**Aligned Lesson Plan 5**  
*Build a Structure That Survives an Earthquake*

| Cristina Geisler | About the author/teacher:  
| Grade Level: 11-12 | Science Teacher: Physics  
cgeisler@sd206.org  
Bloom Township District 206  
Chicago Heights, Illinois |

| Related Unit: Earthquakes and Mechanical Waves | Lesson Length: (two-hour period) |

| NGSS Standards: ESS2-1, ESS2-2 |  |
| 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. |  |
| Waves and Their Applications in Technologies for Information Transfer: MS-PS4-1, HS-PS4-1, MS-PS4-2 |  |
| Earth and Human Activity: HS-ESS3-1, MS-ESS3-2 |  |
| HS-PS1-7 Use mathematical representations of phenomena to support claims |  |
| HS-PS1-4 Develop a model based on evidence to illustrate the relationships between systems or between components of a system |  |
| CCSS ELA: [CCSS.ELA-Literacy.WHST.11-12.2](#) |  |
| Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. |  |

Enduring Understandings  

| Essential Questions |

| ● Engineers must understand Science, Technology, Engineering, and Mathematics (STEM) to create structure to meet code, safety specifications, and budget constraints. Designers, Scientist, and Engineers use scale models and prototypes to test design theories. (HS-ETS1-2) | Why buildings collapse and what can be done to make buildings safe? |
| ● 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. **HS-ESS2-1 HS-ETS1-2** | How could you add structural elements to reduce resonance in a building? |
- Understandings about science and technology: Structures are designed to provide solutions to a human need. Engineers must understand Science, Technology, Engineering, and Mathematics (STEM) to create structure to meet code, safety specifications, and budget constraints. Designers, Scientists, and Engineers use scale models and prototypes to test design theories. (HS-ETS1-2) **HS-ESS2-1**

- Identify existing structure locations vulnerable to extreme weather risks, and develop appropriate strategies to minimize such risks. (ESS2-1, ESS2-2, HS-ETS1-2, **CCSS.ELA-Literacy.WHST.11-12.2**)

<table>
<thead>
<tr>
<th>Transfer Goals</th>
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<tbody>
<tr>
<td>• Asking questions (for science) and defining problems (for engineering)</td>
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<tr>
<td>• Planning and carrying out investigations</td>
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<tr>
<td>• Analyzing and interpreting data</td>
</tr>
<tr>
<td>• Constructing explanations (for science) and designing solutions (for engineering)</td>
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<tr>
<th>Learning Objectives</th>
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<tr>
<td>1. Describe how diagonal braces, shear walls, and rigid connections provide paths for the horizontal load resulting from an earthquake. HS-ETS1-2</td>
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<tr>
<td>2. Observe how added structural elements strengthen a model wall to withstand shaking. HS-ETS1-2</td>
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<tr>
<td>3. Construct a structure that will be able to withstand earthquake shaking. <strong>HS-ESS2-1</strong> HS-ETS1-2</td>
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<tr>
<td>4. Students will be able to perform and interpret scientific measurements. (<a href="https://www.loc.gov/item/mpc2005002674/PP/">CCSS.Math.Practice.MP4)</a></td>
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<tr>
<th>Library of Congress: Primary Sources Tools:</th>
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<tr>
<td><a href="https://www.loc.gov/item/00694425">https://www.loc.gov/item/00694425</a></td>
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<td><a href="https://babel.hathitrust.org/cgi/pt?id=mdp.39015059171234;view=1up;seq=81">https://babel.hathitrust.org/cgi/pt?id=mdp.39015059171234;view=1up;seq=81</a></td>
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<th>Materials/Supplies/Resources</th>
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<tr>
<td>Computers with Internet access</td>
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<tr>
<td>• earthquake generator, you will need the following:</td>
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<td>A 1-inch × 10-foot piece of #40 PVC</td>
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<td>• plastic pipe, which will be cut into two 24-inch pipes and two 30-inch pipes</td>
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<tr>
<td>• Four 1-inch #40 PVC 90o degree elbows</td>
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</table>
To conduct the earthquake experiments, students will need the following:

