What are Earthquakes?

An earthquake results from movement in the earth's crust. The theory used to describe this movement was first published in 1967 and is the theory of "plate tectonics." According to this theory the crust of the earth is made up of plates that are moving in different directions. The earth's crust is 50 to 60 miles thick, and the plates move at speeds of fractions of inches up to 5 inches a year. As the plates move against each other, tension develops slowly along "faults." A fault is the zone between two plates or blocks of the earth's crust. The tension is periodically released suddenly when there is a slip along the fault line. The size of the surface area that moves when a fault ruptures determines the amount of energy released. Therefore the size of the fault surface area is well correlated with the severity of the earthquake that results. Although earthquakes and volcanoes occur most commonly along faults, earthquakes can also occur within plates. Examples of this are significant earthquakes that have occurred in Idaho, Wyoming, Utah, and Nevada.

The area where the fault first moves is called the "hypocenter" of an earthquake. This is usually deep in the earth. The area on the surface of the earth, directly above the hypocenter, is called the "epicenter."

Earthquakes are described by a number of parameters such as type, location, magnitude, and intensity. Some elementary understanding of this natural phenomenon is necessary for those who want to understand what to expect from earthquakes. The following information can also dispel myths about earthquakes.

Types of Earthquakes

Faults can move in different directions. If they move horizontal to each other, a "strike slip" earthquake results. Strike slip faults displace parts of the earth's surface laterally. For example, if a strike slip fault crosses a road, the road becomes offset. An example of a strike slip fault is the San Andreas Fault. Because the San Andreas Fault is moving in a horizontal plane, the likelihood of California "falling into the ocean" when "the big one" hits is not a realistic outcome.

If the movement along the fault is vertical, a "dip-slip" earthquake results. A "normal" dip-slip earthquake occurs when the overlying block slips down and the underlying block slips up. Examples of normal dip-slip faults are the type of earthquake that occurs in the Pacific Northwest. Geologic data indicate that about 1000 years ago a normal dip-slip earthquake raised the area that is now Seattle by 23 feet and created many of the lakes around the city.

A "reversed" dip-slip earthquake results when the overlying block slips upward and the underlying block slips down. Reversed dip-slip earthquakes occur along the New Madrid Fault. Reversed dip-slip faults are associated with a sinking of the earth and are the origin of large portions of the Mississippi basin. If a reversed dip-slip fault does not extend to the earth's surface, which would expose new crust, the earthquake is called a "blind thrust fault." Accessory fault systems to the San Andreas Fault are blind thrust faults. Therefore earthquakes in California are commonly associated with bulging and dipping of the earth's crust but not with major vertical displacements. The Northridge earthquake was a blind thrust fault originating 8 miles below Northridge. Other examples of blind thrust faults are the 1971 San Fernando and 1991 Sierra Madre earthquakes, in which the ground was raised.

Movement of the earth's crust in earthquakes results from movement along the fault, ground shaking, soil liquefaction, ground failure, and primary ground ruptures and failure. In earthquakes the ground does not open up large crevices that swallow buildings. On the contrary, a crevice in the earth’s crust would not be associated with an earthquake because traction between plates is needed for earthquakes to occur. Forces that produce gaping holes in the earth’s crust would have the opposite effect to earthquakes.

Movements along fault lines can also occur along many angles. The many differences in the range of motion that can produce earthquakes make it difficult to locate exactly the hypocenter of an earthquake.

