint compound (drywall “mud”)
  - Interior plaster
  - Exterior stucco
  - Asbestos-cement siding
- Wall materials that may contain lead-based paint consist of enamel paint applied to:
  - Doors, windows, and trim
  - Kitchen and bathroom walls and cabinets
  - Exterior metals

As discussed in Section 9.2.4, the consultant should test for the presence of regulated hazardous materials and, if the results of the tests are positive, recommend appropriate abatement and waste disposal measures.

#### **5.7.4 Establishing the Cause of Cracks**

In addition to details of individual cracks, the pattern of cracking provides an excellent indication of the source, cause, and age of cracks in wall sheathing. Shrinkage cracks occur at planes of weakness or emanate from openings or reentrant corners. Initial earthquake-induced cracking of wall finishes also occurs at these locations, so distinguishing between the two causes is not always easy. Where cracks appear consistently at corners of multiple openings in both the interior and exterior finishes of a given wall line, the cracks are, absent indicators to the contrary, most likely earthquake induced. More random cracking or cracking that occurs in only the exterior or interior finish is likely due to non-earthquake causes. Earthquake-induced cracking should be reasonably consistent over the length of any given wall line as illustrated in Figure 5.10. Cracking confined to only a portion of the building may be due to non-earthquake causes. For example, cracking caused by differential settlement is associated with changes in floor slopes and generally occurs in or is much more pronounced in one portion of the building as illustrated in Figure 5.4. If there are signs of earthquake-induced permanent ground deformation at the site and a technical consultant concludes that the earthquake caused differential foundation movement, then the associated cracking of wall finishes is likely earthquake related. Otherwise, highly localized cracking of wall finishes is likely related to non-earthquake causes. Very straight vertical cracks indicate a construction joint, a control joint, or an addition to the building. Very straight horizontal cracks can indicate a location of poorly lapped wire mesh; such a location is likely to attract shrinkage cracking.

The most reliable indicator of an earthquake contribution to an observed wall crack is the presence of corresponding earthquake damage to doors, windows, and adjacent cosmetic finishes that would otherwise be operable and well-maintained. Absent any corresponding damage, the age of cracks can often be determined by visual examination of the crack surfaces. Visible indicators are most reliable in the weeks immediately following the earthquake and become less so as time passes, cracks weather, repairs are made, and other events intervene to obscure fresh damage.

Characteristics of cracks that provide clues as to whether the cracks are fresh or a long-term condition include:

- Contamination of crack surfaces: Fresh cracks exhibit clean fracture surfaces free of paint.
- Grout, caulk, or other patching or repair material in the crack, or other evidence of past repair, such as drywall tape.
- Dirt, dust, or other debris in the crack.
- Sharpness of the crack edge: Fresh cracks exhibit sharp edges free of weathering, rounding, or erosion. If the surface has been painted, the condition of the paint along the crack edge can be a very good indicator. A sharp fresh break in the paint indicates that it developed recently. A rounded edge on the paint indicates that the crack was present when the wall was last painted. Slight curling of the paint along the crack edge indicates that the crack is not recent, but developed since the wall was painted. Note that cracks in protected locations, such as inside closets or behind furniture will not “weather” and may look sharp and fresh for many years.
- Relative color of the crack surfaces and the exposed surface of the element.
- Recent differential movement between adjacent elements is generally manifested by exposure of unpainted surfaces, torn caulk or expansion joint material, staining or debris remnants, gaps between trim, and the abutting surface, etc.

## **5.8 Repair Methodologies**

The appropriate repair of lateral system and bearing walls must consider the nature, extent, cause, and significance of the damage. Where earthquake damage has occurred in other components of the house, wall repair should be considered as one component of a more general repair plan. For example, if the house has been racked out of plumb, it should be straightened prior to repairing wall finishes, doors, and windows. Where the damage is structurally significant, a structural repair will be necessary. In all other cases, a nonstructural repair is appropriate.

Table 5-1 gives appropriate repair methods for typical earthquake damage patterns. If the cause of an observed damage pattern cannot be determined, or if the damage is outside the description given in the table, a structures specialist should be retained to specify appropriate repair. The repair methods listed in the table are further discussed below.

**Note:** The repair methods presented in this chapter presume that the building materials are free of regulated levels of hazardous materials. If testing as recommended in Section 9.2.4 indicates the presence of regulated levels of asbestos or lead, the abatement and waste disposal recommendations of the environmental consultant should be incorporated into the overall scope of repair.

Some California jurisdictions have local building code provisions that impose additional repair requirements if the earthquake damage exceeds either a certain percentage of the wall line's strength or if the cost of repair exceeds a certain percentage of the wall line's replacement cost. Damage patterns described above as structurally insignificant represent less than a ten percent capacity loss. Repair cost as a percentage of replacement cost may be estimated by a contractor. If the structural significance of the damage or the application of building code provisions are in question, an assessment should be performed by a structures specialist.

Table 5-1 does not include any jurisdiction-specific upgrade requirements. If such requirements apply, then an engineered repair will likely be needed.

## **5.8.1 Crack Repair**

### **5.8.1.1 Stucco**

- Fine cracks (i.e., 1/64-inch wide or narrower) should not be patched, especially if the stucco is not painted. On painted stucco, cracks this fine will be sealed by a fresh coat of paint. When determining the area to be painted, consideration should be given to obtaining a reasonably uniform appearance.
- For cracks up to 1/8-inch wide, the crack should be opened to the brown coat by beveling the crack edges to accept patching material. Patch with flexible vinyl base patching compound. Stucco should be applied to match the existing surface texture, as necessary. The stucco should be refinished as necessary to match adjacent areas. When determining the area to be refinished, consideration should be given to obtaining a reasonably uniform appearance.

**Table 5-1. Repair methods not requiring technical consultant assistance for nominal earthquake damage to woodframe wall surface materials**

Wall Component	Earthquake Damage Pattern	Repair Method*
Stucco	Cracks up to 1/64-inch wide	No crack repair
	Cracks up to 1/8-inch wide, no delamination, no spalling	Rout, patch, and refinish
	Extensive minor cracking	Remove color coat, rout, patch, and recoat
Drywall	Short cracks up to 1/64-inch wide	Patch and refinish
	Cracks following taped joints or corner bead	Remove existing tape and joint compound, retape, and refinish
	Cracks up to 1/8-inch wide through drywall	Remove and replace drywall to nearest studs beyond crack (minimum 32 × 48 inches), refinish
	Nail pops	Add drywall screw 1 inch from original fastener, set or remove original fastener, patch and refinish
Gypsum lath and plaster	Short cracks up to 1/64-inch wide	Patch and refinish
	Cracks up to 1/8-inch wide, no delamination or significant spalling	Rout, patch, and refinish
Construction joints	Minor movement	Caulk, patch, or repaint to match pre-earthquake condition

\* Repair methods presented in this table presume that the building materials are free of regulated levels of hazardous materials. If testing as recommended in Section 9.2.4 indicates the presence of regulated levels of asbestos or lead, the abatement and waste disposal recommendations of the environmental consultant should be incorporated into the overall scope of repair.

- When the number of cracks to be patched becomes extensive, it may be more economical to remove the existing finish coat with sandblasting and then apply a new finish coat. The process of sandblasting will accentuate cracks visible in the finish coat and expose cracks in the brown coat. It is important to note that cracks exposed by the sandblasting are shrinkage cracks that date from the original application of the stucco and not earthquake-induced cracking. A stucco finish coat, even if painted with latex paint, has no ability to conceal earthquake-induced cracking of stucco. When determining the area to be refinished, consideration should be given to obtaining a reasonably uniform appearance.

### **5.8.1.2 Drywall**

- Where cracking follows panel joints or corner beads, existing tape and compound should be removed. The joint should then be retaped, retextured, and repainted. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.
- Short (less than about 6-inches long) cracks less than about 1/64-inch wide extending from the corners of openings may be patched using drywall tape and joint compound, retextured and repainted. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.
- Where cracks greater than about 6-inches long extend through the drywall, the cracked piece should be removed to the nearest stud on either side of the crack (32-inch minimum width, 48-inch height) and replaced, retextured, and repainted. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.
- Nail pops may be repaired by adding a drywall screw adjacent to the nail pop, resetting or removing the “popped” fastener, patching, retexturing to match the adjacent finish and repainting. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.

### **5.8.1.3 Gypsum Lath and Plaster**

Where the plaster is cracked but remains firmly attached to the lath, repairs can be accomplished by cleaning the crack and patching, texturing, and painting to match the existing surface texture and finish. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.

## **5.8.2 Construction Joints**

Where minor movement has occurred at construction joints, only cosmetic repairs are necessary. Where these joints were simply painted, the appropriate repair is to clean and repaint the joint. Where caulking and/or grout along the joints has cracked or spalled (such as along shower enclosures), the appropriate repair is to remove the cracked material, clean the separation, and recaulk or regROUT the joint where necessary. It should be noted that even after the repairs are complete, cracks and/or separations may reappear due to the normal effects of material shrinkage, temperature changes, and minor differential movements of supporting elements (soil or structure). The reoccurrence of damage is unrelated to the earthquake. If damage occurred because there was no joint where there should have been one, then again, the damage is generally not structurally significant.

### **5.8.3 Technical Consultant Repair Recommendations**

The following repair procedures are typical repairs that might be recommended in a structures specialist report. They should not be used in the absence of recommendation by a structures specialist and are presented here for reference only.

#### **5.8.3.1 Stucco Repair**

Where the stucco has buckled, delaminated, detached from the framing, or is severely cracked, the existing stucco should be removed back to intact, securely attached stucco. The underlying building paper should be repaired or replaced as necessary, and any new paper should be properly lapped with the existing paper. New wire mesh should be installed and nailed to the framing and it should overlap existing mesh by at least 6 inches. Stucco should be applied, in three coats, to match the existing thickness and surface finish. The stucco should be refinished as necessary to match adjacent areas. When determining the area to be refinished, consideration should be given to obtaining a reasonably uniform appearance.

#### **5.8.3.2 Drywall Repair**

Fractured gypsum wallboard panels should be replaced in kind. Where the attachment of the drywall to the framing has loosened significantly, new fasteners should be installed around the wall perimeter and along panel joints showing signs of relative movement. The repaired areas should be refinished as necessary to match adjacent areas. When determining the area to be refinished, consideration should be given to obtaining a reasonably uniform appearance.

#### **5.8.3.3 Plaster Repair**

Where the lath has fractured (or where plaster damage suggests fracture of the gypsum lath), the damaged pieces should be removed to soundly attached plaster and/or lath, new lath installed and the area replastered. Where larger areas of repair are involved, and it is more economical to do so, lath and plaster should be removed to the limits of the wall panel and replaced with drywall.<sup>53</sup> When determining the area to be refinished, consideration should be given to obtaining a reasonably uniform appearance.

#### **5.8.3.4 Framing Repair**

Severe damage to stucco or interior wall finishes indicates substantial wall racking and the possibility of damage to woodframing members, especially nailed connections at the sill or top plates. These conditions call for assessment by a structures specialist. If framing damage is found, replacement, renailing, or “sistering” of the affected members is usually the appropriate repair, but that judgment should be left to the structures specialist.

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<sup>53</sup> If drywall is used, modification of trim at ceilings, floors, windows, and doors, may be necessary. If the plaster being replaced is 5/8-inch thick plaster reinforced with expanded metal lath over 3/8-inch gypsum lath, it may be necessary to install 1/2-inch plywood sheathing beneath the drywall to restore the strength of the wall assembly. Installation of 1/2-inch plywood will eliminate the need for modification of trim, in most cases.



#### **5.8.3.5 Building Realignment**

When a building has been permanently racked out of plumb by more than 1/2 inch over a height of eight feet, as evidenced by a consistent pattern of damage to finishes, inoperable doors and/or windows, and out-of-plumb measurements of door and window jambs, it will generally be necessary to remove finishes from the racked walls, plumb the building, and reinstall finishes. It is essential to distinguish between overall earthquake-induced racking of the building and normal construction tolerances or other pre-existing conditions.

#### **5.8.4 Permits, Upgrades, and Retrofits**

Depending upon the nature and scope of damage and proposed repair, building permits and other government agency approvals may be required by the local jurisdiction. In addition to normal changes in the building code over time, some jurisdictions have building code requirements that mandate upgrading portions or all of the building, if certain damage thresholds are exceeded. Check with the local building department to determine the existence of any applicable local requirements.

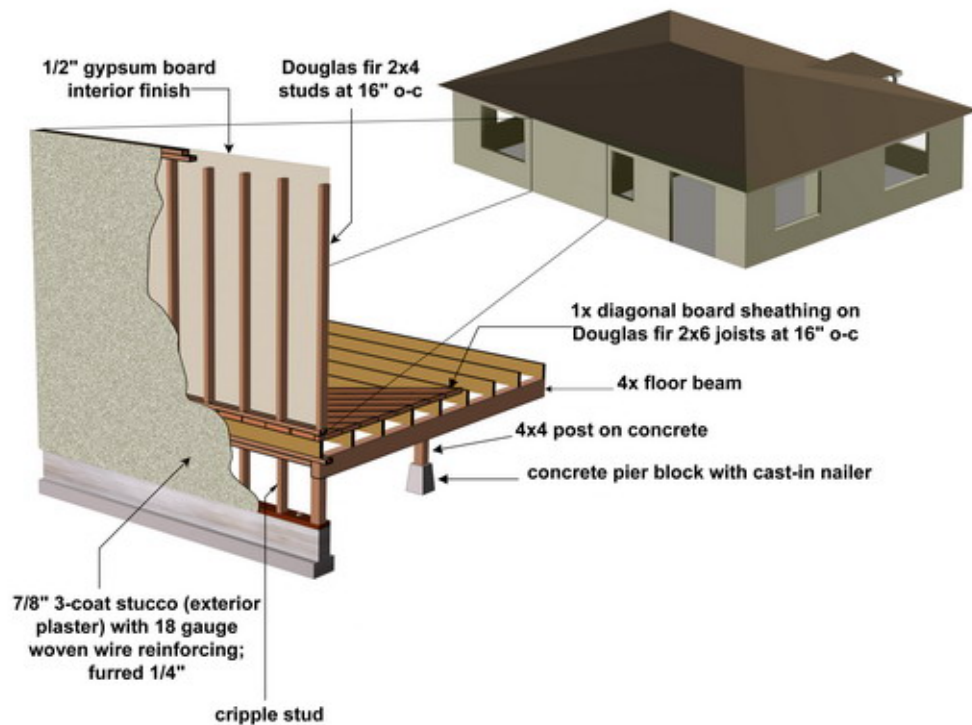


Figure 5.1. Typical wall construction for older single-story houses in California – sheathing materials may vary [CUREE].

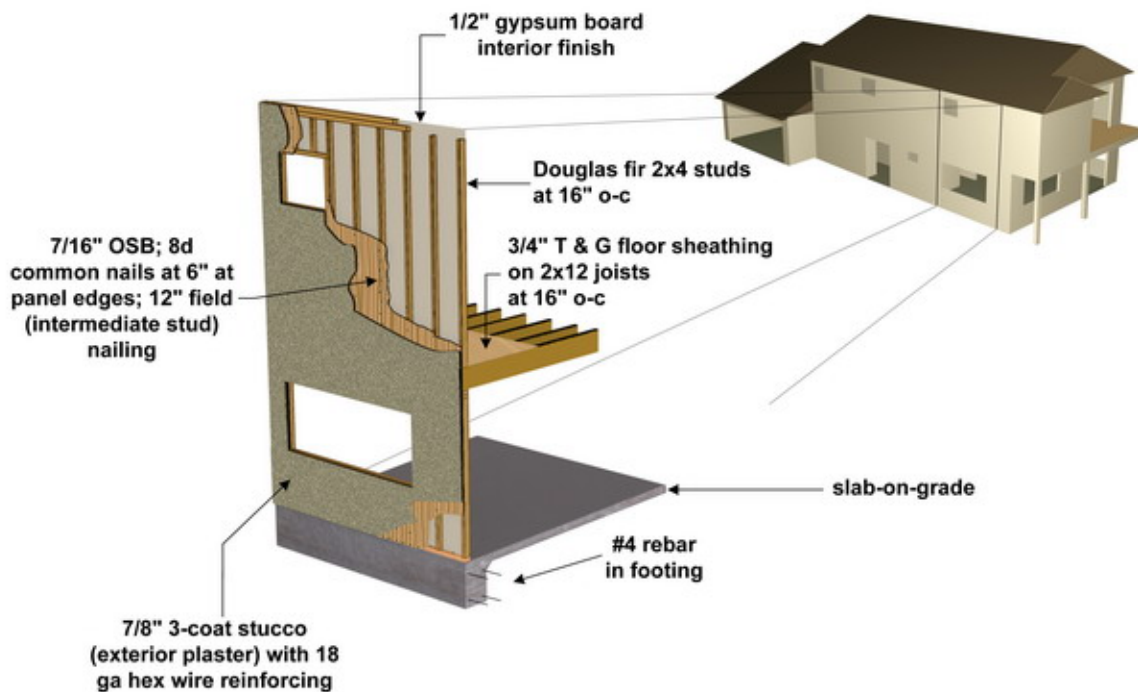


Figure 5.2. Typical wall construction for more modern two-story houses in California – sheathing materials may vary [CUREE].

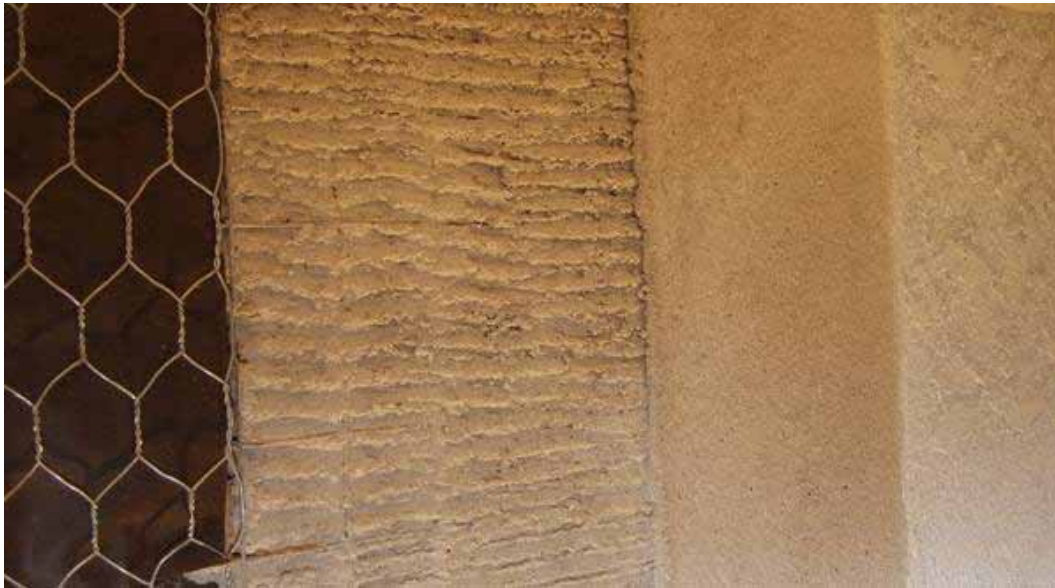


Figure 5.3. Mock-up of typical three-coat stucco showing building paper, wire lath, scratch coat, brown coat, and finish or color coat [Exponent].

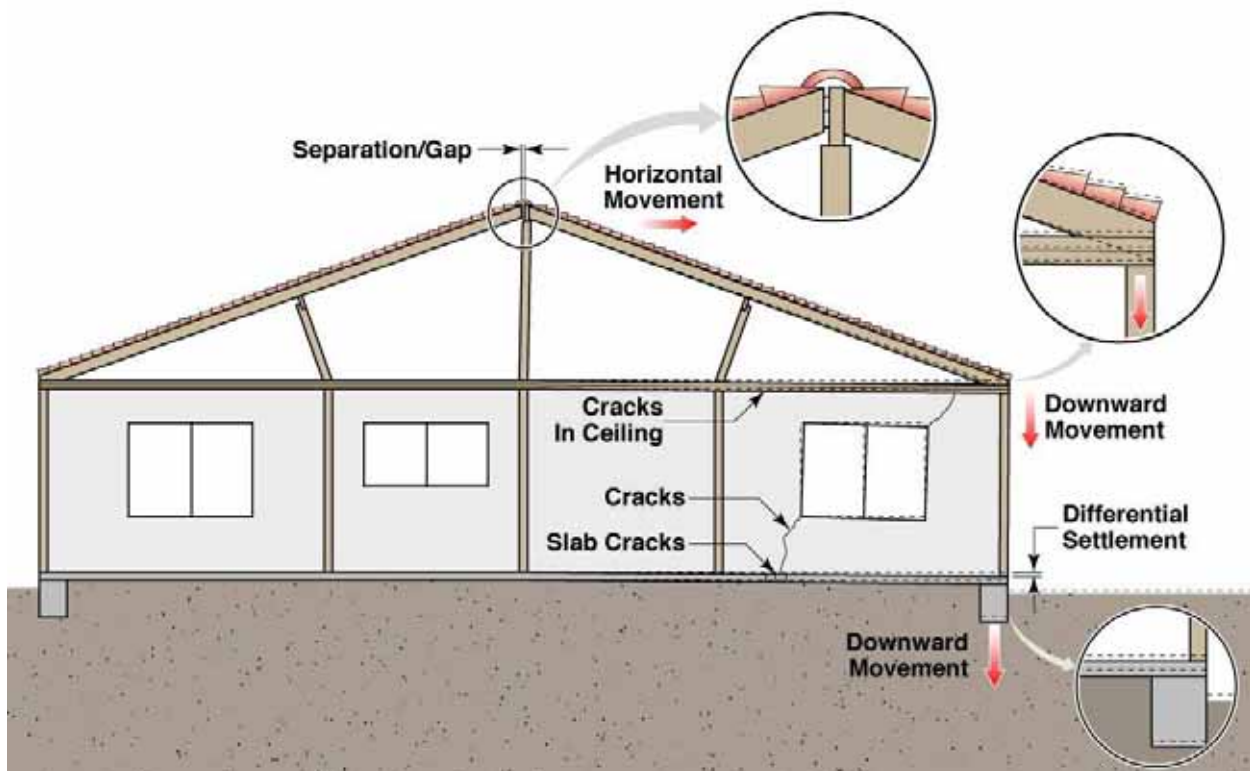


Figure 5.4. Illustration of common effects of differential settlement [Exponent].



Figure 5.5. Diagonal shrinkage cracks extending from the corners of a wall opening in stucco (not earthquake damage) [Exponent].



Figure 5.6. Semi-random, semi-orthogonal grid work of non-earthquake shrinkage cracks in stucco – note that cracks are highlighted by patching material applied in the course of repainting the building [Exponent].





Figure 5.7. Roughly linear vertical non-earthquake shrinkage cracks corresponding to the locations of underlying studs; crack locations have been highlighted with parallel lines of blue chalk [Exponent].



Figure 5.8. Magnified crazing cracking (not earthquake damage) in stucco – circle is 5/8-inch across; bumps are grains of sand in stucco texture [Exponent].



Figure 5.9. Stucco terminated at weep screed on mudsill of recent addition (right) juxtaposed with stucco extended down onto the original foundation (left), as was commonly done prior to the early 1970s – slab-on-grade floor with continuous perimeter footings shown (not earthquake damage) [Exponent].

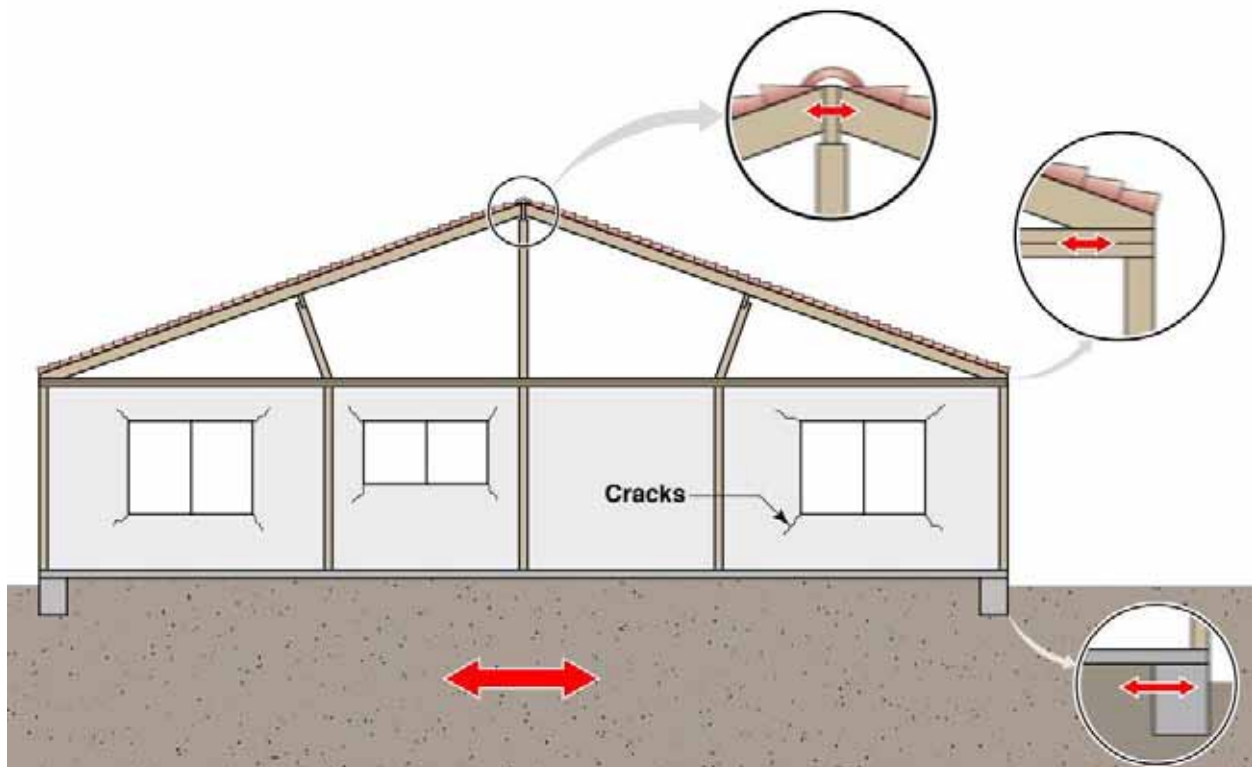


Figure 5.10. Typical crack pattern in wall finishes due to minor earthquake shaking [Exponent].





Figure 5.11. Severity of earthquake-induced cracking of wall finishes of multi-story buildings generally decreases at upper stories [Exponent].



Figure 5.12. Severe cracking and spalling of stucco wall test specimen after earthquake load testing [Exponent].



Figure 5.13. Earthquake-induced “X” cracking in stucco panels between windows (thin brick veneer had been installed over stucco).

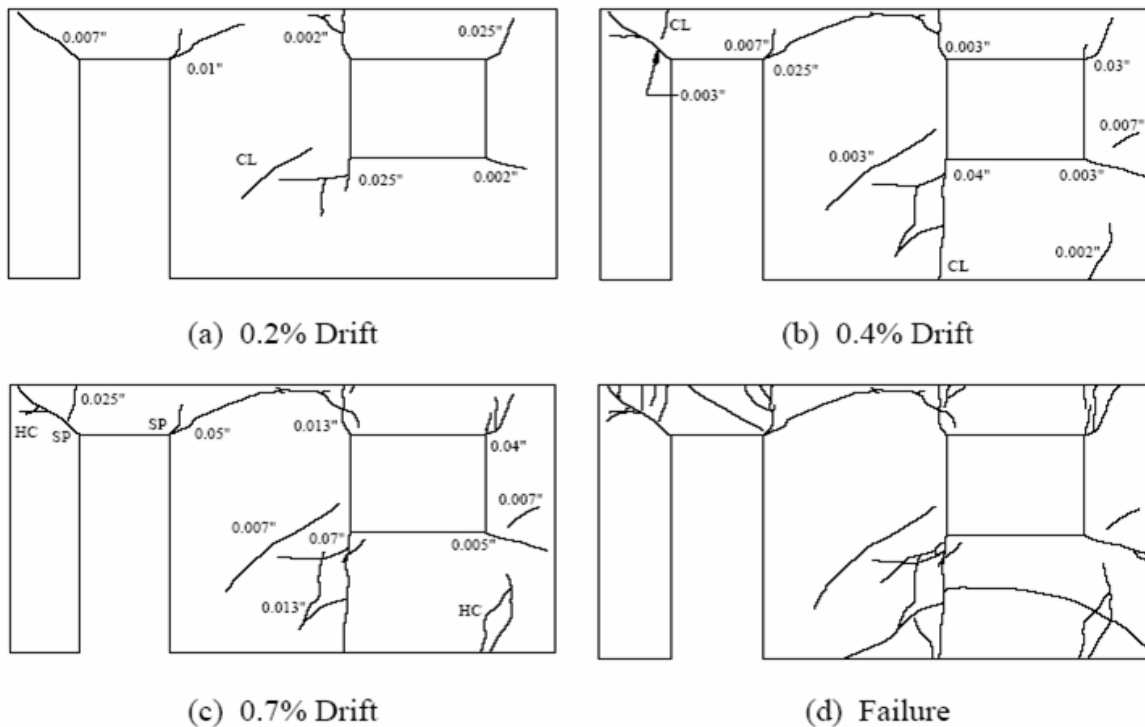


Figure 5.14. Relationship between seismic drift (racking) of wall and cracking of stucco finish of laboratory test specimen [CUREE].



Figure 5.15. Earthquake-induced delamination of stucco from woodframing and associated damage to aluminum door frame [Exponent].



Figure 5.16. Earthquake-induced crack in stucco at sill line where stucco was extended down over the foundation, as commonly done prior to the early 1970s (concealed framing is raised wood floor over continuous perimeter concrete stem wall) [Exponent].





Figure 5.17. Earthquake-induced cracking of drywall as a result of strong shaking [Exponent].



Figure 5.18. Earthquake-induced cracking and delamination of gypsum lath and plaster [Exponent].



Figure 5.19. Earthquake-induced cracking of ceramic tile [Exponent].



Figure 5.20. Earthquake-induced cracking and buckling of stucco at the plate line where stucco was extended onto the perimeter concrete stem wall [Exponent].



Figure 5.21. Stucco cracking and buckling at cripple wall following the 2003 San Simeon Earthquake [Exponent].





Figure 5.22. Earthquake-induced racking and delamination of stucco as viewed from backside (garage) [Exponent].



Figure 5.23. Earthquake-induced displacement of an interior partition due to inadequate attachment to floor slab [Exponent].



## **6 Floors, Ceilings, and Roofs**

### **6.1 Quick Guide**

#### **6.1.1 What to Look For**

- Shifted or dislodged clay or concrete roof tile; impact damage to roof from falling chimneys, displaced rooftop heating, ventilating, and air conditioning (HVAC) units.
- Significantly sagging roof ridgelines; signs of movement between rafter tails and wall finishes.
- Buckled/dislodged flashing or tearing of roof membrane at roof/wall intersections in split level buildings, additions, appendages, porches, or other building irregularities. Tearing of roof membrane or deck waterproofing at reentrant corners.
- Damage to ceiling finishes and framing in vicinity of chimneys; damage to chimney flashing; gaps between masonry chimney and adjacent wall.
- Separations or cracks in ceiling or floor finishes at split-levels, reentrant corners, additions, appendages, or other building discontinuities.
- Fresh cracking of ceiling finishes, especially at reentrant corners; cracks along corner bead at stairwell openings; cracking or tearing of finishes at ceiling/wall juncture; multiple “nail pops.”
- Cracking of stucco along the mudsill level accompanied by indications of relative permanent displacement (sliding) of the building relative to the foundation; cracking or splitting of mudsills, bulging at plate line.
- Significantly sagging or bouncy floors.
- Signs of movement between floor and exterior hardscape or retaining wall along the uphill side of homes on sloping sites.
- A pattern of fresh cracks, gaps, or joint separations in floor finishes.
- Impact damage to floor finishes from falling contents.

### 6.1.2 When to Call a Technical Consultant

If any of the following damage patterns are observed, a structures specialist<sup>54</sup> should be retained to perform an inspection of the house:

- Indications of relative movement such as separations or cracks in ceiling, roof, or floor finishes at building irregularities such as split levels, additions, or porches.
- Cracking of stucco along the mudsill level accompanied by indications of relative permanent displacement (sliding) of the building relative to the foundation; cracking or splitting of mudsills.
- Significantly sagging or bouncy floors consistent with loss of support.
- Signs of movement between floor and exterior hardscape or retaining wall along the uphill side of homes on sloping sites.
- A pattern of fresh cracks, gaps, or joint separations in floor finishes.
- Significantly sagging roof ridgelines; signs of movement between rafter tails and wall finishes.

If the building was constructed prior to 1980 and repair work will involve disturbance of certain types of floor or ceiling finishes that may contain asbestos or lead-based paint, a suitably qualified and licensed environmental consultant should be retained to test for the presence of regulated hazardous materials and, if necessary, recommend appropriate abatement and waste disposal measures. See Section 9.2.4 for additional information.

### 6.1.3 Repair Guidelines

- Clay or concrete roof tiles that have shifted out of alignment can be removed and reset in the affected areas. Removal and replacement of felt underlayment and cleats is generally not required unless damaged by the earthquake.
- Where clay or concrete roof tiles have fallen and broken, repair is possible if tile pattern is still available. Color matching may require replacement of a complete facet (plane) of the roof, using undamaged tile to patch other facets (planes). Removal and replacement of felt underlayment and cleats is generally not required unless damaged by the earthquake.
- Where roofing has been damaged by impact from falling chimneys, or rooftop HVAC units, localized repair may be possible if matching material is

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<sup>54</sup> Structures specialists include Licensed Civil Engineers specializing in structural engineering, Licensed Structural Engineers (Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Structural Engineer), and Licensed Architects with expertise in structures. See Section 9.3 for additional discussion.

available. Otherwise, replacement of at least the damaged facet (planes) will be required for color matching.

- Impact damage and tearing of roof membrane at reentrant corners on low-pitched (i.e., “flat”) roofs can be repaired by an experienced roofing contractor.
- Damaged flashings at chimneys should be repaired in conjunction with repair or replacement of the chimney. Damaged flashings at building discontinuities should be repaired in conjunction with repair of underlying framing.
- Minor earthquake damage to ceiling finishes can be addressed as described in Section 6.8, and as shown in Table 6-1.
- Repair of impact damage to floor finishes depends upon the nature and extent of the damage as well as the type of floor finish. Isolated damage to wood floors can be spot repaired. More extensive damage will require sanding and refinishing. If replacement tile is available, chipped or cracked ceramic, or stone tile can be removed and replaced, otherwise complete removal and replacement may be required.

## 6.2 Summary

Roofs, ceilings, and floors – the horizontal diaphragms in buildings – are typically robust and do not generally sustain serious damage in most buildings, even in areas of very strong ground shaking. Common damage patterns include shifting or falling of unsecured roof tile, damage to finishes and framing around masonry chimneys, minor cracking of ceiling finishes at reentrant corners, and impact damage to floor finishes from falling objects. If indicators of structural damage are not found, such damage should be considered cosmetic and repaired in accordance with the guidelines presented below in Section 6.8.

