

# Earthquake Hazards and Wood Frame Houses

What You Should Know and Can Do



**Center for Planning and Development Research  
College of Environmental Design  
University of California  
Berkeley, California 94720  
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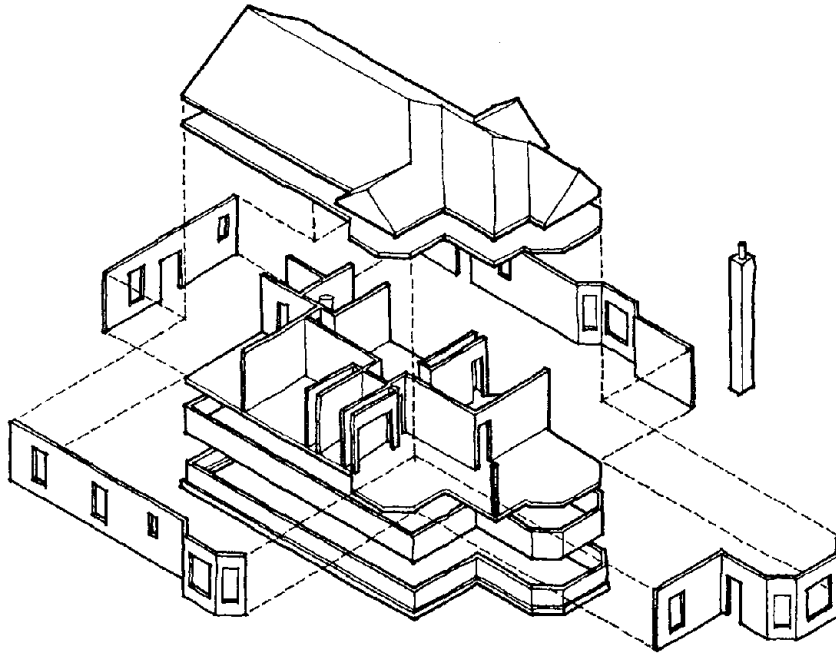
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# Foreword

The objective of this manual is to help you to improve the seismic resistance of your home. The procedures outlined here can help you to identify geological hazards of your site and to correct structural weaknesses of wood frame buildings. They will not necessarily bring your home up to code. Nor can they prevent geological weaknesses such as landslides or earth faults from causing significant damage to your home during earthquakes.

The information included here is the result of a review of past earthquake damage and recommendations from an advisory panel including experts on earthquakes. Thirty homes in the Bay Area were carefully assessed and improvements reviewed to determine which structural changes were most appropriate to recommend to the individual homeowner.

For more information on specific materials and construction details, you should consult professionals to assess your particular building and location. For any structural work on your home, you will need to obtain the necessary building permits.

It is our hope that earthquake advisory services might be established where homeowners and renters in earthquake prone regions could receive advice and instructions on how to improve individual dwellings.

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# Chapter 1

## Understanding Earthquakes

Several centuries ago, people believed that mysterious shaking of the ground was caused by a restless monster supporting the earth. In parts of South America, it was a whale; in Japan, it was, at first, a great spider, and then, a giant catfish. For the lamas of Mongolia, it was an immense frog; everytime the frog shook his head or stretched one of his feet, an earthquake occurred immediately above the moving part. Aristotle was the first to forward the idea that earthquakes were the result of air or gases attempting to escape from subterranean cavities.

Following the San Francisco earthquake of 1906, researchers concluded that earthquakes were directly related to faulting--the rupture of the earth's crust. The large displacement of land along the existing San Andreas fault led to the hypothesis that rocks along the fault had released elastic energy that had been stored for perhaps a century since a previous earthquake (Figure 1).

Current theories of motion in the earth's crust--plate tectonics--indicate that the relative movement of adjacent "plates" on the planet's surface displaces the ground surface along the seam or fault line. When this movement is continuous, no elastic energy is stored in rocks. If, however, friction stops the motion, elastic deformation of the rocks occurs along the fault. When pressures grow beyond the elastic limits of the rocks, a sudden rupture can occur releasing the stored energy in

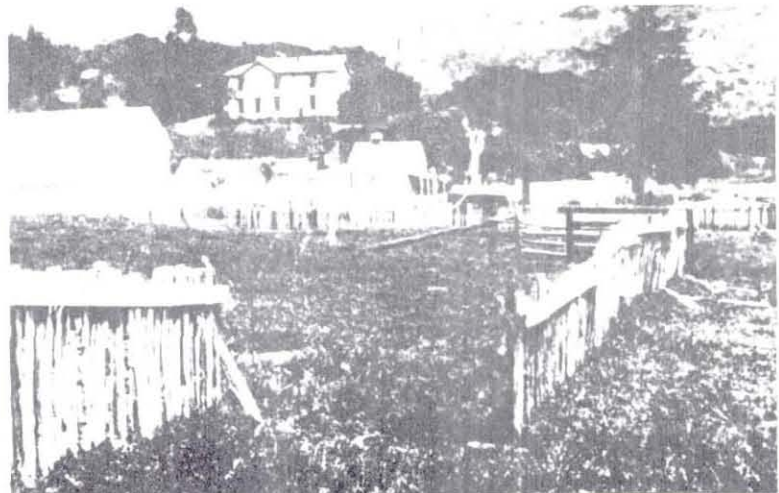


Figure 1 Displacement Along a Fault Line

Displacement along a fault resulting from the 1906 San Francisco earthquake is responsible for the dramatic gap in this once continuous fence near Point Reyes.

the form of seismic waves--an earthquake.

Not all earthquakes are caused by this process, however. Some earthquakes occur in conjunction with volcanic activity. Other earthquakes are associated with the collapse of underground caverns and mines or with the progressive extraction (or injection) of underground oil (or water). Massive landslides, man-made nuclear explosions and heavy water loads behind man-made dams can also trigger seismic waves.

An earthquake, then, is the shaking of the ground by seismic waves which are generated by the release of energy from an elastic deformation, volcanic activity or man-made causes.

## THE BEHAVIOR OF SEISMIC WAVES

There are three types of seismic waves generated during an earthquake (Figure 2). Primary ('P') compression waves and secondary ('S') shear waves start at the source (focus) of an earthquake and then travel outwards to the earth's surface. Surface ('L') waves (both Love and Rayleigh waves) occur near the ground surface - above the earthquake's focus. The interaction of these three wave types affects the type and intensity of ground shaking and damage to buildings.

When 'P' and 'S' waves reach the surface of the ground, most of their energy is reflected back into the interior of the earth, creating simultaneous upward and downward movements. These movements can considerably increase ground shaking. Shaking intensity also depends on the focal depth of an earthquake, which affects the amount of energy that reaches the earth's surface. Most California earthquakes have had shallow earthquake foci-- down to a depth of 40 kilometers below the earth's surface. These shallow earthquakes are potentially the most damaging since the energy release is spread over a relatively small area.

When the energy released from an earthquake produces faulting (an actual crack in the ground), the length of the new displacement (fault break) affects the duration and intensity of the earthquake and therefore affects ground shaking. There is now considerable evidence that earthquake waves and shaking are also significantly affected by both type of soil and landscape features. The nature and depth of bedrock, sandy and water-filled soils, or artificial land fill can either increase

or decrease the amplification of surface waves. The 1906 San Francisco earthquake demonstrated that the most severe shaking, and, consequently, greater damage occurred in deeper, softer soil such as bay mud and artificial fill. Bedrock tends to be more stable.

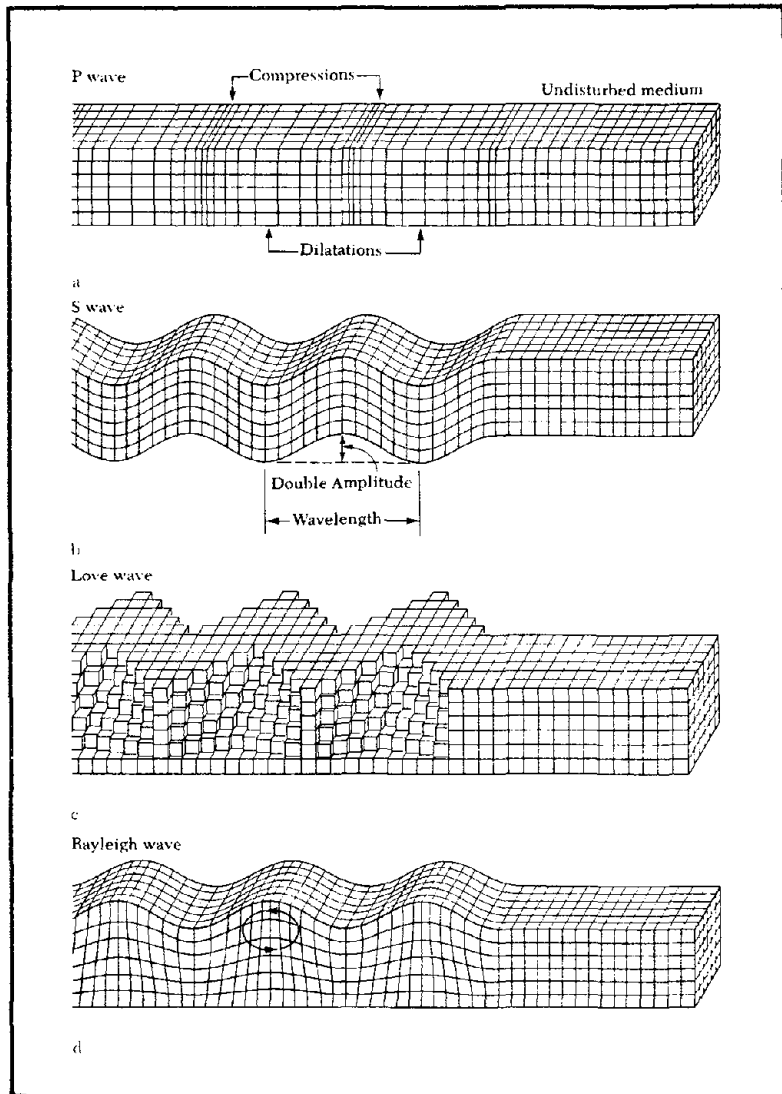


Figure 2 Seismic Wave Effects

Examples of the ground motions resulting from different seismic waves (see glossary entry for seismic wave.) A combination of these ground shaking patterns is felt by built structures above.

