Engineering Geology

Lecture-7

Earthquakes

- Earthquake, any sudden shaking of the ground caused by the passage of seismic waves through Earth’s rocks. Seismic waves are produced when some form of energy stored in Earth’s crust is suddenly released, usually when masses of rock straining against one another suddenly fracture and “slip.” Earthquakes occur most often along geologic faults, narrow zones where rock masses move in relation to one another. The major fault lines of the world are located at the fringes of the huge tectonic plates that make up Earth’s crust.
- There are approximately 1 million earthquakes a year that can be felt by people somewhere on Earth. However, only a small percentage of these can be felt very far from their source. Earthquakes can be compared with one another by the energy they release, their **magnitude**, or by their intensity of shaking, referred to as ground motion, and the resulting impact on people and society (the damage it causes).

Causes of Earthquakes

- An earthquake is caused by a sudden slip on a fault. The tectonic plates are always slowly moving, but they get stuck at their edges due to friction. When the stress on the edge overcomes the friction, there is an earthquake that releases energy in waves that travel through the earth's crust and cause the shaking that we feel.
- Pakistan is split along the boundary between the Eurasian and Indian plates where the India plate slides northward relative to the Eurasia plate in the east. The Eruasia Plate is also being shoved by the Arabia plate as it subducts northward beneath the Eurasia plate along the boundary south of this map.

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Earthquakes

- **Epicenter:** When a news release is issued about an earthquake, it generally gives information about where the earthquake started, known as the epicenter. The **epicenter** is the location on the surface of Earth above the **focus,** which is the point at depth where the rocks ruptured to produce the earthquake.

Earthquakes

- The news also reports **moment magnitude,** which is a measure of the energy released by the earthquake. The moment magnitude is based in part upon important physical characteristics, including the area that ruptured along a fault plane during an earthquake, the amount of movement or fault slip during an earthquake, and the rigidity of the rocks.
- Before the use of moment magnitude, Richter magnitude, named after the famous seismologist Charles Richter, was used to describe the energy released by an earthquake. Richter magnitude is based upon the amplitude, or size, of the largest seismic wave produced during an earthquake. A seismograph is an instrument that records earthquake displacements; seismographs produce seismographic records, or seismograms. The amplitude recorded is converted to a magnitude on a logarithmic scale; that is, each integer increase in Richter magnitude represents a tenfold increase in amplitude. For example, a Richter magnitude 7 earthquake produces a displacement on the seismogram 10 times larger than does a magnitude 6.

Seismograph

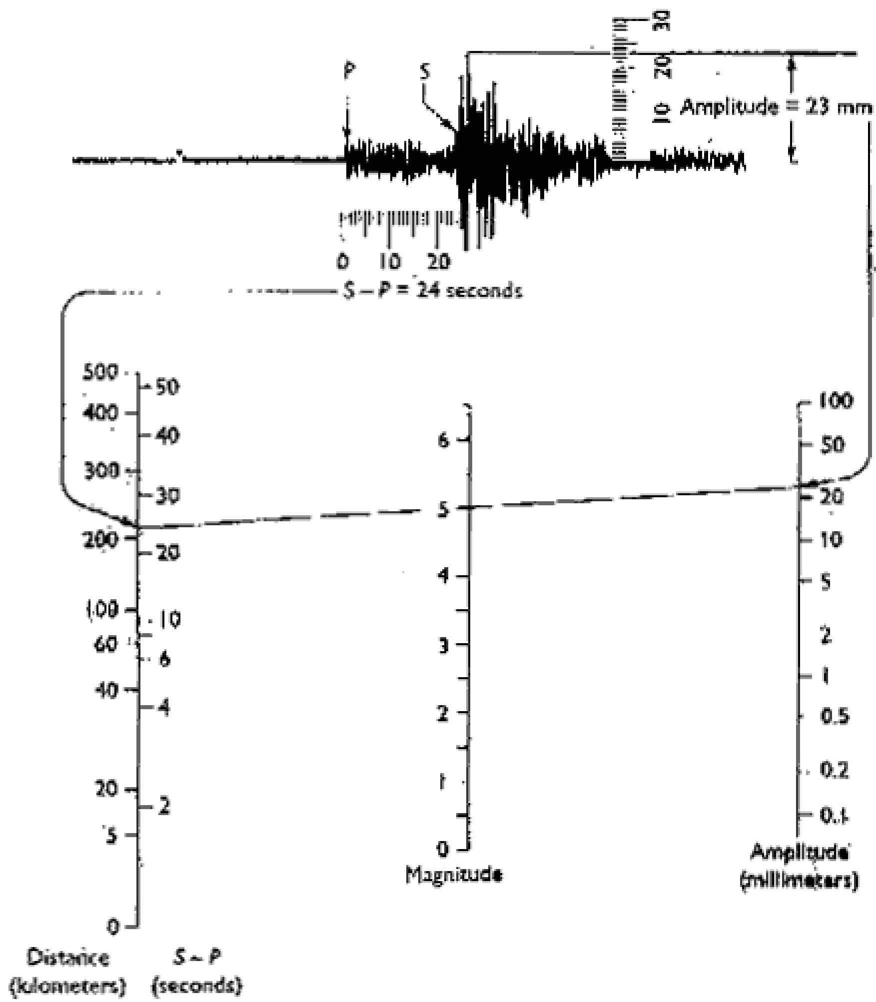
Although the Richter magnitude remains the best known earthquake scale to many people, earthquake scientists, known as seismologists, do not commonly use it. For large, damaging earthquakes the Richter magnitude is approximately equal to the moment magnitude, which is more commonly used today.

