Smithsonian

STC

SCIENCE AND TECHNOLOGY CONCEPTS™

MIDDLE SCHOOL

Earth's Dynamic Systems

Investigation 1.1

Krakatau, 1883

Materials

For you

- Science notebook

For your group

- 1 Krakatau Card Set

Procedure

1. Krakatau (Figure 1.1) is sometimes referred to using its English name, Krakatoa. In 1883, people all over Indonesia and around the world observed phenomena related to events happening on Krakatau. The Krakatau Card Set includes some observations and illustrations of the phenomena.
2. The Krakatau Card Set describes several locations near the island. Use Figure 1.3 to locate the following:
   - **a.** Anjer
   - **b.** Bantam (now Banten)
   - **c.** Batavia (now Jakarta)
   - **d.** First Point
   - **e.** Java
   - **f.** Krakatau
   - **g.** Merak
   - **h.** Sunda Strait
   - **i.** Sumatra
   - **j.** Tyringen
3. Read or examine each card in the Krakatau Card Set. Think about how you described the term "phenomena" during Getting Started. Select one card that you think represents a good example of a phenomenon. Record your example in your science notebook and explain why you think it is a good example of a phenomenon. Be prepared to share your example with the class.
4. Continue reading and examining each card in the Krakatau Card Set. In your science notebook, record any questions you have about the phenomena. Discuss these questions with your group.
5. Discuss where you think the island went and why the events that were happening made people record the observations and illustrations they did. Record your group's responses in your science notebook.
6. In your science notebook, explain what you think happened on Krakatau in 1883. Support your explanation using your prior knowledge and evidence from the card set. (**Note:** You may wish to organize your explanations using events that occurred before, during, and after what occurred in 1883.)
7. Between 1880 and 1884, many seismic events occurred in Indonesia near Krakatau. A summary of these events is shown in Table 1.1. Read through the descriptions of each seismic event. In your science notebook, record any questions you have about the phenomena.

Figure 1.3
Map of Java and Sumatra
CREDIT: Margaret Baxter/© Carolina Biological Supply Company

Table 1.1. Seismic Events Occurring Near Krakatau		
Date	**Time**	**Remarks** (with distance and direction of cities from Krakatau noted)
Sept. 1, 1880	4:35 p.m.	Several earthquakes, largest with epicenter in Bantam (155 km E) felt as far as northern Australia; the lighthouse on Java's First Point (74 km SSE) is damaged.
Mar. 10, 1882	4:57 p.m.	Earthquake with epicenter in Pekalongen (485 km E); felt in Bantam (155 km E).
May 9–10, 1883		Earthquakes felt at Java's First Point lighthouse (74 km SSE).
May 15–20, 1883		Earthquakes felt at Ketimbang (40 km NNE).
May 17, 1883	10:25 a.m.	Light tremor felt at Anjer (55 km E).
May 27, 1883	2:00 a.m. 3:55 a.m.	Two shocks felt at Tyringen; last also felt in Pandeglang (74 km E × N).
May 27, 1883	3:30 a.m. 4:20 a.m.	Earthquake ("horizontal shock") felt at Teluk Betong (80 km NNW) lasts 15 sec. Three "heavy jolts" are felt at 3:30 and 4:20 a.m. at lighthouse on Java's First Point (74 km SSE).
May 27, 1883	4:00 a.m. 4:30 a.m.	Two shocks are felt at Valakke Hoek lighthouse (75 km SSW).
May 31, 1883		During night of May 31–June 1, hopper *Bintaing* is "suddenly rocked" in water while anchored at Blinjoe (500 km NE).
July, 1883		Earthquakes felt in Java.
Aug. 26, 1883	7:30 p.m.	Six earthquake shocks felt during the night.
Aug. 26, 1883	7:50 p.m.	Severe earthquakes reported at Java's First Point lighthouse (74 km SSE).
Aug. 26, 1883	8:30 p.m.	Violent eruptions occur on Krakatau; strong ground shaking felt in Anjer (55 km E).
Aug. 27, 1883	2:00 a.m. 3:00 a.m.	Two earthquakes reported at Anjer (55 km E), believed to be air wave effects from eruption.
Aug. 27, 1883	1:30 a.m. 3:00 a.m. 4:00 a.m.	Three earthquakes reported at Java's First Point lighthouse (74 km SSE), believed to be air wave effects from eruption.
Sept. 1, 1883	3:45 a.m. 4:30 a.m.	Earthquakes felt at Menes (56 km SSE).
Sept. 1, 1883	4:00 a.m.	Earthquake felt at Tjimanoek (72 km SSE), 2 tremors.
Sept. 14–15, 1883		Four earthquakes felt in Padang (800 km NW) during the night.
Sept. 18, 1883	12:45 p.m. 1:00 p.m.	First earthquake felt at Ranjkas Betong (Bantam), second recorded at 1:00 p.m. at Malimping (Bantam) and Java's First Point lighthouse (74 km SSE).
Sept. 26, 1883		Detonations [from Krakatau] were distinctly heard, and tremors of the ground were reported [in Penang].
Dec. 6, 1883	7:30 p.m.	An earthquake is felt over a large part of Bantam (155 km E).
Jan–Feb. 1884		Earthquakes are felt at the Vlakke Hock lighthouse (75 km SSW).
Feb. 23, 1884		Near Batavia (160 km E), ground tremors, rattling of doors and windows, and a red glow in the west observed in the evening.
Dec. 6, 1884	7:03 p.m.	Earthquake felt over most of Bantam (155 km E).

