UNIT FOUR

Can Buildings Be Made Safer?

This unit is designed to allow students to construct an understanding of how the shaking of the ground during an earthquake causes damage to buildings and how buildings can be made better able to withstand this shaking. The activities and experiments of this unit culminate in an exciting performance assessment. Like the activities in Unit 1, these require considerable teacher preparation and will be enhanced by the widest possible involvement of community members outside the classroom.

Lesson 1, Building Fun, is designed as an attention-grabber, allowing students to discover the physical properties of some materials, practice working together, and most of all, have fun while establishing the need for constraints in building performance requirements. Students are given Styrofoam strips and a variety of connection devices and asked to build a stable structure of any kind.

Lesson 2 provides students with real experience in reinforcing or bracing a wall to carry the horizontal loads of an earthquake. They learn three engineering techniques and experiment with them on a model wall. Students develop the ability to make load path diagrams to predict and describe how static and dynamic forces travel though a wall.

Lesson 3, Building Oscillation Seismic Simulation, or BOSS, is an opportunity for students to explore the phenomenon of resonance while performing a scientific experiment that employs mathematical skills. The students are intrigued by a discrepant event involving the BOSS Model and are then set to work experimenting with the natural frequencies of structures. They experience how structures behave dynamically during an earthquake.

Lesson 4, Earthquake in a Box, engages students in constructing and using an instrument similar to one scientists use to model the impact of earthquake shaking. The materials and the procedure are both uncomplicated. This activity reinforces the major role of horizontal (lateral) forces in an earthquake and the importance of designing structures to withstand them.

In Lesson 5, The Building Challenge, students apply what they have learned in the first four activities. They are challenged to build a Styrofoam structure that can sustain the maximum horizontal load possible. The students' performance in this building contest is an authentic assessment of the ideas developed in Unit 4.

Take time to do all the activities in this unit with your class. They are all important, not only because this unit is more closely integrated than the other units, but also because it deals with an aspect of earthquake safety that is usually not treated elsewhere in high school and junior high learning materials. It will kindle your students' enthusiasm for science, architecture, and engineering.

4.1

Building Fun

RATIONALE

Students investigate the physical properties of building materials and design while considering how these might affect the way a structure withstands forces.

FOCUS QUESTIONS

What kind of structure would you build for fun?

What are the properties of some uncommon building materials?

How do structures stand up to extra forces?

OBJECTIVES

Students will:

1. Build a model structure.
2. Describe what may happen to a structure when a load is applied.
3. Describe the physical properties of some materials.

MATERIALS

for the teacher

- Master 4.1a, Building Engineering: Teacher Background Information
- Photos, books, slides, and/or videos with images of earthquake damage (See Unit 1 Resources.)
- Band saw or other saw
- One brick

for each small group

- 6 or more sticks of Styrofoam, 2.5 cm x 2.5 cm x 15 cm 1 in. x 1 in. x 6 in.)
- 3 pieces of string, each 30 cm long (*optional*)
- 10 paper clips (*optional*)
- About 20 toothpicks

TEACHING CLUES AND CUES

The lessons in this unit are a set. Plan time to do them all, for maximum learning and enjoyment.

Give yourself plenty of time for gathering and cutting materials. There is potential for some mess, so leave time for the students to clean up.

If you are not able to obtain visuals to introduce this lesson, do a quick demonstration with a deck of cards instead. Build card houses and let students take turns knocking them down by shaking the surface they rest on, or invite them to build and test the structures. The point is only that buildings need more than walls and a roof to withstand stress.

- Masking tape for labels

PROCEDURE

Teacher Preparation

1. You may want to invite an architect, engineer, geologist, or seismologist to visit your class during Lesson 4 of this unit, when students will again design model buildings. The guest expert could initiate the building challenge and help students to understand the concepts involved.

2. Read the teacher background information on Master 4.1a. If possible, assemble visuals from among those listed in the Unit 1 Resources.

3. Draft a few students to cut the Styrofoam into pieces, or ask the industrial arts instructor to help. (Styrofoam is easily cut on a band saw.) Finally, collect the building materials for this lesson and put them into piles on a table in the front of the room.

A. Introduction

Set the stage by asking students to tell what they know about the effect of earthquakes on buildings and other structures, both from personal experience and from reading, television, movies, or other sources. Be protective of their right to say what they remember, even if it may sound exaggerated to other students. If you have pictures or slides of earthquake damage, show them now.

B. Lesson Development

1. Divide the class into cooperative working groups of three to five students each. Explain that throughout this unit the groups will be known as seismic engineering teams, or SETs. Encourage each SET to choose a name.

2. Ask the groups to collect materials and build the strongest structures they can with the materials and the time allotted. Do not direct or criticize their efforts. This activity is for fun. When students try again in Lesson 4, they will be able to apply what they have learned in this unit.

3. After 20 to 30 minutes, call a halt to construction. Have a spokesperson for each group bring its structure to the materials table in the front of the room and describe the structure to the class. Ask students to explain why they built what they did.

4. With all the structures on one table, ask the class what would happen if you were to place a brick on top of each structure. Have the brick in hand, but do not actually crush any structure. Explain to the students that the brick is simulating the static force of gravity (vertical load) that every structure must carry. In this case, the Styrofoam is quite strong for its weight, so the brick can also represent the weight of all the nonstructural elements of a building, such as floors, wall coverings, and electrical wiring. Expect the students to protest because they were not told their structures had to support a brick. Explain that this activity was only an introduction and a chance to discover the physical properties of the materials.

VOCABULARY

Horizontal load: the sum of horizontal forces (shear forces) acting on the elements of a structure.

Lead: the sum of vertical force (gravity) horizontal forces (shear forces) acting on the mass of a structure. The overall load is further broken down into the loads of the various parts of the building. Different parts of a building are designed and constructed to carry different loads.

Vertical load: the effect of vertical force (gravity) acting on the elements of a structure.

TEACHING CLUES AND CUES

Cut more Styrofoam than you will need for this lesson—about 35 strips per group—since you will also use these strips in Lesson 4. If some of the strips are less than uniform, use them now, saving the best ones for Lesson 4.

5. Now ask the students what would happen if you shook the base of each building. Test a few gently while the students observe. What if you held the base of each structure and pushed horizontally on the top? Test a few, but again, try not to break any structure. Explain that buildings experience horizontal loads or dynamic forces during earthquakes. One way to simulate these forces is simply to push or pull a structure from the side.

C. Conclusion

Tell students that at the end of this unit there will be another building activity, but this time it will be a contest to design and build structures that can support a horizontal load. What they learn in this unit can be applied in the contest. Let them know there will be clearly defined parameters and all groups will have an equal opportunity to succeed. Label the structures with SET names and put them aside for the contest at the end of this unit. ▲

4.1a MASTER PAGE

Teacher Background Reading

Building Engineering

During an earthquake, a marked spot on the Earth might be seen to move erratically, tracing out a random path resembling that of a wandering insect. “Ground motion” is a literal description, since the ground moves (generally for a distance measured only in centimeters) relative to its starting point. The ground motion that is important in determining the forces on a building is acceleration. As the seismic waves move through the ground, the ground moves back and forth. Acceleration is the rate at which ground movement changes its speed.

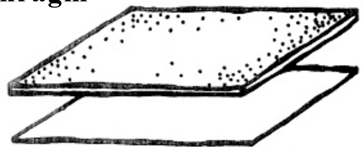
Two other unit measures are directly related to acceleration. Velocity, measured in centimeters per second, refers to the rate of the motion at a given instant. Displacement, measured in centimeters, refers to the distance an object is moved from its resting position. If you move your hand back and forth rapidly in front of your face, it might experience a displacement of 20 to 30 centimeters in one second and its acceleration and velocity may be quite high, but no damage will be done because the mass of your hand is low. In a building with a mass in the thousands of metric tons, tremendous forces are required to produce the same motion. These forces are transmitted throughout the structure, so if the movement repeats for some minutes the building may shake to pieces.

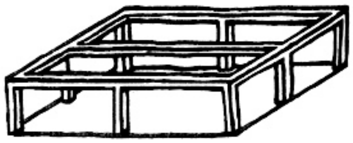
To overcome the effects of these forces, engineers rely on a small number of components that can be combined to form a complete load path. In the vertical plane, three kinds of structural systems are used to resist lateral forces: shear walls, braced frames, and moment-resistant or rigid frames. In the horizontal plane, diaphragms (generally formed by the floor and roof planes of the building) or horizontal trusses are used. Diaphragms are designed to receive lateral force between the vertical resistance elements (shear walls or frames). Shear walls are solid walls designed to carry the force to the vertical resistance system. In a simple building with shear walls at each end, ground motion enters the building and moves the floor diaphragms. This movement is carried by the shear walls and transmitted back down through the building to the foundation. Braced frames act in the same manner as shear walls, but may not carry as much load depending on their design. Bracing generally takes the form of steel rolled sections (I-beams), circular bar sections (rods), or tubes. Rigid frames rely on the capacity of joints to carry loads from columns to beams. Because these joints are highly stressed during movement the details of their construction are important. As a last-resort strategy, rigid frames use the energy absorption obtained by deformations of the structure before it ultimately fails.

