ShakeAlert® activities for formal and informal learning settings

Designing earthquake-resistant structures—Engineering for safety

How can we design buildings to withstand an earthquake?

Version 01/24/22

Activity modified from [FEMA Seismic Sleuth's "Build a Better Wall"]

OVERVIEW

This activity develops an understanding of why buildings collapse and what can be done to make them more resilient to earthquake ground shaking. Learners investigate the impact of seismic waves on building response to lateral (shear) forces by simulating shaking on a model-scale wall (Figure 1). Learners experiment with methods to improve building design to withstand forces exerted into the model wall.

Three different 5-, 20-, and 45-minute options provide opportunities to explore basic concepts of seismic structural engineering design. A 5-minute activity demonstrates the importance of designing buildings to resist shear forces (Vocabulary, Appendix A) experienced during earthquake ground shaking. The 20-minute hands-on activity allows learners to apply shear wall and diagonal bracing to reinforce a model wall. A 45-minute option allows learners more time to add additional types of structural design elements to their model wall. Seismic retrofits make our cities and communities more earthquake resilient.

Why is it important to learn about earthquakes and their effects on buildings and structures? More than 143 million people are exposed to potential earthquake hazards in the U.S. that could cost thousands of lives and billions of dollars in damage. Earthquake hazard mitigation strategies improve the preparedness of communities and households prior to an earthquake event. The ShakeAlert® Earthquake Early Warning system for the West Coast of the U.S. aims to complement earthquake mitigation and preparedness efforts. ShakeAlert detects significant earthquakes quickly so that alerts can be delivered to people and automated systems.

Beginner

5 min | 20 min | 45 min

Large Group | Small Groups

Demo | Materials

Time: 5-, 20-, and 45-minute guided activities that can be adapted for audience and venue.

Audience: This can be done with novice and experienced geoscience learning groups.

Figure 1: Learners reinforce basic wall model.

OBJECTIVES

Learners will be able to:

- Explain how structural reinforcement carries the horizontal and vertical loads of a building during earthquake shaking.
- Explain the importance of seismic engineering design and retrofitting of unreinforced buildings for earthquake resilience.
- Articulate how mitigation is part of a suite of sustained preparedness actions to reduce the risk of damaging impact on buildings and the built environment.

Table of Contents

MATERIALS, TOOLS AND CONSTRUCTION

Materials needed to build one (1) model wall with 4 sections (2 cells by 2 cells; Appendix B)

- 1" x 3" wood, 12" long (for the base)
- 10 wood tongue depressors (jumbo 6" craft sticks)
- 3 wood screws (#8 x ½")
- 6 bolts (8-32 x ½")
- 18 washers (#8)
- 6 nuts (#8-32)

Optional: **Materials needed to build one model wall with 9 sections** (3 cells by 3 cells)

- 1" x 3" wood, 20" long (for the base)
- 21 wood tongue depressors (jumbo 6" craft sticks)
- 4 wood screws (#8 x ½")
- 12 bolts (8-32 x ½")
- 32 washers (#8)
- 12 nuts (#8-32)

Tools needed for assembly of the wall

- Eye protection
- Electric drill
- 11/64" drill bit to accommodate the 8-32 bolts
- Scissors
- Phillips head screwdriver
- Scrap wood for a protective work surface while drilling
- Several rubber bands (to bundle tongue depressors while drilling)

Reinforcing components for each model wall

- 1 manila file folder
- 1 template pattern (Appendix B) for reinforcing components
- 10–16 small binder clips (1/4" or 5/16th capacity)
- 10" string
- 1-quart Ziploc bag to hold components for each model wall

Construction of the model wall and structural reinforcement components

Detailed directions for constructing the model wall appear in Appendix B. Watch a video of the construction and use of the model wall.

Materials for the 5-minute activity

- One demonstration model wall (either 2 X 2 cells or 3 X 3 cells. See Appendix B for size description.)
- One bag of reinforcement supplies which has additional structural members (representing beams and shear walls; Appendix B template, page 11).
- Print or computer project Appendix C Images of first floor structural failure

Materials for the 20-minute activity

- One model wall for each learner group
- One bag of reinforcement supplies for each group

Materials for the 45-minute activity

- Computer and projection system for larger groups
- One model wall for each learner group
- One bag of reinforcement supplies which has additional structural members and small clips for each learner group
- Print Types of Structural Reinforcing found in Appendix B for each learner group. Note: use page protectors to reuse the sheets.
- Have available both Appendix D (Instructor Background Non-Technical Building Engineering) and Appendix E (FEMA Resources for Seismic Design and Retrofitting Homes).

RELEVANT MEDIA RESOURCES

Videos

- Build a Better Wall: How can we make a building more earthquake proof? (5min 54s) Lecture demo by Dr. Robert Butler using the 9-cell model.
- Build A Better Wall 1: Parts & Construction: How can a building be made stronger for earthquake safety? (9min 15s) Lecture demo of the 4-cell model by Dr. Robert Butler.

Animations

- Buildings In Earthquakes—How does construction affect the intensity of shaking that you feel? (6min 25s)
- Take 2: Myth-conceptions Magnitude vs. Intensity: Is seismic intensity really different than an earthquake's magnitude? (1min 55sec)
- Building Resonance: Structural stability during EQs Why do some buildings fall in earthquakes? (5min 31s)

Related activity

- Variations of the BOSS Model of building resonance. [How can we model the effect of resonance on buildings during an earthquake?]

INSTRUCTOR PREPARATION

Familiarize yourself with the following resources:

- Appendix A—Vocabulary
- Appendix B—Instructions for constructing the model wall frames
- Appendix C—Images of first floor structural failure in 5-minute activity
- Appendix D—Instructor Background Non-Technical Building Engineering
- Appendix E—FEMA Resources for Seismic Design and Retrofitting Homes

ACTIVITIES AND DEMONSTRATIONS

IF YOU HAVE 5 MINUTES

Did You Know?

