Engineering for Earthquakes

Grade Levels: 3-5
Duration: 60 min

This lesson challenges students to create a structure that can withstand the ground movement of an earthquake.

Outline

Frame the Challenge	10 min total
Activate Prior Knowledge	5 min
Introduce Design Challenge	5 min
Design Challenge	**50 min total**
Prototype (Build and Test)	15 min
Share Solutions	10 min
Iterate	15 min
Debrief	10 min

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Concepts/Skills
Structural engineering, Forces, Natural hazards: Earthquakes

Objectives
Students will...
- Observe and explain simulations of the forces at play during an earthquake.
- Use strong engineering principles to design a structure that will withstand the shaking of a simulated earthquake.
- Compare solutions, reflect and iterate to improve their designs.

Materials and Preparation

Tools and Peripherals

1 of each per group

- □ Scissors
- □ Hole punch
- □ *Optional*: Crop-a-dile power punch *(for punching holes in plastic and thick cardboard)*
- □ Live Load — 1 set of "weights" per test rig. Weight approx 85-90g (3 oz) each.
  - □ 3 small activity dough containers
  - □ 1 deck of playing cards

We leave glue off this list on purpose. Forgoing glue will allow for more rapid iteration of designs. This also will allow you to recycle and reuse materials for another session.

Building Materials

Look for items that match the categories; see the suggestions below for ideas. Try to provide a couple different types of items for each category. Materials can vary among groups and do not need to be identical.

Structural Pieces

15-20 per group

- □ Wood craft sticks
- □ Chopsticks/wooden or plastic dowels
- □ Straws
- □ Pencils
- □ Toothpicks
- □ Paper, junk mail
- □ Cardboard, cut into different sizes and shapes
  - 3"x3" squares
  - 5"x5" squares
  - 3"x5" rectangles
  - □ Thin cardstock, food boxes
  - □ Thick boxes
- □ Plastic sheets or paper plates

Connectors

20-30 per group

- □ Rubber bands
- □ Tape (give teams 5" only after they have started building and testing)
- □ Pipe cleaners (chenille stems)
- □ String
- □ Twist ties
- □ Foam balls (small or half sphere)

Tech Tips

See our educator guides and videos for more design challenge facilitation techniques.

- Materials Strategies
- Framing the Challenge
- Prototyping: Test, Reflect, Iterate

Test Rig - DIY Shake Table

This lesson details a Shake Table with side-to-side movement. There are many other options for building Shake Tables. Choose the style that fits your materials and setting.

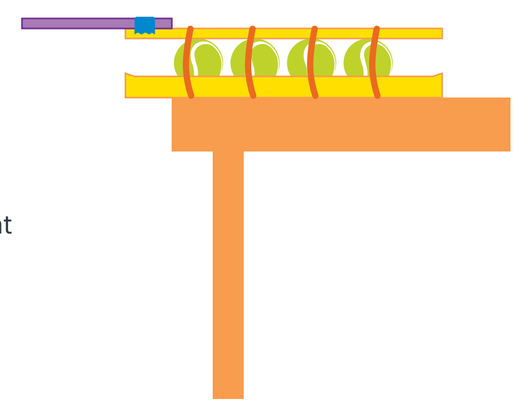
Simple Shake Table: Create a Shake Table out of a smooth/slippery surface and a piece of cardboard (8.5" x 11" up to 15" x15"). Simply tape the base of your structure to the cardboard and slide it from side to side!

Advanced Shake Table: For a Shake Table that moves three directions, create a "Shake Box." See our Tech at Home guide for a DIY version or look for a version online that matches your materials.

Test Rig Materials	At Testing Station
□ **Top:** One sheet of cardboard, or a similarly rigid, flat material (approx 11" x 15.5") □ **Bottom:** One box lid/ rigid flat material with a lip/side (same size as top sheet) □ **Middle:** 4-5 balls of the same size (tennis balls/bouncy balls) □ A ruler □ Four long rubber bands 	□ Tape □ 2-4 (large) 2" binder clips □ 3 sets of extra Live Load "weights" for Challenge Card extensions 

Building the Test Rig

Build at least two test rigs per class.



