1 INTRODUCTION

by Timothy P. McCormick, P.E.

COURSE OVERVIEW

This course describes retrofit methods for light wood frame buildings that have structural weaknesses for resisting earthquakes. The training focuses on understanding how these retrofit methods work and how to install them. It also shows how to avoid making typical retrofitting errors. This course is not intended to teach you how to design a retrofit, but rather how to implement one. Much of this information is also useful for other types of work, such as the construction of new houses or apartment buildings.

This training will benefit:

- Contractors who wish to learn how to do seismic retrofit work or wish to improve their current seismic retrofitting skills.
- Building Inspectors who are responsible for checking seismic retrofit work.
- Plan Reviewers who approve designs for the seismic retrofit of wood structures.
- Property Owners who want to retrofit their wood frame buildings.
- Realtors who need to understand the earthquake weaknesses of existing dwellings and ways to retrofit them.
- Lenders and Insurers who need to understand the seismic weakness of existing buildings and the retrofit methods that reduce their risks.
- Construction Attorneys who need to understand proper installation and retrofit techniques.

Although this course was developed in California, there are over 30 of the nation s states that are exposed to damage by earthquakes. Many of these states have wood frame structures similar to those in California. As a result, the retrofit techniques discussed in this course have widespread importance.

TRAINING OBJECTIVES

By the end of this training, you should be able to:

- Generally explain how shaking damages wood frame structures during an earthquake.
- Identify the key components of a retrofit (shear walls, holdowns, foundation, anchor bolts, sill plates & other connections).
- Describe how the components connect together to form a proper seismic retrofit.
- Compare and contrast the different material types available for each component of a retrofit.
- Recall the installation steps for each component.
- Recognize the typical errors made during installation and how to avoid making them.
- Understand basic methods for reducing earthquake hazards of chimneys, water heaters, tanks, building appendages, gas lines, brick veneer, and other nonstructural items.
- List basic safety measures to consider when doing retrofit work.
- Recognize areas of potential liability related to construction and ways to avoid or reduce liability.
- Generally explain the building permit requirements, warranties, and liabilities related to seismic retrofit work.

THE REASONS THAT OWNERS RETROFIT

There are many reasons for retrofitting. Owners who occupy the building may retrofit to ensure the safety of their family. Landlords may wish to avoid future loss of income from a vacant and damaged building. Many insurance companies will not write earthquake or homeowner s insurance until needed retrofitting is done. Some cities and counties mandate seismic retrofits when alterations reach a specific dollar amount or enough square footage is added to the building.

Special real estate transfer rules exist in California for residential dwellings. If the structure was built prior to January 1, 1960 and it contains one to four living units of conventional light-frame construction, the transferor must disclose any of the following deficiencies they are aware of:

- The absence of anchor bolts securing the sill plate to the foundation.
- The existence of perimeter cripple walls that are not braced with plywood, blocking, or diagonal metal or wood braces.
- The existence of a first-story wall or walls that are not braced with plywood or diagonal metal or wood braces.
- The existence of a perimeter foundation composed of unreinforced masonry.
- The existence of unreinforced masonry dwelling walls.
- The existence of a habitable room or rooms above a garage.
- The existence of a water heater that is not anchored, strapped, or braced.

The transferor is also required to disclose any material information within the transferor s actual knowledge regarding any corrective measures or improvements taken to address the items listed above. See the California Government Code Section in Appendix B for full details.

MANY BUILDINGS NEED RETROFITTING

California Government Code Section 8897 says, there are approximately 1,200,000 homes in the State of California which may not be bolted or anchored to their foundations or do not have adequate cripple wall bracing. These homes were generally built prior to the 1950 s and can represent one-half of the existing housing stock. Because there will be many houses that will need retrofitting, contractors who know how to do the work correctly will be in great demand!

Question: *Why are we concerned with housing?*

Answer: Because the Northridge earthquake in January 1995 caused more than 48,000 housing units to become uninhabitable in Los Angeles and Ventura counties. Previously the Loma Prieta earthquake in October 1989 caused more than 16,000 housing units to be uninhabitable throughout the Monterey and San Francisco Bay areas. Approximately one-fourth of the total uninhabitable housing units in the Loma Prieta earthquake was from buildings with one-to-four dwellings.