- Did you know that buildings can be designed to safely respond to the forces from earthquake ground motion?
- Using a simple model wall frame, we can provide key structural elements to stabilize the wall to resist and transfer lateral shear forces that result from earthquake shaking. Remind learners that the model demonstrates only certain characteristics of real walls.

Preparation

- Prepare a demonstration model wall making sure each bolt and nut connection between the craft sticks are lightly tightened so that the wall will stand upright on its own, but with a shake, will collapse. Also have reinforcement supplies available: shear wall, structural members, gussets, string, and small binder clips.

Procedure

1. Show learners the model and tell them that it represents part of the frame of a building. Describe the horizontal and vertical components of the unreinforced wall.

   Questions for Discussion:

   - If I give the base of the wall a sharp push from the left (point in the correct direction), what do you think will happen? (*It might or will fall.*)
   - Which direction will the wall fall? Ask learners to point in the direction. Then give the base of the model wall a sharp push to the right. (*The wall will collapse in the opposite direction due to Newton's 3rd law of motion, that every action has an equal and opposite reaction.*)

2. After the wall falls, reset the wall to standing upright.

   Question for Discussion:

   - What held the wall up before the shake? (*Inertia! Newton's first law of motion states that an object will remain in a balanced position unless there is an external force applied, such as an earthquake! The weight or force of gravity is balanced between the interaction of the vertical and horizontal elements.*)

3. Earthquakes cause the ground to move in all directions, but we will only model shaking in one direction. Structural engineers know that buildings need to resist shearing—that is, back-and-forth—motions which can cause structures to fall off their foundations as the ground shakes, or cause walls to collapse.

   Question for Discussion:

   - Did you notice which level of the wall collapsed first? Why do you think that happened? (*The ground floor failed first because it was too weak to transfer enough horizontal force to move the upper stories. Note: A real world example are buildings that have "soft stories" (soft first floors) such as houses with garages below living areas and ground floors with unreinforced cripple walls. See Figures 2a and 2b.*)
     Show enlarged versions of structural failure photos or project the images (APPENDIX C).

Figure 2a: Soft first floor garage lacking shear strength collapsed house.

Figure 2b: Cripple wall lacking shear strength collapsed house.

4. Let's see what we can do to strengthen the wall. Attach the 6" square of file folder to one of the lower cells using a small binder clip on the horizontal and a clip on each of the vertical craft sticks.

Question for Discussion:

- What will happen when I give the model wall a shake? (*The lower wall will remain standing, and the top floor will fail.*)

5. Continue adding different types of structural reinforcing elements to resist shear forces including:
   - Gusset—a triangular plate or bracket for strengthening an angle in framework (as in a building or bridge)
   - Cross members in V- or X-style cross bracing uses two diagonal members to resist sideways forces, depending on the direction of loading.
   - Steel cable — used in cross bracing holding structural members in tension.
   - Moment connection —Rigid connections do not permit any motion of the structural elements relative to each other. (Firmly tighten the nut against the bolt.) Note: Rigid moment connections need to be carefully designed to accommodate the maximum load anticipated.

   Point out that the structural members create a load path for the mass of the structure to be carried to the ground. If all of the components of a building or structure are not tied together, the individual sections will move independently and can pull apart, allowing partial or total collapse to occur.

IF YOU HAVE 20-MINUTES

Did You Know?

- Did you know that structural reinforcement can be applied to older structures as well as new construction?

Science and structural engineering help to solve design challenges for cities in earthquake vulnerable regions. Improved seismic design and seismic retrofitting are long term (mitigation) strategies to increase overall preparedness. This results in homes and other buildings that are better able to withstand moderate to large seismic events, improving resilience to earthquake shaking.

This activity builds on the 5-minute activity and allows learners in small groups to design and experiment with their own combinations of structural reinforcement using the model wall. (Optional: Have students use the engineering design process (see Appendix F) to create and test their designs.)

Instructor Preparation

Prepare enough model wall frames and bags of reinforcing components for each learner group.

Check that model wall connections are lightly tightened so that the wall will stand upright on its own, but with a shake, the wall will collapse (Figure 3). Also have reinforcement supplies available: shear wall, structural members, gussets, string, and small binder clips.

Procedure

1. Start with the 5-minute activity including the questions and instruction.
2. Distribute the model wall frames with accompanying bags of reinforcing components to each learner group.
3. Ask learner groups to experiment with the reinforcing components taking turns trying different types and combinations of reinforcing (8–10 minutes).
4. Return supplies. Summarize the activity and ask learners for key take-away ideas they learned and why structural reinforcement is important.

Questions for Discussion:

- What would happen to pictures and objects hanging from a wall during an earthquake? What could be done to keep them from falling off the wall or shelf? (*Pictures and objects will sway and potentially fall.)*

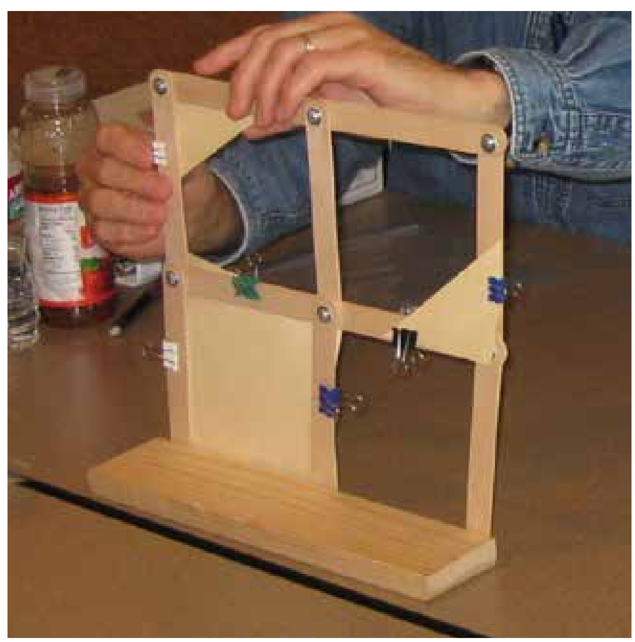


Figure 3: Learner adds a gusset to the basic 4-cell model wall frame. Image source: SERC

Pictures can be secured with hangers designed to prevent the picture hanging wire from shaking off the hook. Museum putty can safely secure objects onto shelves. Dishes in cabinets can be secured with seismic latches that keep cabinet doors closed.)

