

# Seismic Slinky Modeling P and S Waves

Version 05/06/21

Incorporated Research Institutions for Seismology ([www.iris.edu/earthquake](http://www.iris.edu/earthquake)) activity modified with permission for ShakeAlert ([www.shakealert.org](http://www.shakealert.org)). See [www.iris.edu/hq/inclass/video/202](http://www.iris.edu/hq/inclass/video/202) for original version.

## OVERVIEW

In this activity, learners will model seismic waves using a Slinky® to experience how seismic waves interact and move through the Earth (Figure 1).

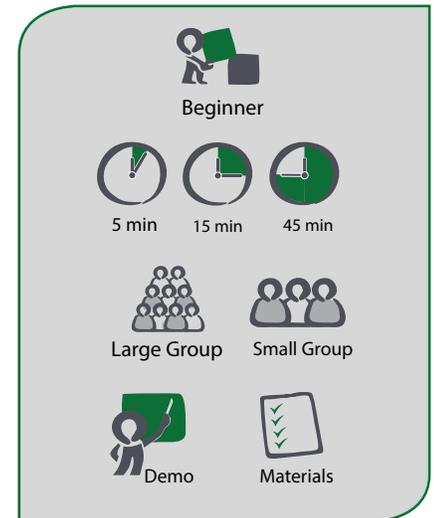
Three different options provide opportunities to understand the characteristics of different types of seismic waves. During the 5-minute activity learners observe an animation about fast-traveling P waves and the slower-traveling S waves then discuss the basics of the ShakeAlert Earthquake Early Warning system. The 15-minute activity provides hands-on experience of how P and S waves travel using a Slinky®. The 45-minute or longer activity provides learners an opportunity to explore additional seismic wave concepts and how they relate to real world situations. See Appendix A for vocabulary terms used in this activity.

Why is it important to learn about seismic waves? More than 143 million people are exposed to potential earthquake hazards in the U.S. that could cost thousands of lives and billions of dollars in damage. The foundation of earthquake early warning depends on the detection of the faster, less damaging P wave, and the ability to send an alert before the slower, more damaging S wave arrives. The ShakeAlert® Earthquake Early Warning system for the West Coast of the U.S. detects significant earthquakes quickly so that alerts can be delivered to people and automated systems. Early notification about potential strong shaking that may cause damage is fundamental to earthquake hazard mitigation.

## OBJECTIVES

Learners will be able to:

- Use the model as a tool to observe and understand seismic wave properties.
- Describe the difference between P and S waves based on the direction of particle motion relative to the direction of propagation.
- Understand that seismograms show characteristics of each type of seismic wave.



Time: 5-, 15-, and ≥ 45- minute guided activities that can be adapted for audience and venue.

Audience: This can be done with novice and experienced geoscience learning groups.



Figure 1: Seismic Slinky® demo

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## MATERIALS

### Materials for the 5-minute activity:

- Computer with projection system
- Small 3" Slinky
- (optional) Tape

### Materials for the 15-minute activity:

- 2 or more 3" Slinkies—metal is best, but plastic will also work
- String or tape to connect shorter Slinkies together for the demonstration
- OPTIONAL though recommended: An extra long metal Slinky© (for example "Super-Spring and stand" 7.88 in. [20 cm]) works best for a large group demonstration (Figure 3)
- Blue or green painter's tape to create a short line of tape on the floor
- Stop watch (if you wish to time the waves)
- Computer projection to show seismic-wave animations

### Materials for 45-minute activity:

#### Instructor-led and learner-group demonstrations

Explorations 1 and 2, large group demonstration:

- Basketball or soccer ball
- 3-5 small Slinkies
- Duct tape
- Computer projection system

Explorations 3 and 4, large group demonstration:

- 2 or more small Slinkies—metal is best, but plastic will also work
- String or tape to connect shorter Slinkies together
- OPTIONAL and recommended: A large metal Slinky© (for example "Super-Spring and stand") works best as a whole-class demonstration
- Computer projection system

Table Groups:

- Explorations 1–4
- 1 or 2 small Slinkies for each table group (metal is best, but plastic will also work)
- Learner Worksheets: Seismic Slinky Explorations (Appendix E) for each learner

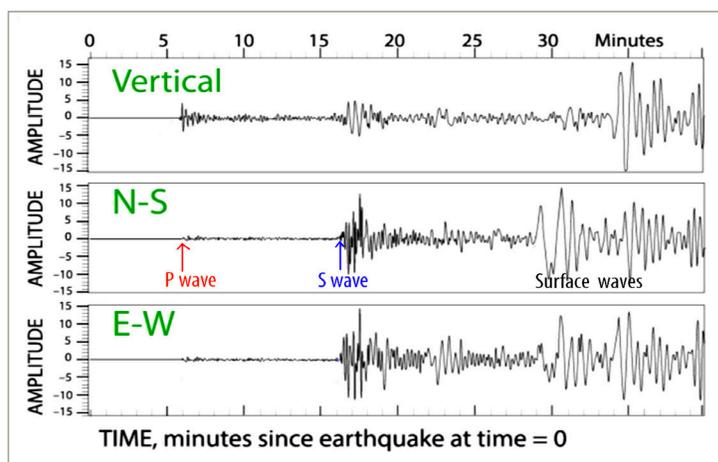


Figure 2: The different behavior of P, S, and surface waves explain how the 3 seismometers in the seismograph station have different seismograms. (Screen grab from animation, "3-Component Seismogram"; link in Relevant Resources on next page.)

- 1) The vertical component shows the compressive P wave bumping up from beneath; it has very little horizontal movement.
- 2) The S wave is moving side to side in the direction of travel, so it has much more side-to-side motion (apparent on the north-south and east-west components of the seismogram) and a smaller effect in the vertical (or less of a bump) from beneath the station.
- 3) Surface waves have a huge effect on all components because of their more complex motions.



Figure 3: Super-sized Slinky and stand available at scientific supply sources.

## RELEVANT MEDIA RESOURCES

### Video:

- [Seismic Slinky: Modeling P & S Waves in the Classroom](#) (Figure 1)
- [Seismic Waves Viewer](#) (tutorial)—How do seismic waves move across and through the Earth? Features the March 11, 2011 M9 Tohoku earthquake and tsunami.

### Animations:

- [3-Component Seismogram Records Seismic-wave Motion—How do we capture the motion of an earthquake?](#)
- Download optional file, "GIF 3-component seismograms" from the animation page: [3-Component Seismogram Records Seismic-wave Motion](#)
- [Download animations of seismic-wave motion.](#)
- [Subduction Zone: Simplified model of elastic rebound](#)

### App:

- [Seismic Waves Viewer App](#)

## INSTRUCTOR PREPARATION

Wave motions can be demonstrated with an easily recognized and common toy, the Slinky®.

Yes! Rocks are elastic! Seismic wave energy is a dynamic or short-lived change in the arrangement or position of rock materials. As the energy goes through the rock, it can deform in response to the seismic wave and then return to their original position. The exact nature of the deformation depends on the type of seismic wave and the materials they pass through. The Slinky® allows learners to observe energy moving through matter (the slinky coils), and briefly see the Slinky® deform or change in response to the movement.

Earthquakes produce two main types of seismic waves: body waves and surface waves. Both P and S waves are body waves which travel through the body (or interior) of the earth. Rayleigh and Love waves are surface waves which travel in the uppermost layers (surface) of the earth. Surface waves are not modeled in these activities. Each wave type moves through materials differently. Waves can also reflect, or bounce off boundaries between different layers of the earth. The waves can also bend, or refract, as they pass from one layer into another. Scientists learn about Earth's composition

## NOTE

- Caution learners to treat the Slinkies with care as they can tangle and become bent.
- Ideally, have at least one "Super" sized Slinky ("Super Spring") for a large group demonstration. This Slinky is 8" when compressed and can be found at scientific supply sources with different names. Treat the Super Slinky with extra care, as it is particularly prone to tangling.

by studying the paths and speeds of seismic waves traveling through Earth. Although earthquakes create different types of seismic waves, the focus of this activity is on P and S waves and how they inform earthquake early warning.

### Review the relevant media resources listed above and Appendix A–F:

- Appendix A: Vocabulary
- Appendix B: ShakeAlert: Implementing Public Earthquake Early Warning for the U.S.
- Appendix C: Personal Protective Actions Poster
- Appendix D: Types of Seismic waves
- Appendix E: Learner Worksheets; Instructor Answer Key
- Appendix F: NGSS SCIENCE STANDARDS

## ACTIVITIES AND DEMONSTRATIONS

### IF YOU HAVE 5 MINUTES

#### Did You Know?

An earthquake generates seismic waves that have specific characteristic motions as they travel through the earth. We will learn about two seismic waves (the P and the S wave) as we watch a short animation. We will also discover the differences in the seismic wave arrival times for these two waves. The P wave travels faster than the S wave. When we detect the P wave, we can provide critical earthquake early warning of potentially damaging earthquake shaking with the S wave that follows.



## Preparation:

- Have the following ready to show on the instructor's computer projection system:
  - "[How do we capture the motion of an earthquake?](#)" (2:53)
  - Image: "[ShakeAlert Earthquake Early Warning Basics](#)"
- Have one small Slinky ready for a demonstration

## Directions:

1. Show the animation "[How do we capture the motion of an earthquake?](#)" If time is short, cue the animation to start at 1min20sec to focus on the speeds of the P and S wave (2:53)
2. Following the animation, demonstrate how P and S waves travel. Use a small Slinky on a flat surface such as a table. Demonstrate a P (or primary wave) with one of the following methods (Figure 4):

- **Method A:** Stretch the Slinky to at least 8" between your hands on a flat surface. Send a quick, sharp forward pulse of energy down the length of the Slinky.