SOURCE: Simkin, T., & Fiske, R. S. (1983). *Krakatau, 1883—The volcanic eruption and its effects.* Washington, DC: Smithsonian Institution Press.

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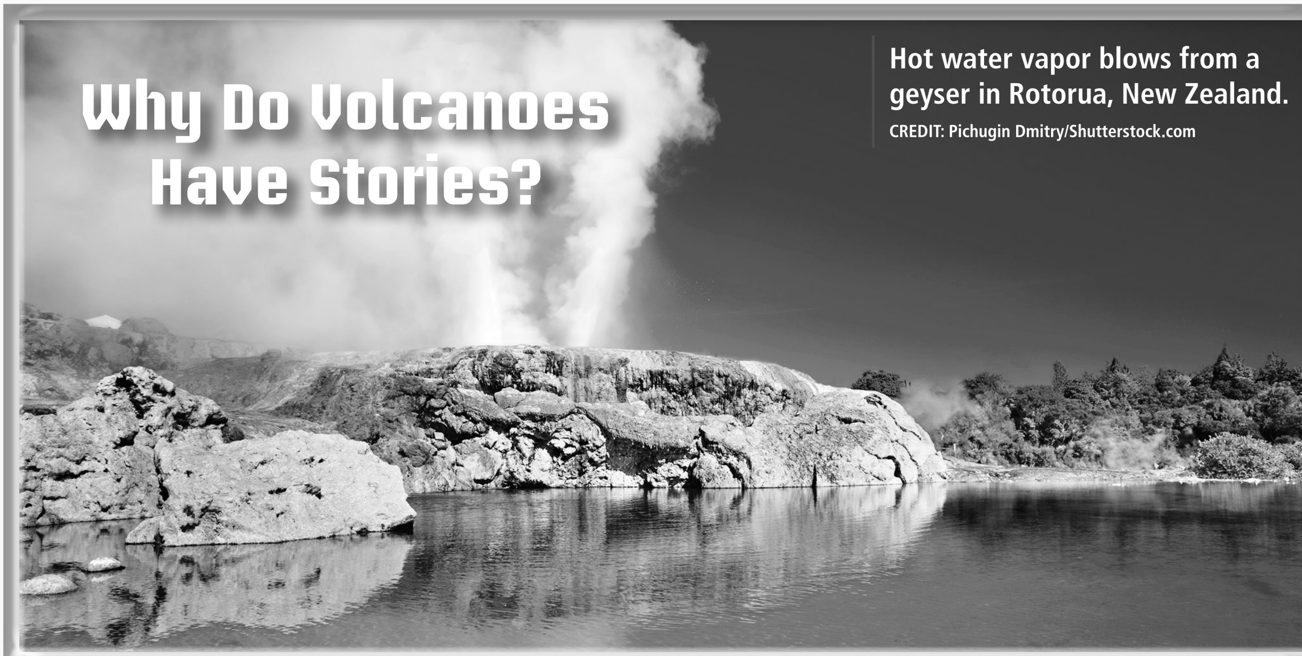
Investigation 1.1 *continued*

8. Discuss your questions with your group. Then, discuss what a seismic event is and what the data set in Table 1.1 represents. Record your group's responses in your science notebook.
9. How do you think scientists collected the data in Table 1.1? What challenges do you think you would encounter collecting seismic data from the 1800s? Record your ideas in your science notebook and be prepared to discuss them with the class.
10. In your science notebook, explain why you think seismic events occur in Indonesia. Support your explanation using your prior knowledge.
11. New Zealand is an island about 12,070 kilometers (7,500 miles) southeast of Indonesia. In New Zealand, the Maori people have stories that describe the geologic processes and phenomena they observe on their island. Read Building Your Knowledge: *Why Do Volcanoes Have Stories?* and then discuss the questions that follow the reading passage with your group. Record your group's responses in your science notebook.

Figure 1.4
Map of New Zealand
CREDIT: Margaret Baxter/© Carolina Biological Supply Company

Figure 1.5
Volcanic and seismic events are observed all over the world. Do you think these events are related? Why or why not?
CREDIT: Fotos593/Shutterstock.com

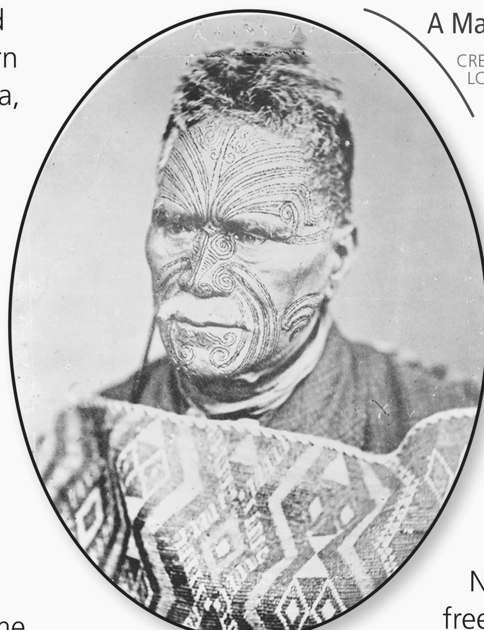


Hot water vapor blows from a geyser in Rotorua, New Zealand.
CREDIT: Pichugin Dmitry/Shutterstock.com

Why Do Volcanoes Have Stories?