Architecturally, rigid frames offer a certain advantage over shear walls or braced frames because they tend to provide structures that are much less obstructed internally than shear wall structures. This allows more freedom in the design of accompanying architectural elements, such as openings, exterior walls, partitions, and ceilings, and in the placement of building contents, such as furniture and loose equipment. Nevertheless, moment-resistant frames require special construction and detailing and therefore, are more expensive than shear walls or braced frames.

Note: *Adapted from FEMA 99, October* 1990, Non-technical Explanation of the NEHRP Recommended Provisions.

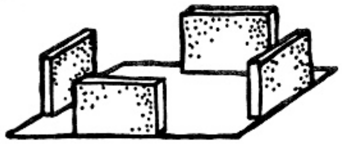
Diaphragm

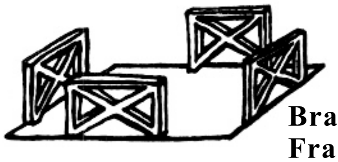




Moment Resistant

Shear





Braced Frame

4.2

Structural Reinforcement:

The Better Building

RATIONALE

Students will learn how diagonal braces, shear walls, and rigid connections strengthen a structure to carry forces resulting from earthquake shaking.

FOCUS QUESTIONS

How may the structure of a building be reinforced to make it better able to withstand earthquake shaking?

OBJECTIVES

Students will:

1. Recognize some of the structural elements of a building.
2. Describe how the horizontal and vertical structural elements carry the horizontal and vertical loads of a building.
3. Describe how diagonal braces, shear walls, and rigid connections provide paths for the horizontal load resulting from an earthquake.
4. Observe how added structural elements strengthen a model wall to withstand shaking.

MATERIALS

For the teacher: Materials for one model wall

- Master 4.2a, Building a Model Wall
- 21 jumbo craft sticks, about 15 cm x 2 cm x 2 mm thick
- Electric drill with 3/16" bit
- Goggles for eye protection
- 1 piece of thin wood (about 2 mm thick) 45 cm x 6 cm (about 18 in. x 2 in.)
- 1 piece of sturdy wood (2 x 6) for a base, about 45 cm (18 in.) long
- 16 machine bolts, 10 x 24, about 2 cm long (.75 in.)
- 16 machine screw nuts, 10 x 24
- 32 washers, #8

TEACHING CLUES AND CUES

Jumbo craft sticks are available at craft and hobby stores. They are larger than ice cream sticks, about the size of tongue depressors.

You may want to build this model and the one in Lesson 4.3 at the same time, and introduce them both in the same class period. This would allow two groups to be actively engaged with the models of the same time.

- 7 small wood screws

reinforcing elements for one wall

- 2 pieces of string, each approximately 25 cm (10 in.) long
- 1 piece of thin wood (about as thick as the craft sticks) 20 cm x 2 cm (about 8 in. x 1 in.)
- 1 piece of lightweight cardboard, about 15 cm x 15 cm (a little less than 6 in. square)
- 8 small paper clamps to fasten wood and cardboard

for each small group

- One set of the above supplies if they are each building a model wall
- One copy of Master 4.2b, Load Paths Worksheet
- Pens and pencils

PROCEDURE

Teacher Preparation

Assemble the model wall, following the diagram on Master 4.2a, Building a Model Wall, and try it out before class. Be sure the bolts are just tight enough to hold the structure upright when no force is applied.

A. Introduction

Tell students that this lesson is designed to demonstrate how the structural elements of a wall carry forces. The activity deals with three structural elements that carry the lateral shear forces caused by ground shaking during an earthquake: diagonal bracing, shear walls, and rigid connections. It is designed around an apparatus called the model wall. Remind the students that this is a model, designed to demonstrate only certain characteristics of real walls.

B. Lesson Development

1. Show students the model and tell them that it represents part of the frame of a building. Describe the components of the wall, and ask them, “What holds this wall up?” The answer is in the interaction of the vertical and horizontal elements, but try to keep the students focused on discovery, since in this activity they will see the architectural principles demonstrated. Explain to students that what they refer to as weight will be called the force of gravity in this lesson.

2. Now ask students to predict what would happen if you quickly pushed the base of the wall, simulating an earthquake. Remind them that an earthquake may cause ground shaking in many directions, but for now we are modeling shaking in one direction only.

3. Divide the class into the same seismic engineering teams (SETs) as for Lesson 1 and give each group one copy of Master 4.2b, Load Paths Worksheet. Invite students to take turns investigating the model’s response in their small groups.

VOCABULARY

Braces or Bracing: structural elements built into a wall to add strength. These may be made of various materials and connected to the building and each other in various ways. Their ability to withstand stress depends on the characteristics of the materials and how they are connected.

Lead: the sum of vertical forces (gravity) and horizontal forces (shear forces) acting on the mass of a structure. The overall load is further broken down into the loads of the various parts of the building. Different parts of a building are designed and constructed to carry different loads.

Lead path: the path a load or force takes through the structural elements of a building.

Rigid connections: connections that do not permit any motion of the structural elements relative to each other.

Shear force: force that acts horizontally (laterally) on a wall. These forces can be caused by earthquakes and by wind, among other things. Different parts of a wall experience different shear forces.

Shear walls: walls added to a structure to carry horizontal (shear) forces. These are usually solid elements, and are not necessarily designed to carry the structure’s vertical load.

Structural elements or structural features: a general term for all the essential, non-decorative parts of a building that contribute structural strength. These include the walls, vertical column supports, horizontal beams, connectors, and braces.

a. Instruct one student in each group to push at the bottom of the model from the lower right or left side. (When pushed just fast enough, the model should collapse at the first floor only.) Ask students why the other floors didn't collapse. (The first floor collapsed because it was too weak to transfer enough horizontal force to move the upper stories. It could not transfer the shaking to the upper stories.)

b. Direct students' attention to the load path diagrams on Master 4.2b and explain that pushing the base of the building is equivalent to applying force horizontally to the upper stories. A force applied horizontally to any floor of a building is called the shear force on that floor. Shear forces can be caused by the ground shaking of an earthquake as well as by high winds. Invite students to carefully apply horizontal forces at different points on the model to simulate earthquake shaking. (Earthquakes affect buildings at ground level.)

4. Ask students how they could add structural elements to create a path for the load to follow to the ground when strong forces act upon the structure. Help the students discover the effect of adding a shear wall, diagonal bracing, and rigid connections, using string, cardboard, extra wood, and clamps, as in the diagrams on the master. On each of the three diagrams provided, have students draw a force arrow (a vector) and trace the path the force takes to the ground.

5. Challenge students to design and build three different arrangements of the six structural elements depicted on the worksheet. Each time they modify the design they must modify the diagram to show the new load path. Check each structure and diagram until you are sure that students understand the concepts. When a structure is well reinforced, you should be able to push on the upper story and slide the whole structure without any of the walls failing.

6. Either have the groups discuss the questions on the master, with one student recording each group's response, or ask individual students to write responses to specific questions. After all the groups finish the questions, have a reporter for each SET present its response to one of the questions. Allow the class to come to some consensus on their responses to that question, then proceed to another group until all the questions have been discussed.

C. Conclusion

As a closing activity, challenge a volunteer to remove an element (a craft stick) that, according to the load path diagram, is not carrying any load. Have the student unbolt one end of that element and push the reinforced structure to see if it holds. It will, if the load path is correct.

Finally, help the students connect the behavior of their model walls to their mental images of real buildings during an earthquake. Emphasize that the back and forth, horizontal component (or shearing) of ground shaking is the force most damaging to buildings. Buildings are primarily designed to carry the downward pull of

TEACHING CLUES AND CUES

This activity is designed as a demonstration or as a group activity. If you decide to have each group build a model wall you will need more materials.

Encourage students to choose roles within their SETs and later report their results by role, with the technician reporting the data, the engineer describing the calculations, the scientist explaining the relationships, and the coordinator facilitating.

Students may try both pushing the structure directly and moving the table. Shaking the table on which the structure rests would simulate the transfer of energy from the ground to the building.

