Unit 3

Earthquake Causes and Characteristics

INTRODUCTION

In the last unit, we explored the historical importance and intent of Executive Order 12699. In later sections of this course, we will take a closer look at evaluating a community's safety. First we need some basic information about earthquakes and their effects on the built environment. The built environment includes all buildings, transportation lines and structures (e.g., bridges), communications lines, and utilities. This unit and Unit 4 will give us background on earthquake causes, characteristics, and effects. These units will provide us with the terminology and concepts we need to evaluate mitigation practices in our communities.

Unit 3 answers the following questions:

- What causes an earthquake?
- What are an earthquake's characteristics?
- How do we measure earthquakes?

WHAT CAUSES AN EARTHQUAKE?

Scientists have formulated several theories to explain the causes of earthquakes. The theory of plate tectonics seems to explain much of the earthquake activity the world experiences, but there is also intra-late activity that is well away from the plate boundaries. Intra-plate activity is less understood.

Plate Tectonics

First presented in 1967, the theory of plate tectonics postulates that the earth once was covered by a single crust, or plate, with no oceans. We could think of the earth at this time like a hard-boiled egg, with a thin hard shell extending over the entire surface of the earth. Over time, this single shell, or plate, started to split and drift into separate plates of land or ocean crusts. Now the earth's surface looks much like a spherical jigsaw puzzle; all the plates fit together. Figure 3-1 shows the largest plates as they are today.

The plates over the earth are in constant slow motion. The plates generally move in one of three ways—colliding, spreading, or sliding. Plates experience convergent plate movement when they collide or bump into one another. When they spread or move away from one another, they experience divergent plate movement. Plates also can slide by one another with lateral plate movement. Any one of these plate movements can cause an earthquake. Constant movement of the plates puts a tremendous stress on the earth's rock. Figure 3-2 illustrates these movements.

Earthquakes tend to occur at the boundaries of plates. Convergent, divergent, and lateral movement all can cause earthquake activity. Where plates diverge (move away from each other), molten rock from beneath the earth's crust rushes up to fill in the resulting rift and forms a ridge. These ridges add even more pressure on the divergent plates as they continue to push adjacent plates away from one another. The Mid-Atlantic Ridge, located in the middle of the Atlantic Ocean, is a good example of a ridge formed by the divergent movement of plates.

Convergent plates experience the movement of one plate below the edge of another. As plates collide, the edge of the heavier ocean plate is pushed down into the earth's interior by the lighter continental plate, and a trench forms between the plates. As this occurs, material from the lower plate is "recycled" by melting into the earth's interior. This whole process is called subduction. Major earthquakes, such as the 1964 Alaskan earthquake, can occur in areas where subduction has occurred. Figure 3-3 illustrates the formation of an ocean ridge caused by divergent plates and a subduction trench caused by convergent plates. Plates also can grind past each other laterally, causing the edges to lock and release. This is happening along the San Andreas fault, which runs most of the length of California.

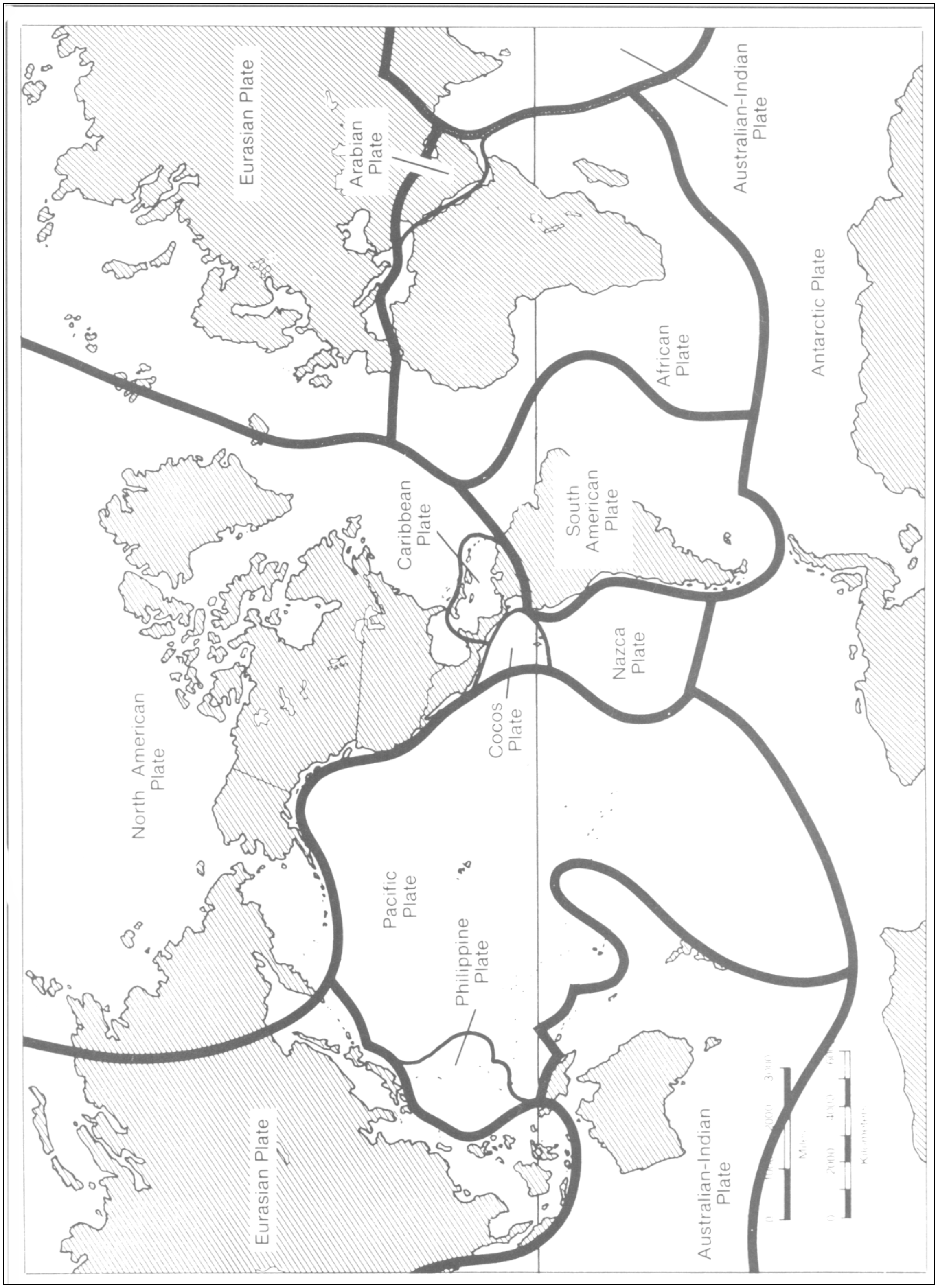


Figure 3-1 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

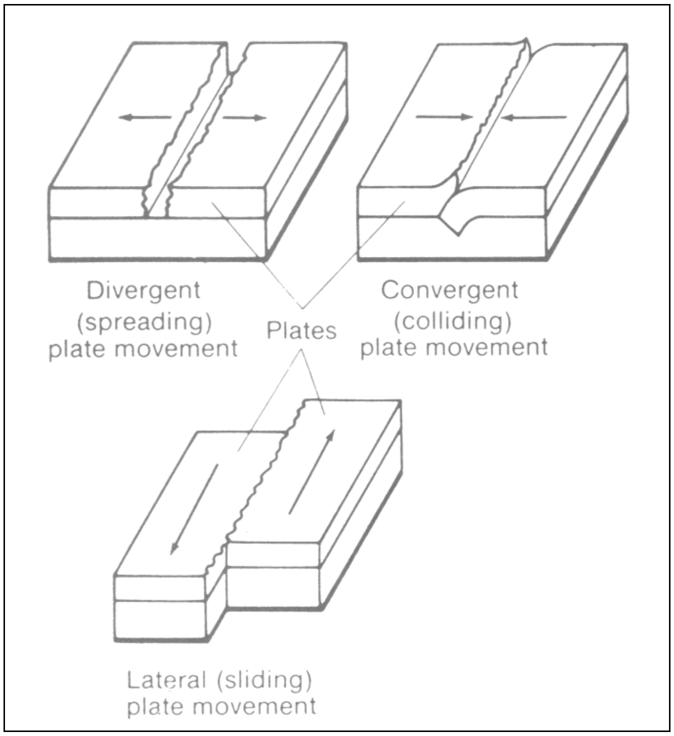


Figure 3-2 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

Maps of earthquake activity throughout the world show that earthquakes most frequently occur at the boundaries of plates. Figure 3-4 graphically displays where the major earthquake zones lie. Compare this map of world earthquake activity to the map of the earth's plates in Figure 3-1. Do you see that earthquake activity mirrors plate boundaries? The "Ring of Fire," well known for its high level of earthquake and volcano activity, lies on the Pacific Plate edge.

