CHAPTER 4
EARTHQUAKES

Important Concepts

1. An *earthquake* occurs when movement along a fault zone results in a sudden release of built-up strain energy in the lithosphere. Most earthquakes occur at plate boundaries.

2. The point of first break or movement along a fault is called the earthquake's *focus* (or *hypocenter*). The point on the earth's surface directly above the focus is called the *epicenter*.

3. There are several types of earthquake, or seismic, waves:

    (a) *P (primary) waves* are compressional waves that cannot travel through the earth's liquid outer core.

    (b) *S (secondary) waves* are shear waves and cannot travel through the earth's core. Both P waves and S waves are classified as *body waves,* because they travel through the earth's interior.

    (c) *Surface waves* travel along the earth's surface, some causing vertical ground motions and others horizontal shearing motions. Much of the structural damage during earthquakes is caused by the surface waves.

4. P waves travel faster than S waves. The difference in the first arrival times of P waves and S waves, as detected by seismographs, is a function of the distance to the earthquake's epicenter. The epicenter of an earthquake can be determined from S–P time difference recorded at three or more seismograph stations.

5. The *magnitude* of an earthquake is a measure of the amount of ground displacement or shaking associated with the earthquake and is usually reported using the Richter magnitude scale (although *moment magnitude* is a better measure of the released energy). The Richter scale is logarithmic.

6. The *intensity* of an earthquake is a measure of the damaging effects of an earthquake at a particular location and is usually reported on the Modified Mercalli scale. The damage caused by an earthquake depends not only on its magnitude, but also on other factors, such as the distance from the epicenter, the integrity of the structures and their foundations, and population density.

7. Earthquake-related hazards include:

    (a) Ground shaking and fault displacement.

    (b) Ground failures, including landslides and liquefaction. *Liquefaction* is a quicksand condition arising in wet soil shaken by seismic waves.

    (c) *Tsunamis*, or seismic sea waves, and coastal flooding.

    (d) Fires caused by fuel line and storage tank ruptures and electrical system damage.

8. Some progress in earthquake prediction and forecasting has been made by recognizing the presence of *seismic gaps* and by studying precursor phenomena and earthquake cycles. Unfortunately, it is not yet possible to precisely predict the timing, size, or precise location of a future major earthquake.

9. It may be possible to induce the generation of small earthquakes by injecting fluids into locked sections of major faults and thus prevent the occurrence of major earthquakes. Although attractive in principle, the concept has not been tested yet because of potential technical, legal, and political problems.

10. Although we cannot control earthquakes, improved earthquake prediction and forecasting, heightened public awareness of earthquake phenomena and hazards, the development of comprehensive disaster-response plans, and proper land-use and engineering practices can reduce the risk of loss of life and property damage caused by earthquakes.

11. Areas of recognized earthquake risk in the United States include southern Alaska, the western states, the Midwest along the New Madrid fault zone, and sections of the east coast. Canada, although less active seismically than the United States, still has the potential for significant earthquakes.

Key Terms

aftershocks
body waves
creep
earthquake
earthquake cycle
elastic rebound
epicenter
fault
focus
intensity
liquefaction
magnitude
Modified Mercalli Scale
moment magnitude
precursor phenomena
P waves
Richter magnitude scale
seismic gap
seismic waves
seismograph
S waves
surface waves
tsunami

Multiple Choice

1. Slow, gradual movement along a fault is called
    a. slip.
    b. creep.
    c. elastic rebound.
    d. liquefaction.

2. The point of first break on a fault during an earthquake is called the
    a. slip.
    b. epicenter.
    c. point of weakness.
    d. focus.

3. Earthquakes originate in the
    a. lithosphere.
    b. asthenosphere.
    c. mantle.
    d. outer core.

4. Earthquake P waves
    a. travel more slowly than S waves.
    b. are a type of surface wave.
    c. cannot pass through the earth's core.
    d. are compressional waves.

