ShakeAlert® activities for formal and informal learning settings

Earthquake Machine (Activity 1 of 2)

Investigate how earthquakes happen with simple hands-on models

Version 12/14/20

Activity modified from IRIS activity (Earthquake Machine Lite: Defining an Earthquake)

The Earthquake Machine is a simple model that helps learners visualize the inputs and outputs of an active fault system that leads to earthquakes (Figure 1). This Earthquake Machine activity (1 of 2) introduces the basics of the model through a qualitative approach. In the followup, Earthquake Machine (Activity 2 of 2), learners explore earthquake frequency and magnitude through a quantitative approach.

Here we present three activities done in 5-, 15-, and/or 30-minute time frames. Instructors can use the activities for exploration or demonstration purposes. The 5-minute activity explores what creates an earthquake with the snap of your fingers. In the 15-minute activity, learners explore the stick and slip behavior of faults with the Earthquake Machine model.

In the 30- to 45-minute activity, learners explore different aspects of forces, faults, and friction found in complex earthquake systems with the Earthquake Machine model. Each of the activities is appropriate for a range of education and/or public outreach venues. The Earthquake Machine works best when learners have some knowledge of plate tectonics, earthquakes and faults. Use the Earthquake Machine after the Introduction to Faults and Plate Tectonics activity.

Why is it important to learn about the stick-slip behavior of faults and why earthquakes happen? More than 143 million people are exposed to potential earthquake hazards in the U.S. that could cost thousands of lives and billions of dollars in damage. An understanding of earthquakes and their unpredictability is fundamental to earthquake hazard mitigation. An important tool for mitigation is the ShakeAlert® Earthquake Early Warning system for the West Coast of the U.S. which detects significant earthquakes quickly so that alerts can be delivered to people and automated systems.

Beginner

5 min | 15 min | 30–45 min

Large Group | Small Group

Demo | Materials

Time: 5-, 15- and 30-minute guided activities that can be adapted for audience and venue.

Audience: This can be done with novice and experienced geoscience learning groups.

Subject: Natural Hazards: Earthquakes, Geoscience.

Figure 1: Earthquake Machine set-up.

OBJECTIVES

Learners will be able to:

- Use the Earthquake Machine model to demonstrate the causes of earthquakes, noting the flow of energy through the system
- Summarize the interplay of forces, faults and friction in an earthquake
- Describe basic physics concepts to include sliding and static friction, forms of energy and conversion from one form to another, and the elastic properties of materials.
- Describe the role of models in the process of science.

TABLE OF CONTENTS

MATERIALS, TOOLS AND CONSTRUCTION

Materials needed to build one (1) Earthquake Machine:

- 1 – 4" block cut from 2x4 lumber
- 1 – 4"x36" Sanding belt with the heaviest grit possible (50-60 Grit)
- 1 – Sheet of sandpaper, with the heaviest grit possible (e.g. 60 Grit)
- 1 – Screw eye 12x1-3/16" (or similar)
- 2 – Rubber bands (size 19 is best)
- 1 – 16-in strip of Duct Tape

Tools needed for assembly:

- Saw
- Scissors
- Drill
- Heavy-duty staple gun & staples

Construction of the Earthquake Machine:

Watch a video of the construction and use of the model: Construction of the Earthquake Machine and see Figure 2.

1) Trace one of the 4" wood blocks on the back of a sheet of sandpaper, adding one inch to the length.
2) Place the sandpaper over the bottom of the block and fold the long edges up on to the ends of the block. Staple the sandpaper to the edges (Figure 2).
3) Screw one 12x1-3/16" screw eye into the cut end of the block about 1/2 inch from the base at the edge of the sandpaper. It helps to make a small pilot hole either with a nail or a drill so the screw eye is more easily attached (Figure 2).
4) Feed a rubber band through the screw eye and loop to secure.
5) Loop a second rubber band through the first to create a chain of 2 rubber bands.
6) Use scissors to cut the sanding belt so it is no longer a loop.

Set up the Earthquake Machine for use:

1) Smooth the sanding belt out on the lab table, grit side up, so that there are no waves in it. It helps to roll it backwards on itself to help flatten it.
2) Use duct tape to secure each end to the table.
3) Place the block on one end of the sanding belt (Figure 1).

For the 5-minute demonstration:

- Your hands and ability to snap your fingers

For the 15-minute demonstration:

- One Earthquake Machine set up as described in the materials section
- Spare rubber bands, sandpaper, and tape

For the 30–45-minute activity: Materials for each table group to explore one of the following variables:

Earthquake Machine models for each table group.

- Variable 1: Extra wood block
- Variable 2: Manilla file folder or construction paper, cut into 1-inch wide strips, Scissors, Tape
- Variable 3: Small piece of sandpaper cut to fit the narrow side of the 2x4 wood block
- Variable 4: Wooden board slightly larger than the belt, Several books, Sandpaper
- Variable 5: Additional 2x4 wooden blocks with different grits—heavy, medium, and fine.
- Variable 6: 2x4 wooden block with sandpaper and two rubber bands
- Variable 7: Additional 2x4 wooden blocks with sandpaper and two rubber bands

RELEVANT MEDIA RESOURCES

Videos

- Earthquake Machine Model: Segments 1 and 2
- Earthquake Machine: Demo of the 2-block model

Animations

- Earthquake Machine: 1-block model & simple graph
- Earthquake Machine: 2-block model: graphing time vs. strain

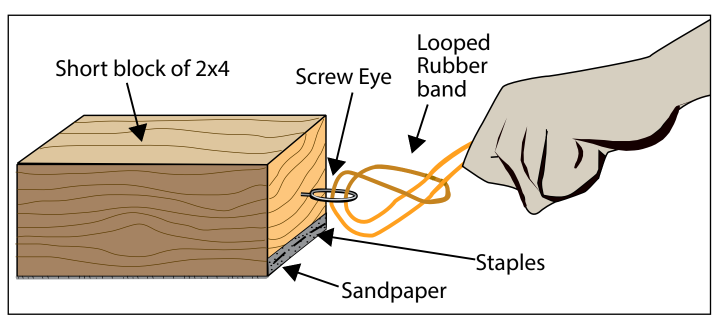


Figure 2: Parts of the Earthquake Machine.

