**Earthquake Engineering and Design Challenge**

**Short Description:**

In this lesson students will design and build an earthquake-resistant structure using the engineering design process. Students will work in teams and manage budgets for materials, designs before building, building the structure and then testing the final product.

This lesson is based on the 2016 SMILE program’s middle school challenge. The lesson that follows has been modified to work in a standard classroom setting.

**Goals:**

The goal of this lesson is for students to design and build an earthquake-resistant structure using the engineering design process. The structure must meet specific design criteria: maximize structure height, maximize earthquake resistance, minimize structure cost, and students must use the materials they “purchase” from the store with the provided budget.

* Using the engineering design process, build and refine an earthquake-resistant structure.
* Each structure must meet specific design criteria (see Specific Design Criteria For Structures section below).
* To build the structures, teams use the materials they purchase from the store with the provided budget.

**Background:**

Earthquakes occur when energy stored in elastically strained rocks is suddenly released. This release of energy causes intense ground shaking in the area near the source of the earthquake and sends waves of elastic energy, called ***seismic waves***, throughout the Earth. Most of the earthquakes are confined to narrow belts of land and these belts define the boundaries of the plates. The interiors of the plates themselves are mostly free of large earthquakes, that is, they are ***aseismic***.

The energy of the earthquake is measured by how much "shaking" occurs. The shaking can vary in its intensity. Some earthquakes shake everything (high intensity), and others are not felt at all (low intensity). There are two ways to measure this shaking: ***Richter Scale*** and ***Modified Mercalli Scale***. The Richter Scale is a mathematical measurement of the intensity of the ground shaking, as measured on a seismograph. It is actually a measurement of the size of the waves produced by the earthquake. The Modified Mercalli Scale measures how people feel and react to the shaking.

Seismic waves radiate outward from the focus (point at which the earthquake starts). These waves cause damage in some areas, but not in others. Many factors effect damage. One of the most fundamental is distance. Seismic energy is lost as waves travel through the earth, so the further you are from the epicenter of an earthquake, the less shaking you will likely feel. Another important factor is the type of ground through which the waves travel. For instance, if the waves shake sand particles, the energy will tend to make the particles settle. This may cause the Earth’s surface to sink; large movements can occur, damaging human structures. In contrast, if the wave passes through hard, solid rock, no settling occurs and the movement will be less. Basically, the more tightly bound a material is, the less it will settle in response to seismic waves.

The damage caused by earthquakes is dependent on the intensity of the earthquake and the type of ground a structure is built on. A third factor is the materials used in a building’s construction. In earthquake country, unreinforced building materials like brick are not suitable, because these structures are weak. It takes just a little energy to cause the mortar to break loose, causing the building to collapse. Materials like wood are much more resistant to earthquake shaking, because these structures are flexible. A seismic wave can easily pass through a wood structure with little breakage.

**Materials:**

* Cardboard base (16” x 16”)
* Construction material purchasing form (1 per team)
* Team worksheet
* Ruler with cm and inches
* 1 bag of angel hair pasta
* 1 bag of spaghetti
* 1 bag of penne
* 1 bag of small and large linguine
* 1 bag of mini and large marshmallows
* 1 bag of spice drops
* 1 bag of gummy bears
* 1 bag of large gumdrops
* Shake table (make from baking sheet, or see shake table instructions below)

**Specific Design Criteria for Structures**

|  |  |
| --- | --- |
| **Requirement** | **Specification** |
| Footprint | No larger than provided cardboard base |
| Height | At least 25 to 50 cm tall |
| Cost | No more than $25 million |

**Directions:**

1. Divide students into teams.
2. Provide them with a worksheet that contains their general structure criteria, a budget sheet, and a cardboard base to build their structure.
3. Explain to students that they are trying to build a structure that can withstand a **6.0** magnitude (magnitude increases with the duration of shaking for this challenge) earthquake for **30 seconds** using the materials from the Materials Purchasing Form.
4. Students will then fill out the first section of the Team Worksheet, which will be provided to track preliminary designs and design tests improvements.
5. Students will then fill out the Materials Purchasing Form, and request building material from the Store Manager.
6. Then they build the structure.
7. They then proceed to test their design upon approval.
8. Students make improvements. They should fill out the Engineering Modifications Section in the Team Worksheet.
9. Students will test the improved design one last time**.**
10. After they have completed the last test, students should fill out the Earthquake Engineering and Design Discussion Questions.
11. As a class, discuss what lessons they learned about structure shape and design.