Intraplate Activity

Plate tectonics involves interplate, or "between-plate," activity. Although this theory explains plate boundary earthquakes, it does not explain *all* seismic activity. Many large, devastating earthquakes occur *within* continents, away from plate edges. These earthquakes are caused by intraplate activity. The 1811 and 1812 New Madrid fault earthquakes in the central United States are a good example of earthquakes caused by intraplate activity.

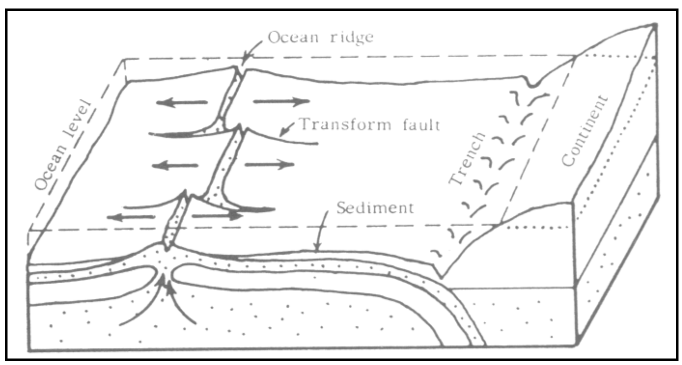


Figure 3-3 *Source: Steinbrugge, K. Earthquakes, Volcanoes, and Tsunamis: An Anatomy of Hazards, 1982.*

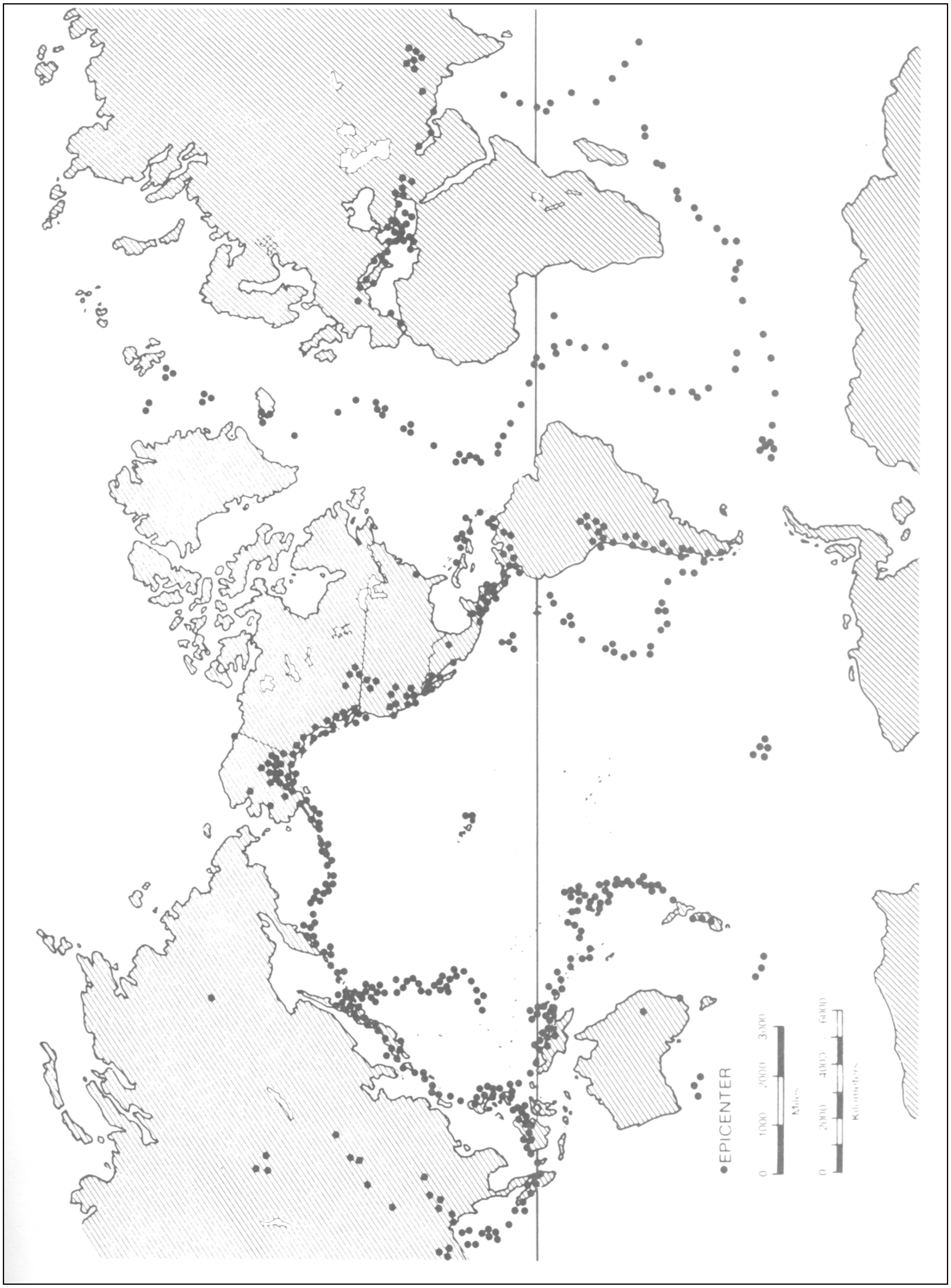


Figure 3-4 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

Earthquakes of this type probably result from more localized geological forces such as mid-plate compression (often themselves being the indirect result of plate tectonics); however, they are harder to predict.

Faults

Plate movement or other forces can cause tremendous stress on the rocks that make up the earth's outer shell. When rock is strained beyond its limit, it will fracture, and the rock mass on either side will move. This fracture is called a fault. Faults often are classified according to whether the direction of movement is predominantly horizontal or vertical. Figure 3-5 shows examples of horizontal and vertical fault movement. A fault can cut at any angle into the earth and does not always cut to the surface. A fault is accompanied by displacement of one side of the fracture with respect to the other. Scientists use certain terms to describe the direction of one fault block in relation to the other block.

Sudden Rupture

Not all faults will cause earthquakes. But, if there is a sudden rupture and movement of rock along a fault line, the vibrations we call an earthquake will result. We think of the earth's rocky surface as hard and impregnable. However, rock under extreme pressure can have elastic properties. Try simulating an earthquake with a shallow plastic mould filled with gelatin. If you gently stretch the surface by pulling on the sides of the mould, you begin to stress the gelatin, just like rock can be stressed by geological forces. What do you think will happen when the gelatin is stretched as tight as possible and a small slit is made in the surface? The rupture rips through the gelatin, and the gelatin quivers as it snaps back into a relaxed state. The same thing happens during an earthquake when a sudden rupture occurs along a fault. As the rupture travels through the rock, energy is released that creates the motions associated with an earthquake. If a fault rupture is shallow enough, the fault line may appear on the earth's surface. Figure 3-6 shows a fault rupture.