New Zealand, a large island country in the southwestern Pacific Ocean near Australia, is almost always blowing off steam. If volcanoes are not exploding, then hot springs, geysers, and boiling lakes are active. When the British came to explore New Zealand, they found indigenous people called the Maori living there.

The Maori have many myths and legends that they tell to share their culture and to explain natural phenomena. One Maori tale, "How Volcanoes Got Their Fire," tells how fire came to volcanoes in New Zealand. In another tale, "Battle of the Giants," volcanoes act like giant people.


A Maori king from the early 1900s
CREDIT: Library of Congress, Prints & Photographs Division, LC-USZ62-109768

How Volcanoes Got Their Fire

A powerful medicine man named Ngatoro led his people from Hawaii to New Zealand in canoes. After they arrived, Ngatoro took his female slave, Auruhoe, and climbed the volcano Tongariro. He asked the rest of his people to stop eating until he and Auruhoe returned. He believed this would give him strength against the cold air high on the mountain. Ngatoro and his slave stayed longer than expected. His people got hungry and began eating again. When that happened, Ngatoro and Auruhoe felt the freezing cold. Ngatoro prayed to his sisters back in Hawaii to send fire to warm them. The sisters heard his cry for help and called up fire demons who began to swim underwater toward New Zealand. When the fire demons came up at White Island to find out where they were, the earth burst into flames. The demons reached the mainland and continued to travel underground toward

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Tongariro. Wherever the fire demons surfaced, hot water spewed from the earth and formed a hot spring or geyser. Finally, the fire demons burst out of the top of Tongariro. Their fire warmed Ngatoro and helped save his life, but Auruhoe was already dead from the cold. To remember the journey of Ngatoro and Auruhoe, the Maori called the mountain Ngauruhoe.

Battle of the Giants

Three volcanoes—Taranaki, Ruapehu, and Tongariro—lived near each other. Taranaki and Ruapehu both fell in love with Tongariro, but she could not decide which one she preferred. Finally, they decided to fight for her. Tearing himself loose from the earth, Taranaki thrust himself at Ruapehu and tried to crush him. "I'll get you," fumed Ruapehu. He heated the waters in his crater lake until they were boiling. Then he sprayed scalding water over Taranaki and on the countryside around him. The scalding bath hurt Taranaki badly. Furious, he hurled a shower of stones at Ruapehu. The stones broke the top of Ruapehu's cone, which ruined his good looks. "I'll show him," said Ruapehu. He swallowed his broken cone, melted it, and spat it at Taranaki. The molten cone burned Taranaki badly, and he ran to the sea to cool his burns. ■

Discussion Questions

1. Why do you think the Maori people tell stories like "How Volcanoes Got Their Fire"?
2. How do nonscientific stories differ from scientific explanations?
3. What sorts of geologic processes might the Maori people have been describing in the telling of "Battle of the Giants"?

According to the legend, Mount Ruapehu's broken top was caused by the stones that the volcano Taranaki hurled at it.

CREDIT: Pi-Lens/Shutterstock.com

Mount Ngauruhoe is located on the North Island of New Zealand.

CREDIT: TrashTheLens/Shutterstock.com

Student's Name ____ Date _____________ Class ___________

Student Sheet 2.R: How Earthquake Resistant Is Your Home or School?

1. Imagine that you live in a high-risk area for earthquakes. Complete the checklist in Table 1 to determine how earthquake resistant your home or school is. Then, complete the checklist in Table 2 to determine things you should avoid if an earthquake hits.

Table 1. Checklist for Earthquake Resistance			
Items to Check	**Questions to Ask**	**Yes**	**No**
Bookshelves	Are they secured to the wall?		
Cabinets	Are they built into or fastened to the wall?		
Heavy objects	If they are stored on shelves or in cabinets, are they stored low, so they are not above your head?		
Glass	Are there any mirrors or glass near your living area or classroom seating area?		
Television screens or computer monitors	Are they securely attached to a table, cabinet, or desk? If they are on a cart, are the wheels locked?		
Picture frames and wall hangings	Are they securely attached to the wall?		
Hanging plants	Are they in lightweight pots?		

Table 2. Checklist for Things to Avoid During an Earthquake	
Brick chimney	
Outdoor decorations and large signs	
Large windows	
Free-standing walls	
Power lines	
Large trees	

2. Use the information on this sheet to create an earthquake-preparedness plan. What could you do to make your home or school more earthquake resistant? Where would you go if there were an earthquake? Write or draw your plan in your science notebook.