YEAR	DAY	PLACE	MODIFIED MERCALI SCALE	REMARKS
1769	July 28	San Pedro Channel Area	X	Major disturbance with many aftershocks.
1790	?	Owens Valley	X	Major shock.
1812	December 8	San Juan	IX	Church collapsed killing 40.
1812	December 21	Near Lompoc	X	Churches and other buildings wrecked in several towns, including Santa Barbara.
1836	June 10	San Francisco Bay Area	X	Ground breakage along Hayward fault from Mission San Jose to San Pablo.
1838	June	San Francisco	X	Fault ruptures along San Andreas rift. This earthquake is probably comparable with the earthquake of April 18, 1906.
1857	January 9	Fort Tejon	X-XI	One of the greatest historical Pacific Coast shocks. Originated on San Andreas fault in northwest corner of Los Angeles County. Buildings and large trees thrown down.
1865	October 8	San Francisco Peninsula	IX	Extensive damage in San Francisco, especially on filled ground.
1868	October 21	Hayward	X	Many buildings wrecked and damaged in Hayward and East Bay. Severe damage at San Leandro and San Francisco. 30 killed. Rupture of Hayward fault.
1872	March 26	Owens Valley	X-XI	One of the greatest earthquakes in Pacific Coast area. 27 killed at Lone Pine out of 300 population. Adobe houses wrecked.
1899	December 25	San Jacinto	IX	Nearly all brick buildings badly damaged in San Jacinto and Hermit. Chimneys down in Riverside. 6 killed. Another severe shock in 1918.
1906	April 18	San Francisco	XI	Great earthquake and fire. About 80 percent of estimated \$400,000,000 damage due to fire. 700 killed. Greatest destruction in San Francisco, Santa Rosa. Horizontal slipping along San Andreas fault, 6.5 meters.
1915	June 22	Imperial Valley	VIII	Nearly \$1,000,000 damage. 6 killed. Well-constructed buildings were cracked.
1925	June 29	Santa Barbara	IX	\$6,000,000 damage. 13 killed. 70 buildings condemned.
1933	March 10	Long Beach	IX	\$41,000,000 damage, 120 killed. Fire damage insignificant.
1940	May 18	Imperial Valley	X	\$6,000,000 damage, 8 killed, 20 seriously injured. 65-kilometer fault appeared with maximum horizontal displacement of 4.5 meters.
1941	June 30	Santa Barbara	VIII	\$100,000 damage.
1941	November 14	Torrance, Gardena	VIII	About \$1,000,000 damage. 50 buildings severely damaged.
1952	July 20	Kern County	X	\$60,000,000 damage, 12 killed, 18 seriously injured. Railroad tunnels collapsed and rails bent in S-shape. Surface faulting with about a half meter of vertical, as well as lateral, displacement.
1952	August 22	Bakersfield	VIII	Damage \$10,000,000. 2 killed, 35 injured.
1957	March 22	San Francisco	VIII	Damage in Westlake and Daly City area.
1969	October 1	Santa Rosa	VII-VIII	Property loss of \$6,000,000. Felt over an area of 30,000 square kilometers.
1971	February 9	San Fernando	VIII-XI	\$500,000,000 direct physical loss, 65 killed, more than 1,000 persons injured. Felt over an area of 230,000 square kilometers.
1978	August 13	Santa Barbara	VII	\$7,310,000 damage. Moderate structural damage.
1979	October 15	El Centro	**	**
1980	January 24	Livermore	**	**
1980	May 25	Mammoth Lake	**	**

Table 1 California Earthquakes

## Chapter 2 Lessons From Past Earthquakes

California has had its share of major earthquakes over the last two centuries (Table 1), and more are predicted for the future. From research on past earthquake damage, engineers have learned that wood frame dwellings, and particularly single story houses, suffer less structural damage than any other type of residential or commercial structure. But no structure is earthquake proof. Damage can result both from weaknesses in the ground on which a house stands and from weaknesses in the architectural or structural features of the building.

### PROBLEM SITES

Earthquake hazards begin with geology. No matter how well a house is built, it may not survive a strong earthquake if it is located on unstable soil.

Problem sites typically involve surface faulting, landslides, and land settlement. In the past, many houses situated on faults that ruptured have been rendered uninhabitable. Houses situated on unconsolidated or unstable land have suffered a disproportionate amount of damage resulting from landslides. During the 1964 Alaska earthquake, for example, more than 70 homes in the city of Anchorage were demolished by a single large landslide triggered by the earthquake. In contrast, nearby homes outside the landslide area generally suffered no serious damage from the accompanying ground vibrations.

Earthquakes may also consolidate (compact) soils that are soft, poorly compacted or both. Some of the worst damage to wood frame houses resulted from settlement of the numerous fill areas throughout San Francisco during the 1906 earthquake.

### AGE AND CONSTRUCTION

Since the 1933 Long Beach earthquake, California building codes have required increasingly greater earthquake protection for schools and other buildings, including some types of houses. Construction techniques also improved with new technologies developed during World War II. Most pre-1940 houses, then, lack several structural details required by today's codes. The importance of these missing elements was illustrated by a minor earthquake that damaged Santa Rosa in October, 1969. All of the 39 seriously damaged houses in the city of Santa Rosa were of pre-1940 construction.

Of course, no matter how new your house, poor workmanship, and, especially, poor connections between the parts of your building, may greatly increase damage during an earthquake.

#### FOUNDATIONS

Concrete foundations on stable ground have generally withstood earthquake motion well, even in some situations where the concrete was of poor quality and/or not reinforced. There are very few cases of disintegration of unreinforced concrete foundations; as a rule, they can be considered safe unless they show heavy cracking, a sign of ground instability.

In contrast, brick foundations have a record of damage in earthquakes. During the 1906 San Francisco earthquake, many brick foundations cracked or partially fell apart, causing damage to the structures above (Table 2).

Present building codes require foundations to be bolted to the wood sill which supports the floor joists or uprights of the house walls. This requirement generally did not exist prior to 1940. Consequently, substantial structural damage in pre-1940 earthquakes has been attributed to the lack of appropriate connection between the wood structure of the house and the foundation (Figure 3). In the 1906 San Francisco earthquake, many unbolted house frames were displaced from the concrete or brick foundations; damage was usually extensive. Much of the damage from the 1933 Long Beach earthquake was also attributable to slippage on foundations. Similar damage to structurally weak older houses can be expected in future earthquakes, but the

Number of houses examined, with number of houses moved, and number of foundations cracked.

Character of foundation.	San Mateo			Redwood			Belmont, Homestead, and San Carlos.			Burlingame and Mateo Hills.			Total.				
	Houses examined.	Houses moved.	Foundations cracked.	Houses examined.	Houses moved.	Foundations cracked.	Houses examined.	Houses moved.	Foundations cracked.	Houses examined.	Houses moved.	Foundations cracked.	Houses examined.	Houses moved.	Per cent of houses moved.	Foundations cracked.	Per cent of foundations cracked.
Wood	266	47	...	63	23	...	50	2	...	8	1	...	387	73	17	...	...
Concrete	176	51	43	7	7	...	1	...	1	41	1	7	225	59	26	51	23
Brick	160	51	63	8	3	1	16	...	4	46	4	26	230	58	26	94	41
Total	602	149	106	78	33	1	67	2	5	95	6	33	842	190	23	145	—

Table 2 Foundation Damage: 1906 San Francisco Earthquake

improvements resulting from current code requirements can be seen in reports from recent earthquakes which indicate that only older unbolted buildings were displaced from their foundations.

Concrete floor slabs supported by perimeter foundation footings are typical of modern construction. There is no reported difference between the performance during earthquakes of concrete slab floors and more common joist-supported wood floors. When extensively damaged, concrete slabs have shown continuous cracks around the perimeter where footings attach, but it is expected that houses with such floors will be subject to comparatively less damage because there is no crawl space under the house subject to collapse.

#### WALLS AND COLUMNS

Wood frame houses are commonly damaged because of insufficient bracing of cripple stud walls. These walls are commonly used to elevate the house above ground level and to allow access (crawl space) to the substructure and utility lines. Collapse of cripple studs was extensively reported after both the 1906 San Francisco and the 1933 Long Beach earthquakes, and again



Figure 3 Foundation Damage

Wood frame building displaced from foundation during the 1971 San Fernando earthquake. Shingles that overlapped the foundation were undamaged.

in the 1971 San Fernando earthquake. Dwellings with more serious damage frequently had split-level wood floors separated and supported by inadequately braced cripple stud walls. Wherever cripple stud walls were braced with properly nailed plywood or the house was sheathed with properly nailed diagonal sheathing, damage was minimal or nonexistent (Figure 4).

Cripple wall studs and sheathing may be seriously weakened by extensive wood rot or termite infection. In fact, damage to cripple stud walls from the 1906 earthquake is believed to have been compounded by such pre-existing weaknesses.

Many photographs accompanying the literature on past earthquakes show porches that have collapsed from failure of cripple studs or inadequately braced column connections.

Inadequately braced exterior walls have also been damaged, particularly those walls with many door and window openings or with very large openings such as double garage doors or sliding doors. This was the reason that many two story and split-level wood frame houses partially collapsed during the 1971 San Fernando earthquake. In past earthquakes, houses of two or more stories have suffered more damage than single story houses. Damage has been concentrated at the lower floor level; upper floors have exhibited little or no damage unless there was also a general collapse of the first floor or the roof.

For adequately braced structures, damage has usually been minimal, often confined to the cracking of stucco and other surface materials adjacent to openings. Being relatively brittle, stucco applied directly to wood studs without sheathing

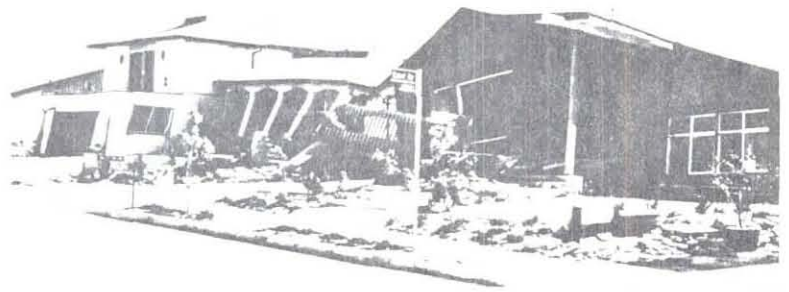


Figure 4 Exterior Sheathing Failure

Failure of exterior sheathing led to extensive damage in the 1971 San Fernando earthquake.



has suffered considerably more damage than wood siding. However, stucco backed by chicken wire and plywood or diagonal sheathing has generally performed very well.

## FLOORS AND ROOFS

Floors and roofs of the typical wood frame house have rarely been damaged in an earthquake; when they were, damage usually occurred at the connections with walls when roof rafters were not properly tied to walls or when walls were inadequately braced.

Heavy roofing materials like terra cotta tiles have caused damage by adding excessive weight to a house, increasing the building's momentum when it shakes. This is a greater hazard for multi-story than single story dwellings because upper story walls separated by floor planes can bulge out or buckle under pressure. Tile and slate roofs have been damaged and caused injuries when individual tiles were not securely nailed. Shingle or tar and gravel roofs that have been re-roofed without old materials being removed have also added unnecessary weight to the house frame, increasing the possibility of damage.

## CHIMNEYS

The earthquake performance of unreinforced brick chimneys built before 1940 is very poor. Many towns throughout the San Francisco Bay Area lost in excess of 80 percent of their brick chimneys in the 1906 earthquake. Since 1940, building codes have required steel reinforcing in chimneys. Current codes additionally require chimneys to be tied to the house. Even with these precautions, about 33 percent of the chimneys in San Fernando were damaged in the 1971 earthquake; many collapsed (Figure 5).

Unreinforced chimneys attached to exterior walls have tended to fall away from the fireplace wall, often striking other portions of the house. On the whole, unreinforced chimneys attached to interior walls have suffered less damage, but those that extend four feet or more above the roofline have frequently fallen through the roof, sometimes causing extensive interior damage. Interior flues are also difficult to reach and are typically more expensive to repair when damage does occur.

## EXTERIOR VENEERS

Exterior masonry veneers, including brick and stone, can be severely damaged unless properly anchored. In fact, some insurance policies specifically exclude earthquake coverage for such veneers because they are frequently pulled off walls by ground shaking.

Veneers that do not extend above four feet in height from the ground have generally performed well in past earthquakes. But higher veneered walls have suffered a disproportionate amount of damage compared to other lighter weight surfacing materials. The damage to the veneer has usually not been accompanied by significant damage to the underlying wood structure. But the damage can be expensive, and falling masonry may cause injuries.

## INTERIOR HAZARDS

One hazardous feature of older houses is the plaster on interior surfaces. It is heavy and fragile, easily damaged and potentially injurious to occupants. Much of the damage to two-story houses in the 1906 earthquake was to ceiling and wall plaster. Heavy furnishings and appliances are another hazard. They have been moved and overturned in strong earthquakes, sometimes causing injury and damaging other personal property.

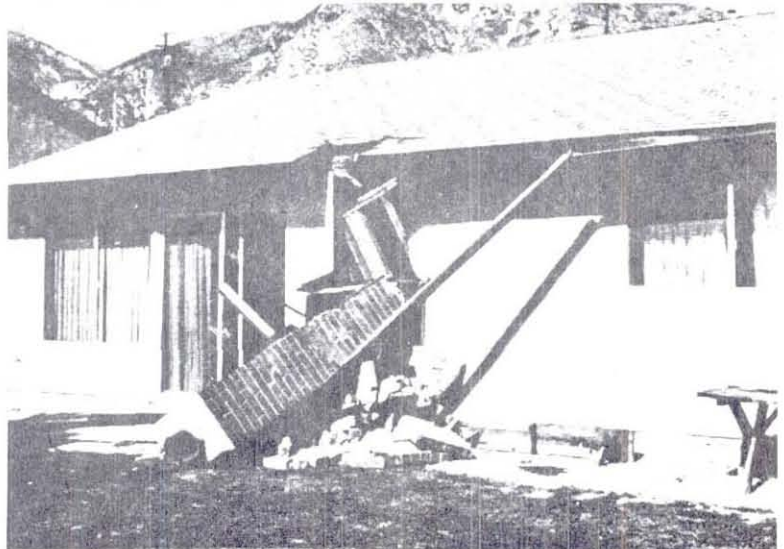


Figure 5 Chimney Collapse

Example of chimney which collapsed during the 1971 San Fernando earthquake.