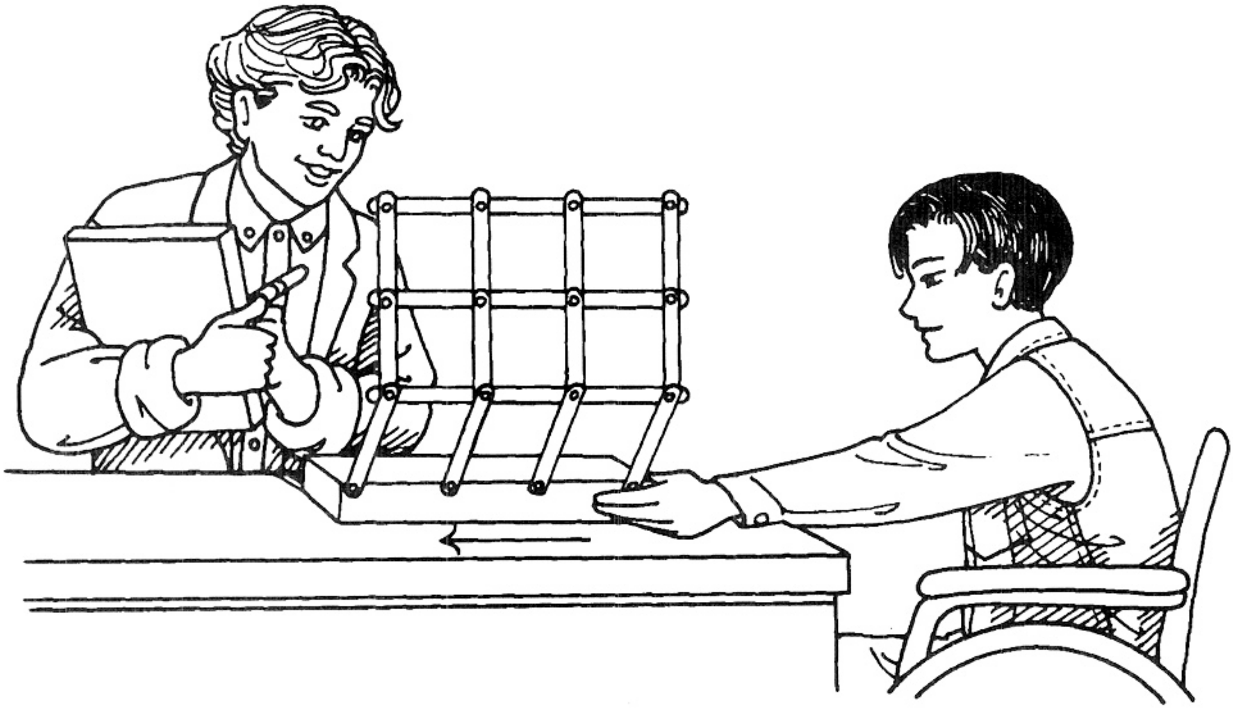
gravity, but to withstand earthquake shaking they need to be able to withstand sideways, or horizontal, pushes and pulls.

ADAPTATIONS AND EXTENSIONS

1. Challenge students to find the minimum number of diagonal braces, shear walls, or rigid connections that will ensure horizontal stability in their models.

2. Invite students to design, construct, and test other structural elements that could make buildings earthquake-resistant, such as square rigid connections. Some might try putting wheels or sleds on the bottom of their buildings.

3. If you have some very interested students, you may give them access to all your building supplies and challenge them to design and construct larger structures. Ask students to consider how they could design a building so that the ground shaking does not transfer to the building. There are new technologies that allow the ground to move, but not the building. One of these is called base isolation. Have students research this topic in periodicals. (See Unit Resources.) ▲

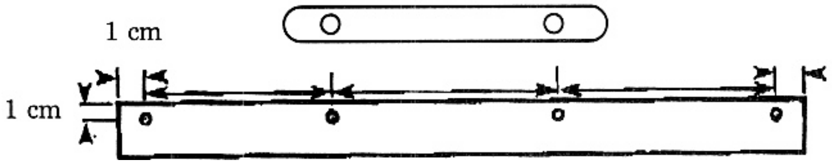


Building a Model Wall

1. Stack 21 craft sticks one on top of the other. Wrap a rubber band around the center to hold them together. Using a 3/16 in. bit, carefully drill a hole through all the sticks at once, 1 cm from the end of the stack. Drill slowly to avoid cracking the wood.

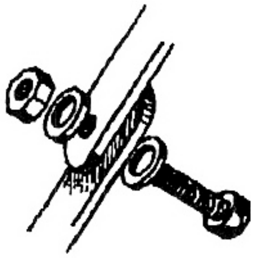
2. Select the thinner of the two large pieces of wood (45 cm x 6 cm). Drill a 3/16 in. hole 1 cm from one end and 1 cm from the edge. Measure the distance between the holes drilled in the craft sticks and space three more 3/16 in. holes at that distance 1 cm from the edge so that a total of four holes are drilled (see illustration).

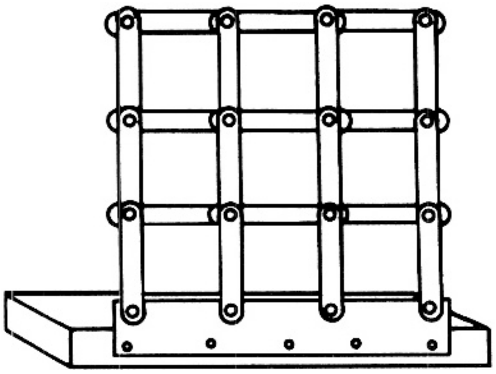
3. Use the small wood screws to mount this piece of wood on the base (the 2 x 6), fastening at the bottom and in the center. Leave the pre-drilled holes sticking up far enough above the top to accept the drilled craft sticks.



4. Using the bolts, washers, and nuts, assemble the craft sticks to build a model wall.

5. Experiment with tightening bolts and washers until they are just tight enough for the wall to stand on its own.





4.2b MASTER PAGE

Load Paths Worksheet

Name ____ Date ______________________

A. Failing Wall

Observe and explain how the wall fails when its base is shaken rapidly back and forth, simulating the motion of a building hit by S waves during an earthquake. Tighten all the nuts just enough to allow the joints to move. Sharply push the base a few centimeters horizontally (right or left).

1. What part of the wall fails first?
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2. Imagine how the horizontal force you applied to the base travels to the upper parts of the wall. What caused the first structural
failure?____
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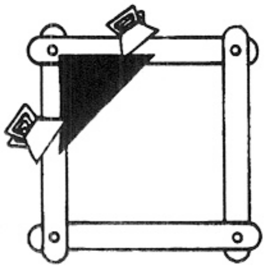
B. Load Paths with Additional Structural Elements

1. Pick up the two rigid connections, one shear wall (cardboard), one solid diagonal brace, and two pieces of string. Add structural elements to your wall to provide paths for the horizontal forces, or loads, to travel through the wall. Study the diagrams below to see how these structural elements provide load paths.



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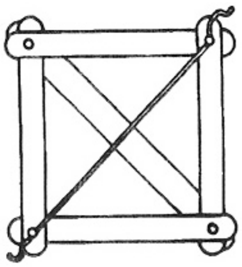

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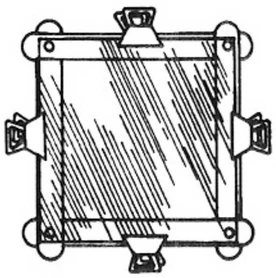

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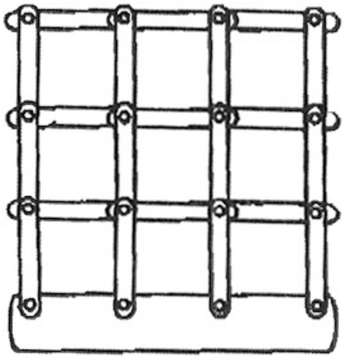
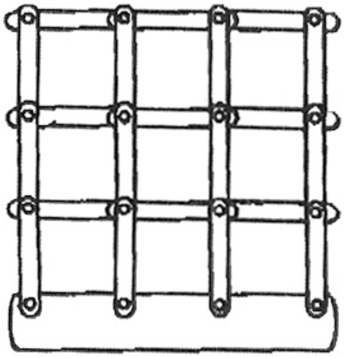
Use arrows to show the load path on each diagram.

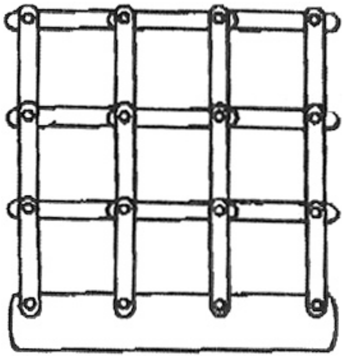
2. Put additional structural elements on your wall and push the third level. If the elements you added provided a load path to the base, the base of the wall should move. If they do not, the wall will fail somewhere. When you discover a setup that works, diagram it and sketch the load paths with arrows. Have your instructor look it over before you continue.



3. Design and build another set of additional structural elements. Sketch the load path here and have your instructor check it. Be sure each member of the team designs a set. The base of the model wall should move when lateral force is applied to the top elements.



4. Design and build a third set of additional structural elements. Use as few additional elements as possible. Sketch the load path and have your instructor check it. Be sure each member of the team designs a set. Test your load paths by removing elements not in the path to see if the building will stand up to a force.



C. Summary

1. What is a load path?

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2. Why must additional structural elements be added to a wall before it can carry horizontal forces?

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3. How many additional elements did you need to add?

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4. Why doesn't the force take some path other than the one you diagrammed?