Lesson Master 2.3a: Design Challenge Scoring Rubrics

Earthquake-Resistant Structure Rubric				
Criterion	**1. Beginning**	**2. Developing**	**3. Proficient**	**4. Exemplary**
Height	Group designed a structure, but it was not self-supporting.	Group designed a self-supporting structure with a height less than 20 cm.	Group designed a self-supporting structure with a height between 20 and 30 cm.	Group designed a self-supporting structure with a height greater than 30 cm.
Mass	Group designed a structure to support fewer than two bags of sand.	Group designed a structure to support two bags of sand.	Group designed a structure to support three bags of sand.	Group designed a structure to support four or more bags of sand.
Stability During Simulated Earthquake	Structure collapsed following magnitude 3.0 earthquake.	Structure withstood magnitude 3.0 earthquake but collapsed following magnitude 6.0 earthquake.	Structure withstood magnitude 3.0 and 6.0 earthquakes but collapsed following magnitude 9.0 earthquake.	Structure withstood magnitude 3.0, 6.0, and 9.0 earthquakes.

Grading Rubric				
Criterion	**1. Beginning**	**2. Developing**	**3. Proficient**	**4. Exemplary**
Written Instructions and Diagrams	Group did not present written instructions or diagrams pertaining to the design challenge.	Group presented either written instructions or diagrams that were unclear or incomplete but pertained to the design challenge.	Group presented either written instructions or diagrams that were clear and pertained to the design challenge.	Group presented written instructions and diagrams that were clear, detailed, and pertained to the design challenge.
Design Implementation	Group constructed a design that did not pertain to the design challenge.	Group constructed a design that somewhat pertained to the design challenge.	Group constructed a design that met the criteria of the design challenge.	Group constructed a design that exceeded the criteria of the design challenge.
Testing and Data Collection	Group did not test its design.	Group did not use appropriate procedures to test its design and did not collect relevant data.	Group used appropriate procedures to test its design but did not collect relevant data.	Group used appropriate procedures to test its design and collected relevant data.
Reflection and Presentation	Group presented methods and results in an incomplete and unclear manner and did not reflect on choices.	Group presented methods or results in an unclear manner or did not reflect on choices based on scientific principles.	Group presented methods or results adequately. Group reflected on choices based on scientific principles most of the time.	Group presented methods or results clearly and accurately. Group always reflected on choices based on scientific principles.

Lesson Master 2.3b: Earthquake-Resistant Design Concepts (page 1 of 5)

Many teams of scientists and engineers work with local, state, and federal lawmakers to identify earthquake hazards and encourage the design and construction of structures to withstand them. An earthquake-resistant structure is expected to include a stable foundation, continuous load paths, adequate stiffness and strength, regularity, redundancy, ductility and toughness, and ruggedness. More information about each of these characteristics follows.

Stable Foundations

At the bottom of a structure sits a foundation, which is in direct contact with the ground below. An earthquake-resistant structure has a foundation that:

- Supports the structure above it
- Minimizes movement and damage
- Anchors the structure
- Resists sliding and overturning (See Figure 1.)

