I. Lesson 4: Building Big

Will a scaled up version of our building perform the same way in an earthquake?
How can we design a building to withstand the forces of liquefaction during an earthquake?

Lesson Description: During this lesson students will use hardware materials (wood, thick cardboard, nails, screws, drills, hammers etc.) to scale up their models of the skyscrapers they designed in lesson 3 in preparation for the culminating Tech Challenge. Students will measure roof drift (sway) and structural stability as indicators of the safety of their building during an earthquake. As an extension, students will "retrofit" their buildings to withstand an earthquake in a liquefaction zone.

Grade Levels: 4-12

Education Outcomes:

Students will:

- Create a scaled up version of their model buildings.
- Determine, explain and justify the types of building modifications that prevent building collapse during an earthquake in a liquefaction zone.

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 solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Addressed: (The following standards are practiced in this lesson but are not explicitly taught and assessed)
Next Generation Science Standards (NGSS)
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.

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

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

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:
Scale, Proportion and Quantity – In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

NGSS Science and Engineering Practices (SEP)
Analyzing and Interpreting Data – Investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria.

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

Scaled Up Skyscraper Design Challenge Materials

> Facilitator Note:
> Having a variety of materials is necessary to give students more flexibility in their designs. A variety of thickness and lengths of wood and/or corrugated cardboard work best for this lesson.

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, nails, screws etc.)
- Different types of corrugated cardboard, wood, plastic or sheet metal
- Weights that can be used to load test materials (Suggested weight is ½ pint water bottle filled with sand. You will need 5 per group. Other objects approximately 1 pound in weight can also be used).
- Team journals from the previous lesson.

Sample Materials

- Safety goggles/glasses
- Wood (wooden dowels approx. ¼ - ½ in. diameter, 7-8 in. squares, 1-2 in cubes, rectangular pieces 8 in x 10 in, popsicle sticks)
- Corrugated cardboard (approximately 3/16th in of an inch thick cut into 10 in x 10 in or 10 in x 12 in pieces)
- Foam core (3/16th in of an inch thick cut into 10 in x 10 in or 10 in x 12 in pieces)
- Screws (variety of sizes so that they can attach the different types of wood, foam core or cardboard)
- Drill bits that match the size of the screws.
- Nails (variety of sizes so that they can attach the different types of wood, foam core or cardboard)
- Hand saws (one per supervised group)
- Rulers (one per group)
- Protractors (one per group)
- Pencils
- Glue guns (one per group)
- Hammer (one per group)
- 1 power drill
- One hand drill per group
- Masking tape
- String
- Clamps to hold materials to a table for construction and shake table for testing (at least 4)
- Structures from lesson 3 challenge

Load Bearing Test Station (optional)

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

Shake table materials and set-up

Materials

- Cardboard (Any type. Needs to be cut into 6 inch x 6 inch pieces. One piece 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 (case of 500) - *optional*
- For a details on building a large scale shake table See The Tech Challenge 2015 Rig plans http://thetechchallenge.thetech.org/challenge/Test%20Rig Building plans will be posted on Oct. 25, 2014.

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 5 sand-filled water bottles at each station (or other 2-pound weights).

Roof Drift Test Materials and 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.

> Facilitator Note:
> This is the same set up found in Lesson 3, Section II, Shake Table and Roof Drift Test Set-up. Please note that the shake table rig in this challenge is larger and more powerful.

Designing for Liquefaction Challenge Materials and Set-Up

Materials

- 12 quart dish tub (any size that can fit the foundation of 8 inch x 8 inch building)
- Tanbark (enough to fill the tub half way).

Set-up

- Fill the dish tub half full with tan bark.
- Place the dish tub on to the shake table.

Alternative Liquefaction Challenge Materials and Set-Up

Materials

- 12 quart dish tub (any size that can fit the foundation of 8 inch x 8 inch building).
- Sand (enough to fill the dish tub 1/2 way).
- Water (enough water to fill the dish tub so that there is 2 inches of water above the sand line).

> Facilitator Note:
> Using this liquefaction shake table is messy but useful. The shaking will cause the water in the soil to rise to the surface and cause the building to sink and/or slide around. This is what happens during actual liquefaction.