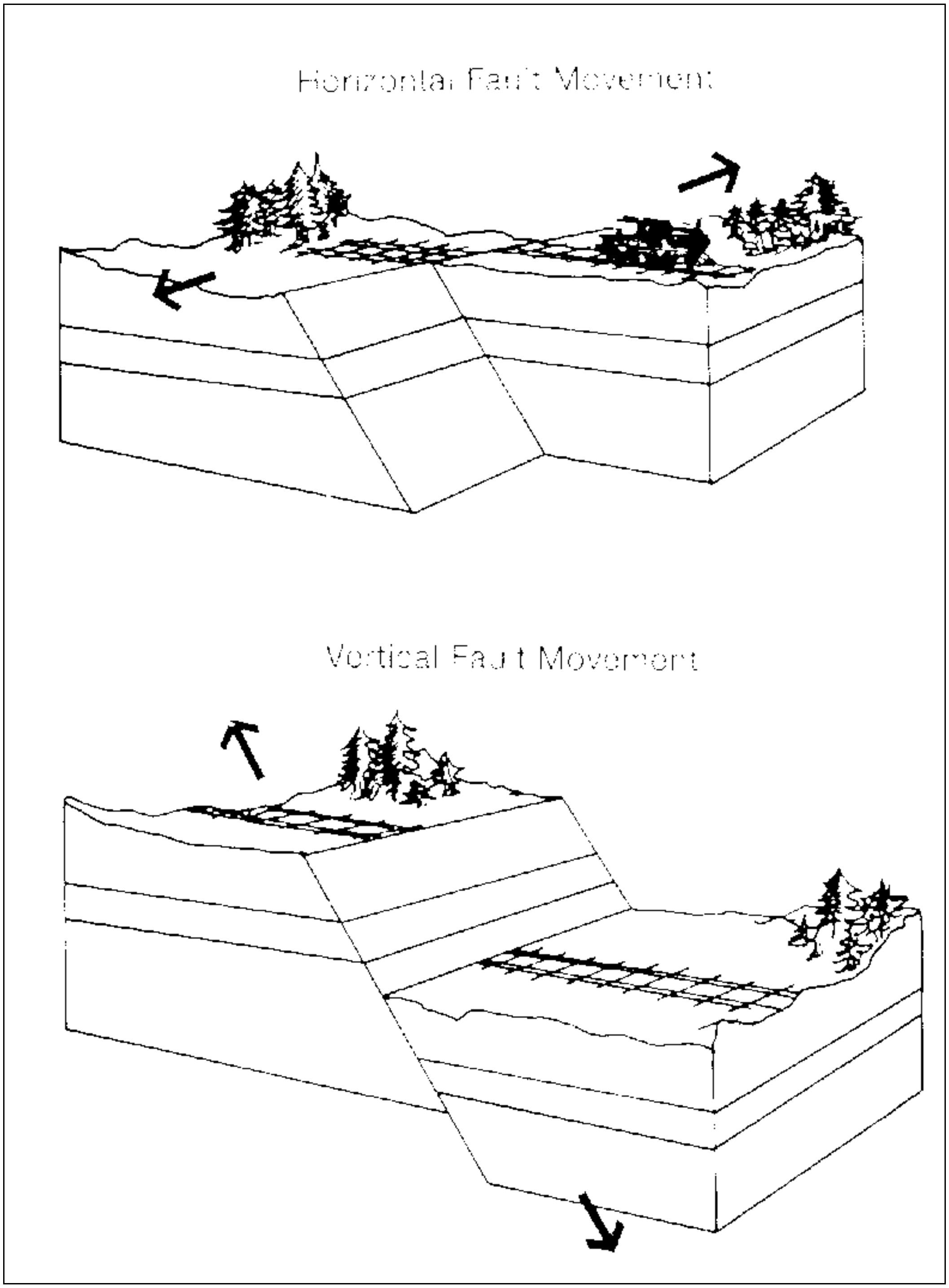


Figure 3-5 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

WHAT ARE AN EARTHQUAKE'S CHARACTERISTICS?

Figure 3-6 *Source: Federal Emergency Management Agency*.

Once the sudden rupture occurs, the earth begins to shake. This shaking is caused by a series of waves known as seismic waves moving from the center of the earthquake out to other parts of the earth. The type of waves involved in an earthquake is a key characteristic of the phenomenon. Next we discuss the types of waves and various soil compositions that affect how far a seismic wave will travel.

Seismic Waves

The four types of seismic waves are grouped into two main categories according to the way they travel from the source, or focus, of an earthquake. P waves and S waves are "body" waves. Love waves and Rayleigh waves are "surface" waves.

Body Waves

Body waves travel through the earth *below* and *on* the surface. Scientists use body waves to determine an earthquake's epicenter, the point on the earth's surface above an earthquake's focus. There are two types of body waves: P waves and S waves.

P waves. The primary wave, or P wave, is the fastest wave to move outward from the earthquake's focus, and it can move through both rock and liquid. The P wave motion is more like a sound wave than an ocean wave. In fact, some P waves actually can be heard as they emerge from the earth and are transmitted as sound waves into the atmosphere. The motion is pushed and pulled along the wave front in a series of compressions and expansions.

The effect of a P wave on a building is like a sharp punch. A child's slinky toy can be used to illustrate P wave motion. If you stretched a slinky across a table as shown in Figure 3-7 and push one end, the force of the push would carry through the slinky to the person on the other end. A P wave repeats this motion over and over in a series of compressions and expansions.

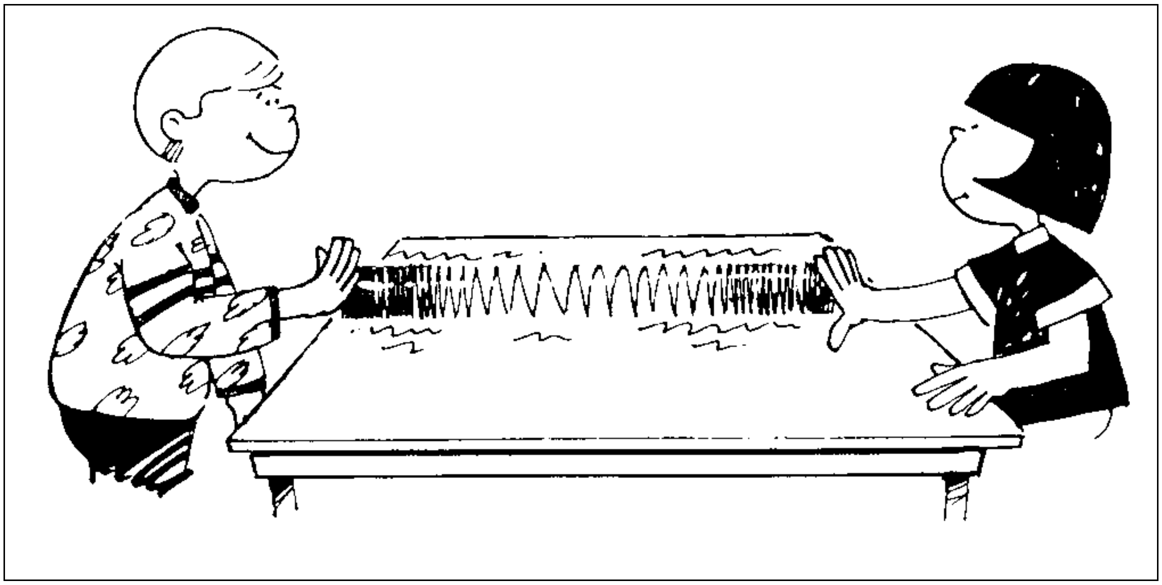


Figure 3-7 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

S waves. Secondary waves, or S waves, move more slowly through the earth. Unlike a P wave, an S wave cannot travel through liquid. At the surface, an S wave produces an up-and-down motion much like rolling waves and a side-to-side motion like a slithering snake. The motion of S waves can be illustrated using the same slinky toy. In Figure 3-8, one child shakes the toy up and down, while the other moves it from side to side. You can imagine that this wave motion is particularly damaging to buildings.