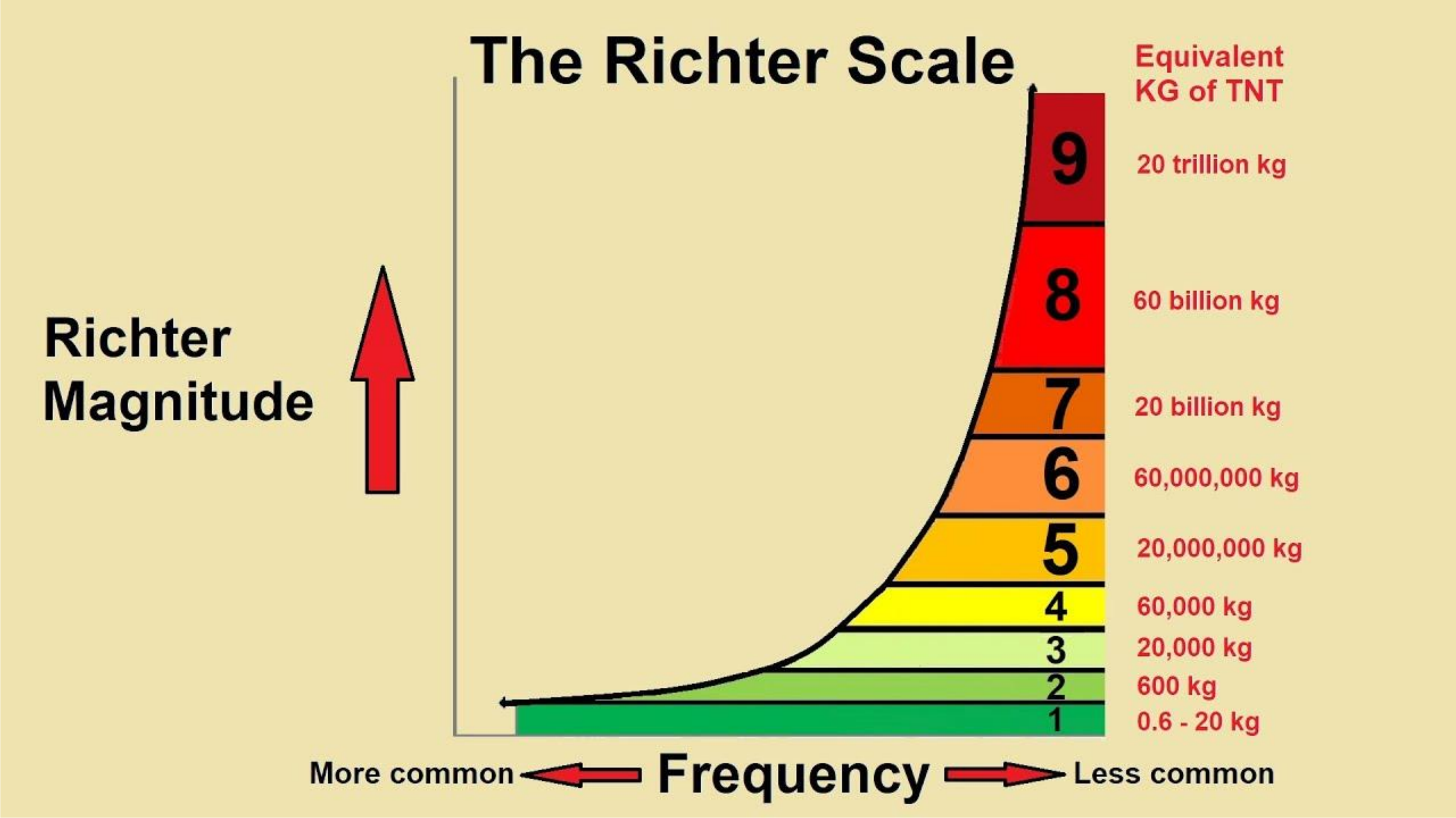
The *seismogram* is the written or digital record of an earthquake. In written form, it is a continuous line that shows vertical or horizontal Earth motions received at a seismic recording station and recorded by a seismograph. The components of a simple seismograph are shown in Figure 6.14a, and a photograph of a modern seismograph is shown in Figure.

