Shake, Don't Break

Program Type: Classroom Program	***Audience Type:*** Grades 3–8

Description: Students will determine the effectiveness of various materials at isolating the base of a structure during a simulated earthquake.

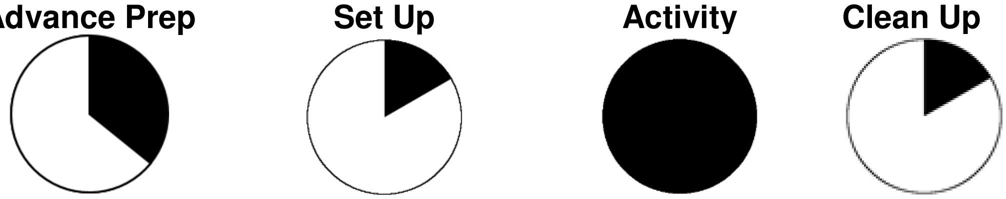
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will apply what they learn about real-life base isolation systems as they construct two different building models
- Students will use the design process to improve their model by experimenting with various materials
- Students will quantify, record, and find patterns in the data generated by the testing of their models

TIME REQUIRED

Advance Prep	**Set Up**	**Activity**	**Clean Up**



5-20 minutes	**10 minutes**	**60 minutes**	**10 minutes**

SITE REQUIREMENTS

- Table space for each group of 3–5 students
- A shake table 2-3 feet wide (see the Advanced Preparation section for an alternative to a museum shake table)

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	10 min
Paper Tower Testing	Group activity	30 min
Dollhouse Testing	Group activity	15 min
Wrap-Up	Large group discussion	5 min

SUPPLIES

Permanent Supplies	Amount	Notes
Shake table	1	If you do not have access to a shake table exhibit, you can create one using the instructions in the advanced preparation section.
Projector, screen, and computer	1	*(Optional)*
Cookie sheets or cafeteria trays	1/group	
Paper reams	3/group	
Dollhouse w/ furniture and people figurines	1	*(Optional)* To use with shake table exhibit or DIY shake table. Can be store-bought or made out of cardboard (if cardboard, add weight to the bottom using paper reams or similar).
Shallow, rectangular bin	1	*(Optional)* Must fit the base of the dollhouse with at least 2" extra on each side.
Magnets	5–10 /group	*(Optional)* Use if using metal tray
Craft wax sticks	20–30 /group	Such as Wikki Stix
Paper cups	4/group	To contain Testing Materials
Cardboard tubes	4/group	To contain Testing Materials
Sticky Tack	1 pack /group	
Wine corks	15–30 /group	**Testing Materials** These supplies can be replaced by similar ones. You will need at least two testing materials for every group. Make sure your chosen materials vary in shape and size (i.e., provide large round objects, small round objects, non-round objects, soft objects, and hard objects).
Small round objects (Ex: bouncy balls)	15–30 /group	
Medium round objects (Ex: Golf balls)	15–30 /group	
Large round objects (Ex: Tennis balls)	15–30 /group	
Cotton balls	30+/group	
Marbles	50+/group	
Beads	300+/group	
Scissors	1/group	

ADVANCE PREPARATION

To set up the final activity, place the furniture and people in the dollhouse. If possible, hang something from the ceiling of the dollhouse to watch during the earthquake.

Shake Table – If you will be using a doll house and do not have access to a shake table exhibit, create your own with these instructions:

DIY Shake Table	Amount	Notes
PVC pipes (at least 2'' in diameter)	2	Any cylindrical objects work as long as they are roughly the same diameter. You can use rolls of butcher paper or full paper towel rolls, taped to keep them from unraveling
Pegboard or plywood	2	Approximately 1.5' x 1.5'. Both pieces must be of equal size and strong enough to hold 3 reams of paper without bending.
Thick rubber bands	4	When flat, rubber bands must be approximately the diameter of the PVC pipe tube. All four rubber bands must be the same size.
Zip ties	8	
Scissors	1	

Procedure:

1. If using plywood, stack the two pieces on top of each other and drill a hole in the corner of each board. The sturdier the material of the boards, the more use you will get out of your shake table. For pegboards, just stack the two pieces and line them up so the corner holes match up.
2. Take the two cylindrical objects and place them between the boards. Line them up so they are parallel to one another (see Figure 2).
3. Use a zip tie to attach a rubber band to the corner of the top board, and another tie to attach the other end of the rubber band to the bottom board. The rubber bands should be taut, but not stretched, when in a resting position. If they are too long, consider folding the rubber bands in half or finding larger cylindrical objects. Clip the ends of the zip ties to avoid injuries. Repeat on all four corners (see Figure 1).