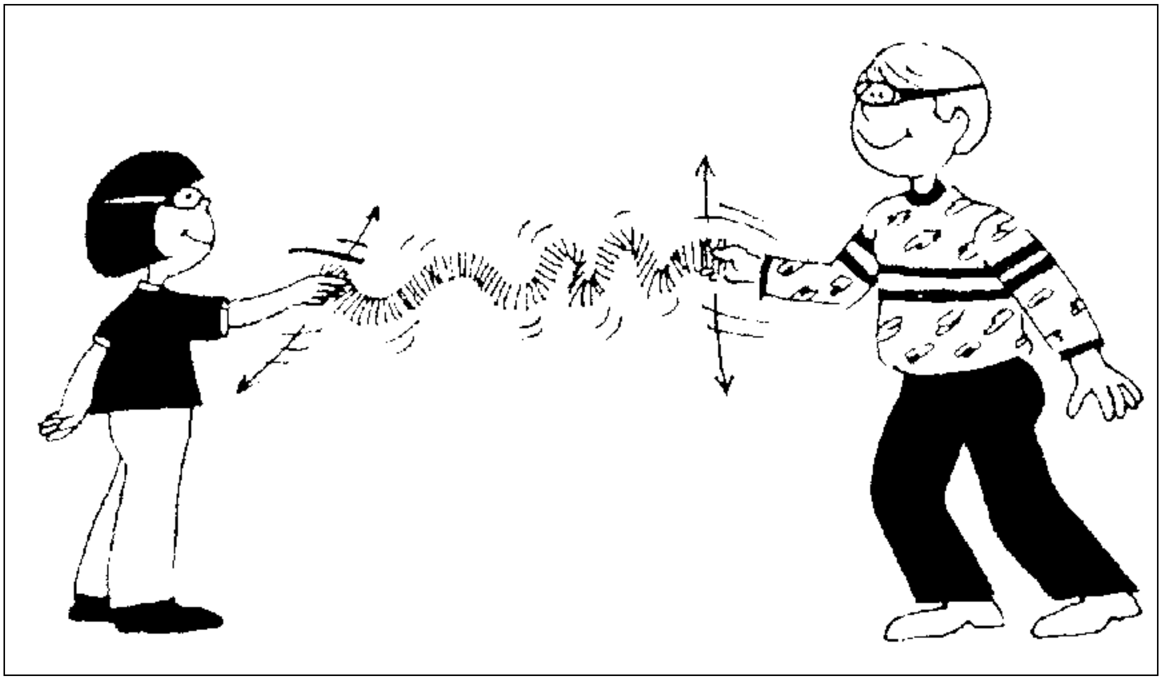


Figure 3-8 *Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.*

Surface Waves

Unlike body waves, surface waves travel only near or at the surface of the earth. They are responsible for the strongest ground shaking and most of the damage to the built environment that occurs in large earthquakes. Love and Rayleigh waves are the two main types of surface waves.

Love waves. A Love wave moves sideways along the surface of the earth in a snake-like motion. Like S waves, Love waves do not move through liquid. Figure 3-9 illustrates the way Love waves make the ground move.

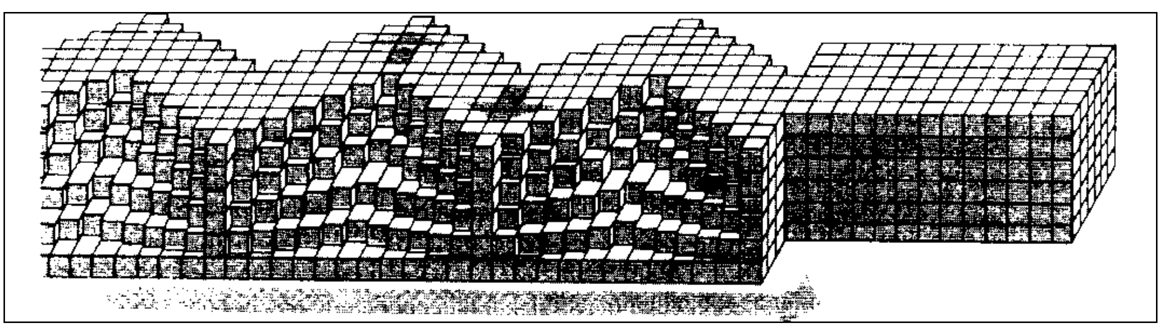


Figure 3-9 *Source: Bolt. Earthquakes, 1993.*

Rayleigh waves. As a Rayleigh wave moves across the earth's surface, the earth moves up and down like an ocean wave. Rayleigh waves can move through the surface of both earth and water. Figure 3-10 illustrates ground motion caused by Rayleigh waves.

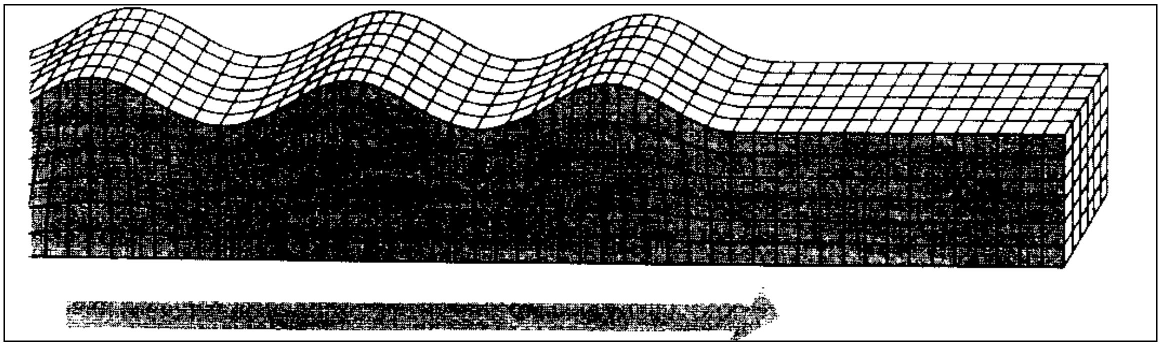


Figure 3-10 *Source: Bolt. Earthquakes, 1993.*

Effect of Soil Composition

The composition of the earth's crust and the physical features of an area will affect the intensity of seismic waves as they move through the ground or along the earth's surface. One concern that seismologists (researchers who study earthquakes) have had about earthquakes east of the Rocky Mountains is that seismic waves remain strong over great distances due to the composition of the crust in the region. For example, a strong earthquake in the New Madrid fault zone near Memphis, Tennessee would be felt, and could cause damage, throughout a much greater area than an earthquake of equal intensity in California. Figure 3-11 shows a map of the intensity lines associated with the 1811 New Madrid earthquake. The curved lines extending out from the center of the earthquake indicate the earthquake's decreasing intensity. The decreasing values of the isoseismal (curved) lines are shown in roman numerals. Intensity values at specific points are given in Arabic numerals. Records show that seismic waves were strong enough to be felt as far away as Washington, D.C., Boston, Canada, and New Orleans. (At the time very few people lived west of New Madrid region, so there is no record of how strong the waves were to the west of the epicenter.) The soil composition east of the Rocky Mountains allows seismic waves to retain strength much further than waves originating on the West Coast and traveling to the Rocky Mountains.