INSTRUCTOR PREPARATION

The simplicity of the Earthquake Machine allows learners to visualize the inputs and outputs of a fault system and explore stick-slip fault displacement behavior on a generic fault. The model's wooden block, rubber band, and sandpaper base all represent an active fault section. The rubber band represents the elastic properties of the surrounding lithosphere, storing potential energy. When the frictional forces between the block and sandpaper are overcome, the block lurches forward with a stick-slip motion.

Here's what each piece of the model represents:

- The wooden block with its attached sandpaper and the sandpaper on the table represent the two sides of an active fault section. The sandpaper represents the contact between the sides of the fault.
- The rubber band represents the elastic properties of the surrounding rocks, storing potential energy as they are deformed. This energy builds up over time.
- Pulling on the rubber band attached to the block is analogous to continuous plate motions at plate boundaries.
- When the frictional forces between the block and sandpaper are overcome, the block lurches forward, which represents ground motion during an earthquake.

Rupture along a fault typically occurs by fits and starts in a type of sporadic motion that geologists call stick-slip. As an earthquake begins, the friction between two sides of the fault is overcome, and the fault begins to fail. Movement will continue until the failure reaches an area where the strength of the rock is great enough to prevent further rupture. In this manner, some of the energy stored in the rock, but not all of it, will be released by frictional heating on the fault, the crushing of rock, and the propagation of earthquake waves (see inset above).

Physics of the Model

With the "base" (or strip of sandpaper) flat, the downward force of gravity pulling the block down acts perpendicular to the base. This is called the "normal force" meaning it is in the direction of gravity. The force on the rubber band is parallel to the base and is the "shear stress" trying to pull or shear the block along the base. Friction is the resistance to shearing motions and is related to the roughness of the interface between the block and the base.

Familiarize yourself with the videos and animations, and with the following before conducting the activities:

Appendix A: Vocabulary
Appendix B: The Science of the Model
Appendix C: Living on Shaking Ground
Appendix D: ShakeAlert® State Fault Maps
Appendix E: Comparing Like and Unlike Earthquake Machine Model to Reality
Appendix F: NGSS Science Standards & 3-Dimensional Learning

For the 5-minute demonstration:

- Practice snapping your fingers and discover which finger combination works best for you (remove lotion).

For the 15-minute demonstration:

- Ahead of class, set up one Earthquake Machine model as described in the materials section.

For the 30- to 45-minute activity, prepare each table group to explore one of the following variables:

1. Add another wood block onto the first
   - Basic Earthquake Machine set up
   - Additional wooden block to place on top of the first block
2. Explore building shaking
   - Manilla file folder or construction paper, cut into 1-inch strips
   - Scissors
   - Tape
3. Reduce the size of the fault plane
   - Attach sandpaper cut to fit the narrow side of the 2x4 wood block
4. Change the angle of the fault plane
   - Attach the sandpaper belt to a wooden board slightly larger than the belt
   - Several books to create an incline for the wooden board

5. Change the amount of friction on the fault system
    - Additional 2x4 wooden block with different grit – heavy 50-60 grit, medium 80-120 grit and fine 360-600 grit
6. Add another block and rubber band
    - Attach a second 2x4 wooden block with sandpaper (same as first block), to the first block with two rubber bands
7. Add another block, rubber band, and/or change sandpaper grit to the first block of a two-block model:
    - Extra blocks or other weights
    - Sandpaper with different grits to cover the first block
    - Tape

ACTIVITIES AND DEMONSTRATIONS

IF YOU HAVE 5 MINUTES

Did You Know?

- Did you know that sudden slip on a fault creates an earthquake, similar to what happens when you snap your fingers?

It's a Snap! An earthquake is caused by a sudden slip on a fault, much like what happens when you snap your fingers (Figure 3). As a quick demo, put your thumb and middle finger (or ring finger) together. With mild pressure, or with greasy fingers, they slide past each other easily with little stress. With dry fingers and higher stress, you can create an audible sound when your fingers rapidly snap.

Figure 3: Finger Snap

Before allowing your fingers to snap, push them together and sideways. Allow friction to keep them from slipping. When you apply enough stress to overcome this friction, your fingers move suddenly, releasing the energy built up between the fingers. The same "stick-slip" process goes on in the earth. Stresses in the earth's outer layer push the sides of the fault together. The friction across the surface of the fault holds the rocks together so they do not slip immediately when pushed sideways or together. Eventually enough stress builds up and the rocks slip suddenly, releasing energy in waves that travel through the rock to cause the shaking that we feel during an earthquake.

Invite learners to try snapping their fingers.

Questions for Discussion:

- Snapping your fingers can't generate an earthquake, but they do transform energy! What is the form of energy that is transformed? *(As your fingers snap, the potential energy between your fingers transforms to kinetic energy in the form of sound.)*
- Some snaps are quiet and some are loud. What creates the difference when some fingers are softer/rougher and some are moist/drier? *(The amount of friction. The harder you press your fingers together the greater the amount of energy stored in your fingers ready to be released as louder sound waves. If your fingers are silky with hand lotion, friction can't build up, and there is no sudden release of energy.)*
- Sound waves are compressive waves, similar to what type of seismic wave generated in an earthquake? *(P waves.)*

IF YOU HAVE 15 MINUTES

Did You Know?

