Lecture notes - Bill Engstrom: Instructor **<u>Earthquakes</u>** **GLG 101 – Physical Geology**

Now that we've seen what faults are and how mountains are built, we can look at what happens when there is movement along those faults which are active today.

The first thing we need to find out is what an earthquake is. What we observe is:

- **Movements that produce earthquakes are usually associated with large fractures in Earth's crust called faults.**
- **Most of the motion along faults can be explained by the plate tectonics theory.**
- **Earthquakes can be caused by faults, the motion of magma, and explosions (e.g volcanoes or nuclear bombs)**

Elastic Rebound Theory – Elastic rebound appears to be the primary mechanism of earthquakes. During the process of elastic rebound:

- **Slippage at the weakest point (the focus) occurs after buildup of strain.**
- **Vibrations (earthquakes) occur as the deformed rock "springs back" to its original shape (elastic rebound). Then the entire process is repeated when the strain builds up again.**

Earthquakes most often occur along existing faults whenever the frictional forces on the fault surfaces are overcome.

So…. Exactly what is an earthquake?

<u>An earthquake is the vibration of Earth, produced by the rapid release of energy.</u>

- **Energy released radiates in all directions from its source, the focus (see below).**
- **Energy is in the form of waves.**
- **Sensitive instruments around the world record the event.**

Where do Earthquakes Originate? Remember these definitions.

- **<u>Focus</u> — also known as the hypocenter, it is the place within Earth <u>where earthquake waves originate</u>**
- **<u>Epicenter</u> — location on the surface <u>directly above the focus</u>**

Now let's look at the different types of seismic waves

<u>Body waves</u> - Body waves (travel through "body of rock"). They travel through the Earth's interior, and there are two types based on the mode of travel.

Primary (P) waves

- **Push–pull (compress and expand) "back and forth" motion, changing the volume of the intervening material**

- **Very fast travel time (4 to 7 KM / Sec). Generally, in any solid material, P waves travel about 1.7 times faster than S waves.**
- **<u>Travel through solids, liquids, and gases</u> (almost any medium)**

Secondary (S) waves

- **"Shake" motion at right angles to their direction of travel . The motion is Up/Down and Sideways**
- **Slower velocity than P waves (2 to 5 KM / Sec.)**
- **Slightly greater amplitude than P waves**
- **<u>Cannot travel through fluids</u> (gases and liquids). They travel only through solids**

<u>Surface waves</u> - Travel along outer part of Earth and cause the most destruction.

- **Their motion is complex**
- ***Cause <u>greatest</u> destruction***
- **Exhibit greatest amplitude and slowest velocity (Slower than body waves)**
- **Waves have the greatest periods (time interval between crests).**
- **Referred to as L waves/Long waves/Love waves AND Rayleigh waves**
  - » **<u>Love wave</u> – horizontal shear wave**
  - » **<u>Rayleigh wave</u> – retrograde/elliptical (ocean wave- like) particle motion. This type has a *large ground motion and <u>cause much of the destruction in earthquakes.</u>***

Destruction from Earthquakes

The amount of structural damage attributable to earthquake vibrations depends on:

- **Intensity and duration of the vibrations (e.g. distance from epicenter)**
- **Nature of the material upon which the structure rests (rock type)**
- **Design of structure (construction type)**

Ground shaking

- **Regions within 20 to 50 kilometers of the epicenter will experience about the same intensity of ground shaking.**
- **However, destruction varies considerably, mainly due to the nature of the ground on which the structures are**

Measuring the Size of Earthquakes

Two measurements that describe the size of an earthquake are:

1. **<u>Intensity</u>—a measure of the *degree of* earthquake *shaking* at a given locale *based on the amount of damage*.**

2. **<u>Magnitude</u> estimates the amount of *energy released* at the source of the earthquake.**

Intensity scales

- **The Modified Mercalli Intensity Scale was developed using California buildings as its standard.**

- **The drawback of intensity scales is that destruction may not be a true measure of the earthquake's actual severity.**

Earthquake destruction

Building Construction and Earthquakes – The construction design and resonance frequency can have a major impact on the amount of damage. Buildings need to be constructed to withstand earthquakes in areas where they are prevalent. The recent earthquakes (2010) in Chili and Haiti are good examples of the differences in construction. Chili has less damage than Haiti which is a poor country with poor construction design. Tall buildings can also respond differently based on their "resonance frequency".

Ground shaking versus material type – More ground shaking occurs in poorly consolidated (loose) sediments than solid bedrock. The lesson – if possible, build or buy a home on bedrock in areas prone to earthquakes.

