

## I. Lesson 3: Seismic Solutions

What makes a building safer during an earthquake?

How does the location of load affect the earthquake safety of a building?

**Lesson Description:** During this lesson, students will be told that their skyscraper will be built near a fault line. As a result students have to design their skyscraper to be safe during an earthquake. Students will determine the best location for the building load so that roof drift is limited during an earthquake.

**Grade Levels:** 4-12

### Education Outcomes:

Students will determine, explain and justify:

- the designs and materials that create safer buildings during earthquakes.
- The location of most of a building load in order to reduce the amount of roof drift during an earthquake.

### Education Standards:

**Met:** (Note: bolded parts of the standards are fully met by this lesson)

#### *Next Generation Science Standards (NGSS)*

**3-5ETS1-1.** Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

**MS-ETS1-3:** Analyze data from tests to determine similarities and differences among several design solution to identify the best characteristics of each that can be combined into a new to better meet the criteria for success.

**Addressed:** (The following standards are practiced in this lesson but are not explicitly taught and assessed)

3-5-ETS1-3: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify a model or prototype that can be improved.

4-ESS3-2: Generate and compare multiple solutions to reduce the impacts of natural Earth process on humans.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

#### *NGSS Cross-Cutting Concepts:*

*Systems and System Models:* Defining the system under study-specifying its boundaries and making an explicit model of that system-provides tools for understanding and testing ideas that are applicable throughout science and engineering.

#### *NGSS Science and Engineering Practices (SEP)*

*Developing and Using Models:* Makes use of models and simulations to analyze systems to identify flaws that might occur or to test possible solutions to a new problem.

#### *Common Core Standards:*

(4-8) CCSS.ELA-Literacy.SL.4.4, 5.4, 6.4, 7.4, 8.4: Present claims and findings, sequencing ideas logically and using pertinent descriptions, facts, and details to accentuate main ideas or themes; use appropriate eye contact, adequate volume, and clear pronunciation.

(6-8) CCSS.ELA-Literacy.RST.6-8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

## II. Advanced Prep & Set-Up for Lesson

### Skyscraper and Load Design Challenges

#### Materials

*NOTE: The following materials are suggestions of the types of materials needed for the lesson. Feel free to modify the following list to easily accessible materials. In general, you will need:*

- Adhesives and attaching materials (glue, tape, rubber bands, paper clips etc.)
- A variety of wires (insulated and metal and pipe cleaner-type materials)
- Different types of wood and thicknesses of paper and plastic
- Other recycled materials (e.g. plastic bottles and containers, cereal boxes, etc.)
- Weights that can be used to load test materials (we suggest ½-pint water bottles filled with sand. You will need 3 per group. Other objects that weigh approximately 1 pound can also be used).
- Team journals from the previous lesson.

#### Sample Materials

- Craft sticks
- Foil
- Wire (Insulated, Metal) – variety of thickness is encouraged
- Pipe cleaners
- Paper (any type but medium thickness paper works best).
- Foam sheets
- Straws
- Recycled plastic bottles/containers
- Coffee Stir Straws
- Rubber bands (multiple sizes)

- Paper clips
- String
- Masking tape
- Bendable plastic (e.g. transparency sheets). *This material is optional but is recommended for grades 4 and 5.*
- ½-pint water bottles filled with sand (3 per group). *Other objects that weigh approximately 1 pound can also be used).*

#### Facilitator Note:

Suggested length of building materials is about 8 inches (the length of the average plastic drinking straw), so that materials are not so long that it makes it easy for students to meet the 2 foot height constraint of the design challenge.

### Shake Table and Roof Drift Test

#### Materials

- Cardboard (Any type. Needs to be cut into 6 inch x 6 inch pieces. One to three pieces per group).
- Pencil (one per group)
- Blank white paper (one sheet per group)
- Ruler (one per group)
- Tape
- Rubber bouncing ball (medium size) - *optional*
- Plastic Gatorade bottle caps (3-5) – *optional*
- Large rubber bands – medium thickness (2) - *Optional*
- Two hand clamps to attach the buildings to the shake table OR thumbtacks (4 per group) - *optional*