A SAMPLE CALCULATION OF THE RICHTER MAGNITUDE (M_L)

Using specially prepared scales, the procedure for calculating the magnitude M_L of a local earthquake is straightforward:

1. Measure the distance to the focus using the time interval between the S and the P waves ($S - P = 24$ seconds).
2. Measure the height of the maximum wave motion on the seismogram (23 millimeters).
3. Place a straight edge between appropriate points on the distance (left) and amplitude (right) scales to obtain magnitude $M_L = 5.0$.




The Richter Scale
Equivalent
KG of TNT
Richter
Magnitude
9
20 trillion kg
8
60 billion kg
7
20 billion kg
6
60,000,000 kg
5
20,000,000 kg
4
60,000 kg
3
20,000 kg
2
600 kg
1
0.6 - 20 kg
More common
Frequency
Less common

Mercalli Intensity	Magnitude	Witness Observations
I	1 to 2	Felt by very few people; barely noticeable.
II	2 to 3	Felt by a few people, especially on upper floors.
III	3 to 4	Noticeable indoors, especially on upper floors, but may not be recognized as an earthquake.
IV	4	Felt by many indoors and few outdoors. May feel like heavy truck passing by.
V	4 to 5	Felt by almost everyone, some people awakened. Small objects moved. Trees and poles may shake.
VI	5 to 6	Felt by everyone. Difficult to stand. Some heavy furniture moves, some plaster falls. Chimneys may be slightly damaged.
VII	6	Slight to moderate damage in well built, ordinary structures. Considerable damage to poorly built structures.
VIII	6 to 7	Little damage in specially built structures. Considerable damage to ordinary buildings, severe damage to poorly built structures.
IX	7	Considerable damage to specially built structures, buildings shifted off foundations. Ground cracked noticeably. Landslides.
X	7 to 8	Most masonry and frame structures and their foundations destroyed. Ground badly cracked. Landslides.
XI	8	Total damage. Few, if any, structures standing. Bridges destroyed. Wide cracks in ground. Waves seen on ground.

Modified Mercalli Scale		Richter Magnitude Scale
I	Detected only by sensitive instruments	1.5
II	Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing	2
III	Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibration like passing truck	2.5
IV	Felt indoors by many, outdoors by few, at night some may awaken; dishes, windows, doors disturbed; autos rock noticeably	3
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects	3.5, 4
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4.5
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos	5
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed	5.5
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	6
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	6.5, 7
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent	7.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up in air	8

CAUSES OF EARTHQUAKE – NATURAL

Earthquakes are a natural consequence of the processes that form the ocean basins, continents, and mountain ranges of the world. Most earthquakes occur along the boundaries of lithospheric plates.