When subjected to strong shaking, roofs, ceilings, and floors in irregular buildings (split levels, one- to two-story transitions, hillside homes, additions, porches) are much more likely to sustain serious damage than are regular, conventional buildings. For those buildings without cripple walls, where floor joists bear directly on the mudsill, (including the upslope edge of hillside homes), splitting of the mudsill can lead to sliding of the building on (or even off) its foundation. Roofs, ceilings, and floors can also sustain damage as a result of ground failure (see Section 3) when permanent ground deformation distorts the building’s foundation resulting in stretching or bending of the roof, ceilings, and floors. If any of these conditions are observed, a structures specialist should be engaged to inspect the house and provide repair recommendations.

There are numerous, long-term non-seismic conditions commonly found in roofs, ceilings, and floors, such as squeaky floors, loose nails, cracks and nail pops in ceiling finishes, or roof deterioration and leakage, that may have gone unnoticed prior to the earthquake. Distinguishing between earthquake-induced damage to these elements and pre-existing conditions due to other factors is essential to accurate assessment of earthquake damage.



## 6.3 Limitations

Only raised wood floors (second story or over crawlspace) of conventional woodframe construction are addressed in this section. See Section 4 for discussion of concrete slab-on-grade floors. A structures specialist should be retained to evaluate damage in buildings of unconventional construction.

## 6.4 Description of Typical Construction

Roof, ceiling, and floor elements in typical woodframe residential buildings in California are constructed of woodframing (joists and rafters) supporting sheathing (wood boards, plywood or OSB panels, plaster or drywall) and connected with nails (Figure 6.1). Roofs, ceilings, and floors serve several functions. As aesthetic elements, most are finished or decorated. As nonstructural elements, roofs protect the living space from the elements, and floors and ceilings subdivide the living space. As structural elements, roofs, ceilings, and floors support vertical loads that include their own weight as well as the weight of people, contents, and occasionally snow. However, they also carry horizontal loads and tie the building together, thus playing a role in the earthquake resistance of woodframe homes. These elements are often referred to as horizontal diaphragms. Their function is similar to that of a beam loaded from the side – they collect the lateral inertial loads and distribute them to the walls and foundation (Figure 6.2).

### 6.4.1 Typical Roof Construction

The two main components of a roof are weatherproofing (shingles, felt, etc.) and structure (framing).

There are two types of roof weatherproofing systems: those for steep or pitched roofs and those for low pitched or flat roofs. There are a wide variety of materials available for pitched roofs, including asphalt shingles, wood shingles, wood shakes, clay tile, concrete tile, metal shingles, various fiber composite shingles, and metal panels. Asphalt saturated felt is typically installed beneath each of these systems as an added barrier to water infiltration. While shingles are securely attached to the roof deck with nails, concrete and clay tile may only be attached in certain areas, such as around the perimeter, while simply resting on wood cleats over the remainder of the roof. Waterproof membrane used on flat roofs generally consists of several alternating layers of building paper (or felt) and hot asphalt topped with gravel or a mineral cap sheet, technically referred to as built-up membrane but commonly referred to as tar and gravel roofing.<sup>55</sup> All roofing systems use flashings at penetrations and perimeters to provide a weather-tight transition to other materials.

Roof structures consist of numerous combinations of structural members (including conventional wood rafters, wood trusses, heavy timbers) and sheathing materials (including spaced or solid wood sheathing, plywood, OSB) depending upon the location and construction vintage. Buildings in snow country have much more substantial roof structures than buildings in warmer

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<sup>55</sup> More modern systems, consisting of sheets of plastic, rubber or other composites are rarely used on residential buildings in California.

areas. Although 24-inch spacing is the most common for rafter and truss spacing, the spacing can range from 12 to 48 inches. Rafters and trusses are supported by exterior and some interior walls. Plywood and OSB are standard in more modern construction, while nominally 1-inch thick, spaced sheathing is common in older construction. Older buildings that have been more recently reroofed will often have plywood installed over spaced sheathing.

### **6.4.2 Typical Ceiling Construction**

Typical ceiling finishes are plaster in older homes and drywall in newer homes. In most houses built since the mid-1930s, plaster is applied over gypsum lath (also called buttonboard); although in older houses (through the early twentieth century) wood lath was used. In all cases, the finishes are nailed (or screwed in the case of modern drywall installations) to ceiling joists (typically at 16-inch spacing) or the bottom chord of trusses (typically at 24-inch spacing). Drywall ceilings are often finished with a textured finish, commonly referred to as acoustical spray or “popcorn” texture. Where the roof structure consists of heavy timbers and solid wood sheathing, the underside of the roof is often left exposed and finished with paint or stain.

Ceilings in most buildings are now insulated, either with fiberglass batts or a variety of loose, blown-in insulation such as fiberglass, cellulose, or rock wool. Exposed beam ceilings are typically insulated with insulation board installed between the wood sheathing and the roofing materials.

### **6.4.3 Typical Floor Construction**

There are two main components of floors: the finish materials (carpet, tile, etc.) and the structure (framing or concrete slab).

A wide variety of floor finish materials are in common usage, including hardwood, carpeting, sheet vinyl, vinyl tile, ceramic tile, stone, and loose laid or floating composite wood flooring. With the exception of the last, all are bonded or nailed to the floor sheathing. In some cases, an underlayment board may be installed over the floor sheathing to provide a smooth surface for the floor finish materials.

Two types of floor construction are commonly found in California: conventional and heavy timber. Conventional framing consists of wood floor joists spaced at 16 inches and supporting board, plywood, or OSB sheathing. Heavy timber framing consists of 4x beams spaced 48 inches apart and supporting 1-1/2-inch thick wood sheathing or 1-1/8-inch thick plywood. Floor joists are supported directly on perimeter foundations or perimeter walls and interior walls and beams. In crawlspaces, the beams are typically supported on wood or steel posts.

In California, the ground floor is often a thin, lightly reinforced, or unreinforced concrete slab cast directly on the ground. These floors are finished with tile, carpet, or sheet vinyl in living areas and left exposed in garages and sometime utility rooms or porches. See Section 4 for further detail.

## 6.5 Non-Earthquake Sources of Damage

Buildings are subject to multiple types and sources of damage, distress, and deterioration during their service life, much of which goes unnoticed or is routinely repaired. This section describes conditions commonly found in roofs, ceilings, and floors in the absence of earthquakes.

Non-earthquake damage to roofs, floors, or ceilings, such as water/decay or insect damage can weaken the structural members and their connections. When such damage is identified, the investigator should continue to inspect the damage to determine whether it could have reduced the building's resistance to earthquake shaking.

### 6.5.1 Non-Earthquake Roof Damage

Common non-seismic roof conditions include leakage at flashings and penetrations, deterioration, deflection and sag, workmanship and material defects, and withdrawal of nails.

Flashings at penetrations, transitions, and roof perimeters are a common source of water leakage, as a result of poor design or poor installation. In many cases, defective installations will be patched with mastic, which provides a short-term fix but not a long-term solution.

Deterioration from exposure to the elements is the most common problem associated with roofs. All roofing materials have a finite service life, the length of which is governed by the composition of the roofing material, the quality of its installation, and environmental exposure. Typical service lives may be as short as 10 to 15 years for wood shingles or low-quality built-up membrane and in excess of 50 years for high-quality clay tile installations. Deterioration occurs gradually and may not result in leakage to the interior of the building until it reaches advanced stages.

In non-snow areas, roof structures are typically designed to be as light as possible with little or no consideration of deflection. As a result, many roofs will exhibit some degree of sag, which will increase with time. Without reinforcing the roof structure, installation of multiple layers of roofing or replacement of wood shakes with concrete tile will exacerbate the visible sag. Sag will often be most noticeable in areas where support conditions of the roof change, such as where a wall intersects the roof framing (Figure 6.3). Sag in the roof is generally not an indication of a serious structural defect.

Some homes in California, especially older homes, are built on unstable soils, which, over time, can lead to differential movement of the foundation and superstructure. Depending upon the structural configuration and the nature of the differential movement, separations may develop in the roof structure, typically at the ridge, eaves, and discontinuities (e.g., at additions or porch attachments).

Neither master craftsman nor the finest materials are generally employed in the construction of roofs. Thus, it is common to find nails that have missed their target, poorly made joints and misaligned framing in attics (Figure 6.4). In addition, framing lumber will shrink, twist, and split as it dries. Due to the fact that wood shrinks much more across the grain than it does along the

grain, miter cuts made in wood will change angle as the wood dries, becoming more acute and giving the visual impression that the rafters have splayed outward.

In the course of reroofing, it is not unusual to find some nails that had been driven flush sticking up slightly (Figure 6.5). This condition can result from shrinkage of the framing lumber, but is more commonly driven by thermal cycling of the roof, which causes nails to back out of the framing over time.

Cracking of mastic used for roofing repairs or penetration seals is very common, often due to large thermal strains at discontinuities and long-term deterioration such as photo-degradation or embrittlement (Figure 6.6).

### **6.5.2 Non-Earthquake Ceiling Damage**

Common non-earthquake problems with ceilings are generally limited to cosmetic concerns including surface irregularities, cracks, and nail pops or dimples.

The most common imperfection with drywall ceilings is tape joints that are visible under low light angles on ceilings with smooth finish. Joints will be spaced at 4 feet in one direction and 8 to 12 feet in the other direction. Related is the problem of “nail pops” and dimpling at fasteners, which develop over time and are generally associated with changes in moisture content in the woodframing (Figure 6.7). The difficulty of preventing nail pops or dimpling and making inconspicuous tape joints over large ceiling areas is one of the reasons that heavy texture finishes are so widely used for ceilings. A related problem is irregularity of ceiling framing which shows up as surface irregularities in the drywall finish.

Fine cracking of ceiling finishes, especially adjacent to reentrant corners, is common in both drywall and plaster ceiling finishes. Due to shrinkage of the plaster, linear cracks extending the width or length of the room will often develop in larger rooms near the centerline of the ceiling. A linear crack will often develop in cathedral ceilings as a result of non-uniform shrinkage of the roof rafters (as discussed in the preceding subsection), resulting in opening of the framing at the interior side of the roof apex.

Where ceilings include exposed wood (either paneling, decking, or heavy timbers), the wood members will typically exhibit various benign natural imperfections that generally go unnoticed, including shrinkage, checking, twisting, and warping. Intersections between exposed wood and drywall generally consist of one material butted against the other, in many cases forming an irregular gap.

Depending upon their structural configuration, long-term differential movement of houses founded on unstable soil can cause cracks in the ceiling finishes, typically at reentrant corners and along ceiling/wall junctures.

### 6.5.3 Non-Earthquake Floor Damage

Common non-earthquake problems with floors include sloping or out of level conditions, construction imperfections, bounciness, squeaks and loose nails, deterioration of finishes, and cracking of lightweight fill.

Many homes in California, especially older homes, are built on unstable soils which, over time, can lead to differential movement of the foundation and superstructure. The result will often be floors that are out of level (i.e., more than 1-1/2 inches between high and low point across the building) with noticeable slope (i.e., greater than 1 inch in 20 feet). Differential foundation movement can also result in gaps between posts and beams in the crawlspace (Figure 6.8). Those gaps leave the beams unsupported, resulting in a sag and bounce in the floor in the vicinity. Soils on or near the tops of slopes can creep or move laterally over time, stretching foundation and the raised wood floor, resulting in tilted support posts (Figure 6.9), cracked mudsills (Figure 6.10), and gaps or cracks in floor finish materials (Figure 6.11).

As with roofs, neither master craftsman nor the finest materials are generally employed in the construction of the floor structure. Thus, when examining floor framing, it is common to find nails that have missed their target, poorly made joints, and misaligned framing. In addition, framing lumber will shrink, twist, and split as it dries. Due to the vagaries of construction, it is not unusual to find misalignment between posts and footings or posts installed at an angle to accommodate the misalignment (Figure 6.12). Most wood floor structures are designed to satisfy minimum building code requirements. As a result, many floors are rather flexible and will exhibit some bounce, even in the absence of any defect or damage in the framing. This condition is especially noticeable in the vicinity of floor lamps, china cabinets, and other vibration sensitive furnishings.

Floor squeaks under foot traffic are a common problem in woodframe floors. Recognized causes of floor squeaks are:

- Use of wet or green lumber (standard practice in California)
- Improper spacing of sheathing panels
- Improper glued floor construction practice
- Improperly driven nails
- Loose blocking or rubbing bridging
- Loose wall/floor connection
- Improperly installed joist hangers
- Loose connection between subfloor and underlayment or subfloor and hardwood flooring
- Use of cement coated nails
- Movement between ductwork and floor

- Variation in joist depth or straightness
- Loose tongue and groove joint in subfloor

Floor squeaks are most common in older buildings where floor construction consists of board sheathing and hardwood flooring. Floor squeaks are generally concentrated in those areas that receive the greatest foot traffic. Improvements in construction materials and techniques over the past several decades have greatly reduced, but not eliminated, the problem of floor squeaks. In the course of replacing carpet, it is not unusual to find some nails that had been driven flush sticking up slightly. This condition results primarily from shrinkage of the framing lumber – see first bullet point above.

As a result of both the flexibility of floor structures and moisture related movement of wood, brittle floor finishes (ceramic tile, stone) installed over wood flooring will often develop cracks, generally over points of support (such as beams or posts). Where the subfloor is flexible, deterioration of grout joints in brittle floor finishes is also a problem. Over time, joints in the underlayment may also telegraph through flexible floor finishes such as sheet vinyl and vinyl tile.

While not common in single-family dwellings, a 1-1/2-inch thick layer of lightweight concrete is often used in place of underlayment for sound control in multi-family woodframe buildings. That fill is unreinforced, is placed with a high water content, and is of low strength, resulting in the development of cracks from shrinkage or traffic loads and deterioration (Figure 6.13).

## 6.6 Earthquake-Induced Damage

The most common earthquake damage patterns in roofs, ceilings, and floors are all essentially nonstructural and include shifting or falling of unsecured roof tile, damage to finishes and framing around masonry chimneys, minor cracking of ceiling finishes at reentrant corners, and impact damage to floor finishes from falling objects. In conventional residential woodframe construction, diaphragms are lightly loaded and will typically experience relatively little distortion during an earthquake. Accordingly, damage to finishes is common, while structural is not.

The most common type of roof framing damage occurs due to failure of an adjacent chimney. Many masonry chimneys, some dating back to the 1930s, are attached to the house with steel straps, one end of which is embedded in the chimney mortar, while the other is nailed to the framing (roof, ceiling, or second floor). Oftentimes when the chimney shifts away from the house the framing connected to the strap is damaged. If it appears that the chimney has shifted more than 1/4 inch from the house, an attic inspection should be conducted to inspect the adjacent framing.

In areas of strong shaking, structural damage to roof, ceiling, and floor framing can occur at building irregularities. There are two types of building irregularities that can lead to damage: vertical irregularities where the plane of the roof, ceiling, or floor is discontinuous (split levels,



one-story to two-story transitions, additions, porches, etc.), and plan irregularities that create reentrant corners (**L**, **T**, and **U** shaped floor plans) as shown in Figure 6.14.

Damage at vertical irregularities occurs when the portions of the building on either side of the irregularity move in opposing directions. If the structural tie across the irregularity is not sufficiently strong (a common situation, especially in older buildings), separation will occur at the discontinuity of the structural diaphragms, with damage ranging from minor finish damage to complete structural separation. Split-level homes represent vertical irregularities in the lateral load path that can lead to separation in discontinuous floor and roof framing (i.e., the horizontal diaphragms). In the past, split-level homes have suffered serious damage due to this discontinuity as shown in Figure 6.15. Modern seismic design principals discourage this condition, or provide special detailing to accommodate it. Discontinuities in horizontal diaphragms should be inspected carefully for indications of framing separation.

In larger woodframe buildings, damage can also occur at the reentrant corners in the floor plan (a condition known as plan irregularity) when the intersecting wings move in slightly different directions during the earthquake, resulting in tension or tearing at the reentrant corner. Damage associated with both vertical and plan irregularity tends to increase with the height of the building. If there are indications of damage associated with a building irregularity, a structures specialist should be engaged to inspect the building and provide repair recommendations.

Roofs, ceilings, and floors can also sustain structural damage as a result of ground failure (see Section 3). Homes that have been subjected to significant differential ground movement can sometimes suffer loss of support of floor joists. This will result in observable floor detachment from the supporting walls and noticeable bounce in the floor. If there are indications of ground failure at a site, as discussed in Section 3, a soils specialist should be engaged to evaluate soil conditions, inspect the building, and provide repair recommendations.

Many of the indicators of earthquake damage discussed below have other potential non-earthquake causes as discussed in Section 6.5 above. Accordingly, it is necessary to evaluate the patterns of indicators to determine which are consistent with earthquake-induced distortions and which are consistent with other causes. Weakening of the structure due to non-earthquake damage to roofs, floors, or ceilings, and the possible effect on earthquake resistance, should also be considered.

## **6.6.1 Earthquake-Induced Roof Damage**

With few exceptions, earthquake-induced damage to roofs is limited to nonstructural or isolated minor structural damage. The most common earthquake-induced damage is shifting or falling of unsecured roof tile and damage to flashings, and in some cases framing around chimneys. Less common damage modes include structural damage at discontinuities, damage due to earthquake-induced ground failure, and deformation or collapse of structurally deficient roofs.

Depending upon the vintage of construction, slope of the roof, and type and brand of tile, clay and concrete roof tile may not be well secured to the roof deck. Rather, only several courses at the perimeter or a percentage of tiles in the field may be positively attached, with the balance of tile being held in place by friction or a wood cleat. During strong shaking, unsecured tile are

commonly displaced (Figure 6.16) and may fall from the roof. Even where all tiles are intended to be secured, there are often pieces that, for a variety of reasons were not secured and may shift or fall. Even tile that are secured may shift slightly.

Roofs may be damaged by masonry chimneys by three means: flashing damage due to relative motion between the chimney and building (Figure 6.17), impact damage from toppling chimneys (Figure 6.18), and damage to framing where steel strap ties from the chimney are attached to roof framing (Figure 6.19). Flashing damage will typically only be discoverable by a rooftop inspection. The other two modes of damage should be readily observable from the ground. If either of the latter two conditions exists; framing in the vicinity of the chimney should be inspected from within the attic.

Roof damage at vertical irregularities can range from minor flashing damage to complete structural separation. Damage at the reentrant corners of a building plan (the inside corner of an L shape for example) typically only occurs in taller (i.e., three story), flat-roofed buildings and is generally limited to tearing of the membrane and possibly tear out of nails in the roof sheathing at the reentrant corner.

The potential for damage to roof framing depends upon the roof geometry, sheathing type, and weight of roofing. Gable roofs with spaced board sheathing (in lieu of plywood or OSB panels) that have had wood shingles replaced with concrete tile without adequate reinforcing are the most vulnerable to racking, or in extreme cases, collapse. Conventionally framed roofs are typically braced in the direction of the ridge with diagonal 2×4 braces from the ridge down to a ceiling joist or top plate. These braces are typically the weakest link in the roof structure. Because the spaced sheathing has relatively little stiffness to resist earthquake forces, the diagonal ridge braces may be subject to significant load in the longitudinal direction, which could cause them to buckle (Figure 6.20) or fail at their connections (Figure 6.21). Thus, the braces and their end connections should be a key inspection point if an attic inspection is performed. Roofs sheathed with plywood or OSB and hip roofs are especially resistant to earthquake damage and, in the absence of irregularities, structural damage during earthquakes is unlikely.

Earthquake damage to pre-fabricated roof trusses is not common. Any observed damage, including splitting or tearing of the metal connector plates, should be evaluated by a structures specialist.

## **6.6.2 Earthquake-Induced Ceiling Damage**

The most common type of earthquake-induced ceiling damage is minor cracking of ceiling finishes at reentrant corners, and cracking along corner beads at the intersection between the ceiling and an opening, conditions commonly found at stairwell openings (Figure 6.22). Ceilings may also sustain damage in areas adjacent to chimneys, where tie straps from the chimney damage framing as the chimney pulls away from the building. Where there are discontinuities in the lateral load path, such as building plans where the second story is set back to mid-length of the garage, cracking of drywall finishes may occur along tape joints (Figure 6.23).

Where ceilings include exposed woodframing, or where there is significant finish damage, framing should be inspected carefully for signs of earthquake-induced movement or shifting (Figure 6.24). It is important to recognize that natural imperfections in wood, including shrinkage, cracks, twisting, and warping as well as irregular gaps where other finish materials abut the wood, are quite common and often mistaken for earthquake damage.

### **6.6.3 Earthquake-Induced Floor Damage**

The most common and serious failure modes for floors are lateral movement and loss of vertical support. Floors are restrained from lateral movement either by direct attachment to the foundation or through walls that are anchored to the foundation. Failure of a supporting wall, as discussed in Section 5, will cause failure of the floor (Figure 6.25). As a result of the strength required to support building occupants and contents, floors generally have sufficient strength to resist the lateral forces imposed by earthquakes and structural damage associated with the direct effects of earthquake shaking is uncommon.

For floors attached directly to the foundation, the weak link in the lateral load path is the mudsill attachment – either bolting to the foundation or nails between the joists and the mudsill. The mudsill is typically a 2×4 or 2×6 pressure treated plate (new construction utilizes 3× plates) that attaches the floor to the foundation. Sills that are inadequately attached to the footing with anchor bolts can split and slide on (or off) the foundation. Sometimes the mudsill is well bolted, but the joists are not adequately nailed to the mudsill, a condition that also leads to a sliding failure (Figure 6.26) or bulging. Sliding of sill plates or sliding (or bulging) of the framing on the sill plate can typically be seen by the damage to exterior finishes. Another indication of sliding or failure of the mudsill is uniform leaning of post supports in the crawlspace consistent with the direction of movement of the floor.

Hillside homes, especially those supported by columns on the downhill side, are particularly vulnerable to failure at the floor/foundation connection. In many cases, the lateral load from the earthquake is concentrated in the uphill mudsill. Failure of that connection can result in complete collapse of the building. A gap between the upslope edge of the floor and any adjacent construction, such as concrete hardscape, indicates possible damage to this connection (Figure 6.27). Damages that suggest lateral movement of the floor should prompt investigation by a structures specialist.

In areas of strong shaking, with extensive disruption of contents, floor finishes may be damaged by the impact of falling debris, ranging from knick-knacks to stone fireplace facings.

An “increase in the number of floor squeaks” under foot traffic is a common post-earthquake complaint. However, as discussed in Section 6.5.3, floor squeaks are common in homes that have never experienced severe ground shaking. It has been suggested that earthquake-induced racking of the floor diaphragm loosens nails that then squeak under foot traffic. However, racking distortion of a magnitude that could loosen floor sheathing or framing connections is highly unlikely for any woodframe residential building that remains habitable.

## 6.7 Assessment Guidelines and Methodology

Initial inspection of roofs, ceilings, and floors consists of visual examination and documentation of nonstructural damage as well as indicators of possible structurally significant damage that would trigger a more detailed inspection. Careful observation and attention to detail are essential, but it is also important to look for patterns of damage – isolated finish cracks are not cause for concern, while finish cracking in the vicinity of a discontinuity indicates possible concealed damage that requires further investigation.

The initial inspection should include interior living space and exterior inspection from the ground, as discussed in the following subsections. Absent indications of concealed damage, roof, attic, and crawlspace inspections are not recommended; entry to these spaces presents its own set of hazards that outweigh the potential benefits. If there are indications that the house may have sustained damage that would be revealed via roof, attic, or crawlspace inspection, an appropriately qualified inspector should conduct that inspection. In some cases a structures specialist will need to be retained to ascertain structural damage and specify appropriate repairs. If there is evidence of ground failure at the site, a structures specialist should be retained to investigate both the geotechnical as well as structural condition of the property.

The following subsections enumerate specific inspection points and observations that are relevant to assessing potential damage to roofs, ceilings, and floors. In practice, the observation and documentation of these items would be part of the overall inspection plan that incorporates inspection points and observations enumerated in other sections of these *Guidelines*.

### 6.7.1 Exterior

Exterior inspection points and observations relevant to assessing conditions that may indicate potential damage to roofs, ceilings, and floors include:

- Foundation and floor system: Concrete slab-on-grade floor or raised wood floor? Is the raised wood floor resting directly on the mudsill or is it supported on cripple walls? Are the cripple walls of uniform height or do they vary in height to accommodate a sloping site? Any signs of racking of the cripple walls? Are there any indications of movement or sliding of the floor at the sill plate level? Evidence of sliding is generally most obvious at building corners at the foundation level. Any gaps between the building and upslope hardscape? Is the hillside building partially supported on columns or posts?
- The presence of vertical irregularities: Are the roof and floor lines continuous or are there changes in elevations, such as split levels, one- to two-story transitions, porches, attached garages, etc.? Any signs of damage at the irregularities? Are there additions, which may be at the same level, but not well tied to the original building? Any signs of damage at the interface between the original building and the addition?

- The presence of plan irregularities: Is the footprint of the building basically rectangular or is it comprised of one or more wings in an **L**, **T**, or **U** shaped floor plan? Any signs of damage at the reentrant corners?
- The presence of masonry chimneys: Are there (or were there) any masonry chimneys in the building? Have they fallen and impacted the roof? Have chimneys on exterior walls collapsed or pulled away from the building?
- Rooftop HVAC units: Have any rooftop HVAC units fallen from their supports and damaged the roof?
- Roofing: Does the building have a clay or concrete tile roof? Have any tile fallen or shifted? Rake tile, tile just below the ridge, and tile just below penetrations or walls, such as chimneys, skylights, dormers, and upper story walls are particularly vulnerable. Are the tile lines straight?
- Rooflines: Is the shape hip, gable, or flat? Any unusual sagging, racking, or distortion of rooflines? Any signs of movement of rafter tails at eave/wall intersection?

### **6.7.2 Interior**

- Floor finishes: Any fresh impact damage? Any patterns of cracks, gaps, or separations in flooring to suggest movement of the underlying structure? Any signs of cracking at reentrant corners of plan irregularities? Any signs of cracking at vertical irregularities?
- Floor structure: Any noticeable sag or excessive bounciness in the floor?
- Ceiling finishes: Any cracks emanating from the corners of openings? Any cracks along corner beads around openings? Any signs of cracking at reentrant corners of plan irregularities? Any signs of cracking at vertical irregularities?

### **6.7.3 Roof**

A rooftop inspection may be performed to check the following items:

- Shifting of roof tile.
- Damage to flashings at chimneys or at building irregularities.
- Damage to membrane roofing at building plan irregularities.

#### **6.7.4 Attic**

If concrete or clay tile are present on a gabled roof, a visual survey of the attic should be made from the scuttle opening, without entering the attic, to determine whether the roof is sheathed only with spaced sheathing, or whether plywood or OSB sheathing has been installed, either as part of the original construction or over the spaced sheathing as part of reroofing.

A more detailed attic inspection should be conducted if any of the following are found during the initial inspection:

- Damage or distress to finishes in the vicinity of building irregularities that suggest movement, separation, or damage to concealed framing.
- Toppling of a chimney onto the roof.
- Pulling of chimney away from building.
- Clay or concrete tile is installed on a gabled roof sheathed only with spaced sheathing.

The detailed attic inspection should focus on:

- The condition of framing and connections at building irregularities.
- The condition of framing and tie straps in the vicinity of any masonry chimneys and the condition of framing in the vicinity of any areas where falling masonry may have impacted the roof.
- For tiled gabled roofs with only spaced sheathing, the condition of longitudinal braces (braces aligned parallel to the ridge board) and their end connections.

#### **6.7.5 Crawlspace**

A crawlspace inspection should be conducted if any of the following are observed in the course of the initial inspection:

- Signs of sliding or movement at the mudsill level.
- Signs of racking of cripple walls.
- Any noticeable sag or excessive bounciness in the floor.



The detailed crawlspace inspection should focus on:

- Condition of the mudsill and its attachment to both the foundation and the floor joists. Especially, check for cracks in the mudsill at anchor bolts.
- Condition of support post connections to beams and footings, including gaps, distress, or tilting.

### **6.7.6 Technical Consultant Assessment**

Assessment by a structures specialist should include detailed exterior and interior visual inspection as well as rooftop, attic, and crawlspace inspections, as warranted and as outlined in Appendix 9C. Based on findings of that non-invasive assessment, the structures specialist may recommend invasive inspection. Invasive inspection may be necessary in those instances when the structures specialist is unable to rule out or reasonably assume the existence of concealed earthquake damage based on their non-invasive assessment. Potential invasive inspection work is outlined in Appendix 9C.

If the building was constructed prior to 1980 and repair work will involve disturbance (demolition, removal, grinding, sanding, etc.) of any of the following types of ceiling or floor finishes, a suitably qualified environmental consultant should be retained,

- Material in floors, ceilings, or roofs that may contain asbestos include:
  - Sprayed acoustic (“popcorn”) ceiling finishes
  - Gypsum joint compound (drywall “mud”)
  - Interior plaster
  - Ceiling tile
  - vinyl floor tile and/or mastic
  - Backing or underside of sheet vinyl
  - Roofing felt
  - Roofing mastic
- Material in floors, ceilings, or roofs that may contain lead consists of enamel paint applied to:
  - Kitchen and bathroom ceilings
  - Enamel paint on concrete floors.

As discussed in Section 9.2.4, the consultant should test for the presence of regulated hazardous materials and, if the results of the tests are positive, recommend appropriate abatement and waste disposal measures.

## 6.8 Repair Methodologies

The appropriate repair of damaged roofs, ceilings, and floors must consider the nature, extent, cause, and significance of the damage. Where earthquake damage has occurred in other components of the building, roof, ceiling, or floor, repair should be considered as one component of a more general repair plan. For example, if the mudsill has been split and cripple walls been racked out of plumb, a repair plan that includes moving the building back into position, repairing the cripple wall, and replacing the mudsill should be developed. Where the damage represents a loss of structural capacity, broadly defined, a structural repair will be necessary. In all other cases, a nonstructural repair is appropriate.

The following subsections present appropriate repair methods for typical nonstructural earthquake damage patterns. If the cause of an observed damage pattern cannot be determined, or if the damage is outside the description given in the following subsections, a structures specialist should be retained to address the issue.

Note: The repair methods presented in this chapter presume that the building materials are free of regulated levels of hazardous materials. If testing as recommended in Section 9.2.4 indicates the presence of regulated levels of asbestos or lead, the abatement and waste disposal recommendations of the environmental consultant should be incorporated into the overall scope of repair.

### 6.8.1 Roofs

Repair of roofing is generally straightforward:

- Clay or concrete tiles that have shifted should be reset. Where tile have fallen and broken or been broken by impact from falling masonry or HVAC units, tile may be replaced in-kind, if the color and pattern of material is still available. In the absence of structural repair work to the roof, removal and replacement of the underlayment is generally not necessary
- Shingle and shake damage by impact from falling masonry or HVAC units may be replaced in-kind, if the color and pattern of material is still available.
- Damaged flashing at chimneys should be repaired in conjunction with repair or replacement of the chimney. Damaged flashing at other locations should be repaired once the underlying structural movement has been evaluated.

### 6.8.2 Ceilings

Table 6-1 gives appropriate repair methods for typical nonstructural earthquake damage patterns in ceilings. If the nature and/or extent of damage are outside the description given in Table 6-1, a structures specialist should be consulted to develop repair recommendations. The repair methods listed in the table are further discussed below.

### **6.8.2.1 Drywall**

- Where cracking follows panel joints or corner beads, existing tape and compound should be removed. The joint should then be retaped, retextured, and repainted. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.
- Short (less than 6-inches long), fine cracks (less than about 1/64-inch wide) extending from the corners of openings, may be patched using drywall tape and joint compound, retextured, and repainted. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.
- Where cracks greater than 6-inches long extend through the drywall, the cracked piece should be removed to the nearest joist on either side of the crack (32-inch minimum width, 48-inch height) and replaced, retextured, and repainted. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.
- Nail pops may be repaired by adding a drywall screw adjacent to the nail pop, resetting or removing the “popped” fastener, patching, retexturing to match the adjacent finish and repainting. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.

### **6.8.2.2 Gypsum Lath and Plaster**

- Where the plaster is cracked but remains firmly attached to the lath, repairs can be accomplished by cleaning the crack and patching, texturing, and painting to match the existing surface texture and finish. When determining the area to be retextured and repainted, consideration should be given to obtaining a reasonably uniform appearance.

### **6.8.2.3 Construction Joints**

- Where minor movement has occurred at joints between wood and drywall or between wood members, only cosmetic repairs are necessary. Where these joints were simply painted or stained, the appropriate repair is to clean and repaint or restain the joint. Where caulking and/or joint compound along the joints has cracked or spalled, the appropriate repair is to remove the cracked material, clean the separation, and recaulk or remud the joint where necessary. It should be noted that even after the repairs are complete, cracks and/or separations may reappear due to the normal effects of material shrinkage, temperature changes, and minor differential movements of supporting elements (soil or structure). The reoccurrence of damage is unrelated to the earthquake. If damage occurred because there was no joint where there

should have been one, then again, the damage is generally not structurally significant.

**Table 6-1. Repair methods not requiring technical consultant assistance for nominal earthquake damage to woodframe ceiling surface materials**

Wall Component	Earthquake Damage Pattern	Repair Method*
Drywall	Cracks up to 1/64-inch wide	Patch and refinish
	Cracks following taped joints or corner bead	Remove existing tape and joint compound, retape, and refinish
	Cracks greater than 6-inches long and up to 1/8-inch wide through drywall	Remove and replace drywall to nearest joists beyond crack (minimum 32 x 48 inches), refinish
	Nail pops	Add drywall screw 1 inch from original fastener, set or remove original fastener, patch, and refinish
Gypsum lath and plaster	Cracks up to 1/64-inch wide	Patch and refinish
	Cracks up to 1/8-inch wide, no delamination or significant spalling	Rout, patch, and refinish
	Delamination or significant spalling	Remove and replace plaster back to sound material, and replaster
Construction joints	Minor movement	Caulk, patch, or repaint to match pre-earthquake condition

\* Repair methods presented in this table presume that the building materials are free of regulated levels of hazardous materials. If testing as recommended in Section 9.2.4 indicates the presence of regulated levels of asbestos or lead, the abatement and waste disposal recommendations of the environmental consultant should be incorporated into the overall scope of repair.

### 6.8.3 Floors

Repair of impact damage to floor finishes is a nonstructural repair that can be performed by an experienced tradesman.

- Most damage to wood floors can be addressed with isolated repairs; complete refinishing of the floor is not typically necessary.
- Damage to tile (vinyl, ceramic, or stone) can be addressed with isolated replacement of damaged pieces, provided matching colors and patterns are available.
- Damage to sheet vinyl will generally require complete replacement.

### 6.8.4 Permits, Upgrades, and Retrofits

Depending upon the nature and scope of damage and proposed repair, building permits and other government agency approvals may be required by the local jurisdiction. Some California jurisdictions have local building code provisions that contain specific repair requirements for certain elements (e.g., masonry chimneys, wood shake roofs) and/or impose code upgrade

requirements if the earthquake damage exceeds some prescribed threshold. The repair guidelines presented herein are intended to represent prevailing best practices and do not include jurisdiction-specific requirements. Rather, the building department should be consulted regarding local requirements.