5. Which of the following is not explained by the elastic rebound theory?
    a. the generation of earthquakes along fault zones
    b. the likely recurrence of earthquakes along the same fault zone
    c. the concept of seismic gap
    d. the common occurrence of fires in earthquake-affected communities

6. At present, we can predict
    a. the regions where major earthquakes are likely to occur in the future.
    b. the year in which a major earthquake will occur along the San Andreas fault zone.
    c. the precise magnitude of an earthquake if and when it occurs.
    d. the likelihood of strange animal behavior before the next earthquake along the New Madrid fault zone.

7. In the United States, earthquake intensity is usually measured on the
    a. Richter magnitude scale.
    b. Modified Mercalli Scale.
    c. Seismic Intensity Scale.
    d. Destruction Magnitude Scale.

8. Relative to an earthquake of magnitude 5 on the Richter magnitude scale, an earthquake of magnitude 7 releases
    a. 2 times more energy.
    b. 20 times more energy.
    c. 100 times more energy.
    d. 900 times more energy.

9. An earthquake having a magnitude of 5–5.9 would be described as a
    a. minor earthquake.
    b. damaging earthquake.
    c. destructive earthquake.
    d. major earthquake.

10. The problem of liquefaction can be somewhat reduced by
    a. injecting lubricating fluids into the soil to reduce the friction between soil particles.
    b. installing efficient underground drainage systems.
    c. compacting the soil as much as possible.
    d. constructing earthquake-resistant buildings in areas prone to liquefaction.

11. Tsunamis
    a. are generated by tidal action.
    b. appear as high breakers in the open ocean.
    c. pose little threat to coastal areas.
    d. can travel at speeds of hundreds of miles per hour.

12. Seismic gaps represent
    a. periods of reduced or no seismic activity in the geologic record.
    b. "locked" sections along otherwise active faults.
    c. areas where there is little or no risk of earthquake activity.
    d. areas along an active fault where surface indications of the fault are absent.

13. Which of the following is an example of an earthquake precursor?
    a. an increase then a decrease in the electrical resistivity of rocks.
    b. changes in water levels in wells.
    c. anomalous animal behavior.
    d. All of the above are possible precursor phenomena.

14. The agency of the United States government authorized to issue warnings of impending earthquakes and other hazardous geologic events is the
    a. National Academy of Sciences.
    b. U.S. Department of the Interior.
    c. U.S. Geological Survey.
    d. Environmental Protection Agency.

15. At present, all of the following nations have government-sponsored earthquake prediction programs except
    a. Mexico.
    b. the United States.
    c. Japan.
    d. the People's Republic of China.

16. Which one of the following states has the greatest risk of experiencing a severely damaging earthquake?
    a. Texas
    b. South Carolina
    c. Michigan
    d. Colorado

Fill In the Blanks

1. The phenomenon in which rocks snap back elastically to their prestress condition after an earthquake is called ___________________ ______________________.

2. The point on the earth's surface directly above the focus of an earthquake is called the ___________________.

3. When an earthquake occurs, it releases energy in the form of___________ ___________, which are divided into body waves and surface waves.

4. ___________ ___________ are body waves that involve a side-to-side motion of molecules of the materials through which they travel.

5. The instrument that is used to detect the ground motions generated by earthquakes is called a ___________.

6. _________________ is a measure of the damaging effects of an earthquake on surface features and on humans.

7. Earthquakes that follow the main shock are called ____________________.

8. An earthquake of Richter magnitude 6 causes ________________ times as much ground movement as one of Richter magnitude 4.

9. ___________ ___________ are events that precede an earthquake and can be used to predict its occurrence.

10. A method of releasing built-up strain along locked sections of faults by pumping fluid into fault zones is called ___________ ___________.

True or False

Indicate whether the following statements are true or false. If false, correct the statement to make it true.

________ 1. Deep-focus earthquakes are concentrated in subduction zones.

________ 2. When an earthquake occurs, S waves from the quake are detected all over the earth.

________ 3. As S waves travel through matter, the matter is alternately compressed and expanded.

________ 4. The farther a receiving seismograph is from an earthquake's epicenter, the shorter the time lag between the first arrival of P waves and S waves.