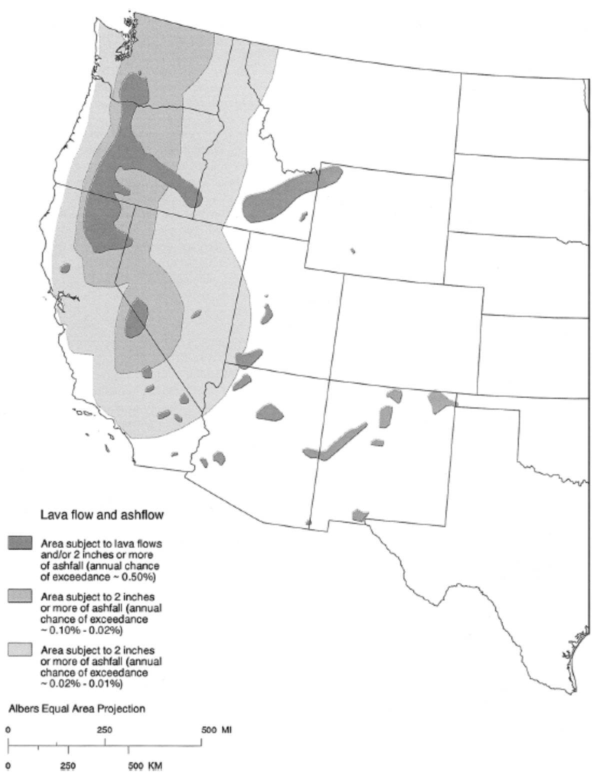

FIG. 8-2 Areas subject to lava flows and ash fall in the contiguous United States. (From Federal Emergency Management Agency: *Multi-hazard identification and risk assessment: a cornerstone of the national mitigation strategy,* Washington, DC, 1997, FEMA.)

Types of Shaking and Waves

The magnitude of an earthquake is determined by the speed at which the movement in the earth is transmitted and by the duration of the movement. The speed of transmission of movement depends to a large extent on the type of soil and rock through which the motion passes. The duration of an earthquake is directly related to the size of the fault line, the surface area along which the slip occurs. The different speeds and direction of the waves are used by seismologists to determine the origin and location of the earthquake. The maximum speed at which fault movements will be transmitted is equal to the maximum speed of sound in rock (3 km/sec = 67,500 mph).

Earthquakes produce four major types of waves. The “P” (compressional or longitudinal) waves travel fast, are high frequency, and do not travel far from the hypocenter. The direction of the P wave is back and forth in the direction of the movement of the wave. P waves result in expansion and contraction of the earth’s crust, analogous to the way in which sound waves travel. P waves are primarily felt close to the epicenter of an earthquake. They are a particular risk to small structures because these are more likely to resonate to fast waves than larger buildings are.

“S” (shear or secondary) waves are slower waves that move back and forth at right angles to the direction of the movement of the P wave. S waves are responsible for most of the damage that results from side-to-side movement in earthquakes. S waves are felt both close to and far from the earthquake origin; they are the waves responsible for most of the shaking felt in earthquakes.