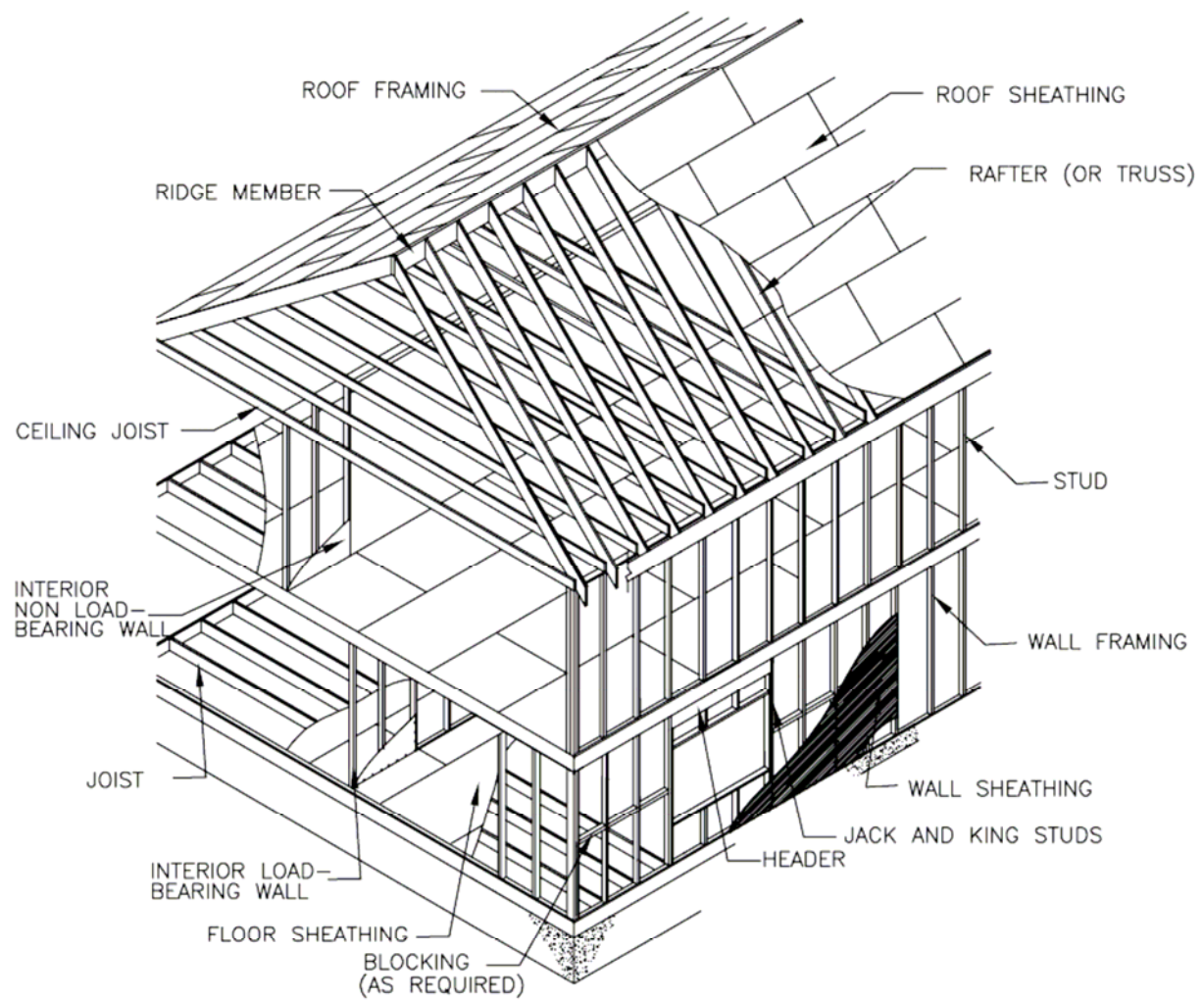


Figure 6.1. Elements of typical woodframe house [HUD].



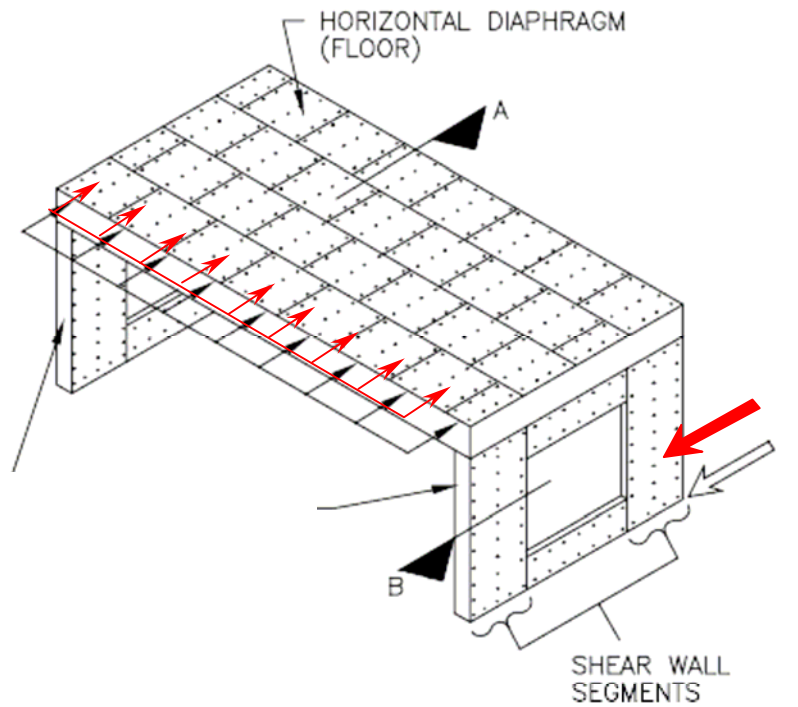


Figure 6.2. Schematic of the role of horizontal diaphragms (floors or roofs) as structural elements resisting earthquake forces [HUD].



Figure 6.3. Heavy tile roof sags between wall supports, located by arrows (not earthquake damage) [Exponent].



Figure 6.4. Poor fit-up of roof framing at rafter to ridge board junction (not earthquake damage) [Exponent].



Figure 6.5. Nail withdrawal from plywood roof sheathing due to long-term moisture cycling (not earthquake damage) [Exponent].



Figure 6.6. Deteriorated mastic at repair of built-up roof (not earthquake damage) [Exponent].



Figure 6.7. Nail pop visible in ceiling (not earthquake damage) [Exponent].





Figure 6.8. Gap between post and pier foundation in crawlspace (not earthquake damage) [Exponent].



Figure 6.9. Tilted support posts in crawlspace (not earthquake damage) [Exponent].



Figure 6.10. Cracked mudsill and missed nails (not earthquake damage) [Exponent].



Figure 6.11. Gaps in flooring due to elongation of floor diaphragm caused by earthquake-induced slope movement [Exponent].



Figure 6.12. As-built misalignment between girder and footing accommodated with offset post (not earthquake damage) [Exponent].



Figure 6.13. Shrinkage cracks in lightweight concrete fill (not earthquake damage) [Exponent].



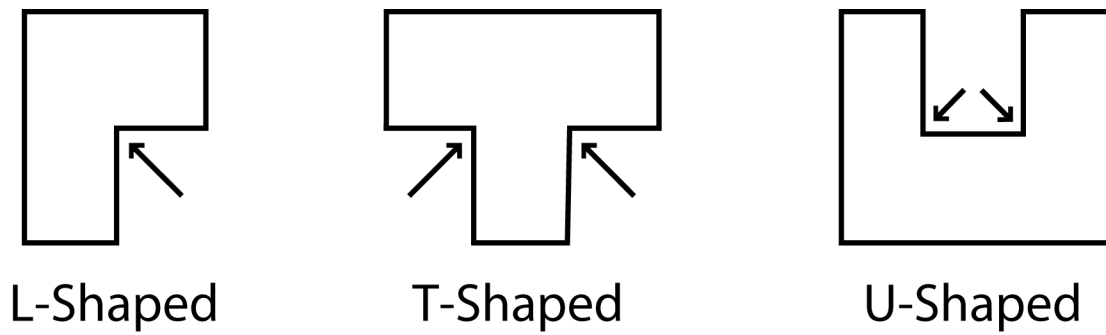


Figure 6.14. Reentrant corners of plan irregularities are likely locations of damage in horizontal diaphragms during strong shaking.



Figure 6.15. Earthquake-induced separation across discontinuous floor and roof diaphragms of a split level house.



Figure 6.16. Clay roof tile and mortar joints shifted by earthquake shaking [Exponent].



Figure 6.17. Buckled chimney flashing due to earthquake shaking [Exponent].





Figure 6.18. Earthquake damage from impact of falling masonry chimney [USGS].



Figure 6.19. Earthquake-induced framing damage due to loads from chimney strap; note the strap was attached to the top of a ceiling joist (left arrow), which split from the bottom (right arrow) when the chimney, located just outside rafter ends in top left of photo, moved relative to the house [Exponent].



Figure 6.20. Diagonal ridge brace buckled due to earthquake; this brace is in line with the brace shown in Figure 6.21 [Exponent].

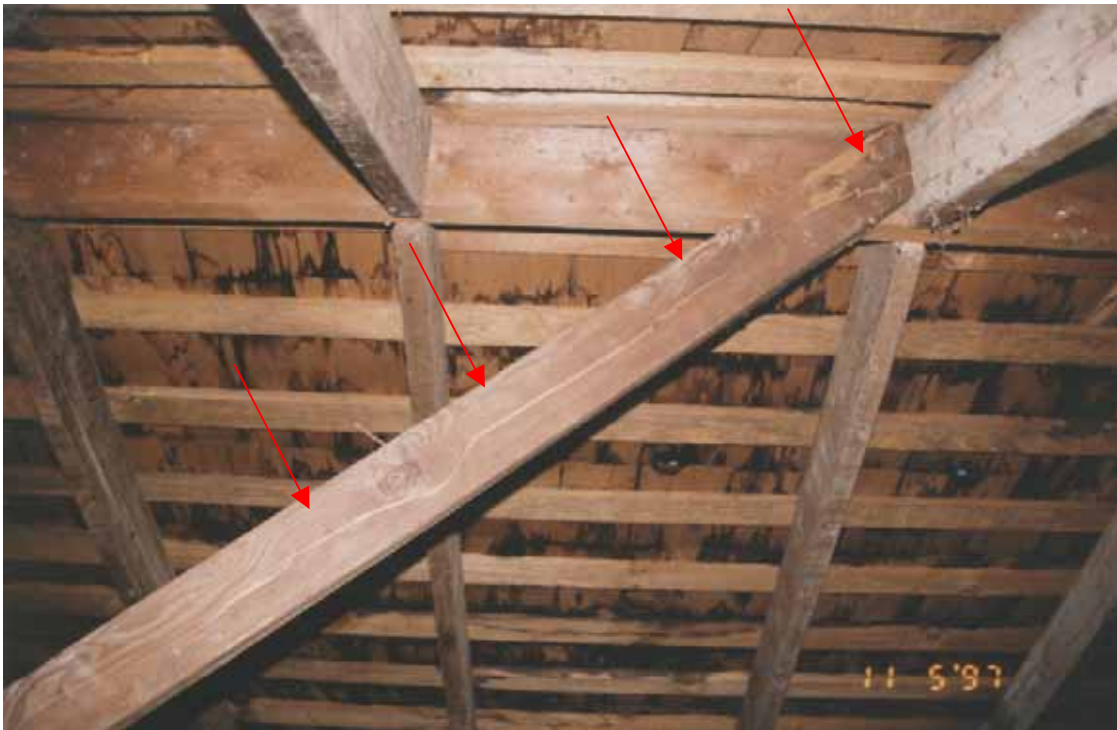


Figure 6.21. Diagonal ridge brace cracked during earthquake; this brace is in line with the brace shown in Figure 6.20 [Exponent].



Figure 6.22. Earthquake damage to ceiling corner bead at stairwell [Exponent].



Figure 6.23. Earthquake damage to tape joints at vertical load path discontinuity [Exponent].





Figure 6.24. Significant earthquake damage to finishes where framing has failed (arrows identify blocking attached to chimney strap) [Exponent].



Figure 6.25. Sagging floor due to earthquake-induced shifting and loss of support [Exponent].





Figure 6.26. Sliding of joists on mudsill due to earthquake [NISEE].



Figure 6.27. Earthquake-induced gap between floor and wall supported on retaining wall on uphill side of house on sloped lot [Exponent].

## **7 Fireplaces and Chimneys**

### **7.1 Quick Guide**

#### **7.1.1 What to Look For**

See Section 7.6 for a detailed discussion of earthquake damage patterns.

- Collapse, visible cracking, tilting, or displacement of the chimney relative to the building.
- Damage to flashing and counter flashing between the masonry chimney and the roof.
- Shifted or loose clay flue tile segments and displaced joint mortar.
- Deterioration of exposed mortar.
- Separation of interior fireplace facing from, or movement relative to, the adjacent wall or firebox.
- Displacement of poorly secured metal flue pipe of factory-built fireplaces.
- Differential movement between fireplace inserts and the firebox.
- Damage that may allow smoke and sparks to enter walls or attic spaces.
- Displaced connection of appliance flues connected to chimneys.

#### **7.1.2 Where to Look**

See Section 7.7 for a detailed discussion of inspection methodology.

- Exterior ground level: Examine exterior portions of the fireplace and chimney for collapse, cracking, tilting, or displacement relative to the building. Use binoculars, especially for taller chimneys.
- Interior: Examine the fireplace facing for signs of relative movement or separation from the surrounding wall and firebox. Examine the firebox for fresh cracking. Where exposed, examine the masonry finishes that wrap around the flue for signs of distress and cracking.

- Rooftop: Examine the flashing for evidence of recent movement between the chimney and building. Inspect the flue lining for displacement or damage. Check for cracking by attempting to rock the chimney.
- Attic: Inspect the chimney for evidence of cracking or shifting. Inspect steel straps (if present) at the connections to the framing for signs of distress and movement. Check metal flues for displacement or damage.

### 7.1.3 When to Call a Technical Consultant

If any of the following damage patterns are observed, a technical consultant should be retained to investigate. See Section 7.7.5 for a detailed discussion of the circumstances indicating the need for technical consultant assistance.

- Concealed damage: If the condition of the chimney cannot be determined based on visual inspection or if there is concern regarding concealed damage to the flue or masonry, a professional chimney inspector (chimney sweep) should be engaged.
- Leaning chimney: If the cause of the leaning is unclear or if damage to building framing is suspected, a structures specialist<sup>56</sup> should be engaged.

Retention of a structures specialist may also be required by local building officials if repair or rebuilding of a masonry chimney is desired.

### 7.1.4 Repair Guidelines

See Section 7.7 for a detailed discussion of inspection methodology.

- Damage from minor relative movements between the chimney, fireplace, facing, and building can be repaired by removal and replacement of failed sealants or grout if the chimney is not damaged.
- Collapsed facings can generally be replaced with like kind materials if the firebox is not damaged.
- For damaged unreinforced masonry chimneys, local building officials may allow the use of the firebox, but require replacement of the entire chimney with an insulated metal flue pipe concealed in a woodframe chase.

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<sup>56</sup> Structures specialists include Licensed Civil Engineers specializing in structural engineering, Licensed Structural Engineers (Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Structural Engineer), and Licensed Architects with expertise in structures. See Section 9.3 for additional discussion.

- For damaged reinforced masonry chimneys, replacement of just the damaged portion with a metal flue pipe concealed in a woodframe chase may be allowed.

## 7.2 Summary

Masonry fireplaces and chimneys are essentially independent, self-supporting structures often constructed on their own foundations, although connected to or abutting walls and upper floors, ceilings, and roofs. Due to their heavy mass, relatively high stiffness, and generally low strength, masonry chimneys are one of the elements most vulnerable to earthquake damage in a home and historically have performed very poorly during earthquakes. Because the masonry chimney and woodframe house respond differently to earthquake shaking, relative movements can occur between the two and cause pounding damage between the chimney and building, particularly at the ceiling and roof. Unreinforced chimneys have a tendency to either crack or overturn at the roofline during strong ground shaking. Reinforced chimneys typically do not suffer as much serious damage. Chimneys constructed along an exterior wall have a tendency to pull away from the building, either creating a gap between the chimney and building, or completely overturning. The firebox of masonry fireplaces will typically not be damaged during earthquakes, but will generally exhibit cracks that formed as a result of thermal stresses during normal use. The clay tile chimney flue liner can be damaged during an earthquake particularly if the chimney is unreinforced and there are voids between the flue and surrounding masonry.

Most California homes with fireplaces built after circa-1980 use factory-built fireplaces with insulated metal flue pipes. The factory-built fireplace is constructed of a light gauge metal. The flue pipes may be concealed by a woodframe chase finished with such materials as stucco, wood siding, or stone veneer. Given their light weight, flexibility, and relative strength, factory-built fireplaces and metal flues are much less vulnerable to earthquake damage.

A thorough inspection of masonry chimneys and fireplaces typically requires assessments from ground level, the building interior, attic, and roof.

Seriously damaged masonry chimneys are generally not repaired with the same materials; rather they are replaced either in whole or in part with metal flues. The interior facings applied around both masonry and factory-built fireplaces sometimes separate and fall if they are poorly secured to the underlying framing. Such finishes can be replaced with the same material, when proper masonry veneer connections are used, provided the fireboxes are repairable or undamaged.

## 7.3 Limitations

This section addresses the most common types of conventional fireplace and chimney construction. Damage to chimneys and fireplaces of unconventional construction, such as cast-in-place concrete, or construction that is structurally integrated with the building should be evaluated by a technical consultant.

## 7.4 Description of Fireplace and Chimney Construction

The overwhelming majority of California residential masonry chimneys are associated with fireplaces. Masonry chimneys can also be used to vent mechanical appliances such as furnaces and hot water heaters, but this is uncommon in California and will generally be found only in homes older than about 50 years.

There are five general types of chimney structures:

1. Unreinforced brick masonry chimneys constructed with lime-based mortars. Such chimneys were typically constructed before 1930 and are the most susceptible to earthquake damage as lime mortars exhibit very low strength properties including low bond strengths with the brick masonry. Lime mortars are so soft that the mortar can be easily removed or scraped away with an object such as the tip of a screwdriver.
2. Brick masonry chimneys constructed with Portland cement based mortars, which exhibit greater strength properties than lime-based mortars and therefore exhibit somewhat better performance during earthquakes.
3. Chimneys constructed with Portland cement based mortars that are reinforced and, if constructed on an outside wall, strapped to the building framing at the attic and floor lines. Masonry chimneys and fireplaces in California are typically reinforced if constructed after provisions of the 1967 Uniform Building Code (or more recent versions) were adopted and enforced by the governing municipality. If constructed on an exterior wall, the code also required strapping the chimney at each floor and ceiling level more than 6 feet above grade.
4. Although not common, monolithic precast or cast-in-place concrete fireplace and chimney units were used in some housing developments in California (Figure 7.1).
5. Non-masonry chimneys consisting of metal flue pipe (either double or triple wall) attached to a factory-built fireplace. The metal flue pipe associated with a factory-built fireplace is typically concealed by much larger woodframe chase covered with wood siding, stucco, or stone veneer intended to architecturally mimic the size of a masonry chimney. The top of the chase is capped off with a metal cap flashing. Due to their light weight, these fireplaces and flues suffer little to no damage during an earthquake.

As illustrated in Figure 7.2 through Figure 7.4, the main components of a masonry fireplace/chimney structure are:

- Foundation: Generally consists of a poured concrete footing.
- Hearth: Consists of the floor of the firebox and outer hearth which extends beyond the front of fireplace.

- Firebox: Consists of an open chamber lined with refractory brick.
- Face or facing: Is a decorative finish of brick or stone masonry applied over the front edge of the firebox and surrounding wall.
- Chimney: Extends from the top of the fireplace up through the roof.
- Flue liner:<sup>57</sup> Constructed of clay tile which are resistant to the detrimental effects of combustion products.
- Crown or cap: Tops the masonry chimney.
- Steel straps: Anchors the chimney to the building at the ceiling and/or roof level (Figure 7.4).
- Flashing: Seals the intersection between the chimney and the roofing.
- Spark arrester: A metal screen covering the flue to prevent the escape of burning embers.

Figure 7.5 through Figure 7.9 illustrates components of a factory-built fireplace/chimney:

- Factory-built fireplace: A sheet metal unit with the hearth and firebox lined with refractory panels
- Face or facing: An optional decorative finish of brick or stone masonry applied over the front edge of the firebox and surrounding wall.
- Metal flue: Consists of interlocking sections of stainless steel and galvanized double wall pipe.
- Fire stops: Consist of flat sheet metal that encircles the flue, laterally stabilizing the flue as well as closing off the space between surrounding framing and the flue.
- Chimney chase: A common but optional woodframe decorative enclosure of the metal flue that may be finished with wood siding, stucco or stone, or masonry veneer.
- Cap flashing: A sheet metal assembly covering the top of the chimney chase.
- Spark arrester: A metal screen covering the flue to prevent the escape of burning embers.

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<sup>57</sup> Masonry chimneys can be either unlined or lined. Unlined chimneys are uncommon and are typically found in homes built before adoption of the first Uniform Building Code in 1927. A typical liner consists of refractory clay flue tile segments that are stacked and mortared at the joints with a refractory mortar. If the chimney is unreinforced, the flue lining typically has a void space between the flue tile and surrounding brick masonry. In a reinforced masonry chimney, this space is more likely reinforced and grouted.



Some masonry fireplaces have been retrofit with fireplace inserts that should not be confused with factory-built fireplaces.

## **7.5 Non-Earthquake Sources of Damage**

### **7.5.1 Firebox**

It is extremely common to observe cracked masonry firebrick in the hearth from thermal-related stresses. This cracking can occur along mortar joints and through the firebrick (Figure 7.10). Such cracking generally has rounded edges and is limited in size and extent. Most of the thermal cracks are less than 1/16-inch wide.

### **7.5.2 Chimney**

It is not unusual for masonry chimneys to exhibit distress and deterioration due to their weight, the quality of materials, and their environmental exposure. The following are common conditions observed in chimneys in the absence of earthquake damage:

- Hairline crack between masonry and exterior wall: A cold joint or discontinuity exists between masonry fireplace/chimneys and the surrounding wall finishes. Hairline cracking at the joint is normal (Figure 7.11).
- Long-term settlement: Compared to the adjacent woodframe building, masonry fireplaces and chimneys are relatively heavy structures, and are often supported on independent, shallow concrete foundations. Differential settlement can occur between the chimney and the house, resulting in distress to the roof flashing and exterior siding or finishes at their interface with the chimney. For a chimney located on an exterior wall, the differential settlement of a chimney foundation can result in gaps (Figure 7.12) between the chimney and house that gradually increase in width towards the top of the chimney (Figure 7.13).
- Isolated cracks: Random cracking of individual bricks (Figure 7.14) and random, isolated cracking of mortar joints are commonly found on most chimneys.
- Combustion products: Combustion products cool and condense as they rise through the chimney flue. The condensation products are acidic in nature and will cause deterioration of the mortar in unlined chimneys or deterioration of the mortar used at joints between flue tile elements in lined chimneys. Even with lined chimneys, flue gases can also leak between the flue tile and masonry at deteriorated joints between the tiles. This type of deterioration is usually located near the top of the chimney where the formation of condensation products from combustion is the greatest.

- Natural weathering: Erosion and deterioration of any mortar is expected on any brick masonry over the long-term. Loose and disintegrated mortar is typically most prevalent above the roofline as this area is subjected to the heaviest weathering from precipitation.
- Shrinkage cracking of crown or cap: The crown of the masonry chimney is constructed of an unreinforced Portland cement mortar mix. This mix will shrink after mortar placement with the potential for shrinkage cracking.
- Thermal expansion and contraction: The heat from combustion will cause the flue tile to expand. If the flue tiles are free to expand and contract this movement should not result in any distress. However, if the crown of the chimney is bonded to the tile this expansion can cause cracking of the crown or, if the crown mortar is well bonded to the brick masonry, lifting of the top few courses of brick.

### **7.5.3 Interior Facings**

Interior masonry facings are generally not well secured to either the wall or firebox. As a consequence, hairline cracks are commonly found at the mortar joint between the facing and the firebox (Figure 7.15) and at the intersection or mortar joint between the facing and wall finishes. Isolated random cracking of the brick or stone and mortar joints of the facing is also common.

## **7.6 Earthquake-Induced Damage**

### **7.6.1 Fireplace**

The firebox of masonry fireplaces typically will not be damaged during an earthquake, but will, in general, exhibit cracking as a result of thermal stresses that develop during normal usage. Earthquake-related cracking of the firebrick requires significant and obvious damage to the surrounding masonry structure (Figure 7.16).

Because of their light weight, factory-built fireplaces suffer virtually no damage during earthquakes. Isolated random cracking of the firebox in either site built or factory-built fireplaces is not earthquake related.

### **7.6.2 Chimney**

Due to their heavy mass, generally low strength, and high stiffness, masonry chimneys are one of the most vulnerable elements to earthquake damage in a home and historically have performed very poorly during earthquakes. Predominant earthquake related failure modes of masonry chimneys are:

- “Bending” failures where horizontal cracks develop (generally at the roof line or shoulder at the top of the fireplace) and the upper portion of the chimney may shift or topple (Figure 7.17 through Figure 7.22).
- Failures at and below the firebox (Figure 7.16 and Figure 7.23) are less common and often associated with movement of the entire building relative to the foundation.
- Relative movement between the chimney and the woodframe building that may create a gap between the chimney and wall (Figure 7.1, Figure 7.24, and Figure 7.25), damage flashings (Figure 7.26), and possibly damage framing where straps from the chimney are attached (Figure 7.24).
- Separations of outer masonry layers (also called wythes) from inner layers of the chimney masonry.

When surrounded by the building, the most common location for earthquake damage to masonry chimneys is at the roofline. Unreinforced chimneys have a tendency to either crack or overturn at the roofline during strong ground shaking (Figure 7.17). Chimneys constructed of lime mortars have a tendency to break apart into smaller units of masonry due to the weak strength properties of this mortar (Figure 7.28). Chimneys constructed with Portland cement mortars, although exhibiting higher bond strengths than lime mortars, break apart into larger elements. Reinforced chimneys typically do not suffer serious damage when confined by the building.

Chimneys constructed along an exterior wall have a tendency to pull away from the building, either creating a gap between the chimney and building, or completely overturning. Unreinforced chimneys tend to break into smaller sections (Figure 7.29), whereas reinforced chimneys generally hold together and move or overturn about the base as a single unit (Figure 7.24).

Damage to the clay tile chimney flue is uncommon in reinforced masonry chimneys where the flue is well supported by grout. The clay tile chimney flue liner can however be damaged during an earthquake if the chimney is unreinforced and there is a void space between the flue and surrounding masonry leaving the flue liner laterally unsupported.

Metal flues perform well during earthquakes, if properly installed. Those flues installed without proper intermediate fire stops are vulnerable to shifting or misalignment which can cause joints between pipe sections to open. Also, poorly attached metal flue chimneys have been observed to separate from houses in past earthquakes. Generally woodframe chases behave as wall panels and should be evaluated as such in accord with Section 5. A unique problem with woodframed or light steel-framed chases that extend above the roof is that some may not be properly framed or attached to the roof structure and may break loose during strong ground shaking.

### **7.6.3 Interior Facings**

Interior masonry facings are often not well secured. Consequently, they may pull away from the wall (Figure 7.30) or collapse (Figure 7.31). Hairline cracks at the intersection between the

facing and wall finishes, or the intersection between the facing and the firebox, should not be mistaken for earthquake related damage.

## **7.7 Assessment Guidelines and Methodology**

The condition of the chimney/fireplace structure should be assessed from the exterior at ground level, from the interior, attic, and roof level. The first step should be determination of the type of fireplace/chimney; masonry or factory-built. Factory-built fireplaces and flues can be distinguished from masonry fireplaces and chimneys by one or more of the following elements: metal firebox (versus masonry); a metal flue pipe extending above the roof; a woodframe chimney chase covered with finishes such as stucco, wood siding, or masonry veneer; and a metal cap on the chimney chase.

### **7.7.1 Ground Level**

From the exterior or ground level look for evidence of collapse (debris may have been cleaned up), visible cracking, tilting, or displacement relative to the building. Use a pair of binoculars to inspect the chimney, particularly if a roof is too steep for safe mounting without special fall protection.

A masonry chimney located on an exterior wall may exhibit a separation along the vertical joint between the chimney and building, which grows in width towards the top of the chimney (Figure 7.25). This separation may be earthquake-induced as masonry chimneys are essentially independent structures and are constructed on their own foundations. This separation can also be caused by long-term differential settlements of the chimney foundation relative to the building's foundation. If a separation is observed, close examination of the joint between the chimney and building is required to better assess the cause. If there are one or more generations of intact sealant between these two elements, it is clear that the earthquake was not the cause. If this gap is open or a failed sealant is observed, additional investigation is necessary to determine the nature and extent of any damage to the chimney or attached framing. A fresh, unweathered appearance to this gap may indicate that the separation resulted from the earthquake. This conclusion should, if possible, be verified at the chimney flashing as discussed in the roof inspection portion of this discussion. By contrast, the accumulation of dust, debris, cobwebs, paint, etc., in an open joint indicates that long-term foundation settlement is the more probable cause.

The shoulder area of any masonry fireplace/chimney on an exterior wall should be carefully inspected for cracking or damage. The transition between the chimney and firebox is a natural location for cracking if the chimney separates from the building. For reinforced chimneys, minor cracking at this location (less than 1/16 inch) is probably not serious; however, the integrity of the flue should be checked with a smoke test. If the chimney is unreinforced, cracking at the shoulder will likely require removal of the chimney, at least down to the shoulder.

To determine the type and condition of the mortar, perform a screwdriver test by probing mortar head and bed joints between masonry at random locations on the chimney, particularly in areas most exposed to weathering. Mortar that is impervious to a screwdriver indicates higher strength

and greater earthquake resistance than mortar that crumbles or chips, which can be an indication of weak mortar with lime content or deterioration due to long-term weathering.

Some masonry chimneys are covered with a stucco finish. It is common to see some shrinkage cracking in the stucco finish; random, weathered cracking is indicative of shrinkage cracking. Earthquake-induced cracking of the masonry will telegraph through the stucco finish; look for fresh horizontal stucco cracking at roofline and chimney shoulder.

### **7.7.2 Interior**

Examine fireplace facings for signs of recent separation from or movement relative to, the adjacent wall and relative to the firebox (Figure 7.15).

Masonry fireboxes should be inspected for fresh, conspicuous cracking. Thermal-related cracking of the firebrick from burning fires is common and often mistaken for earthquake damage.

If a fireplace insert is installed, check for signs of differential movement, such as fresh cracking, between the insert and fireplace.

Where chimneys are exposed on the interior, inspect the finishes that wrap around the masonry flue for signs of distress and cracking.

### **7.7.3 Roof**

Masonry chimneys should be inspected from the roof level whenever it is possible to safely do so. Some roofs are too steep to safely inspect the chimney without fall protection. Occupational Safety and Health Administration's (OSHA's) steep-slope fall-protection regulations apply to roofs that have slopes greater than 4-in-12 (18 degrees) with unprotected sides and work surfaces that are at least 6 feet (2 m) above a lower work level or the ground. If the roof is too steep, some inspection can often be accomplished from a strategically placed ladder and binoculars.

Inspect the chimney for evidence of recent movement between the chimney and building. Most chimneys have metal flashing and counter flashing to weatherproof the roof at this penetration. Relative movement between the chimney and surrounding building can distort the flashing or pull the flashing from under the counter flashing. In some cases roof mastics or sealants have been used to seal problematic flashing details. Such methods have little flexibility and are easily torn by minor relative movements. On chimneys located on exterior walls, multiple layers of mastic/sealant can indicate historic, long-term problems with chimney movement due to differential foundation settlement.

Inspect the crown of a masonry chimney. Cracking of the mortar cap or crown is common, but is generally not caused by earthquakes. However, crown mortar in poor condition could allow shifting of the flue liner at the top of the chimney.

Remove the spark arrestor and use a flashlight or mirror (on sunny days) to illuminate and inspect the clay flue lining (or metal flue pipe in non-masonry chimneys) for displacement and damage. Look for significantly shifted or loose clay flue tile segments and displaced joint mortar. Be careful to distinguish between recent shifting of flue tile segments and mere imperfections in the original manufacture or installation of the flue tile. Recent fractures or offsets often are conspicuous by the lack of creosote build-up.

Note whether there is creosote build-up in the flue, which can indicate heavy use of wood fuels. The condensate of combustion gases is acidic and can cause deterioration of exposed mortars. Natural weathering of the chimney mortar is also most severe above the roofline. It is not uncommon to see deteriorated and eroded mortars on older chimneys.

Tap the clay flue liner lightly with a hard object. A hollow sound will indicate a void space between the liner and brick masonry, a possible indicator that the chimney is unreinforced. A solid sound indicates that there is no void and that the space between the flue and the masonry is grouted and likely reinforced.

For unreinforced masonry chimneys that do not exhibit visible damage from the roof, attempt to rock the top of the chimney (from all four sides, if possible) by firmly pushing it. This task should be performed with extreme caution. Ensure that no harm from any falling masonry will occur before commencing. This inspection may require another person to look for a separation that opens during pushing; although, an experienced inspector can detect cracking by the “feel” of the chimneys response to rocking. There is a distinctly different feel when pushing a cracked chimney – the chimney will rock slightly if damaged while a chimney that is not cracked will feel quite solid and will not rock. This procedure should not be performed on any chimneys with lime mortars or severe weathering due to their extremely poor bond strength. Perform a screwdriver test to check for weak lime mortar or deterioration of Portland cement mortar.

#### **7.7.4 Attic**

Chimneys should be inspected from the attic whenever possible. Care should be taken when entering attic spaces, including use of appropriate eye protection and a respirator as required. Disposable coveralls and kneepads are also advised. Step or place your weight only on the attic framing and not the ceiling finishes. See Appendix 1F for attic inspection safety guidelines.

Chimneys that are internal to the building should be inspected for evidence of cracking or shifting (Figure 7.19). In particular, focus on the portions of the chimney near roof and ceiling lines. Examine the framing surrounding the chimney for signs of pounding (impact between masonry and wood framing) between the chimney and the house or other types of damage. Check the condition of attachment of any steel straps (Figure 7.4) between the chimney and framing, either at the ceiling or roof level.

Chimneys located on the exterior wall may or may not be exposed in the attic area. Wall sheathing may conceal a chimney located on the gable end. Chimneys located along a roof eave will not be visible in the attic; however, if exposed, check for signs of cracking. If constructed in accordance with the 1967 UBC or later edition, the chimney should be secured to the attic framing. Inspect the strap at the connections to the framing for signs of distress and movement.



### 7.7.5 Consultant Assessment

Additional inspections by a technical consultant(s) may be necessary to refine initial assessments if any of the following conditions are noted:

- Damage to flue lining – If it is uncertain whether or not the flue lining was damaged by the earthquake, a camera scan of the flue pipe should be performed by a professional chimney inspector.
- Cracking of chimney – If there is concern regarding cracking of the chimney in inaccessible locations, a smoke test may be performed by a professional chimney inspector.
- Minor differential movement between fireplace/chimney and building – A gap between the building and the fireplace/chimney may represent a long-term condition resulting from differential settlement of the chimney foundation or it may represent earthquake-induced damage. If the cause is uncertain, a technical consultant should be retained.
- Chimney repair – A design professional may be required by local building officials if a masonry chimney is to be repaired or rebuilt using masonry.