## UTILITIES

Unbraced water heaters have presented the most significant utility hazard. Shifting and falling heaters have frequently broken their gas line connections, sometimes resulting in fire.

Historically, the performance of piping in wood frame structures during earthquakes has been good. If a damaged structural element imposes undue weight on the house piping, the piping may leak or fail at a threaded joint. Otherwise, the strength and flexibility of the piping has usually kept it intact during ground shaking.

Air conditioners located on roofs of dwellings are subject to amplified earthquake forces, and many have fallen over or slid when not securely attached to the roof.

# Chapter 3

## Site Hazards

Damage from earthquakes can result from both primary and secondary geological responses to seismic waves:

Primary Response: surface faulting and ground shaking

Secondary Response: subsidence, liquefaction, landslides

### SURFACE FAULTING

Surface faulting results from the relative movements of adjacent blocks of earth. This movement can either be slow--fault creep--which produces no ground shaking, or rapid--a sudden rupture which produces an earthquake. Most damage in earthquakes is not caused by ground faulting by itself, unless buildings are located directly on a fault. In such cases, it is likely that the building foundation will be ruptured, and it is almost certain that the building will be severely damaged.

### GROUND SHAKING

Ground shaking is the major cause of earthquake damage. But it is also the seismic effect that can be most effectively resisted. The intensity of ground shaking and resulting damage that may be expected at your site depend, in a complex way, upon the distance to your site from the earthquake fault, the magnitude of the earthquake, and the geology and soils at your site. Generally, houses located on bedrock experience less severe shaking than houses located on deep, softer soils, even though the former may be closer to the fault.

### GROUND INSTABILITY

Ground instability results from structurally weak soils, unconsolidated (or poorly compacted) sediments, and man-made landfills which may be poorly compacted.

Instability refers here to ground subsidence, liquefaction and landslides. In an earthquake, ground shaking may cause subsidence, the settlement of uncompacted soils. In some cases, subsurface water will be forced upwards, causing a quicksand-like condition referred to as liquefaction (Figure 6). Both subsidence and liquefaction will result in settlement that may be uneven, and that may leave your house tilted and partially sunk. Landslides result from weaknesses in soil which may be set into motion by earthquakes. They may cause severe damage either by sliding into your house or by causing your house to slide along with the soil. Potential damage from landslides and liquefaction

is intensified during rainy seasons when the ground is saturated with water. Occasionally, mature trees and other vegetation can also be uprooted by ground instability or shaking.

#### TSUNAMIS AND SEICHES

Sudden earthquake movements may cause abnormally large ocean waves known as tsunamis, popularly but mistakenly called "tidal waves." They may also cause oscillations known as seiches in inland lakes, reservoirs, rivers, ponds, even swimming pools, all of which can breach or overflow their normal confines. Houses near large bodies of water or houses in flood plains may be subject to flooding. Houses along coastlines may be subject to sudden, powerful tsunami waves.

#### WHAT YOU CAN DO ABOUT SITE HAZARDS

Adjustments to seismic hazards may be grouped into three basic categories:



Figure 6 Damage From Ground Instability

Example of a tilted building resulting from liquefaction following a 1964 Japanese earthquake.

Modifying potential hazards

stable site selection  
structural modifications  
soil and slope stabilization  
land use planning, zoning  
tsunami barriers  
seiche protection  
fire protection

Adjusting to damage

insurance  
public aid and assistance

Modifying potential losses

warning systems  
emergency preparations  
structural modifications  
evacuation procedures

Many of these actions must be undertaken at the community level with public funding. But on your own, you can research available documentation to determine the stability of your site. In California, planning departments compile seismic data for cities and counties in a Seismic Safety Element that now must be included in every General Plan. You may purchase the General Plan for several dollars, or you can usually review a copy at the City Planning information desk or public library.

Seismic activity is not at all uniform in the United States, in California or even within one county. Therefore, you should pinpoint your property on regional and local geological maps to obtain the most accurate information. Begin by determining if your site lies within an active fault zone. In California, the "Alquist-Priolo Special Studies Zones"--designating major active fault zones--were created following the 1971 San Fernando earthquake. These are included in the Seismic Safety Element for affected communities (Figure 7). Superficial identification of faults is very tricky business; many faults have only recently been identified so it is best to consult the latest published maps.

The Seismic Safety Element for your local community should also include information on potential ground instability. Geological maps from the U.S. Geological Survey or the U.S. Soils Conservation Service can indicate where liquefaction and landslides are likely to be hazards. And you may find existing geological or soils reports of both your own and neighboring

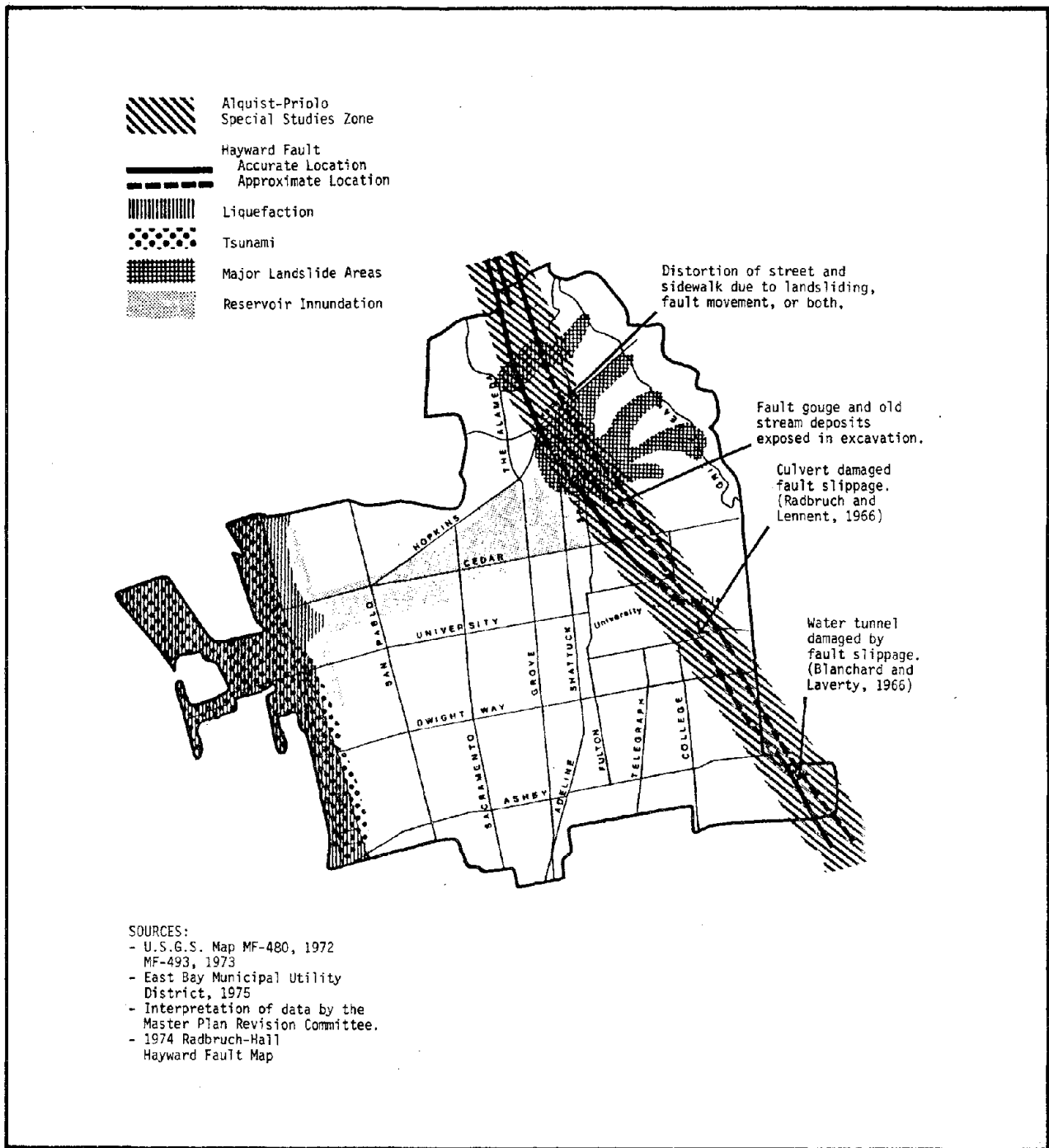


Figure 7 Special Studies Zone

A copy of the special studies zone for the Hayward fault as it runs through Berkeley. For accurate detail, consult the larger, original map included in the Seismic Safety Element.

properties useful or decide to have a soils engineer prepare a new report for your site. You should also survey your property for landscaping details, particularly mature trees, that might need to be removed or braced against ground shaking.

If maps indicate that your property is subject to faulting or ground instability, seek professional advice. There are presently no means available to reduce ground shaking intensities expected at a site. But a geologist or engineer may be able to determine if a fault will bypass your property and whether structural upgrading and/or soil stabilization are feasible and worthwhile.

You can also purchase earthquake insurance. Presently, insurance companies do not discriminate between local differences in site hazards.

If you are considering buying property for new construction, a comparison of projected shaking intensities may help you to select a site that is geologically safer than other sites considered.



# Chapter 4

## Building Hazards

The structural improvements described in this chapter help to prevent damage from ground shaking. But they cannot minimize damage resulting from ground faulting or ground instability. You should seek professional consultation on concrete, steel, masonry and other non-wood frame construction not considered in this chapter. Many older or inadequately reinforced masonry structures have performed poorly in earthquakes.

Most of the recommendations for wood frame houses can be applied to other wood frame buildings including garages and storage shelters. You should survey your property for weak, deteriorated or distorted structures--the lopsided garage or displaced garden wall--that could collapse in an earthquake. They may require strengthening. You may have additional hazards on your property such as inadequately braced or reinforced trellises, gazebos, fences and playhouses.

Visual inspection of your property may be facilitated by the inspection guide provided in the appendix. Floor plans and other measured drawings might prove very useful in planning modifications.

### WHAT YOU ARE WILLING AND ABLE TO DO

In many cases, it will be convenient and economical to do other planned improvements to your house at the same time you are making structural changes to resist earthquakes. Likewise, you can take advantage of any remodeling or energy conservation projects to brace and strengthen the structure of your house.

Many people hesitate to make recommended improvements that can change the aesthetic appearance of their homes. It may be difficult to decide what changes you are willing to make. The discussion of earthquake movements that follows can help you choose which improvements you feel are worthwhile and what risks you would like to reduce. For example, you may choose to replace your chimney with a metal flue if you realize that chimneys are frequently damaged in earthquakes and could cause significant damage to your neighbor's property as well as to your own.

### BUILDING RESPONSE TO EARTHQUAKE SHAKING

The height and rigidity of a building affect its response to earthquakes. As a structure is set in motion by ground shaking, it responds with its own pattern of motion. Tall buildings have

longer natural periods of oscillation or vibration than low-rise buildings which are less flexible. Similarly, soft soil has longer natural periods of oscillation than bedrock which greatly reflects seismic waves. When the periods of building and soil oscillations are the same, the resulting effect--referred to as resonance--can increase the motion of the building and consequently increase the damage to it. Past experience shows that different small, rigid buildings may sustain less damage on soft soils and taller, flexible buildings may sustain less damage on bedrock.

