LOCATING AN EARTHQUAKE EPICENTER

What information can be determined from a seismograph's record of an earthquake? How do seismologists locate the epicenter of an earthquake? How fast do earthquake waves travel?

Objectives

- Use carts traveling at constant velocity to model different types of earthquake waves.
- Measure the difference in arrival time and use it to determine the distance the carts traveled.
- Extend the results to understand how scientists triangulate the location of an earthquake epicenter.

Materials and Equipment

- Data collection system
- Red Smart Cart
- Blue Smart Cart
- Smart Cart Motor (2)
- Meter Stick
- Stopwatch

Safety

Follow regular laboratory safety precautions.

Procedure

1. Connect a Smart Cart Motor to each Smart Cart with the 2 long screws and connection cable. Make sure the spring plunger is all the way in and not pushing on the motor.

2. Connect each cart to your data collection system.

3. Open the Smart Cart Motor control panel on the data collection software. The blue cart represents an earthquake P wave. P waves move at different speeds depending on the type of material they are traveling through. A typical speed is 8 km/s. The motor control panel can set the motor power from 0 to 100. If a power of 100 represents a speed of 10 km/s, what power would model an earthquake P wave?

4. The red cart represents an earthquake S wave. S waves move at different speeds depending on the type of material they are traveling through. A typical speed is 3.5 km/s. If a power of 100 represents a speed of 10 km/s, what power would model an earthquake S wave?

5. Set the power of the blue cart to 80 in the motor control panel and select "auto". Create a graph display of position, blue versus time in the data collection system. Place the blue cart on the floor where it has some room to move. Start recording. Stop after you have collected about 5 seconds of data.

6. Use the tools of the data collection system to measure the slope of the position graph. This is the velocity of the blue cart. Record its value and units below.

   Blue Cart Velocity = __________

7. Set the power of the red cart to 35 in the motor control panel and select "auto". If a power setting of 80 resulted in the value of the blue cart velocity above, predict what the value of the red cart velocity will be at this power setting. It is OK to make a wrong prediction. Show your work and prediction below.

8. Create a graph display of position, red versus time in the data collection system. Place the red cart on the floor where it has some room to move. Start recording. Stop after you have collected about 5 seconds of data.

9. Use the tools of the data collection system to measure the slope of the position graph. This is the velocity of the red cart. Record its value and units below.

   Red Cart Velocity = __________

10. Was your prediction for the red cart velocity close the measured value? Based on the two motor power settings and the measured cart velocities, is the relationship between power and velocity linear? Explain.

11. The location where an earthquake starts is called the focus. The focus can be a few kilometers to as much as 700 km deep. Shallow earthquakes tend to cause the most damage. The earthquake epicenter is the point on the surface directly above the focus. When an earthquake happens, both P and S waves start moving in all directions away from the epicenter. Since the P waves are faster, they move out ahead of the S waves. Because of this, a seismograph will detect the P wave before the S wave. The time between the arrival of the P wave and S wave can be measured from the seismograph data. What would you notice about the difference in arrival time for a seismograph that is closer to the epicenter compared to one that is further away?

12. The velocity of the blue cart is v_P since it represents the P wave. The velocity of the red cart is v_S since it represents the S wave. The velocity of earthquake waves can change as they travel through different material. For this analysis we will assume that their velocity is constant like the cart's velocity. That means we can use these equations for each velocity, $v_P = \frac{x}{t_P}$ and $v_S = \frac{x}{t_S}$. The distance from the seismograph to the epicenter is x and t is the time it takes the P wave and the S wave to reach the seismograph. Which will be larger for a given x, t_P or t_S? Explain.

13. We can use the equations for v_P and v_S to create an equation for x in terms of the velocities and the difference in the arrival time of the P and S waves. The first step is to algebraically solve for t_P in terms of v_P and x. Then solve for t_S in terms of v_S and x. Show all your work below.

14. Since the S wave is slower, t_S will be greater than t_P and their difference, t_{Diff}, will be positive if we set $t_{Diff} = t_S - t_P$. Substitute your equations from above for t_P and t_S in this equation. Solve the resulting equation for x in terms of t_{Diff}, v_P and v_S. Show all of your work below.

15. To simulate how waves move away from an earthquake epicenter, place both carts on the floor parallel to each other. This is the epicenter location, mark it with a pencil or other method. Point the carts in a direction that has a path clear of obstacles for at least 5 m. Make sure each cart is still connected to the data collection system and that the blue cart has a power setting of 80 and the red cart has a power setting of 35. Select "auto" for each cart so that they will both start to move at about the same time.