RETROFIT PRESCRIPTIVE STANDARDS

When you build a new house, you have two ways to design the framing. The first method is to have an engineer or architect create the design. The second is to follow the conventional construction provisions of the Uniform Building Code (UBC). Similarly, there are two ways in which a seismic retrofit can be designed for light wood frame houses. The owner or contractor could hire an architect or an engineer to design the retrofit. There are many houses that have complications that will require an engineer or architect to design the retrofit. Another way to retrofit a house is to use a prescriptive standard.

One or two story wood frame dwellings with no more than four units are usually simple structures (Fig.1.1). Retrofitting them often includes such items as bolts in the sill plate and plywood on the cripple walls. Engineers and building officials have developed guidelines to install these and other items needed for a seismic retrofit. These guidelines are called prescriptive standards .

Even though prescriptive methods are limited to residential buildings containing one to four units, there are several good reasons to have these standards:

1. There are large numbers of one-to-four unit wood frame buildings that have structural weaknesses.

2. The seismic retrofit for many of these structures are simple to install for contractors and many homeowners.

3. Prescriptive standards permit building owners to seismically retrofit simpler buildings without having to hire an architect or engineer to prepare drawings. Although professional advice is generally desirable and frequently required, prescriptive standards may allow appropriate cost savings. This will make retrofitting more desirable.

Fig. 1.1 - Typical Simple Structure House

PRESCRIPTIVE RETROFIT STANDARDS WORK

The Northridge Earthquake taught us that wood frame homes properly retrofitted according to prescriptive standards suffered little to no earthquake damage and remained intact on their foundation. Past earthquakes, including the Northridge earthquake, also showed us that houses retrofitted incorrectly can be damaged just as much as those that were not even retrofitted.

Incorrect or incomplete retrofits can give the homeowner a false sense of security as to how well the home will resist an earthquake. Keep this in mind as we focus on CORRECT methods of installing retrofits that will be effective in reducing the damage to buildings during the next earthquake.

" Incorrect retrofit installations are as bad as having "NO RETROFIT AT ALL! "

WHEN TO HIRE PROFESSIONAL HELP

Since seismic retrofit technology is an evolving process, the participant needs to understand and follow the most current seismic retrofit standards. The authors developed this course using the best available information on the subject at the time. However, this information cannot substitute for professional advice. The services of an architect, civil, structural or geotechnical engineer is frequently required. You will learn more about this throughout the course.

Because the use of prescriptive standards for retrofit work is generally limited to one-to-four unit wood frame residential buildings, commercial and larger residential buildings require the expertise of an engineer or architect to design the seismic retrofit. This is also true for buildings constructed on steeply sloping lots. (Fig. 1.2)

Fig.1.2 - Hillside Homes Require an Architect or Engineer to Design the Retrofit

2 EARTHQUAKE BASICS

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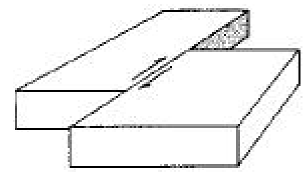
EARTHQUAKE BASICS

This section will give you a basic understanding of the nature of earthquakes and how earthquake forces affect buildings. The more you understand how buildings respond to earthquake forces, the better you will understand what parts of the building resist these forces and how to properly install these structural components.

EARTHQUAKES AND FAULTS

Earthquakes are perceptible movements of the earth's surface. The primary cause of earthquakes is the rupture of faults in the earth's crust and the associated rapid slip on these faults. Large and damaging earthquakes are caused by rupture of faults that are tens to hundreds of miles long. If the fault rupture extends to the surface, we see movement on a fault (surface rupture). But strong earthquakes can occur when the fault rupture does not extend to the surface as seen in both the 1989 Loma Prieta and the 1994 Northridge earthquakes in California.

