Earthquake Tower Challenge

Quick Look

Grade Level: 8 (6-8)

Time Required: 1-2 class periods

Group Size: 4

Subject Areas: Earth and Space, Physical Science, Science and Technology

Summary

Students learn about how engineers design and build shake tables to test the ability of buildings to withstand the various types of seismic waves generated by earthquakes. Just like engineers, students design and build a building to test on a shake table. Once students are satisfied with the performance of their buildings, they put them through a one-minute simulated earthquake challenge.

This engineering curriculum aligns to Next Generation Science Standards (NGSS).

Engineering Connection

In certain areas of the world, earthquakes are a serious concern. Civil and structural engineers who focus on designing buildings, bridges, roads and other infrastructure for earthquake-prone areas must understand seismic waves and how to construct structures that are able to withstand the forces from the powerful ground motions of the Earth. For testing purposes, engineers design shake tables to simulate (or re-enact) the seismic waves produced by earthquakes and verify the stability and survivability of their structures.

Learning Objectives

After this activity, students should be able to:

- Explain the four different types of seismic waves produced by earthquakes.
- Describe the purpose of shake tables and how engineers use them.

Educational Standards

- NGSS: Next Generation Science Standards - Science
- Common Core State Standards - Math
- International Technology and Engineering Educators Association - Technology
- State Standards

Materials List

Each group needs:

- Tower base (two K'nex base sets) 
- Building criteria worksheet (attached at end of document)
- Graph paper (one for each student)
- Colored pencils / markers / crayons

To share with the entire class:

- K'nex pieces
- Stopwatch
- Shake table
- Tape

Pre-Req Knowledge

Students should be able to measure length with a ruler and have an understanding of seismic waves (as provided in the associated lesson).

Introduction/Motivation

How many different kinds of waves can you think of? (Listen to student suggestions and add others. For example, electromagnetic [light, radio], sound, ocean [water], seismic, pressure, compression, standing and sine waves.) No matter what kind of wave, what do they have in common? (Draw a wave on the board and identify its parts.) That's right: amplitude, wavelength, crest, trough, frequency.

What types of waves do we associate with earthquakes? That's right, seismic waves. Seismic waves are waves that move through the Earth and are typically created by earthquakes. For all seismic waves, the amplitude or intensity of the wave is dependent on three things:

1. The depth at which the earthquake took place (the closer to the surface, the greater the amplitude of the wave)
2. The intensity of the earthquake (earthquakes with higher Richter scale ratings produce more intense seismic waves)
3. The composition of the Earth's crust

The people who work in "earthquake engineering" focus on protecting us and the natural and human- built environments from earthquakes. They want to limit our risk of death and damage from earthquakes. How can we possibly make sure that our school or stadium or a skyscraper or a freeway overpass will not collapse in a big earthquake? Well, engineers create shake tables to test the ability of buildings and other structures to withstand the seismic waves produced by earthquakes. To do this, they carefully design and construct shake tables that can accurately re-enact the ground motion of the Earth during earthquakes. Sometimes they test full-size buildings and sometimes they test small-scale model buildings or components. Some shake tables are large enough to put a real-size building on; others are smaller, even tabletop size. By doing this, engineers can test materials, designs, and construction methods to develop building codes and best practices that provide people living in earthquake-prone areas with safe and survivable surroundings.

Engineers must understand everything about the various seismic waves produced during earthquakes and how they cause the Earth to move. Who can tell me the four types of seismic waves that engineers need to simulate? They are:

- P-waves (or primary waves, a type of body wave)
- S-waves (or secondary waves, a type of body wave)
- Love waves (a type of surface wave)
- Rayleigh waves (a type of surface wave)

What do you know about these different types of seismic waves? How are they different from each other? P-waves and S-waves are body waves, which travel through the body of the Earth. P-waves are the fastest of all the seismic waves and can travel through any medium, although they move through solids faster than through liquids and gases. P-waves vibrate the parallel to Earth or in the direction of their propagation. They are similar to a compression wave moving through a slinky. S-waves are the second fastest type of seismic waves, and they can only move through solids. S-waves are transverse or shear waves and move the Earth perpendicular to the direction of propagation. Both P-waves and S-waves are types of body waves and travel through the interior of the Earth.

