Earthquakes – Lesson Outline / Study Guide

1. Introduction
   - Earthquakes are vibrations of the Earth produced by the rapid release of energy during the rapid movement of blocks of the Earth’s crust.
     - The energy released during an earthquake radiates in all directions as body waves (P and S-waves). These body waves travel up to the Earth’s surface and cause destructive surface waves.
     - Seismographs from around the world detect and help locate earthquakes.
   - Earthquakes occur when there is movement between blocks of the Earth’s crust along a fault.
     - Movement along faults can be slow and gradual (movement occurs in small spasms followed by weeks, months, or years of quiet; this is called “creep.”) or movement can be rapid and cause earthquakes.
     - When stresses within the Earth have built up for a long period of time, the lithosphere may rupture when stresses exceed the strength of the rocks. Stresses that build up for long periods of time can cause large displacements along faults which result in large magnitude earthquakes.

2. Movement Along Faults is Mostly Related to Plate Tectonics
   - Most motion along faults can be explained by the Plate Tectonics theory:
     - Normal faulting is caused by tensional stress (Divergent Plate Boundaries).
     - Reverse and thrust faulting is caused by compressional stress (Convergent Plate Boundaries).
     - Strike-slip faulting is caused by shear stress (Transform Fault Plate Boundaries).

3. Terminology
   - Focus – the place deep within the Earth where the crust ruptures and earthquake waves are generated.
   - Epicenter – the location on the Earth’s surface directly above the focus.
   - Fault Trace – the line along which a fault plane intersects the Earth’s surface.
   - Fault Scarp – the cliff formed by vertical movement along a fault. This is an extension of the fault plane which is exposed along the side of the upthrown block of crust.
   - Elastic Rebound – the “snapping back” of rocks to their original dimensions after they rupture; this generates P and S-waves and causes earthquakes.
   - Foreshocks – small earthquakes which can precede a major earthquake.
   - Aftershocks – earthquakes which always occur after the main earthquake. Aftershocks occur because not all of the Earth stresses are relieved by the main earthquake; aftershocks may cause substantial damage because buildings and other structures weakened by the main earthquake can collapse.

4. Seismology: Seismic Waves
   - Body waves include P and S-waves.
     - Body waves travel through the Earth’s interior and include P and S-waves.
     - P-waves travel through solids, liquids, and gases; exhibit a push-pull motion (vibrate parallel to the direction they travel); and move approximately 1.7 times faster than S-waves.
- S-waves travel only through solids and exhibit a “shake” motion (vibrate perpendicular to the direction they travel). S-waves travel slower than P-waves and have a slightly greater amplitude than P-waves.
- Surface waves travel along the surface of the Earth and have a complex motion. They exhibit the greatest amplitude which causes the greatest destruction, travel the slowest of all seismic waves, and have the greatest periods (time between wave crests).

5. Seismographs: Instruments Used to Detect and Locate Earthquakes
- Seismographs are instruments anchored to the bedrock and record ground motion.
  - Seismographs measure both vertical ground motion and horizontal ground motion.
- Seismograms are the paper records which record the time of arrival and amplitude of seismic waves generated during an earthquake (the first arrival of P, S, and Surface Waves, as well as wave amplitude).

6. Triangulation: The Method for Locating Earthquake Epicenters
- Travel-time graphs are created using the arrival times of P-waves and S-waves. These graphs show when P and S-waves arrive from an earthquake at different distances from the earthquake epicenter.
- Seismograms from 3 different seismographs are used to measure the difference in arrival times of P-waves and S-waves.
- The difference in arrival times between P-waves and S-waves are plotted on a travel-time graph to determine the distance from a seismograph station to the earthquake epicenter location.
- For each seismograph station, the distance to the earthquake epicenter from that seismograph station is marked on a map in a circle with the radius equal to the distance determined using the travel-time graph. The epicenter location is where all three circles from the 3 seismograph locations intersect in one point. This method of locating earthquake epicenters is called Triangulation.

7. Measuring the Size of Earthquakes
- Many methods have failed to accurately measure the size of earthquakes. These failed methods include:
  - The amount surface displacement along the earthquake fault.
  - The size of the area affected by surface displacement during an earthquake.
  - The duration of shaking during an earthquake.
- The 2 methods which most appropriately describe the size of earthquake are intensity and magnitude. Of these 2 methods, magnitude is the single best method.
  - Intensity is a measure of the amount of ground shaking based on the amount of damage that occurs during an earthquake at a given location. Damage depends on presence of buildings or structures, therefore it is not an accurate measure of the size of an earthquake.
  - Magnitude uses the amplitude of the largest seismic wave recorded on a seismogram and accounts for the distance between a seismograph station and the earthquake epicenter.
Magnitude is the most accurate measurement of the size of an earthquake:
- Magnitude measurements are logarithmic – each unit of measurement is 10 times greater than the next (for example, a magnitude 6 earthquake is 10 times greater than a magnitude 5 earthquake).
- For each unit of measurement, the amount of energy released increases by 32 times (for example, the energy released by a magnitude 6 earthquake is 32 times greater than the energy released by a magnitude 5 earthquake).
- Measuring earthquakes using magnitude was invented by Charles Richter in 1935.
- Current magnitude measurements use the more sophisticated method of Moment Magnitude, but news reports will report the Richter magnitude because the public is more familiar with Richter’s method.
- On the Earth, many low magnitude earthquakes occur each year, with as many as one million magnitude 2 earthquakes occurring annually.