- Did you know that blocks of rock don't slide smoothly past each other, but stick and then slip?

Earthquakes involve complex interactions of forces, faults and friction. However, we can better see and understand three key factors involved in the "stick-slip" behavior of earthquakes with a model called the Earthquake Machine (Figure 1). The Earthquake Machine can be used as a demonstration, a tabletop manipulative for learners, or as a time of exploration with learners before a formal inquiry investigation (see *Earthquake Machine (Activity 2 of 2)*).

1. Identify the component parts of the Earthquake Machine to your learners (don't explain what each part does at this point):
    a. The table.
    b. A long strip of sandpaper taped to a table.
    c. A wooden block with sandpaper stapled on both ends to one side of the block.
    d. Rubber bands attached to an eye bolt screwed into one end of the wooden block.

e. Your hand ready to pull the rubber band attached to the wooden block.

2. Demonstrate how the Earthquake Machine works before you describe what is happening:
   a. Place the wooden block on the end of a long strip of sandpaper taped to the table.
   b. Slowly pull the rubber bands parallel to the surface of the sanding belt (Figure 2).
   c. The block should stick in place initially and the rubber band will stretch.
   d. When a threshold is reached, the block will jump or slip forward as potential energy stored in the rubber band is suddenly converted to kinetic energy of the block moving. Don't stop pulling the rubber band.
   e. Continue to pull the rubber band at the same rate. The rubber band starts stretching again. This represents the stick-slip process beginning again.
3. We have just seen and heard an earthquake. But how does this stick and then slip behavior actually model what happens in an earthquake? Let's look at each component part of the Earthquake Machine to see if we can find the answer.
   Name each component part and ask learners to describe what each component of the model does in the real world.
   Note: See Table 1 (Appendix E) to compare and contrast how the model is like and unlike reality.

   What is…

   a. The sandpaper attached to the block? *(One block of rock and an adjacent block of rock, or on a larger scale, one plate and another plate.)*
   b. The place where the two sandpaper surfaces are in contact? (*A fault or convergent subduction zone.*)
   c. The rubber band? *(The materials found in rock that can deform elastically.)*
   d. The block of wood and rubber band together? *(A single block of rock or tectonic plate, including its elastic properties.)*
   e. The table? *(This is the block on the other side of the fault (called the nonmoving block/rock). It isn't moving; thus the static balanced forces are locked by friction.)*
   f. The nonmoving block and the rubber band starting to stretch as it is pulled? *(The pulling force stretching the rubber band portion of the rock/plate is stored as elastic potential energy in the rock.)*
   g. The block and rubber band jumping or sliding forward? (*The stored elastic potential energy in the rock overcomes the force of friction holding the block and sandpaper together, creating an earthquake.)*
4. The process we have just seen of the block sticking due to friction and then slipping when friction is overcome by the stored energy is called stick-slip. This is a cycle that repeats in earth movements on a scale from small faults to large plate boundaries, which are actually enormous fault systems. For a deeper background, show the ridge push and slab pull IRIS video: What are the Forces that Drive Plate Tectonics?
5. Explore the stick-slip behavior of earthquakes with the Earthquake Machine as a tabletop manipulative activity for learners. Allow learners to experiment with the non-sandpaper side of the block on the smooth table and then with the sandpaper side of the block on the sandpaper strip to compare differences in roughness and how that relates to friction.
6. Compare and contrast how the Earthquake Machine is both like and unlike reality. Ask learners to think of some comparisons. Refer to Table 1 (Appendix E).

Questions for Discussion:

- What did you notice about how the block jumped or slid forward? *(Answers vary such as it was slow or fast or sudden.)*
- Were there more little jumps compared to bigger jumps? *(Answers vary; typically, yes.)*
- How does this compare to actual earthquakes? *(Worldwide, there are a greater number of small earthquakes than large.)*
- Can you predict what will happen to the block when the rubber band is stretched a longer distance putting more potential energy into the system? *(Since more potential energy is added to the stretching rubber band, the greater the elastic rebound potential when the block moves.)*
- Is there a difference when if you pull the rubber band slowly or fast? *(Answers vary. However, the amount of potential energy remains the same.)*
- Can you predict when an earthquake will happen? *(No.)*
- What would it take to make an earthquake prediction? *(You would have to know where the earthquake will happen, when it will happen and how big it will be.)*
- Is earthquake prediction possible? *(No! But evidence of previous earthquakes on faults indicates the likelihood of a future event, which is called a forecast. Also, the ShakeAlert® Earthquake Early Warning System can provide advance warning of an earthquake that has already begun on the West Coast of the United States. For more information, check out Take 2: Can Earthquakes Be Predicted? Part 1 and Part 2.)*

IF YOU HAVE 30–45 MINUTES

Did You Know?

- Did you know that we can use the Earthquake Machine to learn more about different aspects of forces, faults, and friction found in complex earthquake systems?

By changing one of the component parts of an earthquake system, we can learn interesting clues about the role of forces, faults and friction in an earthquake.

When an earthquake occurs and movement begins on a fault plane, the movement will not proceed smoothly away from the hypocenter (or focus). Any change in the amount of friction along the fault will cause the fault movement to be irregular. This includes changes along the length of the fault and with depth, changes in rock type and strength along the fault and natural barriers to movement, such as changes in the direction of the fault or roughness over the surface of the fault plane.

Learners explore seven earthquake variables that represent different aspects of earthquake **forces, faults, and friction.** Each experiment presents a change to the basic Earthquake Machine set up. As each variable is explored, the set up and results are compared relative to the action of the basic model (Figure 1). Variables are:

1. Add another wood block onto the first
2. Explore building shaking
3. Reduce the size of the fault plane
4. Change the angle of the fault plane
5. Changed the amount of friction on the fault system
6. Add another block and rubber band
7. Add another block, rubber band and change friction on sandpaper grit

Explore as many of the earthquake variables just described as time permits.