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Load Paths Worksheet (key)

A. Failing Wall

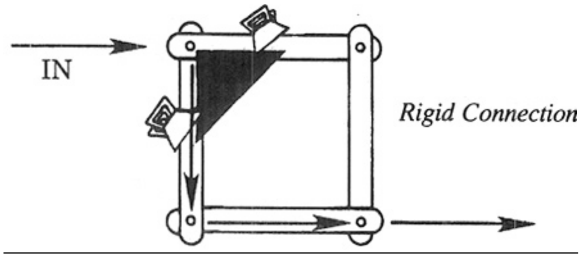
Observe and explain how the wall fails when its base is shaken rapidly back and forth, simulating the motion of a building hit by S waves during an earthquake. Tighten all the nuts just enough to allow the joints to move. Sharply push the base a few centimeters horizontally (right or left).

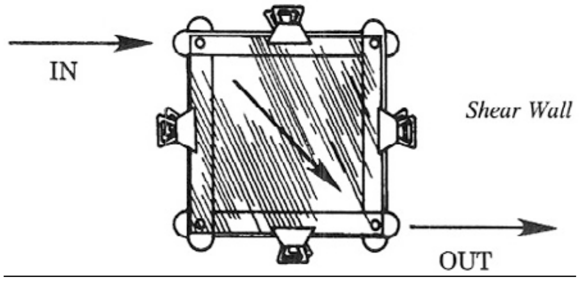
1. What part of the wall fails first? *The first floor*

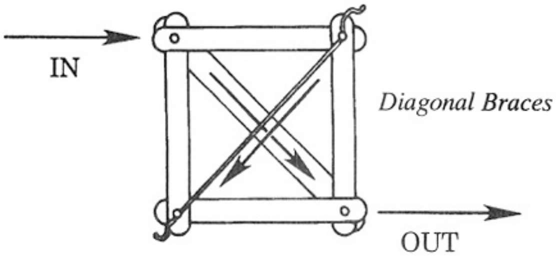
2. Imagine how the horizontal force you applied to the base travels to the upper parts of the wall. What caused the first structural failure? *The first floor has to carry all the load to the upper stories. It transfers forces to move the upper stories.*

B. Load Paths with Additional Structural Elements

1. Pick up the two rigid connections, one shear wall (cardboard), one solid diagonal brace, and two pieces of string. Add structural elements to your wall to provide paths for the horizontal forces, or loads, to travel through the wall. Study the diagrams below to see how these structural elements provide load paths.

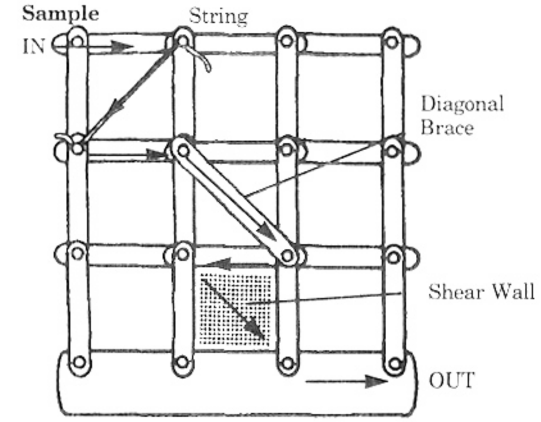




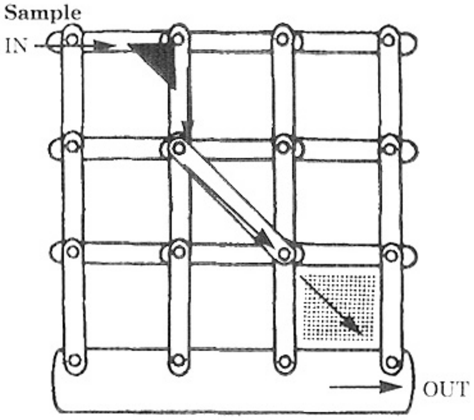


Use arrows to show the load path on each diagram.

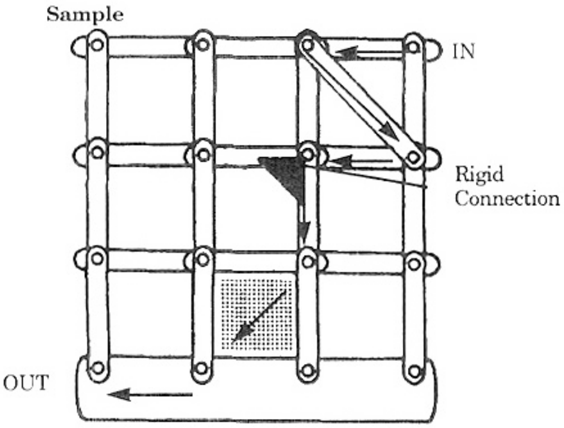
2. Put additional structural elements on your wall and push the third level. If the elements you added provided a load path to the base, the base of the wall should move. If they do not, the wall will fail somewhere. When you discover a setup that works, diagram it and sketch the load paths with arrows. Have your instructor look it over before you continue.



3. Design and build another set of additional structural elements. Sketch the load path here and have your instructor check it. Be sure each member of the team designs a set. The base of the model wall should move when lateral force is applied to the top elements.



4. Design and build a third set of additional structural elements. Use as few additional elements as possible. Sketch the load path and have your instructor check it. Be sure each member of the team designs a set. Test your load paths by removing elements not in the path to see if the building will stand up to a force.



C. Summary

1. What is a load path?
The path that the load (or force) follows through the structural elements of a building.

2. Why must additional structural elements be added to a wall before it can carry horizontal forces?
Normally, buildings only have to support vertical force (gravity). When horizontal forces are applied, as in an earthquake, additional elements are needed to carry them.

3. How many additional elements did you need to add?
Each joint needs only one additional structural element. Only one joint on each floor needs to carry the horizontal force, in this model.

4. Why doesn't the force take some path other than the one you diagrammed?
The diagram shows the places that are strong enough to carry the load. If there were more than one place, the load (or force) would travel through both.

4.3

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 _-in. and _-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

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

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-

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.

cal 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?"

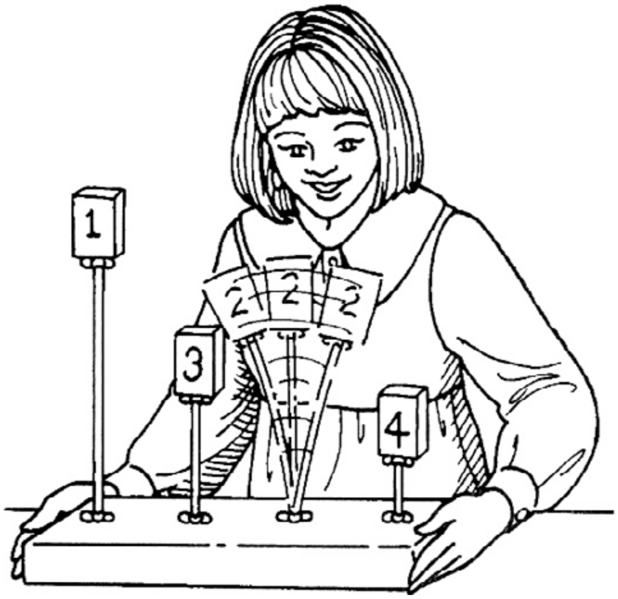
ADAPTATIONS AND EXTENSIONS

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.

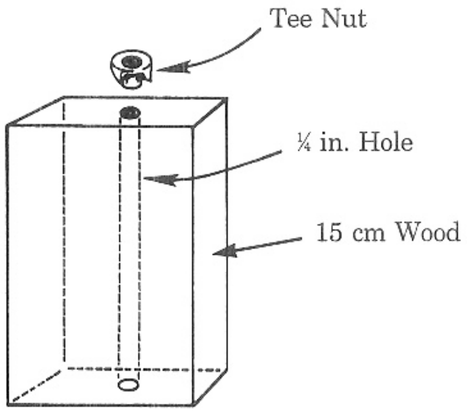
3. To help students connect the numbered rod assemblies to actual buildings, make paper sleeves and decorate them to resemble buildings in your area. At some point in the lesson, slide the sleeves over the rod assemblies to show how buildings can collide, or hammer against each other, during an earthquake.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