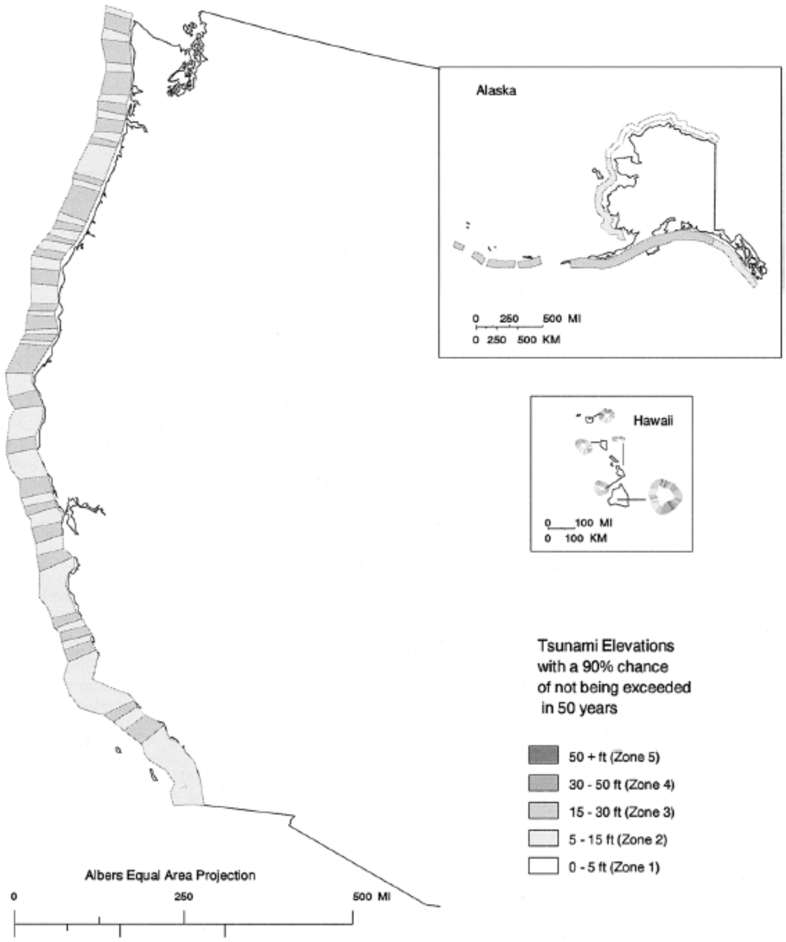

FIG. 8-3 Tsunami elevations with a 90% chance of not being exceeded in 50 years, also known as the 475-year return period elevation. (From Federal Emergency Management Agency: *Multi-hazard identification and risk assessment: a cornerstone of the national mitigation strategy,* Washington, DC, 1997, FEMA.)

Table 8-2 Secondary effects of earthquakes

Soil liquefaction
Landslides
Ground failure
Tsunamis
Fires
Flooding (dam failure)
Release of hazardous materials
Volcanic eruption

These low-frequency waves are most likely to cause damage to large buildings and structures even far away from an earthquake epicenter, although the intensity of movement decays over distance. S waves are felt over a much larger area than P waves.

Raleigh and Love waves travel along the surface. They are low frequency, travel far, and are responsible for a considerable amount of damage. Raleigh waves are orbital waves that spread in a circular motion from the epicenter similar to concentric ripples on the surface of water. Love waves run transversely to the direction of the P waves.

Measurement of Earthquakes (Intensity and Magnitude)

Earthquakes are measured on three scales:

- The Modified Mercalli scale measures intensity.
- The Richter scale measures magnitude.
- The Moment Magnitude scale measures the energy released in an earthquake.

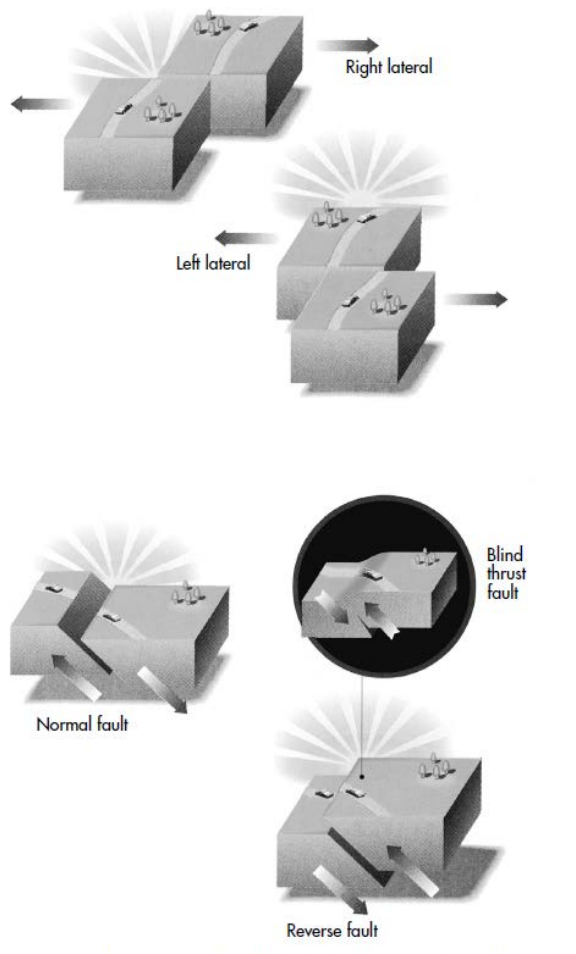

FIG. 8-4 Types of earthquake faults. (From US Geological Survey, Southern California Earthquake Center: *Putting Down Roots in Earthquake Country,* Los Angeles, 1994, Southern California Earthquake Center.)