IF YOU HAVE 45 MINUTES

Did You Know?

- Did you know that wood framed homes that are properly reinforced and tied to their foundations are one of the safest places to be during an earthquake?

In earthquake prone areas of the west coast, many wood framed and unreinforced masonry homes were built before updated building codes with modern seismic standards. People who live in these types of homes are vulnerable to injury and displacement due to serious damage or destruction in an earthquake. The good news is that homes and buildings can be seismically retrofitted to make them structurally safe during an earthquake to sustain as little to no damage as possible. In this activity, we are going to explore several types of structural reinforcement that can make a life saving difference in a home.

We will then apply our new understanding to real world challenges in our cities and communities.

Instructor Preparation

Prepare enough model wall frames for each learner group. Each bag of reinforcing components needs additional supplies including 6 or more structural members and 12-16 small binder clips for this expanded activity (Figure 4).

Check that model wall connections are lightly tightened so that the wall will stand upright on its own, but with a shake, the wall will collapse.

Prepare to project the video: Buildings in Earthquakes—How does construction affect the intensity of shaking that you feel? (6min 25s)

Review and have available Appendices C, D and E for important background information needed for instruction and group discussion.

Appendix F NGSS Science and Engineering Resources provides a context for how the activity fits into STEM design engineering.

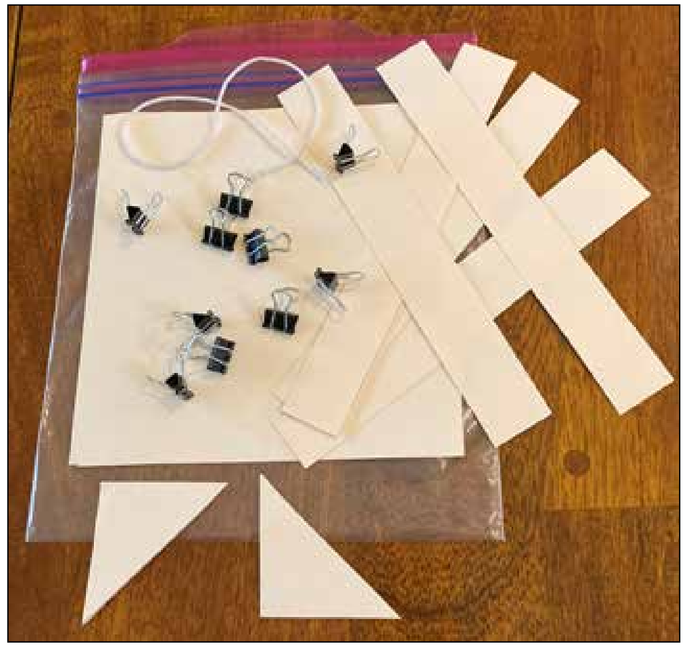


Figure 4: Structural reinforcement components for the model wall frame. Template for reinforcements in Appendix B.

Procedure

1. Start with the 5-minute activity including the questions and instruction.
2. Distribute the model wall frames with the accompanying bags of reinforcing components and a copy of *Types of Structural Reinforcing* (Appendix B) for each learner group.
3. Ask learner groups to experiment by trying different types and combinations of the reinforcing components (15–20 minutes). Then return supplies.

Ask learners to take notes on the 6:25 minute video either in their lab notebook or on paper. Tell learners that the video will help tie the activity to critical real world earthquake resilience challenges and opportunities.

Show the video, Buildings In Earthquakes—How does construction affect the intensity of shaking that you feel? (6min 25s)

4. Lead a discussion about the video using the questions.

Questions for Discussion:

- The type of material and how it is used affects how a building performs during an earthquake. What type of materials generally withstand earthquake shaking? (wood, steel, reinforced concrete) What type of materials are more prone to failure? (*brick, stone and adobe)*

- What types of buildings in general are most prone to failure around the world? (*older, unreinforced masonry buildings)*
- What types of materials and designs are more prone to damage to homes during strong or prolonged shaking? (*Older homes, not tied to the foundation, lower floors without shear strength.*)
- What are the risks for people running out of a building during or following earthquake shaking? (*Unreinforced masonry or stone facades, parapets, and brick chimneys can fall and cause injuries.) What preventive actions should you take during an earthquake? (If you receive a ShakeAlert-powered alert or experience shaking, drop, cover and hold on.*)
- How can homes be made safer? (*Retrofit by tying walls to the foundation and adding plywood shear walls or diagonal bracing*. Figure 5.)
- What are other innovations that can keep larger structures safe from damaging earthquakes? (*base isolation, and tuned mass dampers;* Figure 6).

Figure 5: Structural reinforcements showing gussets, steel bracing and moment connections in an unreinforced masonry building. Image source: Dave Mathews

Figure 6: Base isolators at the Washington Emergency Management Division building. Photo courtesy of Washington State Military Department Emergency Management Division

Questions for Larger Discussion:

The following questions focus on building and home seismic safety and resilience.

