Classroom Demo—Build a Better Wall*

How can we design buildings to withstand an earthquake?

Dr. Robert Butler, University of Portland OR demonstrates structural additions for building strength during an earthquake.

This activity is "designed to allow students to construct an understanding of how buildings respond to earthquakes. Lessons on building design and how earthquake forces act on various designs provide students with information on how to build earthquake resistant structures. Students then apply this knowledge by constructing testing devices and testing their designs. This unit is critical for developing students' understanding of why buildings collapse and what can be done to make buildings safer."

Two optional activities are included to explore earthquake hazards and building damage by constructing model buildings and subjecting them to ground vibration (shaking similar to earthquake vibrations) on a small shake table.

NGSS Science Standards

- From Molecules to Organisms—Structures and Processes: MS-LS1-8
- Motion and Stability—Forces and Interactions: HS-PS2-1, MS-PS2-2
- Energy: MS-PS3-2, HS-PS3-2, MS-PS3-5
- Waves and Their Applications in Technologies for Information Transfer MS-PS4-2
- Earth and Human Activity:MS-ESS3-2
- Engineering Design: MS-ETS1-1, HS-ETS1-1

Contents:

Additional Resources relevant to Build a Better Wall

VIDEOS

Lecture demo by Dr. Butler: **http://www.iris.edu/hq/inclass/demo/build_a_better_wall_2_why_buildings_fail**
How to build the demo set: **http://www.iris.edu/hq/inclass/demo/build_a_better_wall_1_parts__construction**

INTERNET LINKS

USGS has video demonstrations of this activity are available from: **http://sicarius.wr.usgs.gov/woodenbuildings/**

Design a bridge, add structural elements, then set off an earthquake!! Interactive program allows you to design the Bay Bridge...and then destroy it with an earthquake. Select bridge types, seismic safety features and earthquake type: **http://eduweb.com/portfolio/bridgetoclassroom/engineeringfor.html**

*Activity from FEMA **http://www.fema.gov/library/viewRecord.do?id=3558**.
Student worksheets (created by Chris Hedeen, Oregon City High School, Oregon) and NGSS standards are from the Cascadia Earthscope Earthquake and Tsunami Education Program e-binder (http://ceetep.oregonstate.edu/).

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

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 at the same time.

MATERIALS

Teacher: for one model wall

- 21 jumbo craft sticks, about 15 cm x 2 cm x 2 mm thick sticks, about the size of tongue depressors.
- 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
- 7 small wood screws
- 2 pieces of string, each approximately 25 cm (10 in.) long

Reinforcing elements for one wall:

- 1 piece of thin wood (about as thick as the craft sticks) 20 cm x 2 cm
- 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.

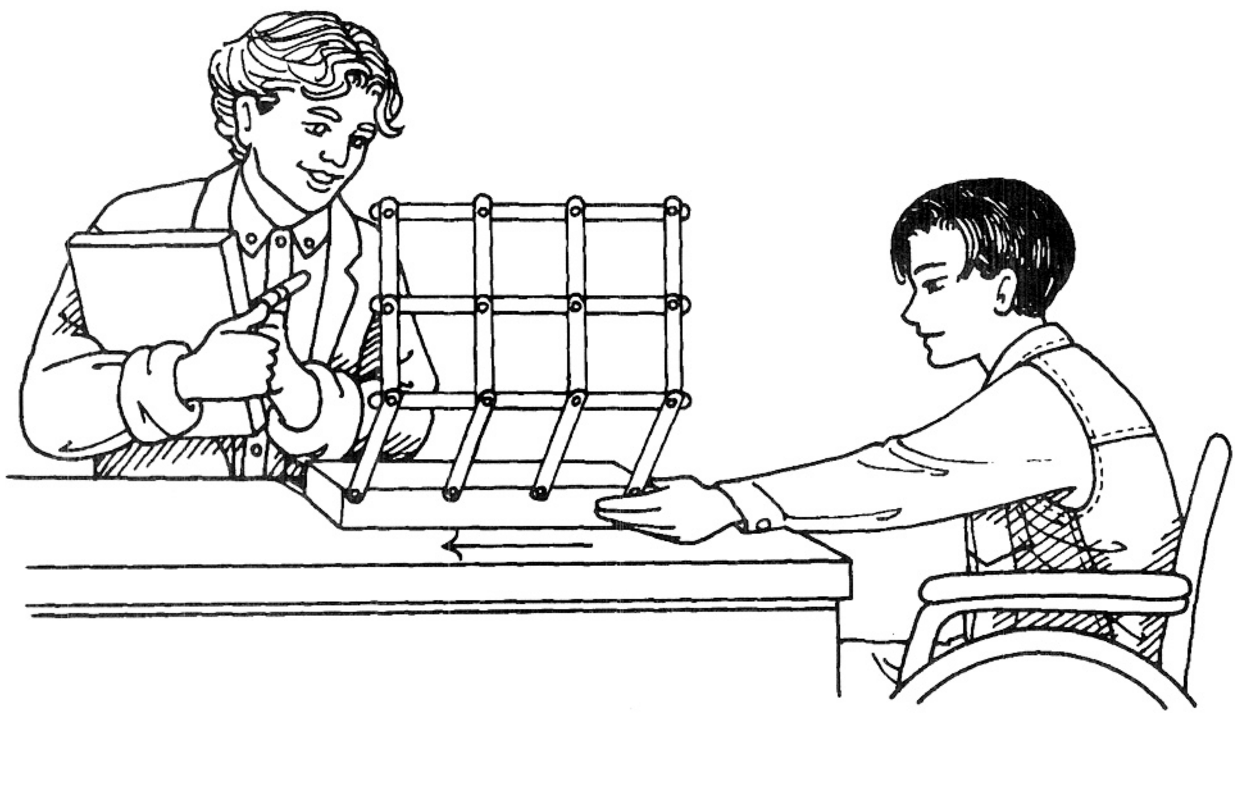
gravity, but to withstand earthquake shaking they need to be able to withstand sideways, or horizontal, pushes and pulls.

