Apply Your Knowledge

1. Use one of the design processes described in Chapter 2 to design and make a simple game for a young child.
2. List five objects you use at school every day. Describe how the parts of each object are joined.
3. Choose five objects, each with a different type of finish. Make a chart to show (a) the material, (b) the finish, and (c) the reason why that finish has been used.
4. List at least three tools you have in your home. State the material and process for which each is designed.
5. Research one career related to the information you have studied in this chapter. Create a report that states the following:
   - The occupation you selected
   - The education requirements to enter this occupation
   - The possibilities for promotion to a higher level
   - What someone with this career does on a daily basis
   - The earning potential for someone with this career

   You might find this information on the Internet or in your library. If possible, interview a person who already works in this field to answer the five points. Finally, state why you might or might not be interested in pursuing this occupation when you finish school.

STEM Applications

1. **ENGINEERING** Design and make an ergonomically correct chair using measurements of students in your class. Your design should do all of the following:
   - Have a seat and back.
   - Support a person weighing at least 200 pounds.
   - Be comfortable to sit in.
   - Be aesthetically pleasing.
   - Be made from corrugated cardboard.
   - Use only glue to connect the parts permanently.
   - Use as little material as possible.
2. **MATH** Choose a wood table or desk in your home or school. Measure the item carefully. Determine the type(s) of wood and other materials you would need to build it. On the Internet or in a local home improvement store, find out what standard lengths and sizes are available in this type of wood. On paper, carefully plan how to build the table with the least amount of scrap. Then make a materials list including how much of each size and type of wood is needed and the cost per piece. Also include any fasteners or adhesives necessary to build the actual table. Based on your materials list, estimate the total cost to build the table or desk.