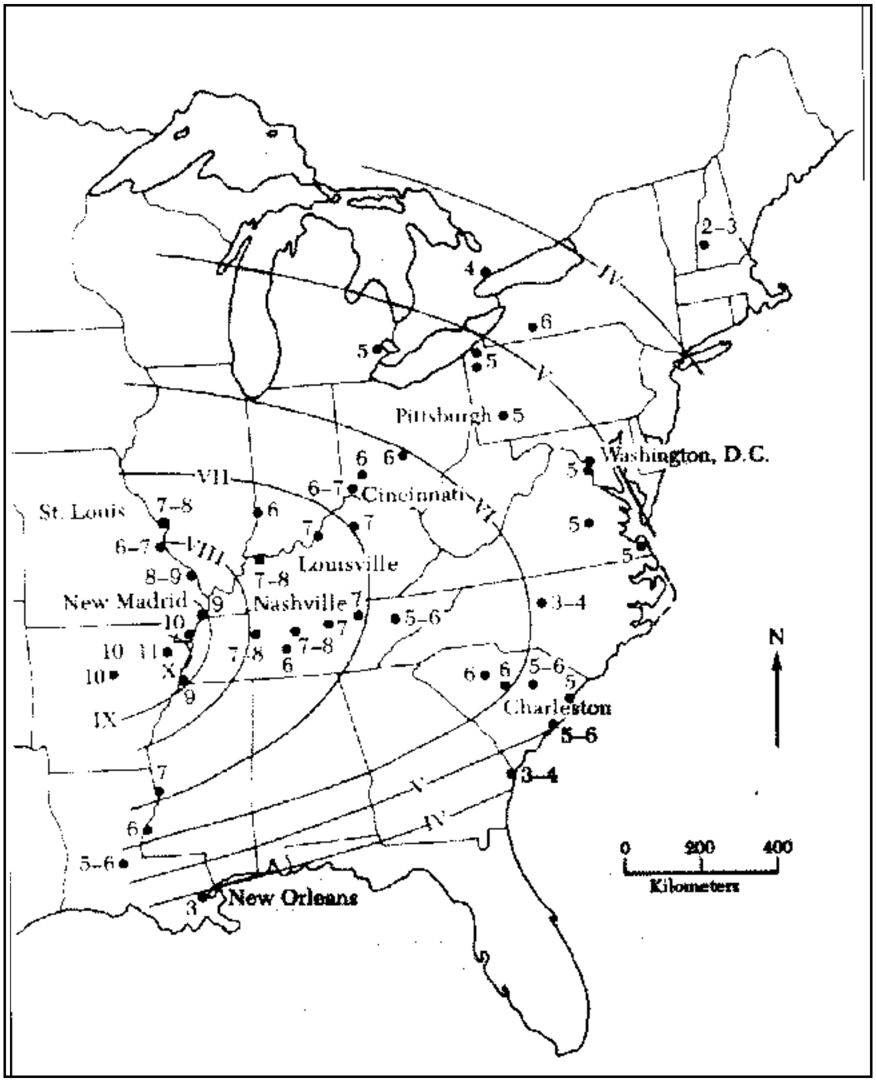


Figure 3-11 *Source: Nuttli, "The Mississippi Valley Earthquakes of 1811 and 1812: intensities, ground motion, and magnitudes," Bulletin of the Seismological Society of America.*

Figure 3-12 compares the areas affected by the 1906 San Francisco and the 1811 New Madrid earthquakes. The magnitudes of these earthquakes were similar, but the San Francisco earthquake affected a much smaller area because the earth's crust in the western United States does not allow seismic waves to travel as far as they do in the east. This is typical, though we have more earthquakes on the West Coast, seismic waves there are not felt at distances as great as those caused by earthquakes on the East Coast or in Canada or Mexico.

The soil composition in your community has a powerful effect on how intense an earthquake will be in your area. Generally speaking, unconsolidated soil or fill amplifies shaking and can make the earthquake feel even stronger than its magnitude might indicate. Topography (the earth's physical features) can focus energy and, again, make the earthquake feel stronger and cause more damage than what might be expected from an earthquake of its size. Therefore, a structure not designed according to mitigation standards will suffer more damage.

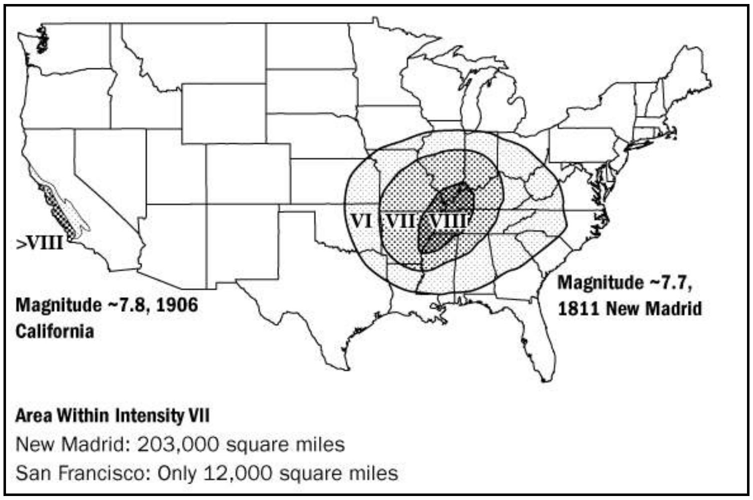


Figure 3-12 *Source: Arch Johnson, Center for Earthquake Research and Information, University of Memphis.*

HOW DO WE MEASURE EARTHQUAKES?

Once an earthquake occurs, it is important to know where the seismic event took place, how intense it was, and what its impact was on the built environment. The more we know about earthquakes and about how and when they occur, the more we can do to lessen their effects on our communities. Two scales are frequently used to measure earthquakes: The Modified Mercalli Intensity Scale measures the intensity or impact of an earthquake on people and the built environment, and the Richter Scale measures the amount of energy released by an earthquake, or its magnitude. In general, magnitude measures the size of an earthquake, while intensity measures the effects, which vary according to how far you are from the earthquake and the soils you are on.

Modified Mercalli Intensity Scale

Early forms of the Modified Mercalli Intensity Scale were developed in 1857. It measures the impact of an earthquake by sending out trained observers to look at the damage done to the built environment and the earth (landslides, etc.) and at the reaction of people to the event. The published intensities of the 1906 San Francisco earthquake were based on this scale. The intensities are given values from I to XII, shown in roman numerals. Figure 3-13 contains the descriptions used to assign earthquake intensity values on a Modified Mercalli Intensity Scale.

One advantage to using the Mercalli Scale is that it relies on the observations of people experiencing an earthquake instead of scientific instruments. This allows seismologists to assign earthquake intensities to historical seismic records, an activity that helps them to estimate seismic risk for earthquake sites today.

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

Figure 3-13 *Source: Naeim. The Seismic Design Handbook, 1989.*

The fact that the Mercalli Scale relies on people's observations is also a disadvantage because this makes evaluation subjective and dependent upon the social and infrastructure conditions of a country. For example, look at the description of intensity value VII on the Mercalli Scale in Figure 3-13. This description would have to be rewritten for a country without chimneys and automobiles. This scale also is not very helpful in an area with little human habitation, since no one would be around to experience the earthquake.

Richter Scale

The Richter Scale was developed in 1935 by Charles Richter of the California Institute of Technology in Pasadena. It is widely used today. The Richter Scale value is calculated by measuring the maximum recorded amplitude of a wave. This measurement quantifies the ground motion and the energy released at the source of an earthquake, which is referred to as its magnitude. For example, an earthquake that measures 4.0 on the Richter Scale would release energy equivalent to 6 tons of TNT, or about as much energy as a small atomic bomb. Richter magnitude is expressed as an Arabic number, which helps to distinguish it from the Mercalli Scale.

The Richter Scale is open ended and logarithmic. This means that there are no upper and lower limits to the scale and that every time the magnitude goes up by one unit, the amount of energy this represents increase thirty times. Look at Figure 3-14. We mentioned previously that a Richter magnitude of 4.0 is equivalent to the energy released by 6 tons of TNT. A magnitude of 3.0 is equivalent to only 397 pounds of TNT; 397 pounds is 30 times smaller than 6 tons.

Both the Mercalli Intensity Scale and Richter Scale often are used to describe earthquakes since they refer to different kinds of information. The Richter Scale describes the amount of energy associated with an earthquake, while the Mercalli Scale describe the effect of the energy. As an example, let's consider the effects of two different earthquakes: the 1989 Loma Prieta and the 1988 Armenian earthquakes. The 1989 Loma Prieta earthquake measured 7.1 on the Richter Scale and about VII on the Mercalli Scale. There was a moderate loss of life (67 people died), and the built environment suffered relatively little damage. Most of the buildings affected in the Loma Prieta earthquake had been built with seismic provisions to reduce damage.

RICHTER	TNT ENERGY	EXAMPLE
1.0	6 ounces	Small blast at a construction site
1.5	2 pounds	
2.0	13 pounds	
2.5	63 pounds	
3.0	397 pounds	
3.5	1,000 pounds	
4.0	6 tons	Small atomic bomb
4.5	32 tons	Average tornado
5.0	199 tons	
5.5	500 tons	Massena, NY, quake, 1944
6.0	6,270 tons	
6.5	31,550 tons	Coalinga, CA, quake, 1983
7.0	199,000 tons	Hebgen Lake, MT, quake, 1959
7.5	1,000,000 tons	
8.0	6,270,000 tons	San Francisco, CA, quake, 1906
8.5	31,550,000 tons	
9.0	199,999,000 tons	Prince William Sound, AK, quake, 1964

Figure 3-14

Source: FEMA 159. Earthquakes. Produced by The National Science Teachers Association, 1992.