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.) ▲

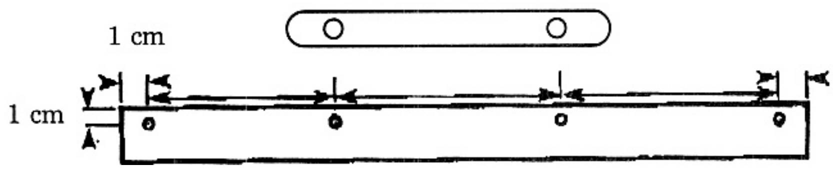


Building a Model Wall

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.

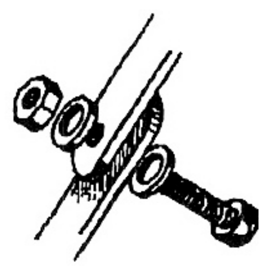
2. Select the thinner of the two large pieces of wood (45 cm x 6 cm). Drill a 3/16 in. hole 1 cm from one end and 1 cm from the edge. Measure the distance between the holes drilled in the craft sticks and space three more 3/16 in. holes at that distance 1 cm from the edge so that a total of four holes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

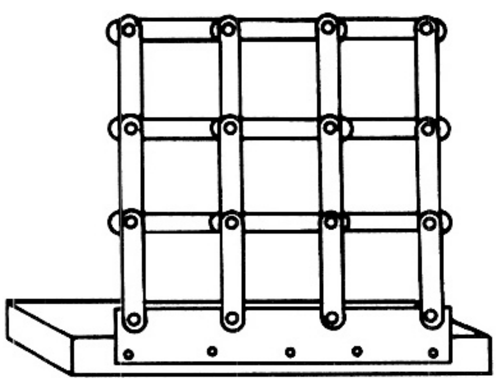
3. Use the small wood screws to mount this piece of wood on the base (the 2 x 6), fastening at the bottom and in the center. Leave the pre-drilled holes sticking up far enough above the top to accept the drilled craft sticks.



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.





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? ____

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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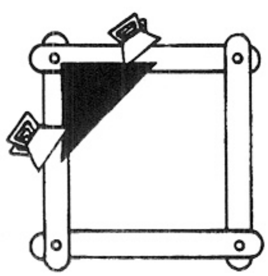
B. Load Paths with Additional Structural Elements

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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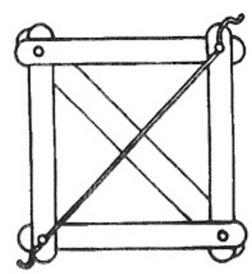

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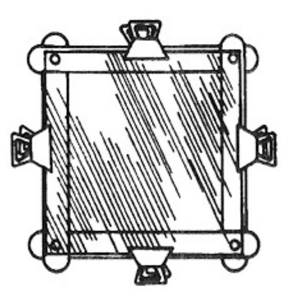

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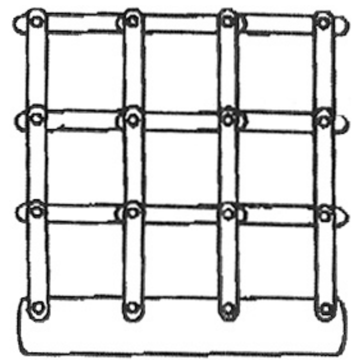
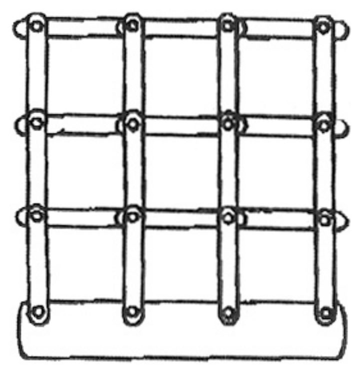
Use arrows to show the load path on each diagram.