- **Method B:** Tape one end of the Slinky to the table surface. Stretch the spring at least 8" holding the opposite end with one hand. With the other hand, quickly hit the first hand sending a forward pulse of energy down the length of the Slinky.  
*Note:* Method A is more visual, however, Method B more accurately demonstrates that energy travels through the medium, rather than the medium itself traveling over a distance.

Explain that a typical P wave travels at 10,000 mph. Sound travels through air at about 750 mph. The P wave usually is not the damaging wave.

3. Next demonstrate an S or shear wave. Stretch the Slinky to at least 8" between your hands on a flat surface. With one hand, quickly create a single motion either side to side or up and down. This motion is perpendicular to the direction of travel (or transverse), which makes the wave travel slower. The S wave travels at about 6,000 mph. P waves travel about 60% faster than an S wave (Figure 5).

## Questions for Discussion:

- Compare the animation of the seismogram and with the Slinky model. What did you notice about the different speeds of the P- and S- waves traveling through the Slinky? Did the speed of the P and S waves modeled in the Slinky replicate what is shown in the seismograph? Why or why not? (*Answers will vary. Some learners may not see any*

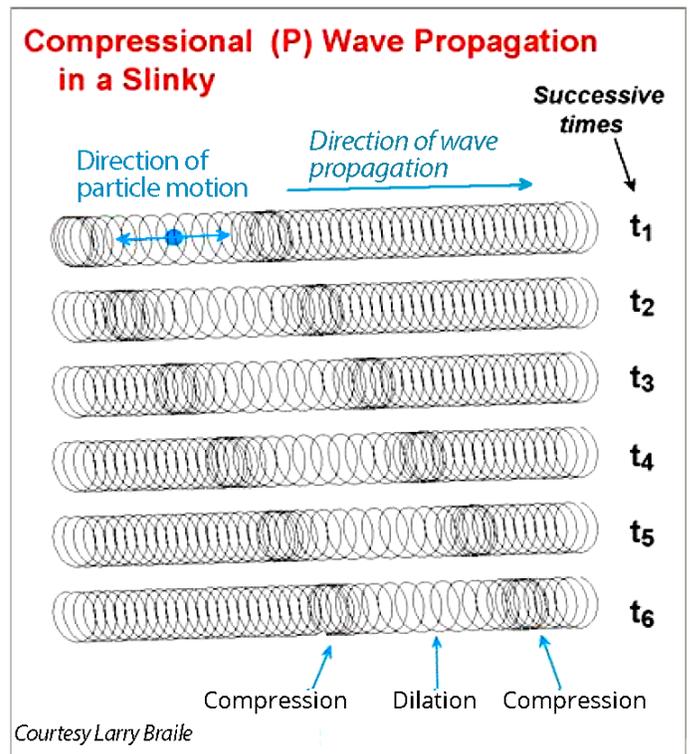


Figure 4: The compressional (P wave) propagation behavior in a Slinky. Notice that the direction of motion is in line with the direction that the wave propagates. [Animation](#).

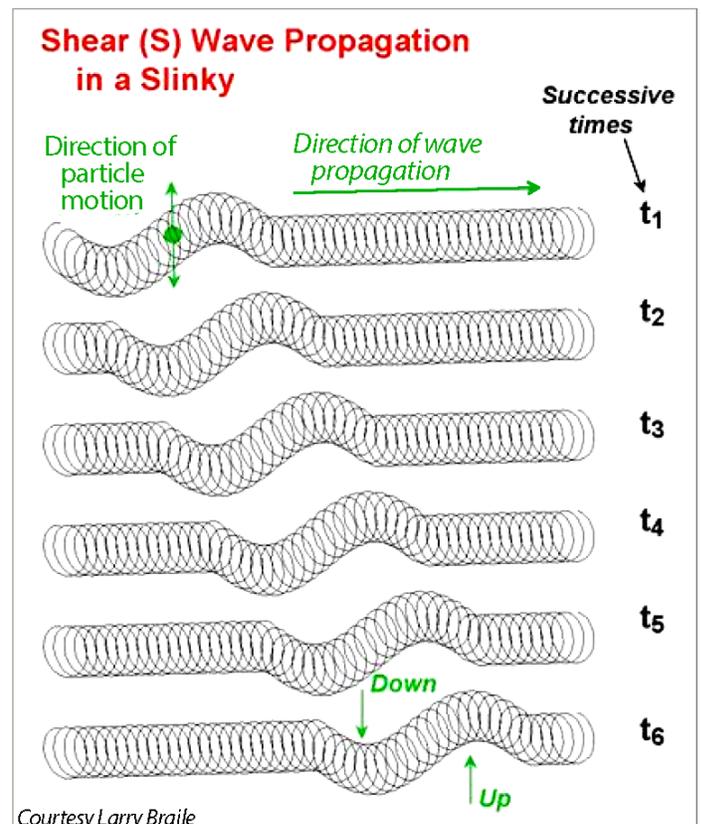


Figure 5: The shear wave (S wave) propagation behavior in a Slinky. Note that the direction of particle motion is perpendicular (transverse) to the direction of wave propagation. [Animation](#).

*difference in the demonstration. If time allows, discuss that the Slinky is a model; we can see the shape of the different types of waves, however the speed is more difficult to show through the model.)*

4. The movement of the Slinky models the propagation of seismic waves through the earth. Remind learners that the waves move away from the earthquake hypocenter in all directions. Note: This concept is demonstrated in the 45-minute activity Exploration 1. The distance between the P- and S-wave arrival times recorded by multiple seismograms (or earthquake records) provides critical information about the magnitude, distance and type of earthquake that has occurred. Because of the difference in the arrival times in P and S waves, the ShakeAlert earthquake early warning system is able to detect the P wave and then send alerts that the more damaging, slower moving S wave will soon arrive. Earthquake early warning can provide valuable seconds to take protective actions, such as Drop, Cover and Hold On.
5. Show the graphic "ShakeAlert Earthquake Early Warning Basics" in APPENDIX B.
6. Read the text on the graphic that describes how the ShakeAlert earthquake early warning system works, pointing out the corresponding labels on the digram itself.

### Questions for Discussion:

- If you receive a ShakeAlert notification, what should you do? (*It depends on where you are and what you are doing as to what protective action you will take. In most instances, locate shelter to protect at least your head and neck, then Drop, Cover and Hold On. For other examples in a variety of settings, see the FEMA poster found in APPENDIX C.*)

### Timing P- and S-wave travel times

If you time the P and S waves with the Seismic Slinky model on the floor, you may discover that the P wave does not travel faster than the S wave, the way it does inside the earth. Watch "[Seismic Slinky: Modeling P & S Waves in the Classroom](#)": which explains that friction and drag on the floor slows the motion of the P wave. The perpendicular motion of the S wave does not exhibit the same amount of drag as the Slinky moves on the floor. The activity "[Human Wave Demo—Modeling P & S waves in Solids & Liquids](#)" human-wave more accurately models the difference in P- and S-wave travel times.

## IF YOU HAVE 15 MINUTES

### Did You Know?



- Did you know that seismic waves move through material, such as through the Earth's interior and along the surface of the Earth?

The Seismic Slinky® helps learners observe key aspects of P- and S- seismic wave behavior. The activity can be used as a whole group, instructor-led demonstration with learner participation with a large super-sized Slinky. Alternatively, the activity can be used with smaller Slinkies as a table group exercise. Learners discover that energy from seismic waves moves through a medium and disrupts the components of the medium only for a moment.

### Preparation:

- Locate a large open area with a hard surface such as a hallway that can be used to stretch the Slinky and for learners to gather and observe the demonstration.
- At the mid-point on the floor where the Slinky will be stretched, place a piece of blue or green painter's tape (about 6" long) on the floor perpendicular to the Slinky's® length. This will provide a reference point as the wave passes over the line of tape.
- Put a small piece of masking tape on a coil in the middle of your Slinky which you will position above the tape on the floor during the demonstration.
- If you don't have a large Slinky ("Super Spring"), this lesson is more effective if you tape two Slinkies together. This allows learners to watch the compressions and dilations travel a longer path which can be timed with a stopwatch. Students can compare the speed of the P wave versus the S wave.
- Review side bars: Why do P waves travel faster than S waves? And Timing P- and S-wave travel times.
- Have a computer data projector ready to show Appendix D: Types of Seismic Waves.
- Review the reference: Types of Seismic Waves found in Appendix D.
- Download animations of [seismic-wave motion](#) to show on the instructor's computer projection system.

### Directions:

1. Start in the classroom with instruction. Learners should understand:
  - Seismic waves transfer energy from place to place by repeated small vibrations of particles in the Earth.
  - Seismic waves pass energy through earth materials. All material returns to the same place after the wave has passed because rocks are elastic, like a Slinky! (The

exception? Materials and structures on Earth's surface that experience such severe ground shaking that they move and deform to the point of failure. The seismic retrofit of buildings and other structures can help them withstand seismic shaking during a moderate to major earthquake.)

- Show Appendix D and explain that we will focus on P and S waves in our explorations.
  - Show the animation of [seismic wave motion](#).
2. Move to the open area you have prepared for the demonstration.
  3. Ask learners to line up on each side of the Slinky demonstration (Figure 6).
  4. Ask a volunteer to hold one end of the Slinky while the instructor holds the other end.
  5. Stretch out the Slinky as far apart as possible without overstressing! Adjust the Slinky location so that the tape marker located on a coil in the center is positioned over the line of tape on the floor.
  6. Demonstrate a P (compressional) wave (Figure 4). Experiment with each of the methods to initiate wave energy:

### Why do P waves travel faster than S waves?

P waves and S waves are body waves that travel through the earth. On average, P waves travel 60% faster than S waves because of the differences in how the waves travel through the layered interior of the Earth.