- Two ½ inch x 36 inch dowels wooden dowels
- One piece of plywood .25 × 24 × 24 inches
- Four eyebolts, .25 × 2.5 inches with .25 inch nuts
- Four hex bolts, .25 × 1 inch, with .25 inch nuts
- Four rubber bands, #64
- One saw
- One drill with .25-inch drill bit
- Hot glue
- Styrofoam packing blocks
- Wood blocks
- Spongy foam
- Cardboard
- Scissors (for cutting the foam board or cardboard)
- Shallow box or pan
- Marbles
- Wood dowels or pencils
- Large sponge
- Sand (optional)
the school districts and the design team reach agreement on the desired seismic performance of the building (i.e., the extent and type of damage that the school district can tolerate). The extent of this damage can be reduced by seismic design measures based on more precise analysis of the earthquake forces that the building will encounter, rather than relying on the simplified analytical methods of the current seismic code.

These more precisely estimated forces may, in some instances, be less than the forces determined by a simple code analysis because less allowance will need to be made for uncertainty in the calculations, and the seismic design and construction cost may be reduced. Increased protection beyond the minimum code expectations, however, will almost inevitably add to the initial cost of the building. The trade-off that the school district must consider is that damage reduction will probably result in design and construction cost increases.

The value to the district of increased investment in seismic protective design and construction is dependent on the likelihood of damaging earthquakes, and some economic analysis can assist in arriving at an affordable solution with satisfactory safety and damage control characteristics. This implies that the cost of protection must be evaluated over the life of the building, rather than only as an item of the initial building cost. As with design to the current code, performance-based design starts with the assumption that the basic purpose of seismic design is to protect the building occupants from collapse and damage that may be life-threatening.

The performance-based design procedure uses input from the information evaluations previously described to develop designs that balance the desired performance levels with the available resources.

https://media.up.edu/Physics/TOLE/EarthquakeTsunamiHazards/LessonPlans/BOSS_ModelOfResonance_TOTLE.pdf

https://www.iris.edu/hq/inclass/video/building_resonance_boss_model_construction_use

https://www.iris.edu/hq/inclass/animation/building_resonance_the_resonant_frequency_of_different_seismic_waves

https://uportland.mediaspace.kaltura.com/media/CEE2+-Animation_of_Building_Collapse_topic3_lesson_plan%29/0_ez4f8jho

https://www.youtube.com/watch?v=_AbUIbH-Als

https://www.youtube.com/watch?v=kzVvd4Dk6sw&feature=related

Engage: How can I get students interested in this? (20 minutes)

Prior Knowledge: Students would benefit from knowledge of wave vocabulary, wave behavior, wave interaction, forces and resonance.

Show students the video from the library of congress.

https://www.loc.gov/item/00694425

From previous lessons review and ask questions like:

How many different kinds of waves can you think of? example answer 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.): amplitude, wavelength, crest, trough, frequency.

What types of waves do we associate with earthquakes? seismic waves. Seismic waves are waves that move through the Earth, and are typically created by earthquakes.

In your opinion, how can a building be made stronger for earthquake safety?

What part of the wall fails first?

Imagine how the horizontal force you applied to the base travels to the upper parts of the wall. What caused the first structural failure?

One of the main causes of damage in an earthquake is the collapse of buildings not strong enough to withstand the shaking. Engineers and architects try to design buildings rigid enough to withstand the shock, but flexible enough to give a little under the stress.

Tell students that one way to protect a building from resonating with an earthquake is to isolate its foundation, or base, from the ground with devices much like wheels. This technique is called base isolation. Structural engineers are now developing the technology to place buildings on devices that absorb energy, so that ground shaking is not directly transferred to the building.

Explore: What tasks/questions can I offer to help students puzzle through this? (120 minutes)

Students will review the concept of natural frequencies of the three buildings in the BOSS model from previous lesson in order to develop an understanding of the effect of earthquake waves on buildings.