Love waves and Rayleigh waves are surface waves, which travel along the surface of the ground. In general, surface waves are slower than body waves—and more destructive. Love waves cause a horizontal shifting of the Earth perpendicular to the wave propagation. Rayleigh waves are a type of sinusoidal wave and move like ocean waves. They are produced by the interaction of P-waves and S- waves. Rayleigh waves are the slowest of all the seismic waves with a speed approximately equal to 3 km/second.

Smart design and testing make buildings resistant to the seismic wave movement of earthquakes. A properly engineered structure does not necessarily have to be extremely strong or expensive, but it must be correctly and intelligently designed to withstand the seismic effects while sustaining an acceptable level of damage. What are your ideas? Let's create our own model buildings to test them.

Procedure

Before the Activity

- Gather materials and make copies of the Earthquake Tower Challenge Worksheets.

With the Students

1. Show students the available materials. Point out that this project follows the steps of the engineering design process: understand the need (requirements, objective), brainstorm different design solutions, select the most promising design, plan (strategy, drawings, measurements, materials), create and test, and improve to make the best solution possible.

2. Identify a few design requirements and constraints:
   - A construction drawing with measurements and analysis must be submitted BEFORE purchasing your materials.
   - The building must fit on the base. The base minimum is 18 cm x 14.5 cm
   - Your building must be at least 27 cm tall.
   - Your building has 2 stories that are each at least 5 cm tall
   - Each story must support the weight of at least 1 weight without collapsing.
   - To survive an earthquake test, the building must not collapse until the shaking stops completely. The weights **must stay** on the building.
   - A full color LOGO/Name of Company must be attached to the tower
   - **You will be given a budget of $50,000**. The costs will be posted on the projector. (They are on page 7 below.)

3. Hand out the worksheets to students. Give them time to independently design and draw their shake tables and buildings, as instructed on page 2 of the worksheet. If possible, assign this as homework the night before so students have a chance to develop their own ideas before coming together in teams to determine the most promising designs.

   (Note to teacher: The shake tables from Science In Motion mostly simulate surface waves. If you would like to model more P-waves, then you can roll the shake table across marbles or tubes.)

4. Divide the class into groups of three or four students each.

5. Have groups brainstorm ideas to build their tower. (If possible, have students individually brainstorm ideas for homework the day before.) Have teams each agree upon a final design that they will construct, then bring their blueprints and budget to the instructor for final approval.

6. Give students time to construct their model buildings, and then use the classroom shake tables to test and modify (improve) the designs. Point out that the testing-improving-testing process is an important part of the bigger engineering design process. That's how weaknesses are discovered and problems solved—before you have an actual earthquake! Emphasize that in the upcoming earthquake challenge they will have only one chance to put their final building designs through a "real earthquake" test to see if they survive, so they must be certain that their buildings are survivable. What works? What doesn't? What could be improved? Test, test, test!

7. Earthquake Challenge: Once teams have completed structures and are satisfied with their stability and robustness, put the structures through a one-minute simulated earthquake challenge in which every team uses the same shaker table.

8. Have one student use a stopwatch to time how long each building survives the earthquake simulation. Remind groups to be ready to record the length of time their buildings lasted, the end building heights, as well as observations about how the building structures behaved under the shaking conditions. Have students watch all team tests to gather observations that they will use to finish the worksheet questions.

9. “Grading” will be based on the rubric provided in the worksheets below.

10. Have students complete the concluding worksheet questions, incorporating what they learned from observing their own and other groups' model building behavior under seismic stress. Have them draw conclusions about the relationship between the appearance of the structure and its building strategies, and its performance. If time permits, lead a class discussion using the concluding questions (see the Investigating Questions section) so students can hear each others' opinions and ideas.

Vocabulary/Definitions

Body Wave: A seismic wave that travels through the Earth rather than across its surface.