#### HOW GROUND SHAKING AFFECTS A WOOD FRAME HOUSE

During strong earthquakes, the ground moves erratically and rapidly in all directions, tending to move buildings in the same manner. Individual building components resist this motion. In doing so, buildings may slide, distort or rock back and forth, possibly toppling over. The tendency of building parts to resist outside movement is due to their strength and stiffness. The earthquake forces that push at them are called "inertial forces." You can reduce the impact of inertial forces by properly bracing and supporting the structure of your house.

- There are four basic structural components of most buildings:
- The horizontal structural elements (roof and floor planes, joists, beams and trusses) tie the walls together and transfer the weight of the building, furnishings and occupants to the vertical structural elements.
  - The vertical structural elements (walls, columns, studs and bracing) support and transfer the load of the horizontal elements and their own weight to the foundation.
  - The foundation supports and ties together the walls and transfers the weight of the building to the ground.
  - The connections (nailing, blocking, joints, etc.) tie all of the above components together.

During an earthquake, forces gathered by the horizontal structural elements must be transferred to the vertical structural elements which, in turn, must transfer them to the foundation. This load transfer is possible only if the elements are well tied together by connections. Because the forces accumulate at the foundation, it comes as no surprise that most seismic damage is found at the foundation level. Often, this area is the easiest to strengthen.

If your house is more than three-stories high, of unusual shape, has a split-level plan, or is supported on "stilts" or poles, you should again seek professional evaluation. Even new dwellings with these common, yet irregular configurations have performed poorly in recent earthquakes. Both new construction and remodelling will require engineering computations.

On the other hand, wood frame houses that are not of unusual size or shape do not require detailed calculations. They are typically built following standard construction practice described in modern building codes. This practice has generally been successful in providing adequate seismic safety for dwellings. But older houses (pre-1940) and some newer houses may require significant improvements to reduce damage and, in some cases, to prevent total collapse.

## HAZARDS YOU CAN IDENTIFY

### Foundation

A good foundation distributes the weight of a structure uniformly to the ground so that differential settlement and consequent cracking is avoided and overall settlement is minimized.

An effective foundation is tied together so that it moves as a unit during an earthquake. This prevents any individual exaggerated movement of its components that can tear the structure apart. The foundation must also distribute to the soil any additional vertical loads induced by the earthquake through bouncing.

Older wood frame houses typically sit on either a brick or unreinforced concrete foundation; a few have wood foundations. Since 1940 most foundations have been constructed of reinforced concrete and are very strong.

What you can do. Carefully inspect your foundation. Has it settled significantly? Are there cracks? You should not be alarmed by "hairline" cracks that result when the concrete shrinks as it cures. Many larger cracks (1/8-inch wide or wider) can be a sign of ground instability. Such cases probably will require professional advice about what corrective measures should be taken.

If your foundation is constructed of wood, unreinforced brick or block masonry, common among pre-1940 homes, it may be

best to replace it partially or fully with a reinforced concrete foundation. [Consult your local Building Codes and Inspection Department; they usually have standardized drawings available that can explain construction procedures (Figure 8).]

### Anchorage and Connections

If a foundation is to serve its function of tying the house together to resist earthquakes, the house must be well anchored to the foundation. Newer houses can be poorly anchored to their foundations and older houses are often not anchored at all. The cost of improving anchorages will be insignificant compared to the thousands of dollars needed to place a house back on its foundation after it slides off in an earthquake, and to repair the damaged structure, utility lines, and other nearby objects.

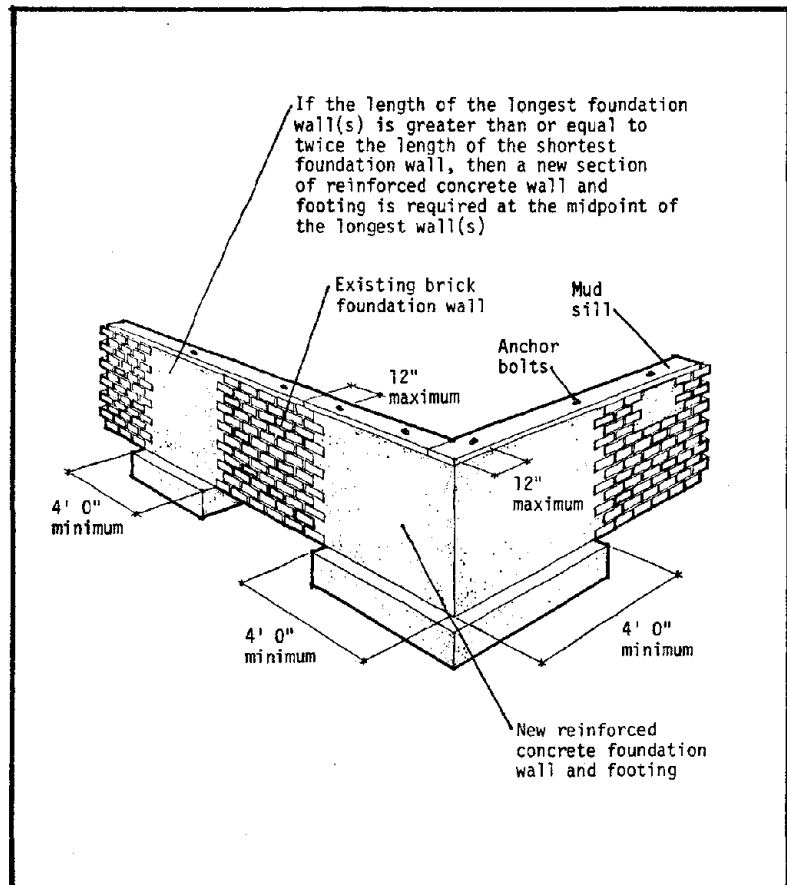


Figure 8 Brick Foundation Repair

Remove all unsatisfactory foundation brickwork from areas indicated on the foundation plan and replace it with new reinforced concrete walls and footings.

What You Can Do. Existing bolts should be inspected carefully, and any loose nuts should be tightened. You can tie an existing house to the foundation with expansion bolts. Typically, the wood sill (usually a 2" x 6", or 2" x 8") is bolted between wall studs and the foundation wall (Figure 9). When you cannot reach the foundation from a crawl space or basement, a metal plate can be used to tie the sill and foundation together (Figure 10). For new construction, you can use anchor bolts that can be "hooked" into wet cement before it dries (Figure 11).

If the newest wood members in your building are not at least six inches above grade (ground level), you may already have

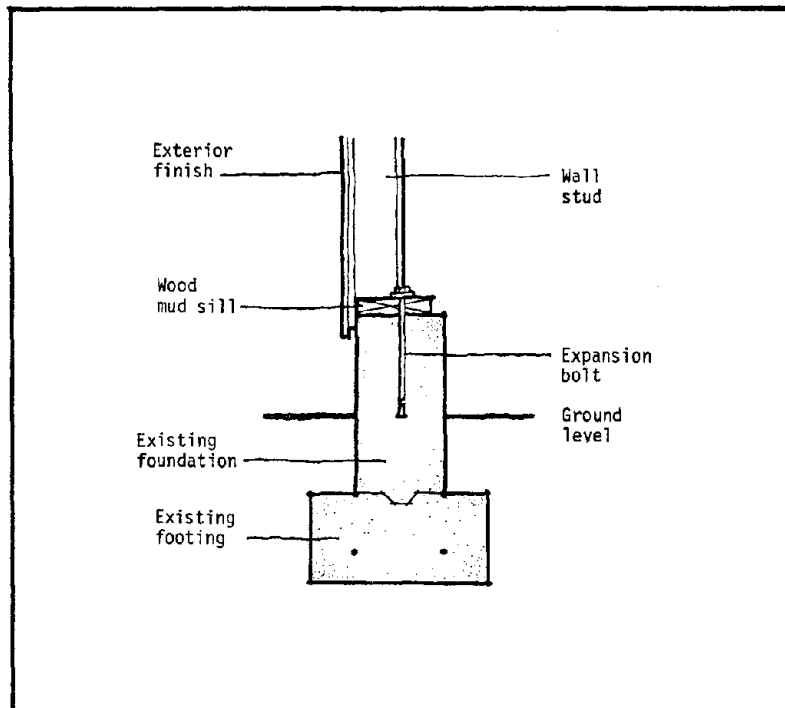


Figure 9 Concrete Foundation Repair with Expansion Bolts

Drill holes through the mud sill and into the concrete foundation wall for the insertion of expansion bolts. Locate the bolts a maximum distance of 12" from the corners of new concrete walls, a maximum distance of 12" from the ends of each piece of wood mud sill, and according to the following rules:

Light House: One story wood frame except where walls and roof are heavy materials such as stucco, plaster or tile. Use 1/2" diameter bolts spaced 6'-0" apart.

Medium House: Two story wood frame with lightweight roof and wall materials and heavy one story homes. Use 3/4" diameter bolts spaced 6'-0" apart.

Heavy House: Two story wood frame with stucco and plaster or full attic or three story wood frame. Use 3/4" diameter bolts spaced 4'-0" apart.

or eventually will have problems with decay or insect infestation. Several improvements are possible:

- Lower the grade of the soil around the house; soil often builds up in this area from planting over the years.
- Provide drainage away from the house, especially around downspouts.
- Add height to the foundation (an expensive and unusual solution, but, occasionally, the only solution).

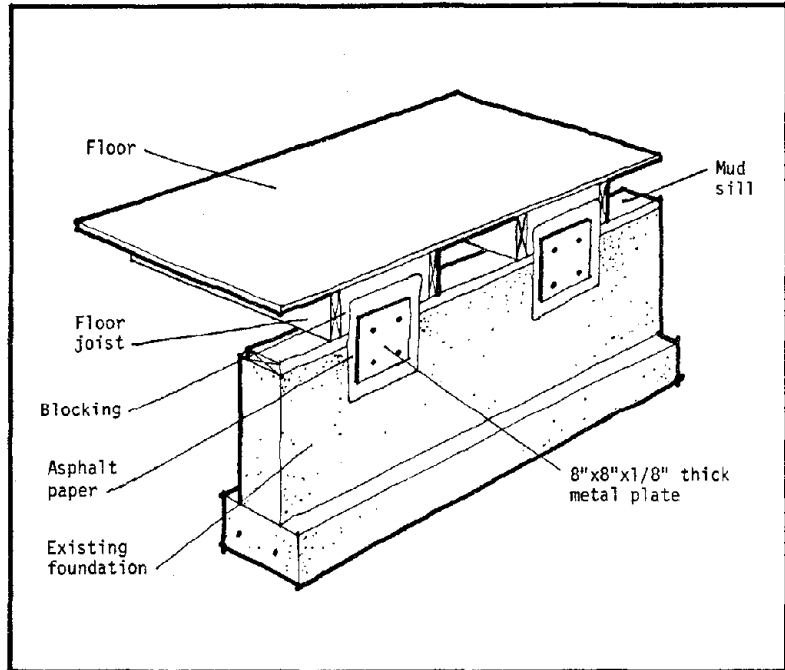


Figure 10 Concrete Foundation Repair with Exterior Metal Plates

Sometimes drilling vertically down into the foundation wall and placing an expansion bolt is not possible from inside the house. Instead of expansion bolts, 8" x 8" x 1/8" thick metal plates can be bolted to the foundation wall and the mud sill from the exterior of the house. Drill holes into the wood mud sill from the exterior of the house for the insertion of 1/2" diameter lag bolts. These bolts should penetrate the mud sill to a depth between 1/2 and 2/3 of the width of the sill. Drill holes into the concrete foundation wall from the exterior of the house for the insertion of 1/2" diameter expansion bolts. These bolts should penetrate the wall to a depth between 1/2 and 2/3 of the wall's width; use an expansion bolt with an appropriate length.

Space the metal plates according to the following rules:

Light and Medium Houses: One story wood frame including houses with heavy roof and wall materials such as stucco, plaster and tile; and two story wood frame houses with lightweight roof and wall materials. Space the plates 6'-0" apart.

Heavy House: Two story wood frame with heavy roof and wall materials such as stucco, plaster and tile or full attic or three story houses. Space the plates 4'-0" apart.

See footnote 1 at the end of this chapter for a discussion of how to place metal plates in the interior of a house.