Set-up

- Fill the dish tub half full with sand.
- Pour the water into the dish tub so that you get a ½ inch of standing water at the top of the sand layer.
- Gently shake the tub for about 45 seconds and then let the tub sit for 3 minutes.
- Decant (carefully drain) the top layer of water out of the tub.
- Place the dish tub on to the shake table.


III. Building Big Lesson Guide

Guiding Questions: Will a scaled up version of our building perform the same way in an earthquake? How can we design a building to withstand the forces of liquefaction during an earthquake?

A. Lesson Introduction (15 – 20 Minutes)

1. Discuss scale and building to scale. Some talking points and questions might include:
   - A scale model is usually a smaller model of an actual building. This model is proportionate to the actual building size. For example before building a soccer stadium, engineers could design a model that has parts that are 1/100th the size of the actual stadium.
   - Engineers may test models of different sizes. For example, they might start with a very small model and then build a larger model. Why might they do this?
   - Do you think models of different sizes will behave exactly the same way? Why or why not?
   - While models help to give us an idea of how one material, shape, etc. might perform compared to another, it is impossible to fully model the exact conditions of the final building.
   - What variables can change as you scale up? (Larger structures have more mass/ have to support more building load. The amount of shaking of an actual earthquake can have more devastating effects on more massive structures. Materials may not perform the same when supporting these larger masses.)

> **Facilitator Note:**
> Scaling up is an important skill to prepare for the larger culminating Tech Challenge. It also gives students a great sense of accomplishment and self confidence when they learn how to build with tools.

2. Introduce the Scaled Up Skyscraper Design Challenge. Some of the information you might share could include:
   - Students will "scale-up" their buildings. Scaling up means that students will construct larger versions of their buildings.
   - This will help them as they prepare for the larger culminating Tech Challenge.

3. Go over safety protocols and testing procedures.
   - When using tools or glue guns, it is really important to stress safety and teach proper handling techniques. (See Facilitator Note.)

4. Go over shake table testing procedures.
   - We recommend having one or more adult-supervised testing stations where one group can test at a time.
   - Make sure to change the location of the load (3-5 ½-pint water bottles filled with sand) during the shake test. Test the building with even and uneven shaking for each load.

> **Facilitator Note:**
> For power tools and saws, we recommend having an adult-supervised station, where students can work one-on-one with an adult to learn to use these tools safely. Students should wear safety goggles and tie back long hair that can get caught in power tools. Reinforce the importance of not touching glue gun tips. Have ice on hand.

5. Discuss the importance of journaling during this lesson.

- Have students 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.
- For journaling discussion points see Lesson 2, Section III.A.5.
- *Math Option:* Have students perform scale/ratio calculations in their journals. For example, If 1 centimeter on their existing structure is scaled up to 1 inch on their new structure, what would be the measurements of their new version in terms of length, width, depth, etc? (See Lesson 5 for a full lesson on scaling up.)

Scaled Up Skyscraper Design Challenge (110 – 120 Minutes)

1. Introduce Scaled Up Skyscraper Design Challenge.
   Challenge:
   Create scaled up/larger versions of the top part of the buildings built in Lesson 3. (Everything except the base)

   Criteria
   - The building must be between 3 – 4 feet tall.
   - The building must have at least three locations to place a load that is the size of three ½-pint water bottles.
   - The loads need to be located between 2 and 4 feet high.
   - The building must be able to attach to the shake table.

   A building is successful if…
   - The building must still be standing after 30 seconds.
   - No pieces have fallen off the building after 30 seconds (including the load).
   - Roof cannot drift more than 2 inches (measured by the length of the pencil marking)
   - The building returns to its original position.

   Constraints
   - Budget: Student can only use the materials given to them.
   - The building cannot experience roof drift of more than 2 inches (full length of pencil marking).
   - *Optional:* Instructor can restrict the amount of glue or adhesive use and/or choose to have students create a budget for materials.

2. While students are building their buildings, ask any/all of the following questions:
   - What materials are you using? Why?
   - What type of modifications are you making to ensure your building is safe during an earthquake?
   - How do these materials compare to past lessons? What are some of the advantages and disadvantages of these materials compared to previous materials we've used?