Engineering Design Process: A series of steps used by engineering teams to guide them as they solve problems: define the problem, come up with ideas (brainstorming), select the most promising design, plan and communicate the design, create and test the design, and evaluate and revise the design. Also called the design-build-test loop.

Love Wave: A surface seismic wave that cause horizontal shifting of the Earth during an earthquake.

Model: (noun) A representation of something for imitation, comparison or analysis, often on a different scale. (verb) To simulate, make or construct something to help visualize or learn about something else (such as a product, process or system).

P-Wave: A seismic pressure wave that travel through the body of the Earth. The fastest of all seismic waves.

Rayleigh Wave: A surface seismic wave generated by the interaction of P-waves and S-waves at the surface of the Earth that move with a rolling motion.

Seismic Wave: A wave of energy that travels through the Earth as a result of an earthquake.

Shake Table: A device for shaking structural models or building components. The movement simulates the ground motions of earthquakes. Also called a shaking table.

Simulation: Imitating the behavior of some situation or process, especially for the purpose of study or experimental testing.

Surface Wave: A seismic wave that travels across the surface of the Earth as opposed to through it. Surface waves usually have larger amplitudes and longer wavelengths than body waves, and they travel more slowly than body waves.

S-Wave: A shear or transverse body seismic wave, with motion perpendicular to the direction of wave propagation.

Assessment

Pre-Activity Assessment

Blueprints and budgets: As either pre-activity homework or the first task of the activity, have group members decide on roles, vote on the best proposed design, and complete and submit the final blueprint and budget to the instructor.

Activity Embedded Assessment

Observations and Questioning: During the activity, move around the classroom to observe students and ask them questions about what they are doing to determine how well they understand the activity. Ask individual students to explain what the group is working on, their strategies, etc.

Earthquake simulation: Use the provided rubric to assess the students' buildings.

Post-Activity Assessment

Conclusion Section of the Worksheet and Class Discussion: Review students' answers to the Earthquake Tower Challenge Worksheet questions to gain an understanding of why they think certain structures performed better than others. See whether or not students thought the ability of their shake tables to accurately represent seismic waves helped in the evolution of their building designs. Explore the questions in a class discussion format so that students can hear each others' opinions and ideas (see the Investigating Questions section).

Investigating Questions

(Note: These questions are included on the worksheet as part of the post-activity assessment.)

1. During construction, how did you test the strength and stability of your structure?
2. During construction, what strategies did you use to strengthen the weaker areas? Why?
3. How long did your building last through the "earthquake"?
4. Describe what happened to your building while it was going through the "earthquake."
5. What are the strongest parts of your building? Why?
6. What are the weakest parts of your building? Why?
7. If you had 5 more rods, where would you add them? Why?
8. Which types of seismic waves did the shake table imitate (simulate)? Explain the movements and speeds. Explain how it does this.
9. Based on what you noticed from your group and other groups, which designs and strategies worked the best?
10. Why do you think this particular type of design worked the best?

Additional Multimedia Support

- For good descriptions and drawings of seismic waves types, see Michigan Tech's UPSeis web page at http://www.geo.mtu.edu/UPSeis/waves.html
- Find more information on earthquakes, earthquake engineering, earthquake shaking table, Love wave, P- wave, Rayleigh wave, S-wave, seismic wave, and wave at https://en.wikipedia.org/wiki/Main_Page

- Show students a 43-second video showing a comparative test of two 12-floor model towers under earthquake simulation, one with seismic base isolation in place and one without. See Earthquake Protector: Shake Table Crash Testing at https://www.youtube.com/watch?v=kzVvd4Dk6sw&feature=related


Base min: 14.5cm x 18cm
Height min. = 27cm
$50,000 Budget
$3000
$2500
$1000
$750
$400
$1,000
$600
$500
$700
$700
$400
Don't take your paperwork/materials home!
Goal = construct the strongest but least expensive tower!