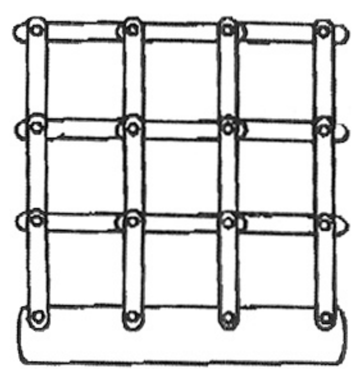
2. Put additional structural elements on your wall and push the third level. If the elements you added provided a load path to the base, the base of the wall should move. If they do not, the wall will fail somewhere. When you discover a setup that works, diagram it and sketch the load paths with arrows.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

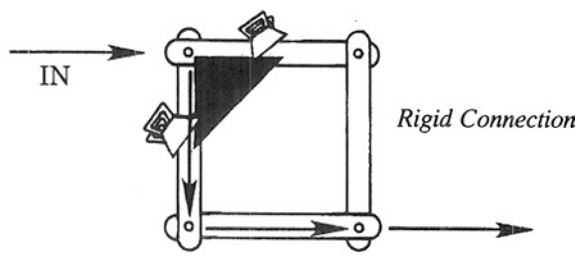
Observe and explain how the wall fails when its base is shaken rapidly back and forth, simulating the motion of a building hit by S waves during an earthquake. Tighten all the nuts just enough to allow the joints to move. Sharply push the base a few centimeters horizontally (right or left).

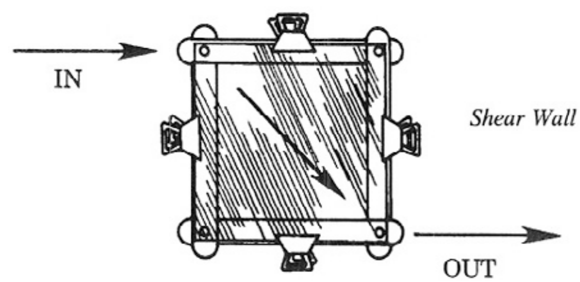
1. What part of the wall fails first? *The first floor*

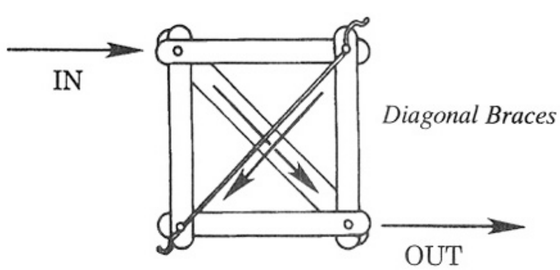
2. Imagine how the horizontal force you applied to the base travels to the upper parts of the wall. What caused the first structural failure? *The first floor has to carry all the load to the upper stories. It transfers forces to move the upper stories.*

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.

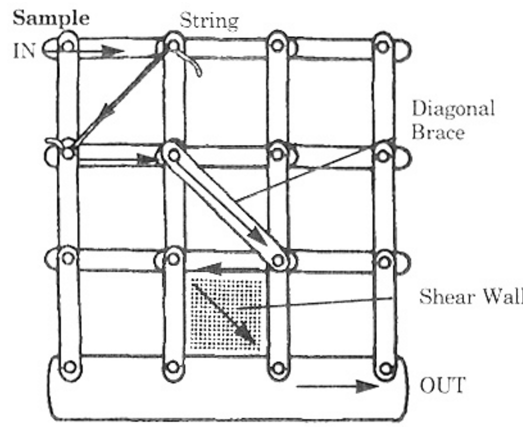




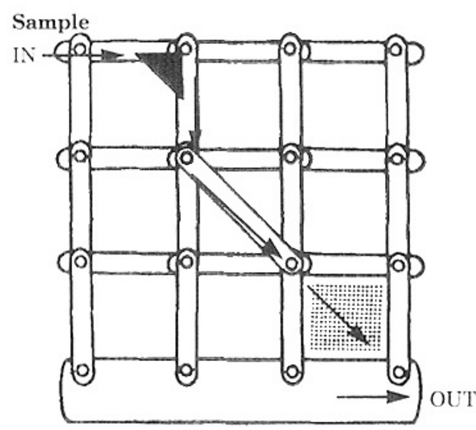


Use arrows to show the load path on each diagram.

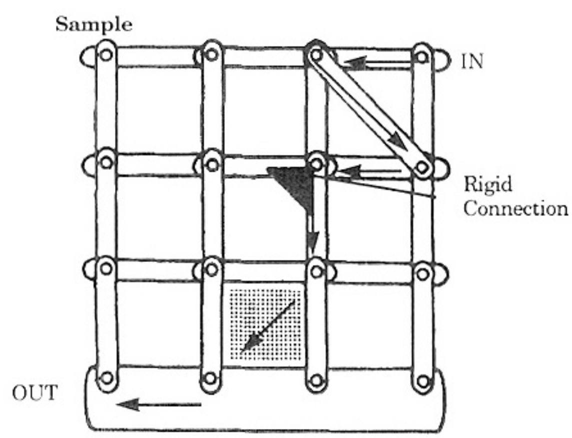
2. Put additional structural elements on your wall and push the third level. If the elements you added provided a load path to the base, the base of the wall should move. If they do not, the wall will fail somewhere. When you discover a setup that works, diagram it and sketch the load paths with arrows.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