1. **Add another wood block onto the first**:

What will happen if we placed a second wood block on top of the first block? Invite learners to make predictions and then experiment with the Earthquake Machine to see what happens (Figure 4). *(Adding the second block increases weight (force) onto the sandpaper, which increases the friction.)*

Questions for Discussion:

- What component is affected by the addition of the second block? *(Friction.)*
- When friction on the fault is increased, what happens to the amount of force in the system? *(It takes more force to make the block move. The additional elastic energy is held in the stretching rubber band until it overcomes the friction of the sandpaper.)*

2. **Explore building shaking**:

Attach a model of a paper building to the block of the Earthquake Machine to show how a building shakes during an earthquake (Figure 5). Experiment with the Earthquake Machine noting differences in building movement with each earthquake event.
As an extension to this variable, a larger research project is presented in Appendix C.

The two block model can also represent some of the complex interactions occurring on the subducting Juan de Fuca plate with the Pacific plate in the Pacific Northwest. Read the inset for description of the plate movements in three distinct zones: locked, transition and slip.

Cardboard Building construction:

a. Cut four strips out of the manila folder; two that are ½″ wide and 5″ long (floor and roof), and two that are ½″ wide and 12″ long (vertical uprights).

b. Fold ½″ on each end of the roof and tape it to the top of the uprights.

c. Fold ½″ on each end of the floor and tape it inside of the upright about halfway up the structure.

d. Tape the vertical uprights to the block of wood with the sandpaper.

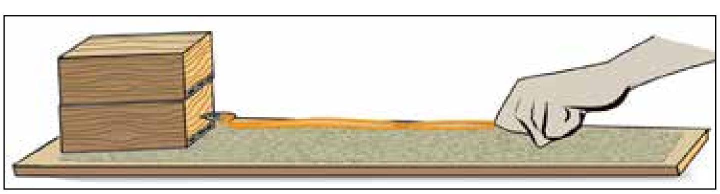


Figure 4: Earthquake Machine with a second block placed on the first.

Figure 5 (right) : Cardboard building attached to the Earthquake Machine.

Questions for Discussion:

- How did the movement of the building change from a small earthquake to a larger earthquake? *(The greater the stored energy creating the jump, the greater the amount of energy was transferred to the building. There is a direct correlation between the amount of slip of the block and the moment magnitude of the event. The further the block slips, the more energy is released, and the more violently the building shakes.)*
- What would happen to the building if it was not attached to the block? *(It would fall down or slip off the block)*
- Why is it important for houses to be attached to their foundation when an earthquake occurs? *(The house won't be shaken off the foundation and be seriously damaged or destroyed.)*

3. **Reduce the size of the fault plane**: What will happen when we reduce the size of the fault plane?
   a. Trace the side of the wood block onto the same grit of sandpaper as used on the bottom of the block.
   b. Cut out the shape and glue to the side of the wood block.
   c. Place the wood block on the narrow edge on the long strip of belt sandpaper and experiment pulling the block with the smaller surface area.

Questions for Discussion:

- What did you notice about changes in the way the block moved on the sandpaper fault? (*Answers vary including smaller, shorter jumps compared to the broader surface of the block*.)
- What might this mean for the magnitude of the earthquake that would happen on a smaller fault plane? (The magnitude would be smaller. Note: See definitions for fault plane and moment magnitude in the Vocabulary; Appendix A).

4. **Change the angle of the fault plane**: What would happen when we change the angle of the fault plane? (Figure 6)
   a. Tape the belt sandpaper onto a board. (Have a prepared board cut slightly larger than the dimensions of the sandpaper belt.)
   b. Raise one end of the board onto a stack of 3 books. The angle of the fault is called "dip" (see Vocabulary, Appendix A). Most faults are not horizontal, but rather either vertical or sloped.
   c. Experiment with pulling the block up the slope of the board compared to the Earthquake Machine flat on the table.

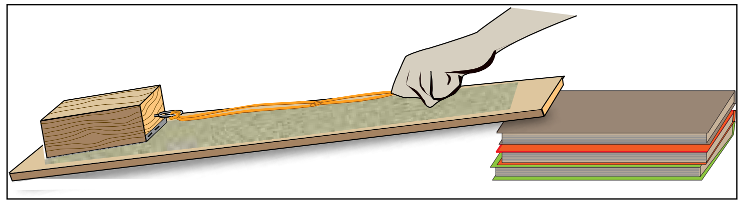


Figure 6: Earthquake Machine on an angled fault plane.

Questions for Discussion:

- What differences did you notice by changing the angle or dip of the sandpaper board/fault plane? *(Answers vary, but in general, the block should move more easily.)*
- What do you think would happen if the board was much steeper increasing the degree of dip? *(Answers vary, typically, the jumps would be shorter.)*
- What if the fault was vertical? *(Much less resistance on the block.)*
- How does the steepness of the slope (degree of dip) affect the complexity of an earthquake fault system? *(Any change in the slope angle will affect the amount and direction of forces on the system. We have to consider the weight of the board (amount of force) both down (vertical) and in the direction of the slope angle of the board. The block presses (or puts a force) against the board at the slope angle too. And the force of friction will resist the block from slipping down the board. These same four forces are at play when the Earthquake Machine is resting on the table. The amount and direction of these forces is what changes. See "Physics of the Model" inset on Page 3.)*

5. **Change the amount of friction on the fault system**: What would happen if we changed the amount of friction on the fault system?
   a. Prepare three (3) Earthquake Machine wood blocks with different grits of sandpaper: heavy, medium and fine. (Figure 7)
   b. Experiment with the different Earthquake Machine blocks including a 4th option with no sandpaper at all. (Simply turn one block over to the opposite side.)