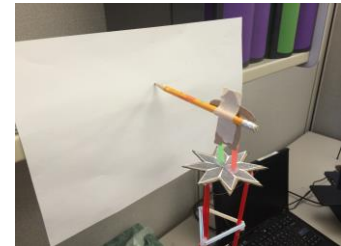
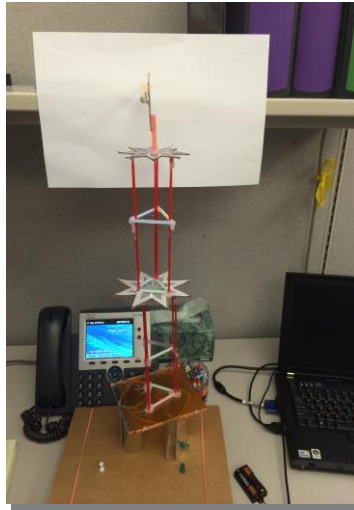
#### Station Set-up

Set up one station for each group as follows:

- Place a variety of materials at each group's station (5 per station).
- Place 3-5 sand-filled ½-pint water bottles at each station (or other 1-pound weights).

### Roof Drift (Building Roof drift) Test Set-Up

- To measure roof drift, tape a piece of white paper to the wall at the approximate height of the highest point of a model skyscraper.
- Students will have to tape a pencil to the top of their building so that when it shakes it makes a marking on the white paper.
- Measuring the length of the line the pencil makes while shaking, will give a roof drift measurement for that building.
- This set-up is illustrated in the pictures to the right.



### Shake Table Set Up (optional)

- You can construct a shake table in a variety of ways. The following link is a great example of a simple-to-construct and use shake table:
  - <http://www.raftbayarea.org/ideas/Shake%20Table.pdf>
  - We suggest adding a Pull Tab and Magnitude Meter to the RAFT shake table to allow for controlled earthquakes. You can find the template for this on page 21 of Museum of Science, Boston's Engineering Adventures Earthquake unit available at: <http://eie.org/engineering-adventures/curriculum-units/shake-things>
- You will need to add anchors to your shake table so that you can attach the buildings to the shake table. The picture below is an example of how you can add anchors to your shake table. You can also use a binder clip to hold down one side of the base.



#### Facilitator Note:

The shake table is optional but recommended. If you cannot use a shake table, you will need to test the structures by manually shaking each structure.

You can also have students design a part of the structure that attaches to the shake table using hand clamps. Hand clamps would limit the amount of building movement on the shake table.

### Load Bearing Test Station (optional)

- Students may want to do some material testing. As such you may want to include a load bearing test station.
- See Lesson 2 Section II Load Bearing Test Set Up for this station.

### III. Lesson 3: Seismic Solutions Lesson Guide

**Guiding Questions:** What makes a building safer during an earthquake? How does the location of load affect the earthquake safety of a building?

#### A. Lesson Introduction (15 minutes)

1. Lead a discussion that draws on students' prior knowledge of earthquakes and engineering for earthquakes. Sample questions might include:
  - How do engineers design buildings to make them safer during an earthquake?
  - While students brainstorm these ideas, record their ideas on the whiteboard/ chalkboard/ overhead/ computer/ paper.
2. Discuss building **roof drift**. Some of the talking points you might discuss include:
  - **Roof drift** refers to the movement of the top of a building compared to its base, which can occur during an earthquake.
  - It is important for a building to have some roof drift during an earthquake to give it some elasticity during an earthquake, because rigidity (stiffness) can cause severe structural damage during a large earthquake.
  - Too much roof drift is not desirable, because it can make the people in the building sick or it may cause the building to hit other buildings next to it.
  - Show the following video that shows a building roof drifting during the 2011 Japan Earthquake:
    - <http://www.youtube.com/watch?v=jBPbJtGOfiE>
  - Show a model building on a shake table and show how you plan on measuring roof drift during the shake table tests.
3. Introduce the vocabulary term: **live load**. Some information to discuss, might include:
  - Review the meaning of **building load** from the last lesson (the total mass that a structure must support including the structure itself and everything in it).
  - The **live load** is the people, furniture and other goods that a structure must support.
  - In this challenge, we will need to design structures that support and protect our live load.
4. Introduce the challenge. Some of the information you might share includes:
  - Students will continue to build and design their model skyscraper.
  - However, there is one change. We have just found out that our building site is near a fault line. This means that we have to design our buildings to be safer during an earthquake.
  - Students are encouraged to perform material load tests on any materials they want to use. *This is not required but recommended.*
5. Discuss journals as an engineering tool. The following are suggested questions and information that you might include in this discussion.
  - In what ways have you already used your journals as engineers? What has been most helpful to you?
  - Is there additional information that you wish you had recorded in your journal? Why?
  - Some of the information that engineers document very carefully include:
    - Sketches and photos of design ideas
    - Data from materials or performance tests
    - Careful documentation of the variables that are changed in each design (of materials, shapes, sizes, load placement, etc.)
    - Documentation of both successful and unsuccessful designs and failure points—so that they can be remedied in future designs
    - Budget for each design
    - Because we will be scaling up our designs for the culminating Tech Challenge, it will be particularly important to document everything so you can replicate successes and correct for failures.
6. As students consider the next challenge, have them discuss and agree with their groups what they will document during this next challenge. Give them some time to set up their journal before beginning the challenge.