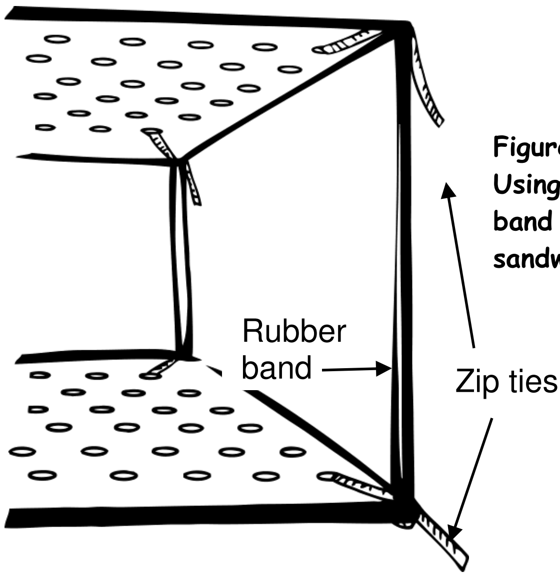


Figure 1: Zip ties and rubber bands. Using zip ties, attach each rubber band to the corners of the sandwiched pegboards,

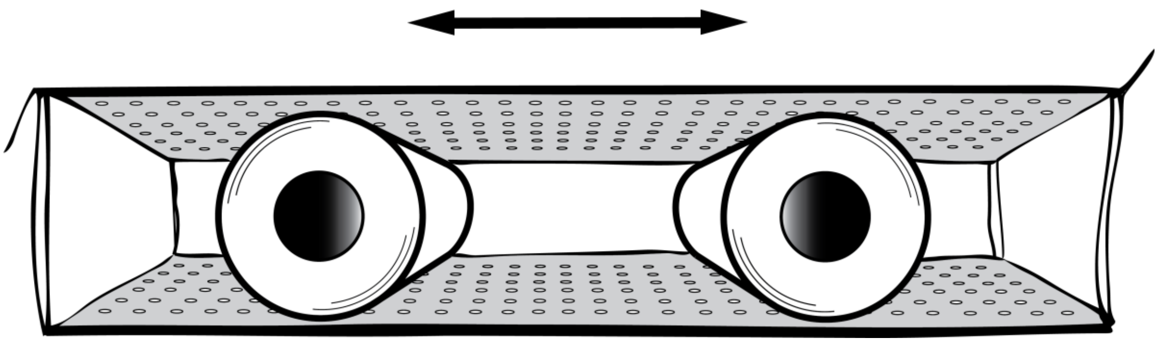


Figure 2: DIY Shake Platform. To shake, simply pull back on the top board like a slingshot. We recommend pulling about 5 inches, but make sure you don't pull too hard and snap the bands.

For an idea on how to build a high-tech shake table, check out:
Kiwiko - "Make an Earthquake Shake Table" https://youtu.be/6HgxiYBkh3U
(Duration 3:29)

SET UP

- Separate each type of testing material into its own container
- Place materials in a central area for easy access
- Set up one cookie sheet or tray at each table with three reams of paper stacked on top (see Figure 3)