Liquefaction of the ground - Unconsolidated materials saturated with water turn into a mobile fluid. For example, in the San Francisco Bay area, in areas where there are saturated sediments a great deal of damage occurs as a result of liquefaction. A feature called "mud or sand volcanoes" are often seen where liquefaction occurs.

Seiches (pr. Say-shays) - These are the rhythmic sloshing of water in lakes, reservoirs, and enclosed basins. The waves can weaken reservoir walls and cause destruction.

Tsunamis, or seismic sea waves - In the open ocean, height is usually less than 1 meter. However, when the waves reach shallower coastal waters, the water piles up to heights that occasionally exceed 30 meters. As we've seen recently in Japan (2011), these waves can be very destruction. These waves are often inappropriately called "tidal waves." They have nothing to do with the tides. They typically result from vertical displacement along a fault located on the ocean floor or a large undersea landslide triggered by an earthquake. Provided there is an early warning system in place, because the waves take some time to travel across the open ocean, where people live far enough away from the epicenter of the earthquake, they can prepare and evacuate areas before the tsunami reaches them. In areas that are closer to the epicenter, such as in Japan in 2011, there is usually not enough time to evacuate.

Landslides and ground subsidence – Whenever the land moves quickly, as with landslides, there is the potential for a lot of damage and potential loss of life. We will cover landslides (a form of mass wasting) in a future lesson.

Fire – Ruptured gas lines from earthquakes is one of the major hazards. If you live in an earthquake prone area (or anywhere for that matter) you should know how to turn off your gas. Fires destroyed much of San Francisco during the great 1906 earthquake.

Ground Rupture - This refers to areas where the land splits apart causing a rupture. These are often long linear features.

Land shift – An example of land shift is the uplift of the sea floor which has been known to occur during an earthquake.

Power outages, water shortages and interruptions in communication can also be caused by earthquakes.

Foreshocks and aftershocks – Major earthquakes are often preceded by smaller shock waves (forshocks). And, many aftershocks or "adjustments" can occur following an earthquake which can also be extremely destructive. Even though we talk about an earthquake, the release of tension along a fault can continue with a series of quakes. Small earthquakes, called foreshocks, often precede a major earthquake by days or, in some cases, by as much as several years.

How can I prepare for an earthquake? Here is a short list of things you can put together.

- Emergency Food & Water
- First Aid Kit
- Essential Medicines
- Flashlight & batteries
- Portable Radio & batteries
- Sturdy shoes
- $Cash$
- Pocket tool kit (like Swiss Army knife or Leatherman)
- Have a plan of communication

- Secure shelves & heavy objects to walls
- Know how to turn off gas, electric and water

Can Earthquakes Be Predicted? As you can imagine, it's difficult to determine exactly when an earthquake can occur, although sometimes we can get a general idea which areas along a fault might be due for one. These are more long range predictions (forecasts).

Long-range forecasts

- Give the probability of a certain magnitude earthquake occurring on a time scale of 30 to 100 years, or more.
- Based on the premise that earthquakes are repetitive or cyclical
- Using historical records or paleoseismology
- Are important because they provide information used to:
- Help develop the Uniform Building Code
- Assist in land-use planning

By looking at historical records, it's possible to make long term predictions by finding seismic gaps, creeping and locked segments or other space-time patterns.

Seismic Gaps

To help predict when an earthquake may occur, geologists look seismic gaps (inactive zones storing strain for future quakes). If an earthquake has not occurred in a particular area along the fault for a long time, this could be a warning of an impending earthquake. Geologists look at the historical record, and determine where these gaps are.

Space-Time Patterns

Other patterns may also be observed. For example, in some cases, earthquakes may occur at regular intervals in line along a fault zone, and the next earthquake could just be the next one down the line.

Creeping and Locked Segments

- **Fault creep sections** – more frequent with minor shaking. These sections have a lower probability of experiencing a major earthquake because the strain is released more frequently.

- **Locked sections** – most fault sections are locked (due to confining pressure). These sections <u>have the potential for great earthquakes</u>.

