Building Earthquake Resistant Structures: Grades 9 to 10

YOUR MISSION

In this activity, you will use marshmallows and toothpicks to design a structure that is capable of resisting the forces experienced during an earthquake. There are two shapes used in designing and strengthening buildings, squares and triangles. In building design, these are called trusses and cross bracing members. You will gain experience in designing a building and learning about the types of energy released by an earthquake.

Watch this video to learn about the world's largest shaker platform.

WHAT'S GOING ON

Engineers are problem solvers and they come up with solutions to problems to better the lives of everyone around them. They do this by coming up with designs, products, technologies, innovations, procedures and systems to make the world a better place.

Civil Engineers are responsible for designing buildings and structures. Two of the more well-known structures in the world are the Eiffel Tower in Paris and the CN Tower in Toronto (Figure 1). Civil Engineers have to make sure they design earthquake-resistant buildings to protect people and property and ensuring the safety of all those who are using them. They can test their designs by simulating the effect natural disasters, such as earthquakes, tsunamis and hurricanes, have on their designs and on the strength of their materials used prior to the actual construction of the buildings.

Figure 1: Eiffel Tower (Paris, France) and CN Tower (Toronto, Canada)

In addition to the vertical force of **gravity**, buildings must also deal with the **horizontal force** of the wind. Most buildings can easily move several feet in either direction, like a swaying tree, without damaging their structure of the building. Engineers need to consider this horizontal movement and how it can possibly affect the people inside the building when coming up with their designs, as the occupants will feel the motion if they are not constructed properly. Each building has what's known as a **natural frequency** which is the **frequency** that the building sways in when it is returning to its original position after any movement.

Inertial forces within the building are created when an outside force tries to make it move, if it is at rest, or changes its rate or direction of motion, if it is already moving. Inertial force takes us back to **Newton's Second Law of Motion**, for when a building shakes it is subject to inertial forces and acts just as if it were a plane, a ship, or an athlete. **Newton's Second Law of Motion** is when the force on an object is equal to its mass times its acceleration.

Acceleration is also a factor in determining the forces on a building, and when acceleration is combined with **duration**, engineers can then consider the impact of earthquake forces over time. In general, several cycles of moderate acceleration, sustained over time, can be much more difficult for a building to withstand than a single much larger peak. Continued shaking weakens a building structure and reduces its resistance to earthquake damage. The **seismic activity** of an earthquake also has an impact; this is the different types, frequency and size of earthquakes that happen over a period of time in a certain area.

Civil engineers also consider the following when coming up with their designs for buildings and structures:

1. **Situational Analysis** - Before something is built, engineers assess the situation and also determine what could go wrong and what the consequences would be. Ignoring the consequences could lead to a design that is unsafe and unreliable. Engineers often undertake a **risk analysis** to determine what are the most probable circumstances and consequences.

2. **Strength** - A stronger, heavier material will generally withstand impacts better than a weaker, lighter material as in the situation of earthquakes. The stronger material will resist deformation under impact. However, it's important to ensure the weight of the material does not affect the flexibility of the structure, in this case. The goal is to determine an optimal solution for increased strength with minimized weight.

3. **Forces** - Buildings create substantial downward vertical forces due to their weight. Safety measures such as damping mechanisms are put in place to absorb external forces created when an earthquake arises. The design should absorb and redistribute forces to minimize the amount of damage to occupants and nearby buildings.

KEY TERMS

Before we get to the actual steps to start the activity, here is a review of the key terms you should know before we start!

- **Gravity:** a force that pulls everything to the centre of the earth.
- **Horizontal force**: a force that acts in a direction parallel to the earth's horizon.
- **Natural frequency:** the frequency in which an object moves, or vibrates, back and forth when it is when pushed by a single force or impulse.
- **Inertial forces:** a force opposite in direction to an accelerating force acting on a body and equal to the product of the accelerating force and mass of the body.
- **Newton's Second Law of Motion:** is when the the force on an object is equal to its mass times its acceleration.
- **Acceleration:** the rate an object changes its velocity (direction of movement on an object or body).
- **Duration**: the time in which something continues to occur.
- **Risk analysis:** engineers often undertake a risk analysis to determine what are the most probable circumstances and consequences of a particular design or project.
- **Seismic activity:** the different types, frequency and size of earthquakes that happen over a period of time in a specific area.

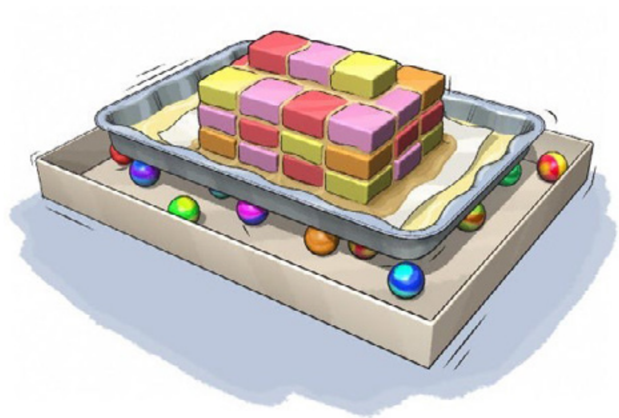
MATERIALS NEEDED

- small box such as a shoebox
- scissors
- small balls such as marbles, ping pong balls, or golf balls (10-20 pcs)
- rubber bands
- tape
- 30 beams (toothpicks or pieces of spaghetti)
- 30 connectors (miniature marshmallows or gumdrops)