In contrast, the 1988 Armenian earthquake measured almost the same magnitude (6.9) on the Richter Scale, but its Mercalli-measured intensity was XI. More than 50,000 people lost their lives, and the built environment was almost totally destroyed. The damage done by the Armenian earthquake was much greater than that done by the 1989 Loma Prieta earthquake, although the magnitudes were almost the same.

This illustrates two important points: one, the magnitude of an earthquake does not always correlate with the intensity or impact, and, two, the quality of the built environment is a big factor in the number of lives lost and the amount of damage done in an earthquake. The building codes used in your community will greatly affect the impact of an earthquake in your area, regardless of the magnitude.

Ground Motion

Measures in addition to intensity and magnitude are needed to predict how an earthquake might affect the structures in a specific community. Knowing how fast, for how long, and how much the ground moves during an earthquake is important for estimating how ground motion will affect the built environment. Seismologists use several concepts to express these measurements: acceleration, duration, velocity, and displacement.

Acceleration

As seismic waves move through the ground, they create a series of vibrations. These movements are translated into dynamic loads or inertial forces that cause the ground and anything attached to it (i.e., the built environment) to vibrate in a complex manner. These inertial forces cause damage to buildings and other structures. Inertial forces are created when an outside force tries to make an object move or change its rate of travel. For example, when you get into your car, you are initially at rest, sitting in the seat. Once you turn the key and step on the gas, the force created moves your body, and you feel a gentle push back into the seat. This inertial force is created by your body, which wants to stay at rest as the car accelerates and pushes you forward. Once you are traveling at a steady 40 miles per hour you do not feel any sensation of motion. As you come to a stop, again you feel a push forward as you decelerate. If you stop suddenly, your body is forcefully thrown forward as it attempts to continue to travel at 40 miles per hour while the car is at rest.

Acceleration is the rate of change of motion. We don’t normally associate acceleration with buildings since we don’t expect buildings to move. During an earthquake, however, inertial forces may cause the upper part of a building to sway while the foundation remains stationary, or they may cause the whole building to “move.” Structures built in seismically active areas must be built to withstand predicted acceleration levels.

Duration

Another important measurement of ground motion is duration. Damage will occur the whole time the ground is moving, so more damage is likely to occur the longer an earthquake lasts. Predictions of the amount of potential damage that could occur in a specific area must include the duration of the ground motion.

Velocity and Displacement

Velocity and displacement are mathematically related to acceleration. Velocity is the speed of an object at an instant in time. Displacement is the distance an object is moved from a resting position, such as how far a building is moved or displaced from its foundation. Seismologists use measurements of displacement to judge the impact of an earthquake on a community.

Velocity is quickly becoming as important as acceleration in determining building damage. Consider the driving example again. If your car decelerates suddenly, the inertial force may cause your head to hit the windshield. The velocity at which your body is traveling at the instant your head hits the windshield determines whether you get a little bump or a fractured skull. For a building, this could mean the difference between superficial damage and building collapse.

None of these measurements alone provides the detailed picture of an earthquake that is needed for further scientific study or for developing present-day design practices. For example, the Richter Scale does not give ground motion information that is important for designers. The Mercalli Scale is subjective and does not cover many new kinds of construction used today. Together they give scientists a good idea of where a seismic event took place, how large it was, and what its impact was on the built environment.

Seismic Hazard Maps

Seismic hazard maps have been developed to give design professionals and emergency response planners an idea of the relative seismic activity of a region. These maps are prepared by the U.S. Geological Survey and are based on the size and location of past earthquakes, their probabilities of recurrence, and the frequency of seismic events in the region. Seismic hazard maps are an important part of the NEHRP *Provisions* and have been adopted by the nation’s model building codes. Hazard maps are an important tool for evaluating and planning a community’s seismic safety. Examples of these maps appear in Figures 3-15 and 3-16. The values on the maps show potential earthquake ground motions, presented in percent of gravity. Figure 3-15 shows short-period ground motions, which affect shorter, stiffer buildings, and Figure 3-16 shows long-period ground motions, which affect taller, more flexible buildings.

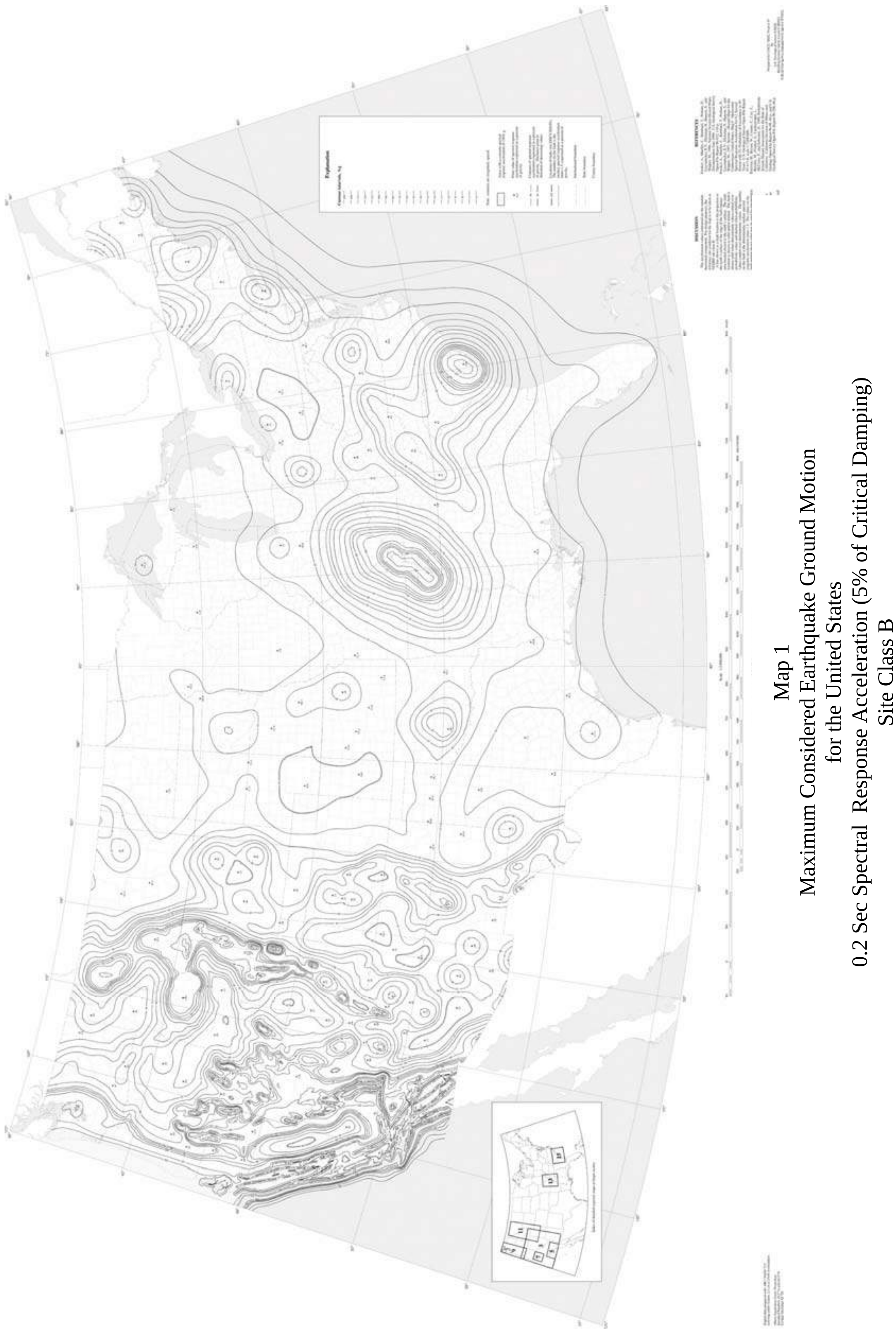
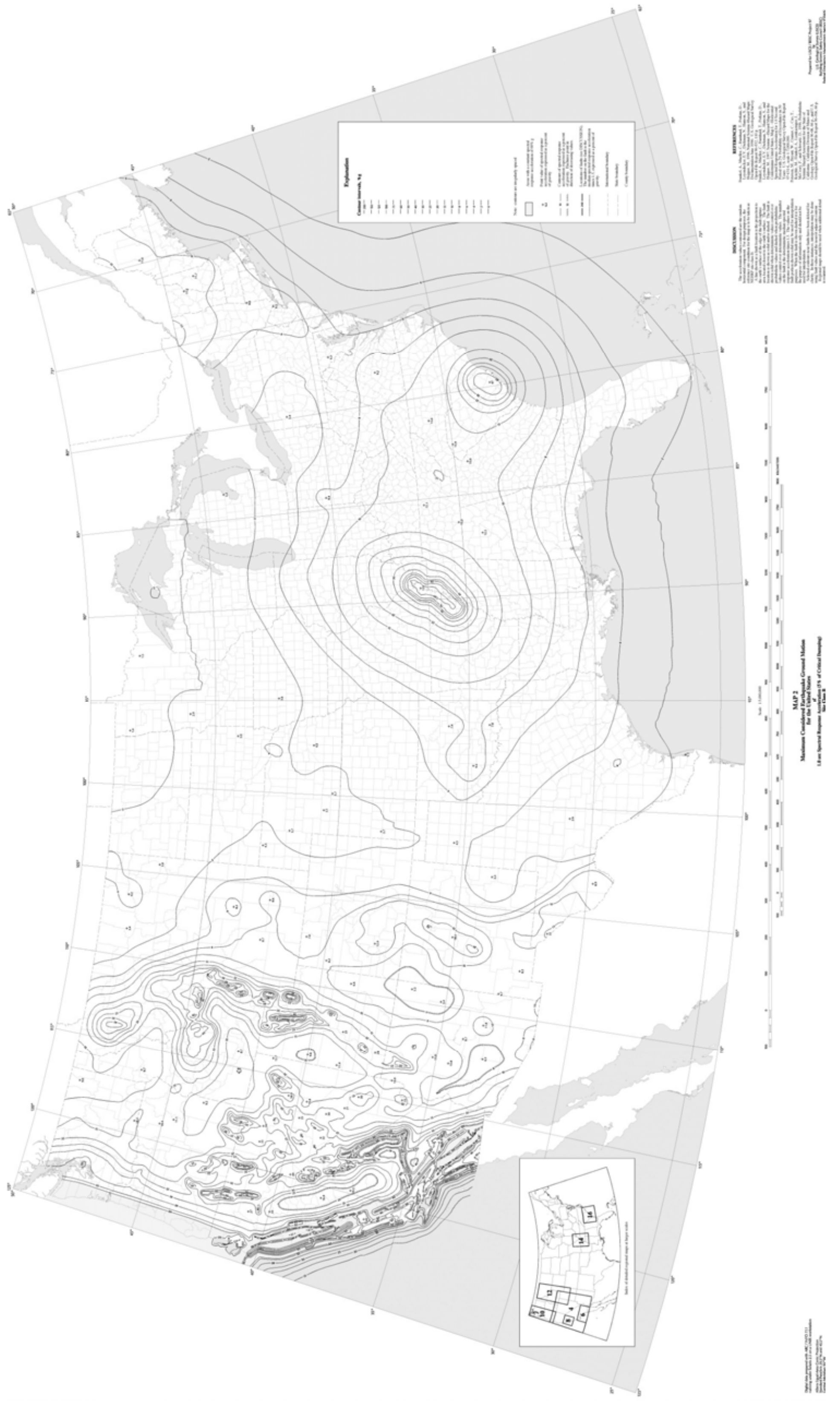