**Facilitator Note:**

Please refer to The Tech's Innovation Process PDF for an overall guide on how The Tech views this process and what we believe can cultivate innovation in all ages.

## B. Safe Skyscraper Design Challenge (50 – 60 minutes)

1. Introduce the Safe Skyscraper Challenge.

### Challenge:

Design a model of a skyscraper that has limited roof drift in an earthquake.

### Criteria (Design Requirements):

- The building must be built on a 6-inch x 6-inch base.
- Total height of the building model must be at least 2 feet (24 inches) high.
- Must have at least two floors of usable space where you can place two live loads represented by two ½-pint water bottles.
- Your live loads must be free to move and must be visible from all sides.
- The structure may not have exterior walls. The internal structure must be visible to view the construction details.
- The building must be able to support and attach to a pencil at its tallest height.
- The building must have a way to attach to the shake table (if a shake table is being used)

### A building is successful if...

- The building must still be standing after 30 seconds of shaking.
- No pieces have fallen off the building after 3 earthquakes (including the load).
- Roof drifts no more than 2 inches (measured by the length of the pencil marking)
- The building returns to its original position.

### Constraints (Design Limitations):

- Schedule: You have 30 minutes to complete this challenge.
- Budget: Student can only use the materials given to them.
- The building roof cannot drift more than 2 inches (measured by the length of the pencil marking)
- **Optional:** Instructor can restrict the amount of glue or adhesive use and/or choose to have students create a budget for materials (See the Facilitator Note)

### **Facilitator Note:**

These are sample parameters. You can adjust them to the materials you have on hand and to the level of your students. For example, you could lower the height requirement. Or you could start them with one load above 4 inches and then after a whole-class test, ask them to add a second floor for a second load.

### **Facilitator Note:**

If you are using a pull tab on your shake table, you can change the testing measure of success to “must still be standing after 3 progressively strong earthquakes.”

### **Facilitator Note:**

One way to have students budget is to give them a set amount of tickets for their materials. Each material costs a different amount of tickets. Stronger, more durable materials cost more, while weaker, harder to use materials cost less. Students can record these budgets in their engineering journals.

2. While the students work on the challenge, walk around the room and ask the following questions to see where students are in relation to the learning objectives/outcomes:

- What types of shapes are you putting into your building design? Why?
- What types of materials are you using? Why?
- What is the overall structure of your building going to look like? Why did you pick this design?
- Are you going to make your building artistic? How? Why or why not?

3. It is recommended to have multiple shake stations. It is also recommended that one group tests at a time. As groups test, discuss the following with the group.

- What did you notice?
- What are some of the limitations of your design? What specifically failed during the shake test? How? Where? How can you improve your design?
- What designs are most successful? Why do you think so? How do you know?

### **Facilitator Note:**

To make the challenge more difficult, conduct a shake test in which you shake the building in an uneven way. This makes the challenge more realistic because during earthquakes shaking is typically uneven.

During testing, talk about failure and how it is an integral part of the design process. Discuss how failure leads to stronger and safer designs because it shows engineers the weaknesses in their designs. During this discussion, have students reflect on how they responded to their own failures and help them change how they look at failure.