- Why would homeowners want to retrofit their homes for earthquake safety? (*Improve a home's ability to keep residents safe during an earthquake and the house habitable after a major disaster. Reduce repair costs after a seismic event. Reduce earthquake insurance premiums. The goal of retrofitting is for homeowners to shelter in place and survive a major earthquake.*)
- What are some of the challenges to retrofitting homes and buildings? (*Answers vary and may include: cost, unaware of earthquake risk, unaware of deficiencies in their house/building, lack of building codes for retrofitting and enforcement, lack of legislative will power to make systemic changes in laws and building codes, inferior or incomplete retrofits by contractors or homeowners, and other factors, lack of home ownership.*)
- What are some positive steps that can be made to reduce risk to buildings and homes? (*Answers vary and may include: becoming more aware of issues and vulnerabilities, passing building codes for home retrofits, more grants made available to assist with the costs of retrofitting, homeowners making their own retrofit improvements to their homes.*)

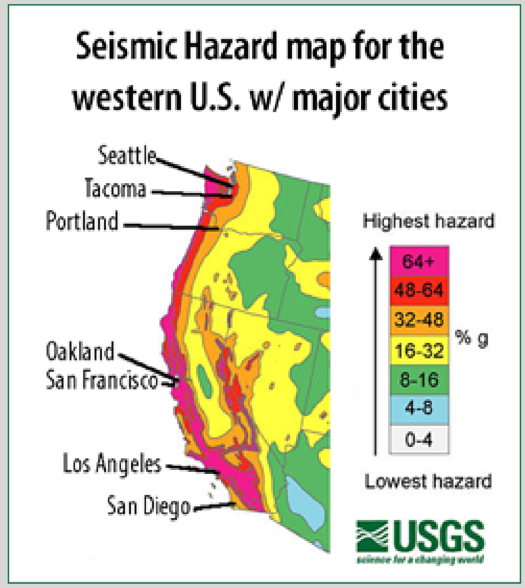
What percentage of homes in earthquake-prone areas are vulnerable to damage from an earthquake?

Some examples:

- Between 2 and 3.5 million single-family homes in California could be damaged in an earthquake of magnitude 8.0 or higher along the San Andreas Fault. Source: CoreLogic, 2016 CoreLogic® California Earthquake Risk Analysis

- A 2019 survey of Oregon housing data found that the vast majority of the 1,750,540 single-family housing units distributed throughout the state are located in areas of high seismic risk. Over 50% of these homes were built before Oregon had any seismic building standards. In Portland, it is much worse. 78% of Portland homes were built before the first seismic standard in 1974. Source: Oregon Seismic Safety Policy Advisory Commission, 2021 Publication 21-02, Single-Family Home Retrofit in Oregon.

- It is estimated that in King County, Washington (which includes Seattle, Tacoma and other cities along the I-5 corridor), more than 250,000 homes do not meet earthquake safety codes. Source: Seattle Homeowners Plan for the Next Earthquake



Seismic hazard map. Highest-hazard zone in Washington, Oregon, and Northern California is due to potential Great earthquake along the Cascadia Subduction Zone. Highest-hazard zone for much of California is due to the San Andreas Fault Zone.

APPENDIX A—Vocabulary

Braces or Bracing—structural elements built into a wall to add strength. These may be made of various materials and connected to the building and each other in various ways. Their ability to withstand stress depends on the characteristics of the materials and how they are connected.

Gusset—a triangular plate or bracket for strengthening an angle in framework (as in a building or bridge)

Load—the sum of vertical forces (gravity) and horizontal forces (shear forces) acting on the mass of a structure. The overall load is further broken down into the loads of the various parts of the building. Different parts of a building are designed and constructed to carry different loads.

Load path—the path a load or force takes through the structural elements of a building.

Rigid connections or moment connections—connections that do not permit any motion of the structural elements relative to each other. Rigid moment connections need to be carefully designed to accommodate the maximum load anticipated.

Shear force—force that acts horizontally (laterally) on a wall. These forces can be placed on buildings by earthquakes and by wind, among other things. Different parts of a wall experience different shear forces.

Shear walls—walls added to a structure to carry horizontal (shear) forces. These are usually solid elements and are not necessarily designed to carry the structure's vertical load.

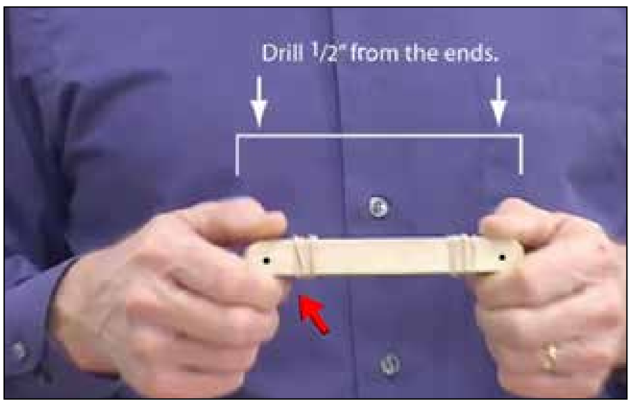
Structural elements or structural features—a general term for all the essential, non-decorative parts of a building that contribute structural strength. These include the walls, vertical column supports, horizontal beams, connectors, and braces.

APPENDIX B—Directions for constructing the model wall

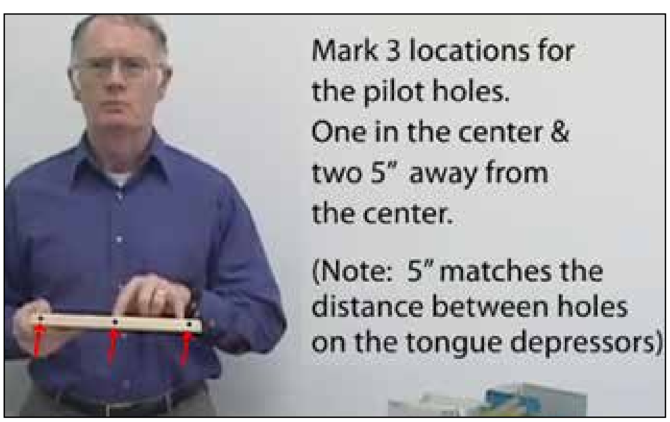
Watch video on how to construct the 4-cell model wall. Images in steps 1–6 below are screen grabs from the video:
Build A Better Wall 1: Parts & Construction: How can a building be made stronger for earthquake safety? (9:15 minutes)