8. Sources of Earthquakes and Plate Tectonics
- Approximately 95% of earthquakes originate in a few narrow zones on the Earth:
  - Circum-Pacific belt (ring of fire).
  - From the Mediterranean Sea region to the Himalayan Mountains.
  - Along the oceanic ridge system.

9. The San Andreas Fault
- The San Andreas Fault is the most studied fault system in the world.
  - Displacements along this fault occur along segments 100-200 km in length.
  - Some segments of the San Andreas Fault exhibit creep, while others regularly slip producing small earthquakes.
  - Other segments store elastic energy for hundreds of years and when they rupture, large magnitude earthquakes occur. Large magnitude earthquakes (“great quakes”) occur along these segments every 50-200 years.

10. Earthquake Damage
- Damage from earthquakes can result from the following phenomena:
  1. Ground Shaking:
  - Regions close to an earthquake epicenter (20-50 kilometers distance from the epicenter) will experience about the same amount of ground shaking, HOWEVER, destruction varies considerably due to the type of ground buildings and structures are built on.
  - Principle damage done by ground shaking is from differential movement within the same building (e.g., one part of a building moves up, while the other part moves down).
  - Surface seismic waves are lower frequency and higher amplitude than P or S-waves. Consequently, surface waves are the most destructive of all seismic waves.
  - Other factors regarding destruction from ground shaking include:
    • Duration of ground shaking: The longer the ground shakes, the more damage that occurs.
    • Proximity to earthquake epicenter: The closer a location is to an epicenter, the more likely damage will occur.
    • Local geology – The softer the ground (soil or rock), the more seismic surface waves are amplified, resulting in greater destruction.
• Building factors:
  ▫ Wood-frame buildings, such as single-family houses, flex relatively well during an earthquake and typically experience less damage than other structures.
  ▫ Unreinforced masonry (brick) buildings are the most dangerous during an earthquake (they commonly collapse).
  ▫ High-rise buildings are designed to be flexible; they are tied into bedrock whenever possible.

2. **Liquefaction** – Loose sand saturated with water can turn into a mobile fluid that is incapable of supporting buildings or structures.

3. **Surface Rupture** – the ground surface can break and cause damage to buildings and structures.

4. **Tsunamis** – displacement along faults located on the seafloor, or a large undersea landslide triggered by an earthquake, can cause tsunamis.
   - In the open ocean, tsunamis travel at speeds of 500-600 miles per hour.
   - In the open ocean, tsunamis are imperceptible (impossible to see). Typically, tsunami height in the open ocean is less than 1 meter.
   - In shallower coastal waters, the water piles up to heights that occasionally exceed 30 meters (100 feet) in height.

5. **Seiches** – rhythmic sloshing of water in lakes and reservoirs.

6. **Landslides** – landslides can be triggered by ground shaking.

7. **Ground Subsidence** – the ground surface may settle or slump along shallow faults.

8. **Fires** – fires almost always result from earthquake damage.

11. **Earthquakes and Evidence for Plate Tectonics**
• The global distribution of earthquakes is a good fit for the model of Plate Tectonics.
  - A connection exists between deep-focus earthquakes and oceanic trenches/subduction zones.
  - Only shallow-focus earthquakes occur along divergent and transform fault plate boundaries.
  - Earthquake foci are classified as:
    □ Shallow – located at depths from 0 - 70 kilometers.
    □ Intermediate – located at depths between 70 - 300 kilometers.
    □ Deep – located at depths of greater than 300 kilometers.

12. **Earthquake Prediction**
• **Short-range predictions:** Currently no reliable method exists for making short-range predictions.
• **Long-range predictions:** These predictions are given as a probability of a certain magnitude earthquake occurring in a certain time period (for example, there is a high probability for a magnitude 7 earthquake to occur in the next 30 years in the area of the City of Oakland).
  - Long-range forecasts are based on the premise that earthquakes are repetitive or cyclical. Historical records (paleoseismology information) are used to make long-range predictions.
  - Long-range forecasts provide information for developing the Uniform Building Code for constructing safer buildings and for proper land-use planning.