________ 5. Calculation of the Richter magnitude of an earthquake is based on the maximum amplitude of seismic waves recorded on the seismogram and adjusted for the distance of the seismograph from the epicenter.

________ 6. Earthquakes are extremely rare events.

________ 7. On the Modified Mercalli Scale, an earthquake of intensity I is the most destructive.

________ 8. Buildings constructed on deep soil usually suffer less structural damage than those built on bedrock.

________ 9. During the 1906 San Francisco earthquake, 70% of the damage was due to fire rather than to ground movement.

________ 10. It is now possible to predict the timing and size of major earthquakes.

________ 11. If you are indoors during an earthquake, run outdoors immediately.

________ 12. The 1989 Loma Prieta earthquake has increased, not reduced, the near-term likelihood of failure along the peninsular segment of the San Andreas fault.

Review Questions

1. What are the different types of seismic waves associated with an earthquake? Which of these is likely to cause most damage to buildings?

2. Explain the difference between the Richter magnitude of an earthquake and its intensity based on the Mercalli Scale. Which of these is a better gauge of the energy released during an earthquake?

3. What are the factors that determine the damage (loss of life and property) caused by an earthquake?

4. What is the correlation between plate tectonics and the distribution of earthquakes? Why are deep-focus earthquakes concentrated along subduction zones?

5. At the present time, how well can we predict future earthquakes in terms of their likely location and timing? Explain your answer.

6. List at least three kinds of earthquake-related hazards, and describe what, if anything, can be done to minimize the danger that each poses.

7. Explain the concept of minimizing the risk of a major earthquake by artificially producing smaller earthquakes along the San Andreas fault zone.

Surfing the Net

Excellent, comprehensive treatment of earthquakes and related hazards, with links to many other sources (National Earthquake Information Center, U.S. Geological Survey):
<http://wwwneic.cr.usgs.gov/

Global seismic risk maps (final report of the Global Seismic Hazard Assessment Program, 1999):
<http://seismo.ethz.ch/GSHAP>

Excellent collection of images of photographs and artworks related to many earthquakes and information on earthquake engineering (The National Information Service for Earthquake Engineering):
<http://nisee.berkeley.edu/>

Information on tsunamis, especially the 1998 Papua New Guinea tsunami (U.S. Geological Survey):
<http://walrus.wr.usgs.gov/tsunami/index.html>

Information on hazards related to earthquakes, especially those applicable to the San Francisco Bay area (The Association of Bay Area Governments):
<http://www.abag.ca.gov/bayarea/eqmaps/eqmaps.html>

Research relevant to plate tectonics and earthquakes (The Geological Survey of Japan):
<http://www.gsj.go.jp>

CHAPTER 4 ANSWER KEY

Multiple Choice

1. b
2. d (figure 4.4)
3. a
4. d
5. d
6. a
7. b
8. d
9. b (table 4.2)
10. b
11. d
12. b
13. d
14. c
15. a
16. b (figure 4.31)

Fill In the Blanks

1. elastic rebound
2. epicenter
3. seismic waves
4. S waves
5. seismograph
6. Intensity
7. aftershocks
8. 100
9. Precursor phenomena
10. fluid injection

True or False

1. True

2. False. S waves do not reach the part of the earth on the opposite side from an earthquake because they cannot travel through the liquid outer core.

3. False. S waves are shear waves that involve a side-to-side motion of molecules as they travel through the earth. P waves involve back-and-forth vibrations or compression of molecules in the direction of wave travel.

4. False. The farther a receiving seismograph is from an earthquake's epicenter, the greater the time lag between the first arrival of P waves and S waves.

5. True

6. False. Hundreds of thousands of earthquakes of all magnitudes occur each year, although most are magnitude 5 or less (table 4.2).

7. False. An intensity of XII is the most destructive on the Modified Mercalli Scale (table 4.3).

8. False. Buildings constructed on deep soil usually suffer more structural damage than those built on bedrock.

9. True

10. False. Partly because earthquake precursors are not yet completely understood, consistently reliable earthquake predictions are at least a decade or more in the future.

11. False. Remain indoors during an earthquake, seeking protection beneath a table or desk, or in a doorway.

12. True