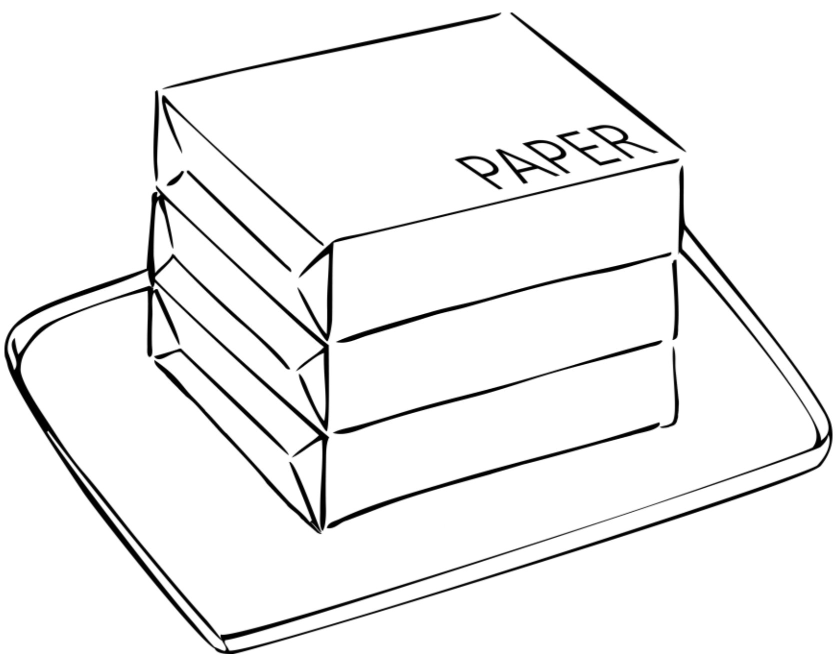


Figure 3: Paper tower set up.

INTRODUCTION

10 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

What are some things people need to worry about during and after earthquakes?
Buildings collapsing, bridges/roads breaking, tsunamis, water supply contamination.

Think about the effect of earthquakes on houses and other buildings. In a big earthquake, the ground will shake and ripple in waves. That is bad news for buildings connected to the ground through their foundations – usually a big block of concrete poured under the base of a building that is firmly attached to the frame (think "skeleton") that holds the walls, roof, and everything else.

What happens to the house when this big block of concrete starts shaking and rippling?
The house walls crack, windows break, things fall off walls and shelves, etc.

If you have a projector and internet access, show one of the following videos to introduce the topic:

Wired Science 8 - "High Tech Quake Survival" (2008)
http://youtu.be/Il1M8o0BHPc
(Duration 4:05)

Seeker – "How We Design Buildings to Survive Earthquakes" (2016)
https://youtu.be/c4fKBGsllZI
(Duration 3:58)

One way engineers can protect buildings is to use base isolation. Base isolation means separating the base of the building from the ground so that the building can remain in place while the ground moves back and forth underneath it. This helps protect the structure from major damage or collapse during an earthquake.

Today we are going to use what we know about base isolation to design and test different ways to make buildings safer during earthquakes.

GROUP ACTIVITY

Paper Tower Testing

35 minutes

First demonstrate how the students will be testing their structures and what they are looking to prevent. Shake the cookie sheet with the paper reams for 10 seconds.

These three reams of paper represent a three-story building. Notice when I shake the cookie sheet (the foundation) they quickly separate and fall off. The challenge today is to invent a way to isolate the base of your three-story building so it can survive the earthquake.

Demonstrate how the tower moves when there are bouncy balls underneath it to show successful base isolation.

How can we decide if our design worked? *The paper reams stayed stacked, they did not wobble as much during the shaking, etc.*

While you are testing, record your results on the data sheet. You can rate the different materials you tried based on how much the building separated or fell apart while shaking.

Divide students into groups of 3–5.

Round 1:

For the first round, each group must choose **one** material box at a time to test as a base isolator (e.g., just tennis balls, just marbles, or just wine corks). See Figure 4. Instruct them to return materials to the center area as they finish testing each one so that other groups can try them out. Each group must only have **one** supply box at their table at a time.

Remind the students to make sure the paper is neatly stacked before testing and to shake for a full 10 seconds to obtain the best data.