(Touch here to return to intro page)

Teacher Background Reading
Building Engineering

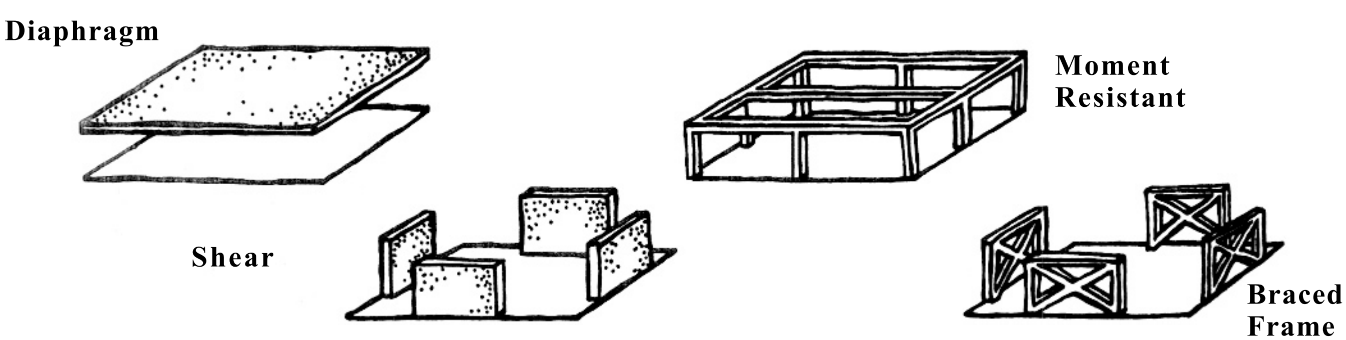
During an earthquake, a marked spot on the Earth might be seen to move erratically, tracing out a random path resembling that of a wandering insect. “Ground motion” is a literal description, since the ground moves (generally for a distance measured only in centimeters) relative to its starting point. 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.



Two Activities—Base Isolation for Earthquake Resistance

This activity is a companion to **Build a Better Wall** and the **BOSS Model** activities.

Explore earthquake hazards and damage to buildings by constructing model buildings and subjecting the buildings to ground vibration (shaking similar to earthquake vibrations) on a small shake table.

Base isolation is the most powerful tool of earthquake engineering. It is meant to enable a building to survive a potentially devastating seismic impact through a proper initial design or subsequent modifications. Contrary to popular belief base isolation does not make a building earthquake proof.

The buildings are constructed by two- or three-person teams of students. Use the Build A Better Wall method, or the Marshmallow method on the following pagees. After construction, the buildings are tested with, and without a shake table by subjecting them to earthquake shaking to see which designs and constructions are successful.

Comparison of the results of the building contest with photographs of earthquake damage is used to reinforce the concepts of building design and earthquake risk. (modified from Braile link below*)

NGSS Science Standards

- From Molecules to Organisms—Structures and Processes: MS-LS1-8
- Motion and Stability—Forces and Interactions: HS-PS2-1, MS-PS2-2
- Energy: MS-PS3-2, HS-PS3-2, MS-PS3-5
- Waves and Their Applications in Technologies for Information Transfer: MS-PS4-2
- Earth and Human Activity: HS-ESS3-1, MS-ESS3-2
- Engineering Design: MS-ETS1-1, HS-ETS1-1, HS-ETS1-3

Base isolation, also known as seismic or base isolation system, is a collection of structural elements which should decouple a structure from the ground. If the ground below a building shifts abruptly to the left as shown in the experimental buildings here, the building with base isolation on the right becomes an inertial mass that stays in the same place during the jolt due to structural elements that decouple it from the earth.

Since 2000, members of the Earthquake Engineering Research Centre (EERC) at Bristol University have been running an international competition to design earthquake resistant model buildings. The competition was originally developed to educate UK school students about the effects of earthquakes on structures and to help them investigate and develop solutions to a simple design problem. Many different, and often innovative, structural solutions to the problem have been developed by students over the last four years and in 2004 base isolation systems were used to great effect

Related animation and video:

Building Resonance:

http://www.iris.edu/hq/inclass/animation/building_resonance_the_resonant_frequency_of_different_waves

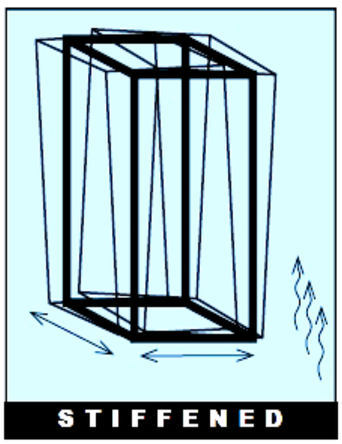
* Earthquake Shaking – Building Contest and Shake Table Testing Activity by Larry Braile:

http://web.ics.purdue.edu/~braile/edumod/building/building.htm

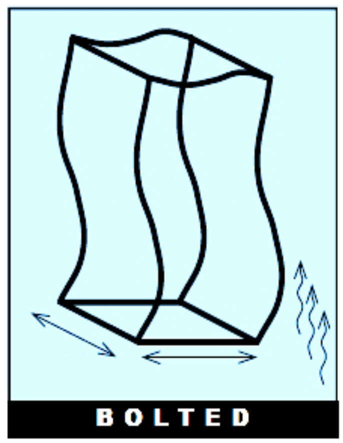
Background on Base Isolation for Earthquake Resistance