3. As groups test, discuss the following with the group:
   - How does your scaled up version of your model compare to your previous version? What was the same in terms of how each performed? What was different? Why do you think this is?
   - How does the location of load change the way the roof drifts? Does the roof drift change with the different types of shaking?
   - When the shaking is uneven, how does this affect roof drift? What are some things you could do to limit the roof drift when shaking is uneven?
   - When the shaking is even, how does this affect roof drift? What are some things you could do to limit the roof drift when shaking is even?

> Facilitator Note:
> The larger versions should be harder to stabilize due to higher **center of gravity**. Structural stability in relation to the location of the load depends on the type of shaking that occurs during an earthquake. Typically, loads that are higher up will cause more roof drift when shaking is even. This can be compensated for by increasing the mass of the bottom of the structure so that the structure itself has a lower **center of gravity**.
>
> **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.

4. When students are done building, lead a debrief based on the following questions:
   - What are some strengths of your building designs? How do you know?
   - What are some areas you could work on to improve your building designs? Why?
   - What were some failure points in your design? How can you improve these parts of your design?
   - When shaking is uneven, where is the best place to put the load for the building?
   - When shaking is even, where is the best place to put the load? Why?

B. Designing for Liquefaction Challenge (50 – 60 minutes)

1. Discuss liquefaction. Some talking points might include:
   - **Liquefaction** is when the soil liquefies. This means that the soil starts acting like a liquid. This happens during a powerful earthquake.
   - When the soil liquefies it causes the ground to sink or move a lot. As a result liquefaction can cause roads to sink or buildings to collapse.

2. Show the following videos that illustrate liquefaction:
   - http://geology.com/usgs/liquefaction/ (Soil Liquefaction with Dr. Ellen Rathje)
   - http://www.youtube.com/watch?v=I3hJK1BoRak

3. Discuss retrofitting. Some talking points might include:
   - **Seismic retrofitting** is when engineers make modifications to an existing building to make it safer.
   - An example of retrofitting would be when engineers added cross-bracing on the outside of older dorm buildings at UC Berkley. (See image: http://hazardmitigation.calema.ca.gov/hazard_mitigation_success_stories/seismic_retrofitting)
   - Since the 1989 earthquake, engineers have retrofitted thousands of buildings in the bay area to make them safer and more likely to withstand a powerful earthquake.

4. With the class, brainstorm some ways engineers might retrofit buildings to withstand liquefaction. While students brainstorm these ideas, feel free to write down the ideas on the whiteboard/chalkboard/overhead/computer/paper.

5. Present the Liquefaction Design Challenge:

   <u>Challenge</u>
   It has just been discovered that students are constructing their skyscrapers in a liquefaction zone. As a result students must retrofit their buildings to be safe in a liquefaction zone.

   <u>Criteria</u>
   - The building must support a load of three ½-pint water bottles (3 pounds in total)
   - Must use the same building from the Scaled Up Skyscraper design challenge
   - All other criteria and constraints from the previous challenges apply to this challenge. These are listed below:
     - The building must be between 3 – 4 feet tall.
     - The building must have at least three locations to place a load that is the size of three ½-pint water bottles.
     - The loads need to be located between 2 and 4 feet high.
     - The building must be able to attach to the shake table.
     - The building must withstand at least 30 seconds on the shake table without structural damage.

   <u>A building is successful if…</u>
   - The building is still standing after 30 seconds.
   - No pieces have fallen off the building after 30 seconds (including the load).
   - Roof does not drift more than 2 inches (measured by the length of the pencil marking)
   - The building returns to its original position.

   <u>Constraints</u>
   - Students cannot take apart their buildings. They can only add to the building for this challenge.

> **Facilitator Note:**
> You might get a better effect from shaking the liquefaction tray manually. It is easier to get uneven shaking and the force needed to make the sand liquefy. With vigorous, uneven shaking the sand will begin to separate, crack and sink. This is an accurate representation of liquefaction during an earthquake.

6. While students are retrofitting, ask any/all of the following questions
   - Why are you adding this part to your building? Why do you think it will help?
   - What might happen to your building in a liquefaction zone? How will you prevent this from happening?