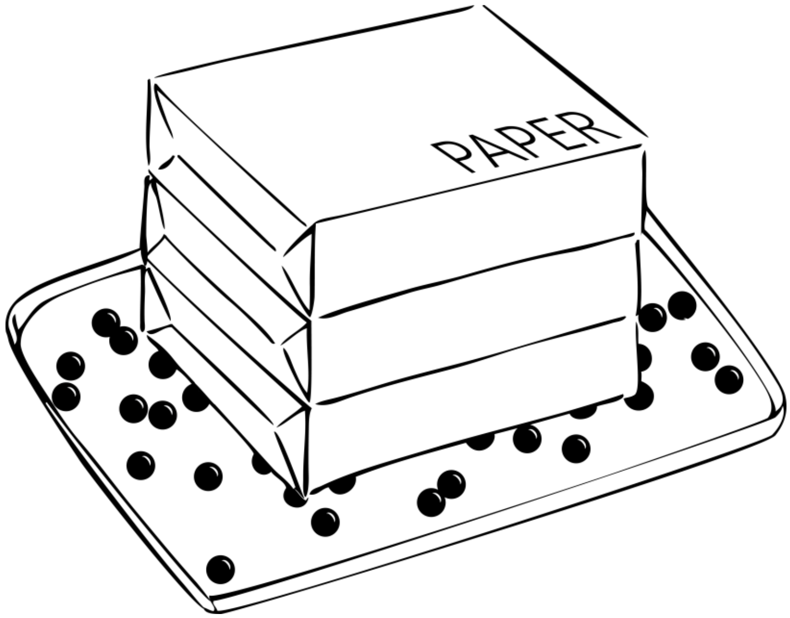


Figure 4: Paper tower testing example.
This model includes marbles as a base isolation method.

Once students have had a chance to try each material separately, lead discussion on what worked or what didn't work as well. Use the worksheet as a guide for the discussion.

Round 2:

Now, you will take what you learned about each material and begin to get creative! You will be able to test combinations of each material to find the most effective way to protect the building. There is one catch: You will have fewer numbers of each item. How will you keep the testing material in the right spot underneath the tower? I will pass out some additional supplies so that you can improve on your creations.

Pass out the additional materials (sticky tack, paper cups, scissors, craft wax sticks, cardboard tubes, and/or magnets). Groups may have a difficult time keeping the testing materials from scattering out from underneath the paper reams while testing. The paper cups, cardboard tubes, or craft wax sticks are helpful for containing the objects so they don't roll away (see Figure 5). Allow the students to cut their containers to whatever size they think is necessary. Sticky tack or magnets will add traction to keep the containers from moving away with the testing material.

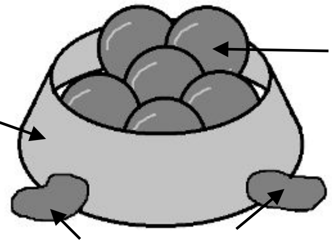


Figure 5: Marbles held in place using a modified paper cup.

Depending on the group, you may present various challenges: limit the number of materials they can use, shake the tray in more than one direction, shake intermittently to replicate aftershocks, etc.

What is happening? Does the paper tower move differently with different-sized balls? What happens when you use a cylindrical object instead of a sphere? How does the paper stack move differently when there are more or fewer objects in the tray? What happens if you mix and match? Did the tower fall off the shake table completely even though the stack stayed together?

GROUP ACTIVITY

Dollhouse Testing (Optional)

15 minutes

A building is not just the outside structure. Think about what you see in the building you are in (other people, furniture, hanging ceiling lamps, etc.). What happens to the interior of a building when an earthquake hits?

For this round, you will work in your group to discuss what objects worked best as base isolators. We will pick our top three and see if they work in making an earthquake-safe base isolation method for this miniature house. There are objects inside, and we will take note of how much everything moves around. The catch is you only get one try.

Show the students the dollhouse so they know what size it is. Ask each group which base isolators worked best in the previous activity, and choose your top three (or more, depending on time) as a class.

What will you have to consider as you plan?
House is larger, so you can't stack balls under entire base. Heavier, etc.

When the groups are finished, have a final showcase to test all of the designs. Before testing, let each group point out the notable aspects of their designs to the rest of the class.

When students are ready, put the dollhouse on the shake table and test each group's design, resetting the objects inside the house every time.

What happened to the house? Did the house stay on the table? Did anyone fall down or fall completely out of the house? What stayed put? What fell over? What sort of base worked best?

Would it be different if your house were built on a slope or on a hill?

What happens when buildings are near each other?