## 7.8 Repair Methodologies

Appropriate repairs are a function of the nature and extent of earthquake damage, original construction details, and local building code requirements. Once damage to the fireplace/chimney has been assessed, the local building officials should be consulted for guidance as to damage level triggers and corresponding repair requirements, if any. An example of local requirements for repair of earthquake-damaged fireplaces and chimneys is presented in Appendix 7A.

Damage from minor relative movement, (such as damage to flashings, mastic, caulking or relative movement between the facing and the wall or firebox) that does not extend to cracking of a masonry chimney can be repaired with like kind and quality materials. Damaged or collapsed interior masonry facings can also generally be replaced with in-kind materials if the chimney and rest of the fireplace are undamaged or repairable.

In reinforced chimneys, cracking without significant offset can be repaired by routing out and tuck-pointing the cracked mortar joints. For more serious damage to a properly reinforced chimney, it will generally be necessary to demolish that portion of the chimney above the level of damage (assuming it has not collapsed) and rebuild the upper portion or replace just the upper portion with a metal flue pipe tied into the remaining portion of the undamaged chimney flue.

For damaged unreinforced masonry chimneys or damaged flue liners, the local building official may allow use of the undamaged firebox, but require replacement of the entire chimney with an insulated metal flue pipe (similar to that installed with factory-built fireplaces) enclosed in a woodframe chase.

Even well designed and constructed masonry fireplaces and chimneys are vulnerable to damage even under ground shaking of moderate intensity. Given this poor seismic performance, it is recommended that damaged fireplace/chimneys not be replaced with in-kind materials. Rather, it is recommended that they be replaced with a factory-built fireplace and metal flue which will provide much better performance in future earthquakes. The building official may require that any owner rebuilding with masonry have the entire fireplace/chimney structure engineered by a structures specialist.



Figure 7.1. Monolithic precast concrete fireplace and chimney that cracked at the shoulder (oval) and pulled away from the building (arrow) due to earthquake.

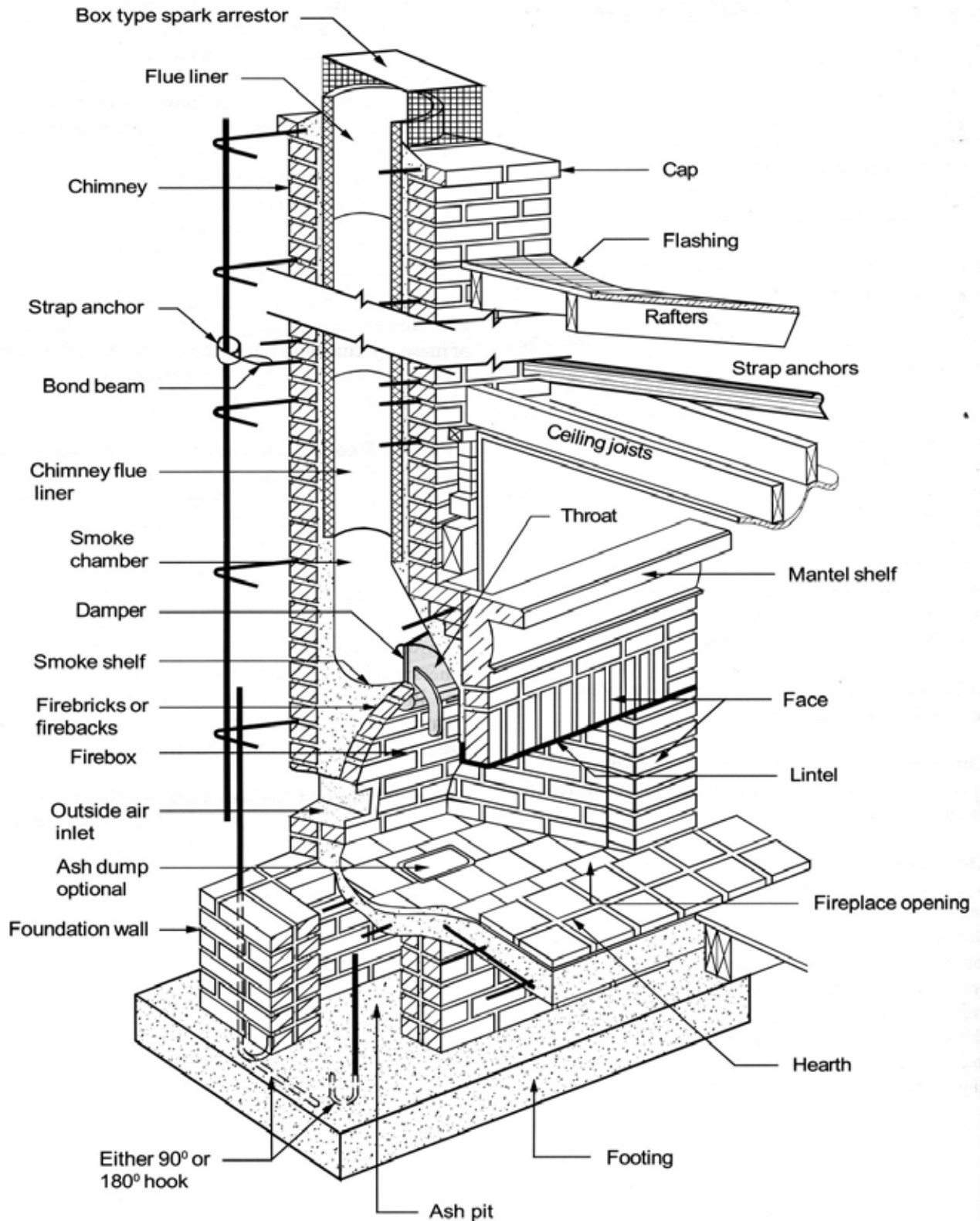


Figure 7.2. Schematic diagram of masonry fireplace and chimney structure [MIA].  
 [From *Masonry Fireplace and Chimney Handbook*, courtesy of the Masonry Institute of America, <http://www.masonryinstitute.org/>.]

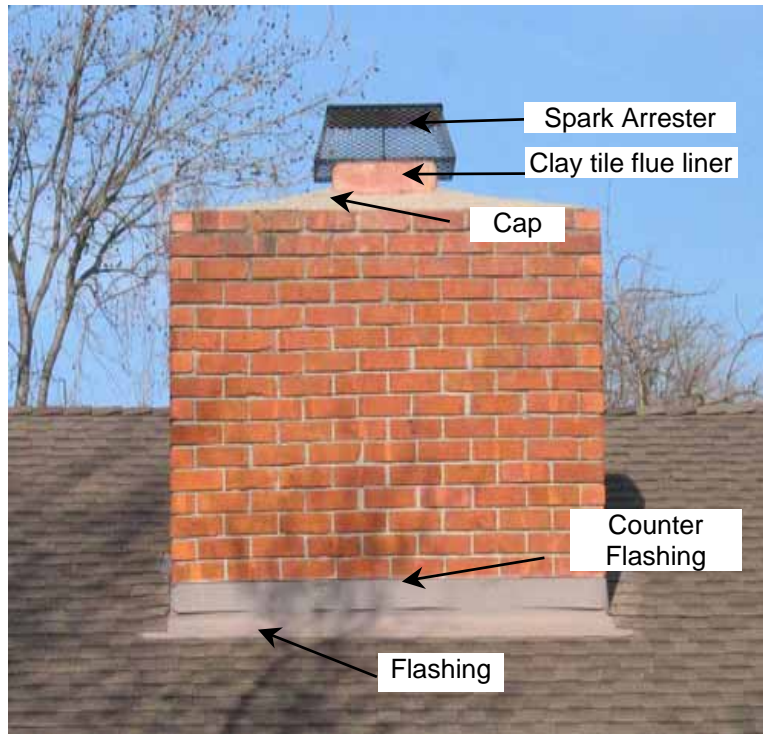


Figure 7.3. Masonry chimney above the roof (no damage) [Exponent].



Figure 7.4. Chimney visible in attic – note undamaged steel tie strap between chimney and framing [Exponent].

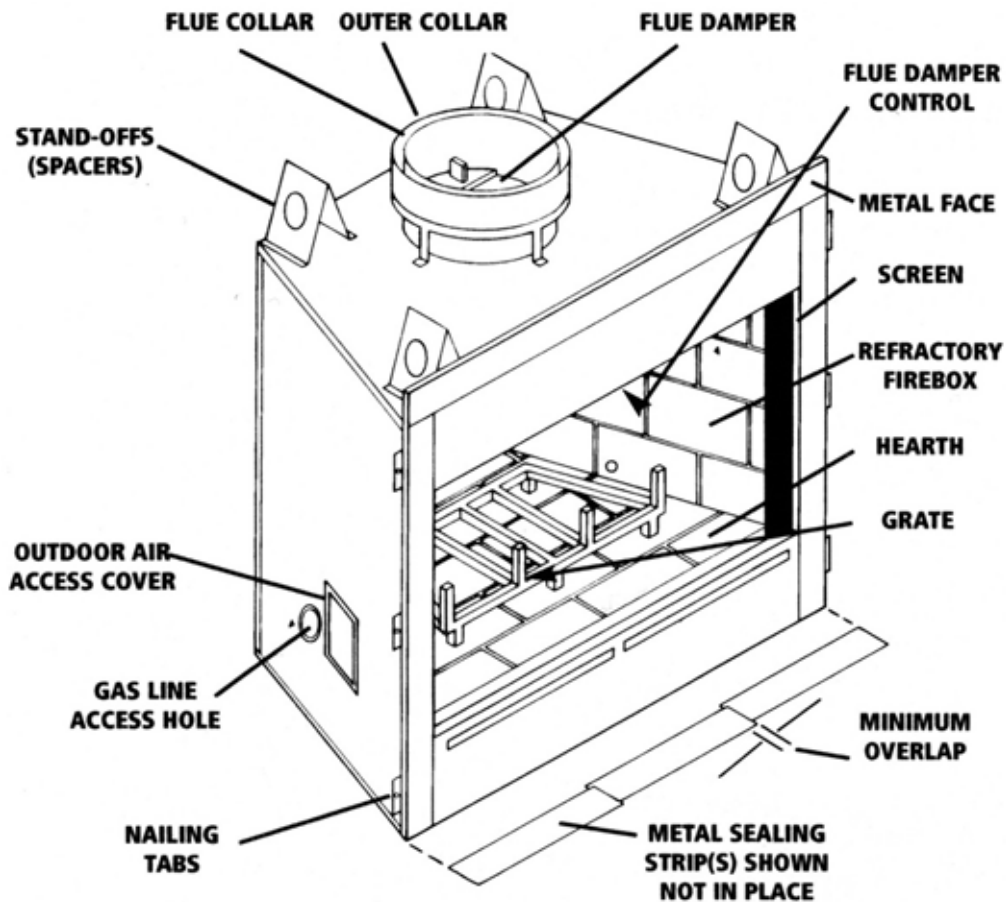


Figure 7.5. Schematic diagram of a factory-built fireplace [HEF].  
 [From *HEARTH Handbook for Building Officials: Solid Fuel Hearth Systems*, where it appeared as “Guidelines for typical firebox installation” on pg. 10, courtesy of the HEARTH Education Foundation.]



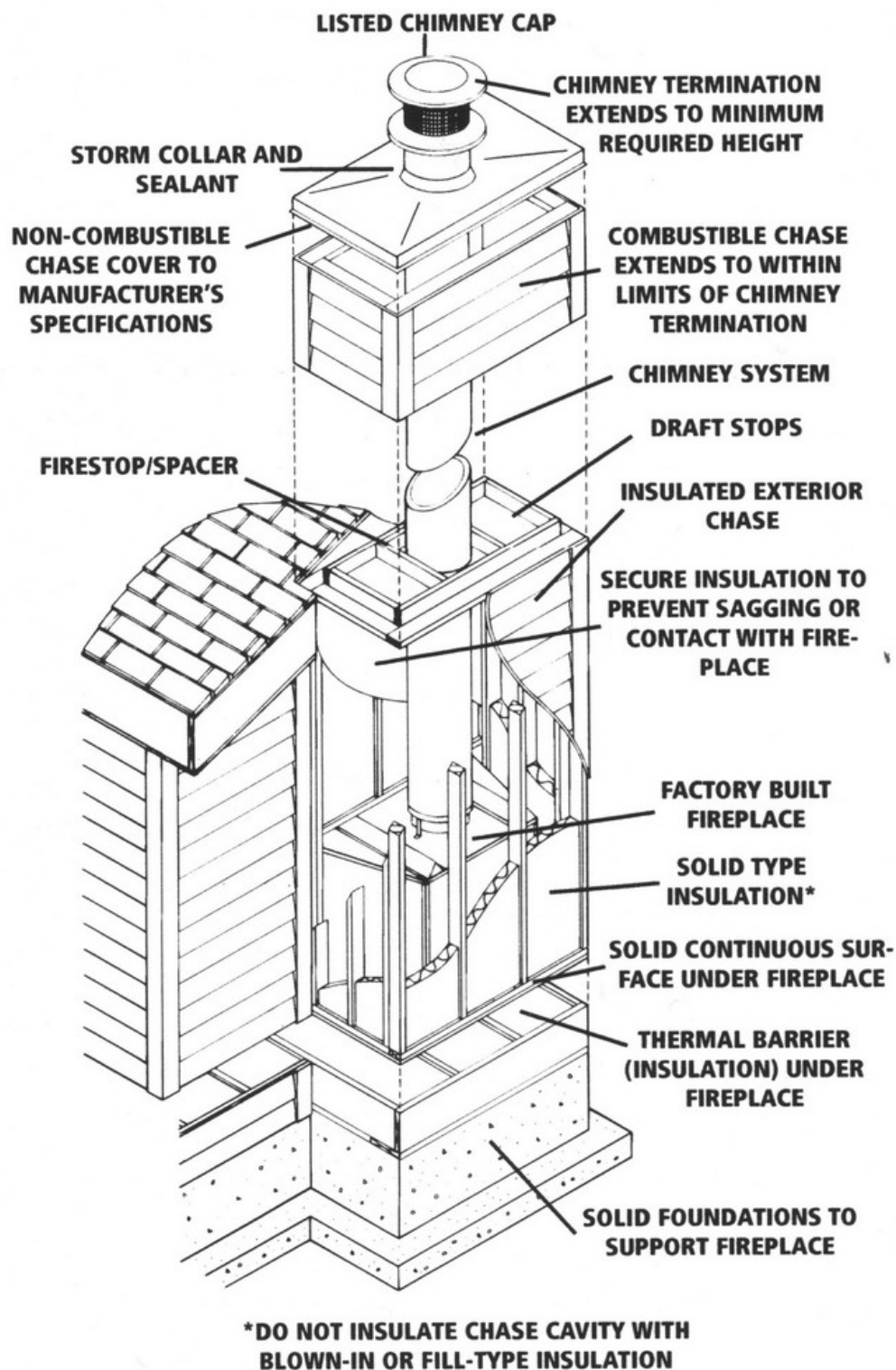


Figure 7.6. Schematic diagram of a factory-built fireplace and chimney assembly [HEF].  
 [From *HEARTH Handbook for Building Officials: Solid Fuel Hearth Systems*, where it appeared as "Guidelines for typical firebox installation" on pg. 19, courtesy of the HEARTH Education Foundation.]



Figure 7.7. Factory-built fireplace and metal flue in woodframe chase during construction (no damage) [Exponent].



Figure 7.8. Stucco-clad, woodframed chimney chase (no damage) [Exponent].



Figure 7.9. Firebox of factory-built fireplace with brick patterned refractory panels (no damage) [Exponent].



Figure 7.10. Typical thermal cracking of firebrick and mortar lining hearth and firebox of a masonry fireplace (not earthquake damage) [Exponent].





Figure 7.11. Normal crack between masonry fireplace/chimney and exterior stucco wall (not earthquake damage) [Exponent].



Figure 7.12. Gap between chimney and house – note mortar filler used to fill previous gap, movement since that repair, paint in gap, cobweb spanning gap (not earthquake damage) [Exponent].



Figure 7.13. Tapered gap between chimney and house that has resulted from long-term differential settlement of fireplace foundation; note mortar filler used to fill previous gap (not earthquake damage) [Exponent].



Figure 7.14. Random isolated cracking of brick and mortar joints commonly found on masonry fireplaces and chimneys (not earthquake damage) [Exponent].



Figure 7.15. Mortar joint between firebox and masonry facing where hairline cracks are frequently found (not earthquake damage) [Exponent].



Figure 7.16. Failure of masonry fireplace at firebox level caused by 1994 Northridge Earthquake [Reitherman].





Figure 7.17. Failure of masonry chimney above roofline caused by the 2001 Nisqually Earthquake [Exponent].



Figure 7.18. Failure of masonry chimney at roofline caused by the 2001 Nisqually Earthquake [Exponent].

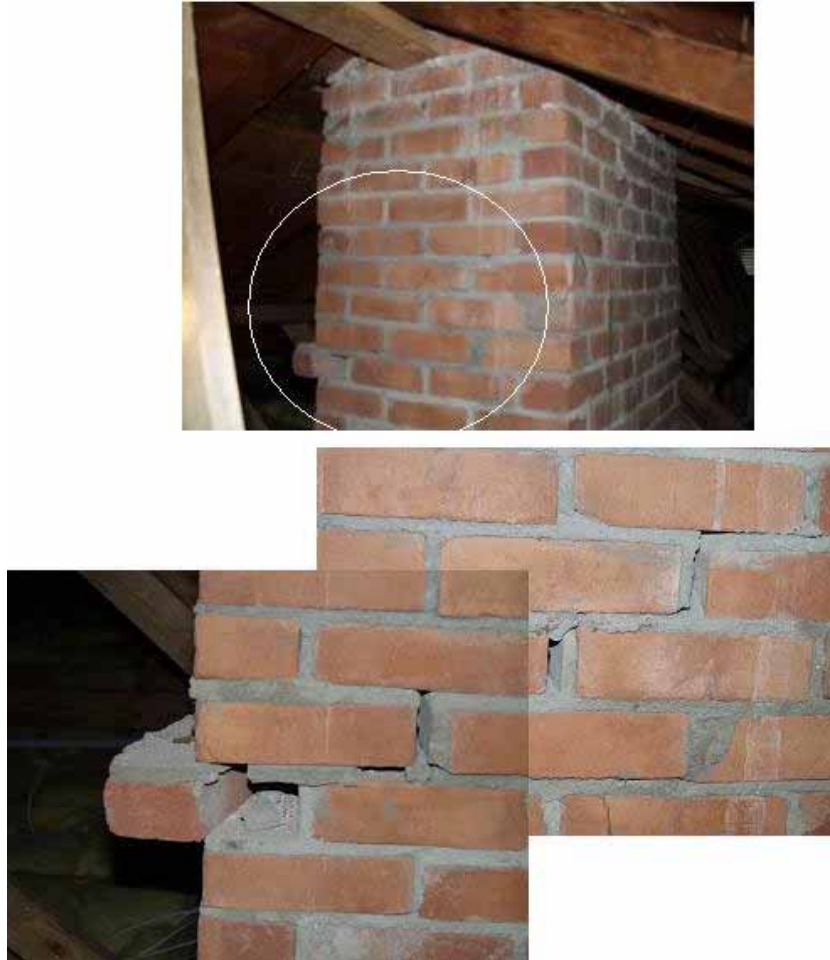


Figure 7.19. Failure of masonry chimney in attic caused by the 1994 Northridge Earthquake [Exponent].



Figure 7.20. Failure of masonry chimney at gable caused by the 2001 Nisqually Earthquake [Exponent].



Figure 7.21. Failure of masonry chimney mid-story caused by the 2001 Nisqually Earthquake [Exponent].





Figure 7.22. Damage to masonry chimney at shoulder.



Figure 7.23. Failure of masonry fireplace at foundation level caused by the 1994 Northridge Earthquake [Exponent].



Figure 7.24. Masonry chimney and fireplace that has tilted away from the structure, and torn loose woodframing to which steel tie straps from the chimney were attached – caused by the 1971 San Fernando Earthquake [Cluff].



Figure 7.25. Earthquake-induced tapered separation between masonry chimney and exterior wall caused by the 2001 Nisqually Earthquake; note also damage to top of chimney due to deterioration of mortar [Exponent].



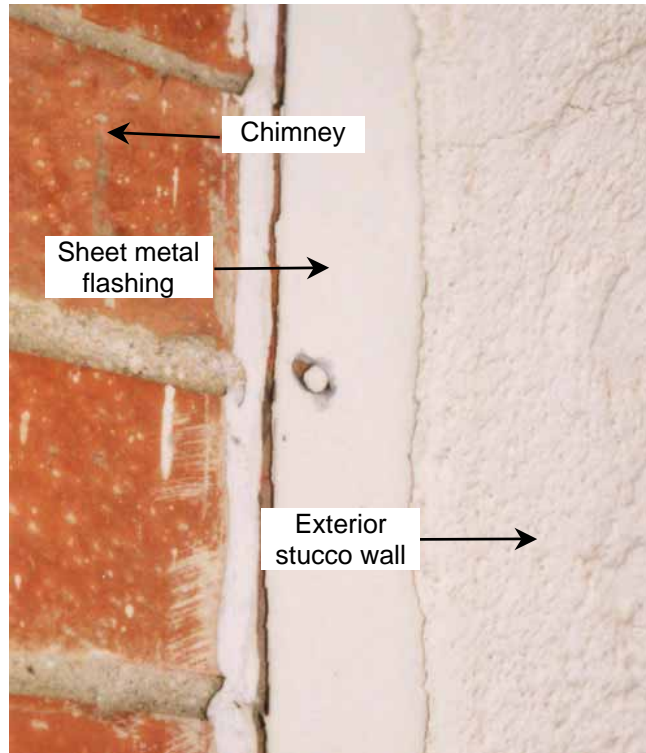


Figure 7.26. Relative cyclic movement between chimney and building during the 1994 Northridge Earthquake indicated by elongated hole in metal flashing and gap between caulking and flashing [Exponent].



Figure 7.27. Tearing of flashing between chimney and roof caused by relative movement between chimney and building during 1994 Northridge Earthquake [Exponent].



Figure 7.28. Rooftop debris from collapse of masonry chimney during the 2003 San Simion Earthquake [Dyce].



Figure 7.29. Collapsed unreinforced masonry chimney.





Figure 7.30. Masonry mantle which separated slightly from the wall finish during the 1994 Northridge Earthquake [Exponent].



Figure 7.31. Collapsed masonry facing during the 1994 Northridge Earthquake [Exponent].



Figure 7.32. Illustration of rocking procedure for checking for chimney for earthquake-induced cracking [Exponent].



## **Appendices Section 7**

### **7A Guidelines for Repair of Earthquake Damaged Masonry Chimneys**

Following is Information Bulletin 1-2004 issued by the Building and Safety Division of the Community Development Department of the City of San Luis Obispo as published on the website of the California Seismic Safety Commission

(<http://www.seismic.ca.gov/HOG/Chimney%20Bulletin1.pdf>).



## RECONSTRUCTION AND REPLACEMENT OF EARTHQUAKE DAMAGED MASONRY CHIMNEYS

This Los Angeles Department of Building and Safety (LADBS) standard plan provides prescriptive details to facilitate the reconstruction of an earthquake damaged masonry chimney using a new factory-built metal chimney or replacement of an earthquake damaged masonry firebox and chimney with a new masonry firebox and a factory-built metal chimney. The two methods are titled:

1. **RECONSTRUCTION OF EARTHQUAKE DAMAGED MASONRY CHIMNEY USING A NEW FACTORY-BUILT METAL CHIMNEY**; and,
2. **REPLACEMENT OF EARTHQUAKE DAMAGED MASONRY FIREBOX AND CHIMNEY WITH A NEW MASONRY FIREBOX AND A FACTORY-BUILT METAL CHIMNEY**.

Masonry chimneys are required to be designed in accordance with LAMC Section 91.3102.7 and must be either free standing or supported from the attached structure. Reconstruction or replacement of a damaged masonry chimney **is not allowed** with masonry unless completely removed, redesigned and constructed to current code requirements. This will require structural plans and calculations prepared by a civil engineer, structural engineer, or architect licensed by the State of California. These structural plans and calculations must be reviewed prior to permit issuance at the plan check counter of a LADBS Construction Services Center.

A building permit is required for either method. Method 1, reconstruction of the chimney, does not require plan check and the permit can be issued at the LADBS Construction Services Center or electronically by facsimile or through the internet ([www.ladbs.org](http://www.ladbs.org)). Method 2, replacement of the firebox and chimney, does require plan check and the permit can only be issued at LADBS Construction Services Center. For Method 2, provide the following indelible plans:

1. A plot plan drawn to scale showing the shape of the parcel, the perimeter of the building, and the setback of the building and fireplace perimeter to all parcel boundaries.
2. A floor plan drawn to a scale of 1/4 inch to 1 foot showing the existing use of each room adjacent to the fireplace.

## **RECONSTRUCTION OF EARTHQUAKE DAMAGED MASONRY CHIMNEY USING A NEW FACTORY-BUILT METAL CHIMNEY**

### **Unreinforced Masonry Chimneys**

Damaged unreinforced masonry chimneys shall be repaired by:

- Utilizing **Section “B”** of this standard.
- Removal down to the throat of the nearest undamaged firebox.
- Construction of a concrete bond beam on top of the remaining firebox.
- The concrete bond beam need not be anchored to the building.

### **Reinforced Masonry Chimneys**

Reinforced masonry chimneys shall be repaired based on the following damage cases:



#### **CASE 1 - Damaged above the Ceiling/Roof Line**

- **Section “A”** of this standard shall be utilized for repair.
- The old reinforced masonry shall be removed down to the roof line.
- A concrete bond beam shall be constructed on top of the remaining reinforced masonry chimney.
- The concrete bond beam shall be anchored to the building.

#### **CASE 2 - Damaged below the Ceiling/Roof Line of a One-Story Building**

- **Section “B”** of this standard shall be utilized for repair.
- The old masonry shall be removed down to the throat of the firebox.
- A concrete bond beam shall be constructed on top of the remaining firebox.
- The concrete bond beam need not be anchored to the building.

### CASE 3 - Damaged below the Ceiling Line of the First Floor of a Two-Story Building

- **Section “C”** of this standard shall be utilized for repair.
- The old masonry shall be removed down to the throat of the firebox.
- A concrete bond beam shall be constructed on top of the remaining firebox.
- The concrete bond beam need not be anchored to the building.

### CASE 4a - Damaged Between the Ceiling/Roof Line and the Second Floor of a Two-Story Building

- **Section “D”** of this standard shall be utilized for repair.
- The old reinforced masonry shall be removed down to the second floor-line.
- A concrete bond beam shall be constructed on top of the remaining masonry chimney.
- The concrete bond beam shall be anchored to the second floor diaphragm.

### CASE 4b - Damaged Between the Ceiling/Roof Line and the Second Floor of a Two-Story Building (Firebox Located at Second Floor)

- **Section “B”** of this standard shall be utilized for repair.
- The old masonry shall be removed down to the throat of the second floor firebox.
- The remaining portion below the second floor is undamaged.
- A concrete bond beam shall be constructed on top of the remaining firebox.
- The concrete bond beam need not be anchored to the building.

## **REPLACEMENT OF EARTHQUAKE DAMAGED MASONRY FIREBOX AND CHIMNEY WITH A NEW MASONRY FIREBOX AND A FACTORY-BUILT METAL CHIMNEY**

Metal chimney/masonry fireplace combinations for new construction are allowed provided the firebox construction complies with LAMC Section 91.3102.7 for new construction and the bond beam firebox transition does not extend more than seven (7) feet above grade and the construction complies with the details in this standard.

The prescriptive details provide that the concrete footing/masonry firebox combination is self supporting and does not rely on or provide support to the building. The following conditions shall apply:

- All mortar and grout shall be sack mix only; no on site mixing of cement, sand and lime shall be permitted.
- Reinforcing steel shall be minimum grade 40 with main vertical bars continuous from footing to bond beam.
- Tack welding shall not be permitted.
- All voids within the masonry shall be solidly grouted.

## CHIMNEY SPECIFICATIONS

1. All factory-built chimney assemblies (pipes, spark arrester, and anchor plates) shall be tested to U.L. Standard 103 by a testing laboratory approved by the City of Los Angeles.
2. Chimneys shall be listed by the testing laboratory as “Residential Type and Building Heating Appliance Chimney” when used for wood burning fireplaces. Chimneys listed as only a “Building Heating Appliance Chimney” are for installation in other than one-or-two-family dwellings.
3. Chimneys for fireplaces with a closed air-tight combustion chamber shall be designated “Type HT”.
4. Factory-built chimney assemblies shall be used and installed in accordance with the terms of their listing and the manufacturer’s instructions.
5. The masonry to metal chimney transition shall be accomplished through the use of a 12 gage steel adapter cone which is imbedded in the concrete bond beam as detailed in this standard plan. A “paroc” basalt insulation gasket shall be installed between the adapter cone flange and the metal chimney anchor plate.

## ADDITIONAL REQUIREMENTS

### Maximum Height

The height of the chimney above the roof shall be limited to ten feet under this standard.

### Diameter of Metal Chimney

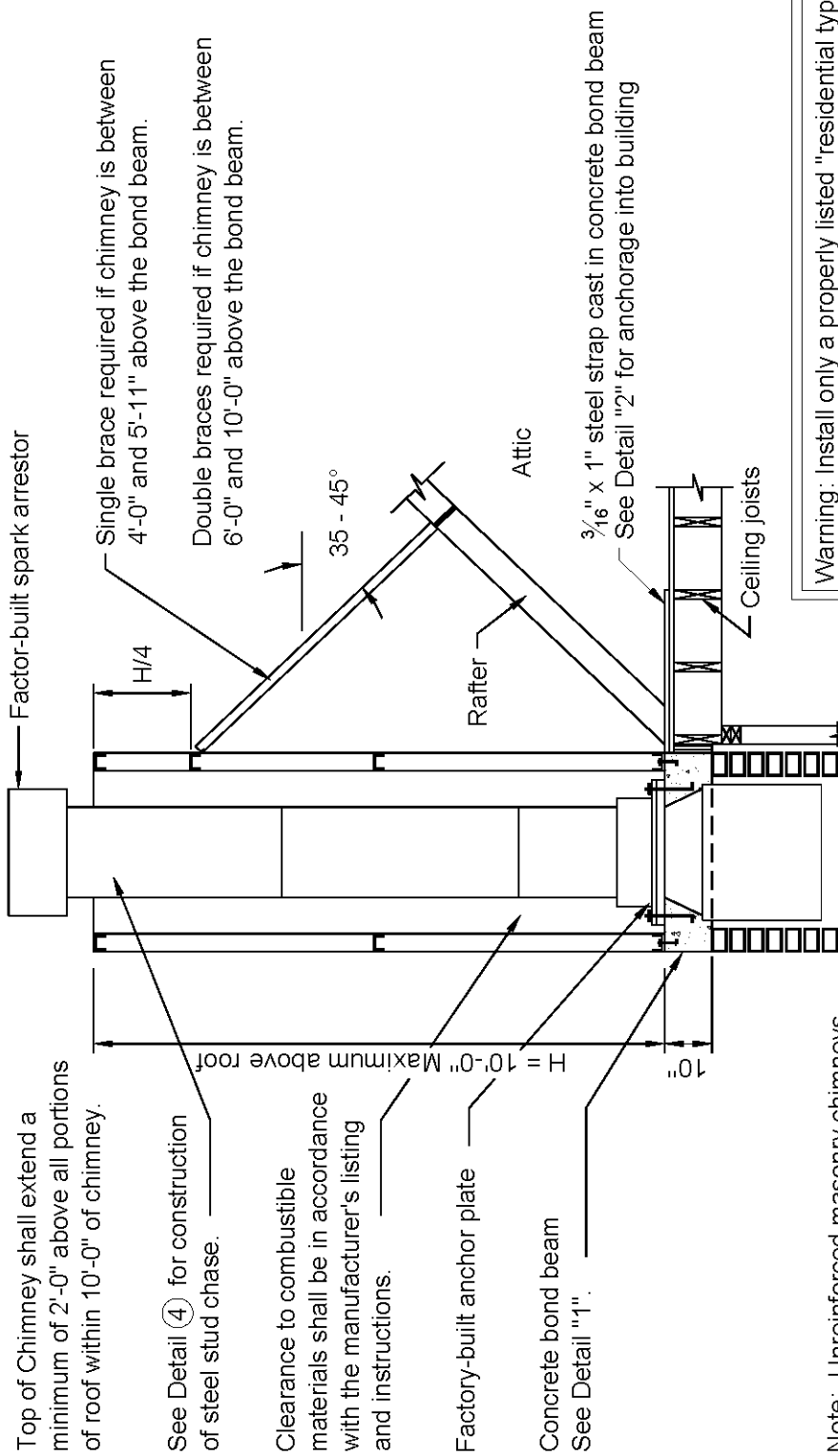
The diameter of the factory-built metal chimney assembly shall be based upon the manufacturer’s specifications and instructions for the least dimension of the existing flue, whichever is greater.

### Draft Stop

A draft stop consisting of drywall or plywood shall be provided to separate the chase from wood members of the existing building.

### Inspection

The firebox, chimney, and other undamaged areas MUST be carefully visually inspected for cracks or voids, which may permit the access of flames or smoke to the surrounding wood framing, prior to any construction.