Earthquake K'Nex Tower Challenge

Your corporation has been hired as the structural engineers in charge of designing a new 2-story art/music/dance studio in San Francisco. There are many building codes you must follow. Each floor of the building must support **at least** one weight. Also, the building will be located near the San Andreas fault; therefore, your building must be able to withstand **both** small and large earthquakes. Since the building will be used for artistic arts classes, you may be as creative as you like with the shape and design of the building (it does not need to be box shaped).

<u>Your building must meet the following requirements (CHECKLIST):</u>

_______A construction drawing with measurements and analysis must be submitted BEFORE purchasing your materials.

_______The building must fit on the base. The base minimum is 18 cm x 14.5 cm

_______Your building must be at least 27 cm tall.

_______Your building has 2 stories that are each at least 5 cm tall

_______Each story must support the weight of at least 1 weight without collapsing.

_______To survive an earthquake test, the building must not collapse until the shaking stops completely. The weights **must stay** on the building.

_______ A full color LOGO/Name of Company must be attached to the tower

You will be given a budget of $50,000. The costs will be posted on the projector.

JOBS: All 4 people in the group can build, but each person has a specific job:

Architect/Company Logo Designer - Design and draw the building on graph paper. Throughout the building process, you need to make sure that your building is being constructed according to your plans. Draw a full color LOGO of your team that will be taped to your tower.

Name ________________________________

Transportation Chief - Deliver checks and pick up supplies. You are the only member of the group who is allowed to leave the construction site. You will also be in charge of keeping track of inventory and ordering whatever supplies are needed for the next day.

Name ________________________________

Accountant - Keep track of company funds and record in the balance sheet each day. You must know exactly how much has been spent and how much is left over.

Name ________________________________

Head Builder - Even though everyone can help build, you have a final say on how things must be built. You must work closely with the Architect to ensure the blueprint plans are being followed.

Name ________________________________

TOWER ARCHITECT BLUEPRINT REQUIREMENTS:

You must have your Blueprint drawing complete and approved before you buy any materials!

1. EACH person in the group makes a rough sketch of their own ideas. Architect makes the final decision.
2. Two Drawings - BIRD's EYE VIEW and STREET VIEW
    a. Full scale drawings - each square on your graph paper is __________ cm
    b. Scale Factor: ______cm = 1 cm actual on K'Nex pieces
    c. Length, Width and Height measurements - all labeled in cm
3. Label and Color ALL materials used
4. Add up the TOTAL cost $$$. Do not exceed $50,000.

ITEM	# needed	Cost

Students: ____

TOWER CHALLENGE RUBRIC:

<u>Group Grade:</u>

____	20 points	A clear, detailed COLORED construction sketch was completed with **length**, **width**, **height** and **costs**. All important design features and all critical measurements should be labeled on the sketch.
____	20 points	Building stands by itself, has a minimum base of 14.5 x 18 cm, is at least 27 cm tall, and has 2 stories that are each at least 5 cm tall and has a **full colored LOGO/Name of Company** taped to the structure.
____	15 points	Group members worked together, were respectful and stayed on task
____	10 points	Building supports 1 weight on the first story.
____	10 points	Building supports 1 weight on the second story.
____	1 point	Building remains standing with 1 weight on the second story after a mild earthquake.
____	1 point	Building remains standing with 1 weight on the second story after a major earthquake.
____	1 point	Building remains standing with 1 weight on the second story and 1 weight on the first story after a major earthquake.
____	1 point	Building remains standing with 2 weights on the top second and 1 weight on the first story after a major earthquake.
____	1 point	Building remains standing with 2 weights on the top second and 2 weights on the first story after a major earthquake.

______ 80 points TOTAL

______**BONUS 10 points**: The building in EACH CLASS that is the **least expensive**, that can hold the most **weight/ remain standing after a major earthquake** will be awarded 10 bonus points.

Investigating Questions

1. During construction, how did you test the strength and stability of your structure?

2. During construction, what strategies did you use to strengthen the weaker areas? Why?

3. How long did your building last through the "earthquake"?

4. Describe what happened to your building while it was going through the "earthquake."

5. What are the strongest parts of your building? Why?

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