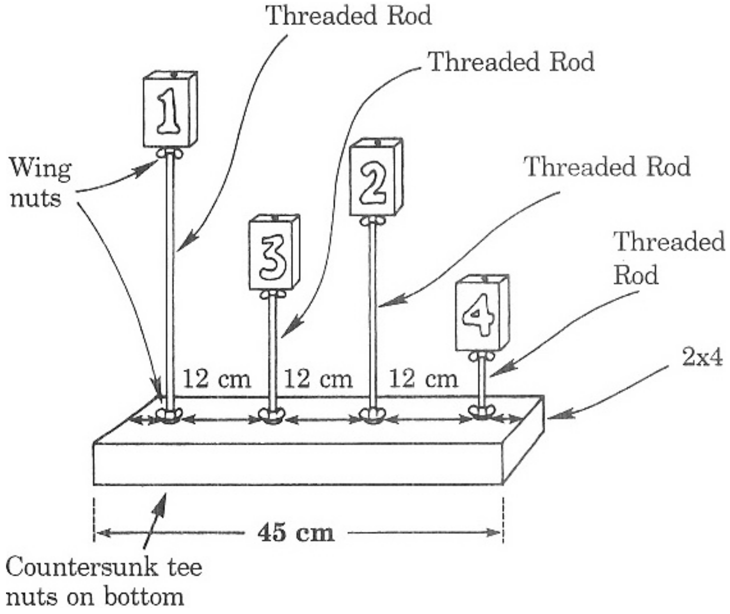


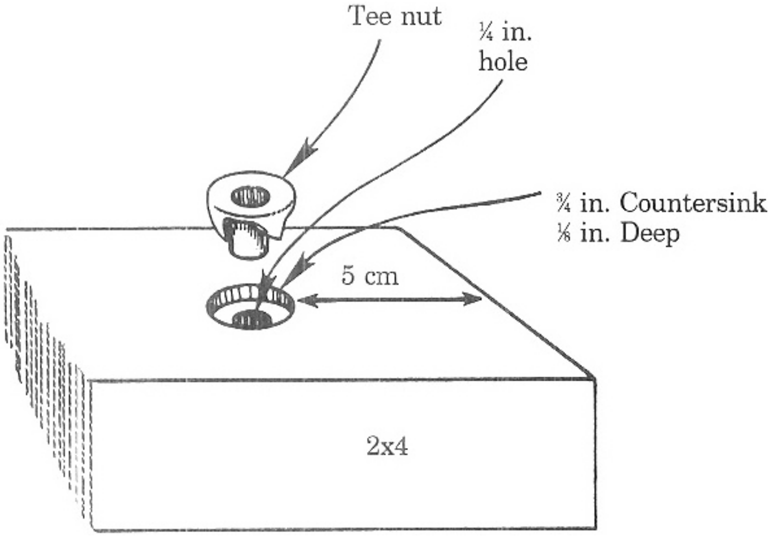
BOSS Model Assembly

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.







BOSS Worksheet

Name ____ Date ____________________

Cooperative Group ______________________________ Scientist ______________________________

Coordinator ______________________________ Technician ______________________________

Engineer ______________________________

Record oscillation times in the data table below in the appropriate place for each rod assembly. These times are measured in seconds per 10 cycles. Repeat the measurement four times to minimize human error, then record.

Caution: Start the stopwatch as a numbered block reaches its maximum swing and start counting with zero, otherwise you will end timing only nine swings. Practice this until your times for 10 oscillations are fairly close to each other.

Calculate the ***average time*** for each oscillation by adding four measurements and dividing by four. Record.

Calculate the natural ***frequency.*** Divide 10 cycles by the average time (do not simply move the decimal point). Frequency is measured in hertz, or cycles per second. Record.

A. Data Table: Oscillation Times

Rod Assembly	Oscillation Time (sec/10 cycles)				Avg. Oscillation Times (sec/10 cycles)	Natural Frequency Hertz (cycles/sec)
	Trial 1	Trial 2	Trial 3	Trial 4		
#1						
#2						
#3						
#4						

1. How much variation do you notice among the four trials? ____

2. What relationship do you notice, if any, between the height of the rods and their natural frequencies?

____

____

B. Heights of the Rod Assemblies

1. Measure the height of each rod assembly from the base to the top of the block and record it.

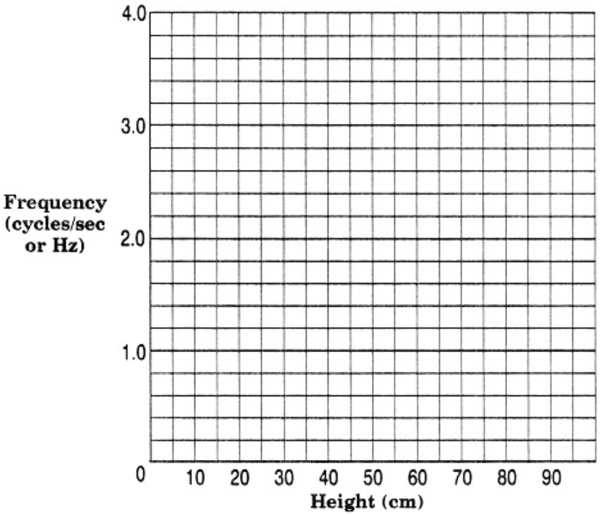
Rod Assembly	Height (cm)
#1	

#2	
#3	
#4	

2. What is the approximate difference in height between #1 and #2, #2 and #3, and so on?

____
____

3. Plot the height versus the natural frequency of each rod assembly on the graph provided. You should have four data points. Connect the points with the best fitting straight or curved line you can.



4. What kind of line did you get from your data?

____
___

5. As the height of the rod assemblies gets larger, what happens to their natural frequency?

____
____
____
____
____

C. Summary

1. What variable is manipulated in this experiment? (How do the four rod assemblies differ from each other?)

____
____

2. What is the responding variable in this experiment? (What did you measure?)

____
____

3. What does oscillate, or vibrate, mean?

____
____

____
____

4. Define *frequency*.

____
____

____
____

5. Why does only one rod assembly oscillate greatly (or resonate) when you wiggle the base?

____

6. What is resonance?

____

____

____

7. How are the rod assemblies like buildings?

____

____

____

8. (*extra credit*) How can a building be protected from resonating with seismic vibrations?

____

____

BOSS Worksheet (key)

Record oscillation times in the data table below in the appropriate place for each rod assembly. These times are measured in seconds per 10 cycles. Repeat the measurement four times to minimize human error, then record.

Caution; Start the stopwatch as a numbered block reaches its maximum swing and start counting with zero, otherwise you will end timing only nine swings. Practice this until your times for 10 oscillations are fairly close to each other.

Calculate the ***average time*** for each oscillation by adding four measurements and dividing by four. Record.

Calculate the natural ***frequency.*** Divide 10 cycles by the average time (do not simply move the decimal point). Frequency is measured in hertz, or cycles per second. Record.

A. Data Table: Oscillation Times

Rod Assembly	Oscillation Time (sec/10 cycles)				Avg. Oscillation Times (sec/10 cycles)	Natural Frequency Hertz (cycles/sec)
	Trial 1	Trial 2	Trial 3	Trial 4		
#1					11	0.9
#2					6.7	1.5
#3					5	2.0
#4					3	3.3

1. How much variation do you notice among the four trials? *Oscillation times vary by less than 10 percent.*

2. What relationship do you notice, if any, between the height of the rods and their natural frequencies?
The shorter the rod, the higher the natural frequency. The taller the rod, the lower the natural frequency.

B. Heights of the Rod Assemblies

1. Measure the height of each rod assembly from the base to the top of the block and record it.

Rod Assembly	Height (cm)
#1	89
#2	73
#3	57
#4	42

2. What is the approximate difference in height between #1 and #2, #2 and #3, and so on?
Approximately 15 cm, the height of the wooden rectangle at the top of each rod assembly.

Note: *Data will vary with specific BOSS model and student. Values in the tables are to assist the teacher and are* ***not*** *to be used in evaluating students.*

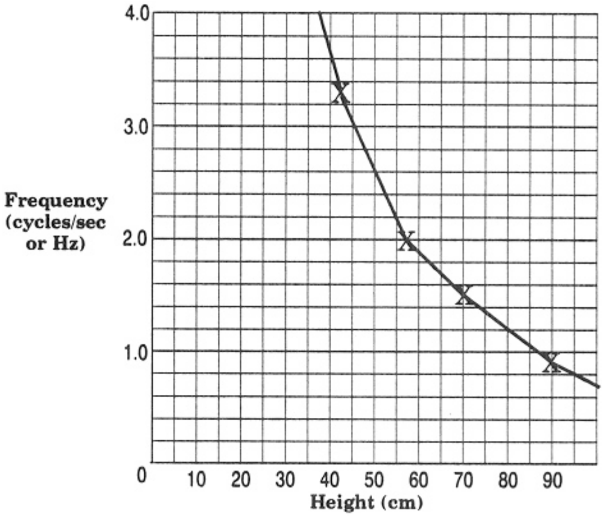
3. Plot the height versus the natural frequency of each rod assembly on the graph provided. You should have four data points. Connect the points with the best fitting straight or curved line you can.

4. What kind of line did you get from your data?

A symmetrical curve, or hyperbolic curve.

5. As the height of the rod assemblies gets larger, what happens to their natural frequency?

As the height increases, the natural frequency decreases.



C. Summary

1. What variable is manipulated in this experiment? (How do the four rod assemblies differ from each other?)

The height of the rods varies.

2. What is the responding variable in this experiment? (What did you measure?)

The natural frequency of each rod assembly.

3. What does oscillate, or vibrate, mean?

Wiggle back and forth, or move repetitively.

4. Define *frequency*.

In this case, the frequency is the number of oscillations per second.

5. Why does only one rod assembly oscillate greatly (or resonate) when you wiggle the base?

The vibration only adds up in one rod, or only one rod will resonate at each shaking.

You have found the rod's natural frequency.

6. What is resonance?

When a structure is vibrated at its natural frequency, the vibrations add up. This is called resonance.