1. Lay the ruler on the "Top" flat sheet of cardboard, demarcated side down, with at least 4 inches of overhang.
2. Tape the ruler in place and flip the cardboard over.
3. Place the piece with the ruler on top of the "Bottom" box lid/cardboard.
4. Bind the two pieces together loosely using the 4 rubber bands. Make sure that the rubber bands are on the sides perpendicular to the side with the ruler.
5. Pull the top and bottom apart and slip the balls in between. Make sure to distribute the balls evenly so that the top piece of cardboard is level.
6. If you pull on the ruler, the top platform should spring back and forth.
7. Tape the "Bottom" in place on the table to make sure that it doesn't move.
   - Try pulling the ruler back a few times and releasing, making sure that the top platform returns to its starting position each time.
   - When you get a sense for how far back to pull the top platform for a substantial shake, mark that distance on the table with a piece of tape. This will better ensure consistent testing.
   - Baseline recommendation is about 2 inches, however it is recommended that you test shaking the table a variety of ways to see what works best for your situation. Example: for a larger earthquake a back and forth motion for 5 seconds can also work.
8. Build and test a sample structure and add the "live load" weights.
9. During testing, attach the student structures to the base of the shake table using a small amount of tape or binder clips.

Preparation

1. Choose some resources for students to reference if they get stuck. Check the links in the Appendix, or gather a few books on buildings, structures, construction, or geometry. Photos of local buildings and structures can also be helpful!
2. Decide how students will form teams for this challenge.
3. Build 2 Test Rigs and test that they will work.
4. Prepare the classroom for the activity, including laying out the materials and setting up the testing area. Make sure to place the shake tables in a location where all students can see testing take place.

Adaptation for Beginning Engineers

Prepare materials in advance:

- Cut cardboard into a variety of shapes and sizes.
- Pre-punch holes into the cardboard.
- Arrange "sets" of materials for each group to work with.

Adaptations for Distance Learning

If teaching remotely, have students use the Tech at Home guide to create their own shake table based on available resources. Share a video resource asynchronously to excite students in the challenge and schedule a variety of both synchronous and asynchronous prototyping sessions. A forum or Question/Answer board can serve as a place for students to support each other as they prototype as well. For more tips on adapting Design Challenges to a virtual setting see our Educator Tips for Remote STEM Learning.

Frame the Challenge

Activate Prior Knowledge *(5 min)*

1. Find out what students already know about earthquakes, natural disasters and their effects on buildings and structures.
2. Guiding questions for student reflection or class discussion can include:
   - *What do you know about what causes earthquakes?*
   - *How do natural disasters affect buildings/structures?*
   - *How would you build a stable structure?*
   - *What kinds of shapes do you see in structures (buildings, bridges, playgrounds, scaffolding)? What makes them stable?*
3. During the discussion, introduce relevant vocabulary (**tectonic plates, mainshock, aftershock, earthquake and structural engineers**) and point out:
   - When two tectonic plates finally slip and release energy, this causes an earthquake.
   - We are still figuring out how to reliably predict earthquakes.
   - We can prepare for earthquakes and natural disasters by reducing the possibility of building damage and collapse.
   - There is a whole group of professionals who work together to design and build structures to withstand earthquakes, called engineers.

Video Options:

- Tech at Home: Engineering for Earthquakes How to Video
- KQED's Spotlight on Structural Engineering
- Major 7.1 Earthquake in Southern California

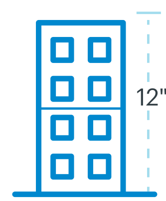
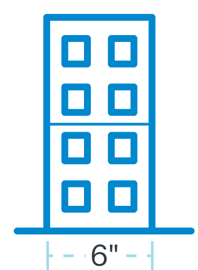
4. Record their ideas and observations about how to build stable structures to inform their designs later.
   - Learners may notice that many tall buildings are smaller at the top, use triangle beams as support, and use girders/bracing to support taller sections.
   - Let them share what they already know, but use the challenge itself as a chance to discover and test these ideas rather than sharing facts and data with them upfront.