P waves are compressional waves that move in line with the direction of travel. As the interior of the Earth is almost incompressible, P waves transmit their energy quite easily through the medium and therefore travel quickly.

S waves are shear waves, which means that the wave motion is perpendicular to the direction of wave propagation. Thus, the wave energy travels less easily through the medium, and S waves are slower. In addition, liquids cannot sustain shear, so S waves do not travel through the Earth's liquid outer core. The differences in wave properties between P- and S waves provides evidence that the Earth's interior is layered.

- a. One person should cup his or her hand over the end of the Slinky and hit that hand with the fist of the other hand, making sure that the motion is toward the opposite end. Repeat several times to get enough energy to travel the distance needed. Though not as visual as the next method, this method more accurately demonstrates that energy is transferred through a medium (like a sound wave) rather than the medium moving (like a ball being thrown).
- b. One person holds the end of the Slinky and quickly pushes the coils forward and back a short distance with a short burst of energy (as shown in video demonstration). The compressional disturbance will propagate to the other person. Notice that the wave does not stop when it reaches the end of the slinky, but reflects off the end and heads back to where it started. This will continue until the wave energy dies out.

### Questions for Discussion:

- What happens to the P wave as it travels? (*The leading edge of the wave compresses the coils, and then they rebound (dilate) back to their starting position.*)
7. Demonstrate the S (shear) wave (Figure 5). This is done by moving your hand abruptly left and right (or up and down), for a range of about 18–24" (as shown in video demonstration). This motion causes energy to travel through the coils perpendicular to the direction of travel, also known as a secondary or transverse wave.

### Questions for Discussion:

- What happens to the amplitude of the S wave as it travels? (*The amplitude decreases with distance. See Vocabulary in Appendix A.*)



Figure 6. Learners spread out to watch the large group demonstration. Roger Groom's Mount Tabor Middle School Earth-science class.

- The motion by which you moved the Slinky was purely perpendicular to the direction of propagation, yet the disturbance you created still propagates away from the source, along the Slinky. Why is that? (*Energy is transferred from one coil to the next because each coil is connected and the Slinky is elastic. This model is very similar to rocks in the earth.*)
- Which waves would be more destructive to structures? (*S waves are more damaging than P waves because they have greater amplitude and produce vertical and horizontal motion of the ground surface.*)
- Why are the speeds of P and S wave arrival times at recording stations critical for earthquake early warning systems? (*Because of the difference in the arrival times in P and S waves, the ShakeAlert earthquake early warning system is able to detect the P wave and then send alerts that the more damaging, slower moving S wave will soon arrive. Earthquake early warning can provide valuable seconds to take protective actions including Drop, Cover and Hold On.*)

## IF YOU HAVE 45 MINUTES



### Did You Know?

- Did you know that we can model different characteristics of seismic waves such as the direction of wave propagation, travel times, elastic rebound, and wave interference?

Four explorations each begin with an instructor led direction and demonstration with learner participation. Table groups then continue to explore each topic in small table groups. A learner worksheet helps students record observations and summarize the key points for each focus topic. Instructors can select as many Explorations as they choose. Doing all four explorations could take more than one class period.

### Exploration 1—Seismic Slinky Wave Propagation:

Seismic waves travel outward in all directions from the hypocenter. Seismographs in an array of locations can determine the location of the hypocenter.

### Exploration 2—Seismic Slinky Wave Travel Time:

Seismograms show seismic wave travel times. The distance between P and S wave arrival times help determine the distance to the hypocenter.

### Exploration 3—Stored Energy and Elastic Rebound:

The slow buildup of strain on a fault due to plate motion, is similar to what happens when coils on one end of the Slinky are gathered up, storing potential energy before being released in an earthquake.

### Exploration 4—Constructive and Destructive Wave

**Interference:** When seismic waves interfere constructively, greater amplitudes and shaking will occur. Wave interference is greatly enhanced in loosely consolidated sediments that collect in basins and valleys areas.

### Materials:

#### Full group demonstration of Explorations 1 and 2:

- One basketball or soccer ball
- 3–5 small Slinkies
- Duct tape
- Cellophane or masking tape
- Computer projection system

#### Demonstration set up:

- Use Duct tape to securely attach the base rings of each Slinky onto a basketball or soccer ball. Place masking tape over the whole Slinky to temporarily hold the slinky in its coiled position until ready to use. Continue with the remaining 3 or 4 Slinkies in different orientations (Figure 7).

*Note:* Do not place a Slinky to hang vertically to reduce the effects of gravitational pull.

Leave space to hold the ball with both hands.

#### Full group demonstration of Explorations 3 and 4:

- One large Super Slinky or two small Slinkies tied or taped together
- Computer projection system

#### Demonstration set up:

- Locate a large open area with a hard surface such as a hallway that can be used to stretch the Slinky and for learners to gather and observe the demonstration.

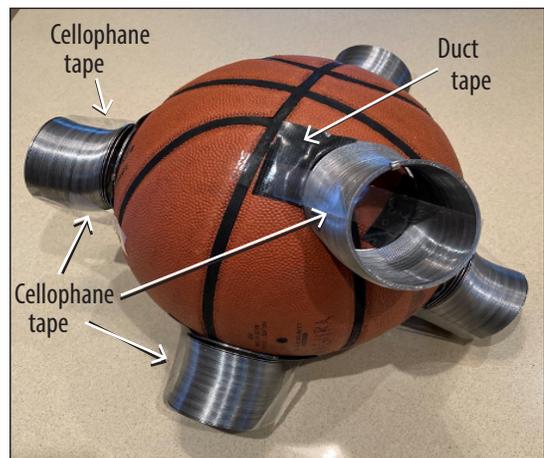


Figure 7: Five Slinkies attached to a basketball in different orientations.

- If you don't have a large Slinky ("Super Spring"), this lesson is more effective if you tape two Slinkies together. This allows students to watch the compressions and dilations travel a longer path which can be timed with a stopwatch. Students can compare the speed of the P wave versus the S wave.
- For Exploration 4, it is helpful to use lines created by floor tiles to help learners measure the relative amplitude of the waves being generated.

**For each table group of Explorations 1–4:**

- 1 or 2 small Slinkies
- Learner Worksheet for each person (Appendix E)

**Demonstration set up:**

- Print Learner worksheets for individuals or as a group (Appendix E)

**Video and Animations for the Explorations:**

- Have computer animation ready to show:
  - For Exploration 1: [3-Component Seismogram Records Seismic-wave Motion](#) (2:53)
  - For Exploration 2: Seismic waves: [P and S wave particle motion and relative wave-front speeds](#) (54 sec.)
  - For Exploration 3: Subduction Zone: [Simplified model of elastic rebound](#)
  - For Exploration 4: Buildings and Bedrock: [Effects of Amplification and liquefaction](#) (1:24)
  - For Exploration 4: [Seismic Waves Viewer —How do seismic waves move across and through the Earth?](#) Features the 11 March 2011 Tohoku, Japan earthquake and tsunami

**Directions:**

1. Distribute the Learner Worksheet found in Appendix E for each learner and one or two small Slinkies to each table group.
2. Each exploration topic begins with a large group demonstration then moves to table groups for further exploration. Each exploration has review and synthesis questions found in the Learner Worksheet. Note: To reduce transition time, an instructor could do the large group demonstration for Explorations 1 and 2 at the same time since both use the basketball with 5 Slinky's attached. In a similar manner, Explorations 3 and 4 could be done at the same time since they require moving to a large open area to use the Super Slinky.

3. Following the explorations and learner worksheet, discuss as a whole group:
  - New insights learned (see instructor answer key)
  - Synthesis questions about how earthquake generated seismic waves affect people and their communities. Topics may include:
    - How P waves are used for earthquake early warning, and as the first signal to Drop, Cover and Hold On as protective measures.
    - How slower moving and more damaging S and rolling surface waves affect human made structures.
    - What can be done to build more earthquake resilient communities.

**Exploration 1—Seismic Slinky Wave Propagation**

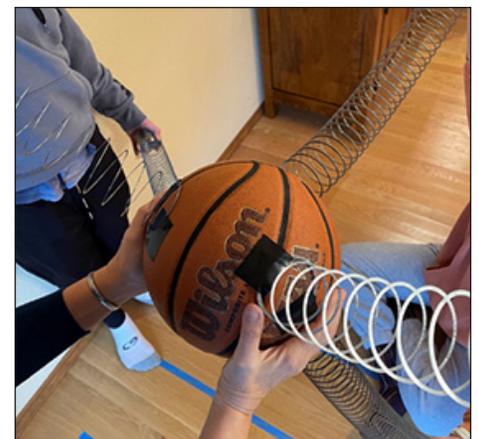
**Main Concepts:** a) Seismic waves travel out in all directions from the hypocenter. b) A wide array of seismometer locations help scientists find the location of an earthquake's hypocenter.

**Before the demonstration:**

- Be prepared to cover the main concepts of the exploration topic
- Show the animation: [3-Component Seismogram Records Seismic-wave Motion](#) (2:53)

**Full group demonstration:**

- A. The instructor holds the basketball or soccer ball which has five small Slinkies taped in different places (Figure 8). Hold the ball in the air so that the Slinkies can be arrayed in different orientations.
- B. Ask volunteer learners to hold the ends of the Slinkies in different orientations. (Avoid hanging a Slinky in a vertical orientation to reduce the effects of gravitational pull.)