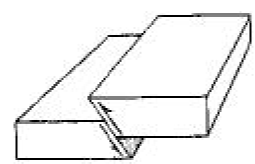
Fault rupture of the ground generates vibrations, or waves, in the rock that we feel as ground shaking. Because faults are weaknesses in the rock, earthquakes tend to occur over and over on these same faults. Most of the major faults in the United States, particularly in California, are strike-slip faults. For these types of faults, the rupture extends almost vertically into the ground and the ground on one side moves past the ground on the other side of the fault. (Fig. 2.1) California s largest fault, the San Andreas, is a strike-slip fault formed where two large chunks of the earth's crust, or plates, move past each other.



Strike-Slip Fault Diagram

Fig. 2.1

Another type of fault is the thrust fault where ground on one side of the fault moves up and over adjacent ground (Fig. 2.2). These faults are much more common in the Los Angeles area than in the Bay Area because the San Andreas Fault makes a large bend to the west there before heading northwest. This bending causes thrust faults in southern California.



Thrust Fault Diagram

Fig. 2.2

Farther north, these same two crustal plates are pushing against each other, with the Pacific Plate diving under the North American Plate along large plate-boundary thrust or subduction zone faults (Fig. 2.3). Thus, Oregon, Washington and Alaska are all subject to huge earthquakes caused by this movement, in addition to the more common strike-slip earthquakes. The 1964 Good Friday Alaska earthquake was an example of one of these plate-boundary earthquakes.

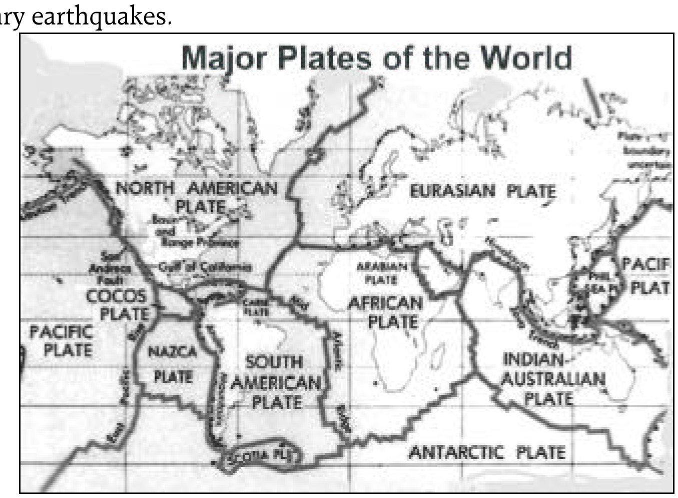
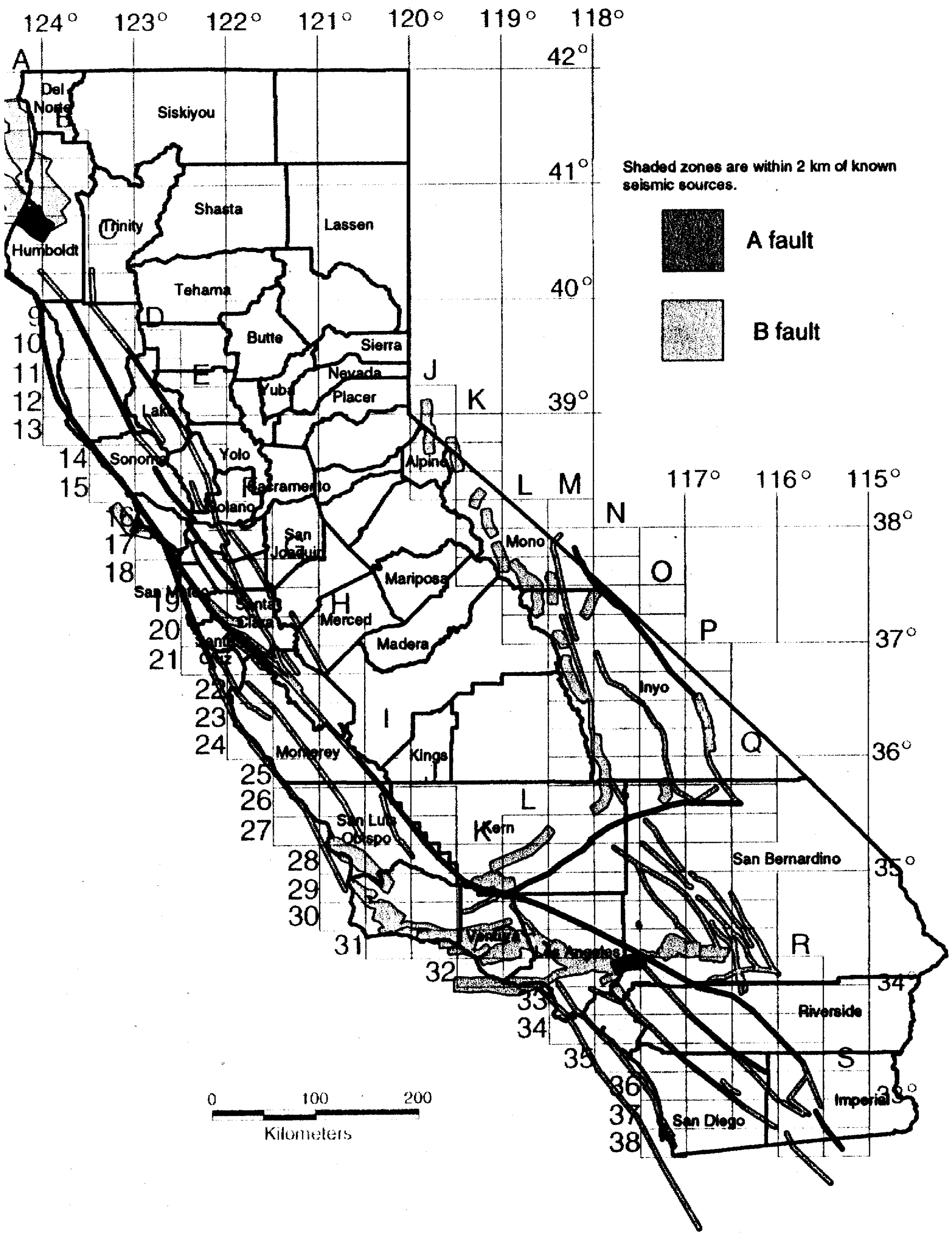