The first attempt to describe the impact of earthquakes came from Italy, where Mercalli developed a subjective scale that described the extent of damage resulting from an earthquake. This intensity scale has since been modified and is referred to as the Modified Mercalli Intensity

(MMI) scale. The MMI scale is based on field reports of persons who experienced the earthquake and the visible consequences (Table 8-3). The first scale used to describe the magnitude of earthquakes was developed by Gutenberg and Richter in the 1930s. The Richter scale defines magnitude in terms of the speed of ground movement. Richter scale magnitude is measured by seismographs ideally located at a standard distance (62 miles) from the epicenter. Practically, however, several readings are used to determine the magnitude of the earthquake. The Richter scale is logarithmic, meaning that every unit increase in magnitude (e.g., from 4.3 to 5.3) indicates a tenfold greater movement. The Richter scale closely approximates the amount of energy released. The largest earthquakes reach 8.8 to 8.9 on the Richter scale. The approximate conversion of Richter scale units to energy units is 31.6, so that a unit increase on the Richter scale is analogous to a 31.6-fold increase in the amount of energy released. Earthquakes with higher Richter scale magnitudes have increased duration and are felt over a greater distance. Higher magnitudes do not, however, directly translate into a proportional increase in shaking at the epicenter. As such the Richter scale is not a good measure or predictor of damage caused by a particular earthquake.

Table 8-3 Comparison of the Modified Mercalli Intensity (MMI) and the Richter Magnitude scales for describing the severity of earthquakes

Level	Description	MMI scale effect	Richter Magnitude scale (approximate equivalent in TNT energy)
I	Instrumental	Usually only detected by seismographs	1.0 (6 oz)
II	Feeble	Noticed only by few persons, who usually are at rest on upper floors of buildings; suspended objects may sway	2.0 (13 lb)
III	Slight	Like the vibration of a passing heavy truck, felt only by most persons indoors, especially on upper floors of buildings	3.0 (400 lb)
IV	Moderate	Will be felt indoors and outdoors; some may be awakened as dishes, windows, and doors rattle; hanging objects sway noticeably	3.1-3.4 (1 ton)
V	Rather strong	Felt by most persons; people awaken from sleep; dishes and windows may be broken, and plaster may crack	3.5-4.2 (small, 6 tons)
VI	Strong	Felt by all; dishes and windows are broken; objects fall off shelves and pictures off walls; church bells may ring; some heavy furniture may move; some fallen plaster and chimneys	4.3-4.8 (small, 35 tons)
VII	Very strong	General alarm; difficult to stand; walls crack, and plaster falls off walls; small landslides; ripples seen on ponds and lakes	4.9-5.4 (moderate, 800 tons)
VIII	Destructive	Masonry cracks, chimneys fall, and poorly constructed buildings are damaged and may collapse; falling of chimneys, monuments, walls, towers, and elevated tanks; changes in well water	5.5-6.1 (moderate, 2500 tons)
IX	Ruinous	General panic; houses collapse and underground pipes break; damage to reservoirs; buildings shifted off foundations; cracks in ground appear	6.2-6.9 (large, 35,400 tons)
X	Disastrous	Most masonry buildings destroyed; many other buildings destroyed, and railway tracks bend; landslides can be expected on riverbanks and steep slopes	7.0-7.3 (major, 1 million tons) (typical nuclear bomb)
XI	Very disastrous	Few buildings remain standing; bridges and dams destroyed; most services destroyed; landslides and floods occur; underground pipelines are out of service; earth slumps and landslips occur in soft ground	7.4-8.1 (major <7.8, 1 billion tons)
XII	Catastrophic	Total destruction; objects thrown into air as ground rises and falls in waves; large rocks displaced	≅8.2 (great, >7.8, 1 billion tons)