16. Mark a position at the end of the clear path with a pencil mark or other method. This is the seismograph position. Have a lab partner with a stopwatch stand by this position. Start recording, the carts should start moving toward the marked position. Start the stopwatch when the blue cart representing the P wave arrives at the seismograph position. Stop the stopwatch when the red cart representing the S wave arrives at the seismograph position. Stop recording, this should stop the motor on each cart. Retrieve the carts and repeat 2 more times. The carts should go fairly straight if aimed well but you may have to do a few extra trials if they don't. It is OK to slightly nudge an off-course cart, but this will reduce the quality of your data. If they keep curving, check to make sure the spring plunger is all the way in and not pushing on the motor. Record your 3 trials below and calculate the average time.

    Trial 1 time = ________ s Trial 2 time = ________ s Trial 1 time = ________ s

    Average time = t_{Diff} = ________ s

17. Use your equation for x in terms of t_{Diff}, v_P and v_S to calculate the distance to the earthquake epicenter. Remember that v_P is the velocity you measured for the blue cart and v_S is the velocity you measured for the red cart. Show your result and all your work below.

18. Measure the distance from the epicenter location to the seismograph position with a meter stick and record it below. How close is this to your calculated distance? Describe one specific reason that could have resulted in this difference.

Questions and Analysis

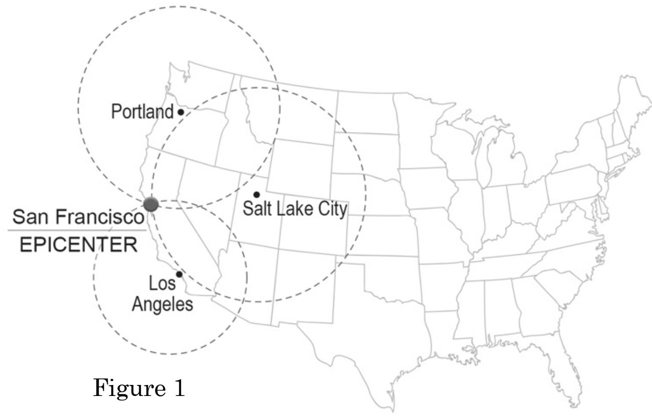

Figure 1

1. Scientists determine the distance to an earthquake epicenter from seismograph data in a similar way. However, they don't know the direction to the epicenter. You could tell because you could see where the carts were coming from but you can't normally see earthquake waves. Scientists can still find the location of the epicenter by using data from multiple seismographs as shown in Figure 1. There was a seismograph in Portland, Salt Lake City, and Los Angles. Each one measured the P and S wave data and determined the distance to the epicenter. The epicenter must lie on a circle centered at the seismograph with a radius equal to the distance to the epicenter. Where the 3 circles meet is the location of the epicenter. Which seismograph had the largest t_{Diff}? Which had the smallest? Explain.

2. As stated earlier, an actual earthquake P wave can travel at 8 km/s while a typical S wave moves at 3.5 km/s. Suppose there is an earthquake with an epicenter that is 1200 km from your seismograph. How many seconds will it take the P wave to reach your seismograph? How many seconds will it take the S wave to reach your seismograph? Show your work below.

3. The seismograph in the above problem was far enough away from the epicenter so that there would not have been any local damage. A seismograph located 100 km from the epicenter of a large earthquake may not be so fortunate. What is the difference in the arrival time, t_{Diff}, of the P and S waves for a seismograph that is 100 km from the epicenter? Show all of your work below.

4. The damage caused by earthquakes is done primarily by surface waves, also called Love waves and Raleigh waves. They travel with about the same range of velocities as S waves. The arrival of the P wave can serve as a warning that the damaging surface waves are coming soon. The difference in the arrival time, t_{Diff}, could also be the warning time and sent out to cell phones. Imagine that you received a warning on your cell phone and 10 seconds later you felt the surface waves. You might have had time to duck and cover, pull your car off the road, or take other actions to be safe. How far away would the earthquake epicenter have to be to give you at least 10 seconds of warning time? Assume the P wave velocity is 8 k/m and the S and surface wave velocity is 3.5 km/s. Show all of your work below.

5. From a single seismograph location, scientists can measure earthquake waves from anywhere on Earth, even those that travel through the center of the Earth. By combining data from multiple seismographs, they can locate every earthquake epicenter. After enough seismographs had been deployed, scientists noticed a pattern. Most earthquakes occurred along lines that formed the boundaries of what looked like large puzzle pieces. These "puzzle pieces" were tectonic plates and this was important evidence that helped scientists develop the theory of plate tectonics. The Earth has an average radius of 6371 km. How much time would it take a P wave to travel straight through the center of the earth to the other side? Show your work below.

6. P waves are a type of wave called a longitudinal wave. This means the displacement of the shaking is in the same direction that the wave travels. Sound is an example of a longitudinal wave. Longitudinal waves can pass through liquid. S waves are examples of transverse waves. This means the displacement of the shaking is perpendicular to the direction that the wave travels. Light waves and a vibrating guitar string are examples of longitudinal waves. Except for light, longitudinal waves can't travel through liquid. What can you conclude from the fact that only P waves show up on seismographs that are on the opposite side of the Earth from the epicenter? Explain.