WRAP-UP

5 minutes

From this activity, we learned that just by adding something to separate the building and the ground we could make a building safer during an earthquake. No matter what type of base isolation we used, the building still moved a little during the earthquake. However, we were able to notice big differences in having a fixed versus an isolated base.

If time allows, you can show one of the other videos from the introduction if you were not able to do so at the beginning.

CLEAN UP

10 minutes

- Have students sort the materials and put them back in their separate bins

BACKGROUND INFORMATION

During an earthquake, intense ground shaking causes buildings to sway and vibrate, resulting in structural damage. A powerful earthquake may result in the complete collapse of buildings, bridges, and other structures—resulting in billions of dollars of losses, not to mention human death and injury.

Engineers are trying to find different ways to make buildings more earthquake safe, especially in urban areas near fault lines. One technique is base isolation. In a base-isolated building, rollers, sliders, elastic feet, or other elements physically separate the foundation of a building from the main structure. In the event of a quake, the base of the building can roll or slide back and forth, but the primary structure doesn't sway or bend. This technology dramatically reduces the amount of structural damage a building suffers during an earthquake (see Figure 6).

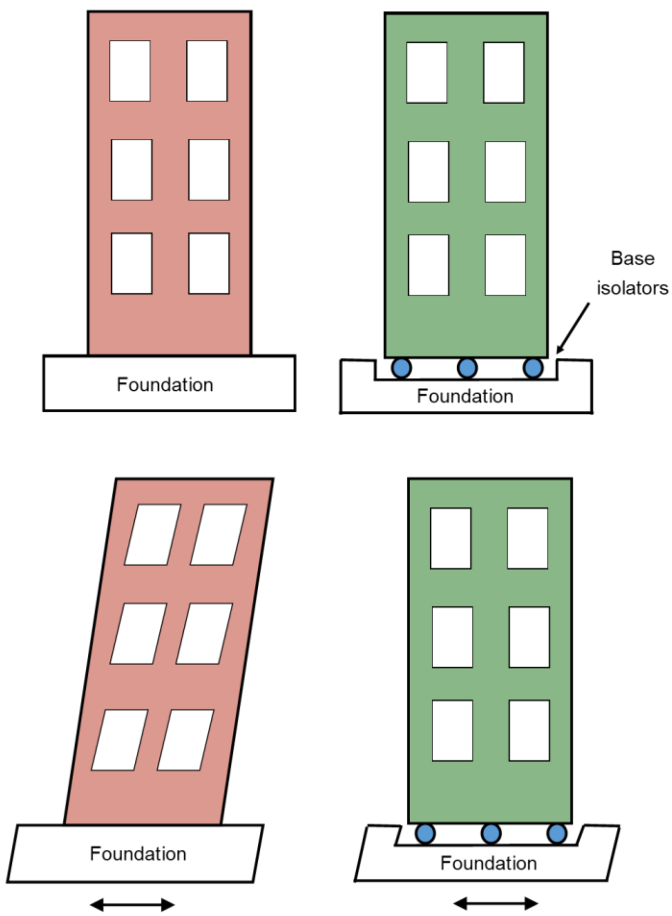


Figure 6: Simplified diagram illustrating base isolation in buidlings.

Figure 7 shows an aerial view of Apple Park, corporate headquarters of Apple Inc. in Cupertino, CA. This seven-story, ring-shaped building sits atop 700 base isolators. For more information on Apple Park and other base-isolated buildings around the world, see:

Lewis, Scott. "The 10 Largest Base-Isolated Buildings in the World." *Engineering News-Record,* 2017, www.enr.com/articles/42366-the-10-largest-base-isolated-buildings-in-the-world.

Figure 7: Aerial view of Apple Park, corporate headquarters of Apple Inc. (Image: Michael Estigoy, www.flickr.com).