Figure 3-15 *Source: U S. Geological Survey.*



Map 2
Maximum Considered Earthquake Ground Motion
for the United States
1.0 Sec Spectral Response Acceleration (5% of Critical Damping)
Site Class B

Figure 3-16

Source: U.S. Geological Survey.

UNIT 3 - SUMMARY

This unit presented information on the characteristics and causes of earthquakes. In this unit, we explored the following questions:

- What causes an earthquake?
  - Plate tectonics
  - Faults
  - Sudden rupture
- What are an earthquake's characteristics?
  - Seismic waves
  - Effect of soil composition
- How do we measure earthquakes?
  - Modified Mercalli Intensity Scale
  - Richter Scale
  - Ground motion
  - Seismic risk maps

The knowledge you have gained in this unit will help you understand the effect an earthquake can have on the built environment, which we will cover in more depth in the next chapter. To check your understanding of this section, complete the Unit Review and check your answers before moving on to the next section.

Unit 3

Earthquake Causes and Characteristics

Unit Review

Directions: For each question, circle the letter of the correct response and check your answers with the Answer Guide at the end of the unit.

1. The 1811 and 1812 New Madrid earthquakes are examples of earthquakes caused by:

   a. plate tectonics.
   b. intraplate activity.
   c. liquefaction.
   d. subduction.

2. Because of the soil composition of the eastern and central parts of the United States, seismic waves tend to travel:

   a. short distances.
   b. only on the surface.
   c. farther than they do west of the Rocky Mountains.
   d. only as P waves.

3. The land masses around the Pacific Plate show a large degree of earthquake and volcano activity. This area is commonly called _______________.

   a. intraplate activity
   b. the Ring of Fire
   c. Mid-Atlantic Ridge
   d. subduction area

4. The Mid-Atlantic Ridge is a good example of __________ plate movement.

   a. divergent
   b. convergent
   c. fishbowl
   d. torsional

5. When one plate slides over another, a trench is formed and material from the lower plate is forced into the earth's interior. This process is called:

   a. convergent plates.
   b. divergent plates.
   c. subduction.
   d. a fault.

6. When rock is suddenly displaced along a fault line, _________ results.

   a. subduction
   b. convergent plate
   c. intraplate activity
   d. an earthquake

7. What common substance could you use to demonstrate sudden rupture along a fault line and the resulting violent shaking associated with an earthquake?

   a. Gelatin
   b. Paper
   c. Sand
   d. Fabric

8. Which one of the following attributes is **<u>not</u>** associated with a P wave?

   a. It is a body wave.
   b. It is more like an ocean wave than a sound wave.
   c. It is the fastest wave.
   d. It travels through rock and liquid.

9. The 1989 Loma Prieta, California, earthquake measured 7.1 on the Richter Scale and VII on the Modified Mercalli Scale. The 1988 Armenian earthquake measured 6.9 on the Richter Scale and XI on the Modified Mercalli Scale. If the magnitude measurements were similar, why were the intensity measurements for these two earthquakes so different?

   a. An error was made when the values were calculated.
   b. There is never a correlation between these two measurements because they measure different things.
   c. The buildings were taller in Armenia.
   d. Fewer buildings collapsed and less people died in Loma Prieta because the buildings were better constructed to withstand earthquakes.

10. Which one of the following attributes is ***not*** associated with a Love wave?

    a. At the surface it produces both up-and-down and side-to-side motions.
    b. It is a surface wave.
    c. It has no vertical motion.
    d. It cannot travel through liquid.

11. When an outside force (like an earthquake) tries to move an object or changes its rate of travel, what kind of forces are created?

    a. Seismic
    b. Mercalli
    c. Velocity
    d. Inertial

12. The Modified Mercalli Intensity Scale measures an earthquake's:

    a. magnitude.
    b. intensity.
    c. P waves.
    d. response spectrum.

13. The Richter Scale measures an earthquake's:

    a. magnitude.
    b. intensity.
    c. P waves.
    d. response spectrum.

14. A trained observer described the damage by an earthquake as, "Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop." He would rate the earthquake on the Modified Mercalli Intensity Scale as:

    a. IX.
    b. V.

15. "The rate of change of motion" is the definition of:

    a. acceleration.
    b. duration.
    c. velocity.
    d. period.