Introduce the Challenge *(5 min)*

1. Before explaining the details of the challenge, hook student interest with a story and/or video.
   - Use a story/narrative that ties your challenge to the real world and learning goals.

Some examples:
- *An asteroid crashed into the earth near your town. It caused earthquakes under the skyscrapers downtown.*
- *Godzilla's stomping is shaking the nuclear power plant. Make sure it doesn't collapse and cause a meltdown.*
- *Keep the cars and trains on both levels of the Bay Bridge safe during the next big earthquake!*

2. Next, introduce the design problem, criteria and constraints. Explain it to students and address any questions they might have.

Design Problem	Design and create a structure that can withstand an earthquake.		
Criteria	• Needs to stay fully standing after three tests (ruler pulled at least 2"). • Should be at least two stories and 12" tall. • **Second iteration:** Must hold one set of live load weight on the upper levels.	 Two stories	 Live load
Constraints	• Must be able to stand on its own. • Base should be 6"x6" or smaller.		

3. This challenge asks students to build a structure that remains standing after a simulated earthquake mainshock and its two subsequent aftershocks.
   - Even a partial collapse is dangerous in a real earthquake. The structure must be completely intact at the end of all three tests/quakes.
4. Introduce students to the materials and testing area.
5. Demonstrate the Shake Tables.

Design Challenge

Prototype (Build and Test) *(15 mins)*

1. Divide students into teams of 3-5 for the Challenge.
   - Consider using roles with students that align with careers. *For example*: Architect - draws and takes notes; Foreperson - manages time and tasks; Building Inspector - does a final building check before testing
2. Encourage learners to test early and often. They don't have to build the full structure before trying it on the Shake Table.
   - *For example:* They can test one floor, then add the next, or test ways to attach the wall to the base.
3. During the prototyping time, support teams with open-ended questions to guide the process:

   Just Getting Started:
   - *Which materials or combination of materials do you think will stay sturdy AND flexible in an earthquake?*
   - *What kinds of shapes and structures are more stable when pressure or force is placed on them?*

   Problem-Solving After Testing
   - *What did you notice about the way your structure performed in an earthquake?*
   - *Where are the failure point(s) in the structure? What caused the failure?*
     - *How can your team start to alter that part of the design?*
   - *Were certain connection techniques stronger than others? Certain materials?*
   - *What can you adjust to make it more stable?*

   Pushing Design Further
   - *What can your team try to make this design even better (ex: more reliable, realistic, taller)?*
4. Encourage learners to use key vocabulary and concepts as they discuss and reflect on their testing.
5. Provide reminders on time and if teams feel like they have a stable structure, have them add the **live load** weights and test again.
   - Remember: **Live load** weights will only be added after students have built a standing structure.

Extension
Have students photograph or draw structures in their neighborhood/city to use as a resource during building. They can highlight the shapes that they notice.

Adaptation for Beginning Engineers
If students are struggling to get a structure to stand without collapsing, have them test out some ideas from the Strength of Shapes.
- They can build a square with dowels and rubber bands that connect the edges.
- If they push on any of the corners, their square will deform.
- Have them add in a beam diagonally from one edge to another. (It doesn't have to go from one corner to another.) This should help stabilize the square.
- In construction, triangles are considered to be the most stable structures when they are used appropriately.

Adaptation for Advanced Engineers
Try using the Google Science Journal App to capture some data.
- Safely secure and suspend a cell phone in the uppermost level of your structure with the accelerometers recording.
- Record the motion of the test.
- Have students try to reduce the motion "sensed" on the upper level each time they iterate. (Remember some say is good in structural design, but extreme motion can cause collapse.)

Share Solutions *(10 mins)*

1. At the end of the time limit, learners stop even if they haven't been able to complete their structure (or iteration of their structure).
2. Have each team demonstrate their structure on a Shake Table while sharing what they built and why. Sharing questions can include:
   - *Tell us about your structure.*
   - *What did you discover? What did you change as you built?*
   - *Did you find certain techniques to be stronger than others? Certain materials?*
   - *What would you adjust/change in your next iteration?*
3. Keep the sharing simple and focused. Have learners give each other positive feedback on their designs. Encourage them to tell the presenting team one thing they liked or noticed.