Faulting

The process of fault rupture, or *faulting,* can be compared to sliding two rough boards past one another. Friction along the boundary between the boards, analogous to a fault plane, may temporarily slow their motion, but rough edges break off and motion occurs at various places along the plane. For example, lithospheric plates that are moving past one another are slowed by friction along their boundaries. As a result, rocks along the boundary undergo strain, or deformation, resulting from stress produced by the movement. When stress on the rocks. exceeds their strength, the rocks rupture, forming a fault and producing an **earthquake.**

CAUSES OF EARTHQUAKE – HUMAN ACTIVITIES

Several human activities are known to increase or cause earthquake activity. Damage from these earthquakes is regrettable, but the lessons learned may help to control or stop large catastrophic earthquakes in the future. Three ways that the actions of people have caused earthquakes are

- Loading the Earth's crust, as in building a dam and reservoir
- Disposing of waste deep into the ground through disposal wells
- Setting off underground nuclear explosions

Reservoir-Induced Seismicity

During the 10 years following the completion of Hoover Dam on the Colorado River in Arizona and Nevada, several hundred local tremors occurred. Most of these were very small, but one was M 5 and two were about M 4.[12] An earthquake in India, approximately M 6, killed about 200 people after the construction and filling of a reservoir. Evidently, fracture zones may be activated both by the increased load of water on the land and by increased water pressure in the rocks below the reservoir, resulting in faulting.

Deep Waste Disposal

From April 1962 to November 1965 several hundred earthquakes occurred in the Denver, Colorado, area. The largest earthquake was M 4.3 and caused sufficient shaking to knock bottles off shelves in stores. The source of the earthquakes was eventually traced to the Rocky Mountain Arsenal, which was manufacturing materials for chemical warfare. Liquid waste from the manufacturing process was being pumped down a deep disposal well to a depth of about 3,600 m (11,800 ft). The rock receiving the waste was highly fractured metamorphic rock, and injection of the new liquid facilitated slippage along fractures. Study of the earthquake activity revealed a high correlation between the rate of waste injection and the occurrence of earthquakes. When the injection of waste stopped, so did the earthquakes (Figure 6.25).[13] Fluid injection of waste as an earthquake trigger was an important occurrence because it directed attention to the fact that earthquakes and fluid pressure are related.

Nuclear Explosions

Numerous earthquakes with magnitudes as large as 5.0 to 6.3 have been triggered by underground nuclear explosions at the Nevada Test Site. Analysis of the aftershocks suggests that the explosions caused some release of natural tectonic strain. This led to discussions by scientists as to whether nuclear explosions might be used to prevent large earthquakes by releasing strain before it reached a critical point.

Protective Measures

The mechanism of earthquakes is still poorly understood; therefore, such adjustments as warning systems and earthquake prevention are not yet reliable alternatives. There are, however, reliable protective measures we can take:

- **Structural protection**, including the construction of large buildings and other structures such as dams, power plants, and pipelines able to accommodate moderate shaking or surface rupture. In the 1988 Armenia earthquake (M 6.8) but the loss of life and destruction in Armenia were shocking. At least 45,000 people were killed, and near-total destruction occurred in some towns near the epicenter. Most buildings in Armenia were constructed of unreinforced concrete and instantly crumbled into rubble, crushing or trapping their occupants. The 2005 Pakistan M 7.6 earthquake killed over 80,000 people. Many of the deaths occurred as buildings with little or no steel reinforcement collapsed to resemble a stack of pancakes. However, since most buildings in the Los Angeles Basin are constructed with wood frames or reinforced concrete, thousands of deaths were avoided in Northridge earthquake of magnitude M 6.8 in 1994.