Short-range predictions - Currently, there are no reliable methods for making short-range earthquake predictions. The goal would be to provide a warning of the location and magnitude of a large earthquake within a narrow time frame. Research has concentrated on monitoring possible <u>precursors—phenomena that precede an earthquake</u> – e.g. measuring *uplift, subsidence, and strain in the rocks, water level changes, foreshocks, low frequency radio waves, and animal behavior.*

Measuring the size of earthquakes

Seismology – study of earthquake waves

- **The study of earthquake waves dates back almost 2000 years to the Chinese.**
- **Seismographs are instruments that record seismic waves. These records the movement of Earth in relation to a stationary mass on a rotating drum or magnetic tape**
- **More than one type of seismograph is needed to record both vertical and horizontal ground motion.**
- **Records obtained are called seismograms.**

Recall – Earthquake "size" described by two measurements:

1. **Intensity—a measure of the degree of earthquake shaking at a given locale based on the amount of damage**
2. **Magnitude estimates the amount of energy released at the source of the earthquake.**

Measuring the Size of Earthquakes

Magnitude scales

Richter magnitude—concept introduced by Charles Richter in 1935. The Richter Scale is based on the amplitude of the largest seismic wave recorded and accounts for the decrease in wave amplitude with increased distance.

The Richter Scale

- **Is a Log-scale based on wave amplitude (height)**

- ***Increase of 1 (one)* Richter magnitude is a *factor of 10 increase in wave amplitude*.**
- **Example: Mag 5 is 10 times greater in Richter magnitude than Mag 4 and 100 times greater than Mag 3.**
- **Magnitudes less than 2.0 are not felt by humans.**
- **Each unit of Richter magnitude increase corresponds to a tenfold increase in wave amplitude *and a 32-fold energy increase.***

KEY POINT *- Earthquake Magnitude and Energy Equivalent (Remember this)*
Although the Richter Magnitudes are based on 10 fold increases….

- **It takes thirty (30) times the strain energy to create a 10 fold increase in wave amplitude.**
- **Mag 7 releases thirty (30) times the strain energy as Mag 6 and 900x the energy of Mag 5.**

Or….

- **900 Mag 5 quakes release the same amount of energy as 1 (one) Mag 7 earthquake.**

Other magnitude scales - Several "Richter-like" magnitude scales have been developed. Moment magnitude was developed because none of the "Richter-like" magnitude scales adequately estimate very large earthquakes. Other scales may be used more by geologists but Richter is more commonly referred to on the NEWS.

Locating the Source of Earthquakes

Recall the Terms

- **Focus— within Earth where earthquake waves originate**
- **Epicenter— surface location directly above the focus**
- **The epicenter is located using the difference in P and S waves velocities.**

Locating the epicenter of an earthquake

- **Three station recordings are needed to locate an epicenter.**
- ***Each station determines the time interval between the arrival of the first P wave and the first S wave at their location.***
- **A travel-time graph is used to determine each station's distance to the epicenter.**

- **To locate the epicenter a circle is drawn around each seismic station with a radius equal to the distance to the epicenter. The point where all three (3) circles intersect (called "<u>triangulation</u>") = the earthquake epicenter.**

Source of Earthquakes

The locations of earthquakes around the globe help define plate boundaries.

Earthquake belts

- **About 95% of the energy released by earthquakes originates in a few relatively narrow zones that wind around the globe.**
- **Major earthquake zones include the Circum-Pacific belt, Mediterranean Sea region to the Himalayan complex, and the oceanic ridge system.**

Earthquakes—Evidence for Plate Tectonics

- **A good fit exists between the plate tectonics model and the global distribution of earthquakes.**
- **The <u>*connection of deep-focus earthquakes and oceanic trenches*</u> is further evidence.**
- **<u>*Only shallow-focus* earthquakes occur along divergent and transform fault boundaries</u>.**

Earthquake depths

- **Earthquakes originate at depths ranging from 5 to nearly 700 kilometers.**
- **Earthquake foci are arbitrarily classified as:**
  - **Shallow (surface to 70 kilometers)**
  - **Intermediate (between 70 and 300 kilometers)**
  - **Deep (over 300 kilometers)**
- **Definite patterns exist.**
  - **Shallow-focus earthquakes occur along the oceanic ridge system.**
  - **Almost all deep-focus earthquakes occur in the circum-Pacific belt, particularly in regions situated landward of deep-ocean trenches.**

Subduction zones/Trenches - *Earthquake Distribution Near the Tonga Trench(western Pacific) – good example*

From the depth/location of the foci at subductin zones we can determine the fault plane and find out

- **Which plate is subducting**
- **The angle of subduction**

Remember this…..

Wadati-Benioff Zone (usually just called the Benioff Zone) – This is the zone of deep-focus earthquakes (zone of increasing depths to focus/foci away from trench) along the subduction zone.

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