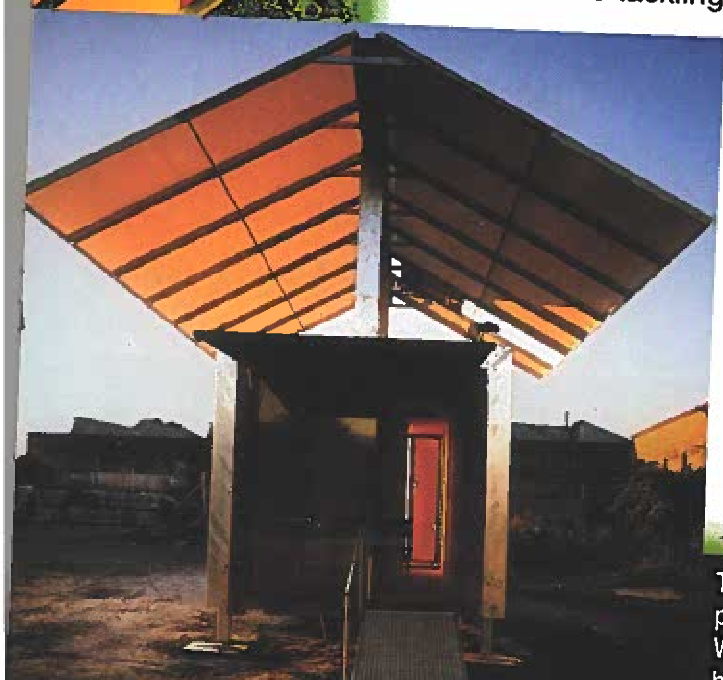
CHAPTER 6

Structures

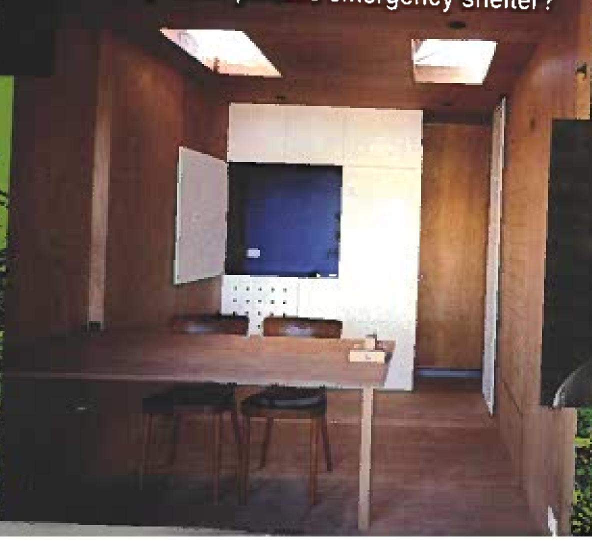
Better by Design

Sean Godsell designs emergency shelters

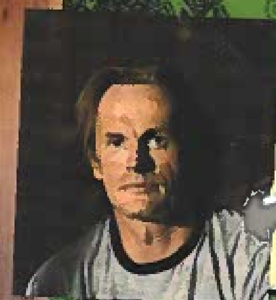
Earthquakes, floods, and hurricanes leave thousands of people needing short-term relief housing immediately. Architects around the world are tackling this problem. Some have designed inflatable concrete tents. Others have designed homes built from recycled wood pallets. Sean Godsell, an Australian architect, has designed the *Future Shack*. Made from a mass-produced, inexpensive, and durable shipping container, it has a parasol roof made from recycled plastic that packs into the container when closed and collects rainwater when open. Also packed inside the container during shipping are solar panels to generate electricity, water storage tanks, and telescoping legs to support it on uneven terrain. *Future Shack* can easily be shipped and transported by road or rail.



A shipping container provides the basis for a self-contained refugee housing unit.



The interior of the Future Shack unfolds to provide basic items such as a table and sink. What other mass-produced products could be adapted to provide emergency shelter?



"Architects have the power, if we trust them, to transform our lives."
—Sean Godsell

Reading Target

Creating an Outline

An outline is an orderly statement of the main ideas and major details of a text passage. Each main idea or detail is written on a separate line. Creating an outline can help you understand and remember what you read. Read each section of this chapter carefully. Then use the Reading Target graphic organizer at the end of the chapter to create an outline of the chapter.

Key Terms

- *abutments*
- *arch bridge*
- *cantilever bridge*
- *compression*
- *dynamic load*
- *load*
- *pier*
- *reinforced concrete*
- *shear*
- *static load*
- *stays*
- *structures*
- *strut*
- *suspension bridge*
- *tension*
- *tie*
- *truss*

Objectives

After reading this chapter, you will be able to:

- Identify the loads acting on structures.
- Analyze the forces acting on a structure.
- Demonstrate how structures can be designed to withstand loads.
- Explain various bridge designs.
- Describe methods of reinforcing high-rise buildings.

Useful Web sites:

www.seangodsell.com/
www.architectureaustralia.com.au/aa/aaissue.php?article
firmitas.org/
www.architectureforhumanity.org/

Structures are all around us. We build them to live in or to cross a river. We build them to carry wires, to receive radio waves, and to transport people. Houses, bridges, and towers are not the only types of structures; airplanes, boats, and cars are structures, too.

Many structures enclose and define a space, including the homes in which we live. At times, however, a structure is built to connect two points. Examples of these structures include bridges and elevators. Other structures are meant to hold back natural forces, as in the case of dams and retaining walls. Some structures are meant to be temporary, such as the *Future Shack* described in the Better by Design feature at the beginning of this chapter. Others are permanent and need to withstand weather and various other forces over time.

Everyone has built some kind of structure. Have you constructed a ramp for a skateboard? Perhaps you built a tree house from a variety of scrap materials. Maybe you made a model crane, a dollhouse, a tunnel for a model railroad, or a sand castle on the beach. **Figure 6-1** shows two structures. What is the purpose of each?

Not all structures are made by humans. Living organisms, such as trees and our bodies, are natural structures. A giant redwood tree must be rigid enough to carry its own weight. Yet it is able to sway in high winds. The bones of a skeleton have movable joints. They permit activities such as running and lifting. **Figure 6-2** shows both natural and human-made structures.