7. How are the rod assemblies like buildings?

They have mass that is attached to the base by a structure.

Or—They have fixed bases attached to freely oscillating tops by tall, stiff structures.

8. (*extra credit*) How can a building be protected from resonating with seismic vibrations?

Dampen the building's vibration with something like the shock absorbers on a car.

Isolate the base of the building from the ground. (Accept other reasonable suggestions.)

4.4

EARTHQUAKE in a Box

RATIONALE

In cooperative SETs (seismic engineering teams), students win construct an inexpensive shake table for testing structures they have built.

FOCUS QUESTIONS

How do earthquake engineers use shake tables to model the effects of an earthquake on buildings, bridges, and other structures?

OBJECTIVES

Students will:

1. Construct a model of a shake table.
2. Design structures of various types and use the shake table to test their seismic survivability.
3. Analyze the failures of their design models and suggest ways to reduce damage.

MATERIALS

for each small group

- One copy of Master 4.4a, Shake Table Directions
- One piece of cardboard approx. 28 cm by 38 cm (11 in. x 15 in.)
- Wide packaging tape
- Hole-punching tool
- Metric ruler
- One cardboard box with flaps removed, approx. 30 cm by 40 cm by 20 cm (12 in. x 16 in. by 8 in. deep)
- Dark blue or black marker
- Phillips screwdriver
- 3 strands of packaging string, one about 30 cm long (12 in.) and two about 60 cm long (24 in.)
- 4 heavy-duty rubber bands

VOCABULARY

Retrofitting: making changes to a completed structure to meet needs that were not considered at the time it was built; in this case, to make it better able to withstand an earthquake.

Variable: in a scientific experiment, the one element that is altered to test the effect on the rest of the system.

TEACHING CLUES AND CUES

Use corrugated cardboard for greatest strength.

The size of the box may vary, as long as the size of the cardboard varies with it.

- Paper clips
- Two craft or ice cream sticks
- VCR and videotape (*optional*; see adaptations)
- A variety of materials for building structures, such as sugar cubes, ice cream sticks, small interlocking blocks, peanut butter (for mortar), dry spaghetti, straws, pipe cleaners, paper clips, cardboard, string, aluminum foil, and Styrofoam

TEACHING CLUES AND CUES

A gallon plastic jug with the top cut off makes an excellent storage container for the dry materials.

PROCEDURE

Teacher Preparation

1. Several days before you plan to do this activity, ask students to bring cardboard boxes and building materials from home. Suggest the items at the end of the materials list; students may think of others on their own. Gather the remaining materials, including extra odds and ends for students who forget, and arrange them in a convenient place.

2. Following the directions on Master 4.4a, build one shake table to use as a demonstration model.

A. Introduction

Tell the class that earthquake engineers use devices called shake tables to model the effects of an earthquake on buildings, bridges, and other structures. In this lesson, students will build simple shake tables and use them to test their own model structures.

B. Lesson Development

1. Direct students to gather into SETs as for the other lessons in this unit.

2. Distribute one copy of Master 4.4a, Shake Table Directions, to each team. Invite students to assemble their materials and build the shake tables. Offer assistance only as needed.

TEACHING CLUES AND CUES

Give students plenty of time to complete this step.

Use a paper clip to anchor one end of the rubber band, and a second paper clip as a needle to thread the rubber bands through the holes.

3. When all the groups have completed their tables, list these 10 variables on the chalkboard or poster paper:

- shape of structure
- height of structure
- construction materials
- shape of structural elements (triangle or rectangle)
- nonstructural exterior features (overhanging moldings, heavy decorative panels)
- foundation strength
- siting (type of soil structure is built on)
- duration (how long the earthquake lasts)
- intensity (how intense earth shaking is at the building's site)
- frequency

Ask each SET to select three variables from the list and design one model to test their impact, singly or in combination, when the structures are placed on the shake table. Remind students to include lifelines like bridges and electrical wires with their supports, as well as houses and other buildings.

4. Have students in each SET take turns operating the model, while the other members of the team record their observations.

5. Assign each SET to write a brief report, based on the notes from testing, that includes

- a summary of the team's observations
- reasons why their design suffered and/or resisted damage
- suggestions for making each design more quake resistant
- suggestions for retrofitting structures, where applicable
- diagrams illustrating all of the above

C. Conclusion

Invite one representative from each SET to share the highlights of the team's report. When all the reports have been given and discussed, conduct open discussion around one or more of these topics:

- How do municipalities develop building codes for earthquake-prone areas?
- Should schools, senior citizen homes, hospitals, fire stations, police stations, and other essential facilities be forced to follow tougher earthquake codes? Why? Why might governments encounter resistance to these standards? (because of the expense involved, among other factors)
- Is it possible to develop a classification system for types of structures and their reaction to an earthquake? What factors would such a system include?

ADAPTATIONS AND EXTENSIONS

1. If a VCR is available, have each team record its experiments and play them back in slow motion for detailed observation. Try to determine the frequency of each structure.

2. Challenge students to develop improved shake table designs, based on this model and their own ideas. Some students may choose to develop a shake table and test their best model structures as a science fair project.

3. Interested students might design a lifelines model that effectively illustrates the impact of a damaging earthquake upon buried pipe, sewer, gas, oil, water, and electrical lines.

4. As a research project, students might assess, in dollars and cents, the, loss of property that has occurred in specific earthquakes because of structural and nonstructural failures, then research the cost and availability of earthquake insurance in:

TEACHING CLUES AND CUES

Work with the class to standardize the operating procedure as much as possible. Have them practice putting the string in one short jerk, and be sure that everyone uses approximately the some kind of pull. This will allow you to compare the work of various groups, and make students' results reproducible.

- your respective area
- New Madrid, Missouri
- San Francisco, California
- Boston, Massachusetts
- Anchorage, Alaska
- Kona, Hawaii
- Charleston, South Carolina
- Syracuse, New York
- other geographic areas of interest

Do the insurance policies have the same premiums and regulations in all of the above geographic areas? Explain. Is all earthquake damage covered by insurance? Why or why not? ▲

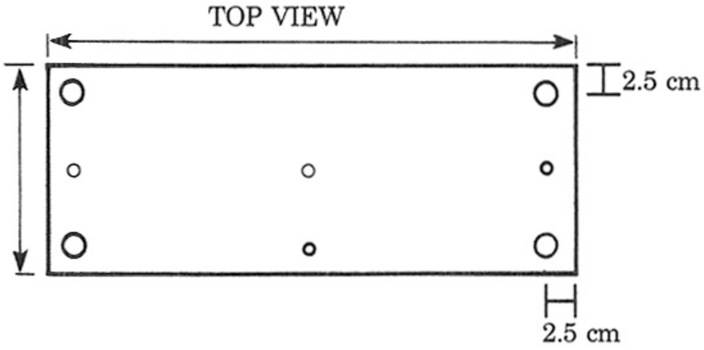
Note: *This activity was inspired by one developed by Katharyn E. K. Ross, (1993), "Using Shake Tables in The Pre-College Classroom: Making The Impact of Earthquakes Come Alive," Proceedings: 1993 National Earthquake Conference, Central United States Earthquake Consortium, Memphis, TN, Vol. 1, pp. 423-429.*

4.4a MASTER PAGE

Shake Table Directions

A. The Shake Platform

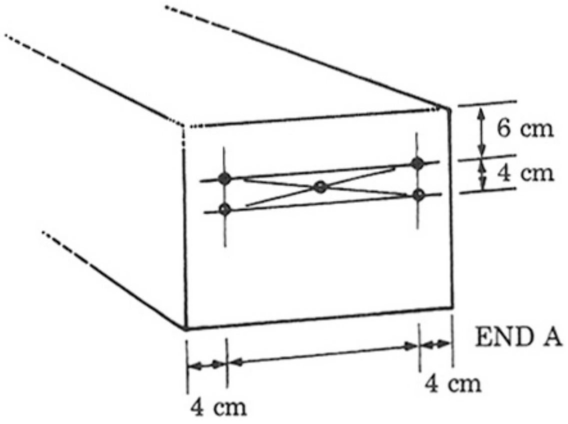
1. Reinforce the cardboard by covering all four edges with packaging tape or doubling the thickness.
2. Center a hole in each corner of the piece of cardboard 2.5 cm (1 in.) from both edges.



3. Locate the center of the long side of the cardboard by measuring halfway between the two holes you made at the comers in step 2. Punch a hole at that center point, one inch from the outside edge on one side. Repeat for the two short sides. Punch a hole in the exact center of the cardboard. You now have a total of eight holes in the platform.

B. The Shoe Box

1. On one of the two ends of the box that is 30 cm across (one of the shorter sides), measure 6 cm (about 2.5 in.) down from the top and mark this point. Draw a straight line through the point all the way across this end of the box. Measure 4 cm (about 1.5 in.) in from the right edge along the line and mark this point. Punch a hole there with the Phillips screwdriver. Punch another hole in the center of the box bottom.