Carefully inspect the condition of the wood sill. Dark discoloration, salt precipitates, or fungus are all indications of deterioration. If any of these conditions exist, you can jab the sill at different places with an ice pick or a pocket knife to locate the soft pockets of decay.

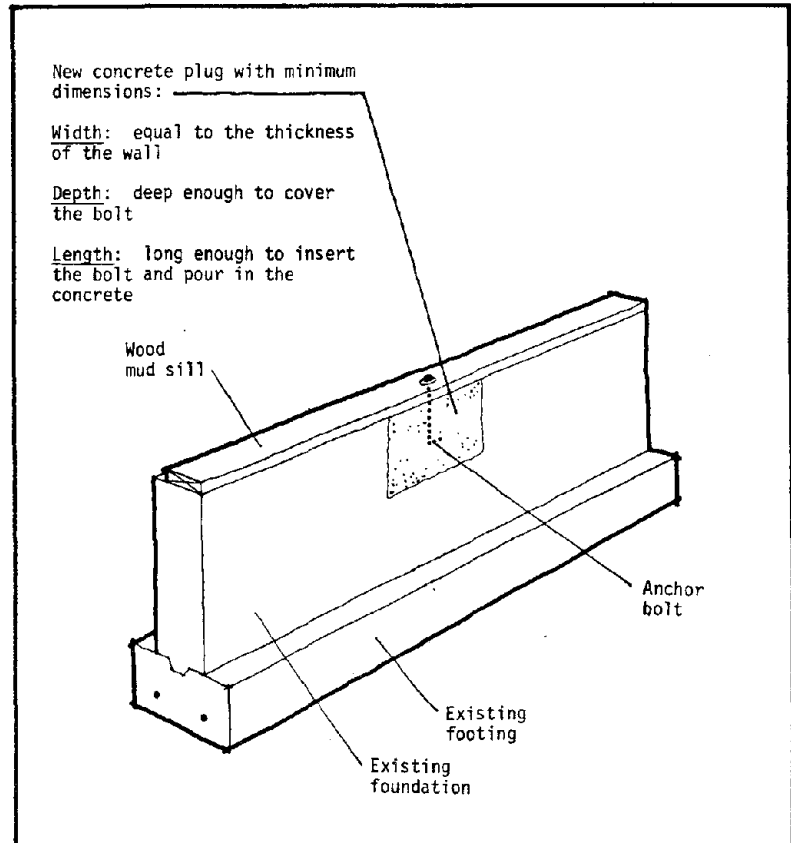


Figure 11 Concrete Foundation Repair with Anchor Bolts

When existing concrete foundation walls are too deteriorated to receive new expansion bolts, concrete plugs with anchor bolts can be used. Insert anchor bolts into holes drilled through the wood mud sill and into the hole vacated for the concrete plug. Locate the bolts a maximum distance of 12" from the corners of the foundation walls, a maximum distance of 12" from the ends of each piece of wood mud sill, and according to the following rules:

Light House: One story wood frame except where walls and roof are heavy materials such as stucco, plaster or tile. Use 1/2" diameter bolts spaced 6'-0" apart.

Medium House: Two story wood frame with lightweight roof and wall materials and heavy one story homes. Use 3/4" diameter bolts spaced 6'-0" apart.

Heavy House: Two story wood frame with stucco and plaster or full attic or three story wood frame. Use 3/4" diameter bolts spaced 4'-0" apart.

Any deteriorated sills or other wood members should be replaced. You should attempt to determine what caused the deterioration and take preventative action. If termites appear to have been the cause, you may chemically treat sound existing wood and use treated wood for replacement. Current research, however, indicates that many chemicals pose a health hazard. Pentachlorophenols and arsenite compounds should be avoided. To prevent future termite infestation, make sure that no wood contacts the soil below or near your house. Such contact provides food and a convenient path for termites to get to the rest of your house.

Moisture is likely to cause wood to rot. Possible sources of water include leaking pipes or toilet fixtures, insufficient separation between soil and sill caused by soil buildup against the house in planted areas, rain water leakage, or insufficient crawl space ventilation. Providing a vent with an area of at least 1.5 square feet for each 25 linear feet of basement or crawl space wall will normally alleviate any critical ventilation problem.

Most of the other structural connections in your house depend upon nailing, and other metal connection devices. The number of different connections that you may encounter is great, and some knowledge of carpentry will be useful. You will not be able to inspect most connections without dismantling parts of your house, and few that you can inspect will be easily accessible to hammer and nail. So it is a good idea, when modifying or remodelling parts of your house, to improve connections as they become accessible. Be careful when adding nails so they don't destroy a perfectly good connection. Pre-drilling a hole slightly smaller than the diameter of the nail or placing nails away from the ends and edges of boards will prevent the wood from splitting now or at some later date.

### Bracing

It is difficult to construct a building without some bracing since it would collapse during construction. The bracing is generally either plywood sheets or wood or steel straps nailed diagonally across the studs in the wall. So your house is braced at least minimally. But bracing requirements in recent building codes have been increased as more is learned about the effects of earthquakes. It is now fair to say that inadequate bracing of



cripple stud walls is the most common deficiency. Without bracing, cripple walls (short walls that extend from the foundation up to the first floor) can severely deform and even collapse during intense ground shaking. In wood frame construction, exterior stud walls and selected interior stud walls need to be laterally braced along their length. The braced sections are referred to as "shear walls" and are needed to resist the lateral and vertical motions of earthquakes. Without such bracing, stud walls tend to fall over like a row of dominoes.

What You Can Do. In most cases, it will be impossible to assess existing bracing without probing into sections of the wall, so you should proceed with caution. First look in places where probing and subsequent patching will be the least visible: under sinks, under stairs, in closets. Exterior walls should be braced with well nailed wood boards or plywood sheathing. Gypsum board, fiberboard and particle board sheathing, adequately nailed diagonal wood braces or steel straps, and lath and plaster can also be used in specific instances, although their effectiveness is limited.

You probably will brace cripple walls from within the crawl space, being careful not to create moisture problems (Figure 12). Cripple walls less than 14 inches in height should be constructed of solid material, e.g., solid blocking. Those more than 14 inches high should be braced according to Table 3. To be functional, the width-to-height ratio of a shear section of a cripple wall should be no greater than 2:1.

Frequently, vertical cripple wall studs are not as wide as sill plates. In order to provide a flush surface for nailing plywood, additional wood blocking (Figure 13) may have to be added.

In regions that experience intense ground shaking, all exterior walls and main transverse walls (interior walls that extend continuously from foundation through every floor level) should have lateral bracing (Table 3). This should be placed near the ends of the wall and at regular intervals in between. These intervals will vary with the height and design of each building.

In addition to walls you should check post and beam connections that may require additional bracing. This may be accomplished with additional steel bracing (Figures 14 and 15) or with plywood gusset plates.

## Chimneys

It is not uncommon to find masonry chimneys that are inadequately braced or that lack reinforcing steel. These conditions may add to damage resulting from an earthquake.

What You Can Do. Past earthquake records indicate that bracing a chimney will not necessarily prevent it from collapsing or sustaining serious damage. But since it may reduce the extent

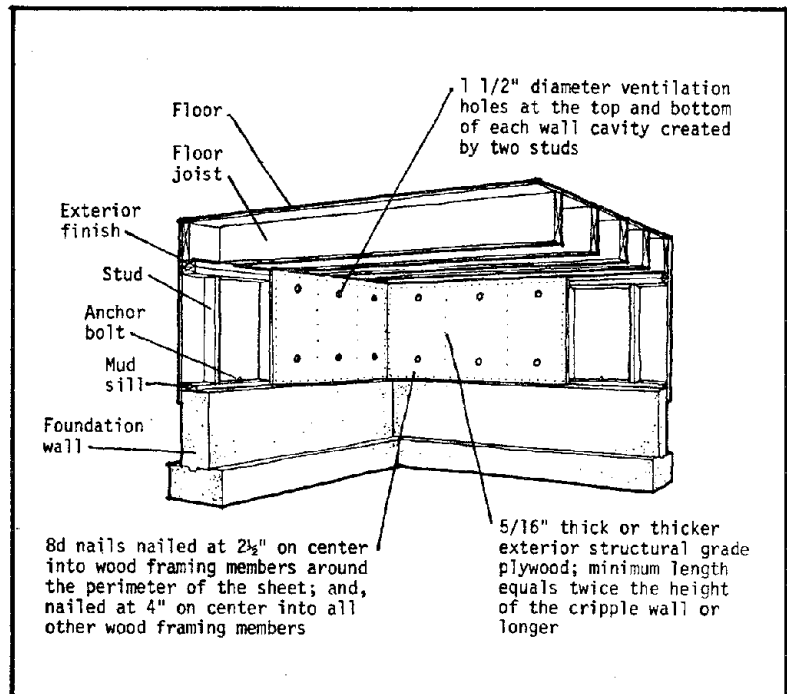


Figure 12 Cripple Wall Bracing at Wall Corners

Nail 5/16" thick or thicker exterior structural grade plywood sheets at the corners of cripple walls. These sheets should be at least twice as long as their height and according to the rules described below. The plywood should be nailed every 2-1/2" around the perimeter and every 4" into wood framing members behind the interior of the sheet. Additional wood blocking may have to be added to existing framing members so that the sheet can be properly nailed. Holes may have to be cut in the sheet to help ventilate the crawl space. There should be at least 1-1/2 square feet of air vents to the exterior of the house for each 25 linear feet of foundation wall. Holes must be cut in the sheet to ventilate the wall cavities created by the sheet and each pair of studs.

Use the following rules for determining the required length and width of the plywood:

Light House: One story wood frame except when walls and roof are heavy materials such as stucco, plaster or tile. Nail at least 3 linear feet of plywood at the ends of each cripple wall.

Medium House: Two story wood frame with lightweight roof and wall materials and heavy one story houses. Nail at least 4 linear feet of plywood at the ends of each cripple wall.

Heavy House: Two story wood frame with stucco and plaster or full attic or three story wood frame. Nail at least 6 linear feet of plywood at the ends of each cripple wall.

See footnote 2 at the end of this chapter for a discussion of how to brace cripple walls at midspan instead of at the corners.

FIRST FLOOR	of a 3-story building:	40% of length of floor
SECOND FLOOR	of a 3-story building:	25% of length of floor
FIRST FLOOR	of a 2-story building:	25% of length of floor
CRIPPLE WALL	of a 3-story building:	80% of length of wall
CRIPPLE WALL	of a 2-story building:	50% of length of wall
CRIPPLE WALL	of a 1-story building:	25% of length of wall

Table 3 Shear Walls: General Rules of Thumb for Length of Bracing

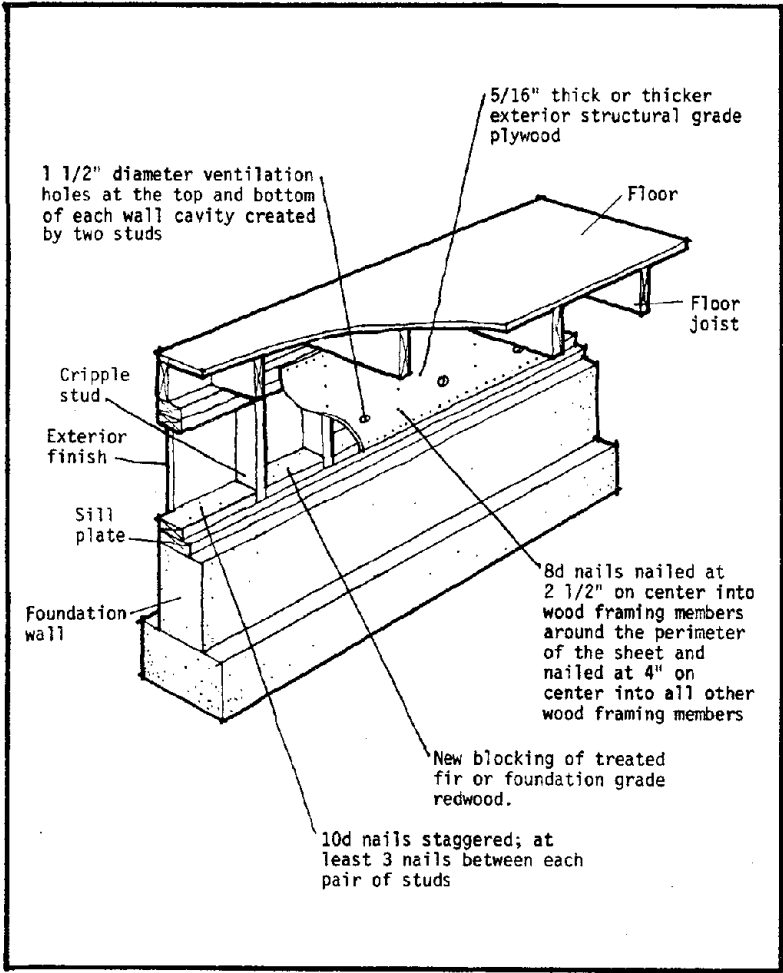


Figure 13 Cripple Wall Blocking

When cripple studs are narrower than the sill plate, nail blocking (pieces of wood) on top of the sill plate between studs to provide a flush surface to support the plywood sheets. An alternative to nailing blocking between studs, as above, is to nail wood strips on the faces of the studs; this makes the faces of the studs flush with the face of the mud sill.

of damage, bracing is recommended, particularly where such bracing might direct a chimney's fall away from the house, an automobile, or frequently used outdoor area.