Figure 7: Examples of different grit sandpaper. Lower grit offers more friction; fine grit slips more easily.

Questions for Discussion:

- What does the grit of the sandpaper represent in the Earth? *(Characteristics, like grain size, of a rock.)*
- How much energy was stored in the system (that is, how far was the rubber band stretched) before the earthquake jump for each type of sandpaper grit? (Figure 7). *(This will vary depending on the sandpaper grit you choose. Look closely at the grain size. Typically the heavy grit, lower-numbered sandpaper provides more friction, and so more energy will need to be added to the system before the block slips.)*
- How large did the earthquake slips appear with the different grits? (*The slip varies with the type of sandpaper tested. Heavy grit (lower number) often produces fewer and larger earthquakes*.)
- In general, how does changing the friction or rock type in an earthquake system affect the kind of earthquake that will result? *(Rock with larger particle size surface area locks more tightly. This requires greater energy to overcome the increased friction. Greater energy required to overcome friction results in larger earthquakes.)*

6. **Add another block and rubber band**: What will happen when we connect a second block of wood to the first with another rubber band? (Figure 8)
   a. Using a single block of wood and sandpaper with an eye screw on one side, attach a second eye screw to the opposite end of the block. This becomes the first block in a series of two blocks.
   b. Connect a second block of wood and sandpaper to the first block with two rubber bands.
   c. Place both blocks on the sandpaper belt taped to the table.
   d. Experiment by pulling gradually and consistently on the rubber band connected to the first block.

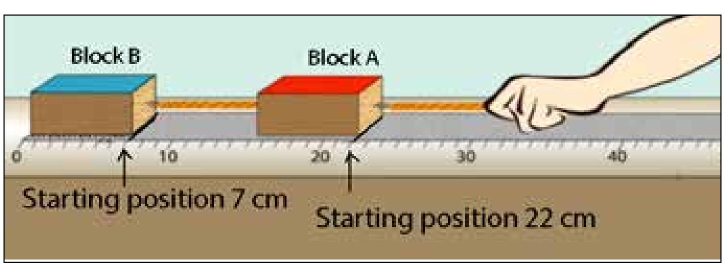


Figure 8: Two-block Earthquake Machine.

Questions for Discussion:

- When the first block moved, and the second block remained locked, what happened to the rubber bands between the two blocks? *(They stretched, storing potential energy.)*
- When both blocks moved at the same time, what happened to the total energy in the system? (*It decreased, as the energy was released in seismic waves.)*
- Would the magnitude of the earthquake be the same when both blocks moved (at the same time) as when just one block moves? (*No, the energy would be greater, resulting in a larger magnitude earthquake. When the two blocks move at the same time, this would be equivalent to a large earthquake along the main San Andreas Fault. See inset below.*)

7. **Change friction**: What would happen if we used the two-block model, but changed the friction on the first block of wood? The two block model can also represent some of the complex interactions occurring on the subducting Juan de Fuca Plate with the Pacific Plate in the Pacific Northwest (Figure 9). Read the "Background" in inset on next page for description of the plate movements in three distinct zones: locked, transition and continuous slip.

Directions:

a. Follow the directions as for step #6 above.
b. Turn the first block of wood over so that the smooth surface is against the sandpaper belt and the sandpaper side is facing up.
c. Place both blocks on the sandpaper belt taped to the table.
d. Experiment by pulling gradually and consistently on the rubber band connected to the first block.

San Andreas Fault Background

The San Andreas Fault Zone is the main part of the boundary between the Pacific tectonic plate on the west side and the North American plate on the east side. The "zone" part of the name means that it's a system with a main fault and many sub-parallel faults that all together take up the motion between the two plates. The "zone" is best described with the two-block earthquake machine model, where one of the blocks represents the main San Andreas Fault and the second block represents a rupture of one of the adjacent segments. See maps in APPENDIX D.

Questions for Discussion:

- What part of the subduction zone does the first block of the Earthquake Machine being pulled represent? (*The transition zone.*)
- What part of the subduction zone does the second block represent? (*The shallow locked zone.*)
- Cascadia last ruptured on January 1700, just over 300 years ago. What can the slow slips of the first block indicate about the probability of another megathrust earthquake in the Pacific Northwest? (*This is a subject of heavy debate among scientists, so let the learners discuss. See inset at right for more information.*)

An additional activity titled "*Living on Shaking Ground*" (Appendix C) presents a science and society exploration of the challenges and constraints facing cities, states and their governing agencies located in earthquake country.

Cascadia Subduciton Zone Background

The Cascadia Subduction Zone (CSZ) "megathrust" fault is a 1,000 km long dipping fault that stretches from Northern Vancouver Island to Cape Mendocino California. It separates the Juan de Fuca and North America plates. New Juan de Fuca plate crust is created offshore along the Juan de Fuca ridge. The Juan de Fuca plate moves toward, and eventually is shoved beneath, the continental North American plate. At depths shallower than 30 km or so, the CSZ is locked by friction. The strain slowly builds up along this fault segment as the subduction forces act, until the fault's frictional strength is exceeded and the rocks slip past each other in a "megathrust" earthquake. The fault's frictional properties change with depth, such that immediately below the locked part is a strip (the "Transition Zone") that slides in "slow slip events" that slip a few cm every dozen months or so. This relieves the plate boundary stresses there, but may add to the stress on the locked part of the fault. Below the transition zone, geodetic evidence suggests that the fault slides continuously and silently at long term plate slip rate (Figure 9).

