Stories of the Present

How do we know?—Seismic wave lab

Earth Science Essentials

by Russ Colson

You will need to have 2 long bungee cords, one ¼ diameter (about 20-24') and another 3/16" diameter (15-20'). You will need a spring balance that can measure >= 8 oz. You will need a timing device.

In prehistoric times, the ancient Hevea, a race of scholars, inhabited the world, leaving behind ruins and weathered stone texts as testimony that they were once here. One of the most mysterious of the ruins is the Great Bungee, a bungee cord stretching across the Bungee Sea from the Great Pole on the west coast of Brasiliensis. The Seismea, the race presently inhabiting the world, have never crossed the Bungee Sea. Without knowing the width of the sea, they fear to cross in their small boats.

The Seismea have finally translated the ancient stone texts and have discovered that the Great Bungee crosses the entire sea. Part way across, the Great Bungee passes an island that the ancient Hevea used as a way station on their journeys across the sea. From the Great Pole on the western shore, a 3/16 bungee stretches to the island, where it is stitched to a second ¼" bungee that continues the rest of the way across the sea. The ¼" bungee is attached to a second Great Pole on the other side.

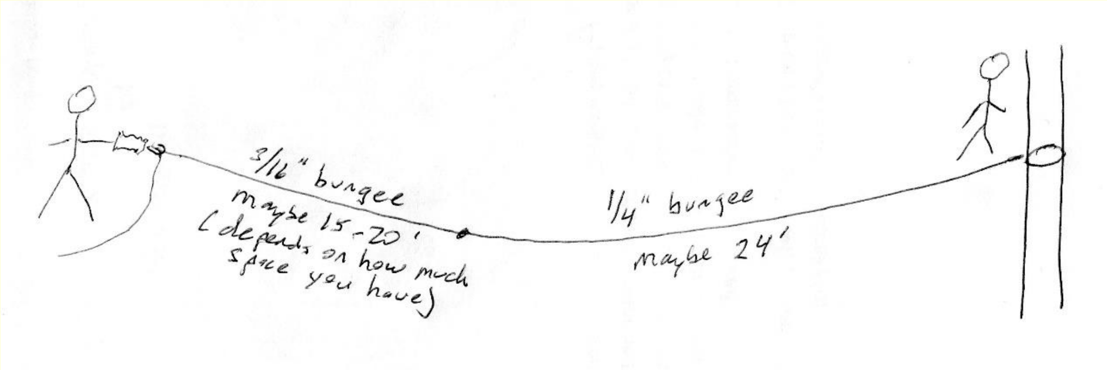
One curious Seismean twangs the Great Bungee and times how long it takes for the wave to return. She observes a reflected wave in 3 hours and 21 minutes. She observes a second reflection in 4 hours and 32 minutes. She recognizes that the second wave is not due to the wave bouncing back and crossing a second time, because it is not twice as long as the first return time. She infers that the first returned wave was the time for the wave to travel to the island on the 3/16" bungee and return. The second reflection is the time for the wave to travel to the island, then cross the second part of the sea on the ¼" bungee, and then return.

She realizes that by measuring the velocity of the waves through bungee cords with the same properties as the Great Bungee, she can determine both the distance to the island and the distance across the sea without ever having to cross the sea. She measures the tensional force on the Great Bungee and finds it to be 8 oz of force.

She then begins her experiments.

Initially she tests her mental model for how the waves cross the sea on the Great Bungee.

1) Take your Bungee cords and spring balance. Tie the Bungee cords together. Tie the ¼" bungee end to something solid and stretch out the cord to 8oz of force.



Experiment with the two bungee cords to confirm that some energy from the wave reflects back from the join between the two bungees and some of the energy continues on. It might be helpful to have a partner help with this.

Write down an explanation for how you confirmed that some of the energy reflects and some continues on at the join between the bungees. You should also include a measurement of how long it takes a wave to travel to the join in the bungees and back, and also how long it takes the wave to travel the entire distance of the bungee cord.

It's possible to follow the wave with your eye, taking note when it reflects back at the suture between the two bungees. It's also possible to feel the vibration in the cord when the reflected wave returns. This reflected wave returns much sooner than a wave could be reflected back from the far end of the ¼" cord, as shown by the measurements below.