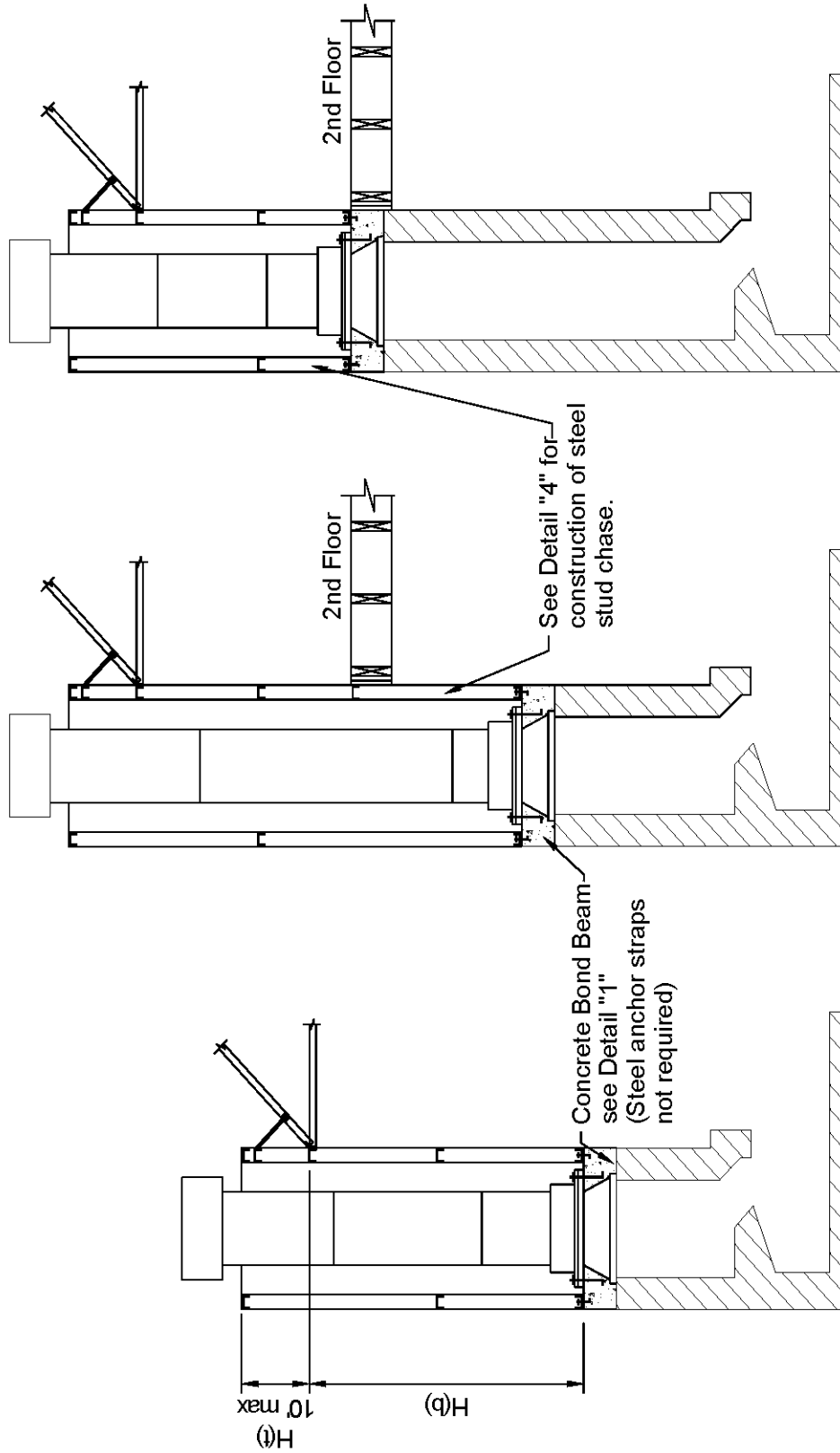
Note: Unreinforced masonry chimneys shall be removed down to the throat.

Warning: Install only a properly listed "residential type and building heating appliance Chimney on wood burning fireplaces. Chimneys for fireplaces with a closed air-tight combustion chamber shall be "TYPE HT" designation. Any other type of chimney may create a potential fire or safety hazard.

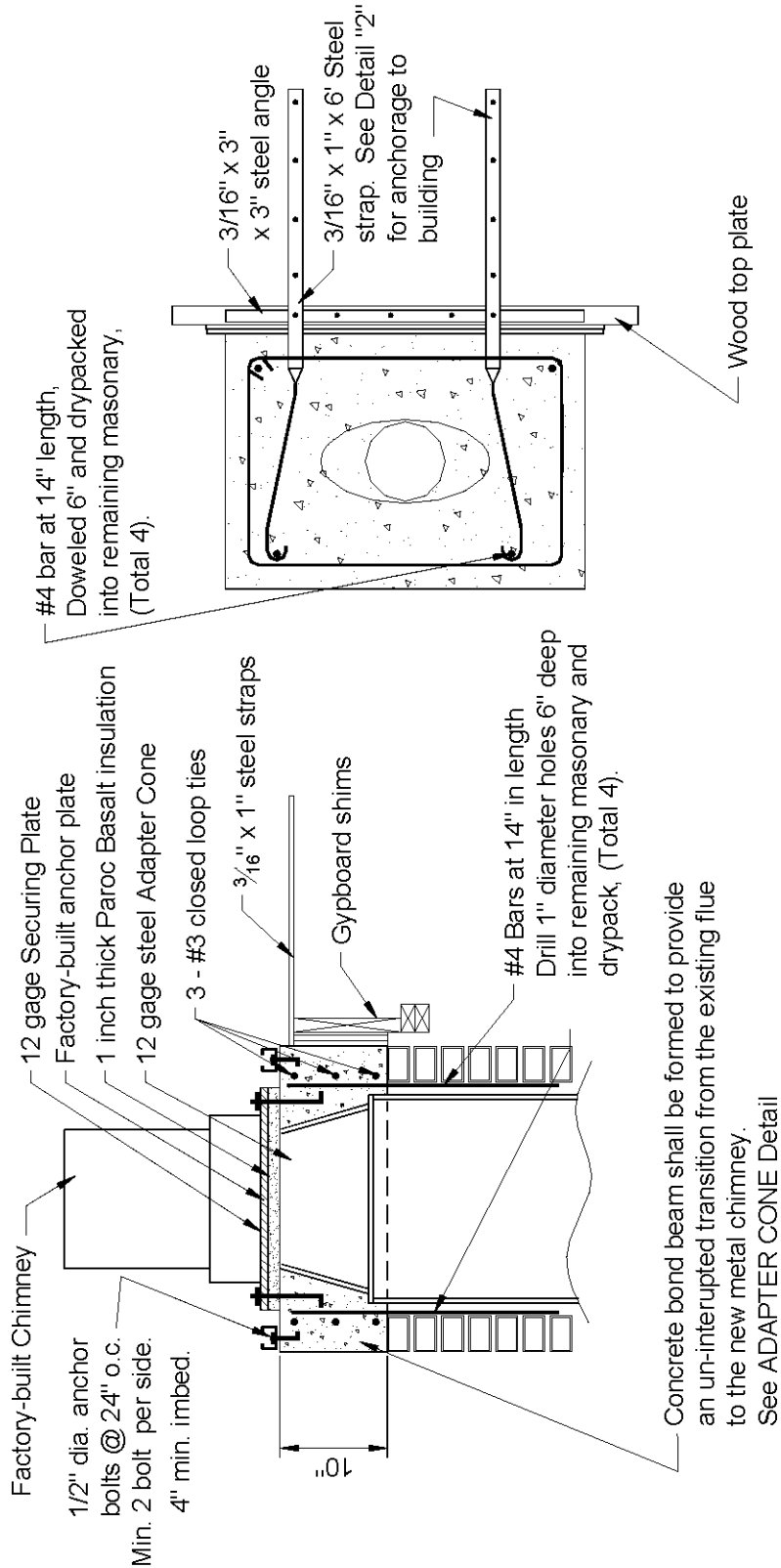
## A Chimney Damage Above Roof Line

### SECTION

Top of chimney shall extend a minimum of 2'-0" above all portions of roof within 10'-0" of chimney.



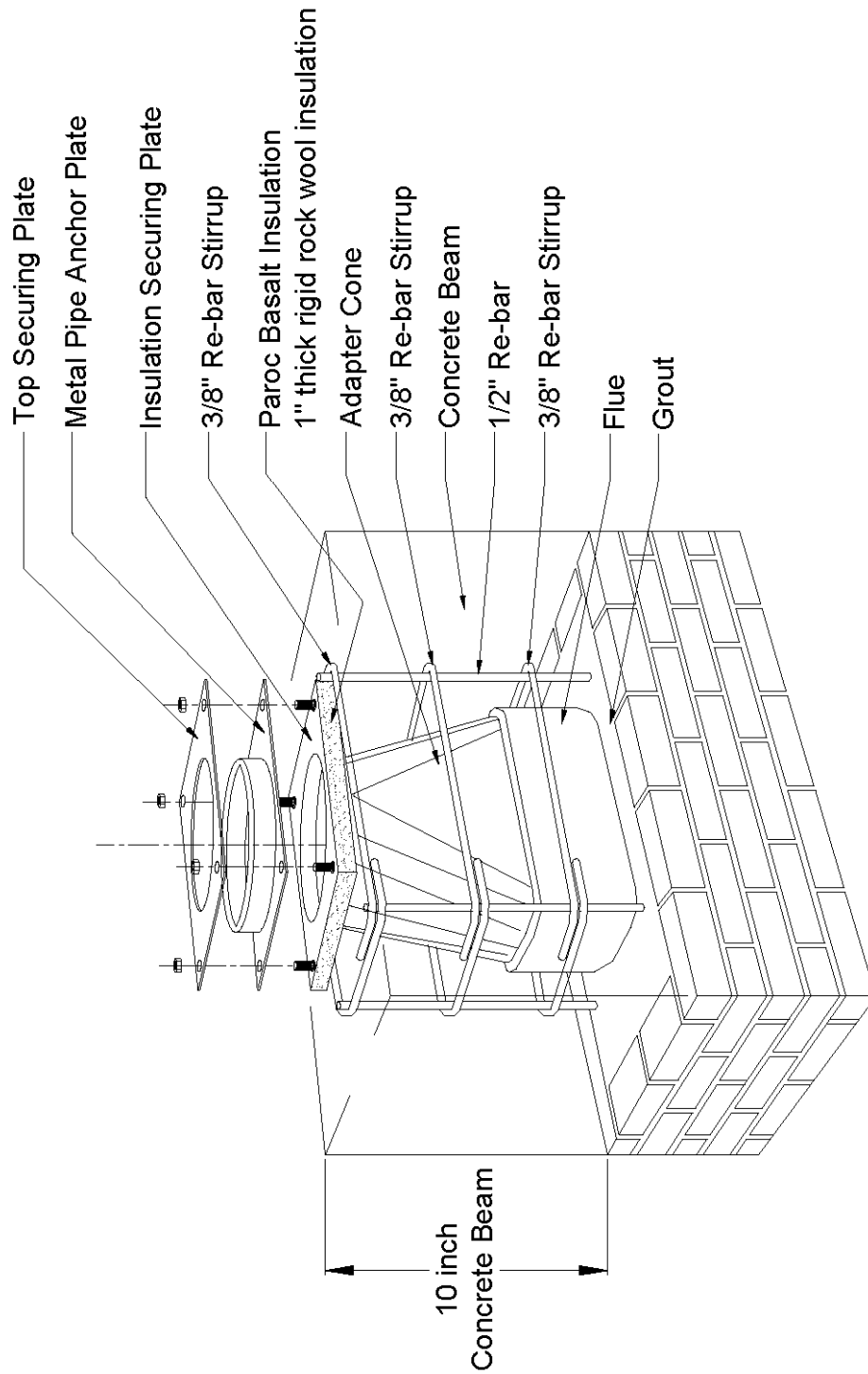




**Section at Bond Beam**

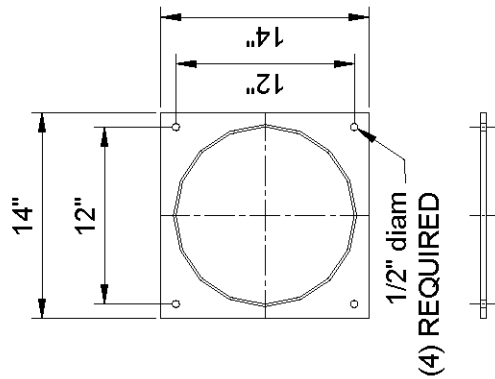
**DETAIL 1**

**Plan View**

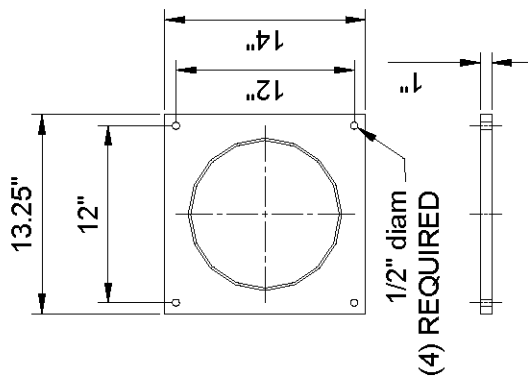


Adapter Kit

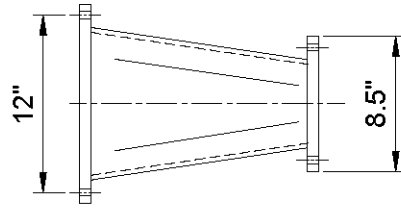
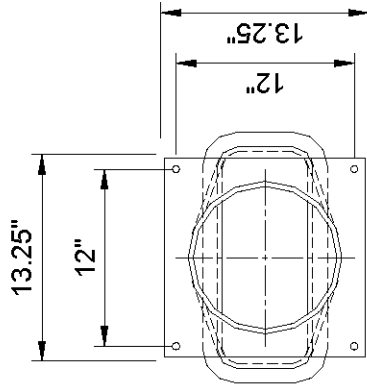
**DETAIL A**  
TRANSFORMATION FROM MASONRY  
FIREPLACE TO METAL CHIMNEY



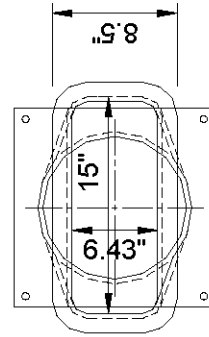
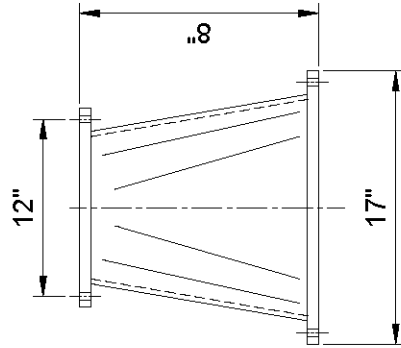
SECURING PLATE  
MATERIAL: 12 GAGE STEEL  
FINISH: BLACK PAINT



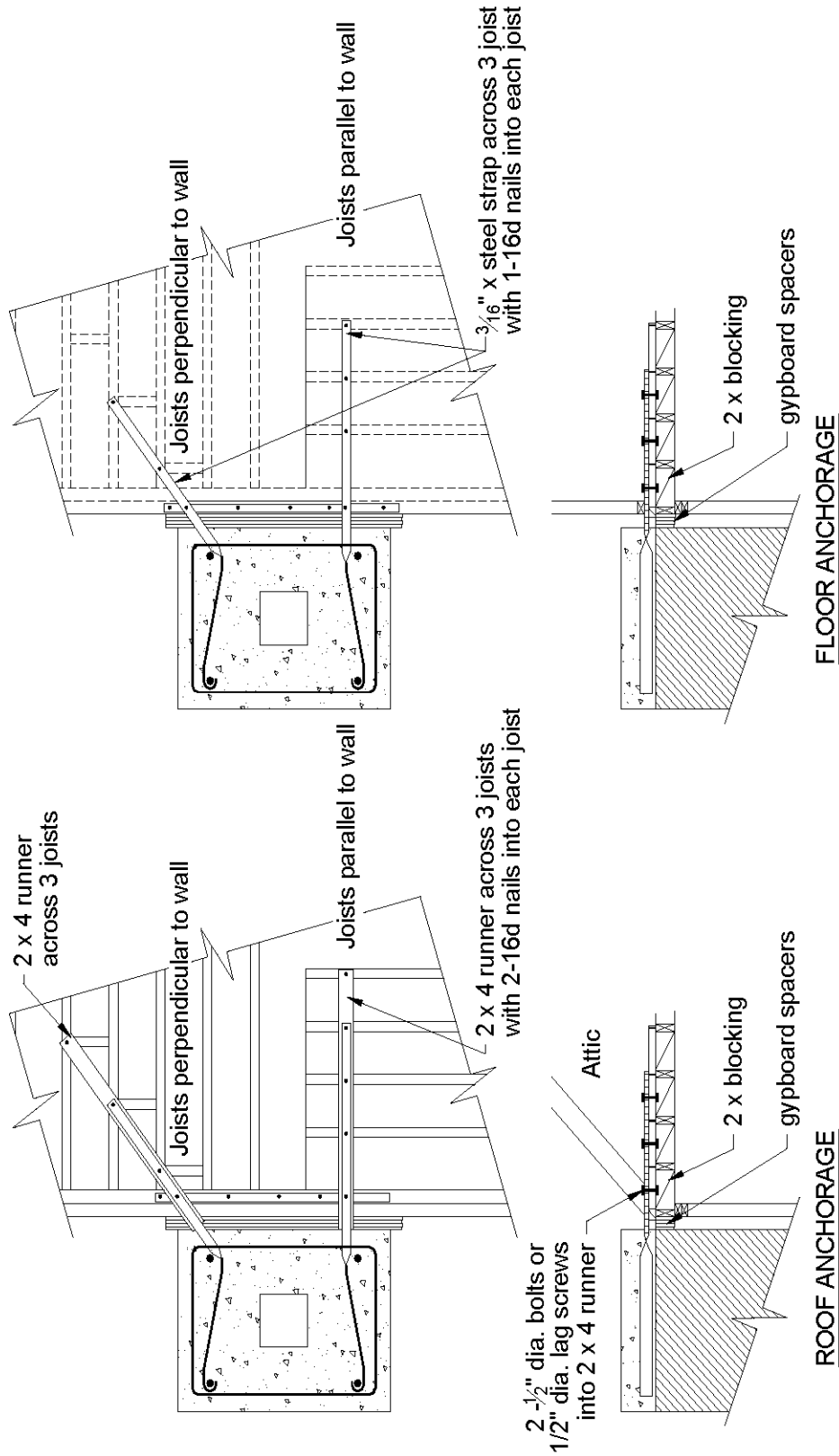
INSULATION  
MATERIAL: PAROC BASALT  
INSULATION



ADAPTER ONE  
MATERIAL: 12 GAGE STEEL  
FINISH: BLACK PAINT  
MEASUREMENT IN INCHES

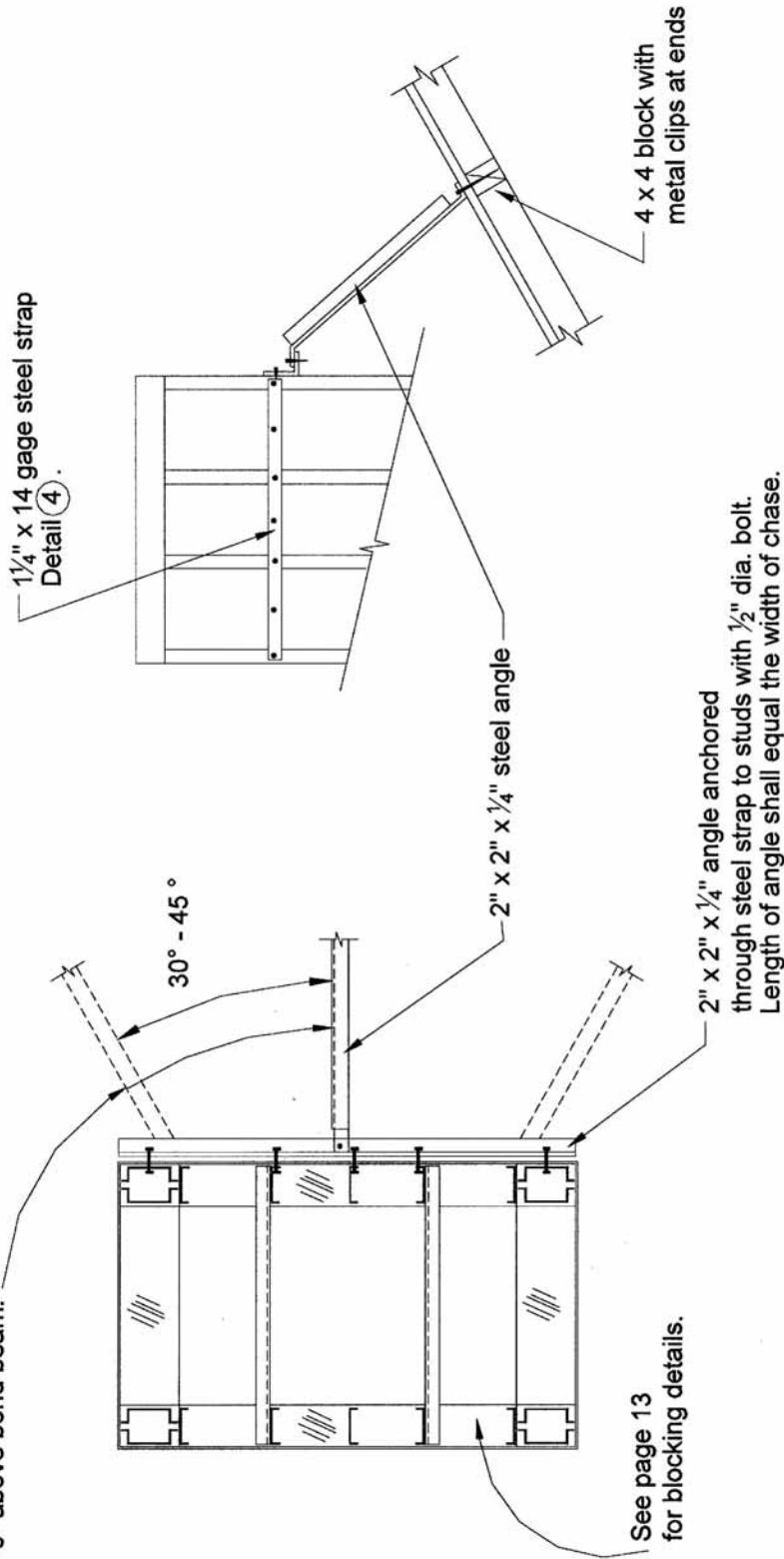


## ADAPTER CONE




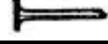


**DETAIL 2**  
**(Concrete Bond Beam Anchorage Into Building)**

Single brace required if chimney is between 4'-0" and 5'-1" above the bond beam. Double brace required if chimney is between 6'-0" and 10'-0" above bond beam.



**DETAIL 3**  
(Roof Brace)

Covering Material	Fasteners
Laths for stucco	No. 8 x 5/8" sheet Metal screws at 6" o.c.  
Plywood	No. 6 Bugle head screws at 6" o.c. at chase and 12" o.c. at interior edges and fields.  

#### STEEL STUDS SPECIFICATIONS:

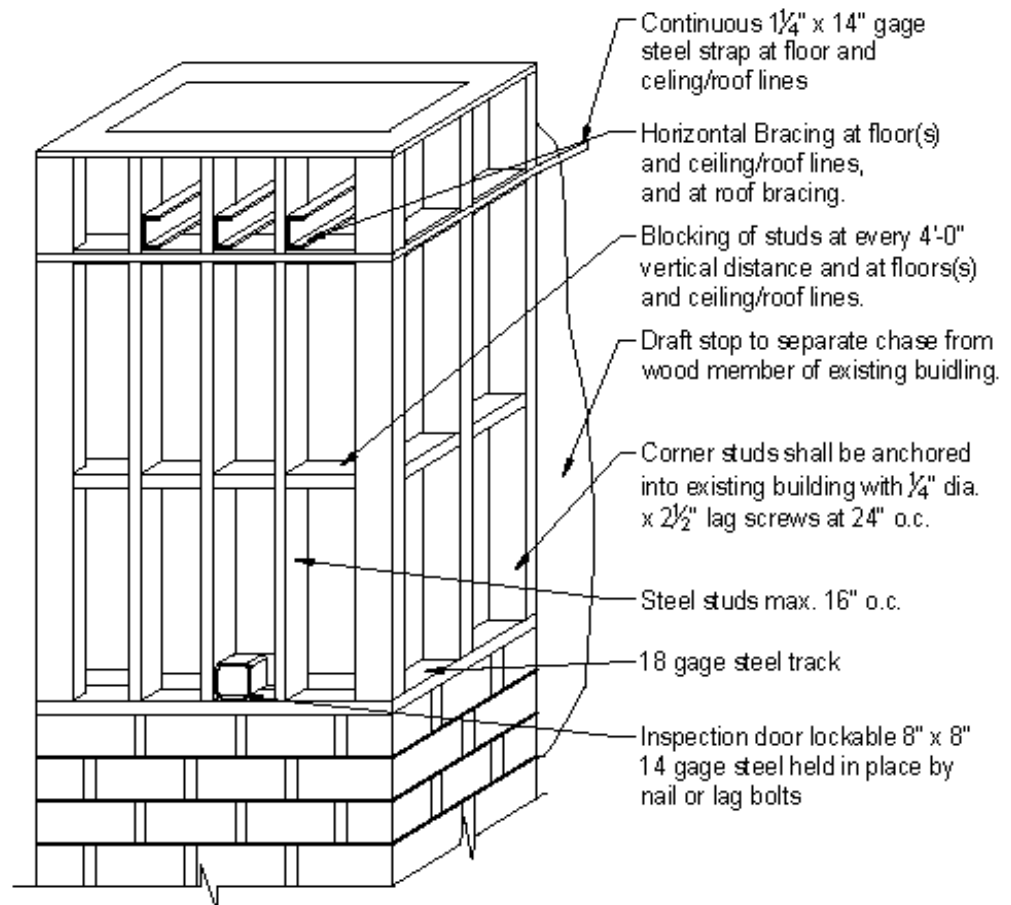
All steel studs shall be either galvanized or factory painted "C" type stud.

Minimum 18 gage  
Minimum width 3½"  
Minimum Fy = 33 ksi

#### COVERING

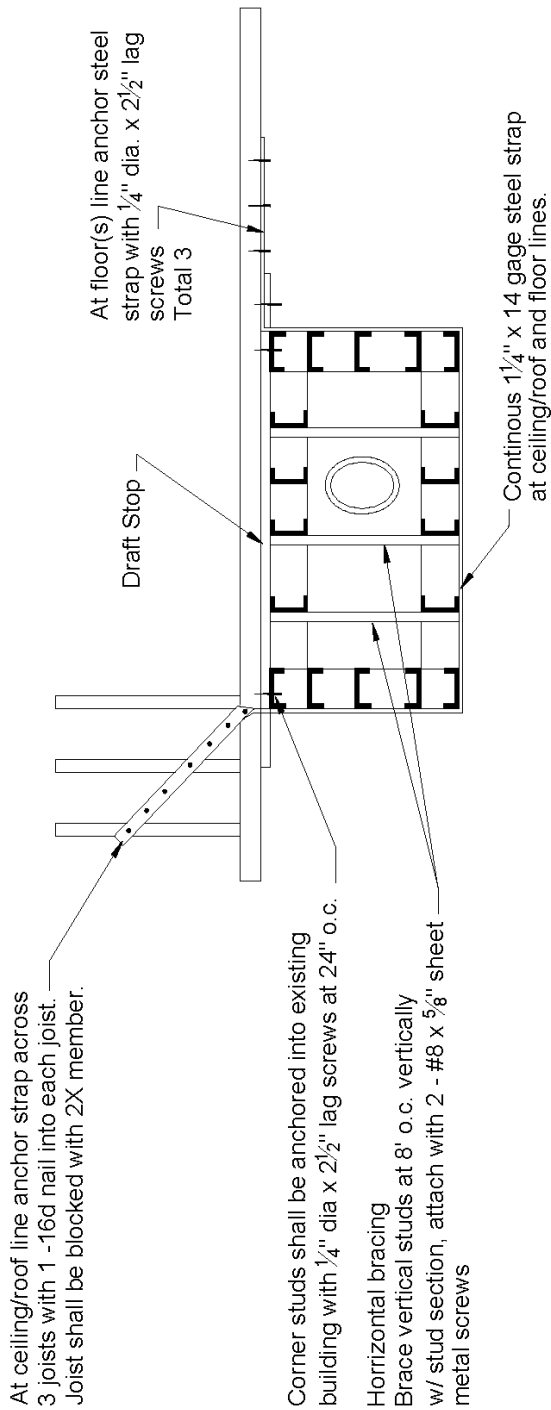
Steel stud chase may be covered with stucco or adhered veneer.

Note: Adhered veneer shall be a max. 1" with plywood backing (⅝" min.) and shall be installed per division 30 of the L.A. building code.

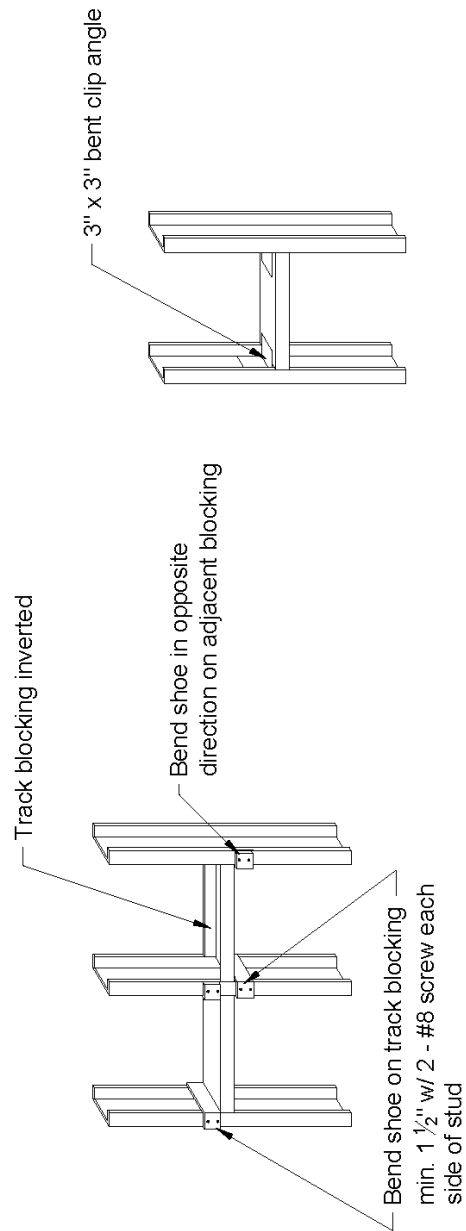


**Detail ④**





## Strapping & Bracing Detail @ Ceiling/Roof and Floors



Bent Shoe Option

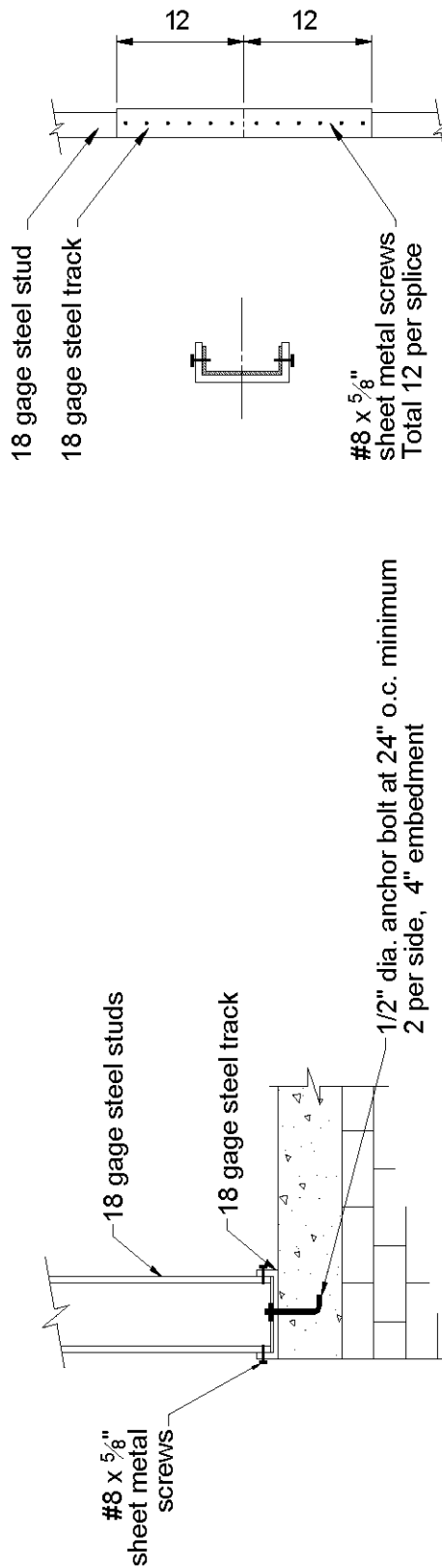
Angle Clip Option

## Blocking Details

## Inspection Requirements

The permit holder or his agent shall notify the Department when the chimney is ready for each of the following inspections:

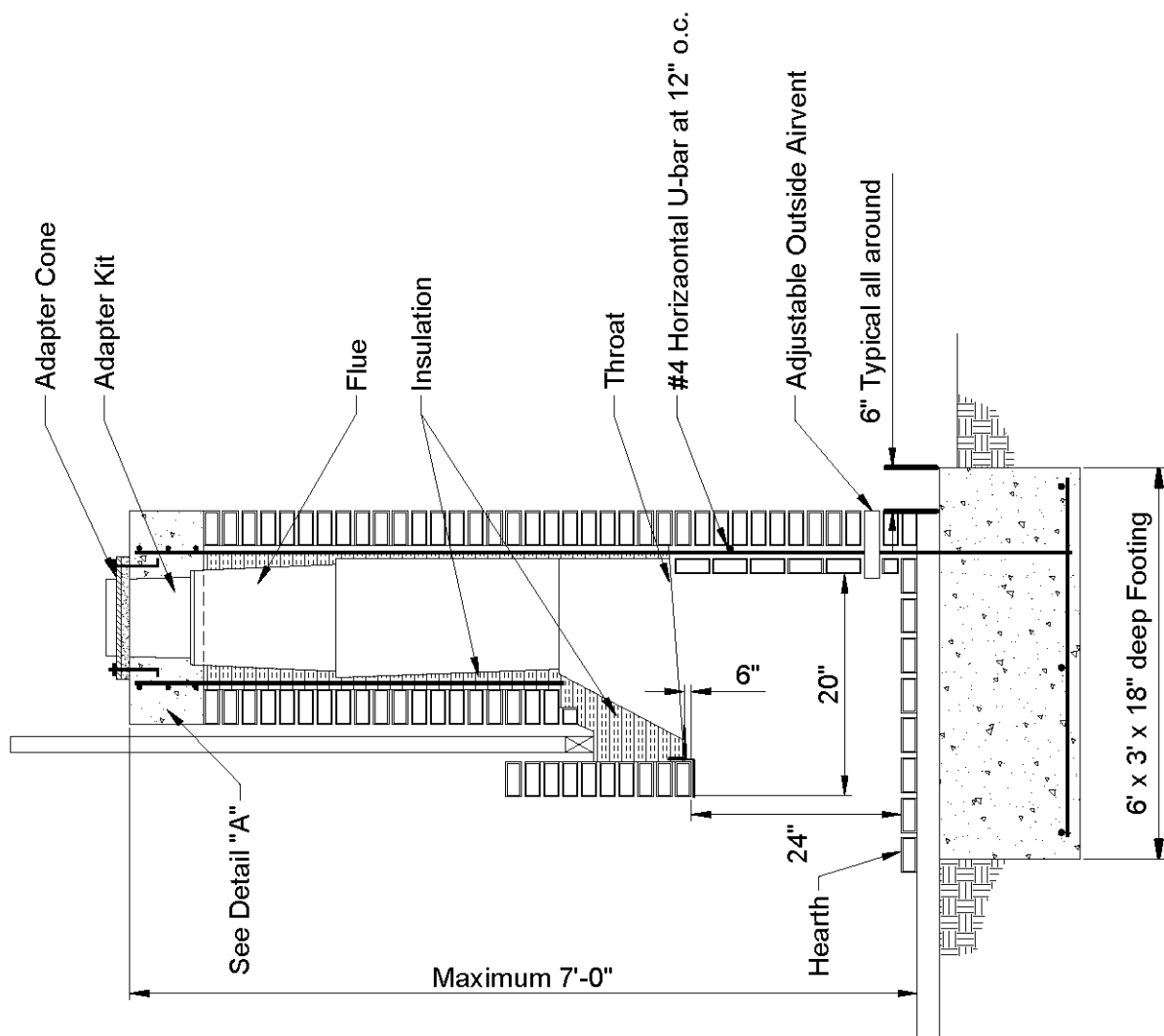
1. Concrete Bond Beam: When the form and required reinforcing steel are in place but before any concrete is poured.
2. Framing: When all members including but not limited to bracing, blocking, metal chimney or flashing are in place, but before any covering is in place.
3. Stucco: When the backing and lath is in place ready for stucco.
4. Final: When the chimney is completed.