WHAT YOU NEED TO DO

Part 1: Make an earthquake simulator

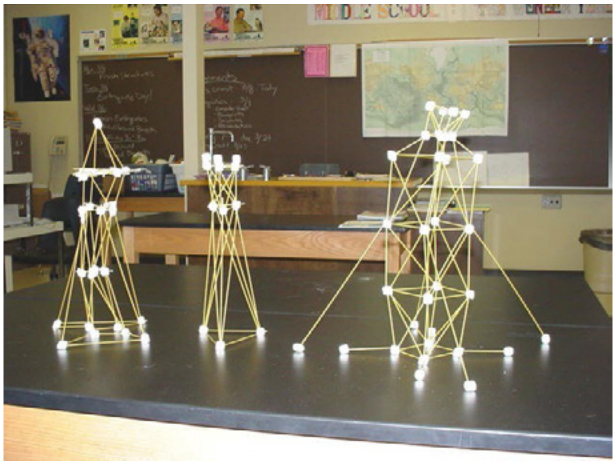
Place a handful of marbles (or other balls) in the shoebox. Trim the lid of the box to create a platform that rests on the marbles. Leave about 1 inch of space between the cut lid and the side of the box. Now you have an earthquake simulator, let's test some structures!



Part 2: Build structures from toothpicks and marshmallows

- Using no more than 30 connectors and 30 beams design a structure that will hold up to an earthquake.
- 2Before you start, make a triangle and a square using the connectors and beams. Press down on the shapes with your fingers.

  What do you notice? Is one shape stronger than the other? Which would be a better choice for constructing an earthquake resistant structure?
- Plan your structure—draw a sketch.
- Build it.
- Test it.



You can use two small pieces of tape to secure your structure to the lid.

- Start with a gentle earthquake. Use your finger to gently shake the lid. Observe how your structure moves.
- Gradually increase the strength. How hard do you need to shake the building to make it fail?
- Note weak points in your structure and think about how you can improve them.
- Make modifications and test again! Was your first design successful at resisting an earthquake? Were you able to improve your design? What changes did you make? How do you think that engineers change their minds between original design and final product? Why are triangles stronger than squares? You can look up tension and compression for answers.

During the shaker test, you can time yourself. You are aiming for the longest recorded time and to have the structure with the least damage for the optimal design.

To extend the challenge, you can:

1. Introduce a minimum height requirement or require the building to hold a certain amount of weight such as 5 pennies. Change the number of connectors or beams allowed. Build with other materials. If you used toothpicks originally try spaghetti next.
2. Download an accelerometer app onto a phone and place it on the lid during the "earthquake" to measure the intensity.

FURTHER REFLECTIONS

1. Which shapes worked best to create a strong structure?
2. Can you think of any other ways to make your building withstand more inertial forces?
3. How can you strengthen your design to limit the horizontal sway or restrict any unnecessary further movement?
4. Take a moment and do some of your own research to find out how the tallest buildings in the world are built to resist factors such as wind turbulence and seismic activity.
5. If you were a civil engineer, what could you do to improve building safety for occupants?

ENGINEERING DESIGN PROCESS

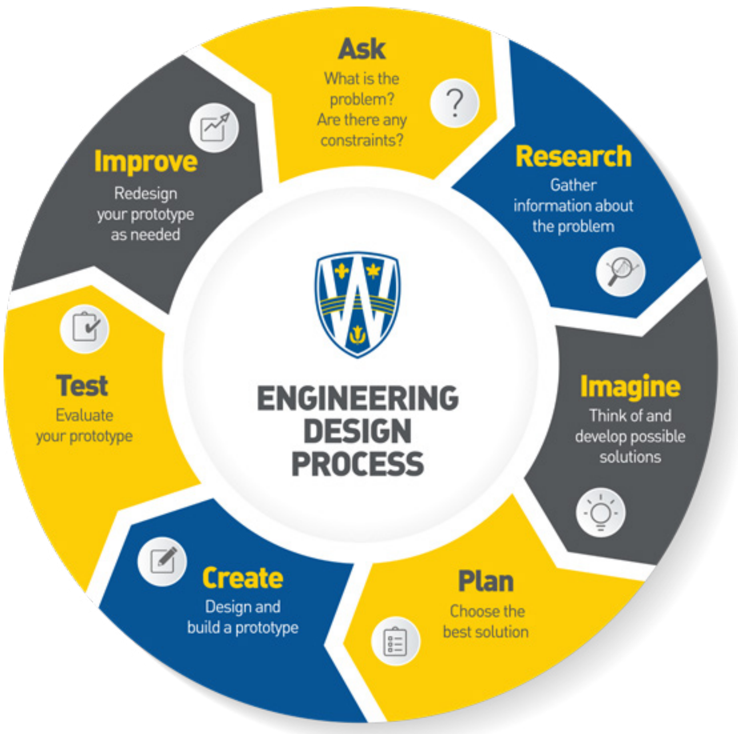
All engineers use the Engineering Design Process to plan, build, test and reflect on their designs and when coming up with solutions to a problem. The steps for the Engineering Design Process are listed below. Use the Engineering Design Process to test and improve your design.

First, think of the problem.

How can you fix it? Think of as many ideas as you can that you think will solve this problem.

It might be helpful to first sketch out your ideas on a piece of paper. Make as many different designs as you can!

Test and compare all of your solutions. Which one solves the problem and works the best?



CURRICULUM UNIT CONNECTIONS

Grades 9 to 10 – Earth and Space Science – Climate Change

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