Have available the primary resources tool and discuss with class about the seismic design for a school district. Show the data table and explain how prior to building the school building there are performance code discussion about the seismic performance of the building.
# Primary Source Analysis Tool

<table>
<thead>
<tr>
<th>Observe</th>
<th>Reflect</th>
<th>Question</th>
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## Further Investigation

[https://babel.hathitrust.org/cgi/pt?id=mdp.39015059171234;view=1up;seq=81](https://babel.hathitrust.org/cgi/pt?id=mdp.39015059171234;view=1up;seq=81)
Table 2-4: Damage Control and Building Performance Levels

<table>
<thead>
<tr>
<th>Overall Damage</th>
<th>Collapse Prevention Level</th>
<th>Life Safety Level</th>
<th>Immediate Occupancy Level</th>
<th>Operational Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Little residual stiffness and strength, but load bearing columns and walls function. Large permanent drifts. Some exits blocked. Infills and unbowed parapets failed or at incipient failure. Building is near collapse.</td>
<td>Some residual strength and stiffness lost in all stories. Gravity-load bearing elements function. No out-of-plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair.</td>
<td>No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable.</td>
<td>No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All systems important to normal operation are functional.</td>
</tr>
<tr>
<td>Nonstructural components</td>
<td>Extensive damage.</td>
<td>Falling hazards mitigated, but many architectural, mechanical, and electrical systems are damaged.</td>
<td>Equipment and contents are generally secure, but may not operate due to mechanical failure or lack of utilities.</td>
<td>Negligible damage occurs. Power and other utilities are available, possibly from standby sources.</td>
</tr>
<tr>
<td>Comparison with performance intended for buildings designed, under the NEHRP Provisions, for the Design Earthquake</td>
<td>Significantly more damage and greater risk.</td>
<td>Somewhat more damage and slightly higher risk.</td>
<td>Much less damage and lower risk.</td>
<td>Much less damage and lower risk.</td>
</tr>
</tbody>
</table>

Source: NEHRP Guidelines for the Seismic Rehabilitation of Buildings (FEMA 273)

Reducing Seismic Risk Through Performance-based Design. The general principles of performance-based design are discussed in earlier sections of this chapter. For seismic risk reduction, performance-based design starts with the recognition that some damage will be incurred in a severe earthquake even in a well designed and constructed building. Prior to the seismic design,
the school districts and the design team reach agreement on the
desired seismic performance of the building (i.e., the extent and
type of damage that the school district can tolerate). The ex-
tent of this damage can be reduced by seismic design measures
based on more precise analysis of the earthquake forces that the
building will encounter, rather than relying on the simplified
analytical methods of the current seismic code.

These more precisely estimated forces may, in some instances,
be less than the forces determined by a simple code analysis be-
cause less allowance will need to be made for uncertainty in the
calculations, and the seismic design and construction cost may
be reduced. Increased protection beyond the minimum code ex-
pectations, however, will almost inevitably add to the initial cost
of the building. The trade-off that the school district must con-
sider is that damage reduction will probably result in design and
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tective design and construction is dependent on the likelihood
of damaging earthquakes, and some economic analysis can as-
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and damage control characteristics. This implies that the cost of
protection must be evaluated over the life of the building, rather
than only as an item of the initial building cost. As with design
to the current code, performance-based design starts with the
assumption that the basic purpose of seismic design is to protect
the building occupants from collapse and damage that may be
life-threatening.

The performance-based design procedure uses inputs from the
information evaluations previously described to develop designs
that balance the desired performance levels with the available
resources.
Discuss with the class the different variables that need to be considered when constructing a building durable enough to survive a catastrophic earthquake. Help students understand that the following factors contribute to the durability of a structure:

- Distribution of weight
- Variation in shape
- Variation in height
- Variation in foundation material

Explain to students that they will work in pairs in order to build their own miniature buildings to test these four factors. Before they begin, have students do some initial research on earthquakes and earthquake engineering.