Fig. 2. 3

State of California Index Map



PROXIMITY TO FAULTS

The magnitude of an earthquake is frequently given as a number on the Richter scale. This scale measures the amplitude of ground motion. Local ground motion from the earthquake will depend on the distance from the fault source to the building and the surface geology under the building.

Earth scientists use certain terms to define seismic distances. The point at which the slippage occurs is called the focus, or hypocenter. The distance from this hypocenter to the surface of the earth is termed the focal depth. The point directly above the hypocenter is called the epicenter ("epi" being Greek for "above"). The locations of earthquakes are frequently given by their epicenter (Fig. 2.5).

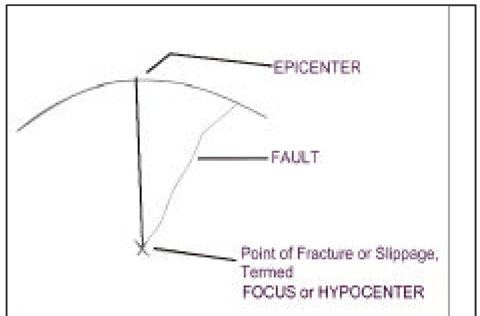


Fig.2.5 Location of Focus and Epicenter

Earthquakes release energy along the entire portion of the ruptured fault surface. Because of this, the distance between the building and the fault source is more important that the distance to the actual epicenter. The Index Map on the left shows the active fault zones in California. The 1997 Uniform Building Code uses this information to determine when earthquake forces on buildings must be increased due to fault proximity (Fig. 2.4). Calculated earthquake forces can increase up to 100 per cent for buildings near large faults.

SURFACE GEOLOGY EFFECTS

Surface geology can amplify the earthquake ground motion. The same districts in San Francisco that were strongly damaged in the great San Francisco earthquake of 1906 were also damaged in the 1989 Loma Prieta earthquake. These damage-prone districts are built on bay mud sites that can amplify ground shaking by a factor of 6 when compared to sites on rock. Sandy soils can amplify shaking by a factor of 2 (Fig.2.6).