16. Study the figures below. Figure 3-17 shows the intensity values, based on the Modified Mercalli Intensity Scale, for various areas on the San Francisco peninsula after the 1906 earthquake. Figure 3-18 is a generalized geological map of the San Francisco peninsula. What do the two maps illustrate about the soil composition and earthquake intensity?

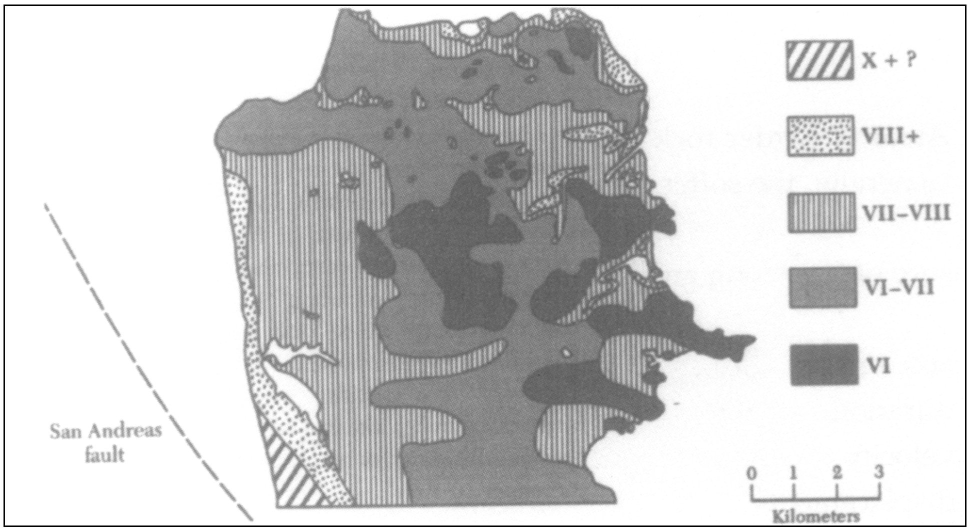


Figure 3-17 *Source: Bolt. Earthquakes, 1988.*

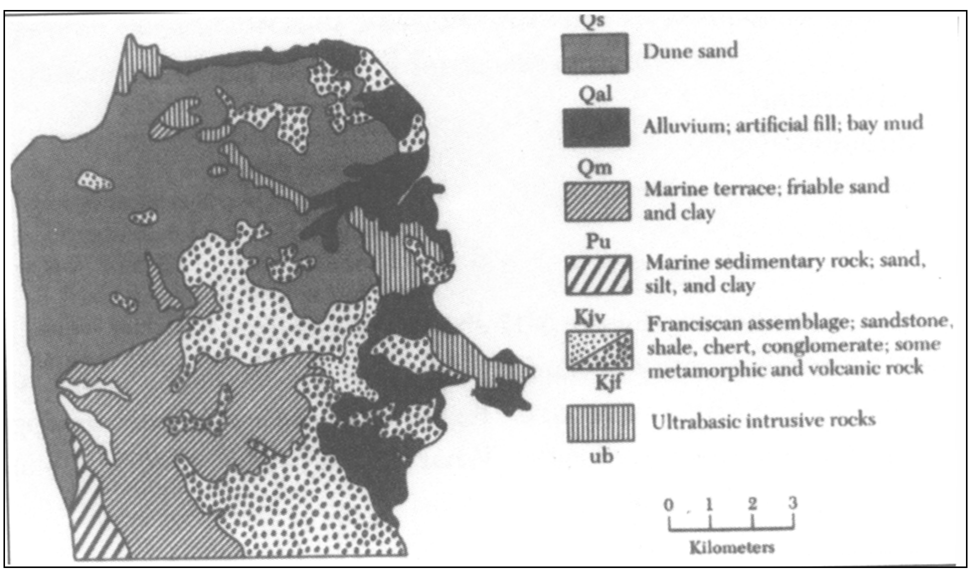


Figure 3-18 *Source: Bolt. Earthquakes, 1988.*

a. Areas of harder rock suffered more damage.
b. Generally, the softer the soil, the more intense the earthquake impact.

17. A measure of how long an earthquake lasts is called

    a. acceleration.
    b. duration
    c. velocity
    d. displacement

18. The speed at which an object is traveling at an instant in time is called:

    a. acceleration.
    b. duration.
    c. velocity.
    d. displacement.

19. The distance an object is moved from a resting position is called:

    a. acceleration.
    b. duration.
    c. velocity.
    d. displacement.

20. Why is it important to measure the magnitude, intensity, and ground motion of an earthquake?

    a. It helps communities decide on appropriate mitigation steps to take in the event of future earthquakes.
    b. It helps communities prepare accurate seismic risk maps.
    c. It helps communities design seismically safe buildings by predicting what forces a structure may have to endure in an earthquake in a specific area.
    d. All of the above.

Unit 3

Earthquake Causes and Characteristics

Unit Review - Answer Guide

1. The 1811 and 1812 New Madrid earthquakes are examples of earthquakes caused by:

   b. intraplate activity.
   Reference: p. 3-4

2. Because of the soil composition of the eastern and central parts of the United States, seismic waves tend to travel:

   c. farther than they do west of the Rocky Mountains.
   Reference: pp. 3-11 and 3-12

3. The land masses around the Pacific Plate show a large degree of earthquake and volcano activity. This area is commonly called ________________.

   b. the Ring of Fire
   Reference: p. 3-4

4. The Mid-Atlantic Ridge is a good example of __________ plate movement.

   a. divergent
   Reference: p. 3-2

5. When one plate slides over another, a trench is formed and material from the lower plate is forced into the earth's interior. This process is called:

   c. subduction.
   Reference: p. 3-2

6. When rock is suddenly displaced along a fault line, _____ results.

   d. an earthquake
   Reference: p. 3-6

7. What common substance could you use to demonstrate the sudden rupture along a fault line and the resulting violent shaking associated with an earthquake?

   a. Gelatin
   Reference: p. 3-6

8. Which one of the following attributes is ***not*** associated with a P wave?

   b. It is more like an ocean wave than a sound wave.
   Reference: p. 3-8

9. The 1989 Loma Prieta, California, earthquake measured 7.1 on the Richter Scale and VII on the Modified Mercalli Scale. The 1988 Armenian earthquake measured 6.9 on the Richter Scale and XI on the Modified Mercalli Scale. If the magnitude measurements were similar, why were the intensity measurements for these two earthquakes so different?

   d. Fewer buildings collapsed and less people died in Loma Prieta because the buildings were better constructed to withstand earthquakes.
   Reference: pp. 3-15 and 3-16

10. Which one of the following attributes is ***not*** associated with a Love wave?

    a. At the surface it produces both up-and-down and side-to-side motions.
    Reference: p. 3-10

11. When an outside force (like an earthquake) tries to move an object or change its rate of travel, what kind of forces are created?

    d. Inertial
    Reference: p. 3-17

12. The Modified Mercalli Intensity Scale measures an earthquake's:

    b. intensity.
    Reference: pp. 3-13 to 3-15

13. The Richter Scale measures an earthquake's:

    a. magnitude.
    Reference: p. 3-15

14. A trained observer described the damage by an earthquake as, "Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop." He would rate the earthquake on the Modified Mercalli Intensity Scale as:

    b. V.
    Reference: p. 3-14

15. "The rate of change of motion" is the definition of:

    a. acceleration.
    Reference: pp. 3-17 and 3-18

16. Study the figures below. Figure 3-17 shows the intensity values, based on the Modified Mercalli Intensity Scale, for various areas on the San Francisco peninsula after the 1906 earthquake. Figure 3-18 is a generalized geological map of the San Francisco peninsula. What do the two maps illustrate about the soil composition and earthquake impact?

    b. Generally, the softer the soil, the more intense the earthquake impact.
    Reference: pp. 3-11 and 3-12

17. A measure of how long an earthquake lasts is called:

    b. duration.
    Reference: p. 3-17

18. The speed at which an object is traveling at an instant in time is called:

    c. velocity.
    Reference: p. 3-18

19. The distance an object is moved from a resting position is called:

    d. displacement.
    Reference: p. 3-18

20. Why is it important to measure the magnitude, intensity, and ground motion of an earthquake?

    d. All of the above.
    Reference: this unit.