4. Do a whole-class test of each design and share out the following debrief questions as a group.
  - Which building designs were the most successful? Why?
  - Point out groups that used diagonal supports (**trusses** or **cross bracing**). Why did students add these? How did it affect their structure? Why? (Trusses make structures stronger because they spread out the forces created by the load. Cross bracing helps prevent a square structure from folding or sheering The following video demonstrates this concept:
    - [http://www.iris.edu/hq/programs/education\\_and\\_outreach/videos#M](http://www.iris.edu/hq/programs/education_and_outreach/videos#M)
  - Discuss building shapes and construction materials used in student design. Discuss what type of designs created a building with less roof drift (Triangles are stronger because the diagonals spread out the forces created by the load).

### C. Adding Load Design Challenge (30 - 40 minutes)

1. Introduce new constraints (the addition of loads). Suggested questions and information for this discussion include:
  - Review that **building load** is the force that a structure needs to support including the mass of the structure itself and everything it contains.
  - Where do you think the majority of a building's load needs to go in order to make it safe during an earthquake? Why?
  - While students brainstorm these ideas, feel free to write down the ideas on the whiteboard/ chalkboard/ overhead/ computer/ paper.
2. Present the following design challenge:

#### Challenge:

Locate the safest place to place a load in your building to limit the roof drift of the building during an earthquake.

#### Criteria:

- Must use skyscraper from the previous design challenge
- Must have at least two locations where live loads (1/2-pint water bottles filled with sand) can be freely placed and can be seen from all directions.
- The structure may not have exterior walls. The internal structure must be visible to view the construction details.

#### A building is successful if...

- The building must still be standing after 30 seconds of shaking.
- No pieces have fallen off the building after 30 seconds of shaking (including the live load).
- Roof doesn't drift more than 2 inches (measured by the length of the pencil marking)
- The building returns to its original position.

#### Constraints

- Student can only use the materials given to them.
- The building roof cannot drift more than 1 inch (measured by the length of the pencil marking)
- **Optional:** Instructor can restrict the amount of glue or adhesive use and/or choose to have students create a budget for materials.

#### **Facilitator Note:**

There is the possibility that students will design **seismic dampeners** to limit the roof drift of their buildings with loads. If this is the case, discuss seismic dampeners and have students compare their designs to the building designs with seismic dampeners. Have them reflect on and discuss how they could create a dampener to make their building design better.

A **seismic dampener** is a device or building add-on that dampens the effect of the shaking during an earthquake. An example is a large weight attached to hydraulic arms that are designed to move when the building shakes.

This video shows the Taipei 101 seismic dampener working during an earthquake: [http://www.youtube.com/watch?v=ohKgE\\_mwMmo](http://www.youtube.com/watch?v=ohKgE_mwMmo)

For more information on the Taipei 101 seismic dampener, see Appendix A.

3. Test and share-out individual designs. The following are examples of questions you might discuss during the share-out.
  - Where is the best location for the building's load? Why do you think this?
  - If you place the load all the way at the top of the building, what happens to the building's roof drift? Why do think this happens?
  - If you place the load closer to the bottom of the building, is the building roof drift more or less than if the load was closer to the top? Why do you think this?
  - Do you think there are any other design components you could add to the building to make the building safer during an earthquake?
  
4. Test all models together in a "city block" to see how building roof drift affects other buildings during an earthquake. The following are suggested steps and questions for this activity.
  - Have students place their buildings next to each other on a table. Shake the table for a count of 10 and see how the building's roof drift next to each other.
  - What happened? What did you notice?
  - Were there some buildings that were affected by other buildings? How?
  - What allowed other buildings to withstand the earthquake?
  - When there are many buildings next to each other, why it is important for an engineer to limit the amount the building roof drifts during an earthquake? (To avoid crashing into other buildings)
  
5. Share out the following debrief questions as a group:
  - Review the initial brainstorm from the beginning of the class. Ask students to compare their designs to that class brainstorm.
  - Which designs best withstood earthquakes? Why?
  - What one or two improvements could you make to make your building even safer during an earthquake?

**Facilitator Note:**

In general, the lower the **center of gravity** of a structure, the more stable and balanced it will be and the less likely it will be to tip over or sway.