**Tips for building with candy:**

1. Build horizontal layers first before stacking them vertically.
2. Hold the pasta very close to the tip when inserting into gumdrop to prevent the pasta from bending or breaking.
3. Slowly press the pasta into the gumdrop. Watch carefully for signs of bending or breaking. If pasta breaks, try a new piece or use a different part of the gumdrop.
4. If too many pieces of pasta are inserted too close together, gumdrops will crack.
5. Pasta can bend, and may need to if it is the last piece in a layer to be assembled.
6. Check pasta for any curves or twisting before using, as it may result in morphed or distorted structure.
7. Break pasta pieces into uniform lengths before beginning. Make more of these than you think you will need and make sure you always have one available to make a template for the next piece.
8. Develop the dimensions for your tower before building to ensure your pasta connects diagonally across your sides.
9. Gumdrops cannot be cut.
10. Think about the structures weight.
11. Build modularly.
12. Cut materials into the same size and insert to ensure similar distance.

**Roles for Teacher:**

Rotate through the positions as the students complete each step (Store Manager, Pre-Test Inspector, and Testing Crewmember). Position details are provided below.

**Store Manager:**

The store manager takes order slips from students and provide students with the purchased materials. Mark all fulfilled order slips to indicate materials were paid for and received by students (either collect or mark it to make sure they paid for materials).

**Pre-Test Inspector:**

Pre-test inspection will determine if a team is ready to test their structure. Teams will raise their hands when they are done building their structures. Check that the team worksheet has been properly filled out and the built structure meets all design criteria. Passing pre-test inspection grants teams permission to proceed to testing and may assign a test time if necessary.

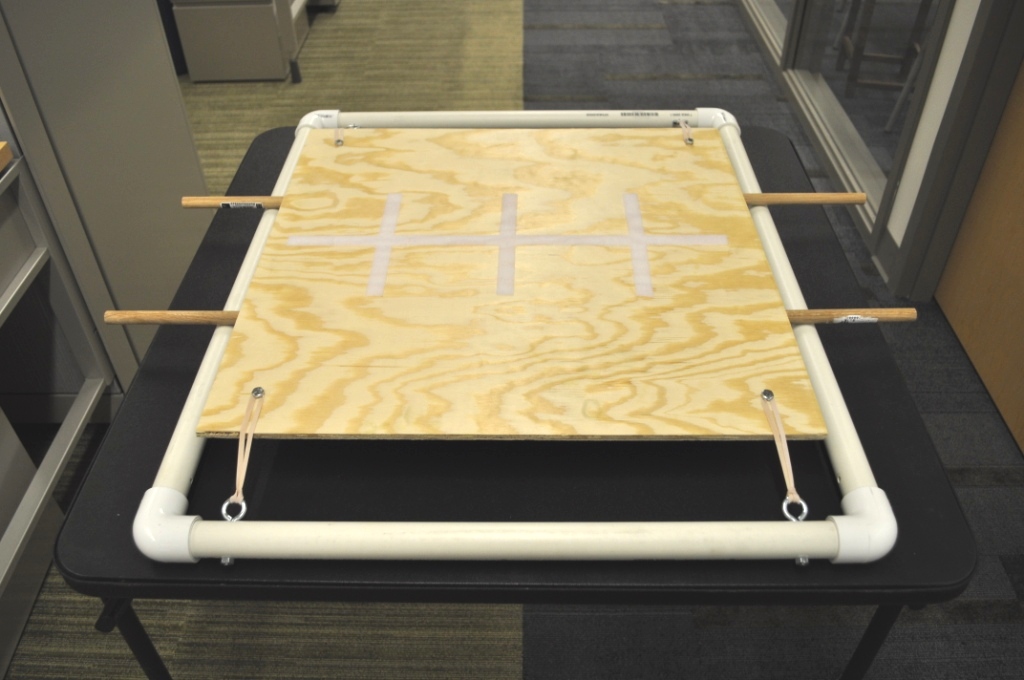
**Testing:**

Testing Crewmembers will run a check-in table for testing. Students who have received approval to proceed with testing will check-in and receive a test time. Assist students in loading and unloading their structures from the shake table. When the groups have built their structure, they are all tested at once.

**Shake Table Options:**

1. Place structure on baking sheet or shake table.
2. Shake the baking sheet or shake table back and forth for a set length of time (the longer the duration the higher the magnitude).
3. After the set time is over, students then make improvements to their structure based on results.
4. NOTE: For impartial shakers, it is best to have a designated shaker to be consistent and use the same time duration for every test. This eliminates bias, and unfair shaking between groups.

**Do-It-Yourself Shake Table Instructions:**

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Finished product based on the shake table instructions.