Behind the garage shown in Fig. 2.7 is a stream that saturated the soil with water. The building moved and settled because the earthquake shaking floated the soil grains in the water and the soil was able to flow. This type of ground failure is called *liquefaction*. When special soil problems like liquefaction or landslides may occur, a geotechnical engineer should be hired for advice.


Fig. 2.7 Liquefaction Failure

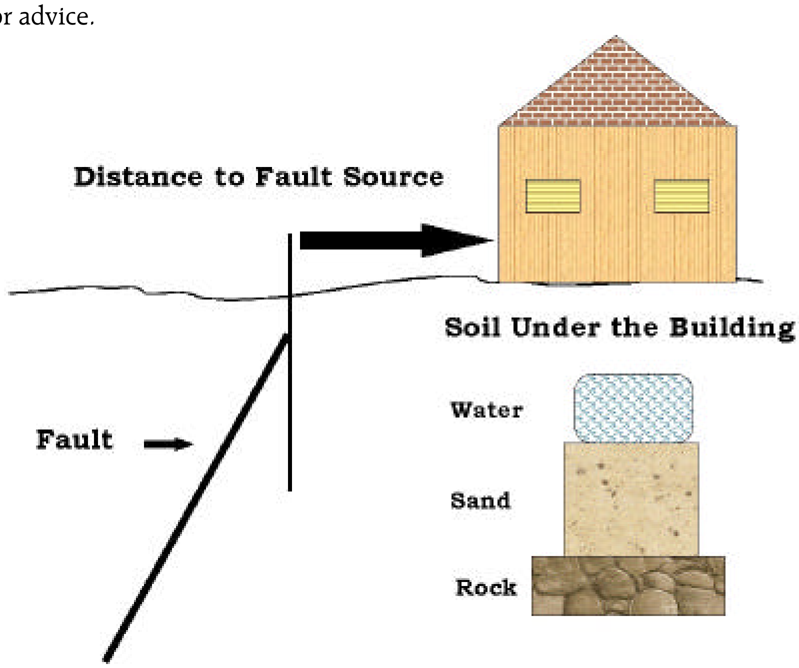


Fig. 2.6 Factors Affecting Earthquake Forces

INERTIA FORCES

Inertia is the tendency for an object at rest to remain at rest, or of an object in motion to remain in motion. Force is the energy required to move or accelerate the object. Inertia forces move or accelerate an object and they are proportional to the object's weight. Seismic forces on buildings are inertia forces.

Consider a person standing in the bed of a pickup truck. If the pickup truck accelerated rapidly, inertia would tend to keep that person's body in its original location. Similarly, if the pickup truck decelerated, the person would be thrown forward. (Fig. 2.8) The same reaction occurs in a building when the ground moves. The building moves back and forth, with the bottom of the building moving with the quake and the top tending to remain in place. Now imagine two persons in the back of a pickup truck: one weighing 100 pounds and the other 200 pounds. As the truck accelerates, the individual that weighs 200 pounds would be pushed back with twice as much inertial force as the person who weighs 100 pounds.