The simplest form of base isolation uses flexible pads between the base of the building and the ground. When the ground shakes, inertia holds the building nearly stationary while the ground below oscillates in large vibrations. Thus, no force is transferred to the building due to the shaking of the ground. The flexible pads are called base-isolators and structures using these devices are called base-isolated buildings.

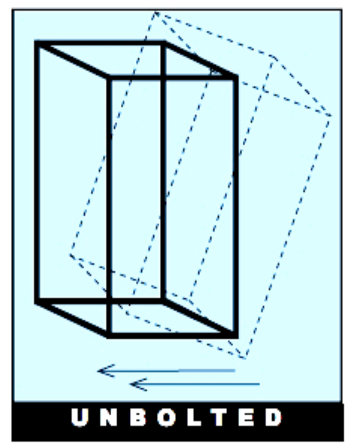
Traditional Earthquake Mitigation Techniques



Shock and vibrations sent into and contained within stiffened frame.



Stresses on cabinet frame and travel of shock and vibrations.



Reaction of a cabinet to seismic ground motion.

ADAPTATIONS AND EXTENSIONS from the BOSS Model (Activity)

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.

Many base isolators look like large rubber pads, although there are other types that are based on sliding of one part of the building relative to other. Base isolation is particularly effective for retrofitting low to medium height unreinforced masonry buildings, such as historic buildings. Portland's historic Pioneer Courthouse has been seismically retrofitted using base isolation. Experiments and observations of base-isolated buildings in earthquakes indicate that building acceleration can be reduced to as little as one-quarter of the ground acceleration.

Lead-rubber bearings are frequently used for base isolation. A lead rubber bearing is made from layers of rubber sandwiched together with layers of steel. The bearing is very stiff and strong in the vertical direction, but flexible in the horizontal direction.

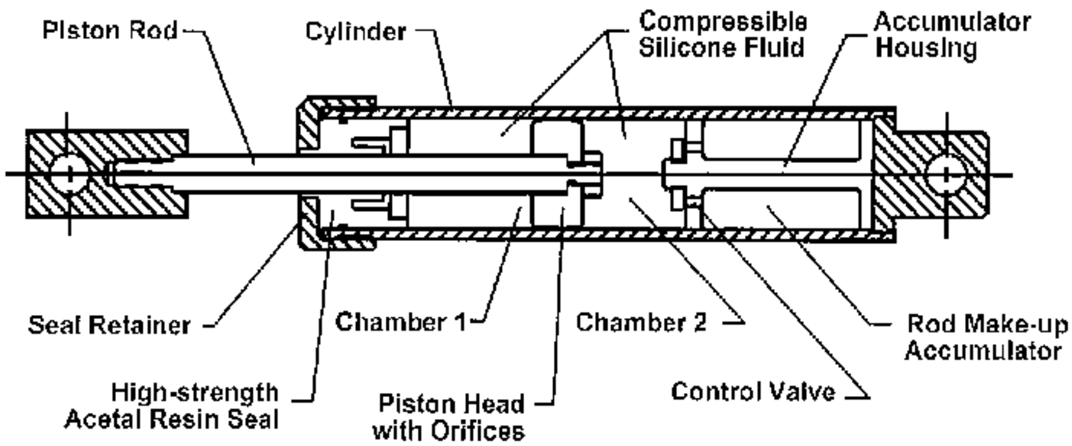
Spherical sliding isolation uses bearing pads that have a curved surface and low-friction materials similar to Teflon. During an earthquake the building is free to slide both horizontally and vertically on the curved surfaces and will return to its original position after the ground shaking stops. The forces needed to move the building upwards limit the horizontal or lateral forces that would otherwise cause building deformations.

Working Principle

To get a basic idea of how base isolation works, first examine the diagrams above that illustrate traditional earthquake mitigation methods. When an earthquake vibrates a building with a fixed foundation, the ground vibration is transmitted to the building. The buildings displacement in the direction opposite the ground motion is actually due to inertia. In addition to displacing in a direction opposite to ground motion, the un-isolated building is deformed. If the deformation exceeds the constraints of the building design, the structure of the building will fail. This failure often occurs in the ground floor because most of the building's mass is above that level. Also many buildings have "soft" ground floors with many windows or unreinforced spaces for parking or lobbies.