**Materials:**

* 2 ft. by 2 ft. plywood (or other wood as available, recommend .25 – .5 inch thick)
* 2.5 inch to .625-inch diameter wood dowels, approximately 36 inches long (note: hard woods are more durable, especially if the table is used for heavier items, i.e. liquefaction demos.)
* 1-inch x 10 ft. PVC schedule 40 pipe that will be cut into 2 – 24 inch pipes and 2 – 30 inch pipes.
* 4 – 1 inch PVC schedule 40, 90 degree elbows
* 4.25-inch x 2.5-inch eye bolts with corresponding 1/4 inch nuts
* 4.25-inch x 1 inch hex bolts with .25 inch nuts (Note: hex bolts may be longer or shorter depending on the thickness of the 2 ft. x 2 ft. board utilized.)
* 4 – rubber bands (recommend #64 bands)
* Velcro strips (or other material to hold the structure to the shake table surface)

**Procedure:**

Construct the shake table (this process takes about 1/2 hour):

1. Cut the PVC pipes into two 30 inch and two 24 inch pipes. Drill 5/16 inch holes 2 inches from each end of the 24 inch pipe sections. Join the pipes with the PVC elbows forming a rectangle.
2. Insert the eye bolts into the drilled holes on the 24 inch PVC pipes and fasten with the 1/4 inch nuts.
3. Drill 5/16 inch holes in the four corners of the 2 ft. x 2 ft. plywood. Center the holes 2 inches from each edge. Insert the 1/4 inch hex bolts and corresponding nuts in these holes and fasten. Leave some play so that the rubber bands can be wrapped around the bolts.
4. Place the dowels on top of and perpendicular to the 30 inch PVC pipes. Place the plywood on top of the dowels. Wrap one rubber band around each eye bolt and then around the hex bolt nearest it. Now tighten the hex bolt to a snug fit securing the rubber bands in place.
5. Place the Velcro on the plywood in a configuration such that it is able to hold your structure securely on top during the shaking activity.

**Shake Table Reference:**

Jason Lloyd; NEES EOT (2011), "NEES Teaching Demonstration: Shake Table Assembly," <https://nees.org/resources/2938>.

**Earthquake Engineering and Design Challenge Team Worksheet**

**Directions:**Fill out the sheet paying careful attention to your structure’s essential design qualities, and then bring this paper and your structure to the shake table to start the testing process. Do some preliminary design tests before submitting your structure for official testing.

**Team Name:** ­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Building Name:** ­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**General Structure Design Criteria:**

* Structure should be designed and built to **maximize structure height.**
* Structure should be designed and built to **maximize earthquake resistance.**
* Structure should be designed and built to **minimize structure cost.**
* Structure should be designed and built to **meet footprint requirements.**

**Essential Structural Design Qualities**

**(What important design characteristics does your building have?)**

**Sketch of your team’s structure**

**Material Purchasing Form**

|  |  |  |  |
| --- | --- | --- | --- |
| **Item** | **Item Price**  **(In Dollars)** | **Number**  **Ordered** | **Subtotal Price** |
| Angel Hair pasta (1 oz) | 500,000 |  |  |
| Spaghetti (1 oz) | 1,000,000 |  |  |
| Penne (1 oz) | 1,500,000 |  |  |
| Small Linguine (1 oz) | 2,000,000 |  |  |
| Large Linguine (1 oz) | 2,500,000 |  |  |
| Mini Marshmallow | 500,000 |  |  |
| Large Marshmallow | 750,000 |  |  |
| Spice Drop | 1,000,000 |  |  |
| Gummy Bear | 1,000,000 |  |  |
| Large Gumdrop | 1,250,000 |  |  |
| Orange Slice | 1,120,000 |  |  |
|  |  | **Total Price** |  |

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| Orange Slice | 1,120,000 |  |  |
|  |  | **Total Price** |  |

**Earthquake Engineering and Design Challenge Test Form**

**Test 1: Test Administrator Initials:** \_\_\_\_\_\_\_\_\_\_\_

Total structure cost (in millions of dollars): $\_\_\_\_\_\_\_\_\_\_

Structure meets footprint requirements: yes no

Structure meets minimum height requirements: yes no

Maximum earthquake magnitude the structure resisted: \_\_\_\_\_\_\_\_\_\_

**Engineering Modifications to Meet or Exceed Design Criteria – describe below**

**Test 2: Test Administrator Initials:** \_\_\_\_\_\_\_\_\_\_\_

Total structure cost (in millions of dollars): $\_\_\_\_\_\_\_\_\_\_

Structure meets footprint requirements: yes no

Structure meets minimum height requirements: yes no

Maximum earthquake magnitude the structure resisted: \_\_\_\_\_\_\_\_\_\_

**Engineering Modifications to Meet or Exceed Design Criteria– describe below**

**Earthquake Engineering and Design Challenge Discussion Questions**

**Team Name:** ­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Structure(s) Name(s):** ­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**What type of planning did your team to before you started building? How did this planning help your team successfully complete the challenge?**

**How did the weight and the relative strength of your building materials affect the height of your building?**

**What structural elements of your team’s structure made it earthquake resistant?**

**What was your team’s strategy to keep the cost of your structure as low as possible?**

**What strategies did your team use to work together to complete the challenge?**