Splice shall be staggered a minimum of 12" vertically.  
Maximum one splice per stud.

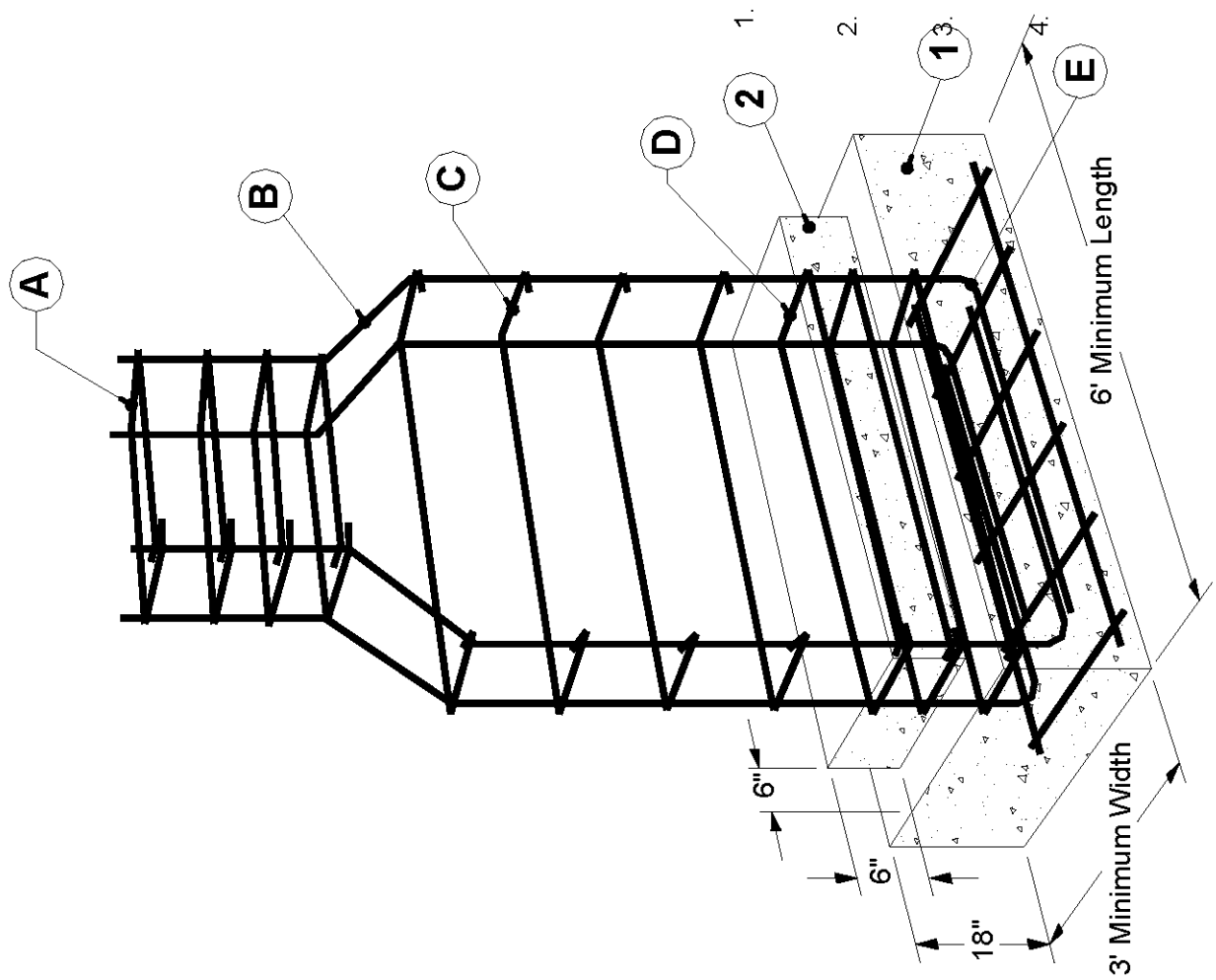
Track Detail

Splice Detail



**New Firebox - Cross Section Typical 36" Fireplace**





## Detail (B)

### Typical 36" Fireplace

- A. #3 Stirrup @ 6" o.c.
- B. 4 - #4 Rebar
- C. 3 - #4 /stirrups in foundation
- E. 6 - #4 Tiebars

The fireplace foundation at ground level. 6'-0" long x 3'-0" x 1'-6" deep Minimum.

The fireplace foundation above ground shall be formed at 5'-4" long x 2'-1" wide x 6" high.

The 4 - #4 vertical bars will have a 4' right angle bend extending across the foundation.

The four vertical bars will be temporary anchored to the above ground foundation forms placed at 6" from each corner. This will insure the correct placement for the vertical reinforcement steel.

## 8 Mechanical, Electrical, and Plumbing Systems

### 8.1 Quick Guide

#### 8.1.1 What to Look For and Where to Look

- **IMPORTANT** – Immediately following an earthquake, check the entire property, especially near appliances, for the smell of gas. If gas odor is detected, turn off the gas at the meter where it enters the house as illustrated in Figure 8.2. Locate and repair leaks before turning gas back on. If the gas odor persists after the gas has been shut off, vacate the building, and contact the gas utility company immediately.
- **IMPORTANT** – Before entering a damaged, vacant building verify that gas is off. Check the gas meter for damage and position of main gas valve, either a manual valve or a seismically-activated gas shut-off valve as shown in Figure 8.1. A closed manual valve will typically have its knob at 90 degrees to the pipe as shown in Figure 8.2. Gas meters are typically outside the home in an accessible area. Do not enter the building if gas odor is detected.
- Check overhead electrical service wires (if present) for loose wires, excessive sag, or exposed conductors.
- Check the water heater(s) for toppling, shifting, leakage from tank, leakage from water connections (Figure 8.3), displaced flue connection (as shown in Figure 8.4), and damage/leakage at gas line or electrical connection. Water heaters can typically be found in garages, basements, or closets.
- Check the air conditioning condenser unit(s) for toppling, shifting, and damage/leakage at refrigerant and electrical lines. Condenser unit for air conditioning systems are located outside the building, either at grade or on the roof.
- Check the evaporative cooling unit(s) for toppling, shifting, and damage/leakage at power and water connections. The units are typically found on the roof as shown in Figure 8.5, in attics, garages, basements, or closets.
- Check the furnace(s) for shifting, damage/leakage at gas line, flue connection, electrical connection, and condensate drain connection. Furnace/air conditioning units can be found in garages, basements, attics, closets or on rooftops as shown in Figure 8.6 and Figure 8.7.
- Check gas clothes dryers and gas stoves for damage/leakage at the gas line.
- Check toilets for rocking or broken closet collar bolts.



- Check water flow/pressure at all sinks.
- Check water flow in clothes washers, built-in dishwashers, water dispensers, etc.
- Check freestanding wood stoves for toppling, shifting of the stove or flue.
- Check fuel oil tank (if present) for toppling, shifting, damage/leakage at fuel connection. Fuel oil tanks are typically found in the basement, near the furnace unit.
- Check propane tanks (if present) for toppling, shifting, damage/leakage at fuel connection. Propane tanks are typically found in rural locations away from the home on a concrete slab.
- Check roof-mounted solar panels (if present) for shifting and leakage at water connections.
- Check for other signs of water damage or evidence of leakage from water supply lines or sprinkler systems.
- Check pool and spa equipment and piping for shifting, connection failures, broken piping.

### **8.1.2 When to Call a Consultant**

There are a variety of conditions that may require attention from qualified service personnel or contractors. If any of the following conditions are observed, qualified service personnel should be retained to perform an inspection of the house:

- Contact the local natural gas utility if gas odor was detected. Any leaks must be located and repaired before turning gas back on.
- Contact a plumber if reduced water flow to appliances or faucets is observed. Inline screens, filters, and bubble strainers may need to be cleaned.
- Contact a qualified HVAC repair person or contractor if any of the following are observed:
  - Misaligned flues or exhaust vents from any gas, oil, or wood-fired appliance as illustrated in Figure 8.4. In this event proper ventilation must be verified.
  - Leakage from refrigerant lines at the condenser or evaporator coil.
- Contact a leak detection service if any of the following conditions are observed:
  - Sliding or shifting of the building or concrete slab-on-grade floor relative to the foundation (see Section 4).

- Ground cracking or failure at the property or in the vicinity (see Section 3). A plumber should leak test the sewer lateral and pressure test the underground water piping.
- Seepage or leakage in the basement, crawlspace, utility closets, or at the baseboard in the basement or on the ground floor of the structure.
- Saturated zones of soil adjacent to the perimeter of the structure.
- Contact an electrician if any wiring was pulled loose as a result of shifting of equipment or structural damage as shown in Figure 8.8 and Figure 8.9.

If the building was constructed prior to 1980 and repair work will involve disturbance of materials that may contain asbestos, a suitably qualified and licensed environmental consultant should be retained to test for the presence of regulated hazardous materials and, if necessary, recommend appropriate abatement and waste disposal measures. See Section 9.2.4 for additional information.

### 8.1.3 Repair Guidelines

Repair of typical earthquake damage to mechanical, electrical, and plumbing (MEP) systems generally consists of component repair or replacement in kind.

## 8.2 Summary

The single most important aspect of conducting a post-earthquake assessment of damage to mechanical, electrical, or plumbing system is to verify that hazards do not exist from damaged mechanical, electrical, or plumbing systems. **In particular, if there are conditions observed that call into question the integrity of gas lines, furnace or water heater flues, or electrical connections, contact appropriate utility companies or service personnel before restoring utility services to the home.**

Typical residential mechanical, electrical, and plumbing systems consist of one or more heating and air conditioning systems; electrical service and branch circuits to which plumbing or mechanical equipment may be hard wired, low voltage wiring for phones and alarm systems, coaxial cable TV wiring, built in appliances, plumbing fixtures, water and gas supply lines, and sewer lines.

Earthquake damage to mechanical, electrical, and plumbing systems and equipment typically occurs where:

1. Large, heavy pieces of equipment (e.g., water heaters, propane tanks, fuel tanks, etc.) are not properly restrained as shown in Figure 8.3.
2. Rigid water, gas, refrigerant, electrical, or other connections to equipment do not allow relative motion between the equipment and the building.

3. Significant displacement occurs at penetrations of partitions or slabs resulting in breakage of pipes or conduits.
4. Permanent earthquake-induced ground displacement occurs rupturing buried utility lines.

Thus, an inspection of these systems should include a review of all large and/or heavy pieces of equipment in the home. This will include water heaters, air conditioning condenser units, furnaces, toilets, and any type of liquid storage tanks.

Ductwork, flues, wiring, and piping concealed within walls or floors are generally more robust than the surrounding framing and wall finishes. Thus invasive inspection of concealed systems is generally not recommended.

Damage to water lines inside the home will most likely be in the form of pipe breakage (as opposed to pin holes) and is usually readily apparent via the resultant water damage or unusual accumulation of water in crawlspaces or elsewhere on the property. If there is evidence of ground separation (see Section 3), there is also the possibility of damage to underground water, sewer, and gas lines. Damage to underground sewer lines is more difficult to detect from a visual inspection. However, because sewer lines run underground in a similar manner to water supply pipes, damage to sewer lines is reasonably possible when other utility lines on the property have been damaged or evidence of earthquake induced ground movement is present on the property. If there is evidence of utility line damage, ground separation on the property, or shifting or sliding of a concrete slab-on-grade floor relative to the foundation, contact a leak detection service to verify the integrity of the underground sewer line.

Commonly, the shaking inherent in earthquakes can result in dislodging of corrosion, scale, or other debris in water lines, which can, in turn, result in plugging of filters, aerators or other constrictions in water supply lines. This problem is usually easily remedied by removing and cleaning/replacing the affected filters or aerators.

## **8.3 Limitations**

This document addresses only the mechanical, electrical, and plumbing systems that are typically found in single-family dwellings. It also applies to small, multi-family dwellings that use similar systems. It does not apply, however, to the following:

- Large, high-rise buildings that may have large, common mechanical systems such as chillers, boilers, roof-top water tanks, elevators, fire pumps, cooling towers, etc. Such building systems tend to be more complex and customized than residential systems and a proper assessment will usually involve the use of mechanical engineering consultants.
- Commercial buildings where there may be a significant amount of roof-mounted mechanical equipment, metal ducting, drop ceilings, large diameter piping, etc. Again, proper assessment of such buildings may require the use of mechanical engineering consultants.

## **8.4 Description of Typical Residential MEP Systems**

The MEP systems in typical single-family and small multi-family dwellings are fairly simple. This section provides a brief overview of the most common systems and their major components.

### **8.4.1 Plumbing**

The water supply for a home generally comes from a service tap off of a water main near the street. The service tap will usually have a meter for measuring water usage and a shutoff valve that defines the end of the municipal utility's property. The remainder of the line is the homeowner's property and usually passes underground from the street to a location near the home where it comes above ground to a second shutoff valve. The water line then splits in various directions to supply cold water to various appliances and fixtures throughout the home, including the water heater, sinks, bathtubs, showers, toilets, refrigerators, dishwashers, clothes washers, water softeners, etc., as well as in ground irrigation systems, pools and spas, and, in some cases, a fire suppression sprinkler system. There are a variety of materials used for water distribution piping in the home including, copper, galvanized steel, and polymeric (plastic) materials such as CPVC.

Drain or sewer lines generally feed via gravity back to a sewer main on the street (if in an area with municipal sewers) or to a septic system. In cases where the home is below the street (or septic tank) level, there will also be pumps to lift the wastewater up to the appropriate level. Common sewer piping materials used above and below grade include cast iron, galvanized steel, copper, and plastic. Archaic below grade only materials include clay tile and various asphalt composites.

### **8.4.2 Mechanical**

Most homes of recent construction include mechanical systems used for heating and cooling. The most common system is forced air heating and cooling, which uses a blower and a series of ducts to distribute conditioned air throughout the home. Heating is generally provided via an electric, fuel oil, or gas-fired furnace that is co-located with a blower and cooling coil. This unit is generally found in a basement, garage, attic, or closet. For gas or fuel oil-fired systems, a flue will be present to direct combustion gases outside the house via a vent on the roof. Natural gas is generally supplied via a connection to a gas main that has a meter and shutoff valve. In areas of the country where earthquakes are common, the gas meter may have an automatic valve that shuts off the gas supply in the event of an earthquake. In rural areas where there is no gas service, propane tanks are sometimes used to supply fuel for the property. In certain areas of the country (e.g., New England) fuel oil is commonly used for heating. This fuel oil is similar in composition to automotive diesel fuel and is generally stored in a large tank in the basement near the furnace. Radiant heating systems, which circulate hot water or steam through piping embedded in the floor or connected to radiators, may be found in older construction.

Cooling is generally supplied via a split-system, which is comprised of a condenser unit (that contains the compressor, a fan, and the condenser coil) and a cooling unit (that contains the expansion valve and cooling coil). The condenser unit is generally located outside, either beside

the home or on the roof. The cooling unit is generally located in or adjacent to the same housing as the furnace and uses the same blower and ducting as the heating system.

Evaporative cooling units (aka “swamp coolers”) are common in areas of dry heat. These units use evaporation of a water mist to cool incoming air and consist of a large housing, filter media, and a large blower. The units are generally mounted on the roof and connected to the living space via direct ducting.

### **8.4.3 Electrical**

Electrical power systems consist of a service drop (either overhead or underground) from the utility to an electric meter mounted on the building, a distribution panel with a main breaker (or fuse) and breakers (or fuses) for branch circuits, distribution wiring, and fixtures or electrical devices. The vast majority of residential wiring is flexible cable concealed in walls and ceilings, though plastic or steel conduit is typically used in exposed locations.

In addition to electrical power, most homes will also have a number of low-voltage electrical systems such as telephone, doorbell, intercom, and coaxial wiring for television antennas, satellite dishes, and cable service.

## **8.5 Non-Earthquake Sources of MEP System Damage**

### **8.5.1 Plumbing**

Plumbing systems are subject to multiple types and sources of deterioration and distress during their service life, much of which goes unnoticed or is routinely repaired. This section describes conditions commonly found in residential plumbing and sewer systems in the absence of earthquakes.

- Corrosion of water lines: Corrosion of metallic water lines occurs over time to both the interior and exterior of the pipe. For example, poor water conditions inside the lines can lead to pitting corrosion in copper water lines and unprotected underground steel lines can be exposed to exterior corrosion due to ground water exposure. The rates of corrosion can vary dramatically depending on factors such as water conditions, ground conditions, and the presence of dissimilar metals (e.g., copper and steel in contact). Corrosion in water lines generally appears in the form of pits or holes as opposed to cracks or breaks.
- Scale within water lines: Depending upon water chemistry, mineral deposits can accumulate within water pipes, gradually restricting flow in the pipe.
- Plugged sewer lines: Underground sewer lines are susceptible to plugging by plant or tree roots or other obstructions in the lines. These types of obstructions can generally be cleared via snaking or rooting out the lines. Underground lines will settle and shift with the surrounding soil. In cases of

poor installation or unstable soil, that movement can result in sags in the line where solids collect or in breaks and offsets in the line, which restrict flow or lead to leakage from the sewer. Differential settlement of utility lines can also occur between the building and the surrounding ground, particularly for buildings supported on drilled piers where the surficial soil and utilities can settle independently of the building.

- Water heaters have a limited service life that will be a function of manufacturing quality, water chemistry, and usage. Failure typically manifests as corrosion-induced leakage.
- Washers, gaskets, hoses, and other components wear and deteriorate with time, requiring replacement from time to time to maintain proper function.

### **8.5.2 Mechanical**

Mechanical systems are susceptible to various modes of malfunction and degradation in normal service. Some examples include:

- Low refrigerant pressure: Small leaks in the refrigerant loop of air conditioning systems can lead to a slow loss of refrigerant and degradation in performance.
- Contaminated refrigerant lines: Over time debris from wear, corrosion, or other mechanisms can make the refrigerant in an air conditioning system contaminated.
- Dirt and dust accumulation: Over time ducts, filters, supply and return registers, and blowers can accumulate dust and dirt.
- Poor lubrication, loose belts: Lubrication and belt tension are routine preventative maintenance items for mechanical systems.
- Soot and corrosion in fired furnaces: Combustion products include smoke, soot, and water among other products and these products can build up in combustion chambers over time along with corrosion products, leading to failure of heat exchangers and flue piping.

### **8.5.3 Electrical**

Properly installed electrical power systems are robust and do not generally require maintenance beyond replacement of lamps or an occasional switch. Low-voltage systems are often more complicated and less robust, being vulnerable to loose connections and faulty electronics.



## 8.6 Earthquake-Induced MEP System Damage

With a few notable exceptions, MEP systems are generally robust with respect to the effects of earthquake shaking and do not sustain serious damage. However, MEP systems are attached to the building, rely upon the building for support, and will sustain serious damage in the event of serious structural damage or collapse.

### 8.6.1 Plumbing

The most commonly observed effects of earthquake motion on plumbing systems include:

- Rocking or toppling of water heaters, resulting in damage ranging from dislodged vent piping (Figure 8.4) to breakage of water piping connections (Figure 8.3) and destruction of the water heater. While most water heaters (in California) are now required by code to be “strapped” (as illustrated in Figure 8.10) to reduce the chances of toppling, many of those straps are not sufficient to prevent damaging movements of the water heater during strong shaking. Newer water heaters are also connected to the house piping with flexible tubing (as illustrated in Figure 8.11) that will accommodate minor differential movement of the water heater without failure of the connections. Older installations may be hard piped (as illustrated in Figure 8.12) and are thus much more susceptible to development of leaks in the connecting piping under minor differential movement. Older water heaters (those near the end of their service life) may develop leaks as a result of thermal and pressure cycling as a result of the loss and resumption of water pressure and gas supply following an earthquake.
- Plugging of filters, aerators, and other in-line restrictions due to scale and debris that is dislodged when water supplies are reestablished following an earthquake. This condition is often misdiagnosed as either appliance failure (in the case of dishwashers and clothes washers) or obstructed piping (in the case of sink aerators).
- Breakage of water supply or drain lines due to displacement of heavy equipment (e.g., water line to refrigerator or condensate drain line on an air conditioner).
- Unseated toilets or broken closet collar bolts; broken tank covers.
- Breakage of underground water supply or sewer lines due to earthquake-induced permanent ground deformation (see Section 3).
- Breakage of water supply or sewer lines due to the building shifting relative to the foundation.

### **8.6.2 Mechanical**

The most commonly observed effects of earthquake motions on mechanical systems include:

- Shifting or toppling of water or other liquid tanks. Common examples include water heaters, water tanks, fuel oil tanks, and propane tanks.
- Breakage of gas supply lines to heavy equipment (such as water heaters, furnaces, and stoves) due to differential motion as illustrated in Figure 8.3. These circumstances constitute a safety hazard and the gas company should be contacted to verify proper conditions are present prior to re-establishing gas service to the property.
- Dislocation of exhaust ducts, chimneys, or flues due to motion of equipment as illustrated in Figure 8.4. These situations can constitute a potential safety hazard due to the potential for carbon monoxide and other combustion products to enter the home.
- Shifting of air conditioning condenser units located outside or on the roof.
- Breakage of refrigerant, water or other lines to equipment due to relative motion.
- Dislocation or disconnection of ducting.

### **8.6.3 Electrical**

Electrical systems generally do not sustain significant damage from the direct effects of earthquake shaking. Some observed effects of earthquake motions on electrical systems include:

- Serious structural damage or collapse may cause damage to electrical wiring and fixtures as illustrated in Figure 8.8 and Figure 8.9.
- Failure of connections due to shifting or toppling of hard wired fixed equipment, such as furnaces, air conditioners, and electric water heaters.
- Hanging fixtures such as chandeliers or ceiling fans can be damaged from impact with walls or ceilings from earthquake-induced swaying.
- Damaged electrical fixtures can short circuit or create fires when electricity remains on or is eventually restored.

## **8.7 Assessment Guidelines and Methodology**

### **8.7.1 Plumbing**

An assessment of potential earthquake damage to plumbing systems should include the following:

- Examine water heater for toppling or damage to water, gas, flue, or electric connections.
- Check pressure of water supply to house at hose bib close to water supply service entrance. Reduced pressure indicates problem with municipal supply / local well or the service lateral.
- Check water pressure or flow at all faucets, tubs, showers, and toilets. Reduced pressure may indicate clogged valves, aerators, or shower heads.
- Check water pressure at appliances that use water such as refrigerators, dishwashers, and clothes washers. Reduced pressure may indicate clogged valves or clogged in-line filters.
- If there is evidence of earthquake-induced permanent ground deformation (see Section 3), contact a leak detection service and/or the local water and sewer utility to determine the condition of the underground sewer and water supply lines.
- Check all toilets for signs of rocking, shifting, broken closed collar bolts, etc.
- Visually inspect the property for signs of water damage due to pipe leaks from broken pipes inside wall cavities, crawlspaces, or attics.

### **8.7.2 Mechanical**

An assessment of potential earthquake damage to mechanical systems should include the following:

- Inspect the condition of the gas meter and shut off valve.
- Inspect the condition of the gas line to any gas-fired appliance (e.g., water heater, stove, furnace).
- Look for evidence of shifting or toppling of any liquid storage tanks on the property. These can include water heaters, water tanks, fuel oil tanks, and propane tanks.
- Look for evidence of shifting or toppling of the furnace and the air conditioner condenser unit.

- Look for evidence of shifting, blockage, or damage to any chimney, flue, or exhaust duct for any combustion-related equipment (such as water heater, furnace, fireplace, free-standing wood stove, etc.).
- Turn on the furnace blower and check the airflow from all ducts to verify ducting is still connected.

If the building was constructed prior to 1980 and repair work will involve disturbance (demolition, removal, grinding, sanding, etc.) of any of the following components, a suitably qualified environmental consultant should be retained:

- Mechanical duct or flue joint tape or insulation
- Asbestos-cement (“Transite”) flue pipe

As discussed in Section 9.2.4, the consultant should test for the presence of asbestos and, if the results of the tests are positive, recommend appropriate abatement and waste disposal measures. Old mechanical systems such as furnaces, boilers, and related equipment, should not be dismantled since asbestos may be present in interior compartments.

### **8.7.3 Electrical**

Generally, the greatest risk of earthquake-related damage to electrical systems is when collapse, falling objects, or flammable material can damage or otherwise effect or come in contact with electrical systems which can result in fires or loss of functions. Connections to fixed and relocatable electrical systems and equipment should be checked in the course of inspection of that equipment.

## **8.8 Repair Methodologies**

Following proper assessment of the nature and extent of earthquake related damages, repair of that damage is generally straightforward and generally consists of component repair or replacement in kind. Unique considerations for repair of earthquake damage are discussed below.

### **8.8.1 Plumbing**

If low water pressure or low flow exists, aerators at faucets, shower heads, toilet float valves, and in-line strainers at washing machines, dishwashers, and icemakers should be cleaned and piping flushed. Where buried piping has been damaged by earthquake-induced ground deformation either a local repair or complete replacement will be necessary, depending upon the type of piping and its condition.

### **8.8.2 Mechanical**

Natural gas supply lines to mechanical systems should be shut off if gas is smelled or leaks are heard. Repairs should initially focus on disconnecting damaged or questionable mechanical systems from potential fire sources such as gas or electricity until such time that they can be fully assessed, repaired, or replaced before their functions are restored. Pressure tests to locate leaks in systems may be warranted to fully identify repair needs.

### **8.8.3 Electrical**

Repairs should first focus on disconnecting electricity to damaged or questionable systems until such time that they can be assessed, repaired, or replaced before their functions are restored.

### **8.8.4 Permits, Upgrades, and Retrofits**

Depending upon the nature and scope of damage and proposed repair, building permits and other government agency approvals may be required by the local jurisdiction. In addition to normal changes in the building code over time, some jurisdictions have building code requirements that mandate upgrading portions or components of a building if certain damage thresholds are exceeded. Check with the local building department to determine the existence of any applicable local requirements. As a general rule however, repairs may be made to components of MEP systems without upgrading the entire system as long as the repair work itself is done in accord with current code requirements.



Figure 8.1. Gas meters with seismic shut-off valves [Exponent].



Figure 8.2. Manual gas shut-off valve [Exponent].





Figure 8.3. Displacement of unsecured water heater during 1994 Northridge Earthquake [Exponent].



Figure 8.4. Displacement of unsecured water heater vent during 1989 Loma Prieta Earthquake [Exponent].



Figure 8.5. Toppled “swamp cooler” due to earthquake [Exponent].



Figure 8.6. Rooftop HVAC unit (no damage) [Exponent].



Figure 8.7. Rooftop HVAC unit (no damage) [Exponent].





Figure 8.8. Racking and delamination of exterior stucco resulting in damage to electrical outlet during 1994 Northridge Earthquake [Exponent].



Figure 8.9. Close-up of earthquake damage to electrical outlet box [Exponent].



Figure 8.10. Water heater with flexible piping and securing strapping (no damage) [Exponent].



Figure 8.11. Flexible piping between unsecured water heater and house piping (no damage) [Exponent].



Figure 8.12. Water heater with “hard” piping (no damage) [Exponent].





## **9 Working with Technical Consultants**

### **9.1 Introduction**

Following an earthquake, the services of a technical consultant may be necessary to assist with damage assessment of an affected property. The objective of this chapter is to provide guidance to owners/occupants, insurance claim representatives, and other stakeholders for interaction with technical consultants.

### **9.2 Circumstances Requiring Technical Consultant Services**

As a class, single-family woodframed houses have performed very well in historic major earthquakes, suffering damage to contents, cosmetic damage, but generally only insignificant structural damage. Thus, the services of a technical consultant are generally not required for post-earthquake assessment of single-family woodframed houses. Exceptions, as discussed below, are:

- Buildings where earthquake damage compromising the safety of the building has been identified in the course of a post-earthquake safety assessment of the building (see Section 9.2.1 for more detail).
- Buildings with damage indicating possible structural damage, instability in the ground beneath or adjacent to the building, or damage to buried utility lines (see Section 9.2.2 and subsequent sections for more detail).
- Buildings with construction or configurations known to be vulnerable to earthquakes (see Section 9.2.3 for more detail).
- Earthquake damaged buildings constructed of materials other than woodframe construction, such as adobe, brick, or concrete block masonry, concrete.
- Buildings constructed before 1980 where repair work will disturb finishes or materials that may contain asbestos or lead (see Section 9.2.4 for more detail).

#### **9.2.1 Building Tagging**

For a building that has been red or yellow tagged, a structures specialist should be retained to perform a damage assessment (see Section 1.3.2 for a brief summary of the safety assessment program). If the sole reason for the yellow tag is a damaged chimney, the need for assessment by a technical consultant should be based on the criteria presented in Section 7. If soil failure or instability is one of the reasons for the red or yellow tag, a soils specialist should be retained as well.

### 9.2.2 Damage State

If any of the following conditions is present at a house, a structures specialist should be retained to inspect the property. See Sections 3 through 8 for detail regarding evaluation of these conditions.

- Building has collapsed or is partially collapsed.<sup>58</sup>
- Building superstructure has shifted relative to, or off, its foundation.
- Building as a whole, any story, any walls, any cripple walls, door openings, or columns are visibly out of plumb.
- A pattern<sup>59</sup> of broken windows and sticking/inoperable hinged doors.
- Evidence of separation between various portions of the building, such as:
  - At the “split” in split-level houses.
  - At the juncture of an addition with the original building.
  - At the juncture between a floor or roof and the adjacent wall.
  - At the juncture of porch roofs or patio covers with the main building.
  - At the juncture of breezeway roofs to adjacent buildings.
- Shifting or movement of interior walls and partitions relative to the floor.
- For hillside houses, at the downhill edge: damage to vertical supports; posts visibly out of plumb; broken, slack, or buckled diagonal bracing; or damage to connection between foundation and superstructure.
- Visible distortion of the roofline or significant fresh damage to attic framing.
- Damage to the structure in the vicinity of the chimney.
- A pattern of splitting of framing members (sill plate, hold down locations, floor joists, etc.).
- Linear fissures in ground parallel to the crest of a slope (not to be confused with fissuring caused by drying of expansive soil), rising or bulging of the ground surface, or signs of slope movement (above or below the building).
- Evidence of fresh settlement of floors or exterior pavement.

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<sup>58</sup> As a practical matter, technical assistance is probably not required if the building is obviously a total loss. Engineering assistance may be necessary for safety associated with contents removal and/or demolition.

<sup>59</sup> As discussed in Section 5, observing patterns of damage allows distinction between localized damage and an overall damage pattern. Intent here is to identify an overall pattern of racking of the building.

- Evidence of earthquake-induced permanent ground deformation (fault rupture, liquefaction, lateral spreading, landslide, ridge-top shattering) in the immediate vicinity of the property
- Fresh fractures wider than 1/8 inch or offset by more than 1/16 inch perpendicular to the crack in concrete foundation elements or floor slabs (see Section 4.7.2 for guidance on determining whether a fracture is recent).

### 9.2.3 Structural Configuration

Certain building configurations are particularly vulnerable to earthquake damage, and in some cases that damage may not be obvious to the untrained eye. For buildings with configurations described below that exhibit even slight damage, a structures specialist should be retained to inspect the building for subtle, but structurally significant damage.

- Hillside houses where the ground surface elevation varies by a half story or more over the footprint of the building.
- Multi-story buildings with one or more open sides at the first story.
- Multi-story buildings with irregularities, typically split-level houses.

### 9.2.4 Hazardous Construction Materials

Buildings constructed before about 1980<sup>60</sup> may have been constructed (or modified) with materials that contain asbestos or lead. There are legal requirements for evaluations, abatement procedures, and waste disposal when repair or remodeling work is being done by contractors, or if the amount of material being disturbed is larger than a few square feet. Depending on the type of material and the quantity involved, the debris may become hazardous wastes, which must be handled, transported, and disposed of following appropriate regulations. If repair of earthquake damage will disturb (demolition, removal, grinding, sanding, etc.) materials that may contain asbestos or finishes that may contain lead-based paint, a suitably qualified and licensed environmental consultant should be retained to sample and test the suspect material and, if test results are positive, recommend appropriate measures to remove or otherwise mitigate the hazard and properly transport and dispose of any resulting hazardous wastes.

Materials that may contain asbestos include:

- Sprayed acoustic (“popcorn”) ceiling finishes
- Gypsum joint compound (drywall “mud”)
- Interior plaster

<sup>60</sup> The manufacture of construction materials containing asbestos or lead was banned for most construction materials during the 1970s. However, existing stock was permitted to be used in construction. Thus, there is no specific date when materials containing asbestos or lead were banned from construction. The generally accepted cut-off date for routine testing is 1980.

- Exterior stucco
- vinyl floor tile and/or mastic
- Backing or underside of sheet vinyl
- Mechanical system insulation
- Asbestos-cement (“Transite”) flue pipe
- Roofing felt
- Roofing mastic
- Asbestos-cement siding

Material that may contain lead consists of enamel paint applied to:

- Doors, windows, and trim
- Kitchen and bathroom walls, ceilings, and cabinetry
- Concrete floors
- Exterior walls and surfaces
- Exterior metals

In California, the minimum qualifications for an environmental consultant are state registration as a California Lead Consultant and California Asbestos Consultant. While not required, the Certified Industrial Hygienist credential reflects a higher level of understanding and training with respect to dealing with hazardous construction materials.

### **9.3 Selecting Technical Consultants**

In these *Guidelines*, the term technical consultant is used as a generic term for consultants who are qualified to assess the nature and extent of earthquake damage to residential property and recommend appropriate repairs for that damage. For most earthquake damage issues, the appropriate consultant will be a structures specialist. In California, structures specialists include Licensed Civil Engineers specializing in structural engineering, Licensed Structural Engineers (Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Structural Engineer), and Licensed Architects who are qualified by education, training, and experience in the technical area of post-earthquake damage assessment may also legally offer many of the same services as a Licensed Civil Engineer. A structures specialist can evaluate all components of a building, including the foundation, for structural damage.

Where evidence of earthquake-induced permanent ground deformation is present, the structures specialist may recommend retaining the services of a soils specialist. Soils specialists include Civil Engineers specializing in soils (or geotechnical) engineering, Geotechnical Engineers

(Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Geotechnical Engineer), and Engineering Geologists.<sup>61</sup> Some structures and soils specialists are adequately qualified in both areas of structures and soils to address many of the more common earthquake damage patterns. Thus, for the evaluation of typical earthquake damage at most residential properties, one consultant may be able to address all technical issues. In some circumstances, the services of consultants in other technical specialties, as described in Section 9.4 may be required to assist the structures or soils specialist.

### **9.3.1 When is the Stamp and Signature of an Engineer Required?**

When a building inspection report relies on engineering judgment and expertise to reach conclusions and make recommendations, the stamp and signature of a responsible<sup>62</sup> professional engineer is required [Brandow 1997]. Specific examples of work requiring a responsible professional engineer cited by Brandow are:

- Opinions on structural condition and/or adequacy based on observation, engineering judgment, or calculations.
- Recommendations about required or recommended structural upgrades, strengthening or seismic mitigation.
- Statements comparing structural capacities to Uniform Building Code requirements or other standards such as loading capacity, seismic resistance, vibration issues, deflections, durability, etc.