Energy Dissipation Devices for Earthquake Resistance

Another approach for controlling seismic damage in buildings is to install **Seismic Dampers** in place of some structural elements, such as diagonal braces. These dampers act like the hydraulic shock absorbers in cars that absorb sudden jerks. When seismic energy is transmitted through them, dampers absorb part of the energy, thus damping the vibration of the building. By equipping a building with devices that have high damping capacity, the seismic energy entering the building is greatly decreased. This system has also been used in historic buildings such as City Hall in San Francisco.



Commonly used types of seismic dampers include:

Viscous Dampers *(energy is absorbed by silicone-based fluid passing between piston cylinder arrangement)*

Friction Dampers *(energy is absorbed by surfaces with friction between them rubbing against each other*

Yielding Dampers *(energy is absorbed by metallic components that yield)*

Viscoelastic dampers *(energy is absorbed by utilizing the controlled shearing of solids)*

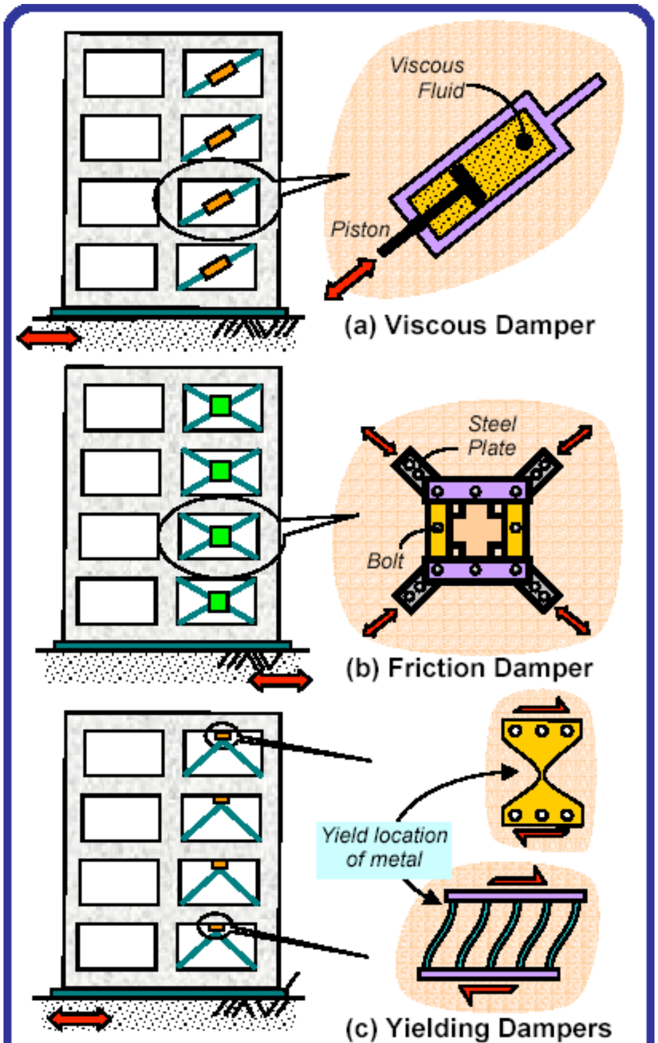


Figure 3: Seismic Energy Dissipation Devices – *each device is suitable for a certain building.*

Modified from article by Javed Kachchhi available online at:

www.architectjaved.com/.../**base_isolation**_techniques_for_**earthquake**_resistance.html

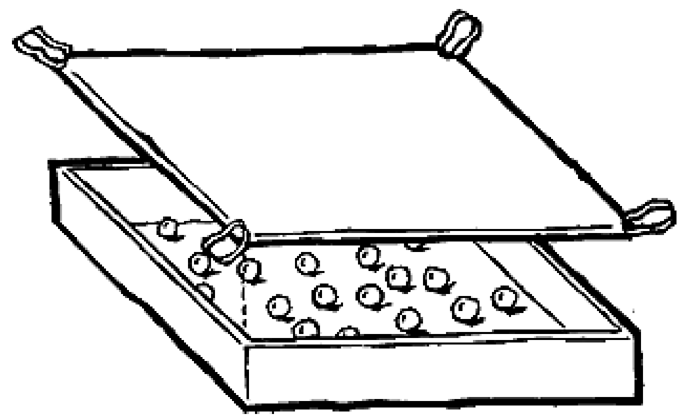
Activity 1: Shake table exercise!*

Introduction

One of the main causes of damage in an earthquake is the collapse of buildings not strong enough to withstand the shaking. Engineers and architects try to design buildings rigid enough to withstand the shock, but flexible enough to give a little under the stress. This exercise will test your design skills and understanding of how different structures will perform in an earthquake.
Good Luck!