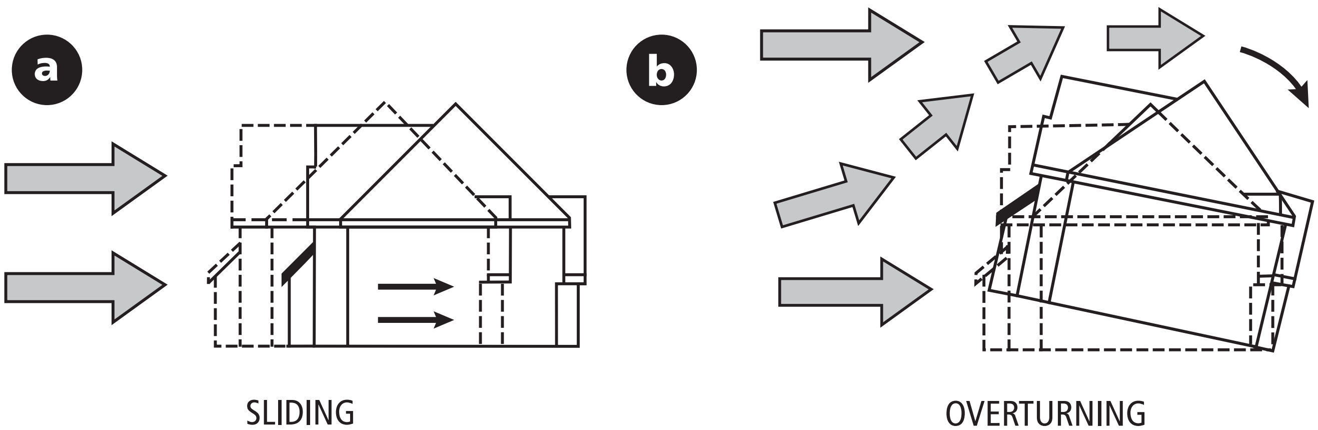
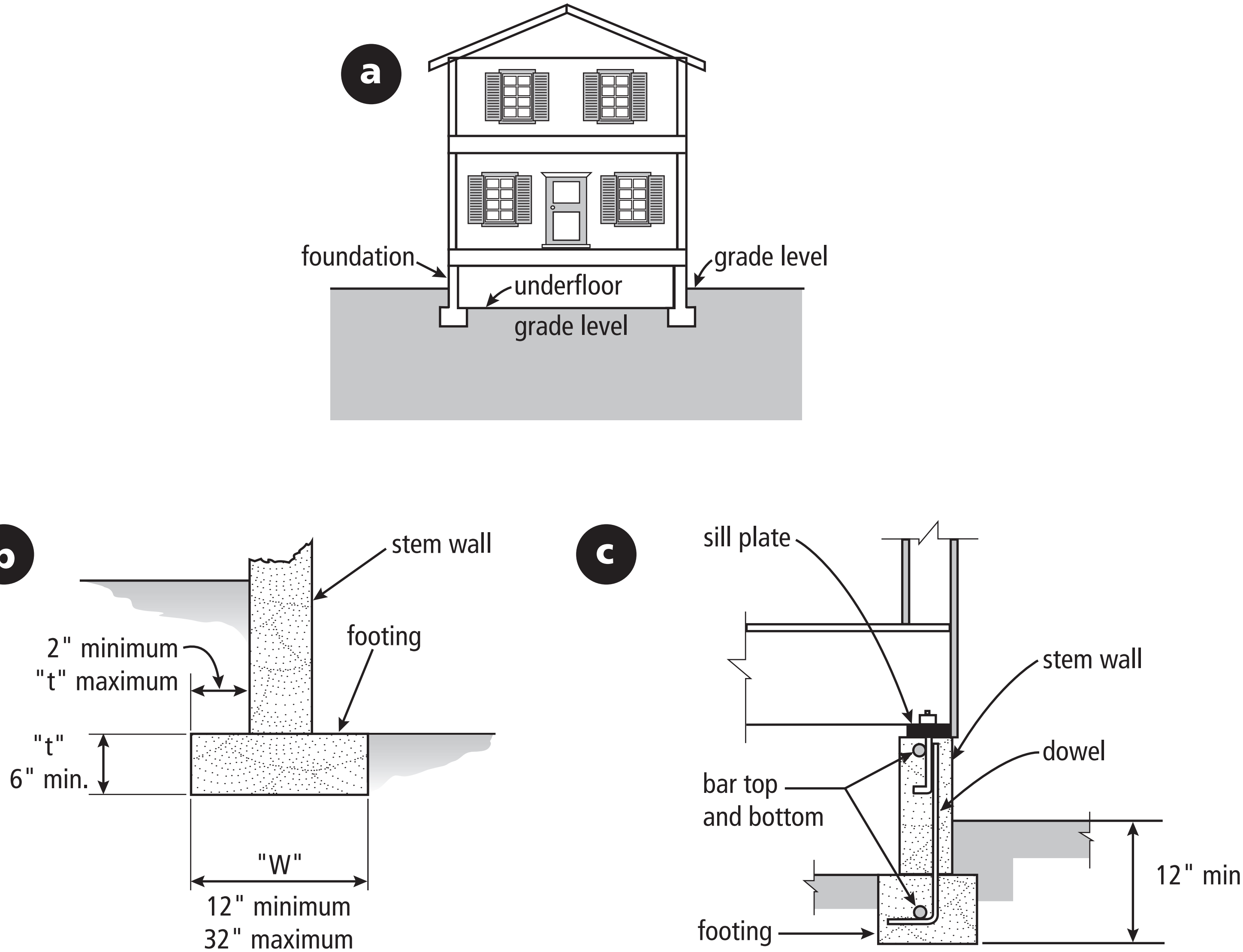


Figure 1

Foundations resist actions that cause sliding (a) and overturning (b).

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

Foundations must also provide stability to the structure if the shape of the ground below the structure changes. Foundations commonly have a large continuous piece (called a slab) and may use T-shaped footings or thicker edges to anchor the house to the ground. (See Figure 2.)



Note: Reinforcing not shown.

Figure 2

Concrete is commonly used to construct foundations that include a stem wall and footing (a).
Recommendations for design and construction include guidelines for both dimensions (b) and reinforcement (c).

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

Continuous Load Paths

The term "load path" is used to describe the transfer of energy through a structure (including walls, floors, and roof). When a structure is stable, a load applied to any part of the structure can be transferred down to the foundation and ground below. (See Figure 3.) If parts of the structure are not tied together as one system, the parts will move independently and can separate. If parts of the structure separate, it may partially or totally collapse. In an earthquake-resistant structure, all parts of the structure are tied together.