Structures and Loads

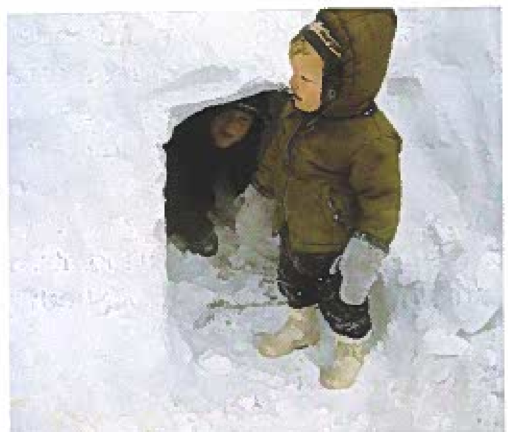
What do all structures have in common? They all have a number of parts, which are connected. The parts provide support so the structures can serve their purpose. One important job of all structures is to support a ***load***. A load is the weight or force placed on a structure. See **Figure 6-3**.

Figure 6-1. A scaffold supports workers while they build structures. Scaffolds are structures, too. They have connected parts and carry workers without collapsing.

Wasp's nest

Shells

Lighthouse



Snow Den

Figure 6-2. Structures are found all around us. Top—Some are found in nature. Bottom—Others are planned and built by humans.

Tower

Figure 6-3. Structures must be able to support the loads they are intended to carry. What loads do towers have to support?

One example of a load on a bridge is a heavy vehicle crossing it. See **Figure 6-4**. Vehicles must also carry loads, such as the weight from their own frame and the passengers they carry. See **Figure 6-5**. The load on a dam is the force of the water behind it. Both vehicles and dams must also support the materials from which they are built. This is part of the load.

Structures vary greatly in size and type. Think about the loads that each of the structures in **Figure 6-6** must withstand. What materials were used in their construction? How are the parts connected together?

All structures must be able to support a load without collapsing. A roof must not only support its own mass but also a heavy blanket of snow. A chair must carry the load of a person sitting still or fidgeting. See **Figure 6-7**. These loads are of two types: static and dynamic.

Figure 6-4. Roads, tunnels, and sidewalks help us travel from place to place by vehicle and on foot. A—Walkways can provide passages through another structure. B—Bridges span rivers, gorges, and railways lines.

Figure 6-5. Structures for transportation must carry people and support other parts of the vehicle.

Figure 6-6. The framework of each building is like a skeleton. Can you see the "skeleton" in each of these structures?

Figure 6-7. The structure of a chair must be such that it can carry the load of a person sitting on it.

Static Loads

Static loads are loads that either do not change or change slowly. They may be caused by the weight of the structure itself. Columns, beams, floors, and roofs are part of this load. Static loads also include the weight of objects placed in or on the structure. Figure 6-8 shows an example of a static load.

Dynamic Loads

A *dynamic load* is a load that is always moving or changing on a given structure. For example, the mass of a person walking across the floor creates a dynamic load. Other dynamic loads include the force of a gust of wind pushing against a tall building and a truck crossing a bridge. See Figure 6-9.

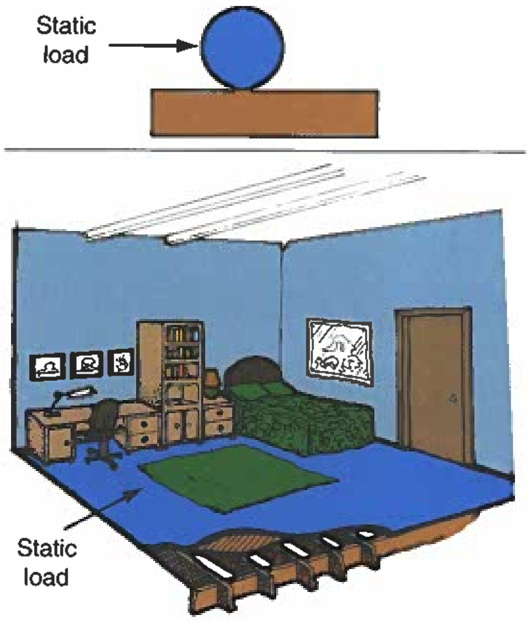


Figure 6-8. Objects at rest create static loads.