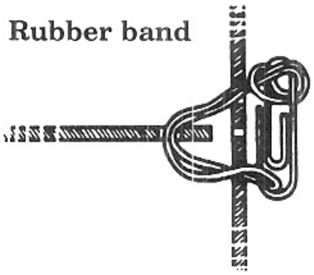
Note: *Size of platform should be 5-8 cm less than box dimensions to allow room for shaking. Dimensions will vary with box size.*

2. Measure 4 cm from the left edge on the same line and punch another hole, as illustrated. Punch two more holes 4 cm beneath the top two. Then, measure to find the point at the center of a four holes on this side. Mark that point and punch one small hole.

3. Follow the same procedure on the opposite end of the box.

C. Putting It Together

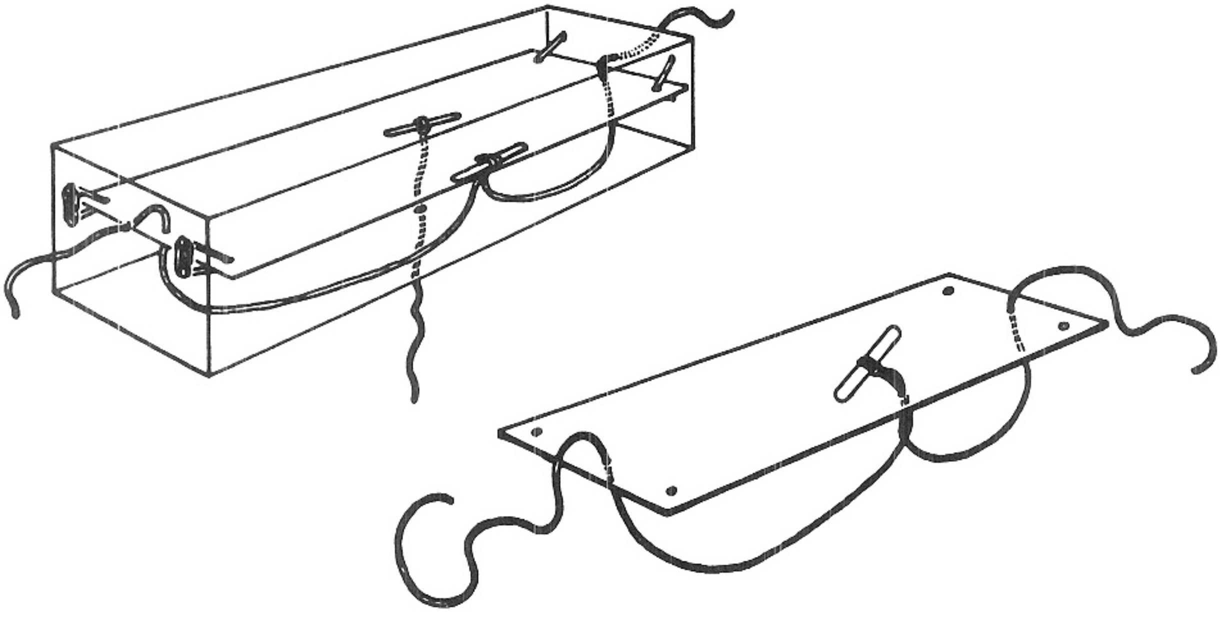
1. Tie the 30-cm length of string securely to the center of a craft or ice cream stick. Pull the free end of the string down through the center hole on the top of the shaking platform. The stick will keep the string from pulling through the hole. Leave enough string to pull through to the outside of the box.



2. Tie the two longer pieces to the center of a craft or ice cream stick. Pull them down through the center hole on the long side of the platform, then out through the center hole on the short sides of the platform. Reinforce the stick with tape if desired. When the table is fully assembled, you will pull on these strings to shake the platform.

3. While one student holds the platform in place inside the box, parallel to the floor, another student will thread a rubber band through the right upper hole in the A end of the box and the right outer hole of the shake platform, then out the lower hole in the box.

Use a paper clip to hold the rubber band in place. Do the same thing with the opposite holes on End A. Then, turn the box and repeat with End B. Pull the loose ends of both strings out through the center holes.



4.5

The Building Challenge

RATIONALE

A model structure can demonstrate the effects of diagonal bracing, shear walls, and rigid connections on a building's ability to carry loads similar to those created by an earthquake.

FOCUS QUESTIONS

How can you design and build a model structure to carry vertical and horizontal loads?

OBJECTIVES

Students will:

1. Use diagonal bracing, shear walls, and rigid connections to provide load paths in a structure.
2. Design and build a structure that will carry both vertical and horizontal loads caused by ground shaking.
3. Measure the magnitude of the shear force or horizontal load a structure can carry.

MATERIALS

for each small group (SET)

- Structures from Lesson 4.1
- 20 Styrofoam sticks, 2.5 cm x 2.5 cm x 15 cm, precut in preparation for lesson 4.1
- 3 pieces of string, each 30 cm long
- 10 paper clips
- 20 toothpicks
- Any materials from Lesson 4.4 that students want to use
- 1 square of tag board, 17.5 cm x 17.5 cm (about 7 in. square), to act as a shear wall
- 2 right triangles of tag board, cut from a 6-cm square, to act as rigid connections

VOCABULARY

Braces, or Bracing: structural elements built into a wall to add strength. These may be made of various materials and connected to the building and each other in various ways. Their ability to withstand stress depends on the characteristics of the materials and how they are connected.

Diagonal braces: structural elements that connect diagonal joints. These braces may be made of solid materials or flexible materials. How they function depends on what they are made of and how they are connected.

Load: the sum of vertical forces (gravity) and horizontal forces (shear forces) acting on the mass of a structure. The overall load is further broken down into the loads of the various parts of the building. Different parts of a building are designed and constructed to carry different loads.

Rigid connections: connections that do not permit any motion of the structural elements relative to each other.

Shaking: in this lesson, rapid horizontal vibration of the base of the model, simulating an earthquake. In an actual earthquake, of course, shaking occurs in many directions.

- 1 square of cardboard, 30 cm x 30 cm or larger (about 1 ft square) to serve as the base
- One copy of Master 4.5a, Building Challenge Design and Analysis Sheet

for the teacher

- Hot glue and glue gun (to be used by one group at a time, under direct supervision)
- Shaking table from Lesson 4.4
- A dog leash or other nylon strap about 2.5 cm wide and at least 60 cm long
- Several meters of string
- A small pulley
- Weights, either a kilogram mass set or a small basket and pennies
- Master 4.5b, Certificate of Achievement
- Slides or videos from the unit resource lists (*optional*)

PROCEDURE

Teacher Preparation

1. If you want to make the testing of student models a special event, make plans now. See Adaptation 1. If you have arranged to involve guest experts, remind them of the date.

2. Prepare the testing setup. Collect all the materials and have them ready to distribute.

A. Introduction

Briefly review with students what they have experienced so far in this series of activities. Especially promote discussion of the ideas developed in Lesson 4.2. Be careful to leave the applications of those ideas very open, to avoid giving students the impression that there is only one right way to design a structure.

B. Lesson Development

1. Direct students to gather in the seismic engineering teams (SETs) they formed in Lesson 1 of this unit. You may want to have students choose roles within the teams, like coordinator, engineer, and technician, to organize the effort and to assign accountability for timing, design, construction, and describing the performance of the structure.

2. Return to each team the structure members built in Lesson 1. Challenge the teams to design and build a new structure that will be tested in a controlled environment. Hand out the worksheets and give students time to design their structures before they receive their materials. Circulate among the groups and approve step 1 and step 2 of the designs as they are completed.

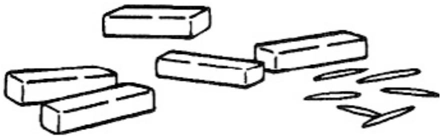
3. Demonstrate the procedure you will use to test the structures.

VOCABULARY

Shear force: force that acts horizontally (laterally) on a wall. These forces can be caused by earthquakes and by wind, among other things. Different parts of a wall experience different shear forces.

Shear walls: walls added to a structure to carry horizontal shear forces. These are usually solid elements, and are not necessarily designed to carry the structure's vertical load.

Structural elements or Structural features: a general term for all the essential, non-decorative parts of a building that contribute structural strength. These include the walls, vertical column supports, horizontal beams, connects, and braces.



4. Hand out all the materials except the glue guns, being certain every team receives the same set of materials. Allow some time for experimentation with the materials before students finalize their load path diagrams. Be sure students in each group have drawn force arrows on their design (step 3) to predict how they think earthquake shear forces will travel through (or load) their structure.

5. Establish how much time the SETs will have to build their structures, either by setting a uniform time for all or by inviting each SET to commit to a time limit and appoint one member of the team to keep track of time. (This could simulate the process of bidding on contracts, and add an extra element of competition.) Then give the signal to begin.

6. When building is finished, use one of the models from Lesson 1 to demonstrate fastening the structures to the center of the cardboard bases with hot glue. Have groups bring their models to the materials table to use the glue gun so you can supervise the process.