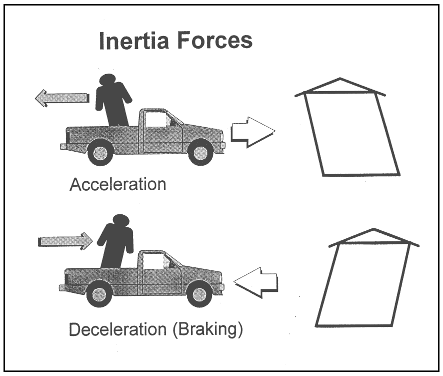


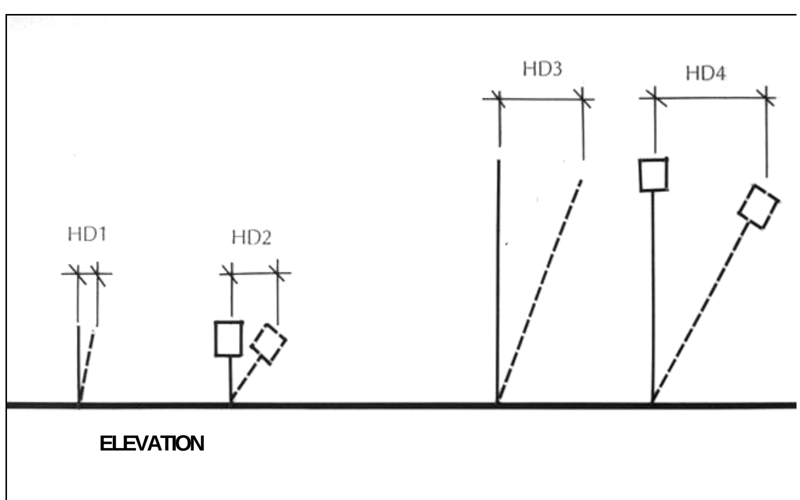
Fig. 2. 8

For another example, let s assume that there are two tract homes. They are side by side on the same street and identical except that one has an asphalt shingle roof and the other has a heavy clay tile roof. Because clay tiles weighs more than asphalt shingles, the home with the clay tile roof will experience higher inertia forces from the earthquake and, most likely, suffer more damage.

EFFECT OF HEIGHT ON BUILDING MOVEMENT

The effects of earthquake forces on buildings are related to both the weight and height of the building. The higher the building s weight is above its support base, the further the top of the building will move under the same earthquake force. Using the left side of Figure 2-9, imagine a one-story building with a height of 14 feet. Let s say the inertia force of the earthquake moved the top of the building 1 inch (HD1). If you put additional weight on that building, the top of the building will move more. Let s say it moved 1-½ inches (HD2).

Using the right side of Figure 2-9, imagine the same type of building that is two stories or 24 feet high. The top of the building may now move 2 inches. The top of the heavier building may move 3 inches. The greater the height, and/or the greater the weight of a building, the more the building will move during an earthquake.



HEIGHT & WEIGHT RELATIONSHIP

PERIOD OF VIBRATION

Earthquakes send out shock waves that travel in all directions up to the surface of the earth. These waves impart horizontal and vertical forces to earth-supported structures. Because buildings are designed to continuously support vertical loads from their own weight and use, they tend to better resist these vertical forces and move up and down safely with the ground. However, horizontal force waves cause buildings to move laterally and vibrate back and forth during an earthquake. Unless the building is properly constructed, these horizontal forces will cause damage.

The time an object takes to vibrate back and forth one complete cycle is known as its period of vibration. The period of vibration is one of the most important factors determining how a structure will respond to ground shaking. For one or two-story wood frame buildings, the period of vibration is about ½ a second. This means that these buildings will go through their complete cycle of seismic motion about two times per second. For an earthquake with strong ground shaking that lasts 15 seconds, the building will go through this cycle approximately 30 times (Fig. 2-10).

Because periods of vibration depend on weight and height, portions of building with different weights and heights will move separately unless all portions of the building are properly connected and tied together. Common examples of different portions of buildings with these problems are chimneys, porches and stories with differing heights (Fig. 2.11-2.13).