Chimneys attached to exterior walls can be securely fastened to the house with tie wires or with bracing placed at frequent intervals along the chimney height. Made with heavy sheet metal or light steel, these connections are usually inexpensive (purchased from a specialty hardware store, construction supplier or custom fabricator) require little expertise to install and may detract little from the appearance of the house.

Another alternative is to replace that part of the chimney which extends above the roof with a metal flue. The height of the flue will vary with local building codes. This approach is more expensive, usually requires outside help, and will alter the appearance of your house (Figure 16).

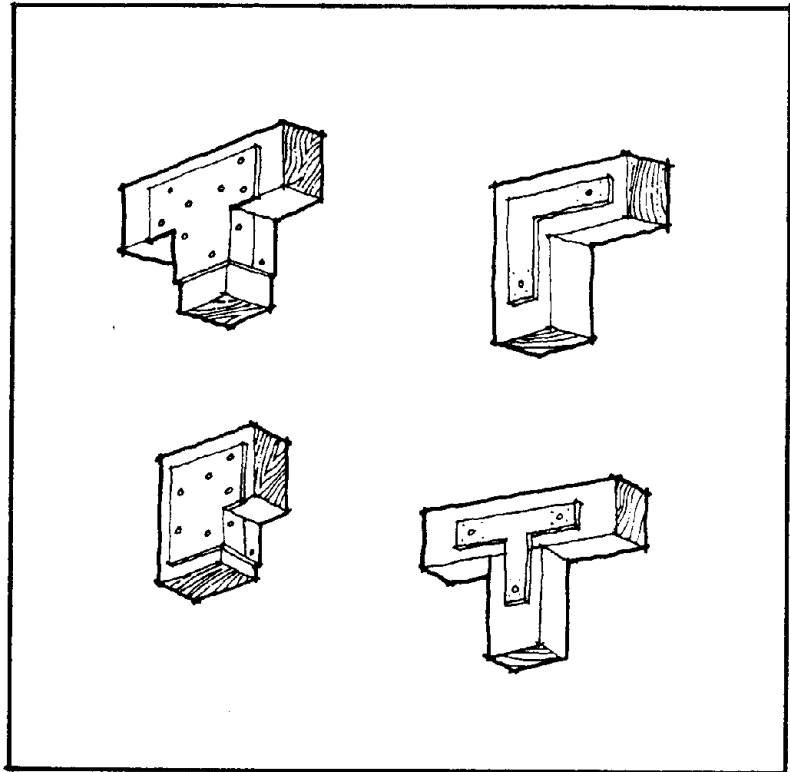


Figure 14 Post and Beam Connections

Attach the tops of posts to beams with brackets, bracing, t-straps, or other appropriate fasteners. Many types are available for the variety of actual conditions encountered in existing homes.

Loose bricks or cracks along a chimney surface should be fixed for fire safety.

Electrical, Mechanical  
and Plumbing Systems

Electrical wires severed during an earthquake can cause electric shock or fires. Power sources may be cut off, preventing the use of communication lines, electric lights and appliances. Overturned electric heaters, irons, ranges, ovens, and toasters can present fire hazards.

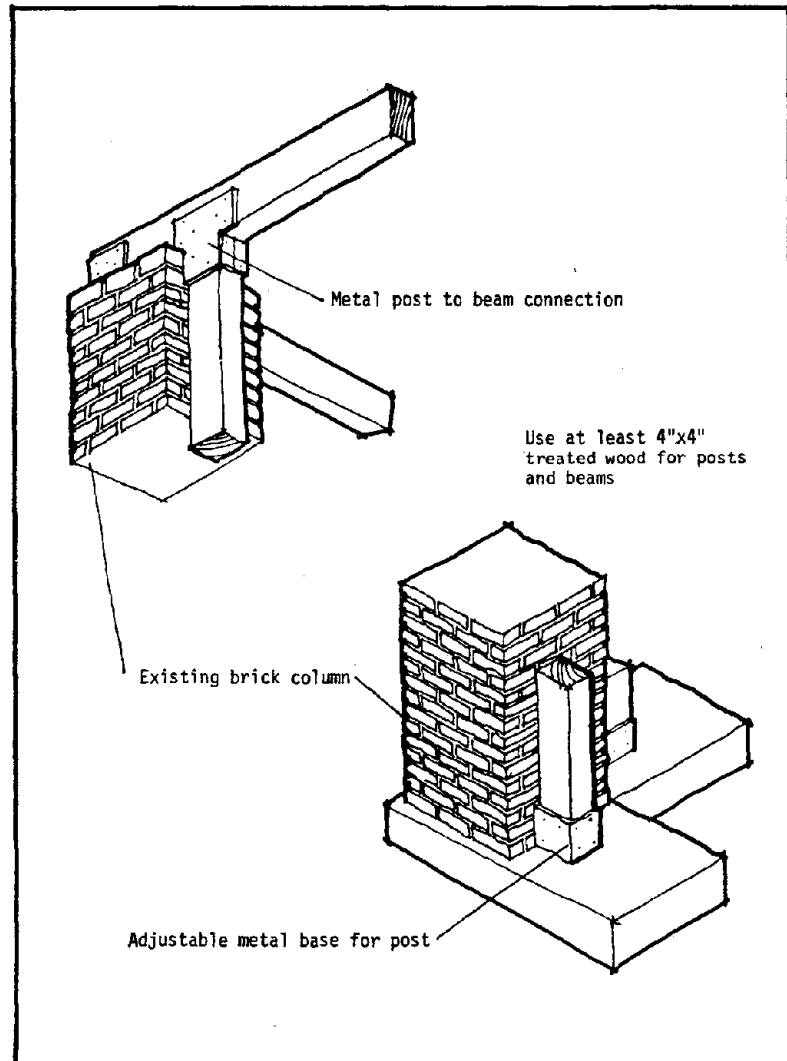


Figure 15 Porch Columns and Beams

When porches are supported by weak masonry columns, new wood posts will provide additional strength. It is critical that these new members be firmly secured at both top and bottom.

The primary hazard from gas facilities is that water heaters, furnaces or other appliances may shift position or fall over, severing connections to the house piping and allowing flammable gas to escape. Major structural damage can also cause breaks or leaks in piping.

Plumbing and sewage lines can be ruptured in a major

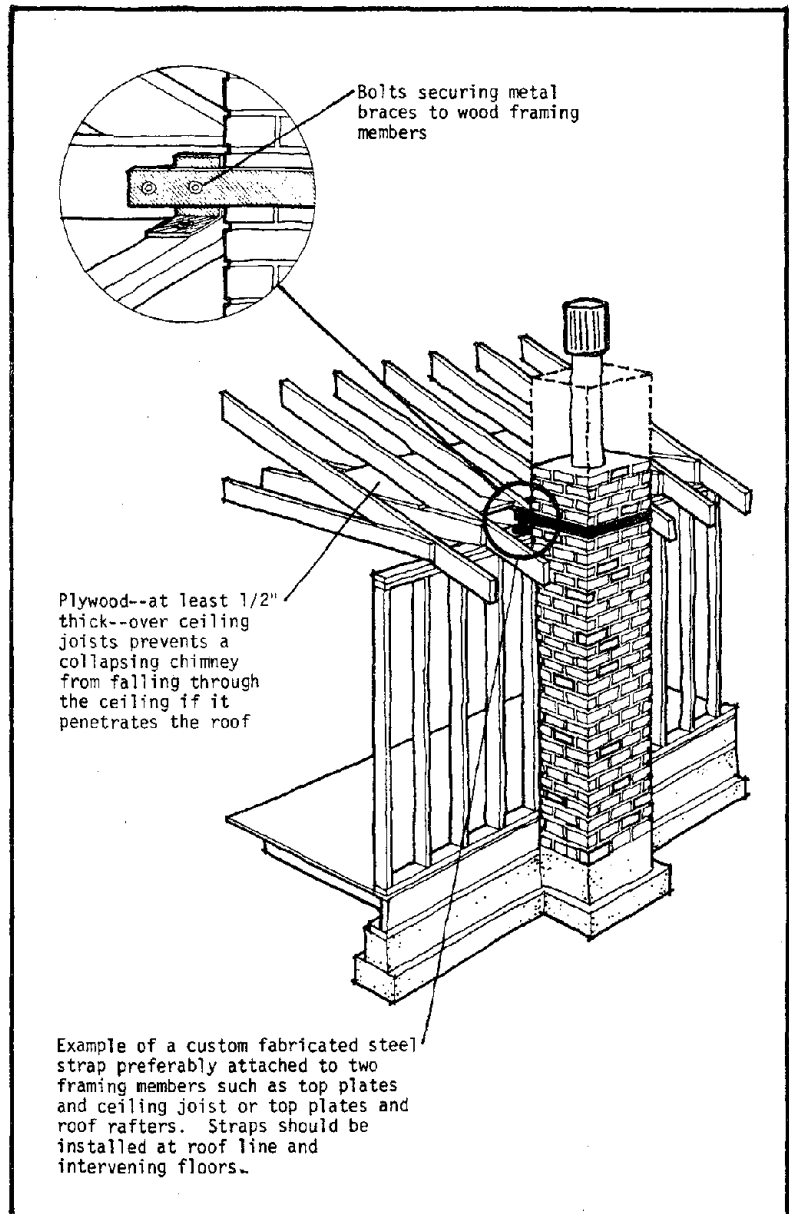


Figure 16 Chimney Bracing

A brick chimney should be braced and it may be reduced in height to prevent toppling.

earthquake. Here the main problem is the loss of water supply for extinguishing fires, drinking, cooking, washing, and first aid. Water leaks may bring about flooding and other damage. Built-in or stable plumbing fixtures like sinks and bathtubs usually are not a problem.

What You Can Do. A first step in reducing hazards from utility services is knowing how they work. Good home repair manuals can provide basic information if you are not familiar with these systems. Because we are so dependent on the services powered by electricity, alternative household resources should be available for emergency use. You should have on hand a fire extinguisher suitable for electric fires, a battery powered radio and at least one flashlight.

Familiarize yourself and family members with the location of the main gas and water valves and how to turn them off if necessary. The water valve usually is near the water meter. Both are often in the sidewalk in front of your house under a cover plate. The gas and electric shut-offs are located at the meters. The main gas shut-off valve is on the inlet pipe next to the meter. Keep a wrench or other suitable tool on hand for turning the handle so that it is crosswise to the pipe. Often there is another shut-off valve in the pipe leading to each of the gas appliances.

A word of caution: once the gas is shut off, do not turn it on without relighting pilot lights on appliances. You can contact your utility company for assistance.

### Excessive Weight

The additional pressure of heavy masses, like tile roofs or waterbeds, can subject the supporting structural members of your house to greater stress and will cause more damage if structural limits are exceeded.