When stretched out at 8oz of force, I had 210" from the end of the 3/16" bungee to the suture. I had 291" from the suture to the far end of the 1/4" bungee. The time for the wave to reflect back from the suture was about 0.75 seconds (average of 0.76, 0.62, 0.69, 0.76, and 0.9 seconds). I needed help to measure the time for the wave to reach the far end of the combined bungee cords (someone to stretch the cord to 8 oz and then make a wave in the cord at one end while I waited at the other end for the wave to arrive). Even so, timing the wave travel time was difficult due to the short time involved and the difficulty seeing when the wave started. The total travel time was about 0.69sec (average of 0.69, 0.69, 0.76, and 0.62 seconds). I could both feel and see the wave arriving at the end, confirming that some of the energy was transmitted through the suture between bungee cords.

Next, measure the velocity of waves in the two different varieties of bungee cord. One way to do this is to untie the two bungee cords from each other, and then, for each one, tie one end to something solid, stretch it out to its full length at 8oz of force, and measure how long it takes a wave to travel a known distance (remember, velocity = distance/time). A big source of error in your measurements will be your ability to time something that happens quickly. Therefore, I recommend that you let the wave bounce back and forth a few times so as to increase the time and make your measurement more precise. Of course, to calculate the velocity, you also need to adjust the distance the wave traveled accordingly. For example, if your cord is 22 feet long, and you time how long it takes the wave to go down and back three times, the distance the wave traveled is 22 feet * 6 = 132 feet = 1584 inches. Report your results below (including calculated velocity for each type of cord in units of inches per second).

Velocity in ¼" bungee cord: Distance from one end of the bungee cord to the other when stretched to 8 oz = 294". I timed 4 back-and-forth trips for a total travel distance of 2352". I repeated the measurements 3 times.

Measured travel times = 2.79, 2.93, and 3.00 seconds for an average of 2.91 seconds. Velocity = distance/time = 2352 inches /2.91 sec = 808.2 inches per second.

Velocity in the 3/16" bungee cord: Distance from one end of the bungee cord to the other when stretched to 8 oz = 281". I timed 3 back-and-forth trips for a total travel distance of 1686". I repeated the measurements 4 times.

Measured travel times = 3.14, 3.14, 3.28, and 3.28 seconds for an average of 3.21 seconds. Velocity = distance/time = 1686 inches / 3.21 seconds = 525.2 inches per second.

Based on your measured velocities, you should be able to calculate a predicted value for travel times in the first part of this activity when the two bungee cords were joined together. Remember that travel time = distance/velocity. Given the lengths of each part of the cord when they were connected together, and your measured velocities, you should be able to predict how long the wave took to travel each segment. How do the predicted values compare to your measured values?

Based on the measured velocities, I would expect that the travel time for the reflection in the 2-bungee cord experiment above would be distance traveled/velocity = 420 inches/525.2 inches/second = 0.8 seconds. Given how difficult it is to measure values for time less than a second, this is reasonably close to my measured value of 0.75 seconds.

Based on the measured velocities, I would predict that the travel time from one end of the double bungee to the other would equal the travel time in the 3/16" bungee + travel time in the ¼" bungee = 210 inches/ 525.2 inches/second + 291 inches/ 808.2 inches/second = 0.76 seconds, slightly more than my measured value of 0.69 seconds, but probably within the uncertainly of my measurement.

Calculate the distance to the island in the Bungee Sea (in miles: there are 5280 feet in a mile and 12 inches in a foot).

The round-trip travel time to the island and back is 3 hours and 21 minutes, which equals 12060 seconds. At 525.2 inches per second, the wave would travel 6333912 inches = 100 miles, round trip. The distance to the island is half this--50 miles.

(note that the characteristics of your bungee cord might not match mine exactly, in which case your distance should match your measured velocity, not my number.)

Calculate the distance across the Bungee Sea (in miles: there are 5280 feet in a mile and 12 inches in a foot).

The second reflection takes 4 hours and 32 minutes. 3 hours and 21 minutes of this is the time for it to travel to and from the island. That means that the time to cross the rest of the sea and return to the island is 1 hour and 11 minutes, which equals 4260 seconds. At 808.2 inches per second, the wave would travel 3442932 inches = 54 miles round trip. The total distance across the sea = 50 miles + 27 miles = 77 miles.

(note that the characteristics of your bungee cord might not match mine exactly, in which case your distance should match your measured velocity, not my number.)

This activity is analogous to measuring distances to layers in the Earth, where we also cannot go. We can measure the seismic velocities in Earth materials and then time how long the waves take to travel down and back through different types of material.