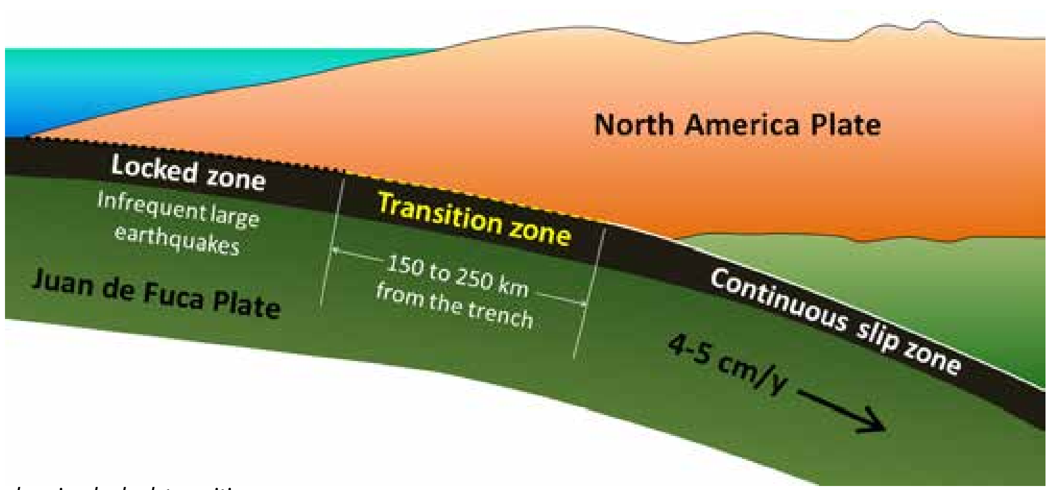


Figure 9: Cascadia Subduction Zone showing locked, transition and continuous-slip zones in the subducting Juan de Fuca Plate. See "Background" in inset above. Modified from graphic by [Steven Earle (2015) CC BY 4.0,](#).

APPENDIX A — VOCABULARY

Dip—Faults can be vertical, horizontal, or somewhere in between. Dip is the angle that describes the steepness of the fault surface. This angle is measured from Earth's surface, or a plane parallel to Earth's surface. The dip of a horizontal fault is zero (usually specified in degrees: 0°), and the dip of a vertical fault is 90°. Most faults are not horizontal, but rather either vertical or sub vertical.

Earthquake—shaking or trembling of the earth that accompanies rock movements. It is the release of stored elastic energy caused by sudden fracture and movement of rocks inside the Earth.

Elastic Energy—Elastic energy is the mechanical potential energy stored in a material or physical system as it is subjected to elastic deformation by work performed upon it. Elastic energy occurs when objects are impermanently compressed, stretched or generally deformed in any manner, e.g. the object will spring back to its original shape.

Elastic Rebound Theory—The slow buildup of elastic strain due to large-scale stresses in the crust on either side of a locked fault (i.e., a fault on which steady movement is not occurring). Once the strain accumulation exceeds the strength of the locked fault, the stored energy is abruptly released by rapid displacement along the fault in the form of an earthquake, whereby the rocks return to their original state, and the cycle repeats.

Energy: Potential and Kinetic—In the Earthquake Machine, potential energy is seen as elastic energy stored in the rubber band. Potential energy can be converted to kinetic energy, which is the energy of motion, heat, and sound when the elastic energy is released from the rubber band and the block slips in an 'earthquake'.

Energy Transfer—The conversion of one form of energy into another, or the movement of energy from one place to another.

Epicenter—The epicenter is the point on the earth's surface vertically above the hypocenter (or focus), point in the crust where a seismic rupture begins.

Fault—A fault is a rock fracture where the two sides are displaced relative to each other.

Fault plane—The plane along which the break or shear of a fault occurs [during an earthquake].

Hypocenter—The hypocenter of an earthquake is the point at depth where the rocks start to fracture. The hypocenter is also called the focus of an earthquake.

Megathrust earthquake—occur on low-angle thrust faults at subduction zones. These are the largest earthquakes in the world with M8.5+. The Cascadia Subduction Zone has produced magnitude 9.0 or greater earthquakes in the past, and undoubtedly will in the future.

Moment Magnitude Mw—provides the most reliable estimate of earthquake size particularly for very large earthquakes. Moment (seismic moment) is a physical quantity proportional to the slip on the fault multiplied by the area of the fault surface that slips; it is related to the total energy released in the earthquake.

Sliding Friction—Sliding friction is the resistance created by any two objects when sliding against each other. This friction is also known as kinetic friction and is defined as the force that is needed to keep a surface sliding along another surface.

Static Friction—Static friction is a force that keeps an object at rest. It must be overcome to start moving the object. Once an object is in motion, it experiences kinetic friction. If a small amount of force is applied to an object, the static friction has an equal magnitude in the opposite direction.

Stick-slip—Earthquakes are "slip" episodes; they are followed by periods of no slip ("stick"), during which elastic strain increases away from the fault. Although some growth of the fault may occur with each earthquake, we can generally assume that for large earthquakes (M>6) the faulting process primarily involves repeated breaking of the same fault segment rather than creation of a new fault surface.