C. Conclusion

As the teams in turn bring their models to the front of the room for testing, test every model two ways—with the shaking table and by applying weight. Tell students they are not allowed to touch their structures during testing.

Ask two students from each team to hold the cardboard base down while you test their model with weights. Use the strap to add horizontal stress in any increment the group specifies. Call out the weights and keep a record on the board of the greatest weight each structure held. Award the certificate of achievement to the teams whose structures withstand the shaking table and hold the greatest stress before breaking. (This may be one team or two.)

Ask one member of each team to describe how their structure behaved in testing. Where did it fail? Why?

Close by connecting the images students have of earthquake damage to buildings with how their structures were damaged by the artificial earthquakes of this event. Slides or videos would help to make this real.

ADAPTATIONS AND EXTENSIONS

1. After you have done this with one class and feel comfortable with it, you may want to make the testing of student models a special event. Create some award for the structure that carries the greatest shear force. Invite your local newspaper reporters and school board members, arrange to use the auditorium, tape appropriate music, and plan refreshments. Take videos of the structure tests. Ask the principal to apply the weights and judge the event, and invite local emergency services officials to attend.

2. The experiences and materials the students developed in this unit make a fine portfolio. Invite students to include drawings of their designs and evaluate their learning by describing how they would build a structure next time or how they would retrofit their structure. ▲

TEACHING CLUES AND CUES

This design may take a full class period.

Trace the structure's outline with a pencil or pen, put glue on the cardboard along the outline, and press the structure down firmly. The hot glue may melt the Styrofoam if applied directly. Warn students not to drip the glue on their hands.

This activity will generate considerable excitement. Let students enjoy it, but maintain order to be sure all students have fun and are treated equally.

Building Challenge Design and Analysis Sheet

Name ____ Date ____________________

Cooperative Group ____________________________ Scientist ____________________________

Coordinator ____________________________ Technician ____________________________

Engineer ____________________________

1. Sketch a design for your structure in the space provided below.

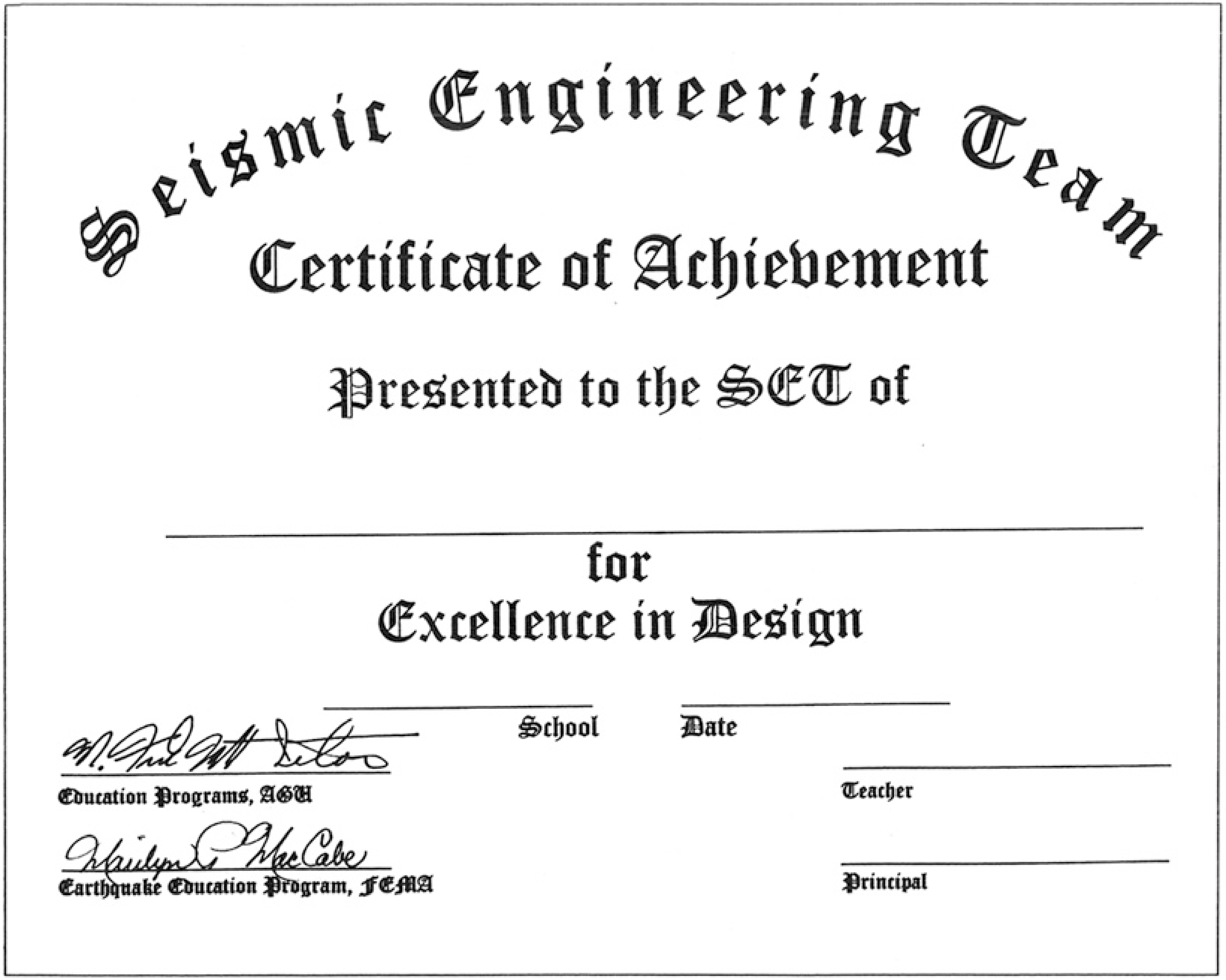
2. Use this space to show what it will look like from the front.

3. Use this space to show what it will look like from the side.

4. Do a load path diagram for your structure on the back of this page.

In all your drawings, show clearly how the joints will be made.
Get your instructor's approval for all four drawings before actually building your structure.

Certificate of Achievement



Seismic Engineering Team

Certificate of Achievement

Presented to the SET of

for

Excellence in Design

School

Date

Education Programs, AGU

Teacher

Marilyn MacCabe

Earthquake Education Program, FEMA

Principal

Books

Arnold, Christopher, and Reitherman, Robert. (1982). *Building Configuration and Seismic Design.* New York: John Wiley and Sons.

Federal Construction Council Consulting Committee on Civil and Structural Engineering. (1992). *Base Isolation for Seismic Safety: Summary of a Symposium.* Washington, DC: National Academy Press. Summaries of nine papers describing the theory and practice of base isolation.

Federal Emergency Management Agency. (October 1990). *Non-Technical Explanations of the NEHRP Recommended Provisions.* FEMA 99. Washington, DC: Building Seismic Safety Council. Explains the necessity of a building code and how earthquakes affect buildings.

Lagorio, Henry J. (1990) *Earthquakes—An Architect's Guide to Nonstructural Seismic Hazards.* New York: John Wiley and Sons.

Moore, Gwendolyn B., and Yin, Robert K. (1984). *Innovations in Earthquake and Natural Hazards Research: Synthetic Accelerograms.* Washington DC: Cosmos Corporation (202-728-3939). Discusses the use of computer-derived earthquake simulations to predict how buildings will respond to earthquake shaking.

Plafker, G., and Galloway, J.P., eds. (1990). *Lessons Learned from the Loma Prieta, California, Earthquake of October 17, 1989.* U.S. Geological Survey Circular 1045. Washington, DC: U.S. Geological Survey.

Salvadori, M. (1990). *The Art of Construction.* Chicago, IL: Chicago Review Press. Simple and readable, expressly written for young readers.

Periodical Articles

Bedway, B. (Feb. 23, 1990). "Building for a Landscape on the Loose." *Science World*, pp. 9+. For ages 12–15.

Boraiko, AA. (1986). "Earthquake in Mexico." *National Geographic* 169: 655–675.

Brady, Gerry. "Desk Top Model Structure for Dynamic Earthquake Demonstrations." U.S. Geological Survey. Applies simple models to predict natural frequency. Plans provided for constructing models of strong column/weak beam and weak column/strong beam buildings, plus descriptions of buildings' reactions to earthquakes and explanations for the results.

Robison, Rita. (November 1989). "Isolated Examples." *Civil Engineering:* 64–67. Describes base isolation in practice.

Rosenstock, L. (March 17, 1989.) "Can Buildings Be Made to Survive Earthquakes?" *Current Science*, pp. 6–7. For ages 10–16.

Taries, Alex. (April 1993). "First U.S. Application of Seismic Base Isolation." *Phenomenal News: Natural Phenomena Hazards Newsletter:* 1-4.

Non-Print Media

The Great Quake of '89. Videodisc and Macintosh software. Includes segments taken from ABC news coverage showing actual damage to the Bay Bridge, Highway 880, the San Francisco Marina, and the downtown. The Voyager Company, Santa Monica, CA; 310-451-1383.

Note: *Inclusion of materials in these resource listings does not constitute an endorsement by AGU or FEMA.*