7. Test and share-out individual designs. The following are examples of questions you might discuss during the share-out.
   - What did you notice about how your building behaved in the liquefaction zone? How was this different from how your building performed on a solid surface?
   - Did your building survive the liquefaction zone? Why or why not?
   - What are some things you could do to your building to make it even safer during liquefaction?

8. Share building designs that engineers actually use to make buildings safer during liquefaction. Below are some links with examples of building designs that built to withstand liquefaction.
   - http://www.ce.washington.edu/~liquefaction/html/how/resistantstructures.html
   - http://www.betterground.com/index.php?option=com_content&view=article&id=172&Itemid=179

9. Have students reflect and share out on their designs. Have students share how their designs compare to actual building designs. Some possible questions to ask are:
   - Do you think your building might perform better in an earthquake than actual building designs? Explain.
   - What modifications might you make to your design to help it perform better in a liquefaction zone?

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.

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.

Liquefaction – When soil with a higher moisture content liquefies during a strong earthquake. This happens because the shaking from the earthquake creates more space for water and other fluids to fill the gaps in the soil. This decreases the strength of the soil. Liquefaction usually causes a sinking effect on the soil. As a result it causes the ground and whatever is built on it to sink. This phenomenon is explained in more detail at:
http://www.ce.washington.edu/~liquefaction/html/what/what1.html

Liquefaction resistance structures – Two methods of resisting liquefaction include building a shallow foundation mat and constructing piles embedded deep in the ground. The first method involves constructing a shallow foundation mat for the building to slide on. The mat should be designed to support the building and limit its movement when the soil liquefies. In this design, parts of the structural foundation are built to have strong attachments to adjacent parts. This is also to limit movement during liquefaction. The second method involves constructing a building on piles that are embedded deeper in the ground. These piles are able to flex with the movement of the soils and are rooted in more stable soils deeper in the ground. One drawback to this design is that if liquefaction bends the piles more than expected, the foundation can sink and cause the collapse of the building.

Seismic Retrofitting –A seismic retrofit is when a building is modified to be safer during an earthquake by adding something to the existing structure. Below are some links that give more information and some examples of seismic retrofitting:

- http://en.wikipedia.org/wiki/Seismic_retrofit
- http://www.earthquakesafety.com/earthquake-retrofitting.html
- http://www.oregonlive.com/portland/index.ssf/2011/04/japanese_quake_spurs_demand_fo.html
- http://hazardmitigation.calema.ca.gov/hazard_mitigation_success_stories/seismic_retrofitting

B. References

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2. "You can retrofit your home." *Earthquake Retrofitting, Foundation Bolting & Cripple Wall Bracing*. N.p., n.d. Web. 25 July 2014. <http://www.earthquakesafety.com/earthquake-retrofitting.html>.

3. "Japanese quake prompts demand for seismic retrofits in Oregon." *OregonLive.com*. N.p., n.d. Web. 25 July 2014. <http://www.oregonlive.com/portland/index.ssf/2011/04/japanese_quake_spurs_demand_fo.html>.

4. "UC Berkeley Seismically Retrofits Buildings to Reduce Potential Earthquake Damage." *Hazard Mitigation Web Portal*. N.p., n.d. Web. 25 July 2014. <http://hazardmitigation.calema.ca.gov/hazard_mitigation_success_stories/seismic_retrofitting>.

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6. "Liquefaction resistant structures." <i>Liquefaction resistant structures</i>. N.p., n.d. Web. 25 July 2014. <http://www.ce.washington.edu/~liquefaction/html/how/resistantstructures.html>.

7. "Liquefaction Mitigation." . N.p., n.d. Web. . <http://www.betterground.com/index.php?option=com_content&view=article&id=172&Itemid=179>.

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9. "What is Liquefaction?." *Liquefaction of Soil During Earthquakes*. N.p., n.d. Web. 25 July 2014. <http://geology.com/usgs/liquefaction/>.

10. "Liquefaction video of Japan Tohoku-Oki Earthquake in Central Park - Water pouring from cracks." *YouTube*. YouTube, n.d. Web. 25 July 2014. <http://www.youtube.com/watch?v=I3hJK1BoRak>.