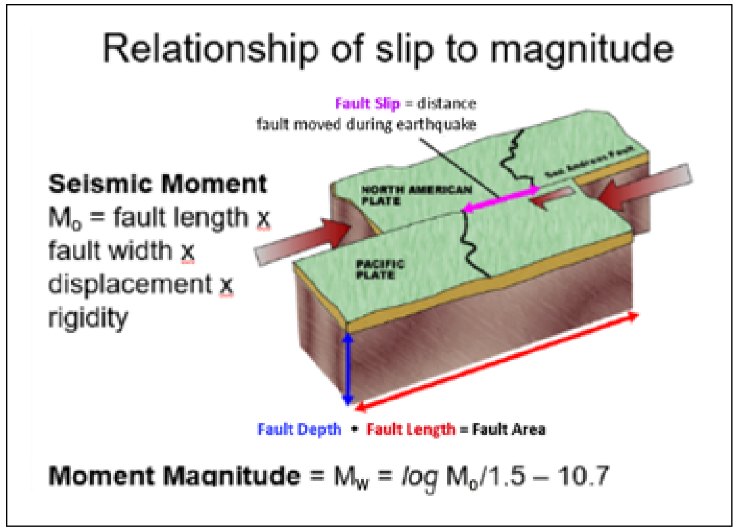
Seismic moment—The seismic moment is a measure of the size of an earthquake based on the area of fault rupture, the average amount of slip, and the force that was required to overcome the friction sticking the rocks together that were offset by faulting.

APPENDIX B —THE SCIENCE OF THE MODEL

The model represents the continuous tension occurring on a fault like the San Andreas Fault in western California (Appendix D), which causes horizontal movement characterized as right-lateral strike-slip fault displacement. In this case, the fault is vertical and the Pacific Plate (on the west) moves northwestward relative to the North American Plate (on the east). The rubber band represents the elastic properties of the surrounding lithosphere, storing potential energy. When the frictional forces between the block and sandpaper are overcome, the block lurches forward with a stick-slip motion.

Learners get to "experience" an earthquake by seeing the release of energy stored in the rubber band and feeling the propagation of seismic waves from an elastic source. While this model accurately simulates the strain energy that slowly accumulates in rock surrounding a locked fault that is released in a sudden slip event, a process known as the elastic rebound theory, it is ultimately a simplification of a complex Earth system. Such simplifications must be understood to interpret the model accurately. Therefore, the relationship between the model and reality should be clearly emphasized to learners (Table 1).

The model not only provides a physical perspective on the generation of earthquakes, but it also illustrates the concept of an earthquake's magnitude, and how this can be calculated based on the physical features of the fault. In our model, the length and width (area; A) of the fault section that slips during an event (represented by the dimensions of the block of wood) as well as the rigidity of Earth materials (μ, represented by the elasticity of the rubber band) are constant for every event generated. The only factor that can vary is the displacement (D) or slip of the fault. As a result, there is a direct correlation between the amount of slip of the block and the moment magnitude of the event (Figure 10). (For further explanation, watch: "[Understanding Moment Magnitude... or What Bumped the Richter Scale?]"



Relationship of slip to magnitude represented by the Moment Magnitude equation (See animation link, below left)

Anchorage, AK 2018, M 7.0

Nisqually, WA 2001, M 6.8

Scotts Mills, OR 1993, M 5.6

Ridgecrest, CA 2019 , M 7.1

Research and Discussion Questions

Earthquakes occur on different types of fault systems along the West Coast of the United States. Ground shaking from plate movements have broad reaching effects to the built environment. Planning and mitigating before an earthquake occurs is a challenge for society.

Discover and debate some of the challenges that affect your area and beyond:

1) What is the history of earthquakes in your area?
2) What are the active (earthquake-creating) faults closest to where you live?
3) How do earthquakes affect homes, public buildings, infrastructure, utilities, hazardous materials (fuel storage)? Consider the following:
    - Construction design
    - Construction materials
    - Location site for geologic hazards
    - Zoning ordinances
    - Building codes
    - City/Community emergency planning
    - Personal, family, and neighborhood planning
    - Earthquake Early Warning notification (ShakeAlert)

Identify challenges and constraints that affect each of the topics listed above.

List possible solutions for taking steps to resolve the identified challenges and constraints.

Consider the constraints and challenges outlined in question 2, to the building you are currently in.

Photo credits:

Alaska courtesy of Natural Hazards, Earthquake Hazards Program, Region 11: Alaska, Alaska Science Center, Geologic Hazards Science Center

Nisqually courtesy of U.S. Geological Survey

Scotts Mills courtesy of Oregon Seismic Safety Policy Advisory Commission

Ridgecrest Branch Library, photos by Richard Wagner (07/06/19)

APPENDIX D — SHAKEALERT® STATE FAULT MAPS

The faults on these maps of Washington, Oregon and California include three different locations within or between the tectonic plates, including:

- Shallow crustal
- Deep (aka, intraplate or intraslab)
- Megathrust (aka, subduction zone.)

Whereas particular faults are not all identified by type (normal, reverse, strike-slip) or location, the prevalence of faults across the region shows the dynamic potential for earthquakes and the critical need for earthquake awareness and preparedness.

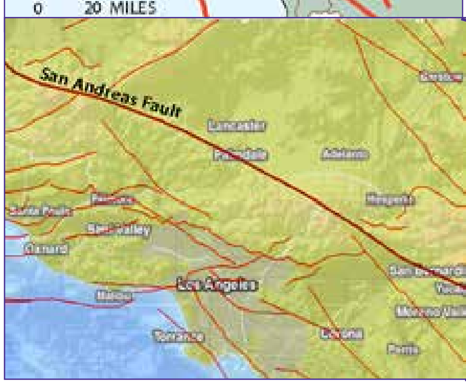
Mapping faults is difficult, and scientists interpret where faults are based on field work, map interpretation, or more recently, on lidar images that can "see" through the forests. Therefore, don't be surprised if fault maps look somewhat different.