Left: *Basic 4-cell model.* ***Right***: *Expanded 9-cell model demonstrated in this video: Build a Better Wall: How can we make a building more earthquake proof?*

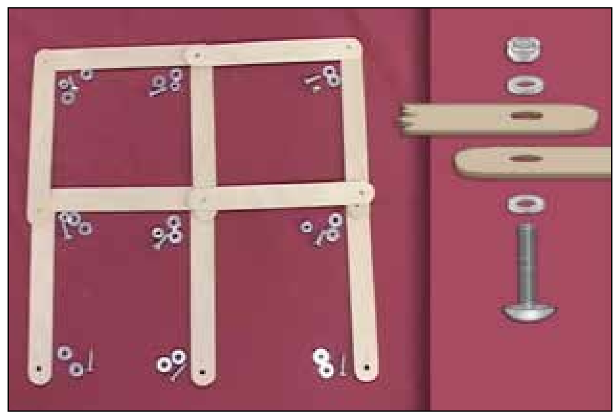
1. Stack about 12 craft sticks one on top of the other. Wrap a rubber band around the center to hold them together. Using a 11/64" diameter drill bit, carefully drill a hole through all the sticks at once, ½" from the end of the stack. Drill slowly to avoid cracking the wood.



2. Mark the location of 3 holes in the base that will hold the first row of craft sticks. The first mark will be in the center of the narrow edge slightly closer to one edge to accommodate the end of the craft stick (see illustration). Then measure and place a mark 5" in each direction from the center also slightly closer to one edge. Use a 11/64" diameter drill bit to drill shallow ¼" pilot holes for the 3 wood screws.

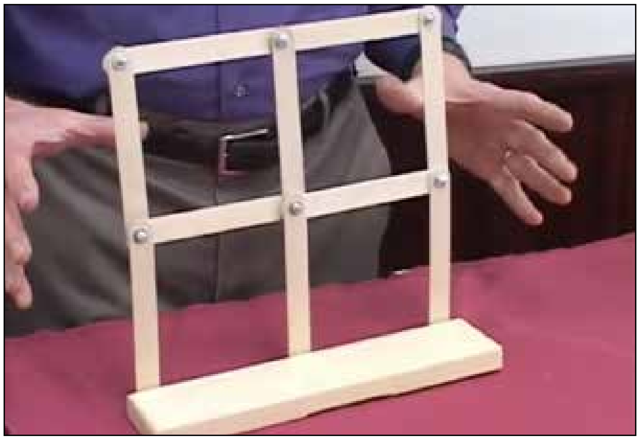


3. Using the bolts, washers, and nuts, assemble the 10 craft sticks to build a model wall. Note: Washers reduce friction and help support the craft sticks as they are manipulated.

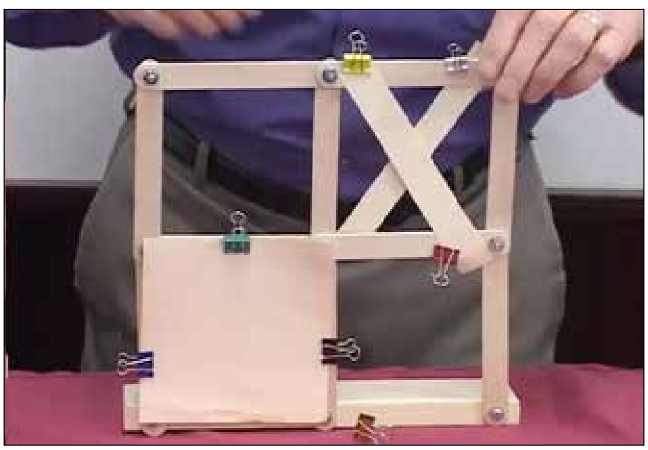


4. Use the small wood screws to mount the assembled wall to the 2" x 6" base, fastening at the bottom and in the center. Leave the pre-drilled holes sticking up far enough above the top to accept the drilled craft sticks. Tighten the wood screws until the tongue depressor can still easily pivot.

5. Experiment with tightening bolts and washers until they are just tight enough for the wall to stand on its own, but loose enough so that the wall will fall with horizontal motion.



6. Now for the fun part: testing the structural reinforcement components. See different styles of structural bracing on page 12.



Notes:

Structural reinforcement components for each wall (Parts shown in photo below, and template for the printout on next page)**:**

After printing and cutting, assemble the reinforcement components in a quart-sized zip lock bag for each model wall.

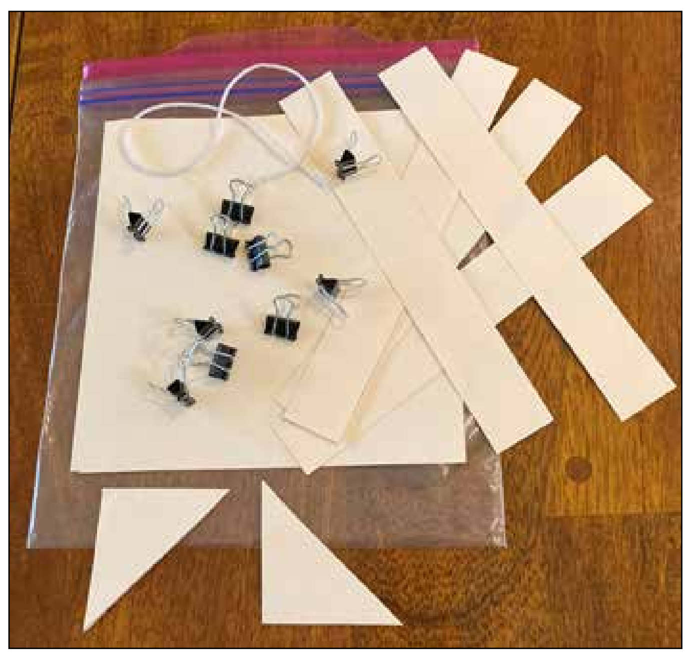
Note: if using a 3 X 3 cell model, provide additional cross members and binder clips.