Materials

- 40 coffee stirrers or cocktail straws
- 40 mini marshmallows
- a 30 cm ruler
- 2 shallow cardboard boxes (the trays used for cases of soda cans work well)
- a pair of scissors
- 10-20 marbles
- 4 short rubber bands
- stapler



Preparation

1. Before building your models, you must first build a shake tray. Place one cardboard box on a table and, with the scissors, cut the bottom out of the second box so that it fits inside the first box with a 2-cm clearance around each side. Place the marbles in the first box and rest the cut piece of cardboard on top of them. Use the stapler to attach one rubber band to each inside corners of the first box and then to the corners of the cardboard insert. The rubber bands should be taut, but not overstretched. To start the tray shaking, pull the insert toward one side of the box and let it go.
2. Using the marshmallows and straws (or stirrers) as building elements, assemble a structure that measures at least 50 cm high.
3. Place the structure on the middle of the shake tray and see how it stands up to your quake. Try building several different designs to see if one particular shape stands up better than the rest.
4. Hold a design competition with your friends. See who can build an earthquake-proof structure using the least amount of material.
5. Try varying the amount of time and the strength of the shaking by how hard you pull on the insert and how tight you stretch the rubber bands.

Questions

1. What structural shapes seem to survive quakes best? Can you think of any existing buildings that use this type of design?

2. What type of earthquake motion was your shake tray simulating? Are there other motions in a quake? How might you duplicate them?

3. Do you think that it is possible to build an earthquake-proof structure? Why or why not?

4. How does the amount of shaking time affect building damage?

5. How does the strength of the shaking affect building damage?

*This activity is from Justin Sharpe, Beal High School, Ilford, Essex.

Activity 2: Base isolation with student worksheet*

Objectives: Observe how base isolation protects buildings during an earthquake.

Grade Level: Middle School

Time: 30 Minutes- 1 Hour

Problem: How can we keep a building from shaking on our shake table?

Materials:

(see following pages)
Shake table
Base isolation attachment
Masses on rods

Vocabulary:

Inertia, inertial force, base isolation, friction

Introduction:

Why do you need to wear a seat belt? If you are in a car going 70 mph and slam on the brakes, you will continue to go at 70 mph (and through the windshield!) unless something like a seat belt stops you.

Newton's first law states that a body in motion will stay in motion and a body at rest will stay at rest unless acted on by an outside force. This is called inertia. It is the tendency of something to stay the way it is.

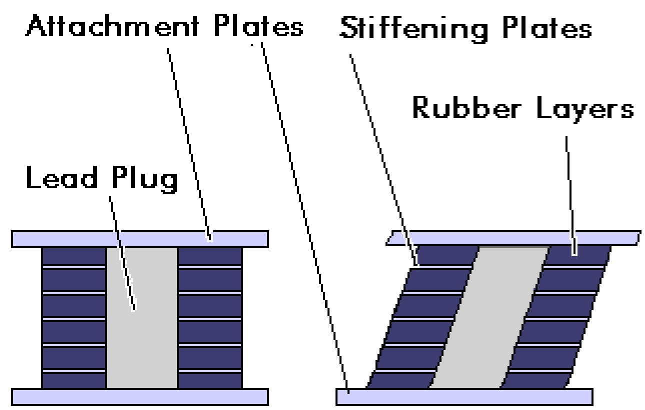
The law of inertia is important when talking about buildings in an earthquake. A building can be thought of as a large mass, and according to the law of inertia, it wants to stay at rest and remain motionless unless acted on by an outside force. In an earthquake, the bottom parts of the building move and the upper parts of the building don't because of inertia. This is called inertial force. This puts a lot of stress on the parts that make up the building. It is this inertial force that engineers have to try and minimize when designing buildings.

One of the ways that earthquake engineers protect a building is to use the inertia of the building to their advantage. If they can keep the body from moving, then the top floor won't move either! So, if an engineer can find a way to keep the earthquake from acting on the building, it won't move. Base isolation is separating the building from the ground so that the earthquake can't affect it.

If you lay a toy car or a skate on a cardboard sheet and yank the cardboard back and forth like the horizontal motions of an earthquake, what happens? The car will not slide as much as the cardboard, but it will still move slightly back and forth. Those wheels on the car and skate "isolated" the top part from the earthquake!

But how do we do that with a big building? In reality, engineers don't use big wheels. Instead, they use a special material between the columns of the building and its foundation. This supports the building so that it can stand, but it lets the "ground" move from side-to-side underneath it.

* Worksheets by: Leslie Bucar, 7-12 Science Teacher, Fond du Lac Ojibwe School, B.S. Biology, B.A.S. Teaching Biology, B.A.S. equiv Teaching Chemistry
Dan Johnson, 7-12 Math Teacher, Fond du Lac Ojibwe School, B.A.S. Teaching Math