For example, a two-story structure transfers loads using:

- The roof–ceiling system and its connections to the second-story walls
- The second-story wall system and its connections to the floor–ceiling system
- The floor–ceiling system and its connections to the first-story wall system
- The first-story wall system and its connections to the foundation
- The foundation to the supporting soil

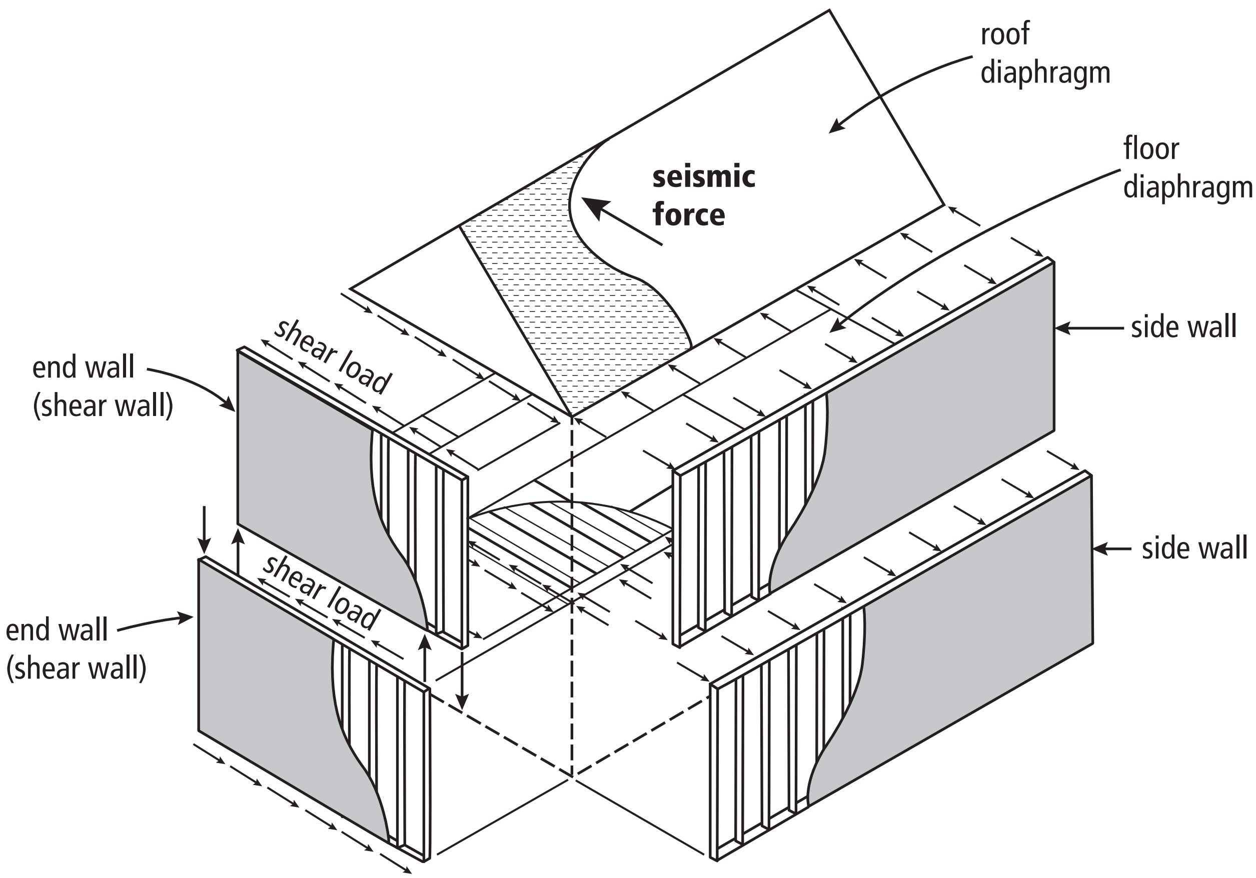


Figure 3

Adequate connection between systems ensures that a seismic force applied to any part of the structure can follow a continuous path through the building and into the foundation and ground below it.

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

Adequate Stiffness and Strength

Strong earthquakes will result in both vertical and lateral seismic forces. Particularly damaging are lateral forces that move structures horizontally. (See Figure 4.) An earthquake-resistant structure features:

- Adequate strength in all roof–ceiling, floor, and wall systems
- Adequate stiffness to limit deformation
- Adequate connection between systems to ensure a continuous load path