Both the Richter and Mercalli scales are limited in their ability to compare one earthquake to another. The magnitude of the Richter scale has to be extrapolated from seismic readings at various distances rather than the standard 62 miles, and the Mercalli scale is subjective and affected by proximity to the epicenter, soil type, and structures affected. Today earthquakes are measured by the Moment Magnitude scale. The moment magnitude is a measure of the total energy released and is measured by instruments. It is calculated in part by multiplying the area of the fault's rupture surface by the distance the earth moves along the fault. The measurement of moment magnitude allows the objective comparison of earthquakes. The Moment Magnitude scale is most similar to the Richter scale (Table 8-3).

Additional information is needed for the assessment of the potential impact of an earthquake.

Of particular importance is the soil type on which structures are built. Sandy soils are most vulnerable to soil liquefaction and therefore result in the greatest amount of damage. Examples of soil liquefaction were seen after the Loma Prieta earthquake, which caused severe damage in San Fransciso's Marina District. Here a lagoon had been filled 80 years previously with sand and debris to increase living space.

In general the most common cause of earthquake-related damage in California is shaking, not soil liquefaction. Soil liquefaction is a great concern in the Midwest, where a relatively small earthquake (Richter scale 6) along the New Madrid Fault would have catastrophic consequences to such cities as Louisville, Kentucky; Memphis and Nashville, Tennessee; and St. Louis, Missouri.

Aftershocks

Aftershocks are earthquakes that follow the initial large earthquake. In general they are smaller than the initial earthquake, but occasionally they are greater. The likelihood of an aftershock decreases rapidly with time. The rate at which they occur is approximately inversely proportional to the time after the main earthquake. For example, on day 2 the chance of an aftershock is half as great and on day 10 it is one tenth as great. The time elapsed after a major earthquake, however, does not affect the magnitude of an aftershock.

Damage

The extent of shaking that results from an earthquake determines the extent of structural damage. The severity of shaking at any particular geographic point is determined by the amount of fault movement, duration of movement, distance from the hypocenter, soil conditions, radiation pattern (the orientation of the fault to the direction of the slip), and directivity (direction of energy focus, which is worst in the direction of the movement of the fault). Therefore the epicenter is not necessarily the site of greatest damage in an earthquake. Other factors such as the hypocenter, proximity to structures, the potential for landslides, and soil behavior (liquefaction) determine the extent of damage.

The condition of the soil underneath a structure greatly affects what happens to a building in an earthquake. Ground failure results from soil liquefaction. Soil liquefaction occurs when the soil moves like a viscous liquid as water-saturated sand or coarse silts react to vibrations. As S waves pass through this soil, the solid components can be rearranged to create voids that then collapse. Occasionally the opposite happens, and sand boils break through to the surface.

Soil liquefaction results in the greatest amount of damage to buildings, which are shaken violently and in some cases sink into the ground. There are three types of soil liquefaction:

Lateral spread occurs on sloping soils (0.3 to 3 degrees). Lateral spread is soil that moves down slope. After the Prince William Sound, Alaska, earthquake in 1964 over 200 bridges were destroyed because of lateral spread of soil.

Flow failures occur on slopes greater than 3 degrees. These are usually the most catastrophic type of soil liquefaction. Here the soil behaves like a viscous fluid and rolls downhill, destroying everything in its path.

Loss of bearing strength occurs in layers of cohesion less soil beneath the surface. These areas can sink, taking whole buildings with them.

As vibrations generated from the movement of a fault move through the earth from rock to soil, the waves decrease in frequency but their amplitude increases. Large-amplitude (slow) waves result in more intensive shaking of buildings. The looser and thicker the soil, the worse the shaking.