*Figure 8: Learners hold 5 Slinkies in different spatial orientations to model how waves propagate in three dimensions.*

- C. The instructor initiates a seismic pulse as a sharp rapid push and pull.
- D. Repeat the seismic pulse several times in different directions.

**Questions for Discussion:**

- What does the basketball represent in the real world? (*The hypocenter of an earthquake.*)
- What do the hands holding the ends of the Slinky represent? (*A wide array of stations that record seismic waves on seismometers.*)
- Why would it be important to record seismic waves in many places? (*Four or more stations are needed to determine the location of an earthquake’s hypocenter.*)

**Table group exploration:** (Brief directions appear on the learner worksheet (Appendix E). The instructor may want to review the directions because they are different from the whole group demonstration the learners just saw.)

- A. Learners return to the table groups and begin their own explorations with small Slinkies.
- B. Two people hold the ends of the Slinky (Figure 9).
- C. Another person pinches a group of coils about 1-inch thick near the center of the stretched Slinky. This will create additional tension on both sides of the extended Slinky. You might have to experiment with the number of pinched coils, and/or how much to stretch the slinky for best results.
- D. Quickly release the pinched group of coils and compressional waves will move away from the center in both directions and return to the center. Explore holding the pinched coils above the table.
- E. Record observations and answer questions on the learner worksheet (Appendix E).

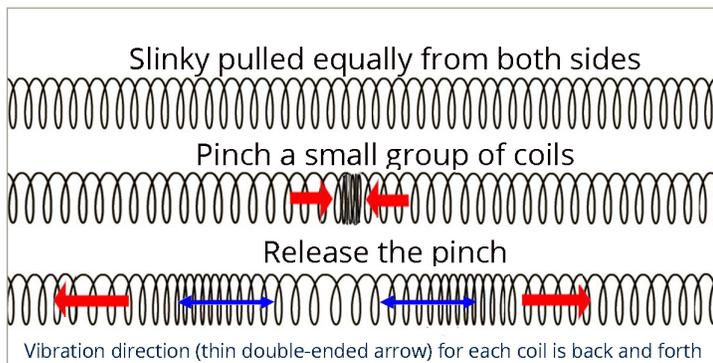


Figure 9: By pinching a bunch of coils at the center of the Slinky® and releasing, wave energy moves away from the “earthquake” in both directions.

**Exploration 2—Seismic Slinky Wave Travel Time**

**Main Concepts:** a) Shorter Slinkies receive seismic waves more quickly from the hypocenter than longer Slinkies. b) Seismograms show seismic wave travel times. The distance between P and S waves arrival times help determine the distance to an earthquake’s hypocenter.

**Before the demonstration:**

- Be prepared to cover the main concepts of the exploration topic.
- Show the video: [Seismic waves: P and S wave particle motion and relative wave-front speeds](#)

**Full group demonstration:**

- A. The instructor holds the basketball or soccer ball which has five small Slinkies taped in different places. This time, the length of the Slinkies are changed in the following ways:
  - One Slinky is stretched to its full length.
  - The remaining Slinkies are shortened to different lengths by gathering up and holding different amounts of coils on the end of each Slinky.
- B. Ask volunteer learners to hold the ends of the Slinkies in different orientations. (Avoid a vertical orientation because of gravity.)
- C. All Slinkies are stretched out by learners in different orientations retaining the same distance between coils (Figure 10).
- D. The instructor initiates a seismic pulse as a sharp rapid push and pull. Repeat the seismic pulse several times in different directions.

**Questions for Discussion:**

- Which wave reached the learner’s hand first, second etc. (*The hand holding the slinky closest to the basketball receives the wave first.*)
- Why do the seismic waves arrive at the recording stations (hands) at different times? (*It takes different amounts of time to arrive at the hands depending on the length of the slinky. The longest slinky should receive the seismic waves last.*)
- What would seismic waves arriving at recording stations at different times help scientists discover? (*The difference between P and S wave arrival times helps determine the location of an earthquake’s hypocenter.*)

**Table group exploration:** (Brief directions appear on the learner worksheet (Appendix E). The instructor may want to review the directions because they are different from the whole group demonstration the learners just saw.)

- A. Learners return to the table groups and begin their own explorations with small Slinkies.
- B. Two learners hold the ends of the Slinky.
- C. Another learner pinches a group of coils about 1-inch thick off-center of the stretched Slinky. You might have to experiment with the number of pinched coils, and/or how much to stretch the slinky for best results. Notice that the waves will travel longer and shorter distances from the pinched coils/hypocenter.
- D. Quickly release the pinched group of coils and compressional waves will move away from the center in both directions and return to the center. Experiment with holding the pinched coils above the table.
- E. Record observations and answer questions on the learner worksheet (Appendix E).

### Exploration 3—Stored Energy and Elastic Rebound

**Main Concepts:** a) The slow buildup of strain on a fault due to plate motion, is similar to what happens when coils on one end of the Slinky are gathered up, storing potential energy before being released in an earthquake. b) Elastic rebound occurs in the deformation of a continental margin, such as the compression of the North American Plate by the subducting Juan de Fuca Plate. Plate motions are recorded by GPS stations in networks throughout the world.

#### Before the demonstration:

- Be prepared to cover the main concepts of the exploration topic.
- The concept of Elastic Rebound Theory (see side-bar on the next page)
- Show 26 sec GIF from: [Simplified model of elastic rebound?](#)



Figure 10: Learners hold 5 Slinkies different distances from the basketball-hypocenter.

#### Full Group Demonstration:

Move to the open area you have prepared for the demonstration.

- A. Ask learners to line up on each side of the Slinky demonstration (Figure 6).
- B. Ask a volunteer to hold one end of the Slinky while the instructor holds the other end.
- C. Stretch out the Slinky as far apart as possible without overstretching!

Demonstrate a P wave with stored elastic energy:

- D. Slowly gather one to two inches of coils on one end of the Slinky into your hand. This process stores elastic energy in the compressed coils of the Slinky (as compared to the other coils in the stretched Slinky). This is similar to how rocks store elastic energy from plate motions prior to slip during an earthquake, like in the elastic rebound process.
- E. Quickly release the gathered coils while still holding on to the last coil of the Slinky. The stored energy will release in a compressional or longitudinal wave that propagates along the Slinky, known as a P wave. Note: The method does not produce a wave as dramatic as that produced by a hit or a shove as demonstrated in the 15 minute activity. Repeat, gathering up different amounts of coils.

Demonstrate an S wave with stored elastic energy:

- F. One person holds the end of the stretched Slinky and uses their other hand to hold a coil about 10-12 coils away from the end of the Slinky.
- G. Slowly pull this coil in a direction perpendicular away from the stretched Slinky to apply a shear displacement to the Slinky. This process stores elastic energy in the Slinky, which is similar to what happens in rocks adjacent to a fault or plate boundary.
- H. After the coil is displaced about 10 cm or so, release it suddenly. This is analogous to the sudden slip along a fault plane in an earthquake. The S wave will propagate along the Slinky away from the source, both in parallel and perpendicular to the Slinky. In this method, the shear wave is not as dramatic as the wave produced in the 15 minute activity.

#### Questions for Discussion:

- What did you notice about the spacing of the coils along the Slinky as the coils on the end were being gathered up? (As the coils were being gathered and compressed, the coil along the remainder of the Slinky were being stretched farther apart. The stretched coils are storing more potential energy.)

- What differences did you see between the number of coils gathered and energy released? (*The greater the number of coils gathered, the greater the energy released.*)
- What part of an active subduction zone is represented by the compressed coils? (*During the process of subduction, strain accumulates on the leading edge of the continental margin of the overriding plate due to friction created by the subducting plate.*)

**Table group exploration:** (Brief directions appear on the learner worksheet (Appendix E). The instructor may want to review the directions for clarity. Encourage learners to explore both P and S waves in their groups in the same way they saw the large group demonstration.)

- Learners return to the table groups and begin their own explorations with small Slinkies.
- Two learners hold the ends of the Slinky.
- On one end, slowly gather and compress at least an inch of coils.
- Quickly release the pinched group of coils while still holding on to one or two coils at the end. The compressional P wave will move away from the end along the length of the Slinky. Experiment with gathering different amounts of coils.
- Repeat the process this time gathering the coils in a direction perpendicular away from the stretched Slinky to apply a shear displacement to the Slinky.
- After the coil is displaced about 10 cm or so, release it suddenly. This is analogous to the sudden slip along a fault plane in an earthquake.
- Record observations and answer questions on the learner worksheet (Appendix E).

## Exploration 4—Constructive and Destructive Wave Interference

### Main Concepts:

- Loosely consolidated sediments in basins and valleys often experience more wave interference. This can lead to both higher amplitudes and longer durations of shaking. Because such effects are geometric in nature, the shaking depends on the characteristics of the incoming waves. The direction of approach of the incoming seismic waves can be very difficult to predict.
- When seismic waves interfere constructively, greater shaking will occur. Geotechnical studies provide critical information regarding building foundations and characteristics to mitigate resonance between soils and building height.

### ELASTIC REBOUND Rocks are elastic!

The crust on either side of a fault deforms due to the effects of stress (force/area), like compression or extension. Strain accumulates on the fault until the force of friction is overcome in an earthquake. The earthquake releases stress along the fault and the rock snaps back into its original position. Strain then begins to accumulate again. This process is known as elastic rebound. It's a good thing rocks are elastic! Even during the shaking of an earthquake, rocks deform momentarily. Because rocks are elastic, they come back to their original position, which prevents a lot of damage and destruction during earthquakes! The long term motion and deformation of the ground can be measured with high-precision ground positioning system (GPS) instruments affixed to the ground. GPS stations located close to the epicenter of an earthquake can measure the motion of the ground as it shakes and deforms during and after the earthquake.

