

Lesson 6: Seismic Waves

The earliest scientists first observed the waves that earthquakes produce before they could accurately describe the nature of earthquakes or their fundamental causes, as discussed in Lessons 1-5. Therefore, the earliest solid scientific advances in seismology concerned earthquake waves. As discussed in Lesson 5, earthquakes occur when elastic energy is accumulated slowly within the Earth's crust as a result of plate motions, and then released suddenly at fractures in the crust called faults. The released energy travels in the form of waves called seismic waves. It is this released energy that puts human beings and human structures in danger. Therefore, it is critical to understand where this energy is released and in what form.

In this lesson, students learn about different types of seismic waves on the basis of where and how the waves move. In addition, students discuss how scientists use earthquake waves to investigate the interior structure of the Earth.

This activity is designed for one 1-hour class period.

Materials

A few Slinkys
1' of white (or other brightly-colored) plastic tape
One 2 meter rope
One Brick
One hammer

Introduction

1. Ask a student to give a definition of an earthquake using the knowledge gained in Lesson 5. Remind students that earthquakes occur when elastic energy is accumulated slowly within the Earth's crust as a result of plate motions, and then released suddenly along fractures in the crust called faults. Tell students that the released energy can travel through the Earth's interior and along its surface, and that it can put human beings and human structures in danger.
2. Encourage students to discuss how they think the elastic energy travels to the surface of the Earth or whether they think it passes through the entire Earth. Use a simple example: Ask students to predict what would happen if they touch one end of a brick and tap the other end with a hammer. If you have a brick and a hammer, allow students to experiment with them. Students should be able to feel the energy of the hammer in their fingertips. Encourage students to guess why they can feel the energy. Explain to them that they can feel it because the energy of the hammer blows travels to their fingertips in the form of waves.
3. Explain to students that earthquake energy travels in form of waves. These waves are called seismic or earthquake waves. There are different kinds of earthquake waves: body waves and surface waves. Body waves pass through the interior of the Earth whereas

surface waves travel along the Earth's surface. Explain that earthquake waves move particles of material in different ways: compressional waves create a back and forth motion parallel to the direction of the waves whereas shear waves create a back and forth motion perpendicular to the direction of the waves.

4. Ask your students where they think the seismic waves of an earthquake originate. Students may answer: along the fault plane or at a single point along the fault. Introduce to your students these two terms: hypocenter (focus) and epicenter. The focus of an earthquake is where rock ruptures and slips, whereas the epicenter is the point on the surface of the Earth that lies directly above the focus.

Caution! While the first seismic waves radiate from the focus, later waves may originate from anywhere across the area of slip. Therefore, all of the energy of an earthquake is not always radiated from the focus, and for this reason, the focus of an earthquake is not always the only source of seismic waves (Wampler, 2002)

5. Encourage students to think about other kinds of energy that travel in the form of waves (i.e. sound, light, etc.). Explain to students when a train whistle screams, the sound they hear has moved through the air from the whistle to their ears in the form of sound waves. Explain to them that waves are disturbances that transmit energy from one point to another by causing periodic (back and forth) motions. The whistle causes the nearby air molecules to vibrate. As molecules begin to vibrate, they bump against each other, and cause the neighboring molecules to vibrate. When the molecules next to their ears start to vibrate, that is when they hear the whistle. Ask students if they can hear sounds in outer space where there is no air. The answer is no. Sound energy cannot travel through a vacuum because there is no medium to be disturbed or vibrated. Ask students if sound energy can travel through solids or liquids. The answer is yes. Sound energy can cause molecules in solids or liquids to vibrate. Ask students why sound energy can travel through solids faster than liquids. Explain to students that in solids, molecules are closer to each other, and can bump each other quicker.

Note! Some people may hear earthquakes when earthquake waves travel through the ground (e.g., from a rumble to a boom). This is because earthquakes can sometimes generate sound waves in the audible frequency range. The sound energy travels through the ground, but can also be transmitted into the air.

Procedures

1. Divide students into pairs or groups of four. Hand each group/pair a Slinky and some plastic tape.
2. Direct students in each group/pair to mark two spots on their Slinky near the center with plastic tape at the top of adjacent loops. Students mark the coils so that they can see the movement of energy along their length.