Fig. 2. 11 - Chimney Vibration Failure

Fig. 2.12- Porch Vibration Failure

Fig. 2.13- One & Two Story Differences

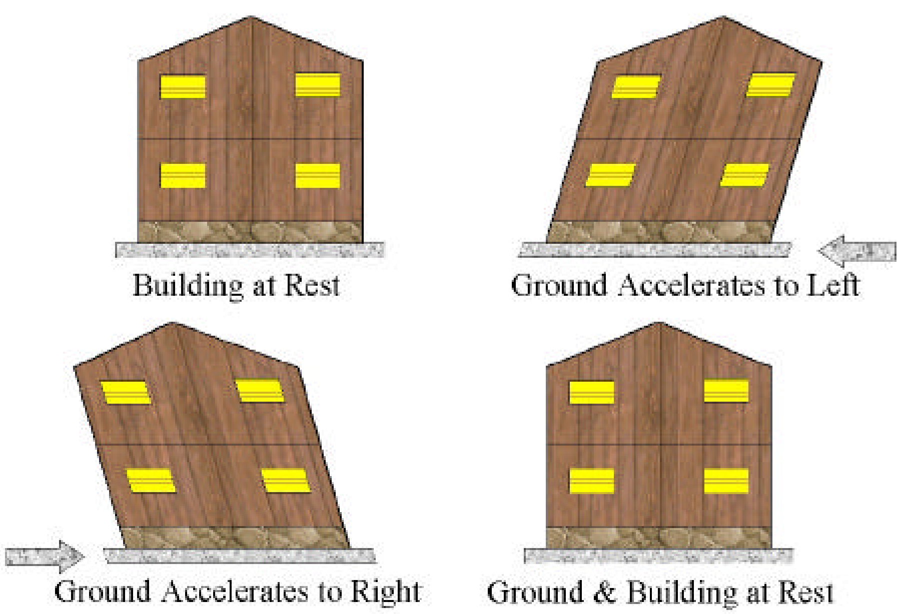


Fig. 2. 10 Cyclic Motion of Building

HORIZONTAL FORCE DISTRIBUTION

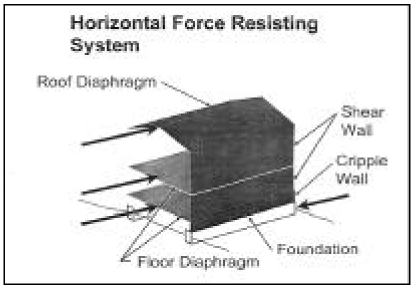


Fig. 2.14

Newton s Second Law of Motion states that force equals mass times acceleration. When the earthquake s sudden movement of the ground accelerates the mass of the building, horizontal forces are created in the building. These forces are distributed throughout the building and are concentrated where the weight is: the floors, roofs and walls.

Consider the two-story building in Figure 2.14. The arrow at the roof represents the seismic force from both the roof weight and one-half of the weight of the walls between the second floor and roofline. The arrow at the second floor represents the seismic force of both the second floor weight and one-half of the weight of the first and second story walls. The arrow at the first floor represents the force at the first floor that is similarly calculated. The arrow at the foundation level is the sum of all these forces that must be transmitted safely into the ground.

BASE SHEAR AND CRIPPLE WALLS

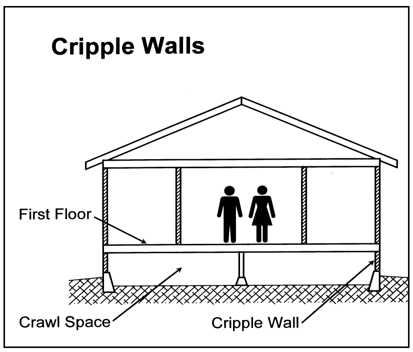


Fig. 2.15

A cripple wall is a wall that is less than full story height. The cripple wall usually occurs between the first floor and the foundation and is generally the most vulnerable part of older buildings (Fig.2.15). These cripple walls are weak because they are typically sheathed with only stucco or horizontal wood siding on the exterior side of the wall. These sheathing materials are weak wall-bracing methods for seismic loads. You will learn more about this in the section on Shear Walls .

Because seismic forces in the building accumulate all the way down to the ground, they are greatest at the base of the building. The seismic force at base of the building is called the *base shear*. Earthquakes often damage buildings at this level (Fig. 2.16). For buildings with cripple walls, this means that the weakest part of the building must resist the greatest force. This is why retrofit standards require strengthening of the cripple walls.

HORIZONTAL FORCE-RESISTING SYSTEM

Fig. 2.16 Base Shear Damage

The horizontal force-resisting system is composed of both horizontal and vertical parts. The horizontal parts are the roof and the floor structures. These parts are called *diaphragms*. The vertical elements are the walls that span between the horizontal elements. These walls are called *shear walls*. You will learn more about these in the section on *Shear Walls*.