For the 15-minute activity (basic 4-cell model wall):

1 Shear wall
2 Cross members
2 Gussets for corner bracing
10 or more small binder clips (1/4" or 5/16th capacity)

For the 5-minute demonstration and the 30- to 45-minute activity (basic 4-cell model wall):

1 Shear wall
6 Cross members
2 Gussets for corner bracing
10" string
16 or more small binder clips (1/4" or 5/16th capacity)



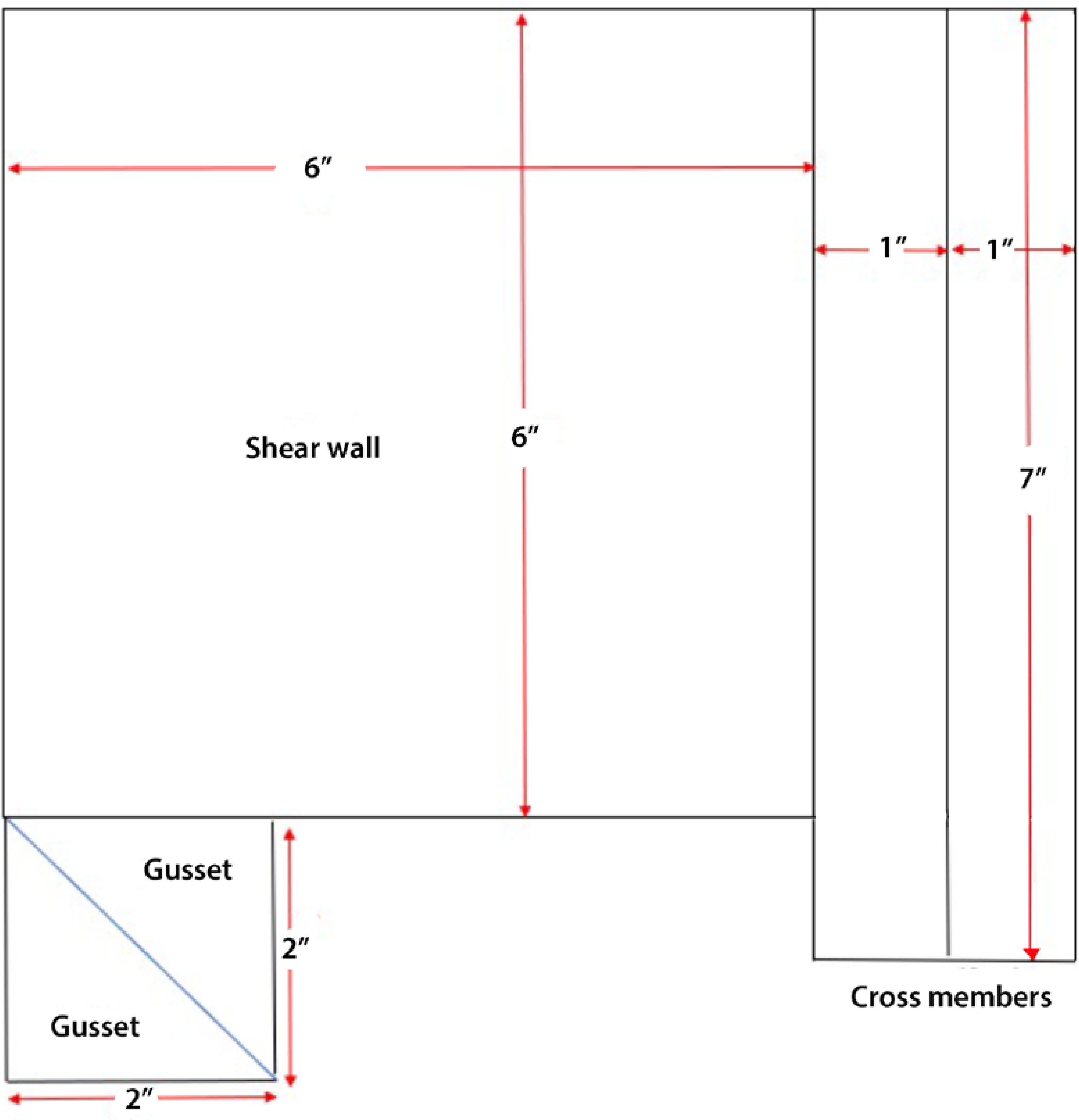
Structural components for adding to the wall. Note that the additional "structural members" are for the 30- to 45-minute hands-on activity.

Structural Reinforcement Template

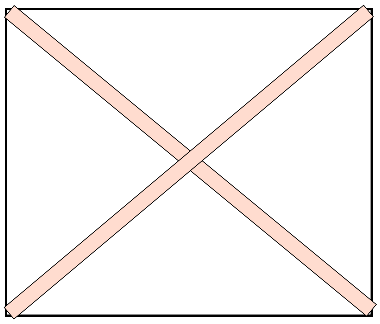
Print on manila card stock or similar.

1 Shear Wall, 2 Cross Members, and 2 Gussets

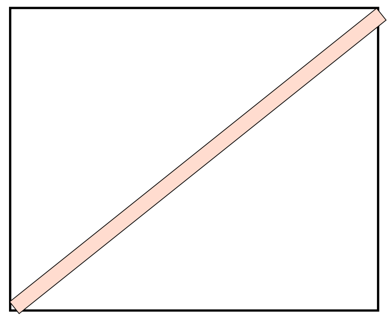
Note: create additional Cross Members for other reinforcement styles (see next page).



