



The BOSS Model:

Building Oscillation Seismic Simulation

RATIONALE

During an earthquake, buildings oscillate. If the frequency of this oscillation is close to the natural frequency of the building, resonance may cause severe damage. The BOSS model allows students to observe the phenomenon of resonance.

FOCUS QUESTIONS

Why do buildings of different heights respond differently in an earthquake?

OBJECTIVES

Students will:

1. Predict how a structure will react to vibrations (oscillations) of different frequencies.
2. Perform an experiment to establish the relationship between the height of a structure and its natural frequency.
3. Describe the phenomenon of resonance.

MATERIALS

for one BOSS Model

- Master 4.3a, BOSS Model Assembly
- 4 pieces of wood, 1 x 4, each 15 cm (6 in.) long
- 1 piece of wood, 2 x 4, for a base, about 45 cm (18 in.) long
- 2 threaded rods, 10 x 24, each 96 cm (36 in.) long
- 2 threaded rods, 10 x 24, each 61 cm (2 ft.) long
- Goggles for eye protection
- Hacksaw or power saw with metal-cutting blade
- Electric drill or hand drill with 1/4-in. and 3/4-in. wood bore bits
- Hammer
- 8 wing nuts, 10 x 24
- 8 tee nuts, 10 x 24

TEACHING CLUES AND CUES



As noted in lesson 4.2, you may want to have one group of students working with this model while another is working with the model wall.

TEACHING CLUES AND CUES



Since the rods can break with rough handling, you may want to buy one or two extra.

- 8 washers, #8
- A wide permanent marker in any color that will contrast with the wood
- Poster paints: red, green, blue, black, and white, and 5 brushes (optional)

for each small group

- One copy of Master 4.3b, BOSS Worksheet
- Pencils or pens
- Stopwatch
- Meter stick

PROCEDURE

Teacher Preparation

Build the BOSS model by following the directions on Master 4.3a. Practice with your model until you've got a feel for each frequency and you can get any of the rod assemblies to resonate. One technique is to use a firm push first, then watch the number you want and wiggle the base very lightly at its natural frequency to get resonance.

A. Introduction

Find out what students already know about the concepts of amplitude, frequency, and resonance. If they are not familiar with these terms, introduce them by building on what students already know from other areas. They may know, for example, that resonance and frequency are used in describing the tone of musical instruments and the quality of sound produced by different recording techniques and players. The phenomenon of resonance also accounts for laser light and for the color of the sky.

B. Lesson Development

1. Direct students' attention to the BOSS model, and explain its name. Ask the students to predict which numbered rod assembly will oscillate the most when you wiggle the base. Have them hold up 1, 2, 3, or 4 fingers to indicate their prediction. (They will probably say number 1 because it is the tallest.)
2. Oscillate the BOSS model so that some rod assembly resonates other than the one most students predicted. This will baffle the students, so let them predict again. Again make the rod resonate for an assembly they did not predict. Finish this demonstration after several tries by making the rod resonate for the assembly most of the students did predict, so that they get it right. Invite discussion.
3. Relate the blocks and rods to buildings of various heights in an earthquake. Ask students if they think buildings would oscillate like this in an earthquake. (They always do, and in some earthquakes the effect is especially pronounced. In the 1985 Mexico City earthquake, the ground shaking resonated with the natural frequencies of 8-to-10-

VOCABULARY



Amplitude: a measurement of the energy of a wave. Amplitude is the displacement of the

medium from zero or the height of a wave crest or trough from a zero point. (In this activity it's how far to the side the block moves.)

Frequency: the rate at which a motion repeats, or oscillates. The frequency of a motion is directly related to the energy of oscillation. In this context, frequency is the number of oscillations in an earthquake wave that occur each second. In earthquake engineering, frequency is the rate at which the top of a building sways.

Hertz (Hz): the unit of measurement for frequency, as recorded in cycles per second. When these rates are very large, the prefixes *kilo* or *mega* are used. A kilohertz (kHz) is a frequency of 1,000 cycles per second and a megahertz (MHz) is a frequency of 1,000,000 cycles per second.

Oscillation or vibration: the repeating motion of a wave or a material—one back and forth movement. Earthquakes cause seismic waves that produce oscillations, or vibrations, in materials with many different frequencies. Every object has a natural rate of vibration that scientists call its natural frequency. The natural frequency of a building depends on its physical characteristics, including the design and the building materials.

Resonance: an increase in the amplitude (in this case, the distance the top of a building moves from its rest position) of a physical system (such as a building) that occurs when the frequency of the applied oscillatory force (such as earthquake shaking) is close to the natural frequency of the system.

story buildings. The effect was severe damage to medium-height buildings that had the same frequency as the ground shaking and resonated with it. Higher and lower buildings were hardly damaged.) Use the BOSS model as a visual aid when describing this event. You may also want to draw attention to the photos or books you used in Lesson 1 of this unit.

4. Divide students into seismic engineering teams (SETs) and distribute one copy of Master 4.3b, BOSS Worksheet, to each group. Tell students that they will take turns performing an experiment with the model, recording their data, and providing the answers asked for on the data sheet. Give these directions:

- a. Hold the base stationary, pull the wooden number 1 out several centimeters to the side, and release it. As the rod oscillates, use a stopwatch to measure the time for 10 oscillations. Record this number.
- b. Practice until you can get almost the same swing each time, then repeat the measurement four times. Calculate the average of these four times. Now calculate the natural frequency of the number by dividing 10 cycles by the average time. Record it. Repeat this procedure for the other three numbers.
- c. Measure the height of each assembly from the base to the top, and record it.
- d. Plot height versus natural frequency on the graph provided. (Students should come up with a hyperbola, a curve representing an inverse relationship in which, as the height of the structure increases, its natural frequency decreases.)
- e. Ask the class: From what you have learned, do the earthquakes with the highest numbers on the Richter Scale always do the most damage? (Students should already know that the amount of damage has to do with population density and other factors, but now they will be aware of something new. To illustrate the relationship of frequency and resonance, use the example of someone pushing a child in a swing. The person pushes a little at a time, over time, and soon the swing goes very high without a big push. Each small push is at the right frequency. Similarly, a building may vibrate with a great amplitude without big earthquake vibrations because the smaller vibrations came at that structure's natural frequency.)