### Before the demonstration:

Be prepared to cover the main concepts of the exploration topic. (See inset box on next page.)

- This exploration demonstrates that waves are energy and two waves can occupy the same physical space at the same time, unlike the mass of an object. This method demonstrates both constructive and destructive wave interference.
- Show the video: [Buildings and Bedrock: Effects of Amplification and Liquefaction](#) (1:24) (This animation reinforces the concept that the amplitude of shaking increases in loose sediments.)
- Show the video: [Seismic Waves Viewer —How do seismic waves move across and through the Earth?](#) Features the 11 March 2011 Tohoku, Japan earthquake and tsunami. (9:23)
  - Point out the different waves as they propagate through Earth.
  - Timestamp 6:50–7:50: P and S waves (red and blue waves) reflect (or bounce) off the outer core and with the surface of the Earth. Where the waves

## Understanding Wave Interference

Two waves can occupy the same physical space at the same time. This wave interaction is called interference. It can be constructive (waves get bigger when they merge; Figure 11) or destructive (they get smaller; Figure 12). Although the waves interfere with each other when they meet, they continue traveling as if they had never encountered each other. When the waves move away from the point where they came together, their form and motion is the same as it was before they came together. Notice the movement of the piece of tape and the amplitude of its movements as the waves interact with each other.

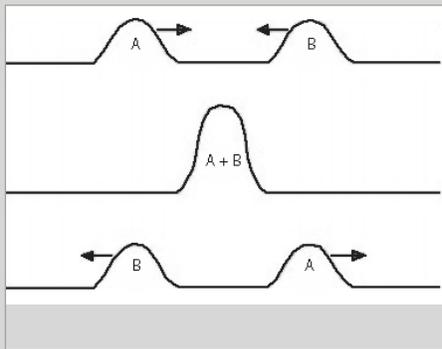


Figure 11: When a wave of amplitude  $A$  and another wave of amplitude  $B$  are in phase with one another, they meet and constructively interfere for a moment and then pass each other. (top) The two waves before they meet each other. (middle) When the two waves meet, they constructively interfere and their amplitudes add up ( $A+B$ , in this case). (bottom) The two waves maintain their original wave amplitudes after they pass one another.

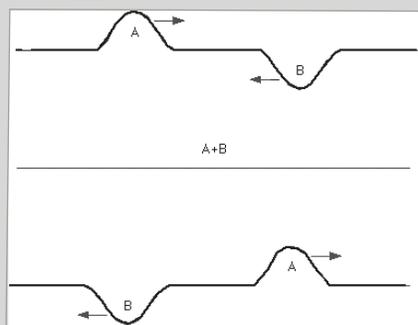


Figure 12: When a wave of amplitude  $A$  and a wave of amplitude  $B$  are out of phase with one another, they destructively interfere (cancel each other out) when they meet up for a moment. (top) The two waves  $A$  and  $B$  before they meet. (middle) The two waves are out of phase with one another, so when they meet, they destructively interfere. Since the two waves had the same amplitude, just out of phase, they cancel each other out. (bottom) The two waves move past each other with their original amplitudes.

overlap and interfere, constructive (or destructive) interference occurs, which increases (or decreases) the amplitude of the waves and the shaking at the Earth's surface.

- (Optional review) Start the video from the beginning to provide context to the M9 Japan earthquake, and to show an animation of the seismic waves across the Earth. In this demonstration, the P waves are in red, S waves are in blue, and the surface-waves (which cause the most damage) are in yellow. At timestamp 1:00, you can see that the P waves propagate away from the epicenter much more quickly than the S waves. As an extension, learners can explore the [Seismic Waves Viewer App](#).

### Full Group Demonstration:

Move to the open area you have prepared for the demonstration. Demonstrate **constructive** wave interference:

- Ask learners to line up on each side of the Slinky demonstration.
- Ask a volunteer to hold one end of the Slinky while the instructor holds the other end.
- Position the Slinky so that it is adjacent to a visible line of floor tiles to use as a visual marker for Slinky wave amplitude.
- Stretch out the Slinky as far apart as possible without overstressing!
- In this demonstration, an S or transverse wave will be generated simultaneously from each end of the Slinky.
- Start by initiating only one S wave along the Slinky by giving a sharp side to side motion about the width of one floor tile or 12".
- Ask learners to notice how far the waves travel in a transverse motion for this amplitude.
- Ask the person at the other end to repeat the same motion back.
- Practice several times until you are able to closely replicate the same energy and amplitude.
- Now, both ends initiate an S wave starting in the **same direction** at the same time with the same amplitude. Repeat several times.

### Questions for Discussion:

- What did you notice when the waves encountered each other? (*The waves increase in amplitude.*)
- When the waves increased in amplitude, what type of wave interference was created? (*constructive interference*)

- How many floor tiles were involved in the initial wave? (*Answers will vary.*)
- If the waves had a starting amplitude of (answer from above 1-2 floor tiles), what was the distance of the constructive wave? (*The amplitude of both waves is added.*)
- What happened to the amplitude of the waves after they met and continued on? (*The waves continued with the same amplitude as they started.*)
- Where would we see waves interacting constructively in the real world? (*Waves interact as they travel through different rock materials, when they reach the earth's surface and reflect back, and when they travel around the world and interact with waves already in motion.*)
- What would we need to do to demonstrate destructive wave interference? (*Answers will vary. We will repeat the same wave demonstration but start the wave using different directions.*)

Demonstrate **destructive** wave interference:

- Once again, start by initiating only one S wave along the Slinky by giving a sharp side to side motion about the width of one floor tile or 12".
- Ask learners to notice how far the waves travel in a transverse motion for this amplitude.
- Ask the person at the other end to repeat the same motion back.
- Practice several times until you are able to closely replicate the same energy and amplitude.
- Now, both ends initiate an S wave starting in **opposite directions** at the same time with the same amplitude. Repeat several times.

### Questions for Discussion:

- What did you notice when the waves encountered each other? (*The waves did not change in amplitude.*)
- If we could video record the waves meeting in slow motion, what do you think we might see? (*The waves would momentarily cancel each other before continuing.*)
- When the waves did not increase in amplitude, as we saw in constructive interference, what type of wave interference was demonstrated? (*destructive*)
- How many floor tiles were involved in the initial wave? (*Answers will vary.*)
- Which waves do you think cause the most damage to buildings and structures? Why is that? (*Constructive waves have greater amplitude and increase ground shaking. Geotechnical studies provide critical information regarding building foundations and characteristics to mitigate the effects of shaking.*)

**Table group exploration:** (Brief directions appear on the learner worksheet (Appendix E). The instructor may want to review the directions for clarity. Encourage learners to explore both S waves in their groups in the same way they saw the large group demonstration. Instructions are repeated here for review.

- Learners return to the table groups and begin their own explorations with small Slinkies.
- Locate an area on the floor that has floor tiles that can be used to measure S-wave amplitude.
- Two learners hold the ends of the Slinky.
- Position the Slinky so that it is adjacent to a visible line of floor tiles to use as a visual marker for Slinky wave amplitude.
- Stretch out the Slinky as far apart as possible without overstressing!
- In this demonstration, an S or transverse wave will be generated simultaneously from each end of the Slinky.
- Start by initiating only one S wave along the Slinky by giving a sharp side to side motion about the width of one floor tile or 12".
- Ask learners to notice how far the waves travel in a transverse motion for this amplitude.
- Ask the person at the other end to repeat the same motion back.
- Practice several times until you are able to closely replicate the same energy and amplitude.
- Now, both ends initiate an S wave starting in the **same direction** at the same time with the same amplitude. Repeat several times.

Repeat the same procedure as above, but this time, demonstrate deconstructive wave interference.

- At both ends of the Slinky, initiate an S wave starting in **opposite directions** at the same time with the same amplitude. Repeat several times.
- Record observations for both constructive and destructive wave interactions and answer questions on the learner worksheet (Appendix E).

### Energy change across a boundary

**(Optional extension)** When a seismic wave encounters a change in material properties, most of the energy crosses the boundary. Some energy does reflect back toward the "earthquake" source due to differences in rock density.

- Tape one metal Slinky to one plastic Slinky
- Initiate a P or S wave
- Observe what happens when the wave crosses the metal to the plastic Slinky, and vice versa

## APPENDIX A—VOCABULARY

**Amplitude**—the maximum disturbance or distance from a constant point. Amplitude is one-half the distance between the crest and trough of one wavelength.

**Body Waves**—waves that move within the Earth's interior or within a body of rock. P and S waves are body waves.

**Compression**—fractional decrease of volume due to pressure.

**Constructive wave interference**—the interference of two waves of equal frequency and same phase, resulting in their amplitudes temporarily added together when they meet.

**Destructive wave interference**—the interference of two waves of equal frequency and opposite phase, resulting in their cancellation temporarily then they meet.

**Earthquake**—the sudden fracture and movement of rocks inside the Earth.

**Epicenter**—the point (map location) on the Earth's surface directly above the hypocenter, or focus of an earthquake

**Elastic Properties**—the measure of an object's ability to change shape when a force (stress) is applied to it, and return to its original shape when the force on it is released.

**GPS Station**—A Global Positioning System is a spaceborne radionavigation system that uses orbiting satellites to determine the exact location of the receiver on the surface of the earth.