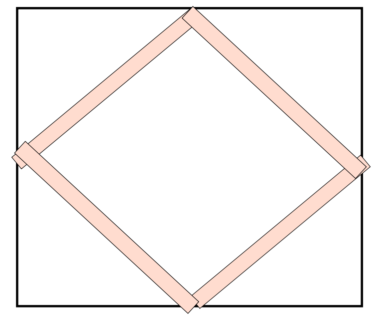
Types of Structural Bracing



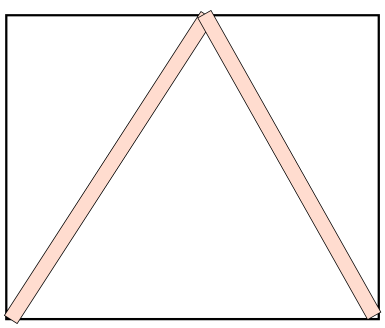
X–cross



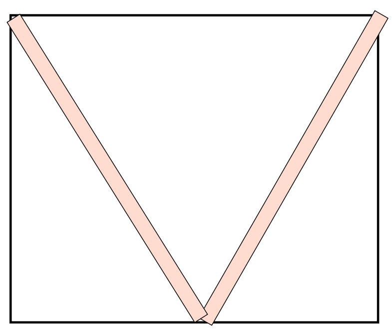
Single diagonal



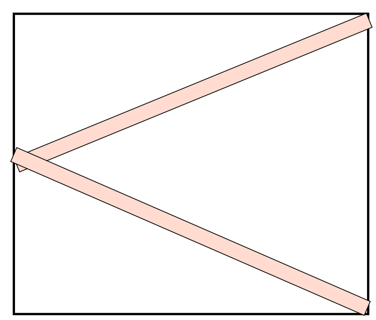
K-K (diagonal sway)



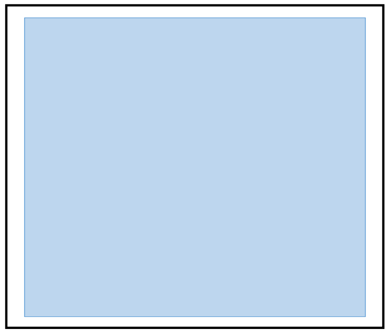
Inverted V (chevron)



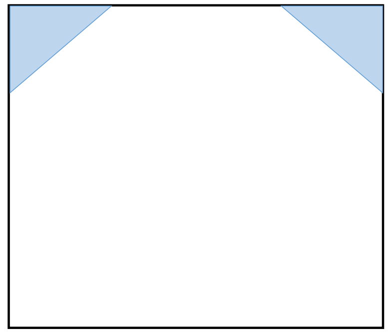
V (inverted chevron)



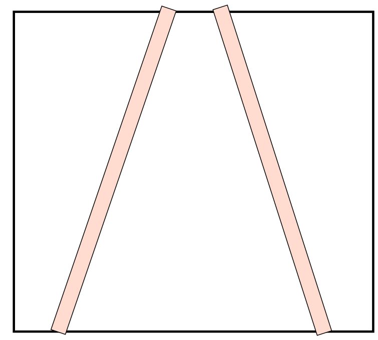
K (right angle chevron)



Shear Wall



Corner (knee)



Eccentric bracing

APPENDIX C—Images of first-floor structural failure (images from Figures 2a and 2b)

Soft first floor garage, lacking shear strength, causes house to collapse during strong shaking. Image source: U.S. Geological Survey

Cripple wall lacking shear strength contributed to house collapse. Image source: U.S. Geological Survey

APPENDIX D—Instructor Background Non-Technical Building Engineering*

During an earthquake, a spot on the Earth might be seen to move erratically, tracing out a random path resembling that of a wandering insect. "Ground motion" is a literal description since the ground moves (generally for a distance measured only in centimeters or less) relative to its starting point. As the seismic waves move through the ground, the ground and buildings sitting on (and in) the ground move back and forth. During this back and forth motion, the velocity of the ground motion changes rapidly (this is called acceleration). The acceleration of the ground determines the amount and direction of force on a building.

Two other unit measures are related to acceleration. Velocity, measured in centimeters per second, refers to the rate of the motion at a given instant. Displacement, measured in centimeters, refers to the distance an object is moved from its resting position. If you move your hand back and forth rapidly in front of your face, it might experience a displacement of 20 to 30 centimeters in one second and its acceleration and velocity may be quite high, but no damage will be done because the mass of your hand is low. In a building with a mass in the thousands of metric tons, tremendous forces are required to produce the same motion. These forces are transmitted throughout the structure, so if the movement repeats for some minutes the building may shake to pieces.

To overcome the effects of these forces, engineers rely on different design systems to transfer forces to the ground. In the vertical plane, three kinds of structural systems are used to resist lateral forces: shear walls, braced frames, and moment-resistant or rigid frames. In the horizontal plane, diaphragms (generally formed by the floor and roof planes of the building) or horizontal trusses are used. Diaphragms are designed to receive lateral force between the vertical resistance elements (shear walls or frames). Shear walls are solid walls designed to carry the force to the vertical resistance system. In a simple building with shear walls at each end, ground motion enters the building and moves the floor diaphragms. This movement is carried by the shear walls and transmitted back down through the building to the foundation. Braced frames act in the same manner as shear walls but may not carry as much load depending on their design. Bracing generally takes the form of steel rolled sections (I-beams), circular bar sections (rods), or tubes. Rigid frames rely on the capacity of joints to carry loads from columns to beams. Because these joints are highly stressed during movement, the details of their construction are important. As a last-resort strategy, rigid frames use the energy absorption obtained by deformations of the structure before it ultimately fails.