For more information on engineering earthquake-proof buildings, see:

Wired Science 8 - "High Tech Quake Survival" (2008)
http://youtu.be/lI1M8o0BHPc
(Duration 4:05)

Seeker – "How We Design Buildings to Survive Earthquakes" (2016)
https://youtu.be/c4fKBGsllZI
(Duration 3:58)

GLOSSARY

Base isolation	Separating the base of a building from the ground to protect the structure from major damage or collapse during an earthquake.
Fault line	A fracture in one of the Earth's tectonic plates.
Tectonic plates	Sections of the Earth's crust that move and whose interactions cause earthquakes, volcanoes, and mountains.
Aftershocks	The series of earthquakes that come after a seismic event. The number of aftershocks and their duration depends on the magnitude of the initial earthquake, but they usually decrease in magnitude over time.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
✓	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
✓	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
✓	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
✓	Systems and system models
	Energy and matter
✓	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				

LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
Earth & Space Science					
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity	✓			
Engineering, Technology, and Applications of Science					
ETS1	Engineering Design	✓	✓	✓	✓

<u>DCI Grade Band Endpoints</u>

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3-5 ESS3.C: Human Impacts on Earth Systems

- Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments. For example, they are treating sewage, reducing the amounts of materials they use, and regulating sources of pollution such as emissions from factories and power plants or the runoff from agricultural activities. (By the end of Grade 5)

Performance Expectations

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
5-ESS3-1	Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Shake, Don’t Break
Appendix

Names: ____

Shake, Don't Break Data Sheet

Instructions: How well did the materials separate, or isolate, the base from the building and prevent the paper reams from separating and falling? Fill out the chart, rating each testing material by circling a number on the scale from 1 to 10. Use the pointers below as your guidelines.

1: All three paper reams collapsed immediately
3: Most reams fell after the shaking began
5: The reams started separating and falling after a few seconds of shaking
7: The paper reams separated some, but stayed mostly in place
10: The paper reams stayed stacked neatly on top of one another

Testing Material	Effectiveness									
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10

Nombres: ____

Hoja de información
Shake, Don't Break (Sacúdete, no te rompas)

Instrucciones: ¿Qué tan exitosos fueron los materiales en separar (aislar) la base del edificio y prevenir que se cayeran las resmas de papel? Llena la tabla, calificando cada material en la escala del 1 al 10. Utiliza los indicadores a continuación como referencia.

1: Las tres resmas de papel se cayeron inmediatamente
3: La mayoría de las resmas se cayeron cuando empezó el movimiento
5: Las resmas comenzaron a separarse y caerse unos segundos después que empezó el movimiento
7: Las resmas se separaron un poco, pero por la mayor parte quedaron igual
10: Las resmas quedaron bien apiladas una encima de la otra

Material de prueba	Eficacia									
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10

FACILITATION GUIDE

Shake, Don't Break

Description: Students will determine the effectiveness of various materials at isolating the base of a structure during a simulated earthquake.

Promoting collaboration and organization

- Have students take turns choosing a material, shaking the tray, and rating the material.
- Students should discuss with their teammates why they think these materials worked well or why they failed.
- Facilitate a conversation about working together and combining different materials for each base isolation technique.

Encouraging iteration

- Encourage students to find different materials they can combine to improve their original designs.
- Ask students why certain materials seem to work better at base isolation than others. Discuss shape, size, material composition, etc.
- To extend the challenge, ask:
  - "Is there a way to keep the building in the center of the cookie sheet?"
  - "What if there's an aftershock? Shake it again and see if it still stands."
  - "Can you use fewer materials?"
  - "How high can you get the building off the ground and still make it safe? How low? Which one do you think is safer for the people inside?"

Helping those who are stuck

- Ask some leading questions to build curiosity and confidence to try again:
  - "What shape do you think would be the best base isolator?"
  - "What materials have you not tried yet?"
  - "Try combining round materials with non-round ones."
  - "Pause after putting your building on the shake table to test. Do you have to spend time balancing the building just right? If so, maybe it's a sign it is unstable to start with."
  - "Are the materials shifting to one spot? What does that do to the building?"
  - "How can you keep the building balanced?"
  - "Is there a way to keep the testing materials in the corners of the building?"

Real-world applications

- Relate the testing materials to real-life building/engineering tools and materials.
- A commonly used base isolation is lead rubber bearings (LRBs), which are a combination of lead, rubber, and steel. This base isolation was developed in the early 1970s.
- Extremely strong magnets can be used to levitate buildings just enough so there is a separation between the base of the building and the foundation. This prevents the building from shaking during an earthquake.