**Hypocenter**—commonly termed the focus, this is the point within the earth where an earthquake rupture starts. It is directly below the epicenter.

**Magnitude**—a number that characterizes the relative size of an earthquake. Magnitude is based on the measurement of the maximum motion recorded by a seismograph.

**P Wave**—the primary body wave; the first seismic wave detected by seismographs; able to move through both liquid and solid rock. Also called compressional or longitudinal

waves, they compress and expand (oscillate) the ground back and forth in the direction of travel, like sound waves that move back and forth as the waves travel from source to receiver. P wave is the fastest wave.

**S Wave**—shear wave, or secondary body wave that oscillates the ground perpendicular to the direction of wave travel. They travel about 1.7 times slower than P waves. Because liquids will not sustain shear stresses, S waves will not travel through liquids like water, molten rock, or the Earth's outer core. S waves produce vertical and horizontal motion in the ground surface.

**Seismic Wave**—an elastic wave generated by an impulse such as an earthquake or an explosion. Seismic waves may travel either through the earth's interior or along or near the earth's surface. Seismic waves travel at speeds of several kilometers per second.

### **Seismograph, seismometer, and seismogram**

A *seismograph* is a station that has three-component *seismometers* (a sensitive instrument that can detect waves emitted by even the smallest earthquakes).

The *seismogram* is a real-time record (physical or digital image) of the vibrations of the Earth, especially earthquakes.

**Shear**—type of strain in which the shape of a material is displaced laterally with no corresponding change in volume.

**Subduction Zone**—the place where two lithospheric plates, one oceanic and one continental, come together. The continental plate will ride over the oceanic plate. Most volcanoes on land occur parallel to and inland from the boundary between the two plates.

**Surface Wave**—waves that move close to or on the outside surface of the Earth rather than through the deep interior like the faster P or S waves. Two principal types of surface waves, Love and Rayleigh waves, are generated during an earthquake.

## APPENDIX B—ShakeAlert®: Implementing Public Earthquake Early Warning for the U.S.

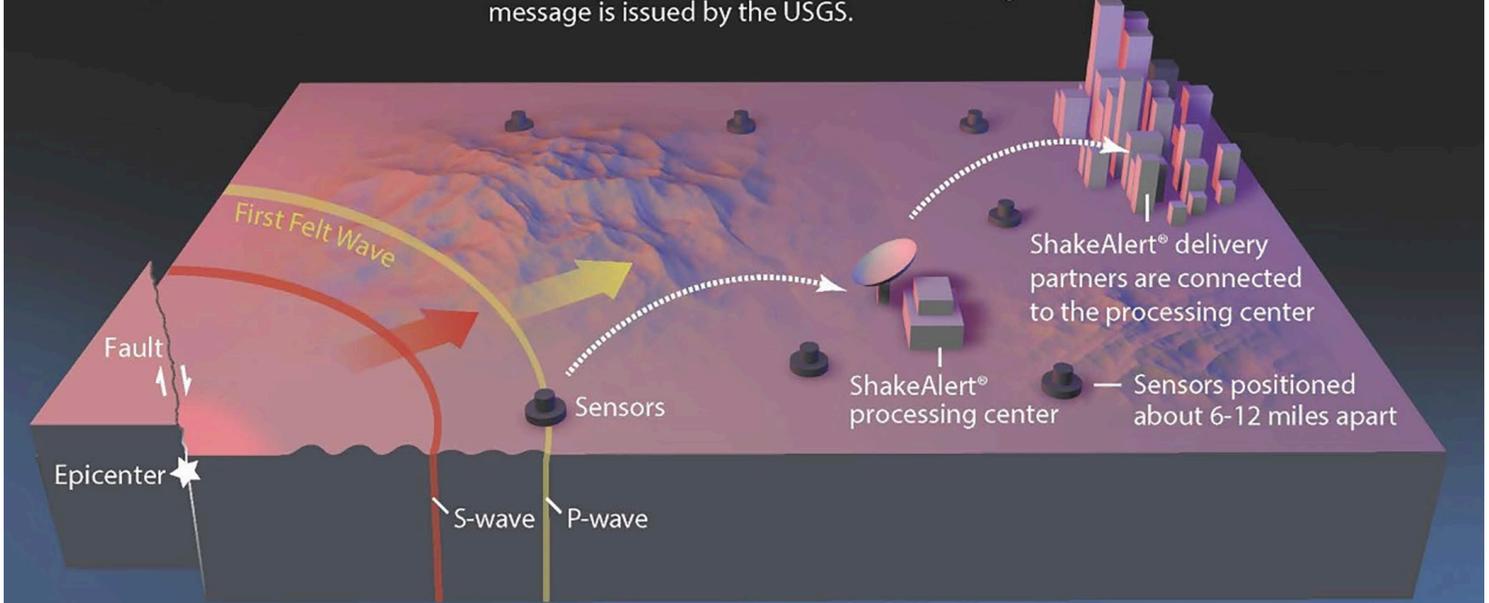
The ShakeAlert® Earthquake Early Warning (EEW) system will reduce injuries, deaths, and property damage by giving people and systems from seconds to take automated and protective actions before stronger shaking arrives.

Since 2006, the U.S. Geological Survey (USGS) along with university partners is developing ShakeAlert in three West Coast states: California, Washington, and Oregon. ShakeAlert is built on the sensor networks of the USGS Advanced National Seismic System.

[CLICK HERE](#) to download the original graphic.

# ShakeAlert® Earthquake Early Warning Basics

- 1 During an earthquake, a rupturing fault sends out different types of waves. The fast-moving P-wave is first to arrive, followed by the slower S-wave and later-arriving surface waves.
- 2 Sensors detect the P-wave and immediately transmit data to a ShakeAlert® processing center where the location, size, and estimated shaking of the quake are determined. If the earthquake fits the right profile a ShakeAlert® message is issued by the USGS.
- 3 A ShakeAlert® message is then picked up by delivery partners (such as a transportation agency) that could be used to produce an alert to notify people to take a protective action such as Drop, Cover, and Hold On and/or trigger an automated action such as slowing a train.



[CLICK HERE](#) to download full-sized poster.

# Protect Yourself During Earthquakes

**1** **In a high rise or office:** Move away from windows. *Drop* into your hands and knees. Cover your head with your arms and *Hold On* to your neck. If there is a table or desk, crawl under and *Hold On* to your shelter, keeping one arm covering your head. If no shelter, crawl next to an interior wall and continue to cover your head and neck.

**2** **Industry, no table or desk:** *Drop* onto your hands and knees. Cover your head with your arms, and *Hold On* to your neck with both hands. For more protection, crawl next to an interior wall or low-level furniture. If canted and unable to drop to the floor, bend forward. Cover your head with your arms, and *Hold On* to your neck with both hands.

**3** **In bed:** Do not get out of bed. Lie face down to protect vital organs, and cover your head and neck with a pillow, keeping your arms as close to your head as possible, while you *Hold On* to your head and neck with both hands until shaking stops.

**4** **In a store:** *Drop, Cover, and Hold On* to an *IS*. Getting next to a shopping cart, beneath clothing racks, or within the foot level of any warehouse racks may provide extra protection. If using wheelchairs (any type), lock your wheels, bend over and cover your head with your arms (if possible), and *Hold On* to your neck with both hands until shaking stops.

**5** **In a classroom:** *Drop, Cover, and Hold On* to an *IS* and *IS*. Laboratories or other settings may require special considerations to ensure safety. Students should also be taught what to do at home or other locations.

**6** **Outdoors:** Quickly move away from power lines, buildings, vehicles, and other hazards, then *Drop, Cover, and Hold On* to an *IS*. This protects you from any objects that may be thrown sideways, even if acting indirectly above you.

**7** **Near the shore or beneath a dam:** When shaking begins, follow instructions on in other sources of this poster. *Drop, Cover, and Hold On* to an *IS* as soon as shaking ceases, with that source still in mind. Walk quickly to high ground or inland as a tsunami may arrive soon. **Beneath a dam:** get to high ground or follow official instructions.

**8** **Driving:** Pull over to the side of the road, stop, and set the parking brake. Avoid overpasses, bridges, power lines, signs and other hazards. Stay in your car until shaking stops. This protects yourself by avoiding falling debris, cracked or shifted pavement, and emergency vehicles.

**9** **In a stadium or theater:** *Drop* to the ground in front of your seat or lean over to reach (if possible), then cover your head with your arms (as best as possible), and *Hold On* to your neck with both hands until shaking stops. Then walk out slowly, watching for anything that could fall during aftershocks.

**?** **Do you know what to do, wherever you are, when the earth begins to shake?**



Why are these protective actions recommended?  
[www.EarthquakeCountry.org/step5](http://www.EarthquakeCountry.org/step5)

Shake Out Practice with millions worldwide:  
[www.ShakeOut.org](http://www.ShakeOut.org)



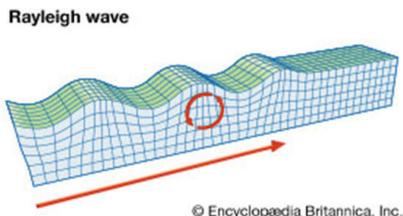
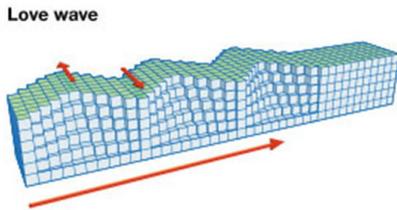
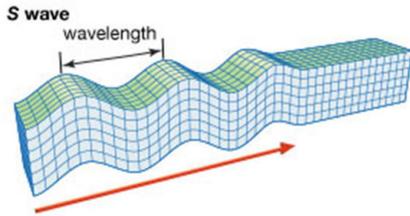
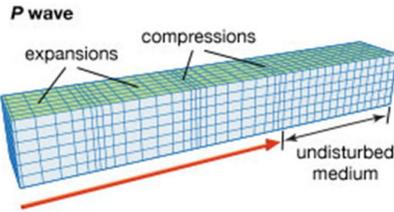
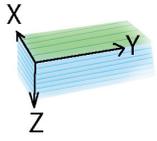
Learn how to reduce injury and damage:  
[www.FEMA.gov/earthquake](http://www.FEMA.gov/earthquake)



# APPENDIX D—Types of Seismic Waves

## Types of seismic waves

Perspective views of seismic-wave propagation through a grid representing a volume of material. X and Y are parallel to the Earth's surface; Z direction is depth.