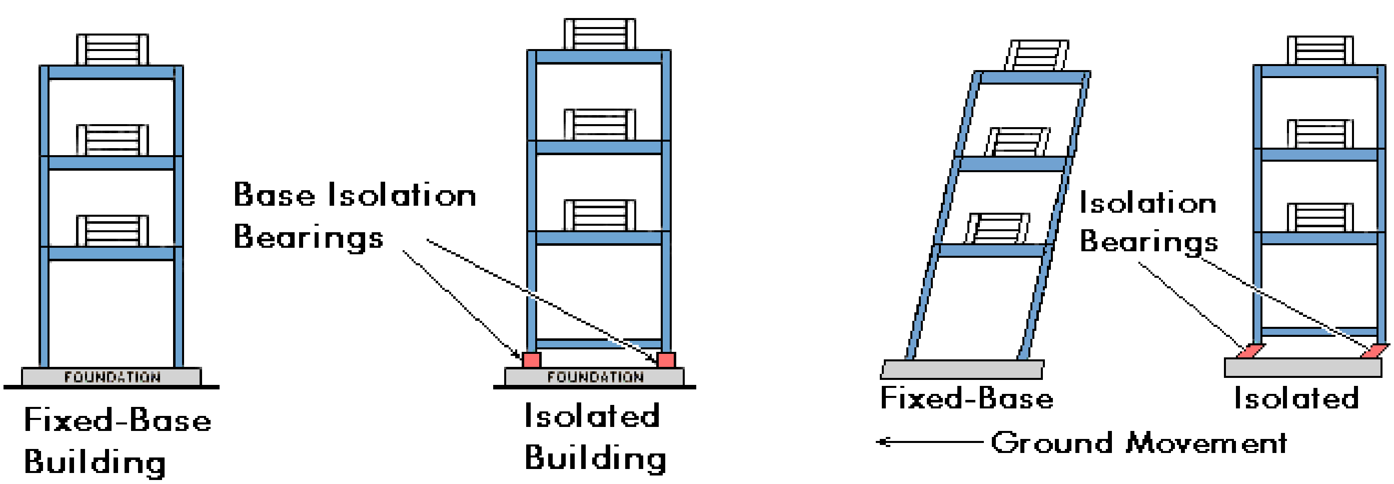
Rubber Pads used in base isolation.

Movement of Building with Base Isolation vs. No Base Isolation

In the pictures above, the building on the left (fixed base) has no base isolation. If you were sitting on the top floor of that building, look how much you'd move in an earthquake! The building on the right, however, has base isolation. When an earthquake comes, the base isolation bearings move, and not the building, so the people on the top floor don't move.

Once we isolate the structure of the building from the earth, we must make sure that the building does not move around too much, and that it goes back to its original position. Engineers use rubber pads to base isolate buildings, and they add into the rubber pads special fillers that increase the pads' friction. This helps lessen the back and forth motion of the building. Friction also absorbs some of the earthquake energy that would otherwise go into shaking the building and reduces the quake's impact on the structure. (Remember that energy never disappears completely but only changes from one form to another and that energy absorbed by friction gets changed into harmless heat.)

Another bonus to adding fillers to our rubber pads is that they offer the advantage of preventing, through friction, the frequent and annoying small oscillations (back-and-forth movements) that even a light wind or a car driving by would have on a building or a bridge built on entirely rubber pads.



Movement of Building with Fixed-base Isolation and with Base Isolation

Name ___________________ Per ____

Base Isolation for Earthquake Safety

Hypothesis:

Write your hypothesis using the problem here.

Procedure:

Even though real buildings use rubber pads as base isolators, we can experimentally look at base isolation by using a set of rollers. In this lab, horizontal rollers will be used as a base isolator and the masses on rods will be used as a building.

1. Attach the horizontal rollers to the shake table using the two screws.
2. Test that the rollers are attached to the shake table by trying to shake it with your hands.
3. Make sure that the safety stops are attached and in position so that the masses on rods will not come off the table.
4. Place the masses on rods plate on the horizontal rollers.
5. Start the shake table and allow it to calibrate using the procedure outlined in the shake table operations manual.
6. Navigate to earthquake mode and select an earthquake to run.
7. When the experiment is over, press the 0 key to exit the main menu.
8. Remove the masses on rods from the rollers and remove the rollers.

Collecting and Analyzing Data:

1. What happened to the masses on rods when the base isolator is in place?

2. Why do we need a space between the edges of the base isolator and the sides of the shake table?

Conclusion:

1 Why is it important to allow the ground to move underneath the building?

2. What would happen if the base of the building moves too much?

3. Would base isolators be able to protect a building if the ground moves up and down? Why?

Teacher Lesson Guide and Base Isolation

Collecting and Analyzing Data Key:

1. **What happened to the masses on rods when the base isolator is in place?**
   The masses on rods didn't move

2. **Why do we need a space between the edges of the base isolator and the sides of the masses on rods table?**
   If the masses on rods table touches the shake table, it is no longer "isolated" by the base and is therefore subjected to all of the forces of the earthquake.

Conclusion Key:

1. **Why is it important to allow the ground to move underneath the building?**
   By allowing the ground to move underneath the building, the building remains relatively motionless which means that the structural components are not stressed as much as if it were moving with the ground.

2. **What would happen if the base of the building moves too much?**
   If the building's base moves too much it can run into other structures on the ground, such as retaining walls, entry steps, or even a perimeter moat. This can cause damage to the building and other structures which is called pounding.

3. **Would base isolators be able to protect a building if the ground moves up and down?**
   No, base isolators are only able to protect a building if the ground is moving horizontally (side to side)

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