Protective Measures

- **Land-use planning,** including the siting of important structures such as schools, hospitals, and police stations in areas away from active faults or sensitive Earth materials that are likely to increase seismic shaking. This planning involves zoning the ground's response to seismic shaking on a block-by-block basis. Zoning for earthquakes in land-use planning is necessary because ground conditions can change quickly in response to shaking. In urban areas, where property values may be as high as millions to billions per block, we need to produce detailed maps of ground response to accomplish zonation. These maps can assist engineers when designing buildings and other structures that can better withstand seismic shaking. Clearly, zonation requires a significant investment of time and money; however, the first step is to develop methods that adequately predict the ground motion from an earthquake at a specific site.

Earthquake Hazard Reduction

The major goals while reducing earthquake hazard are:

- **Develop an understanding of the earthquake source**. This requires an understanding of the physical properties and mechanical behavior of faults as well as development of quantitative models of the physics of the earthquake process.
- **Determine earthquake potential**. This determination involves characterizing seismically active regions, including determining the rates of crustal deformation, identifying active faults, determining, calculating probabilistic forecasts, and finally, developing methods of prediction of earthquakes.
- **Predict effects of earthquakes**. Predicting effects includes gathering of the data necessary for predicting ground rupture and shaking and for predicting the response of structures that we build in earthquake-prone areas and evaluating the losses associated with the earthquake hazard.
- **Apply research results**. Transferring knowledge about earthquake hazards to people, communities, states, and the nation. This knowledge concerns what can be done to plan better for earthquakes and reduce potential losses of life and property.

During an Earthquake

- During an earthquake, the strong ground motion will greatly restrict your motion, and, as a result, your strategy is to **“duck, cover, and hold.”**
- Given your knowledge of earthquakes, you may also try to **recognize how strong** the earthquake is likely to be and **to predict what may happen during** the event. For example, you know there will be several types of waves including **P, S, and surface waves**. The **P** waves will arrive first, and you may even hear them coming. However, the **S and R** waves, which soon follow, have bigger displacement and cause most of the damage. The length of shaking during an earthquake will vary with the magnitude.
- In addition to the “duck, cover, and hold” strategy, you need to remain calm during an earthquake and try to protect yourself from appliances, books, and other materials that may slide or fly across the room. A good strategy would be to crouch under a desk or table, roll under a bed, or position yourself in a strong doorway.
- During the earthquake, there may be explosive flashes from transformers and power poles, and you must obviously avoid downed power lines. At all costs, resist the natural urge to panic.
- After the shaking stops, take deep breaths and organize your thinking in accordance with the plan you developed. Check on your family members and neighbors, check for gas leaks and fires. Your telephones should be used only for emergency calls.

- If you are caught in a theater or stadium during a large earthquake, it is important to remain in your seat and protect your head and neck with your arms; do not attempt to leave until the shaking has stopped. Remain calm and walk out slowly, keeping a careful eye out for objects that have fallen or may fall.
- If you are in a shopping mall, it is important to “duck, cover, and hold,” away from glass doors and display shelves of books or other objects that could fall on you.
- If you are outdoors and an earthquake occurs, it is prudent to move to a clear area where you can avoid falling trees, buildings, power lines, or other hazards.
- If you are in a mountainous area, be aware of landslide hazards, since earthquakes often generate many slides that may occur during and for some time after the earthquake.
- If you are in a high-rise building, you need to “duck, cover, and hold” as in any indoor location, avoiding any large windows. It is likely that the shaking may activate fire alarms and water sprinkler systems. Streets lined with tall buildings are very dangerous locations during an earthquake; glass from these buildings often shatters and falls to the street below, becoming razorsharp shards that can cause serious damage and death to people below.
- Finally, after an earthquake, be prepared for aftershocks. There is a known relationship between the magnitude of the primary earthquake and the distribution of aftershocks in hours, days, months, or even years following the earthquake. If the earthquake has a magnitude of about 7, then several magnitude 6 aftershocks can be expected. Many magnitude 5 and 4 events are likly to occur. In general, the number and size of aftershocks decrease with time from the main earthquake event, and the most hazardous period is in the minutes, hours, and days following the main shock