This is how ocean waves develop on the surface of the ocean.

© Encyclopædia Britannica, Inc.

Wave Type (and names)	Particle Motion	Typical Velocity	Other Characteristics
<b>P, Compressional, Primary, Longitudinal</b>	Alternating compressions (“pushes”) and dilations (“pulls”) which are directed in the same direction as the wave is propagating (along the ray path); and therefore, perpendicular to the wavefront.	$V_P \sim 5 - 7 \text{ km/s}$ in typical Earth's crust; $> 8 \text{ km/s}$ in Earth's mantle and core; $\sim 1.5 \text{ km/s}$ in water; $\sim 0.3 \text{ km/s}$ in air.	P motion travels fastest in materials, so the P-wave is the first-arriving energy on a seismogram. Generally smaller and higher frequency than the S and Surface-waves. P waves in a liquid or gas are pressure waves, including sound waves.
<b>S, Shear, Secondary, Transverse</b>	Alternating transverse motions (perpendicular to the direction of propagation, and the ray path); commonly approximately polarized such that particle motion is in vertical or horizontal planes.	$V_S \sim 3 - 4 \text{ km/s}$ in typical Earth's crust; $> 4.5 \text{ km/s}$ in Earth's mantle; $\sim 2.5\text{-}3.0 \text{ km/s}$ in (solid) inner core.	S-waves do not travel through fluids, so do not exist in Earth's outer core (inferred to be primarily liquid iron) or in air or water or molten rock (magma). S waves travel slower than P waves in a solid and, therefore, arrive after the P wave.
<b>L, Love, Surface waves</b>	Transverse horizontal motion, perpendicular to the direction of propagation and generally parallel to the Earth's surface.	$V_L \sim 2.0 - 4.4 \text{ km/s}$ in the Earth depending on frequency of the propagating wave, and therefore the depth of penetration of the waves. In general, the Love waves travel slightly faster than the Rayleigh waves.	Love waves exist because of the Earth's surface. They are largest at the surface and decrease in amplitude with depth. Love waves are dispersive, that is, the wave velocity is dependent on frequency, generally with low frequencies propagating at higher velocity. Depth of penetration of the Love waves is also dependent on frequency, with lower frequencies penetrating to greater depth.
<b>R, Rayleigh, Surface waves, Ground roll</b>	Motion is both in the direction of propagation and perpendicular (in a vertical plane), and “phased” so that the motion is generally elliptical – either prograde or retrograde.	$V_R \sim 2.0 - 4.2 \text{ km/s}$ in the Earth depending on frequency of the propagating wave, and therefore the depth of penetration of the waves.	Rayleigh waves are also dispersive and the amplitudes generally decrease with depth in the Earth. Appearance and particle motion are similar to water waves. Depth of penetration of the Rayleigh waves is also dependent on frequency, with lower frequencies penetrating to greater depth.

Images© from Encyclopedia Britannica and Table from <https://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.pdf>

[Click here to view Animations of the seismic waves](#)

## APPENDIX E—SEISMIC SLINKY EXPLORATIONS: LEARNER WORKSHEET

Name: \_\_\_\_\_

Period # \_\_\_\_\_ Date \_\_\_\_\_

For each of the Seismic Slinky Demonstrations, complete the table using the smaller Slinky models in your table group to explore the concept.

### Exploration 1: Seismic Slinky Wave Propagation

**Directions:** One or two people stretch the Slinky out on the table. Another person gathers up about 1" of coils in the center of the stretched Slinky. Release the gathered coils and observe what happens.

Diagram the Slinky set-up <b>before</b> the coils are released.	
Diagram the Slinky set-up <b>after</b> coils are released.	
Describe how the Slinky demonstration shows how waves propagate from the origin point, or hypocenter of an earthquake.	
Where would you see a real-world example of how seismic waves propagate?	

### Exploration 2: Seismic Slinky Wave Travel Time

**Directions:** One or two people stretch the Slinky out on the table. Another person gathers up about 1" of coils about 2/3 the distance of the stretched Slinky. Release the gathered coils and observe what happens.

Diagram the Slinky set-up <b>before</b> coils are released.	
Diagram the Slinky set-up <b>after</b> coils are released.	
Describe how the Slinky demonstration shows how wave travel times differ.	
Where would you see an example of different seismic wave travel times during an earthquake?	

### Exploration 3: Elastic Rebound

Directions: One or two people stretch the Slinky out on the table. On one end of the Slinky, slowly gather up at least an inch of coils on the Slinky. Release the gathered coils and observe what happens. Repeat with different amounts of gathered coils. Explore both P and S waves as shown in the large group demonstration.

Diagram the Slinky set-up <b>before</b> the coils are released.	
Diagram the Slinky set-up <b>after</b> the coils are released.	
Describe how the Slinky demonstrates the concept of elastic rebound.	
Where would you see an example of elastic rebound occur during an earthquake?	

### Exploration 4: Constructive and Destructive Wave Interference

**Directions:** Starting on each end of the Slinky at the same time, same direction, and amplitude of force send a quick S wave pulse into the Slinky. Observe what happens to the wave amplitude when the waves meet. Repeat, but this time, start the waves traveling in opposite directions. Observe what happens when the waves meet. What made the wave interactions constructive or destructive?

	Same direction	Opposite direction
Diagram the Slinky set-up <b>before</b> the coils are released.		
Diagram the <b>constructive</b> wave interference you observed when the waves meet in the center.		
Diagram the <b>destructive</b> wave interference you observed when the waves meet in the center.		
With earthquakes, what types of soils increase the seismic wave amplitude?		
How do soil characteristics impact construction decisions in seismically active areas?		

**APPENDIX E—SEISMIC SLINKY EXPLORATIONS: INSTRUCTOR ANSWER KEY**

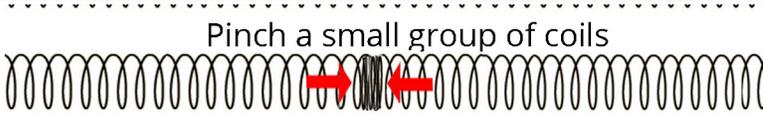
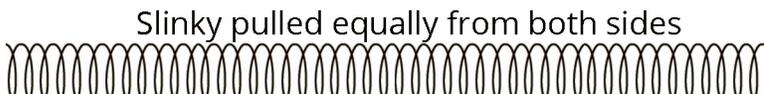
Name: \_\_\_\_\_

Period # \_\_\_\_\_ Date \_\_\_\_\_

For each of the Seismic Slinky Demonstrations, complete the table using the smaller Slinky models in your table group to explore the concept.

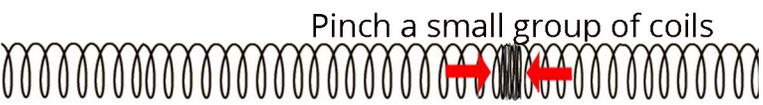
**Exploration 1: Seismic Slinky Wave Propagation**

**Directions:** One or two people stretch the Slinky out on the table. Another person gathers up about 1” of coils in the center of the stretched Slinky. Release the gathered coils and observe what happens.

Diagram the Slinky set-up <b>before</b> the coils are released.	 <p style="text-align: center;">Pinch a small group of coils</p>
Diagram the Slinky set-up <b>after</b> coils are released.	 <p style="text-align: center;">Slinky pulled equally from both sides</p>
Describe how the Slinky demonstration shows how waves propagate from the origin point, or hypocenter of an earthquake.	<p style="color: red;"><i>(Seismic waves radiate out in all directions from the hypocenter.)</i></p>
Where would you see a real-world example of how seismic waves propagate?	<p style="color: red;"><i>(A wide array of seismometers helps scientists determine the location of an earthquake's hypocenter.)</i></p>

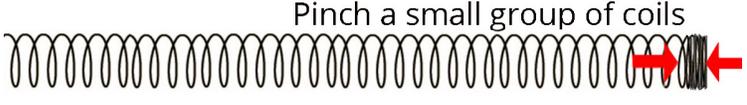
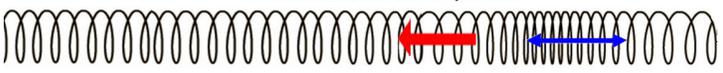
**Exploration 2: Seismic Slinky Wave Travel Time**

**Directions:** One or two people stretch the Slinky out on the table. Another person gathers up about 1” of coils about 2/3 the distance of the stretched Slinky. Release the gathered coils and observe what happens.