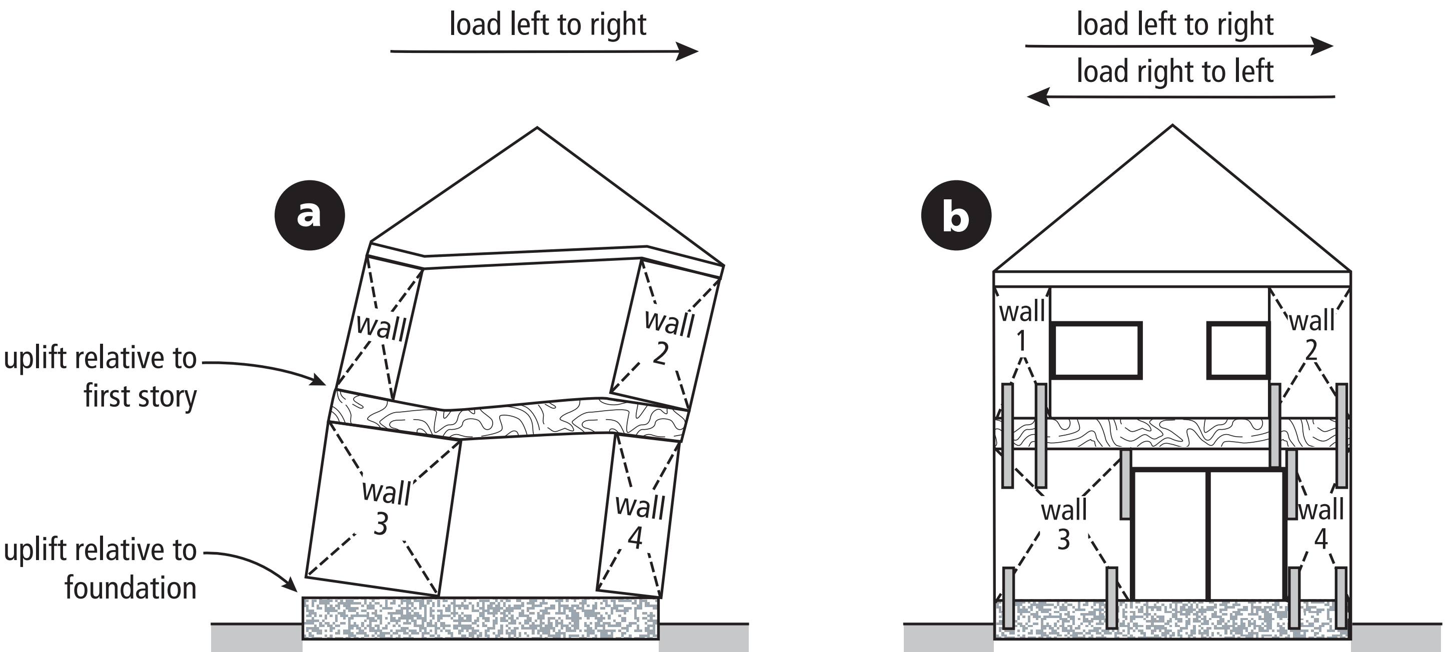


Figure 4

If a structure lacks adequate stiffness or strength, horizontal movement can cause instability (a). Adding hold-down straps helps connect walls on each story and helps resist overturning (b).

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

Regularity

A structure is "regular" if its parts are balanced in terms of mass, strength, and stiffness. A regular structure will respond to shaking in a uniform manner and dissipate energy evenly. An ideal earthquake-resistant structure has:

- A simple, rectangular shape
- Uniform and symmetric walls
- Even weight distribution
- Lower levels with longer bracing walls and upper levels with shorter bracing walls (See Figure 5.)

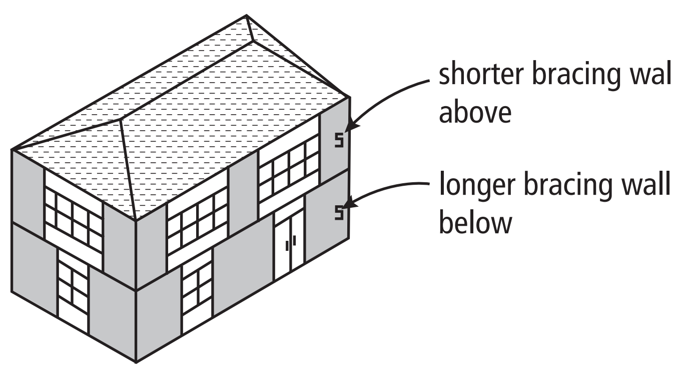


Figure 5

Placing bracing walls adjacent to each other reduces the need to transfer energy through roof and floor systems.

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

Redundancy

Redundancy is when something is repeated over and over again. In earthquake-resistant structures, critical design elements may be repeated in multiple areas. If an earthquake seriously damages a critical element, others may be strong enough to support the structure. (See Figure 6.)

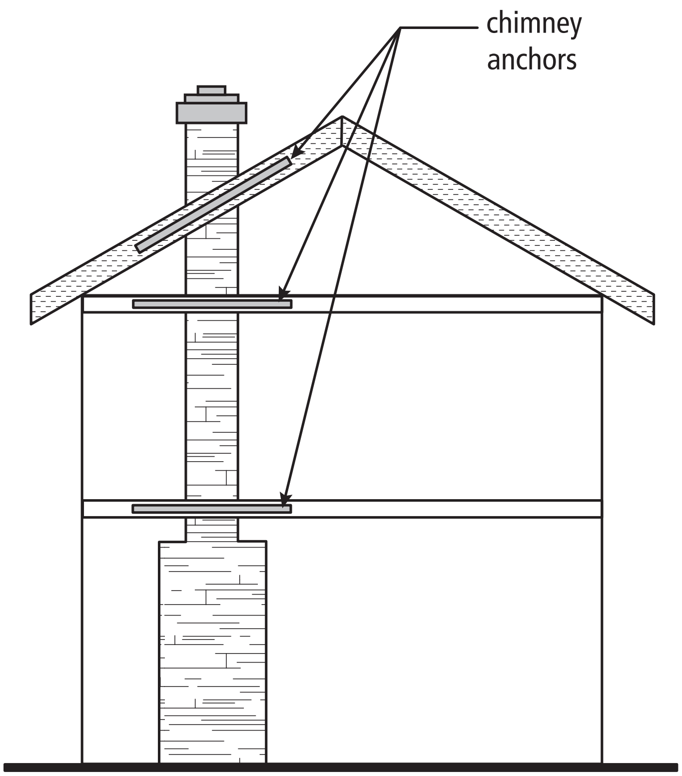


Figure 6

Steel straps are used to anchor a chimney at multiple locations. If one anchor point fails during an earthquake, others may remain intact and hold the chimney in place.