**Center of gravity** is the point in an object where gravity is concentrated—where the mass/weight is evenly dispersed and all sides are in balance.

## IV. Appendices

### A. Vocabulary and Background Information

*The following is the start of a suggested list of words to discuss as you read and discuss with students.*

**Base isolation** – This is when engineers design the bases of the building to sustain limited damage during an earthquake. Buildings are constructed on top of moving bearings that move with the ground. This in turn limits the amount of work the structure does in order to limit movement and as a result limits the amount of damage done to a structure during an earthquake. Below are two videos that show and explain how base isolators work.

- <https://www.youtube.com/watch?v=Nc4JcWn6nYs>
- <https://www.youtube.com/watch?v=J2eHCxB-K7s>

**Building flexibility** – Buildings are designed to be flexible during earthquakes. This is so that they do not sustain irreversible damage during heavy shaking. A lot of buildings are built with replaceable “shocks” that are designed to break and absorb most of the energy during violent shaking. Below is a link that explains this concept.

- <http://www.livescience.com/5680-flexible-building-survives-powerful-test-earthquake.html>

**Building load** – The total mass that structure needs to support. This includes the mass of the structure, everything in it and environmental forces (wind, rain, snow, ice etc.)

**Center of gravity** – the point in an object at which gravity is concentrated. Where gravity is uniform, this is where the mass or weight of an object is evenly dispersed such that all sides are in balance.

**Cross bracing** – When two supports are constructed to cross each other diagonally. This is to increase the diagonal support of a load. Crossing bracing is used in all building designs and is considered the most effective way to disperse and support building loads.

**Crumple zone** – These are parts of a building’s foundation that are designed to crumple during an earthquake. They absorb the majority of the energy from shaking during an earthquake. These sections are designed like a car’s crumple design. Below are links that explain building crumple zones,

- <http://auto.howstuffworks.com/car-driving-safety/safety-regulatory-devices/crumple-zone.htm>
- <http://www.smartplanet.com/blog/smart-takes/engineers-design-self-righting-buildings-to-withstand-70-magnitude-earthquakes/>

**Live load** – The live load is the people, furniture and other goods that a structure must support.

**Load bearing** - The load bearing part of a structure is the section of the structure that supports most of the weight of a structure.

**Load bearing test** – A test where you determine a material’s or structure’s ability to bear different loads.

**Roof drift** –The movement of the top of a building compared to its base, which can occur during an earthquake. Buildings are typically designed to have a little roof drift, because rigidity (stiffness) can cause severe structural damage during a large earthquake (kind of like a Popsicle stick snapping). If the building roof drifts too much during an earthquake people in the building can get sick, the building can sustain severe structural damage (when materials reach their maximum elastic moment) or cause the building to hit other buildings next to it (as in the case of cities that are really densely populated). Below is a video of buildings experiencing roof drift during the 2011 Japan Earthquake.

- <https://www.youtube.com/watch?v=2N4rVjsuFOE>

**Seismic dampener** - A device or building add-on that dampens the effect of the shaking during an earthquake. An example is a large weight attached to hydraulic arms that are designed to move when the building shakes. For a real life example look up the seismic dampener in Taipei 101.



- This video shows the Taipei 101 seismic dampener working during an earthquake:  
[http://www.youtube.com/watch?v=ohKqE\\_mwMmo](http://www.youtube.com/watch?v=ohKqE_mwMmo)
- For more information on the Taipei 101 seismic dampener, please go to the following link:  
<http://geekologie.com/2008/06/the-730-ton-ball-that-keeps-th.php>

**Strengths of shapes** – The strength of the shape depends on the material and its position in relation to the load. Generally, triangles or three-dimensional rectangles or cylinders are able to bear the most loads. This is because the shapes distribute the force of the load more evenly and efficiently. This is why you see lots of triangles in bridges or vertical scaffolding of a building. It is also why you see support columns of a building that are cylindrical or rectangular in shape.

**Truss** – A type of engineering support. It is usually built in the form of a triangle. Due to their structural strength, trusses are used to support large loads over long spans. You will find trusses in building designs. An example of a truss bridge is the San Francisco segment of the Bay Bridge in California. Below is a link that show pictures of different structures that use truss supports.

- <http://science.howstuffworks.com/engineering/civil/bridge4.htm>

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