Diagram the Slinky set-up <b>before</b> coils are released.	 <p style="text-align: center;">Pinch a small group of coils</p>
Diagram the Slinky set-up <b>after</b> coils are released.	 <p style="text-align: center;">Release the pinch</p>
Describe how the Slinky demonstration shows how wave travel times differ.	<p style="color: red;"><i>(Shorter Slinkies receive seismic waves more quickly from the hypocenter than longer Slinkies.)</i></p>
Where would you see an example of different seismic wave travel times during an earthquake?	<p style="color: red;"><i>(Seismograms show seismic wave travel times. The distance between P and S wave arrival times helps determine the distance to the hypocenter.)</i></p>

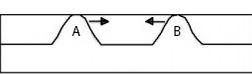
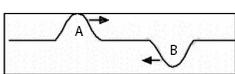
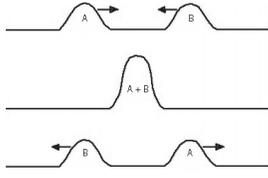
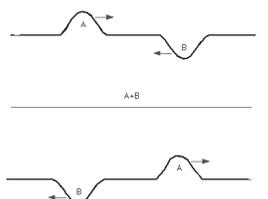
### Exploration 3: Elastic Rebound

Directions: One or two people stretch the Slinky out on the table. On one end of the Slinky, slowly gather up at least an inch of coils on the Slinky. Release the gathered coils and observe what happens. Repeat with different amounts of gathered coils. Explore both P and S waves as shown in the large group demonstration.

Diagram the Slinky set-up <b>before</b> the coils are released.	
Diagram the Slinky set-up <b>after</b> the coils are released.	
Describe how the Slinky demonstrates the concept of elastic rebound.	<i>(The slow buildup of strain on a fault due to plate motion, is similar to what happens when coils on one end of the Slinky are gathered up, storing potential energy before being released in an earthquake.)</i>
Where would you see an example of elastic rebound occur during an earthquake?	<i>(Elastic rebound occurs in the deformation and compression of a continental margin such as the North American Plate by the subducting Juan de Fuca Plate. The plate motions are recorded by GPS stations at networks throughout the world.)</i>

### Exploration 4: Constructive and Destructive Wave Interference

Directions: Starting on each end of the Slinky at the same time, same direction, and amplitude of force send a quick S wave pulse into the Slinky. Observe what happens to the wave amplitude when the waves meet. Repeat, but this time, start the waves traveling in opposite directions. Observe what happens when the waves meet. What made the wave interactions constructive or destructive?

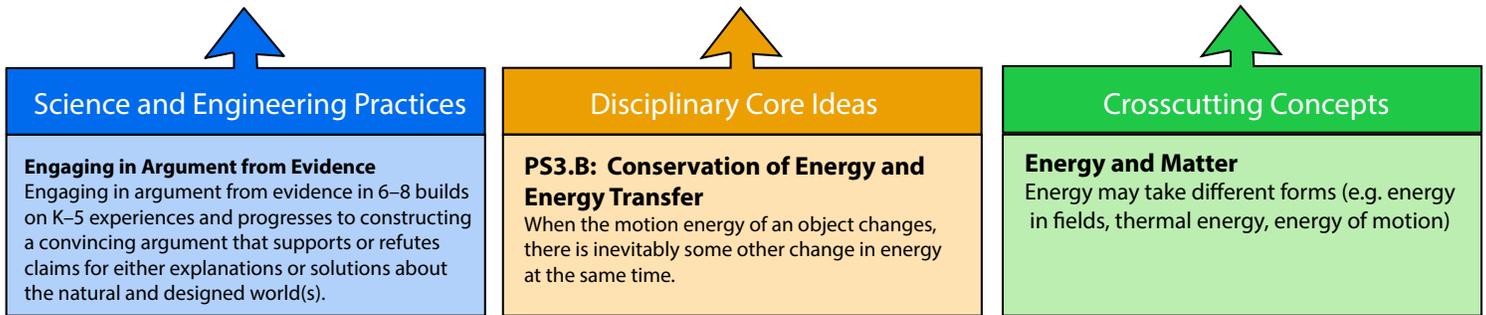
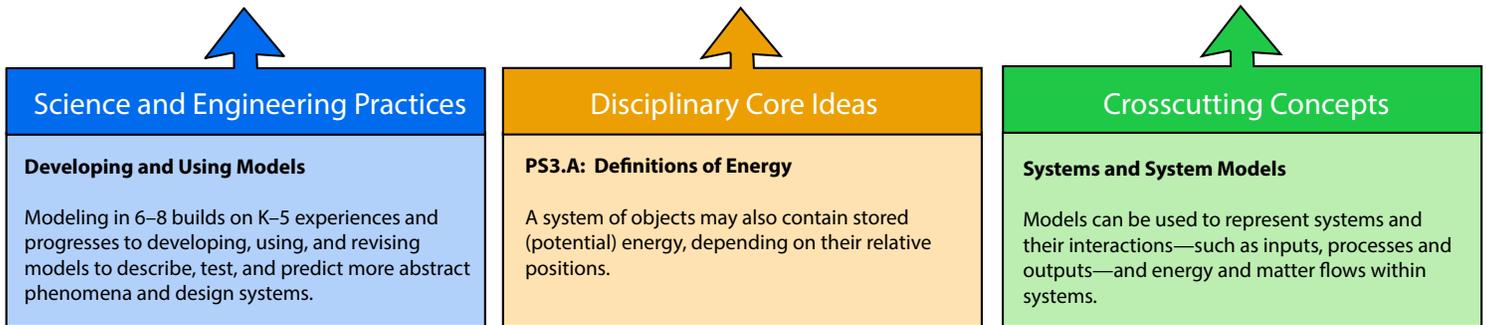
Diagram the Slinky set-up <b>before</b> the coils are released.	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>Same direction</p>  </div> <div style="text-align: center;"> <p>Opposite direction</p>  </div> </div>
Diagram the <b>constructive</b> wave interference you observed when the waves meet in the center.	 <p><i>(When the waves approach each other [top diagram] and then meet up, if the interference is <b>constructive</b>, you will observe a larger amplitude wave for a moment [middle diagram]. The waves then continue past each other at their original amplitudes [bottom diagram]. Note that learners might only see a small change in amplitude.)</i></p>
Diagram the <b>destructive</b> wave interference you observed when the waves meet in the center.	 <p><i>(When the waves approach each other [top diagram] and then meet up, if the interference is <b>destructive</b>, you will observe no wave amplitude in the Slinky for a moment [middle diagram]. The waves then continue at the original amplitude [bottom diagram]. Note that learners might not see the waves disappear completely.)</i></p>
With earthquakes, what types of soils increase the seismic wave amplitude?	<i>(Loosely consolidated sediments in basins and valleys often experience more constructive wave interference because the waves are bouncing around in the basin or valley. This effect can lead to both higher seismic wave amplitudes and longer durations of shaking. These effects depend on the basin geometry, so the wave amplitude depends on the characteristics of the incoming seismic wave and it's direction of approach, which can be very difficult to predict.</i>
How do soil characteristics impact construction decisions in seismically active areas?	<i>How do soil characteristics impact construction decisions in seismically active areas? (When seismic waves interfere constructively, greater shaking will occur. Geotechnical studies provide critical information regarding foundations, building and height to mitigate resonance between subsoils and building height.)</i>

## APPENDIX F—NGSS Science Standards & 3 Dimensional Learning

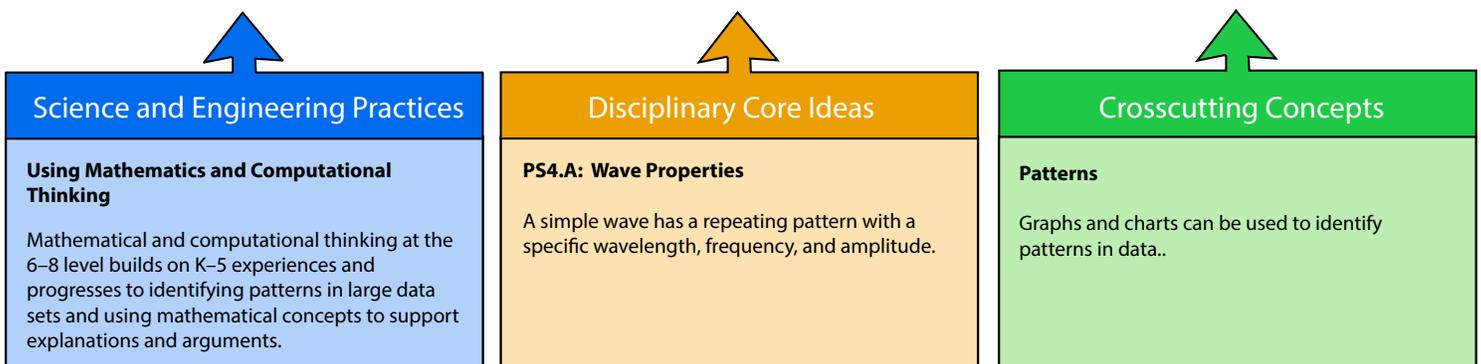
### Earth and Human Activity

Students who demonstrate understanding can:

**MS-PS3-2.** Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system. **[Clarification Statement: Emphasis is on relative amounts of potential energy, not on calculations of potential energy. Examples of objects within systems interacting at varying distances could include: the Earth and either a roller coaster cart at varying positions on a hill or objects at varying heights on shelves, changing the direction/orientation of a magnet, and a balloon with static electrical charge being brought closer to a classmate’s hair. Examples of models could include representations, diagrams, pictures, and written descriptions of systems.] [Assessment Boundary: Assessment is limited to two objects and electric, magnetic, and gravitational interactions.]**



**MS-PS4-1.** Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. **[Clarification Statement: Emphasis is on describing waves with both qualitative and quantitative thinking.] [Assessment Boundary: Assessment does not include electromagnetic waves and is limited to standard repeating waves.]**



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