Extension

Have students conduct additional research on structures and earthquakes based on grade-level resources and content connections. See Resources and References in the Appendix for some specific examples.

Iterate *(15 mins)*

1. Iteration is an important part of the design process. Provide students time to revisit and revise their structures based on their testing, feedback and observations of other team's designs.
2. Once again, teams should use this time to build, test and reflect.
   - Testing may be more rapid at this point as students are making minor adjustments.
3. Teams that have met the initial criteria can do the following to push their designs further:
   - Add **live load** weights.
   - Use the Challenge Cards in the Appendix. Select a card for them, have them choose a card at random, or have them read through and choose an extra challenge for their team.

Debrief *(10 mins)*

1. If there is time, have teams do another round of sharing solutions.
2. Have students reflect on what they learned from the building and iterating process and the larger engineering concepts and real-world application.
3. Lead a short debrief with some of these questions.
   - *From what you observed, what makes structures more stable?*
   - *What other materials would you want to use to build your structures? What type of materials or combinations do you think would work in the real world?*
   - *What did your process tell you about how engineers might approach this type of problem in the real world?*

Standards Connections

Next Generation Science Standards

Grade	Standard	Description	3-Dimensional Focus
4	ESS3-2	Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.	• Constructing Explanations and Designing Solutions • Natural Hazards • Cause and Effect
3-5	ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.	• Constructing Explanations and Designing Solutions • Developing Possible Solutions • Influence of Science, Engineering, and Technology on Society and the Natural World
6-8	ESS3-2	Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.	• Analyzing and Interpreting Data • Natural Hazards • Patterns

Vocabulary

- **Aftershock:** A smaller earthquake following the largest earthquake in a series of seismic events.
- **Buckling:** When a material bends under compression.
- **Compression:** When a force pushes materials together.
- **Earthquake engineers:** Design and analyze structures to withstand minor earthquakes and avoid severe damage or collapse in major earthquakes.
- **Force:** Any influence that pushes or pulls on an object and influences its movement.
- **Live Load:** The weight of everything inside a structure like people and furniture. The placement of the live load will affect how the structure moves in an earthquake.
- **Mainshock:** The largest earthquake in a series of seismic events, determined retrospectively.
- **Shear:** When structural strain increases too much, causing the material to break off.
- **Structural engineers:** Focus on the design and construction of structures to ensure they are comfortable for users while being strong and stable enough to withstand a variety of factors from structural loads to natural disasters.
- **Tension:** A pulling force.
- **Torque:** A twisting force.

Resources and References

- USGS: https://www.usgs.gov/natural-hazards/earthquake-hazards
- USGS Resources for Teachers: https://www.usgs.gov/science-support/osqi/yes/resources-teachers/
- KQED's Spotlight on Structural Engineering: https://www.youtube.com/watch?v=oqpp8L4J4ek
- Strength of Shapes: https://www.teachengineering.org/content/cub_/lessons/cub_trusses/cub_trusses_lesson01_presentation_v5_tedl_dwc.pdf
- "Buildings can Be Designed to Withstand Earthquakes. Why Doesn't the US Build More of Them?" *NY Times*: https://www.nytimes.com/interactive/2019/06/03/us/earthquake-preparedness-usa-japan.html

Engineering for Earthquakes
Challenge Cards

Taller Structure

Can you build a taller structure that still withstands the earthquake and aftershocks?

Bigger Earthquakes

Can your structure withstand longer earthquakes and more aftershocks?

More Reliable

How many earthquakes can your structure withstand in a row without needing repairs?

Materials Limit

Build a stable structure with fewer materials. *For example*, only three different kinds of materials, or no rubber bands.

Shape Limit

Redesign your structure to use only 1 shape?

More Weight

How much weight can your structure hold during an earthquake? Add more live load weight in small amounts, test and repeat till your structure collapses. Rebuild and try again!

Model

Model your structure on a famous building or structure. Can you recreate it AND make it earthquake ready?

Speed Challenge

How quickly can your team work together to revise your structure? Make sure you are all involved and collaborating.

Team Choice

As a team, choose a new way to challenge your structure and your engineering skills!