There are many areas of specialization under the Civil Engineering umbrella. The Civil Engineering specialties of interest for earthquake damage assessment are structural engineering – the analysis and design of buildings or other structures, and geotechnical engineering – the analysis and design of soil conditions for construction. In addition to the basic Civil Engineering license (C.E. or P.E.) California also issues two specialty titles that indicate knowledge and experience beyond that required for the Civil Engineering license alone:

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<sup>61</sup> The difference between a Geotechnical Engineer (a Civil Engineer specializing in geotechnical engineering) and an Engineering Geologist is significant. Engineering Geologists focus on the regional behavior of soil and rock masses whereas Geotechnical Engineers focus on site-specific behavior of soil and rock. Engineering Geologists tend to orient their work towards the effects that geology has on the structure of concern. Geotechnical Engineers investigate the mechanical and physical properties of soil and rock masses and analyze their stability and suitability for the support of structures. The most significant difference is that an Engineering Geologist cannot design repairs or remedial work, whereas a Civil Engineer can.

<sup>62</sup> The term ‘responsible’ is defined in §§ 6703 of the Professional Engineers Act of the Business and Professions Code of the California Statutes ‘The phrase “responsible charge of work” means the independent control and direction by the use of initiative, skill, and independent judgment, of the investigation or design of professional engineering work or in the direct engineering control of such projects ...’



- **Structural Engineer** – A licensed Civil Engineer specializing in structural engineering may also be licensed to use the title Structural Engineer (S.E.).<sup>63</sup>
- **Geotechnical Engineer** – A licensed Civil Engineer specializing in geotechnical engineering may also be licensed to use the title Geotechnical Engineer (G.E.).

While the statutory definition of Civil Engineering is very broad, licensure as a Civil Engineer (with or without the additional titles of S.E. or G.E.) does not imply expertise in all aspects of Civil Engineering, and not all Civil Engineers are qualified to investigate structural damage. California Code of Regulations (16 CCR T. 16, Div. 5, s415) restricts registered Civil Engineers to practice “only in the field or fields in which s/he is by education and/or experience fully competent and proficient.”

### 9.3.2 Qualifications for Engineers and Architects Performing Post-Earthquake Damage Assessment

In addition to their professional license, a structures specialist engaged in earthquake damage assessment of woodframe construction should have the following minimum qualifications:

- Related education or experience in structural and/or geotechnical engineering.
- Experience with the investigation of damaged buildings.
- Knowledge of the effects of earthquakes on buildings and their supporting soils.
- Knowledge of historical regional construction practices for woodframe construction.
- Experience in the design and/or construction of woodframe buildings.

### 9.3.3 Locating Potentially Qualified Engineers

Sources of contact information for potentially qualified engineers are the regional Structural Engineer’s Association of California ([www.seaoc.org](http://www.seaoc.org)), the local chapter of the American Society of Civil Engineers ([www.asce.org/inside/sec\\_brnch.cfm](http://www.asce.org/inside/sec_brnch.cfm)), or Consulting Engineers and Land Surveyors of California ([www.celsoc.org](http://www.celsoc.org)).

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<sup>63</sup> California law requires that specified school and hospital facilities be designed by a Structural Engineer. Otherwise, there is no legal distinction between the services that a C.E./P.E. and an S.E. may offer, so long as they practice in their area of competence.

### 9.3.4 Contracting for Technical Consultant Services

Unless you have knowledge of a consultant's qualifications from another engagement or a reliable source, prior to retaining a technical consultant the following are suggested:

- Check credentials, by obtaining a copy of the consultant's curriculum vitae (resume) or statement of qualifications that should include information on education, work experience, technical expertise, and professional registration (or license) number.
- Check consultant's license – the registration status of engineers, architects, contractors, and geologists licensed in California may be verified at [http://www2.dca.ca.gov/pls/wllpub/wllquery\\$.startup](http://www2.dca.ca.gov/pls/wllpub/wllquery$.startup)
- Review consultant's prior experience to determine whether the consultant meets the qualifications outlined in the preceding section.

It is common and legal for engineers who are not yet licensed to work under the direction of a licensed engineer who is in responsible charge of the work. For post-earthquake safety and damage assessments, it is highly desirable that the licensed engineer in responsible charge of the investigation personally inspects the building. They may be assisted in the investigation by unlicensed engineers and technicians and need not remain at the site for the duration of the investigation, but should spend sufficient time at the site to personally observe all essential aspects of the building condition.

#### 9.3.4.1 Written Contract Specifying the Scope of Services

Assuming that the consultant's credentials are acceptable, the next step is entering into an agreement or contract with the consultant. California law<sup>64</sup> requires, with some exceptions, engineers to provide their clients with a written contract specifying at a minimum:

1. A description of the services to be provided to the client by the professional engineer.
2. A description of any basis of compensation applicable to the contract, and the method of payment agreed upon by the parties.
3. The name, address, and license or certificate number of the professional engineer, and the name and address of the client.
4. A description of the procedure that the professional engineer and the client will use to accommodate additional services.
5. A description of the procedure to be used by any party to terminate the contract.

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<sup>64</sup> California Statutes, Professional Engineers Act, Business and Professions Code, §6749, Written Contracts.

Relevant exemptions are:

1. A professional engineer who has a current or prior contractual relationship with the client to provide engineering services and that client has paid the professional engineer all of the fees that are due under the contract.
2. If the client knowingly states in writing after full disclosure of this section that a contract which complies with the requirements of this section is not required.

Given the infrequent occurrence of earthquakes, most parties involved in post-earthquake damage assessment and repair are operating in unfamiliar territory. Accordingly, effective involvement of technical consultants requires effective communication between all parties if a common understanding of the technical issues is to be achieved. Effective technical consultant involvement begins with a common understanding of the questions to be addressed by the consultant. Consultants must clearly distinguish between structurally significant and nonstructural damage, specify repairs necessary to remedy structurally significant earthquake damage, and identify upgrades to the building that may be mandated by local codes or voluntary upgrades that the engineer believes are desirable. While the technical consultant's scope will generally not include inspection or evaluation of non-earthquake related items, any safety related deficiencies observed in the course of the consultant's inspection, should be brought to the attention of the property owner.

#### **9.3.4.2 Potential Scope of Engineering or Architectural Services**

A structures specialist may be asked to perform any or all of the following services:

- Engineering safety assessment in accord with ATC-20.
- Damage identification and repair recommendations for specific structural elements (e.g., foundation).
- Damage identification and repair recommendations for the entire building and grounds utilizing only noninvasive inspection methods, where appropriate.
- Damage assessment and repair recommendations for the entire building utilizing both noninvasive and invasive methods where appropriate.
- Preparation of a written report of findings and recommendations.

Outline scopes for technical consultant assessment of damage to major building components are presented in appendices to this section, as follows:

- Appendix 9A – Floor Slabs and Foundations
- Appendix 9B – Walls
- Appendix 9C – Roofs, Ceilings, and Floors

Appendix 9D presents a suggested outline for a comprehensive report. However, the scope and detail of the report should be tailored to the needs and circumstances of each client and there should be a clear agreement between the consultant and client regarding the nature and scope of report requested.

The time required to complete the scope of services may range from a few days for limited scope investigations up to three or four weeks for more detailed work. Following a major earthquake, qualified technical consultants in an area will quickly be overwhelmed, so ask for, and agree to, the delivery time before authorizing the work.

Technical consultants generally bill for their services on a time and expense basis, although following a major earthquake, some technical consultants will offer a standard scope of services on a fixed fee basis. Ask for and agree to a budget before authorizing the work.

## **9.4 Other Consultants/Subcontractors**

Based on the results of the structures specialist's initial assessment, it may be necessary to engage other consultants and/or subcontractors. If there are significant issues related to soil at the site, a soils specialist might be required. Subcontractors that may be necessary to assist the technical consultants or address other earthquake related issues are listed below. In the aftermath of a major earthquake, it is essential to verify the business and professional credentials of any consultants or subcontractors prior to engagement.

- Chimney inspection service to inspect the chimney flue.
- General contractor to assist with opening concealed areas for inspection and repairing the inspection openings.
- Carpet contractor to remove and reinstall carpet to facilitate inspection of slabs-on-grade.
- Plumber/pipe inspection service to pressure test or inspect plumbing lines.
- Contractor/consultant to address integrity of the shell of swimming pools, hot tubs, and Jacuzzis.
- Mechanical engineer or HVAC contractor to inspect damage to ductwork, furnaces, and air conditioners.
- Concrete coring service to remove samples of concrete from the foundation.
- Utility location service to locate underground utilities.

- Roofing contractor to assess damage to roofing systems.
- General contractor or construction cost consultant to assist with estimating the cost of unusual or complicated repair work.
- Environmental consultant to test for the presence of mold, if there are indications of significant visible mold growth on building material surfaces – typically a Certified Industrial Hygienist (CIH).

## Appendices Section 9

### 9A Outline Scope for Technical Consultant Assessment of Floor Slab and Foundation Damage

#### 9A.1 Technical Consultant Assessment

A non-invasive structures specialist assessment of floor slab and foundation damage should include an interview with the building owner/occupant, detailed visual inspection, measurement, and sometimes mapping of cracks. For houses with carpeting over slab-on-grade floors, if there are external indications of possible earthquake-induced cracking of the floor slab or foundation, selective pulling of carpets may be appropriate. Specifically:

- For exposed portions of slabs-on-grade, portions of slabs-on-grade covered with brittle (such as ceramic tile, slate, marble, brick pavers) or semi-brittle finishes (sheet vinyl, vinyl floor tile, adhered wood flooring), exposed edges of slab as well as exposed exterior and interior (i.e., from within the crawlspace) portions of stem walls, the following should be noted and documented with field notes and photographs:
  - Type of finish, if any.
  - Condition of finish and width of cracks in finish relative to width of cracks in concrete beneath.
  - Approximate locations or distribution of cracks.
  - Maximum and minimum width of characteristic cracks.
  - Out-of-plane offset across the crack (i.e., vertical offset for slab cracks, horizontal offset of the vertical face of stem walls).
  - For stem walls with an accessible crawlspace, note the crack width on both the interior and exterior faces. Also note the variation in crack width over the height of the wall.
  - Examine the exterior and interior finishes of the woodframe walls adjacent to cracks – cracks caused or widened by an earthquake will cause fresh damage to the adjacent finishes.
  - Examine crack surfaces for conditions that indicate whether the crack is fresh or a long-term condition.
- If the preceding investigation indicates possible earthquake-induced cracking of the floor slab or foundation in areas covered with carpeting, carpeting and padding should be pulled back to expose a portion of the slab in several



rooms.<sup>65</sup> Locations adjacent to visible earthquake damage (for example, in walls or tile floors) should be inspected, and if any slab damage is found, more carpet should be pulled to reveal as much of the damage pattern as is practical. Because repeated carpet removal is costly, time-consuming, and disruptive, extremely thorough documentation and, if possible, direct observations by all stakeholders, is warranted for slabs under carpet. The following should be noted and documented with field notes and photographs:

- Areas of slab exposed for inspection.
- Approximate locations of cracks.
- Maximum and minimum width of each crack.
- Amount, if any of out-of-plane offset across the crack (i.e., vertical offset).
- Examine the exterior and interior finishes of the woodframe walls adjacent to cracks – cracks caused or widened by an earthquake will cause fresh damage to the adjacent finishes.
- Examine crack surfaces for conditions that indicate whether the crack is fresh or a long-term condition.

If significant damage is found, if the full extent or significance of an observed earthquake damage pattern cannot be reasonably assumed from observed conditions, or if the appropriate repair cannot be determined without more information, it might be necessary to determine details of construction that are often difficult to discern. Sometimes this can be done by non-invasive means:

- For a slab-on-grade, the method of construction (single or two-pour system, and the location of the joint between pours) can determine the significance of a crack or the appropriate repair. A horizontal slab-footing joint (Figure 4.7) can sometimes be confirmed by close inspection of the exterior edge of slab. A vertical joint (Figure 4.18) can sometimes be confirmed by pulling carpet<sup>65</sup> along the edge of perimeter walls or by careful observation of exposed areas in unfinished closets or behind wall vents.
- For a house with a crawlspace, the type of foundation (either consisting of shallow spread footings, or pier and grade beams) can determine the appropriate repair. If suspected, they can be confirmed by an excavation or by review of the original plans or building permits.
- For stem walls and slabs, the presence or absence of reinforcing steel can affect the conclusions and recommendations of the structures specialist. Reinforcing can sometimes be determined by close observation at openings

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<sup>65</sup> The carpet should never be pulled without the consent of the property owner. Carpet should be pulled and reinstalled by carpet installers to ensure that carpet is properly stretched and fastened to tack strips.

and edges. Alternatively, reinforcing steel and wire welded wire fabric can usually be detected with inexpensive metal detectors.

- For slabs-on-grade, whether the slab is post-tensioned can determine the significance of damage or the appropriate repair. The ends of post-tensioning strands can sometimes be discerned as regularly spaced patched or grouted holes in the vertical surface at the edge of the slab.

Where there are indications of earthquake-induced permanent ground deformation or indications of fresh cracking in exterior slabs-on-grade, an inspection should be performed on exterior slabs. An exterior slab inspection should include detailed visual inspection, measurement, and mapping of cracks. Observations that affect the structures specialist's conclusions should be documented on a site plan sketch:

- Type of finish, if any.
- Approximate locations and orientations of cracks.
- Locations of control joints and cold joints at additions.
- Maximum and minimum width of characteristic cracks.
- Vertical offset across the crack.
- Approximate age of the crack (i.e., determine whether or not the cracks predate the earthquake).

## **9A.2 Data Analysis**

Following completion of data collection, the engineer must analyze the data, including that obtained from other components of the building, if applicable, to:

- Determine the most logical cause of each damage pattern or condition.
- Determine whether the damage pattern is indicative of any significant underlying mechanism (e.g., slope creep, expansive soil).
- Determine whether the pattern of cracking is indicative of an active (such as slope creep) or dormant condition (such as concrete shrinkage cracks).
- Distinguish between damage that can be primarily attributed to the earthquake and damage or other conditions that are primarily attributable to a non-earthquake cause.
- Determine the structural significance of damage attributable to the earthquake.
- Determine whether local building code provisions require any structural upgrade in conjunction with the repair of structurally significant damage.

- Recommend repairs for structurally significant earthquake-induced damage that will restore the performance element to the level that existed prior to the earthquake.
- Identify any unsafe conditions or damage unrelated to the earthquake that was observed in the course of the consultant's inspection, and recommend follow-up action.

These determinations must be made considering all available information about the condition of the woodframe building, particular vulnerabilities of the building, geotechnical conditions at the site, the intensity of shaking, and spectral accelerations in the vicinity of the site, along with fundamental engineering principles. Non-earthquake factors should be carefully considered as possible causes of observed damage. Damage should be considered earthquake-caused or earthquake-exacerbated when there is a pattern of relevant factors consistent with an earthquake damage mechanism.

If there is structurally significant damage in the foundation or slab-on-grade and its cause, age, or extent cannot be reliably determined or reasonably assumed, additional detailed technical investigation may be recommended to ensure that the nature of the problem is reasonably understood and that the appropriate repairs are specified.

### **9A.3 Invasive Inspection**

Invasive inspection may be necessary in those instances where noninvasive investigation by a structures specialist does not satisfactorily address the issues of causation and significance of cracking in the foundation and/or slab-on-grade floor. Before undertaking invasive inspection there should be a clear understanding of the nature of the testing and associated costs, the nature and significance of information to be obtained, the nature and extent of damage to finishes associated with the invasive inspection, and responsibility for and standards for repair of that damage.

Potential invasive investigative work may include:

- Removal of all carpeting and padding to expose entire slab surface for inspection.
- Removal of concrete cores spanning the more significant or questionable cracks. Cores should be cut with a 4-inch diameter water-cooled diamond tipped coring bit.
  - Cores may be examined visually, in the field for debris, paint, glue, and other indicators of age on the crack surface. In addition, the details of the fracture surface can be examined. Cracks formed by concrete shrinkage very early in the life of the concrete will pass around most of the aggregate along the fracture surface. Cracks that form after the cement paste has gained considerable strength will pass through much of the aggregate.

- Cores may be sent to a petrographer for microscopic examination and carbonation testing which may provide information on the age of the crack.
- If soil movement at the site is suspected, a differential elevation survey of the floor surface may be performed to identify possible differential vertical movement of the foundation and/or floor slab.
- If soil movement at the site is suspected, a geotechnical investigation may be necessary.

Data from the invasive inspection should be incorporated into the technical analysis as discussed in Appendix 9A.2.

## **9B Outline Scope for Technical Consultant Assessment of Wall Damage**

### **9B.1 Non-Invasive Technical Evaluation**

A non-invasive technical evaluation should include an interview with the building owner/occupant, detailed visual inspection, manual testing of the condition of finish attachment, measurement (and sometimes mapping) of cracks, and assessment of the structural significance of any earthquake-induced damage to wall elements. For structurally significant earthquake-induced damage, the structures specialist's report should recommend generic repairs, including work that may be required by local building code requirements. Specifically the following scope of work should be performed and documented with photographs and field notes:

- Exterior
  - Examine the superstructure/foundation interface for evidence of sliding of the building relative to the foundation.
  - Examine the woodframe walls of the raised crawlspace (if any) for structural damage and/or residual racking.
  - Examine the base of stucco walls for evidence of detachment of the stucco from the sill plate.
  - Examine for relative movement or separation between different portions of buildings such as attached garages, “splits” in split-level houses, additions, porches, canopies, etc.
  - Note any broken windows or window or door openings that are not plumb or square.
  - If a decisive judgment cannot be made on the basis of field notes and photographs, sketch the crack pattern on each elevation. When prepared, elevation sketches should include:
    - Exterior features of each elevation: doors, windows, sill line, roof line, and grade.
    - Exterior finish of each elevation: stucco, brick/stone veneer, wood siding, hardboard, aluminum, vinyl, or other.
    - Crack pattern on each elevation: The sketch should clearly show the following: width (measured at representative locations) and approximate length (shown graphically) of typical cracks, spacing of cracks, offsets across a typical crack, maximum and minimum crack widths, nature of cracking (i.e., note the type of crack taper, “||” or “^”). It is

frequently useful to note the absence of cracks where they might otherwise be suspected.

- Evidence supporting the assessment of the age of observed cracks (surface sharpness, debris, staining, etc.).
- Interior
  - Conduct a room-by-room inspection examining the wall and ceiling finishes. Document observations on a floor plan and, if necessary, on wall elevation sketches. Documentation should include:
    - The type of wall finish.
    - Crack pattern on each wall of each room. If a sketch is warranted, it should clearly show: width (measured at representative locations) and approximate length (shown graphically) of typical cracks, spacing of cracks, offsets across a typical crack, maximum and minimum crack widths, nature of cracking (i.e., note the type of crack taper, “||” or “^”). If wall surfaces are finished with wallpaper, feel along the corners of openings for any bulges or tears.
    - Evidence supporting the assessment of the age of observed cracks.
    - Locations of previously repaired cracks, previously repaired cracks that have reopened, and the nature of the repair (patching, repaired with mesh tape).
  - Note any differential movement or separation around fireplaces.
  - Note the relationship between interior finish cracking and any cracking in perimeter foundation or concrete slab-on-grade floor. See Section 4.7 for slab and foundation inspection guidelines.
  - For windows, when the information is relevant to the structures specialist’s assessment, document the following:
    - Type of window (e.g., sliding, double-hung, awning, casement, jalousie, etc.).
    - The condition of windows (e.g., cracked, broken).
    - The operation of the windows (e.g., good, sticks/rubs, inoperable, painted shut).
    - Water staining in finishes around the window.
    - Plumbness of window jambs and levelness of window head and sill measured to the nearest 0.1 degree.



- For doors, when the information is relevant to the structures specialist's assessment, document the following:
  - Type of door (e.g., single/double hinged, sliding, bypass, folding).
  - Condition of operation of door (e.g., good, scrapes at head/floor/jamb top/jamb bottom, does not latch or close completely).
  - Plumbness of doorjamb and levelness of door head measured to the nearest 0.1 degree and direction of tilt or slope.
  - Recent damage to door or hardware, looseness of hinges, especially top hinge.
  - Any previous trimming of door.
  - Any modification to hardware (e.g., strike plate reset, hinges reset).
  - Changes in wear pattern on strike plate.

## **9B.2 Data Analysis**

Following completion of data collection, the structures specialist must analyze the data as discussed in Appendix 9A.2.

If there is potentially structurally significant damage to wall elements and its nature, cause, age, or extent cannot be reliably determined or reasonably assumed, additional detailed technical inspection should be considered.

## **9B.3 Invasive Inspection**

Invasive inspection should be necessary only in those instances when the structures specialist is unable to rule out or reasonably assume the existence of structurally significant concealed earthquake damage based on non-invasive means. Before undertaking invasive inspection there should be a clear understanding of the nature of the testing and associated costs, the nature and significance of information to be obtained, the nature and extent of damage to finishes associated with the invasive inspection, and responsibility for and standards for repair of that damage. Potential invasive investigative work may include:

- Cutting small openings in the stucco (or in the drywall/plaster on the interior face of exterior walls) to check for delamination of stucco from framing or structural sheathing.
- If weep screed is present, removal of small area of stucco at sill to determine if staples used to attach stucco mesh penetrated through the weep screed into the wood sill plate.
- Removal of sheathing or finishes in specified locations to determine the configuration and condition of concealed structural elements.

Results of the invasive inspection should be incorporated into the structures specialist's analysis as discussed in Appendix 9A.2.

## **9C Outline Scope for Technical Consultant Assessment of Roof, Ceiling, and Floor Damage**

The need for assessment by a structures specialist is triggered by visible conditions that suggest structural damage. Such conditions often include:

- Framing damage adjacent to displaced or damaged masonry chimneys (visible in attic).
- Split sills at anchor bolts or sliding of sills along foundation (visible in crawlspace or by removing wall finishes at slab-on-grade floors).
- Connection failures or buckling of diagonal ridge braces (visible in attic).
- Rotation or displacement of piers and posts (visible in crawlspace).
- Cracks or gaps at plan discontinuities such as adjoining split-levels or reentrant corners of the roof diaphragm.

### **9C.1 Non-Invasive Technical Consultant Evaluation**

A non-invasive evaluation by a structures specialist should include an interview with the building owner/occupant, detailed visual inspection, documentation, and assessment of the structural significance of earthquake-induced damage to roofs, ceilings, and floors. For structurally significant earthquake-induced damage, the structures specialist's report should recommend generic repairs, including work that may be required by local building code requirements. Specifically, the following scope of work should be performed and documented with photographs and field notes:

#### **9C.1.1 Exterior**

Exterior inspection points and observations relevant to assessing conditions that may lead to potential damage to roofs, ceilings, and floors, include:

- Signs of racking of the cripple walls.
- Indications of movement or sliding of the floor at the sill plate level.
- Signs of damage at building irregularities.
- Damage to flashings or framing at masonry chimneys.
- Signs of movement or deformation of the roof structure.

### **9C.1.2 Interior**

- Signs of damage to ceiling or floor at building irregularities.
- Sag or excessive bounciness in the floor.

### **9C.1.3 Roof**

- Signs of damage at building irregularities.

### **9C.1.4 Attic**

- Condition of framing and connections at building irregularities.
- Condition of framing and tie straps in the vicinity of any masonry chimneys; and the condition of framing in the vicinity of any areas where falling masonry may have impacted the roof.
- For tiled gabled roofs with only spaced sheathing, the condition of longitudinal braces (braces aligned parallel to the ridge board) and their end connections.

### **9C.1.5 Crawlspace**

- Condition of the mudsill and its attachment to both the foundation and the floor joists.
- Condition of support post connections to beams and footings, including gaps, distress, or tilting.

## **9C.2 Data Analysis**

Following completion of data collection, the structures specialist must analyze the data, including that obtained from other components of the building, if applicable, to:

- Determine the most logical cause of each damage pattern or condition.
- Determine whether the damage pattern is indicative of any significant underlying mechanism (e.g., slope creep, expansive soil).
- Determine whether the pattern is dormant or active.
- Distinguish between damage that can be primarily attributed to the earthquake and damage or other conditions that are primarily attributable to a non-earthquake cause.

- Determine the structural significance of damage attributable to the earthquake.
- Determine whether local building code provisions require any structural upgrade in conjunction with the repair of structurally significant damage.
- Recommend repairs for structurally significant earthquake-induced damage that will restore the performance of the element to the level that existed prior to the earthquake.

These determinations must be made considering all available information about the condition of the superstructure, particular vulnerabilities of the building, geotechnical conditions at the site, the intensity of shaking and spectral accelerations in the vicinity of the site, along with fundamental engineering principles. Non-earthquake factors should be carefully considered as possible causes of observed damage. Damage should be considered earthquake-caused or earthquake-exacerbated when there is a consistent pattern of various relevant factors.

If there is potentially significant structural damage to the roof, ceiling, or floor and its nature, cause, age, or extent cannot be reliably determined or reasonably assumed, additional detailed inspection by the structures specialist should be considered.

### **9C.3 Invasive Inspection**

Invasive inspection should be necessary only in those instances when the structures specialist (and other consultants, as needed) is unable to rule out or reasonably assume structurally significant concealed earthquake damage based on non-invasive means. Before undertaking invasive inspection there should be a clear understanding of the nature of the testing and associated costs, the nature and significance of information to be obtained, the nature and extent of damage to finishes associated with the invasive inspection, and responsibility for and standards for repair of that damage. Potential invasive inspection work may include:

- Cutting small openings in finishes to inspect the condition of concealed framing.
- Removal of sheathing or finishes in specified locations to determine the configuration and condition of concealed structural elements.

The results of the invasive inspection should be incorporated into the structures specialist's analysis as discussed in Section 9C.2.

## 9D Technical Report Guidelines

The appropriate format and scope of a technical report of a post-earthquake damage assessment depend upon the circumstances and needs of the client and may range from a verbal report at the site to a comprehensive written report. An outline for a comprehensive written report for a woodframe house is presented below. This outline may be abbreviated, as appropriate, for the format and scope of report requested by the client.

- The registration stamp and signature of the licensed professional in responsible charge of the work.
- Title page, which includes:
  - Name of the property owner.
  - Address of the property.
  - Name and address of party for whom the report has been prepared, if other than the property owner.
  - Name, address, and phone number of the licensed professional who prepared the report.
- Introduction.
  - Objective of retention and scope of services.
  - Dates and times of site inspections and personnel involved.
  - Limitations/disclaimer, if any.
- Local ground shaking data (see Section 2 for detailed discussion).
  - Copy of the CISM ShakeMap (<http://www.cism.org/>) for the earthquake, with property location indicated,
  - For property location, values from ShakeMap (or other generally accepted source of ground shaking parameters):
    - Instrumental intensity.
    - Peak ground acceleration.
    - Peak ground velocity.
    - Spectral acceleration.
  - Summary of occupant interview re shaking intensity.



- Discussion regarding level of expected damage to a typical woodframe building given the level of ground shaking at the site based on historical performance.
- Description of site and buildings.
  - Topography of site.
  - Condition of surrounding public and private property.
  - Description of building, including:
    - Existing tagging, if any.
    - Summary of detailed safety assessment, if performed in the normal course of the technical consultant's inspection.
    - Known relevant seismic vulnerabilities (e.g., unbraced cripple walls, lack of anchor bolts, split level design), if any.
    - Known relevant pre-existing conditions and modifications.
    - Repairs or modifications since earthquake.
- Observations, discussion, and repair recommendations (including photographs and figures to illustrate key points) for the components of the property listed below (or a subset of the list, if the scope of the technical consultant's engagement is limited<sup>66</sup>). For each item, the report shall clearly identify earthquake-induced damage. For each item of earthquake-induced damage, the report shall clearly identify the like-kind-and-quality repair as well as any code upgrade requirements that may be triggered by the extent of damage.
  - Soil conditions.
  - Foundation.
    - Stem walls.
    - Floor slab.
    - Concrete piers.
  - Walls.

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<sup>66</sup> For example, many earthquake insurance policies do not cover every part of the dwelling and ancillary improvements, and engineers engaged by insurers may be asked to limit their scope of work to covered items.

- Structural sheathing/bracing, including plywood, OSB, manufactured shear walls as well as stucco, drywall, and plaster that function as part of the lateral load resisting system.
- Nonstructural finishes.
- Wall framing.
- Diaphragms.
  - Floor framing.
  - Ceiling finish.
- Attic/roof framing.
- Fireplace/chimney.
- Exterior hardscape.
- Attached improvements (decks, carports, patio covers, etc.).
- Fences, retaining walls, and appurtenant structures.
- Equipment, veneer, roofing, etc., that might constitute overhead falling hazards.
- Appendices containing:
  - Curriculum vitae or resume of technical consultant in responsible charge of work and key contributors.
  - Contact sheets/thumbnail prints of all photographs.
  - Bibliography of information resources
  - Copies of cited reports from sub-consultants.

Reports produced after a given earthquake often use a standardized format and contain similar background information. Since many of these reports can look alike, each report should use numbered pages and should include both the report date and property address (or another unique identifier) on every page.



## 10 Glossary and Acronyms

### 10.1 Glossary

#### A

<b>acceleration</b>	The rate of change of the velocity (speed in a particular direction) as a function of time. Increasing speed over time is sometimes referred to as acceleration, while decreasing speed is deceleration. Ground shaking during an earthquake is typically recorded as an acceleration that varies rapidly. The peak ground acceleration is the largest instantaneous acceleration recorded by a particular station during an earthquake. The accelerations recorded in an earthquake can be used to determine how much force the earthquake creates in a building.
<b>accelerogram</b>	The recording of the acceleration of the ground during an earthquake.
<b>accelerograph</b>	An instrument that records the acceleration of the ground during an earthquake.
<b>active fault</b>	A fault that is likely to have another earthquake sometime in the future. Faults are commonly considered to be active if they have moved one or more times in the last 10,000 years.
<b>adobe clay</b>	A heavy, expansive clay common to many areas of California. Expansive clay soils expand with increasing moisture content and shrink upon drying, commonly resulting in damage to buildings and pavements constructed upon it.
<b>adobe construction</b>	Buildings constructed using sun-baked bricks of adobe clay. Adobe construction is highly vulnerable to damage and collapse during earthquakes.
<b>aerator</b>	A plumbing fitting attached to the end of a faucet used to mix air with water.
<b>aesthetic element</b>	A portion of a building that contributes to the appearance but not the structural function of a building. If the aesthetic element were not there, the safety and stability of the structure would not be compromised.

<b>aftershock</b>	An earthquake that follows the largest earthquake or main shock of an earthquake sequence and originates in or near the rupture zone of the larger earthquake. Generally, major earthquakes are followed by a larger number of aftershocks, decreasing in frequency with time.
<b>alluvium</b>	Gravel, sand, silt, or clay transported and deposited by moving water.
<b>anchor bolt</b>	A steel bolt that attaches wood sill plates (or mudsills) to foundations. Typically anchor bolts are 1/2- or 5/8-inch diameter and are embedded in the concrete foundation when the concrete is cast.
<b>architect</b>	In California, someone who has been granted a license by the Board of Architectural Registration to practice architecture and to use the professional title “architect.”
<b>architectural</b>	Pertaining to elements of a structure that are not part of the load-resisting system, but serve to protect the building from the elements.
<b>asphalt composition shingles</b>	Roof covering consisting of an asphalt-impregnated felt base covered on the exposed side with mineral granules.
<b>asphalt saturated felt</b>	Roof underlayment made from paper or fiberglass saturated with asphalt.
<b>at-grade</b>	At ground level.
<b>attenuation</b>	The decrease in the amplitude or intensity of ground shaking with increasing distance from the earthquake rupture plane. Analogous to a pebble thrown into a pond that makes waves on the surface move out from the place where the pebble entered the water. The waves are largest where they are formed and gradually get smaller as they travel away. This decrease in size, or amplitude, of the waves is attenuation.
<b>awning window</b>	Window that opens by swinging outward on hinges at the top of the window frame.

## B

<b>backfill</b>	Soil used to refill an excavation, typically behind a retaining wall or around exterior foundation walls.
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<b>beam</b>	Generically, any horizontally spanning structural member, supporting vertical loads; in common usage, these terms are used to describe beams, from the largest to smallest: girder, beam, joist, purlin, sub-purlin. Headers are short beams, also called lintels, spanning over doors and windows.
<b>bearing wall</b>	A structural wall that carries weight from the building above.
<b>bedrock</b>	Relatively hard, solid rock that commonly underlies softer rock, sediment, or soil.
<b>bending</b>	A bending load tries to curve or fold a structural member, as opposed to a compression or tension load that compresses or stretches a member along its length.
<b>blind fault</b>	A fault whose rupture is not evidenced at the ground surface.
<b>blind thrust fault</b>	A thrust fault that does not rupture all the way up to the surface so there is no evidence of it on the ground. It is “buried” under the uppermost layers of rock in the crust.
<b>blocking</b>	Members placed in between studs, perpendicular to the studs, to provide additional lateral stability.
<b>board and batten siding</b>	An exterior finish composed of wood boards with thin wood strips (battens) covering the vertical joints between the boards.
<b>bond beam</b>	A masonry course constructed and reinforced to serve as a beam, or a bearing course for structural members.
<b>brace</b>	Structural element that provides stability, i.e., resistance to racking or buckling, and helps position and support structural members.
<b>branch circuit</b>	The portion of an electrical system extending from the final over-current device protecting a circuit to the outlets served by the circuit.
<b>breaker</b>	A switch that automatically shuts off an electric current to prevent too much current from damaging an appliance in the circuit or causing a fire. As opposed to a fuse, a circuit breaker can be reset without replacing any components.
<b>brown coat</b>	The middle coat in a three-coat stucco system.
<b>building pad</b>	A level section of ground on which a structure is constructed.



<b>building paper</b>	Thick paper composed of partly of asphalt, applied to exterior walls and roofs as a first layer of weatherproofing.
<b>built-up membrane</b>	Several alternating layers of building paper (or felt) and hot asphalt topped with gravel or a mineral cap sheet that serves as the waterproofing membrane on a flat roof.
<b>buttonboard</b>	See <b>gypsum lath</b> .

## C

<b>cantilever</b>	A structural element that is fixed at one end and free to move at the other end.
<b>cantilever retaining wall</b>	A retaining wall that acts as a cantilever to resist the force of the mass it is retaining.
<b>capacity</b>	The amount of load, force, displacement, or rotation a structural element can support or withstand without collapse or permanent deformation.
<b>casement window</b>	A window that swings open like a door.
<b>cast-in-place</b>	Concrete poured in the location it will be used at the site, as distinct from pre-cast concrete.
<b>cathedral ceiling</b>	A ceiling that extends to the full height of the roof framing, also known as a vaulted ceiling.
<b>ceiling joist</b>	A beam that is part of the framing that encloses the top of a room to which the ceiling finish is attached.
<b>cement-asbestos shingle</b>	A cement based shingle reinforced with asbestos fibers.
<b>cement board siding</b>	An exterior finish consisting of cement-based boards, often reinforced with cellulose fibers.
<b>chase</b>	Woodframe decorative enclosure of a flue that may be finished with wood siding, stucco, or stone masonry veneer.
<b>chimney strap</b>	A thin strip of metal used to attach a chimney to the surrounding wood framing to prevent toppling of the chimney during an earthquake.
<b>chimney sweep</b>	A tradesman who cleans, maintains, and repairs chimneys.