Encourage them to look for information regarding the four factors that contribute to the durability of a structure. The videos and Websites below offer a good starting point for their research:


https://www.youtube.com/watch?v=c4fKBGslIzI
https://www.youtube.com/watch?v=6J99phNArM

https://www.youtube.com/watch?v=sxpi9A7_syE&feature=youtu.be+width%3A595+height%3A400

https://www.youtube.com/watch?time_continue=16&v=c25HuZeQsyo

- For lower grades or younger students give students the challenge of building a structure that is at least 1 foot tall with only mini marshmallows and toothpicks, and only have them test on a common shake table provided by the teacher. Allow students to create more than one structure so they have the opportunity to change their designs and recognize structures and strategies that work best. Also, provide different materials like dry spaghetti, so they can test to see if some materials work better than others.
- For upper grades or older students, offer more advanced materials for the team shake table construction, such as foam core board, wood, saws, drills and drill bits, and drills to power them.

Teacher resources:
Explain: How can I help students make sense of their observations? (50 minutes)

Review the four variables that contribute to the durability of a building:

- distribution of weight,
- variation in shape,
- variation in height,
- and the type of material used for the foundation.

Discuss what is needed to create earthquake-proof buildings.

For example, what would happen if a building was constructed properly but was built on a sandy foundation?

What issues do builders face when constructing very tall buildings? Refer to previous lesson to discuss resonance and outcomes of most devastating earthquakes in history.

What strategies can be implemented so the damage is not as great next time?

Refer to the engage activity and explain once again that: One of the main causes of damage in an earthquake is the collapse of buildings not strong enough to withstand the shaking. Engineers and architects try to design buildings rigid enough to withstand the shock, but flexible enough to give a little under the stress.

Tell students that one way to protect a building from resonating with an earthquake is to isolate its foundation, or base, from the ground with devices much like wheels. This technique is called base isolation. Structural engineers are now developing the technology to place buildings on devices that absorb energy, so that ground shaking is not directly transferred to the building.

Extend/Elaborate: How can my students apply their new knowledge to other situations?) (4-5 class periods)

Set a class competition and see who can build the tallest freestanding structure that can survive an earthquake on the tabletop earthquake generator.

Have students work collaboratively in groups of three or four students. Each group must design and build the structure they test on the earthquake generator. You may choose materials that are convenient to your location and resources, but the structure must comply with the following specifications:

Rubric:

1. The total mass of the structure may not exceed 1.5 kilograms ____ 10 points
2. No element of the structure may be taller than 30 centimeters ____ 10 Points
3. The elements of the structure may not interlock or stick together in any way____5 points

4. Glue and other fasteners may be used to hold parts together within the single element height limit of 30 centimeters____10 Points

5. The structure must be freestanding. (It may not be stuck in any way to the table.)____10 points

6. Any materials may be used as long as they do not violate any other rule.

7. Students may create shock absorbers or include any new idea that is not suggested in the previous activities as long as it does not violate any other rule.

8. Materials may be placed under the structure as long as they do not in any way harm the earthquake generator. These materials are included in the mass limit.

9. Groups should design a way to make sure that the magnitude of the earthquake is constant throughout the competition.______25 points.

The winner is the group that designs the tallest freestanding structure to withstand the highest magnitude earthquake.

Evaluate: How can I help my students self-evaluate and reflect on the learning? (1-2 class period)

- Test how durable each structure is by placing it on the earthquake generator and simulating an earthquake by shaking the generator. Each group will be testing all of the variables discussed in the explore section. Before conducting the experiment, each group should make a prediction of which structure has the best chances of surviving an earthquake. Students will record their predictions, observations, and conclusions.
- Check for understanding questions will be utilized during small group instruction. Students will be asked open-ended questions during small group and individualized instruction to check for understanding.
- Which types of seismic waves did your shake table imitate (simulate)? Explain the movements and speeds. Explain how it does this.
- Describe what happens to your building when you test it on your shake table.
- How long did your building last through the "earthquake"?
- Describe what happened to your building while it was going through the "earthquake."
- Based on what you noticed from your group and other groups, which designs and strategies worked the best?
- Why do you think this particular type of design worked the best?
- How did the ability of your shake table to accurately represent seismic waves help in the evolution of your building design?
- Think back and describe in your own words the steps of the engineering design process that you went through.
- Self-evaluate: Students will have multiple opportunities to self-evaluate their progress during the class discussions.
- Formative Assessments: Class Discussions
- Summative Assessment: Teacher will collect the model activity