What You Can Do. Inspect your roof for any loose tiles or slates that need to be securely nailed down. When it is time to get new roofing, remove rather than cover the old roofing to avoid adding unnecessary weight to your house's structure. New solar collection devices placed on the roof can also be very heavy. You might consider alternate locations or different devices to avoid adding excess mass. Any heavy roof load, like air conditioners or collectors, should be firmly attached to the house frame.

The distribution of initial earthquake forces may be altered by avoiding any concentration of massive objects inside your house. Is there a heavy accumulation of materials stored in the attic (i.e., several boxes of books) that could be removed altogether or moved to a basement level? Do you have heavy planters or a hot tub supported by a wood framed deck? Have you accumulated a heavy supply of scrap lumber in the rafters of the garage above the workshop that could be removed or stored on the floor? Multiple file cabinets, several large fish tanks, large collections of records or books, waterbeds, etc., are best located in areas with concrete floor slabs supported directly on soil. If this is not possible, at least try to avoid concentrating heavy objects in one place.

### Furniture, Possessions, and Heavy Appliances

Household furnishings are subject to the same erratic movements as is your house during an earthquake. Their movement can be merely a nuisance. Sometimes, it can be a significant source of injury or property damage. Refrigerators, freezers, stoves, ovens, washers, dryers, furnaces, and other heavy appliances may slide or fall over. Water heaters, which have a high center of gravity and a narrow base, are readily upset; they can break gas and water lines or shatter their glass lining when overturned. Refrigerators or other appliances on rollers can bang against walls, counters, and other objects. If cabinet door catches are weak, cupboards may easily spill out their contents.

Tall appliances and furniture are much more likely to topple than short ones. But both can slide in any direction unless they are securely attached to the house frame or sufficient friction exists between them and the floor. Falling books and bookcases are a common problem in earthquakes. A major cause of breakage is objects sliding off shelves and falling out of cabinets, especially in kitchens. In addition chandeliers and other light fixtures fall during an earthquake if they are not adequately secured.

What You Can Do. Think about how furniture may move in an earthquake and consider measures to minimize risk. You may choose lamps, hatracks, plant stands, and the like which have broad, stable bases and are less likely to overturn. Tall bookcases can be bolted or otherwise attached to wall studs. Large books and heavy objects should be placed on lower cabinet shelves. Stereo speakers and similar objects can be secured to



walls by wires and eye bolts or placed at lower levels where they have less distance to fall. Thick carpets may cushion falling objects and hinder rolling. Valuables can be placed in drawers of low profile chests rather than on high shelves of cabinets which may overturn.

Make sure that the movement of hanging plants, chandeliers, and other suspended items will not result in damage. Pictures, bulletin boards or mirrors that "jump" off their hooks can be securely attached to walls by wires threaded through closed eye bolts. Chandeliers and other light fixtures can be secured with an additional safety wire or strap.

Consider the placement of heavy appliances and the possible direction of their fall. You can secure heavy furnishing with many different fasteners, including bolted steel angles or bolt-and-chain anchorages. Flexible piping connections will allow some give-and-take during ground shaking. Water heaters should be bolted to the floor and attached by metal straps to the studs of a solid wall to minimize risk of collapse (Figure 17). Rollers on refrigerators may be removed or locked. Weak door catches may be replaced or strengthened. Breakage of personal objects may be prevented by installing mechanical latches on cabinet doors and drawers, especially file cabinets. A lip on the edge of shelves helps to prevent objects from sliding off.

#### Nearby Structures

Nearby structures may inflict damage through partial or complete structural collapse. Adjacent chimneys, water tanks, power lines, even nearby industries, chemical plants or power plants can pose hazards during an earthquake.

What You Can Do. Homeowners must consider their proximity to potentially hazardous structures as well as the likelihood of their failure. The Seismic Safety Element of local community plans should include information on fire and flood hazards and disaster preparedness plans for a variety of emergency situations. Evaluation of risk may require investigation as to what disaster preparations actually exist for your community.

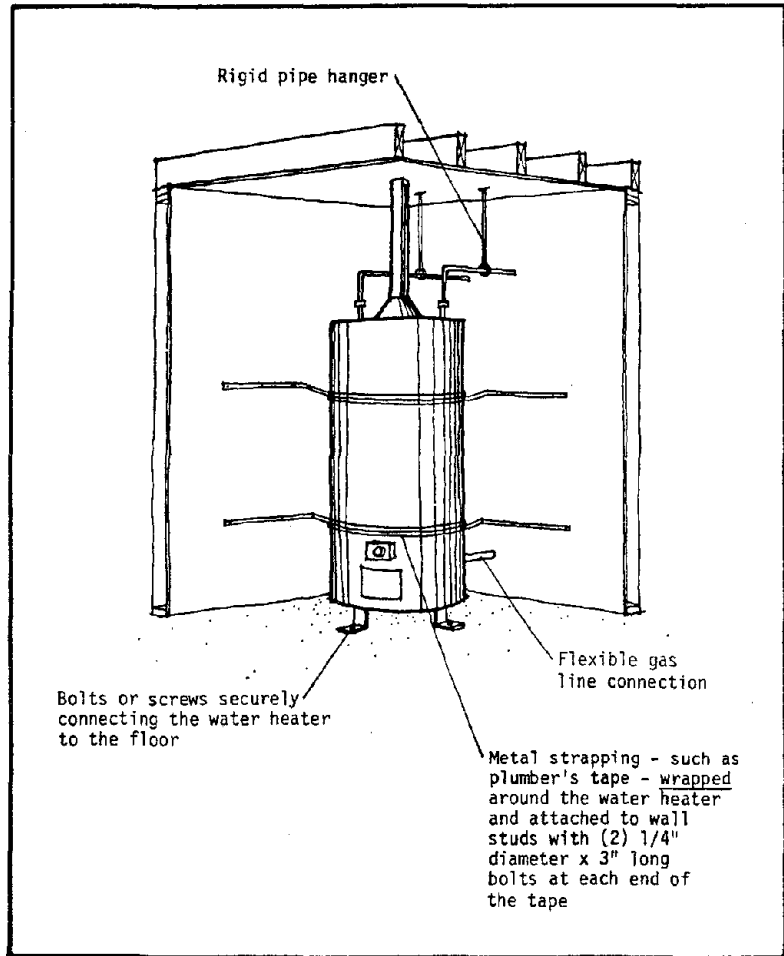


Figure 17 Water Heater Bracing

Gas or electric water heaters should be secured to the floor by bolting them down and strapping them in place with metal plumber's tape. Tape should criss-cross in front of water heater and be securely fastened to the walls with lag bolts.

FOOTNOTES

<sup>1</sup> Sometimes plywood bracing cannot be nailed at the corners of cripple walls. Instead, nail 5/16" thick or thicker exterior structural grade plywood at the midpoint of each cripple wall. These sheets should be at least twice as long as their height and sized according to the rules in Figure 12. The plywood should be nailed every 2-1/2" around the perimeter and every 4" into wood framing members behind the interior of the sheet with 8d nails. Wood blocking (see Figure 13) may have to be added to existing framing members so that the sheet can be correctly nailed. Holes may have to be cut in the plywood to help ventilate the crawl space. There should be at least 1-1/2 square feet of air vents to the exterior of the house for each 25 linear feet of foundation wall. Holes must be cut in the plywood to ventilate the wall cavities created by the sheet and each pair of studs.

<sup>2</sup>Sometimes drilling vertically down into the foundation wall and placing an expansion bolt is not possible from inside the house and it is undesirable to work on the foundation from the exterior of the house. Instead of expansion bolts, 8" X 8" X 1/8" thick metal plates can be bolted to the foundation wall and the mud sill from the interior of the house. An additional piece of wood blocking may have to be added next to the interior face of the mud sill. This provides a solid support for the metal plate. The interior face of the blocking should be flush with the interior face of the foundation wall. The metal plates are then bolted through this blocking into the existing mud sill. Drill holes into the mud sill from the interior of the house for the insertion of 1/2" diameter lag bolts. These bolts should penetrate the sill to a depth between 1/2 and 2/3 of the width of the sill. Drill holes into the concrete foundation wall from the interior of the house for the insertion of 1/2" diameter expansion bolts. These bolts should penetrate the wall to a depth between 1/2 and 2/3 of the width of the wall; use an expansion bolt with an appropriate length. Space the plates according to the rules described in Figure 10.

# Chapter 5 Earthquake Safety Checklist

Preventative improvements to your house and calm behavior during and after an earthquake are the best ways to avoid unnecessary damage and injury.

Experience indicates that most personal injuries during earthquakes are caused by flying glass and debris as people rush out of houses or public buildings. It is important to hold occasional home, office and neighborhood discussions and drills to provide you and your family with the knowledge to avoid injury and panic.

## BEFORE AN EARTHQUAKE

### Survey Your Home with an Eye to Seismic Danger (See Chapter 4)

- Check the location of your home and neighborhood in relation to earthquake hazard zones. This information should be provided in the Seismic Safety Element of your city's General Plan.
- Check to see if your house frame needs to be bolted to the foundation.
- Check to see if posts (beams) need to be securely anchored to posts (piers).
- Check to see if your house has cripple walls under the first floor that need to be braced.
- Check your roof to see if such heavy materials as tile or slate require strong bracing.

### Make Sure Your Personal Property is as Stable as Possible (See Chapter 5).

#### Check on Earthquake Insurance for Homeowners.

- Earthquake insurance is available from many companies as a rider on your homeowner's insurance. Most earthquake insurance policies carry a five percent deductible which means you must pay for the first five percent of the damage; the insurance company pays for the rest.
- Check into the exact terms offered before you buy. You are unlikely to get 100 percent replacement value. But if your house is on unstable soil, near an active fault zone, or structurally weak, earthquake insurance can be a good investment.

#### Be Prepared for Emergency Action.

- Locate your nearest casualty care center for earthquake emergencies. Your City Hall should have information.
- Hold occasional home earthquake drills to provide your family with the knowledge to avoid injury and panic. Conduct calm family discussions about earthquakes and other possible disasters.
- Teach responsible members of your family how to turn off electricity at the main switch, and gas and water at the main valves. Check with your local utilities office for instructions.
- Provide for responsible members of your family to receive basic first aid instruction. Call your local Red Cross, community college or director of emergency services for information about classes. Because medical facilities may be overloaded, the ability of individual neighborhood groups to perform emergency first aid could provide faster assistance and relieve other medical staff for more serious cases. If your neighbors include one or more medical practitioners, it may be helpful to collaborate under their supervision in neighborhood drills to reduce injury and panic during an earthquake.

#### Set Aside Flashlights and a Transistor Radio with Extra Batteries in Case Telephone and Electrical Service are Interrupted.

- One flashlight for each bedroom is recommended, since injuries can occur when people stumble through their houses once shaking has stopped.
- Since telephones are often down or needed for emergency work, a portable (battery-powered) radio may be your best and only source of information. Be cautious about accepting and spreading rumors; earliest reports may exaggerate the magnitude of the disaster. Remember to stock and rotate extra batteries. A car radio may also be available to you.

#### Keep Adequate Supplies on Hand.

- Store water in airtight containers and rotate about every six months. Figure about two quarts per person per day.

Canned fruit juices, soft drinks, and other canned or bottled liquids can substitute for water.

- Never store prescription medicines unless you first consult your physician to find out how often the medication should be rotated, if stored at all. Diabetics, heart patients and others with serious or chronic conditions should discuss emergency supplies with their doctors.
- Keep a first aid kit on hand. Standard kits start at about \$6 and can be augmented with other materials useful in treating injuries.
- A tool kit, including Swiss Army type knife, hammer, screwdriver, pen and paper, may prove useful.
- You may store canned goods (rotating them with your regular household stock every six months) in a metal locker placed somewhere that is likely to be accessible if your house is badly damaged; i.e., an outside shed or well braced interior closet. Be careful about seals on such items as baby foods. Any items stored in glass containers can be placed in the relative safety of a foot locker and might be padded against breakage with rolls of toilet paper, paper napkins or paper towels.
- Purchase an ABC combination fire extinguisher that is good for chemical and electrical as well as wood fires. It can put out small electrical fires, gas fires from a broken line to a stove's pilot light, and other small blazes. Quick action can prevent tremendous dollar losses, particularly if you live in a neighborhood of closely spaced wood frame dwellings.
- A bicycle, if accessible, may be your best source of transportation for the first hours.
- Sleeping bags and tents will be useful if your house becomes unsafe.