<b>cold joint</b>	The intersection of two different concrete placements. This joint forms if the second placement begins after the first placement has begun to set. Cracks and separation often occur at this joint.
<b>collapse</b>	A complete loss of capacity of all or a portion of a structure, resulting in the structure not being able to support its own weight.
<b>color coat</b>	The top layer of a stucco system, also called the finish coat.
<b>column</b>	Vertical structural element designed to support axial compression loads (a crushing force applied in the direction of the length of the member); wood columns are often called posts.
<b>community internet intensity</b>	A measure of the severity of earthquake ground shaking determined by internet responses to an online questionnaire based on the Modified Mercalli Intensity (MMI) scale compiled from citizens in affected areas and summarized as a map showing the assigned MMI level for each ZIP code.
<b>compressional stress</b>	The stress that squeezes something. It is the stress component perpendicular to a given surface, such as a fault plane, that results from forces applied perpendicular to the surface or from remote forces transmitted through the surrounding rock. The value of compressional stress is expressed in units of force per unit cross-sectional area, e.g., pounds per square inch (psi), synonymous with compressive stress.
<b>compressive strength</b>	The maximum amount of compressive stress a material can withstand.
<b>concrete</b>	A mixture of Portland cement, sand, gravel, and water. The water hydrates the Portland cement forming a solid material that holds the sand and gravel together.
<b>concrete block</b>	A block made of Portland cement, sand, gravel, and water formed into a rectangular prism with one or more hollow spaces and used to construct walls. Synonymous with hollow concrete block, concrete masonry unit (CMU), or cinder block; may be either reinforced or unreinforced.
<b>construction joint</b>	A joint formed between during construction, typically between two vintages of the same material or two different materials; a common location for cracks and separation. A

construction joint may be deliberately formed to permit movement of building components relative to one another.

**continuous footing**

A foundation element that extends along an entire dimension or around the perimeter of a structure, as opposed to a pier or post that supports a single element.

**Contractors State License Board** The California state government entity that licenses and regulates contractors in 43 classifications that constitute the construction industry. The status of a contractor's license can be verified at the Board's website:  
<http://www.cslb.ca.gov/>.

**control joint**

A groove, saw cut, or insert that forms a straight line intended to be the place where concrete shrinkage cracks will form; sidewalks commonly have control joints every few feet, for example.

**core**

A cylindrical section of concrete that is removed from a structure for testing and analysis.

**corner bead**

Thin metal angle applied to wallboard corners to form a neat edge and provide some protection against impacts.

**cosmetic damage**

Damage that is nonstructural and has only aesthetic significance.

**cosmetic repair**

Repair of nonstructural damage; typically involves repair or replacement with like kind and quality to restore a reasonably uniform appearance.

**counter flashing**

Flashing folded down to cover base flashing and prevent water intrusion at the flashing joint.

**crawlspace**

The area below the first floor enclosed by foundation walls and/or cripple walls.

**crazing**

A multitude of tiny cracks oriented randomly.

**creep**

Slow, more or less continuous movement occurring on faults due to ongoing tectonic deformation. Faults that are creeping do not tend to have large earthquakes. Also refers to long-term movement of soil, particularly on a slope.

**cripple walls**

Short stud walls extending from the foundation to the framing of the lowest floor.

<b>crust</b>	The thin outer layer of the Earth's surface, averaging about 10-km thick under the oceans and up to about 50-km thick on the continents. The uppermost 15 to 35 km of the crust is brittle enough to produce earthquakes. This is the only layer of the Earth that humans have actually seen.
<b>cut</b>	Soil removed from a slope to form a level building pad. See also <b>cut-and-fill</b> .
<b>cut-and-fill</b>	To form a level pad beneath the building footprint, a slope may be excavated (cut) or soil may be placed on the slope (fill), or a single building lot may be a combination of both. Engineered fill has been compacted by earth moving equipment to minimize settlement.
<b>cut-in bracing</b>	Wood diagonal bracing in older construction which is installed in short segments between the wall studs, like diagonal blocking.

## D

<b>delamination</b>	The process of building materials becoming separated, particularly loss of adhesion or connection between a material and its substrate, e.g., detachment of stucco from the wood framing.
<b>desiccation crack</b>	A soil crack resulting from expansive soil movement.
<b>diagonal brace</b>	An inclined member installed to provide stability to a structure.
<b>diaphragm</b>	A solid area of wall or floor that, by virtue of its shear stiffness and strength, resists racking due to lateral forces.
<b>differential settlement</b>	Settlement of one area of soil that is more than at a nearby location, as when one corner of a building settles more than elsewhere within the building footprint.
<b>dip-slip fault</b>	An inclined fracture where the blocks have mostly shifted vertically. If the rock mass above an inclined fault moves down, the fault is termed normal, whereas if the rock above the fault moves up, the fault is termed reverse. A thrust fault is a reverse fault with a dip of 45 degrees or less. Oblique-slip faults have significant components of different slip styles.

<b>doorjamb</b>	See <b>jamb</b> .
<b>drop ceiling</b>	A ceiling finish suspended below the framing to provide space for piping or ductwork.
<b>drying shrinkage</b>	A reduction in volume as a result of water loss that typically occurs in wood as it dries and in concrete as it cures.
<b>drywall</b>	A wall finish system consisting of gypsum panels attached to wall framing and coated with joint compound and tape to form interior wall and ceiling finishes.
<b>drywall tape</b>	A tape, typically paper or mesh, used to seal the joints between drywall panels.
<b>ductile</b>	Able to undergo a large amount of deformation before failure; flexible.

## E

<b>earthquake</b>	Sudden slip on a fault, and the resulting ground shaking and radiated seismic energy caused by the slip, or by volcanic or magmatic activity, or other sudden stress changes in the earth.
<b>earthquake load</b>	An inertial force developed on a structural member as a result of earthquake ground shaking.
<b>efflorescence</b>	Whitish staining of concrete or masonry caused by water seeping through the material, dissolving salts, and depositing them on the exterior where they remain after the water evaporates.
<b>elastomeric</b>	A flexible, rubber-like adhesive used as a sealant.
<b>engineer</b>	In this document, “engineer” refers to an appropriately qualified and California licensed Civil Engineer, and who may or may not in addition have a Structural Engineer and/or Geotechnical Engineer title authority.
<b>engineered repair</b>	A repair designed or specified by an appropriately qualified and licensed engineer or architect.
<b>engineering geologist</b>	A geologist with a focus on how soil conditions effect structures. However, an engineering geologist cannot design structural modifications. In California, Certified Engineering

Geologists apply geologic principles to the safe development and grading of land, building of structures, search for groundwater resources, cleanup of underground contamination, and repairing of geologic hazards. They investigate geologic constraints such as landslides, ground subsidence, earthquake faults, and erosion and have special training in geology for working on civil engineering problems. Certified Engineering Geologists evaluate the underground conditions of properties in a variety of ways to aid in finding out the engineering and environmental aspects of a project or site. They make evaluations for insurance companies following earthquakes and floods. They are also familiar with regulations pertaining to land use and repair that require permits from various governmental agencies.

[[http://www.geology.ca.gov/publications/consumer\\_guide.htm](http://www.geology.ca.gov/publications/consumer_guide.htm)]

**epicenter**

That point on the Earth's surface directly above the hypocenter of an earthquake.

**exacerbate**

To alter the damage state of pre-existing damage.

**expansive soil**

Soil which has a fluctuating volume based upon the addition or removal of water.

**exterior insulation and finish system (EIFS)**

An exterior cladding consisting of a reinforced polymer attached to foam plastic insulation that is attached to sheathing or directly to framing.

## **F**

**face/facing**

Decorative finish of brick or stone masonry applied over the front edge of the firebox and the surrounding wall.

**failure surface**

The plane along which a structural member or a fault cracks or ruptures.

**fault**

A weak zone in the Earth's crust and upper mantle where the rock layers have ruptured and slipped. Faults form during earthquakes, and earthquakes are likely to reoccur on pre-existing faults.

**fault plane**

The planar (flat) surface along which there is slip during an earthquake.



<b>fault rupture</b>	Movement along a fault plane manifested at the ground surface.
<b>fault trace</b>	Intersection of a fault with the ground surface; also, the line commonly plotted on geologic maps to represent a fault.
<b>felt underlayment</b>	A heavy, asphalt-saturated paper placed underneath exterior finishes, either roofing or siding/stucco, to weatherproof the building.
<b>fiber composite shingle</b>	A roofing material made of fibers cast in a polymer or cementitious matrix.
<b>fill</b>	Soil used to fill in a portion of a slope to create a level building pad. See also <b>cut-and-fill</b> .
<b>fireplace insert</b>	A prefabricated firebox installed as a retrofit in an existing fireplace.
<b>flashing</b>	Material, generally sheet metal or building paper, applied at penetrations and joints to prevent water intrusion to the interior of a structure.
<b>flat roof</b>	A roof with no slope or minimal slope to permit drainage, typically constructed of a built-up membrane.
<b>flexibility</b>	The ability to deform without breaking.
<b>flexural strength</b>	The stress at failure in bending.
<b>floor diaphragm</b>	The elements of a floor, typically the framing together with the sheathing, that resist lateral (horizontal) loads applied to the structure.
<b>floor slab</b>	Concrete slab to which floor finishes are applied.
<b>focal depth</b>	A term that refers to the depth of an earthquake hypocenter.
<b>focus</b>	That point within the Earth from which originates the first motion of an earthquake and its elastic waves. See also <b>hypocenter</b> .
<b>footing</b>	The section of the foundation which transfers the load from the structure to the supporting soil.
<b>foreshock</b>	A small tremor that commonly precedes the largest earthquake in a series, or main shock, by seconds to weeks,

and that originates in or near the rupture zone of the larger earthquake.

**foundation**

The substructure, usually of concrete, which supports the woodframe building and transfers loads to the ground.

**framing**

The skeleton of a structure, the underlying support elements.

**frequency**

The number of times a cyclic event occurs in a certain period of time, such as the ground shaking up and down or back and forth during an earthquake.

## G

**gable end wall**

An exterior wall that comes to a triangular point to support a sloped roof.

**gable roof**

Roof that has a single ridgeline forming two roof planes with rafters extending to opposite sides of the space below; two roof planes sloping from central ridge.

**geocode**

To determine the latitude and longitude of a street address.

**geotechnical engineer**

In this document, a California-licensed Civil Engineer who specializes in geotechnical engineering (soils and foundation engineering) as it relates to the design of structures. In addition to a California Civil Engineer license, a Geotechnical Engineer might also have Geotechnical Engineer title authority (see also engineering geologist).

**geotechnical engineering**

Analysis and design of foundations and soil conditions for construction.

**geotechnical investigation**

Determination of soil properties for use in design and repair of ground failure, foundations, retaining walls, etc. A geotechnical investigation might include soil borings to determine the soil profile and soil sampling for laboratory analysis.

**girder**

A beam, typically a larger, main beam that supports joists or other smaller beams. See also **beam**.

**grade**

The ground surface on which a structure is built.

<b>grade beam</b>	A reinforced concrete beam embedded in the soil that spans between and ties together other foundation elements such as piers or piles.
<b>grading</b>	The preparation of a soil for building a foundation, i.e., creation of a level building pad.
<b>gravity load</b>	A force on an element resulting from the weight of the element and other elements supported by the element.
<b>green lumber</b>	Also called “wet lumber” (though it is not noticeably wet – it has a high internal moisture content); lumber that has not been dried prior to use in construction, which is common in California; the lumber then shrinks after installation as it loses moisture.
<b>green-tagged</b>	A building, which has been investigated and may have suffered damage, but is deemed safe for occupancy.
<b>ground deformation</b>	A permanent change in the ground surface resulting from ground failure.
<b>ground failure</b>	A general reference to landslides, liquefaction, lateral spreads, and any other consequence of shaking that affects the stability of the ground.
<b>ground motion (shaking)</b>	Movement of the earth’s surface from earthquakes or explosions. Ground motion is produced by waves that are generated by sudden slip on a fault or sudden pressure at the explosive source and travel through the earth and along its surface.
<b>gypsum lath</b>	A gypsum-based panel to which an interior plaster finish is applied, also known as buttonboard.
<b>gypsum wallboard</b>	A smooth interior finishing material made from gypsum and typically installed in 4 × 8-ft panels. The key component of drywall.

## H

<b>hardscape</b>	Any exterior pavement such as sidewalks, driveways, patios, and pool decks.
<b>hardware</b>	The metal fittings and fastenings used in construction.

<b>header</b>	A beam that spans over door and window openings. See also <b>beam</b> .
<b>heave</b>	Lifting of structural elements as a result of swelling of expansive soil.
<b>heavy timber floor framing</b>	4x beams spaced 48 inches apart and supporting 1-1/2-inch thick wood sheathing or 1-1/8-inch thick plywood.
<b>hip roof</b>	Roof that has ridge lines extending to the four corners of the rectangular space beneath forming four roof planes; may or may not come to a single point.
<b>hold down</b>	A connection used to tie a wall to a floor or a roof to a wall to prevent the wall from overturning or the roof from uplifting due to lateral loads.
<b>horizontal diaphragm</b>	See <b>diaphragm</b> .
<b>horizontal slab-footing joint</b>	A cold joint, often visible along the exposed exterior slab edge, formed when a concrete slab-on-grade is placed after a concrete perimeter footing is placed.
<b>hypocenter</b>	The calculated location of the focus of an earthquake. The point within the earth where an earthquake rupture starts.

## I

<b>ICRI Guideline No. 03734</b>	“Guide for Verifying Field Performance of Epoxy Injection of Concrete Cracks” – a publication by the International Concrete Repair Institute, providing guidelines for quality of epoxy injection repairs.
<b>inertia</b>	In the context of the effects of earthquake ground shaking on structures, the phenomenon of a structure’s tendency to remain stationary while the ground beneath it wants to move. As a result, horizontal (lateral) forces, called inertial forces, develop in the structure.
<b>instrumental intensity</b>	The numerical value of ground shaking intensity, derived from recorded ground motions, as shown on a ShakeMap.
<b>intensity</b>	A measure of the effects of an earthquake at a particular place on humans, structures, and (or) the land itself. The intensity at a point depends not only upon the strength of the

earthquake (magnitude) but also upon the distance from the earthquake to the point and the local geology (soil conditions) at that point.

**invasive inspection**

An investigation that requires some form of damage to the structure, such as removing wallboard to examine framing or taking a core from a concrete slab.

**isoseismal line**

A line connecting points on the Earth's surface at which earthquake intensity is the same. It is usually a closed curve around the epicenter.

**isoseismal map**

A map connecting points on the Earth's surface at which earthquake intensity is the same. Common isoseismal maps are generated using the Modified Mercalli Intensity (MMI) scale or instrumental intensity values (ShakeMap).

## **J**

**jamb**

The vertical portion of a door or window frame.

**joist**

A support beam that is at least six inches deep and either 2- or 4-inches thick that typically supports floor and ceiling loads.

## **L**

**landslide**

An abrupt movement of surface material down a slope in response to gravity. Landslides can be triggered by an earthquake or other natural causes. Undersea landslides can cause tsunamis.

**lateral load path**

The connection of horizontal diaphragms and shear walls that transfers lateral loads applied to a structure to the ground.

**lateral spreading**

Horizontal movement in sloping ground resulting from liquefaction.

**lath**

Thin wood strips, gypsum panels, or wire mesh, running crosswise to the wall or ceiling framing, providing a base for the application of plaster on interior walls; thin metal lath is common on exterior walls to provide the base for the application of stucco.

<b>lath and plaster</b>	Interior wall finish system consisting of plaster applied to a base consisting of thin wood strips, gypsum panels, or wire mesh.
<b>latitude</b>	The location of a point north or south of the equator. Latitude is shown on a map or globe as east-west lines parallel to the equator.
<b>leak test</b>	A test performed by a plumber or other qualified contractor to locate leaks in water or gas lines.
<b>let-in bracing</b>	Typically, a $1 \times 4$ or $1 \times 6$ diagonal brace; it is nailed to the studs, which are notched to allow the brace to fit within the depth of the stud wall framing; see also cut-in bracing.
<b>lightweight concrete</b>	Concrete made with more porous aggregate than conventional concrete, giving it a lower unit weight.
<b>liquefaction</b>	The process in which water-saturated soil loses strength and takes on the characteristics of a liquid. This effect can be caused by earthquake ground shaking, and typically results in a loss of the soil's ability to support the structures built on it.
<b>load</b>	A force on a member resulting from gravity, environmental sources, such as temperature fluctuations, or other sources of energy, such as wind, earthquake ground shaking, or impacts.
<b>load-bearing</b>	A structural system or member designed to support applied forces in addition to its own weight.
<b>longitude</b>	The location of a point east or west of the prime meridian. Longitude is shown on a map or globe as north-south lines left and right of the prime meridian, which passes through Greenwich, England.
<b>lurching</b>	Lunging of a portion of the ground's surface in an earthquake that results in a permanent deformation (such as ground cracks); not the same as the temporary (transient) movement or vibration of the ground that lasts during shaking.

## M

<b>magnitude</b>	A measure of the strength of an earthquake or strain energy released by it. Originally developed by Charles Richter in 1935. An increase of one unit of magnitude (for example,
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from 4.6 to 5.6) represents approximately a 32-fold increase in the energy released. An increase of two units of magnitude (from 4.6 to 6.6) reflects 1,000 fold increase in energy release (32 times 32). There are no defined limits to this scale; however, rock mechanics seem to preclude magnitudes smaller than about minus 1 or larger than about 9.5. Except in special circumstances, earthquakes below Magnitude 2.5 are not generally felt by humans.

<b>main shock</b>	The largest earthquake in a sequence, sometimes preceded by one or more foreshocks, and almost always followed by many aftershocks.
<b>masonry</b>	Brick, concrete block, stone, or adobe assembled using Portland cement mortar.
<b>mastic</b>	An asphalt-based adhesive commonly used to patch flashing joints.
<b>mesh tape</b>	An adhesive used to join wallboard panels and to repair wallboard cracks. The use of mesh tape as part of the repair reduces the likelihood of the crack reopening.
<b>metal connector plate</b>	Sheet metal plate with teeth used to join members of a wood truss.
<b>Modified Mercalli Intensity Scale</b>	A scale composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction that is designated by Roman numerals. Used to characterize the intensity of ground shaking based on observation of the effects of that shaking on people, buildings, building contents, and the natural environment.
<b>moisture intrusion</b>	Infiltration of liquid water or water vapor to the interior of a structure.
<b>moment magnitude</b>	See <b>magnitude</b> .
<b>mortar</b>	A combination of cement and sand, water, and sometimes other materials, used in masonry.
<b>mudsill</b>	A beam or plank that is laid on the ground or the foundation to support woodframing.



## N

<b>nail pop</b>	A circular crack and/or slight bump in the finish over fastener caused by incomplete fastener installation or shrinkage of wood framing after wall finish application. Nail pops also develop in floor and roof sheathing due to improper installation, framing shrinkage, and thermal and moisture cycling.
<b>natural frequency</b>	The frequency at which a particular object or system vibrates when pushed by a single force or impulse, and not influenced by other external forces or by damping. If you hold a slinky by one end and let it hang down and then give it one push up from the bottom, the rate of up-and-down motion is its natural frequency.
<b>natural period</b>	The time it takes an object or system to complete one cycle of motion (back and forth or up and down) when excited at its natural frequency.
<b>non-bearing wall</b>	A wall that serves only as a partition of space and does not support the weight of any other structural or finish elements.
<b>noninvasive</b>	In the context of this document, typically referring to investigation or testing that does not require exposing covered elements such as wall cavities or excavating soil.
<b>nonstructural</b>	Not a part of the structure of the building that holds it up and is designed to resist horizontal forces.

## O

<b>open exterior wall line</b>	On the exterior of the residence, a line of wall that does not have at least two solid-sheathed wall panels, each at least 32-inches wide, or a line of wall that does not have one such bracing element at least every 25 feet; indicative of a side of the building at that level that may not have the usual degree of horizontal resistance.
<b>oriented strand board</b>	A board made of layers of pressed wood chips, commonly used for sheathing and subflooring.

# P

<b>panel siding</b>	Exterior finish made of panels.
<b>partition</b>	An interior nonstructural, non-load-bearing wall.
<b>pavement</b>	Layer of concrete or asphalt placed to form a road, driveway, patio, or walkway.
<b>penetration</b>	Opening in a roof, ceiling, floor, or wall.
<b>perceptible</b>	That which can be observed or detected without additional measurement or visualization capabilities. For example, a floor slope of less than about 1 inch in 20 feet is generally not perceptible.
<b>pier</b>	In woodframe construction, a short concrete post or column holding up part of the ground-level floor framing; also may be concrete foundation element of column shape embedded in the ground to provide vertical support for the upper portion of the foundation.
<b>plain concrete</b>	Synonymous with unreinforced concrete; concrete that has no reinforcement or less than the minimum amount specified in the building code for reinforced concrete. Many residential foundations and slabs-on-grade are constructed of plain concrete.
<b>plaster</b>	A mixture of gypsum or lime, water, and sand applied wet and allowed to harden. Commonly used as an interior finish material; exterior plaster is called stucco.
<b>plot plan</b>	A drawing indicating the boundaries of a property and the location and orientation of buildings on the property.
<b>prefabricated fireplace</b>	Sheet metal factory assembled fireplace installed at the site; alternative to a masonry fireplace.
<b>pressure test</b>	A test to locate leaks in gas, water, or sewer lines.
<b>prestressed concrete</b>	Concrete that has steel cables running through it tensed up (stressed) to compress the concrete; thereby, reducing the effects of applied tensile loads and increasing its load-carrying capacity; an alternative to reinforced concrete.
<b>prestressing cable tendons</b>	Thick steel wires used to apply a prestress.

# R

<b>racking</b>	The process of forces moving elements of the structure out-of-square or out-of-plumb.
<b>rafter</b>	A roof framing element connecting the ridge beam with the exterior wall; sloping joist of a roof.
<b>rafter tail</b>	The end of a rafter that is visible from the exterior of a building, underneath the eaves.
<b>rebar</b>	A steel reinforcing bar used in concrete.
<b>red-tagged</b>	A building that has been inspected and deemed unsafe to enter following an earthquake.
<b>reentrant corners</b>	Corners whose intersecting walls make an exterior angle of less than 180 degrees.
<b>reinforcing</b>	Elements added to a member to increase its load-carrying capacity. In concrete, reinforcing is typical steel bars; in a slab-on-grade, reinforcing may also be in the form of welded wire mesh.
<b>reinforced concrete</b>	Concrete that has no less than the minimum amount of prestressing steel or non-prestressed reinforcement, as specified in the reinforced concrete design code.
<b>reinforced masonry</b>	Masonry, such as brickwork or concrete block, that has steel reinforcing in it.
<b>responsible charge of work</b>	As defined in §§ 6703 of the Professional Engineers Act of the Business and Professions Code of the California Statutes: “The phrase ‘responsible charge of work’ means the independent control and direction by the use of initiative, skill, and independent judgment, of the investigation or design of professional engineering work or in the direct engineering control of such projects ...”
<b>retrofit</b>	To modify an existing structure, typically to enhance its performance.
<b>ridgeboard</b>	Framing member that runs along the ridge of the roof to which rafters are attached.

**ridge shattering**

Disruption of ground surface, often resembling plowed ground, along a narrow ridge, resulting from focusing of ground shaking due to topographic effects.

## **S**

**safety assessment**

A function of the local government building department; assesses whether a building is safe to occupy and is distinct from the process covered in this document, namely the assessment of any earthquake-caused damage and the repairs needed to restore the building to its pre-earthquake condition.

**sand boil**

Sand and water that come out onto the ground surface during an earthquake as a result of liquefaction at shallow depth.

**scratch coat**

The first of three coats in a stucco system.

**scuttle**

Opening in the ceiling through which the attic is accessed.

**seismic**

Of or pertaining to earthquakes.

**seismic compression**

Decrease in volume of soil above ground water table during earthquake ground shaking that results in ground surface settlement and lateral movement near slopes; prevalent in earth fills and loose sands; magnitude directly related to thickness of susceptible material.

**seismic resistance**

The ability of a structure to withstand seismic forces.

**seismic vulnerability**

The susceptibility of a structure to earthquake damage.

**seismic wave**

An elastic wave generated by an earthquake. Seismic waves may travel either along or near the earth's surface (Rayleigh and Love waves) or through the earth's interior (P- and S-waves).

**serviceability**

The ability of a structural, architectural or MEP element to perform its intended function.

**settlement**

Downward vertical movement of ground surface resulting from densification of soft or loose soils; may occur in soft natural ground, but more often the result of inadequate compaction of fill materials. See also **seismic compression**.

**settlement**

Sinking of a foundation or retaining wall into its supporting soil.

<b>ShakeMap</b>	A rapidly produced map of earthquake ground shaking severity, distributed over the Internet by the California Geological Survey. An automated analog of the MMI map that presents the variation in intensity of ground shaking based on interpolated data from available instruments and a robust model of the topography and geology of the area.
<b>shear stress</b>	The stress component parallel to a given surface, such as a fault plane, that results from forces applied parallel to the surface or from remote forces transmitted through the surrounding rock. If you lean against the edge of the door where the latch is, you are applying shear stress to the door.
<b>shear wall</b>	A vertical structural element (diaphragm) that resists the shearing or wracking deformations generated by the inertial forces in the building.
<b>shed roof</b>	Roof composed of one plane, sloping one direction.
<b>shrink/swell</b>	Movement occurring in expansive soil. As the water content decreases, the soil shrinks. As the water content increases, the soil swells.
<b>shrinkage</b>	The reduction in volume over time of construction materials, particularly wood and concrete or cement-based materials, resulting from a loss of water. If the material is restrained from shrinking, cracking can occur.
<b>shrinkage cracking</b>	Cracking that results when an element is restrained from shrinking freely. Stresses develop as the element tries to shrink that lead to cracking. Shrinkage cracking is extremely common in concrete and other cement-based materials such as stucco.
<b>sill</b>	The horizontal member at the bottom of a door or window opening. Also, the lowest horizontal member of a frame that rests on the foundation.
<b>sill line</b>	Joint between the woodframe superstructure and the concrete foundation.
<b>sill plate</b>	See <b>mudsill</b> .
<b>single-pour system</b>	A concrete foundation placement technique in which the slab-on-grade floor and the perimeter footing are formed at the same time.

<b>slab-on-grade</b>	Concrete slab (floor slab or pavement) that is directly against the soil and derives its support from the underlying soil.
<b>slab-on-ground</b>	See <b>slab-on-grade</b> .
<b>slope creep</b>	Slow downslope movement of soil or rock, usually confined to areas along a slope face or near the top of a slope.
<b>slope failure</b>	See <b>landslide</b> .
<b>soft-story</b>	A story in a multi-story building that has significantly less lateral stiffness to resist earthquake forces than other stories in the building and therefore sustains greater drift during an earthquake; in woodframe buildings, generally a story with fewer walls than other stories. See also <b>weak-story</b> .
<b>soil boring</b>	Excavation of a column of soil to determine the soil profile.
<b>soil profile</b>	The vertical arrangement of layers of soil down to the bedrock.
<b>soil stabilization</b>	Remediation of ground failure such that the soil will be able to support existing structures again.
<b>soils specialist</b>	Civil Engineer specializing in soils or geotechnical engineering; Geotechnical Engineers (Civil Engineers who have satisfied additional experience and testing requirements and are authorized to use the title Geotechnical Engineer); and Engineering Geologists.
<b>spaced sheathing</b>	Roof framing covering consisting of boards placed with spaces in between each board.
<b>spalling</b>	The deterioration of a structure or surface by chipping or scaling of small pieces (spalls).
<b>split-level</b>	A residence constructed with adjacent floor levels differing typically by half a story.
<b>splitting</b>	A condition in wood members where cracking occurs along the grain, but not completely through the member.
<b>spread footing</b>	Shallow concrete footing located under the building perimeter and usually under some interior walls to spread the building weight out over a sufficient area of soil to avoid excessive settlement.

<b>stability</b>	The ability of an element or structure to withstand loading without buckling or wracking or extreme deformation.
<b>stem wall</b>	Portion of the concrete foundation that forms a short vertical wall extending slightly above grade; in a modern house foundation with spread footing, the stem wall is the vertical portion of an inverted T.
<b>stiffness</b>	A measure of how much a material deforms under a given load. For example, glass is stiffer than rubber. If you pull on a piece of glass, it does not appear to deform at all, but it is very easy to stretch a rubber band.
<b>strain</b>	Change in length per unit length or volume per unit volume of a body. In the context of earthquake, small changes in length and volume associated with deformation of the earth by tectonic stresses or by the passage of seismic waves.
<b>strength</b>	The ability of a material to withstand applied forces. In material testing the stress in material at failure.
<b>stress</b>	Force per unit area acting on a plane within a body. Six values are required to characterize completely the stress at a point: three normal components and three shear components.
<b>stress concentration</b>	An area of higher stress within a body. Generally, stress is distributed uniformly throughout a body, such as a wall or beam, but changes in geometry, such as a door or window opening, or the presence of flaws can create areas where stresses are much higher than throughout the rest of the body.
<b>structural capacity</b>	The extent to which an element can provide strength and stability.
<b>structural engineer</b>	A Civil Engineer specializing in structures.
<b>Structural Engineer</b>	In California, a licensed Civil Engineer who has satisfied additional experience and testing requirements and is authorized to use the title Structural Engineer.
<b>structural repair</b>	A repair that restores the structural capacity of an element, as opposed to a cosmetic repair.
<b>stucco</b>	Exterior plaster applied in layers to form the exterior wall finish material.
<b>subsurface investigation</b>	See <b>geotechnical investigation</b> .



<b>superstructure</b>	The portion of the building above the foundation.
<b>surface faulting</b>	Displacement that reaches the earth's surface during slip along a fault. Commonly occurs with shallow earthquakes, those with an epicenter less than 20 km. Surface faulting also may accompany a seismic creep or natural or man-induced subsidence.
<b>surface fault rupture</b>	Tearing and offsetting of the ground surface where the earthquake fault intersects the surface.
<b>T</b>	
<b>tag</b>	The red, yellow, or green placard attached to a building following a post-earthquake safety assessment.
<b>tagging</b>	Synonymous with safety assessment; posting of a safety assessment placard on a building by the authority of the local jurisdiction. Red means unsafe do not enter; yellow is accompanied by notes indicating some localized hazardous condition (e.g., a damaged chimney) that restricts safe occupancy to a portion of a building; green indicates the building inspection found the property safe to occupy. Safety assessments are conducted using different criteria than assessments of required repairs that are discussed in this document.
<b>tape joint</b>	Joint between two adjacent wall board panels, finished by smoothing joint compound over paper tape to hide the joint.
<b>tar-and-gravel roof</b>	See <b>built-up membrane</b> .
<b>telegraphing a crack</b>	Propagation of an underlying crack through another material, as when the trace of a shrinkage crack in a slab-on-grade appears in the floor finish.
<b>test pit</b>	A hand-dug excavation to obtain soil samples for laboratory analysis and to expose and examine foundation elements.
<b>thermal movement</b>	A change in position as a result of temperature fluctuations.
<b>thickened edge</b>	A deepened edge of concrete around the perimeter of a slab-on-grade, forming a footing to hold up loads from walls above.

<b>thrust fault</b>	See <b>fault</b> .
<b>toe</b>	The base of a slope or landslide.
<b>toe bulging</b>	Outward displacement of soil at the base of a slope, indicative of ground failure.
<b>top plate</b>	The highest horizontal member of a framed wall on which rafters or joists rest.
<b>transient earthquake ground movement</b>	Ground shaking that occurs during an earthquake as opposed to permanent ground deformation such as ground failure.
<b>truss</b>	A structural assembly whose members are loaded only in axial tension or compression (loads applied parallel to the member), commonly found in residential roof construction.
<b>twisting</b>	Deformation of a wood member by rotation.
<b>two-pour system</b>	Rather than pouring the concrete slab-on-grade and underlying spread foundation elements together, first the foundation is poured and hardened and later the slab-on-grade is poured, introducing a construction joint between these concrete elements.

## U

<b>underpinning</b>	Deep foundation elements (piers, piles) installed beneath a shallow foundation to extend vertical support down to stable soil.
<b>uninterrupted wall line</b>	A wall without any openings, e.g., doors or windows.
<b>unreinforced masonry</b>	Masonry, such as brickwork, with no steel reinforcing.

## W

<b>weatherproofing</b>	Materials applied to protect the building and its occupants from the elements, mainly to keep water out.
<b>weak-story</b>	A story in a multi-story building that has significantly less lateral strength to resist earthquake forces than other stories

in the building; in woodframe buildings, generally a story with fewer walls than other stories. See also **soft-story**.

**weep screed**

A thin-gauge strip of metal placed behind the stucco where the woodframe wall meets the foundation that directs water behind the stucco so it can drip out; where a weep screed has been used, the stucco does not extend down over the concrete foundation to the ground.

**wind load**

Forces resulting from wind on a building. Similar to earthquake forces, wind loads are applied horizontally.

**wire mesh**

Light-gauge reinforcing in stucco, sometimes referred to as chicken wire.

**wood lath**

Narrow, thin wood strips that serve as a base to which plaster is applied for an interior wall finish.

**woodframe construction**

Synonymous with light timber-framed or light woodframed construction; also called 2×4 construction or stick-built construction. Construction in which the structural elements of the walls, floors, ceilings, and roof consist mostly of lumber nominally 2-inches thick.

## **Y**

**yellow tagged**

A building which has been inspected and declared damaged and unsafe for habitation.

## 10.2 Acronyms

<b>ACI</b>	American Concrete Institute
<b>ASTM</b>	American Society for Testing and Materials (now known as ASTM International)
<b>ATC-20</b>	Shorthand reference to the standardized process for post-earthquake safety assessments, also known as “tagging.” Derived from publication number of the Applied Technology Council series of publications <i>Procedures for Postearthquake Safety Evaluation of Buildings</i> , <a href="http://www.atccouncil.org">www.atccouncil.org</a> .
<b>CGS</b>	California Geological Survey
<b>CISN</b>	California Integrated Seismic Network
<b>CMU</b>	concrete masonry unit
<b>COSMOS</b>	Consortium of Organizations for Strong-Motion Observation Systems
<b>CSMIP</b>	California Strong Motion Instrumentation Program
<b>CUREE</b>	Consortium of Universities for Research in Earthquake Engineering
<b>EERI</b>	Earthquake Engineering Research Institute
<b>EIFS</b>	exterior insulation and finish system
<b>HVAC</b>	heating, ventilation, and air conditioning
<b>ICRI</b>	International Concrete Repair Institute
<b>MEP</b>	mechanical, electrical, and plumbing
<b>MMI</b>	Modified Mercalli Intensity
<b>NISEE</b>	National Information Service for Earthquake Engineering (UC Berkeley)
<b>OSB</b>	oriented strand board
<b>OSHA</b>	Occupational Safety and Health Administration
<b>PEER</b>	Pacific Earthquake Engineering Research Center
<b>SEAOC</b>	Structural Engineers Association of California
<b>USGS</b>	United States Geological Survey