Architecturally, rigid frames offer a certain advantage over shear walls or braced frames because they tend to provide structures that are much less obstructed internally than shear wall structures. This allows more freedom in the design of accompanying architectural elements, such as openings, exterior walls, partitions, and ceilings, and in the placement of building contents, such as furniture and loose equipment. Nevertheless, moment-resistant frames require special construction and detailing and therefore, are more expensive than shear walls or braced frames.

**Note: This text block comes from "Seismic Sleuths" Build a Better Wall Activity, section 4.1, Teacher Background, which is adapted from FEMA 99, October 1990, Improving Seismic Safety of New buildings: Non-technical Explanation of the NEHRP Recommended Provisions .*

APPENDIX E—FEMA Resources for Mitigation, Seismic Design and Retrofitting Homes

FEMA P-749 Earthquake-Resistant Design Concepts An Introduction to the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures / December 2010 Chapter 3 Design and Construction Features Important to Seismic Performance page 35

To satisfy the performance goals of the NEHRP Recommended Seismic Provisions, a number of characteristics are important to the design of buildings and structures to ensure that they will behave adequately in strong earthquakes.

These include:

- Stable foundations
- Continuous load paths
- Adequate stiffness and strength
- Regularity
- Redundancy
- Ductility and toughness
- Ruggedness

FEMA P1100 Vulnerability-Based Seismic Assessment and Retrofit of One- and Two-Family Dwellings

Provides assessment and retrofit provisions of one—and two-family wood light-frame residential buildings. This class of structure represents the most common type of dwelling in the United States. Although this type of construction has generally provided good performance in past earthquakes, there are well-known vulnerabilities that have led to large numbers of homes being rendered uninhabitable or even unrepairable following an earthquake.

The scope of P-1100 is limited and addresses only the most common vulnerabilities which include:

- Anchorage of the walls to the foundation and connection of the first floor above the foundation (homes with a crawlspace and hillside homes)
- Bracing of cripple walls (crawl space homes)
- Lower-level bracing of living space over a ground level garage
- Brick masonry chimneys
- Anchorage of masonry fireplace surrounds

Improved seismic design and seismic retrofitting of vulnerable configurations will increase the probability that homes are available to provide shelter immediately following moderate to large seismic events. The purpose of this prestandard is to provide a methodology to identify and retrofit specific known vulnerabilities in wood light-frame dwellings.

NGSS Science and Engineering Practices

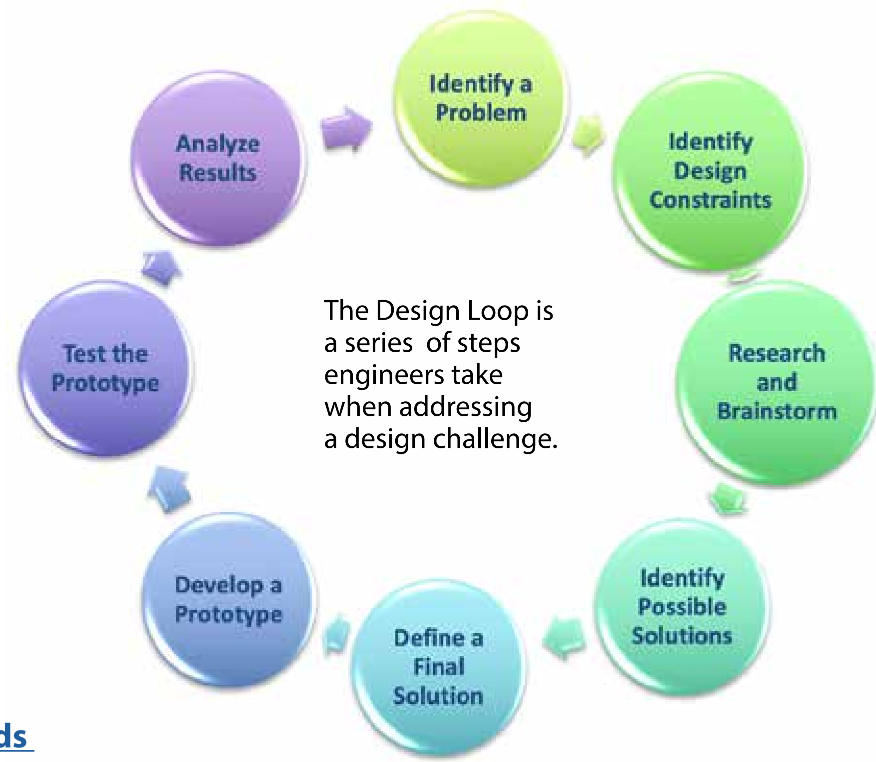
1. Asking Questions (for science) and Defining Problems (for engineering)
2. Developing and Using Models
3. Planning and Carrying Out Investigations
4. Analyzing and Interpreting Data
5. Using Mathematics and Computational Thinking
6. Constructing Explanations (for science) and Designing Solutions (for engineering)
7. Engaging in Argument from Evidence
8. Obtaining, Evaluating, and Communicating Information

NGSS Engineering Design Process

1. Identify a problem
2. Identify design constraints
3. Research and brainstorm
4. Identify possible solutions
5. Define a final solution
6. Develop a prototype
7. Test the prototype
8. Analyse and communicate results

Links to Design Challenge Activities

- The Strongest Strongholds
- STEM Design Challenge: Building Earthquake Proof Buildings and a Shake Table
- Activity: Build an Earthquake Resistant Structure
- Build an Earthquake Proof Structure



NGSS Science and Engineering Standards

Earth and Human Activity

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. •Analyze and interpret data to determine similarities and differences in findings.	**ESS3.B: Natural Hazards** Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces can help forecast the locations and likelihoods of future events. (MS-ESS3-2)	**Patterns** Graphs, charts, and images can be used to identify patterns in data.(MS-ESS3-2) **Connections to Engineering, Technology, and Applications of Science** **Influence of Science, Engineering, and Technology on Society and the Natural World** • The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time.

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