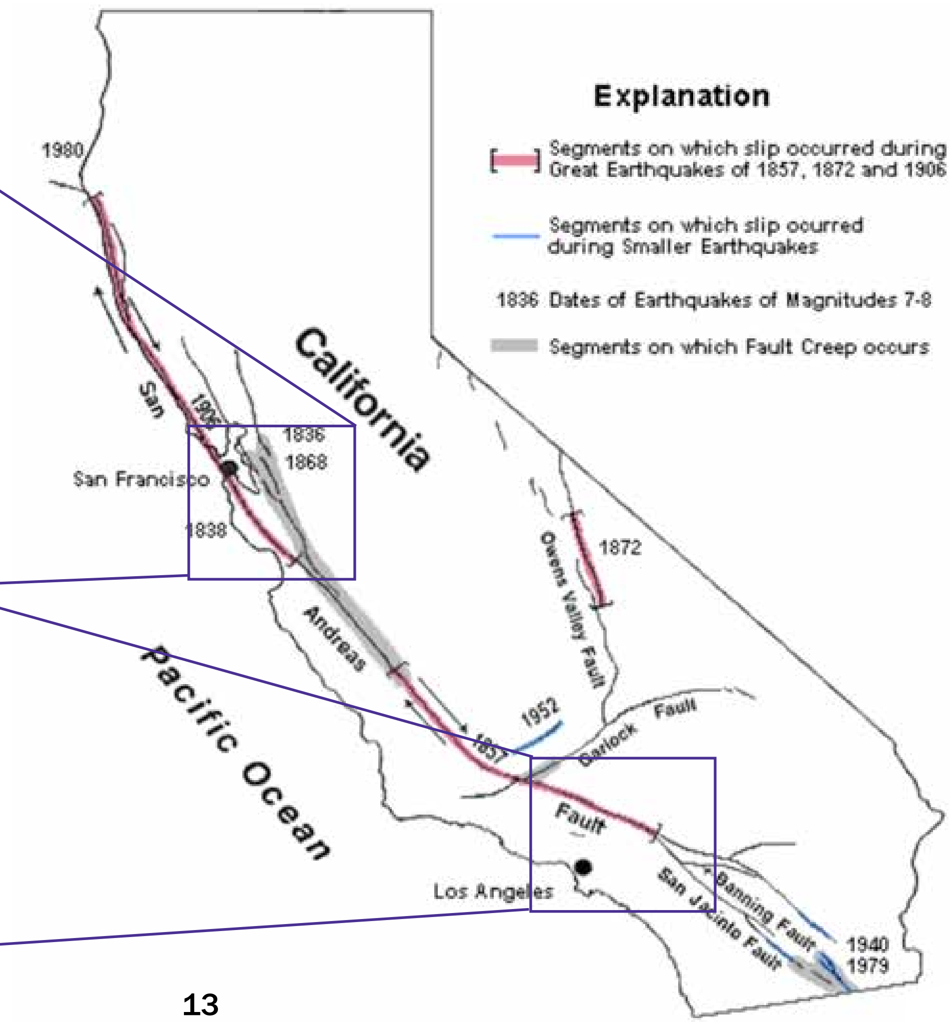
Fault map of Washington and Oregon from the [Pacific Northwest Seismic Network "Recent Events"](#) map. To see faults on the PNSN map, go to "Control Panel" and check the faults box.

Below right: *Fault map of California. See "Explanation". Zoom in on this link to see an [Interactive map of California's faults.](#)*

Below left: *Parallel faults indicate the width of the San Andreas Fault ZONE in the Bay Area. Only major faults are shown.*

Bottom: *Significant faults of the Los Angeles area.*





APPENDIX E — HOW THE MODEL IS LIKE AND UNLIKE REALITY.

***Table 1**. Comparing Like and Unlike characteristics of reality of the Earthquake Machine model.*

LIKE REALITY

The wood block represents the edge of the plate that is locked.

The measuring tape represents the bulk of the plate where plate motion is constant.

Slow pulling on the measuring tape represents the force causing the plate to move.

The rubber band and its deformation represents the elastic materials inside Earth that also store potential energy.

The sandpaper represents the contact between one plate and another plate.

When the locking (frictional in this case) forces are overcome, the potential energy is suddenly converted to kinetic energy.

The moving block represents an earthquake.

Vibrations from the block moving are elastic waves, like seismic waves these radiate out in all directions.

UNLIKE REALITY

The materials are notably different.

The temporal and physical scale the model operates on is notably different.

In Earth, elastic energy is stored over tens to hundreds of years in rocks spanning an area of up to hundreds of kilometers. This is in contrast to the seconds it takes to store energy in the small rubber band.

The block always has fixed dimensions while a fault may be much larger and could slip at any point along it and vary for each earthquake.

In the model, the boundary between the two plates (or sides of the fault) is parallel to the surface. However, in Earth, plate boundaries (and fault planes) are not this horizontal.

Friction only occurs along the bottom of the wooden block in the model but in a fault, friction is more complex and likely on the sides of the block as well.

Energy in the model comes from our hands, but in the Earth the internal heat of the earth and gravity drives the complex forces causing plate movement.

Horizontal tension represents only one type of force causing movement on faults. Compression and shear forces also cause vertical or angular movement on faults resulting in earthquakes.

Earthquake Machine set-up.

APPENDIX F — NGSS SCIENCE STANDARDS & 3 DIMENSIONAL LEARNING

Touch the url links to get more information

Earth's Systems

MS-ESS2-2 Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. http://ngss.nsta.org/DisplayStandard.aspx?view=pe&id=224

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.	**ESS2.A: Earth Materials and Systems** The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.	**Scale, Proportion, and Quantity** Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.

Incorporated Research Institutions for Seismology

IRIS

FACILITATE. COLLABORATE. EDUCATE.

Founded in 1984 with support from the National Science Foundation, IRIS is a consortium of over 100 US universities. In partnership with its Member Institutions and the scientific community, IRIS manages and operates comprehensive, high-quality geophysical facilities that enable exciting discoveries in seismology and the Earth sciences. IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and the verification of a Comprehensive Test Ban Treaty.

NSF