5. Ask the SETs to share and discuss their results. Again point out the connection between the experimental results and the way real buildings resonate. Other things being equal, taller buildings have lower natural frequencies than short buildings.

C. Conclusion

Review the terms and concepts introduced in this lesson. Explain that seismic waves caused by earthquakes produce oscillations, or vibrations, in materials with many different frequencies. Every object has a natural rate of vibration that scientists call its natural frequency. The natural frequency of a building depends on its physical

TEACHING CLUES AND CUES



You may choose to have students build models in class. In that case, you will need to make student copies of Master 4.3a, and assembly will become step 1 under Lesson Development. You will also need more materials.



Instruct students to start the stopwatch as a numbered block reaches its maximum swing and start counting with zero. Often students will start counting with one when they start the stopwatch and end up with only nine swings.

characteristics, including the design and the building materials. Resonance is a buildup of amplitude in a physical system that occurs when the frequency of an applied oscillatory force is close to the natural frequency of the system. In the case of an earthquake, the ground shaking may be at the same frequency as the natural frequency of a building. Each vibration in the ground may come at or dangerously close to the natural frequency of the structure.

Ask the class to hypothesize what would happen when buildings of two different heights, standing next to each other, resonate from an earthquake. Wiggle the BOSS model so that assemblies 2 and 3 vibrate greatly, and let students see how buildings hammer together during powerful earthquakes. If you have some images of this effect from actual earthquakes, show them now.

Entice students to further investigation by leaving them with the question: “How could you add structural elements to reduce resonance in a building?”

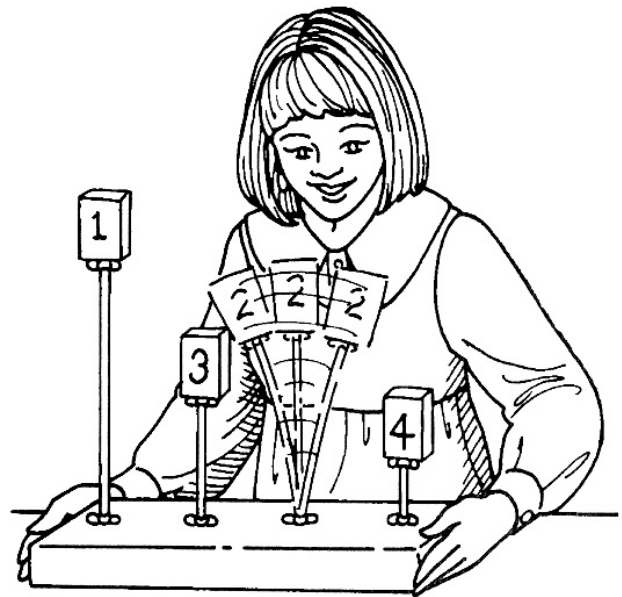
ADAPTATIONS AND EXTENSIONS

1. Tell students that one way to protect a building from resonating with an earthquake is to isolate its foundation, or base, from the ground with devices much like wheels. This technique is called base isolation. Structural engineers are now developing the technology to place buildings on devices that absorb energy, so that ground shaking is not directly transferred to the building.

Invite students to add standard small wheels from a hardware store to their models as an illustration of one of the many base isolation technologies, or add wheels to your own BOSS model, then shake the table. Better yet, place the model in a low box or tray and shake it. Then take out the model, fill the box with marbles or BBs, and replace the model on this base. Now shake the box. Challenge students to come up with other base isolation techniques.

2. If any of your students have studied harmonic motion in a physical science or physics class, challenge them to explain how the BOSS model is an example of an inverted pendulum.

3. To help students connect the numbered rod assemblies to actual buildings, make paper sleeves and decorate them to resemble buildings in your area. At some point in the lesson, slide the sleeves over the rod assemblies to show how buildings can collide, or hammer against each other, during an earthquake. ▲



1. Cut one of the meter-long threaded rods down to 75 cm, leaving the other full length.
2. Cut one of the 61-cm threaded rods down to 45 cm, leaving the other full length.
3. Drill a .63-cm (1/4 in.) hole through the center of one of the short sides in each of the 15-cm pieces of wood. (See assembly diagram.)
4. Hammer a tee nut into the hole on one end of each 15-cm piece.
5. Countersink four 3/4-in. holes about 1/8 in. deep into the 45-cm 2 x 4 at 12-cm intervals, as marked on the diagram. (This will allow you to countersink the nuts so they don't scratch the surface where the model rests.)
6. Drill four 1/4-in. holes in the 45-cm 2 x 4 in the countersunk holes.
7. Hammer a tee nut into each countersunk hole. Turn the board over so the tee nuts are on the bottom.
8. Assemble the rods and the base as shown on the diagram.
9. Use the permanent marker to label the 15-cm 1 x 4 blocks in order, 1, 2, 3, and 4.

Optional: Paint the four 15-cm pieces of wood in four different colors. When they are dry, number them, with the white paint.