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

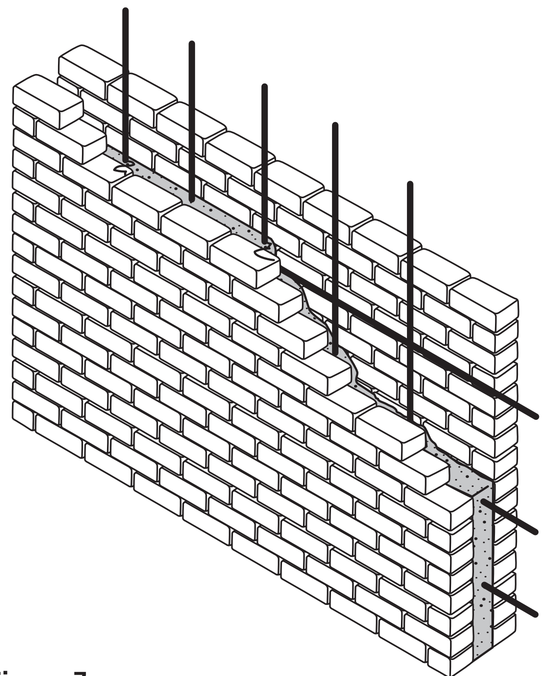


Figure 7

Brick walls can contain steel reinforcing bars. The addition of steel improves both ductility and toughness. Unreinforced brick walls are brittle. During a strong earthquake, unreinforced brick is subject to cracking and collapse.

CREDIT: Adapted from Applied Technology Council. *Unreinforced Masonry Buildings and Earthquakes: Developing Successful Risk Reduction Programs*. October 2009. (FEMA P-774).

Ductility and Toughness

Ductility describes the ability of something to deform without fracturing. Both ductility and toughness allow structures to sustain damage without collapse. Construction materials like wood, bricks, concrete, or steel all have unique properties. An earthquake-resistant design combines these materials in a way that carefully uses one material to protect others from damage. (See Figure 7.)

Ruggedness

Ruggedness describes the ability of a nonstructural building component to remain functional after strong shaking associated with an earthquake. Nonstructural components include architectural features (e.g., ceilings, stairs); mechanical devices (e.g., emergency generators, elevators); electrical components (e.g., transformers, lighting); plumbing (e.g., pipes, fixtures); and fire-suppression systems. The ruggedness of nonstructural components can be tested using real earthquakes or by simulating an earthquake using a shake table.

Learning Framework for Grades 6–8

Make connections between the sciences and engineering at every grade level

Life Science	Earth and Space Science	Physical Science
Ecosystems and Their Interactions LS1-5, LS1-6, LS2-1, LS2-2, LS2-3, LS2-4, LS2-5, LS4-4, LS4-6, ESS3-3, ETS1-1, ETS1-2	**Weather and Climate Systems** ESS2-4, ESS2-5, ESS2-6, ESS3-2, ESS3-4, ESS3-5, PS3-4, ETS1-1, ETS1-2	**Energy, Forces, and Motion** PS2-1, PS2-2, PS2-3, PS2-5, PS3-1, PS3-2, PS3-5, ETS1-1, ETS1- 2, ETS1-3, ETS1-4
Structure and Function LS1-1, LS1-2, LS1-3, LS1-6, LS1-7, LS1-8, LS4-2, LS4-3	**Earth's Dynamic Systems** LS4-1, ESS1-4, ESS2-1, ESS2-2, ESS2-3, ESS3-1, ESS3-2, ETS1-1, ETS1-2, ETS1-3, ETS1-4	**Matter and Its Interactions** PS1-1, PS1-2, PS1-3, PS1-4, PS1-5, PS1-6, PS3-4, ETS1-1, ETS1- 2, ETS1-3, ETS1-4
Genes and Molecular Machines LS1-1, LS1-4, LS3-1, LS3-2, LS4-4, LS4-5, LS4-6	**Space Systems Exploration ©2018** PS2-4, ESS1-1, ESS1-2, ESS1-3, ETS1-1, ETS1-2	**Electricity, Waves, and Information Transfer ©2018** LS1-8, PS2-3, PS2-5, PS3-3, PS3-4, PS3-5, PS4-1, PS4-2, PS4-3, ETS1-1, ETS1-2, ETS1-3, ETS1-4

Research Modules

Why Are Honey Bees Disappearing? LS3-2, LS1-4, LS1-5, ESS3-3, ETS1-1	**What Evidence Suggests Similarities Among Organisms?** LS4-1, LS4-2, LS4-3, ESS1-4	**How Can We Use Technology to Monitor Aquatic Ecosystems?** PS4-1, PS4-2, PS4-3, ESS3-4