To be effective, each part of the horizontal force-resisting system must be adequate and properly connected to the other parts in the system. For example, the roof diaphragm must be strong enough to safely resist the seismic loads. Also, the connections from the roof diaphragm to the shear walls below must be strong enough to give the force to the shear wall. Shear walls at the base of the building must be securely connected to the footing and the footing must be adequate. To have an effective horizontal force-resisting system, there must be a continuous load path. That is, there must be no weak elements between the top and bottom of the structure.

SEISMIC LOAD PATH IN THE BUILDING

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. 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 on 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 weak links in the load path chain (Fig. 2.17).

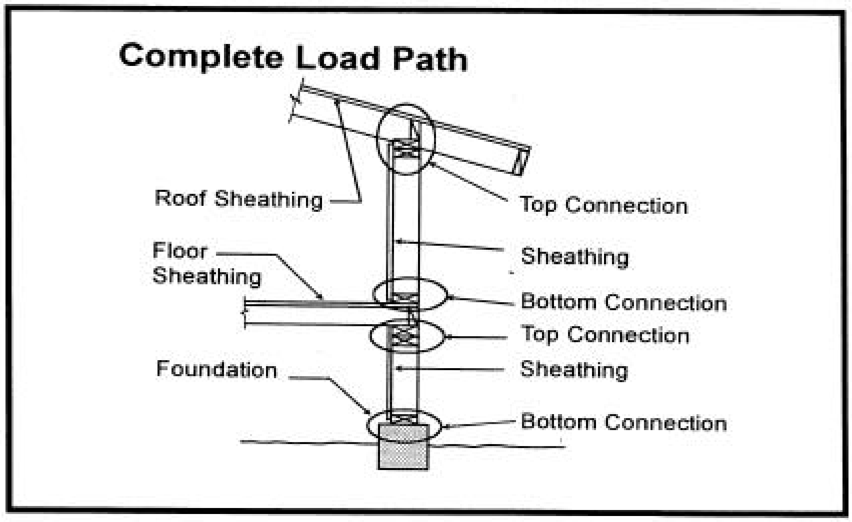


Fig. 2.17

When a part of the load path is weak or missing, damage will occur during an earthquake. If the sill plate is not connected to the foundation wall, the ground will move and leave the building behind (Fig. 2.18). A building without shear walls like the one in Figure 2.19 can collapse. When there is not enough room for an adequate shear wall (e.g. a wall with many large windows), an engineer or architect must design a special frame to resist the horizontal forces, These frames are called *moment frames.*

GRAVITY FORCE-RESISTING SYSTEM

Some of the elements of a gravity or vertical force-resisting system can and will be used to resist the horizontal loads. In the gravity force-resisting system there are live and dead loads transferred from the wood roof rafters to the walls; the live and dead load from the floor loads are transferred to the cripple walls, and then to the foundations where they are resisted by the soil below them.

Alterations to the lateral system should not compromise the ability of the gravity force-resisting system to support these loads. The purpose of the horizontal force-resisting system is to enable the gravity force-resisting system to maintain its support of the structure during earthquakes and windstorms.

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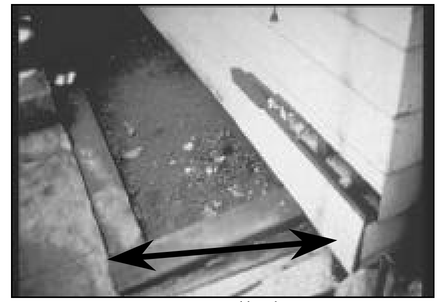

Fig. 2. 18 Missing Sill Plate Connection

Fig. 2.19 No Shear Walls At Garage

Fig. 2.20 Steel Moment Frame

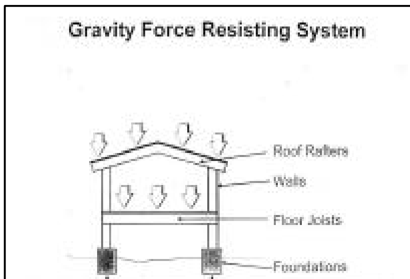

Fig. 2.21