## DURING AN EARTHQUAKE

### How an Earthquake Feels

- The first indication of an earthquake will often be a sharp, dull thud and a distinctive rumbling sound signaling the arrival of compression waves. These will be followed by shear and surface waves which cause the ground to "roll" in a manner similar to sea waves.
- If the earthquake is of large magnitude, the "rolling" ground will cause some people to experience nausea and other

- effects similar to seasickness. Walking will be difficult; you may be thrown to the ground. Since earthquake events are usually not constant, there should be a few seconds between tremors during which you could move to a safer location.

#### Most Important of All: Stay Calm

- Earthquake experiences have indicated that most personal injuries are caused by flying glass from broken windows and falling wall facings and roof parapets as people rush into streets.
- Look around you and move to a safer location during the first few seconds.

#### If Inside:

- Get under a table. Do not rush outside immediately in panic. Watch for falling plaster, light fixtures, high book and china shelves or furniture which may slide and topple. Stay away from windows, mirrors and chimneys. If you live in a multifamily building, do not panic and dash for exits indiscriminately, since stairways may be damaged or jammed with people, and power elevators may fail.

#### If Outside:

- If possible, move to an open area away from hazards. Try to avoid tall buildings, walls, power poles, and large mature trees.

### AFTER THE EARTHQUAKE

#### Injuries

- Check for injury of the people around you. Do not attempt to move seriously injured persons unless they are in immediate danger of further injury. Wear shoes in all areas.

### UTILITIES

- Check for fire hazards or gas leaks. Do not use matches or open flames and do not operate electrical switches including your phone until you are certain no gas leak exists.

- If you smell gas escaping inside a building or see a ruptured pipeline, immediately ventilate the building and evacuate it. Shut off the gas at the meter and do not reenter the building. Notify the gas company or the fire department.
- If gas is escaping from the ground, a gas meter, an excavation, an open pipe, a manhole, a sewer, or a vault, immediately evacuate the affected area and barricade it. Extinguish all open flames, prohibit smoking, and make certain that electrical switches or other possible ignition sources are not operated.
- If gas is burning inside a building, shut off the gas at the meter or at the curb valve. If the gas supply cannot be safely shut off, try to keep surrounding combustibles wet until a gas company emergency crew can control the flow of gas.
- If gas is burning outside, make no attempt to extinguish the fire. Burning gas will not explode. Evacuate the danger area and barricade it. Do not operate the gas valves in the street. Do not use water on burning gas at its point of escape, it is better to keep burning gas ignited. However, combustible material near the fire should be wet down.
- Do not touch downed power lines. If you can, barricade them from other people's contact. Notify the electric company or fire department.
- To avoid contamination and infections, do not use plumbing systems if you suspect or detect any leakages or broken pipes.

#### Stay Informed and Prepared

- Be prepared for additional earthquake shocks. Although most of these shocks are of smaller magnitude, you should anticipate the possibility of a second earthquake as serious as the first.
- Respond to requests for help from your neighborhood, police, fire fighting, civil defense, and relief organizations but do not go into damaged areas unless your help has been requested.
- Tune into local radio stations for information and damage reports.
- Do not use your telephone except for genuine emergency calls since this may cause overloading and failure of the system.



# Appendix A

## Glossary

**ALLUVIUM:** Material commonly composed of sand and gravels which is transported by a river and deposited along the riverbanks.

**ALQUIST/PRIOLO SPECIAL STUDIES ZONE:** An area of approximately one quarter mile wide along potentially hazardous faults. These special studies zones were established by California legislation in December, 1972, to address the need for public safety programs in areas prone to hazardous earthquakes.

**ANCHOR BOLT:** A J-shaped bolt used to secure a wood sill plate to a foundation wall.

**BEARING MEMBER:** A structural member--post, wall, etc.--that supports any vertical load in addition to its own weight.

**BEDROCK:** A solid or consolidated portion of the earth's structure.

**BLOCKING:** Small wood members that are inserted between studs or joists to provide a flush surface for nailing of sheathing, plywood, gypsum board, etc.

**BRACING:** A piece of plywood or an inclined piece of framing lumber or metal tape which is applied to the walls of a building to stiffen the structure.

**CRAWL SPACE:** A shallow space below the living quarters of a basementless house allowing for inspection of the substructure or utility lines.

**CRIPPLE WALLS:** The short vertical walls connecting the foundation wall with the first floor joists.

**ELASTIC DEFORMATION:** The range of tolerance of a material to be deformed by a displacing force and return to its original form after the force is removed.

**ELASTIC ENERGY:** The energy stored during elastic deformation.

**ELASTIC LIMIT:** The upper limits of an elastic deformation above which a material is permanently deformed.

**EPICENTER:** The point on the earth's surface vertically above the focus or source of an earthquake.

EXPANSION BOLT: A bolt with a special mechanism at its base which expands for a secure fit as the bolt nut is tightened.

FAULT; FAULT ZONE: A fracture or zone of fractures in the earth's surface along which adjacent rocks have been displaced relative to each other.

FAULT CREEP: Slow movement along a fault, which does not produce an earthquake.

FAULTING: The movement which produces relative displacement of adjacent rock along a fracture in the earth's structure.

FOCAL DEPTH: The distance between the focus and the epicenter of an earthquake.

FOCUS: The source of an earthquake; the point below the earth's surface at which rupture commences.

FREQUENCY: The number of complete vibrations per unit of time; the unit of frequency is equal to one cycle per second.

GRADE: The ground level around a building.

GROUND INSTABILITY: The failure of the ground to hold together which can result in landsliding, liquefaction or subsidence.

GROUND SHAKING: The vibration of the ground surface produced by seismic waves traveling through it.

INERTIA: The property of matter by which it remains at rest or in uniform motion unless acted upon by some external force.

INERTIAL FORCE: A force opposite in direction to an accelerating force acting upon a building. The inertial force is equal to the product of the accelerating force and the mass of the building.

'L' WAVE: SEE SEISMIC WAVE

LANDSLIDE: A general term for the relatively rapid mass movement of rock or soil under the influence of gravity. Generally, a landslide involves movements along a lubricated plane often found at the interface of permeable and impermeable rock types.

LIQUEFACTION: A process by which soft, water bearing sediments may liquefy (lose their solidity) during moderate to intense ground shaking.

OSCILLATION: The action or fact of moving backward and forward like a pendulum.

'P' WAVE: SEE SEISMIC WAVE

PERIODICITY: The time interval between successive curves of a transverse or shear seismic wave.

PLATE TECTONICS: The theory of plate movements and interaction; an attempt to explain earthquakes, volcanoes, and creation of mountains as consequences of horizontal motions of large plates of the earth's surface.

'S' WAVE: SEE SEISMIC WAVE

SEICHE: Oscillations of water in an enclosed or semi-enclosed basin, including bay, lake, swimming pool, or reservoir.

SEISMIC SAFETY ELEMENT: A distinct section of a city or county general plan which describes local seismic hazards and recommends policies for public safety; mandated by the California legislature in 1971.

SEISMIC WAVE: An elastic wave generated by a natural earthquake force or by a man-made explosion. There are three main types of waves. 'P' waves are the primary seismic waves which travel away from the earthquake focus and result in compression and dilation of the material through which they pass. 'S' waves are secondary seismic waves, slower than 'P' waves, consisting of elastic vibrations transverse to the direction of travel; these waves do not propagate in liquid. 'L' waves are surface waves, slower than 'S' waves. There are two types of 'L' waves: Love waves which have horizontal shear motion transverse to direction of travel, and Rayleigh waves which have vertical motion in the direction of travel.

SHEAR; SHEARING STRESS: The action or force causing two contacting parts to slide upon each other and move apart in opposite directions or displace.

**SHEAR WALL:** A wall which in its own plane carries structural bracing elements to absorb shear deformation from wind, blast or earthquake forces.

**SHEATHING:** A structural covering, usually wood boards or plywood, placed over studs or rafters; properly placed and nailed sheathing can be used to absorb shear stress.

**TECTONICS:** Large scale deformations of the outer part of the earth's structure.

**TRANSVERSE WALL:** Any wall, exterior or interior, that runs perpendicular to the longest direction of the building.

**TSUNAMI:** A long ocean wave usually caused by sea floor movements during an earthquake.

**VELOCITY:** Total distance passed divided by total time taken.

**veneer:** A layer of brick, stone, wood, etc., used as an outer finish or decoration on a building.

**WAVE LENGTH:** The distance between two successive crests or troughs of a wave.

# Appendix B

## Inspection Checklist

### CHECK MAPS AND DOCUMENTS

- |  |  |
|--|--|
| <input type="checkbox"/> (a) Location    | <input type="checkbox"/> (f) Liquefaction                    |
| <input type="checkbox"/> (b) Geology     | <input type="checkbox"/> (g) Flooding                        |
| <input type="checkbox"/> (c) Fault Trace | <input type="checkbox"/> (h) Other                           |
| <input type="checkbox"/> (d) Landslide   | <input type="checkbox"/> (i) Seiche                          |
| <input type="checkbox"/> (e) Tsunami     | <input type="checkbox"/> (j) Location of dams and reservoirs |

### SURVEY SITE

- (a) Neighboring and on-site features, potentially hazardous structures, utility lines.
- (b) Slope
- (c) Mature trees, other vegetation
- (d) Comments \_\_\_\_\_  
\_\_\_\_\_

### INSPECT STRUCTURAL

#### General

- (a) Construction type \_\_\_\_\_
- (b) Condition \_\_\_\_\_
- (c) Additions \_\_\_\_\_
- (d) Levels (Note split-levels, cripple walls, stepped foundations and location of connected garage) \_\_\_\_\_
- (e) Windows \_\_\_\_\_
- (f) Number and location of chimneys \_\_\_\_\_

#### Foundations

- (a) Construction (reinforcement?) \_\_\_\_\_
- (b) Condition \_\_\_\_\_
- (c) Cracks \_\_\_\_\_
- (d) Sill Connectors: type \_\_\_\_\_ spacing \_\_\_\_\_
- (e) Post Anchorage \_\_\_\_\_
- (f) Wood/Ground Clearance \_\_\_\_\_

#### Walls

- (a) Construction and Sheathing \_\_\_\_\_
- (b) Nailing \_\_\_\_\_
- (c) Bracing \_\_\_\_\_
- (d) Openings \_\_\_\_\_
- (e) Comments \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Floors

\_\_\_\_\_ (a) Construction \_\_\_\_\_  
\_\_\_\_\_ (b) Condition \_\_\_\_\_

Interior

\_\_\_\_\_ (a) Wall Construction \_\_\_\_\_  
\_\_\_\_\_ (b) Ceiling Construction \_\_\_\_\_  
\_\_\_\_\_ (c) Condition \_\_\_\_\_

Roof

\_\_\_\_\_ (a) Construction \_\_\_\_\_  
\_\_\_\_\_ (b) Condition \_\_\_\_\_

NONSTRUCTURAL

Parapets, Cornices, Ornamentation \_\_\_\_\_  
\_\_\_\_\_

Chimneys

\_\_\_\_\_ (a) Construction, Reinforcement, if any \_\_\_\_\_  
\_\_\_\_\_ (b) Height above roofline \_\_\_\_\_  
\_\_\_\_\_ (c) Cracks \_\_\_\_\_  
\_\_\_\_\_ (d) Bracing \_\_\_\_\_

Water Heaters \_\_\_\_\_  
\_\_\_\_\_

Furnishings \_\_\_\_\_  
\_\_\_\_\_

Staircases

\_\_\_\_\_ (a) Locations \_\_\_\_\_  
\_\_\_\_\_ (b) Condition \_\_\_\_\_