3. Have two students each hold one end of the Slinky for their group. Stretch out the Slinky to about 3-meters along a floor, table, or other flat surface. Have students take turns compressing about 10-20 coils, and then releasing them rapidly while they hold the end of the slinky, watching the energy wave travel the length of the Slinky.

4. After several repetitions, ask students to describe their observations of the coil and the tape: the coils move back and forth along the length of the Slinky as they compress and expand it. Ask students what kind of earthquake waves this Slinky motion resembles. The answer is compressional waves. Remind them that in compressional waves, particles of material move back and forth parallel to the direction in which the wave itself moves. As a compressional wave passes, the material first compresses, and then expands. P-waves (P stands for primary) are compressional earthquake waves that pass through the interior of the Earth. P-waves change the volume of the material through which they propagate.

Note! P-waves in the air are sounds. P-waves can move faster through the ground than the air, but not all of this energy is in the range of human hearing. When the sound waves are in the audible frequency range, some people may hear them.

5. Now tie one end of a 2 meter rope to the door knob of the classroom door. Ask one student to hold the free end of the rope in his/her hand. Ask the student to back away from the door until the rope is straight with a little bit of slack, and start to gently shake the rope up and down. Allow each student to create this motion. After several repetitions, ask students to describe the rope motion. Ask them what kind of earthquake wave motion this resembles. The answer is shear waves. Remind them that in shear waves, particles of material move back and forth perpendicular to the direction in which the wave itself moves. S-waves (S stands for secondary) are shear earthquake waves that pass through the interior of the Earth. S-waves don't change the volume of the material through which they propagate, they shear it.

Note! The motion of the rope due to shear waves is much easier to observe than the compression waves, but the shear waves travel more slowly than compression waves. In an earthquake, scientists can observe the arrival of compression waves before the arrival of shear waves using seismographs. You may choose to show a close-up of a record (seismogram) for a single earthquake event, and ask your students to point out different seismic waves. In addition, shear waves cause much more damage to structures since it is easier to shake surface rocks than it is to compress them.

6. Encourage your students to critically evaluate their slinky and rope setup. Ask them if they see any limitations associated with their setup. Ask them to compare and contrast their simple setup with actual vibrations caused by seismic waves traveling through the Earth or along its surface. For instance, seismic waves carry energy from the source of the shaking outward in all directions (not in one direction only as the setup shows).

7. (Optional) Both primary and secondary waves are body waves (pass through the interior of the Earth). Surface waves travel along the Earth's surface. Two examples of surface waves are Rayleigh waves and Love waves. Explain to your students that

Rayleigh waves cause the ground to ripple up and down (like water waves in the ocean before they break at the surf line) whereas the Love waves cause the ground to ripple back and forth (like the movement of a snake).

8. Ask the students to recall how scientists use seismic wave observations to investigate the interior structure of the Earth. This is similar to checking the ripeness of a melon by tapping on it. To understand how scientists see into the Earth using vibrations, one needs to understand how waves or vibrations interact with the rocks that make up Earth. Introduce to your students the two simplest types of wave interactions with rocks: reflection and refraction. Ask students to define reflection. They should be able to give simple examples like echoes or reflection in a mirror. Explain to your students that echoes are reflected sound waves, and that students' reflections in a mirror are composed of reflected light waves. Tell students that a seismic reflection happens when a wave impinges on a change in rock type. Part of the energy carried by the wave is transmitted through the material (refracted wave) and part is reflected back into the medium that contained the wave. Refraction can be demonstrated by dropping a coin in a bottle filled with water. The coin changes direction when it hits the water's surface and won't sink to the bottom vertically. In other words, the path of the coin refracts (changes direction) when moving from the air into the water.

9. Explain to students that seismic waves travel fast, on the order of kilometers per second. The speed of a seismic wave depends on many factors. Ask students to think about a few factors that can change the speed of a seismic wave (e.g. rock composition, temperature, pressure, etc.) Ask them to explain how these factors can change the speed of a seismic wave. Students should be able to answer these questions based on the knowledge they acquired throughout this lesson. Seismic waves travel faster in denser rocks; temperature tends to lower the speed of seismic waves; pressure tends to increase the speed.

Caution! The speed of a seismic wave generally increases with depth, despite the fact that the increase of temperature with depth works to lower the wave velocity.

Reference

Wampler, J.M. (2002) Misconceptions – A column about errors in geoscience textbooks, *Journal of Geoscience Education*, 50(5), 620-623