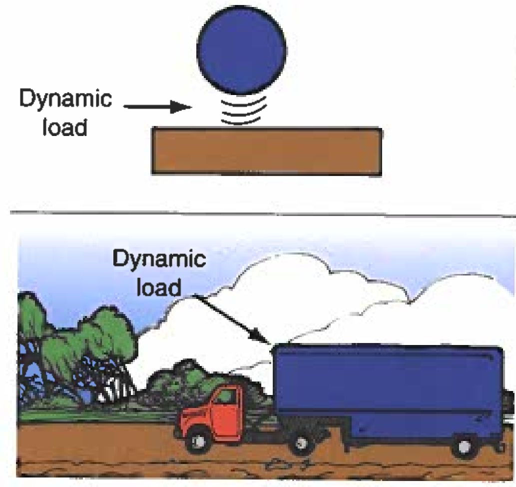


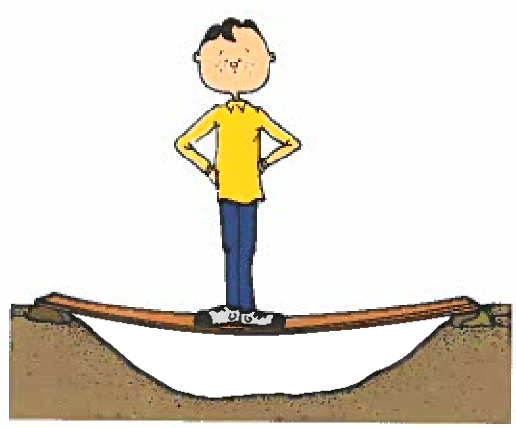
Figure 6-9. Moving objects create dynamic loads.

Forces Acting on Structures

Both static and dynamic loads create forces, which act on structures. To understand these forces and what they do, imagine a plank placed across a stream, as shown in Figure 6-10. When you (the load) walk across the plank (the structure), what would you expect to happen? The plank bends in the middle. The forces acting on the bridge are shown by the foam rubber in Figure 6-11. Notice that parallel lines have been marked on it in Figure 6-11A. If the foam is supported at each end and a vertical load is applied to the center of the foam, it bends. See Figure 6-11B.

Notice what has happened to the parallel lines. At the top edge, the lines have moved closer together. The lines at the bottom edge have moved farther apart. The top edge of the plank is in *compression* (being squeezed) and the bottom edge is in *tension* (being stretched). Along the center is a line that is neither in compression nor in tension. It has no force acting along it. This line is called the *neutral axis*.

Figure 6-10. A person standing on a plank causes the plank to bend. Bending causes compression on the top surface of the plank and tension on its bottom surface.



Bridges are made from many materials. The most common are steel and concrete. Steel is fairly inexpensive, strong under compression and tension, but needs maintenance to prevent corrosion. Steel cables made of wire rope are used to support the mass of the roadway (bridge deck) and the traffic load on it. The towers of many bridges are also made of steel. Steel trusses give rigidity to the bridge deck. They also resist bending.

Concrete is economical and resists fire and corrosion. It is strong under compression but weak under tension. To overcome this weakness, the concrete is reinforced with steel rods wherever it is in tension. The embedding of steel rods to increase the resistance to tension is the basic principle of *reinforced concrete*. See **Figure 6-28**.

The Structure of High-Rise Buildings

High-rise buildings, sometimes called skyscrapers, have only been part of the landscape for about 100 years. In 1903 the Ingalls Building in Cincinnati was built to a height of 16 stories. In 1913 the Woolworth building became the tallest building, with a height of 55 stories. Eighteen years later the Empire State Building was built to a height of 102 stories.

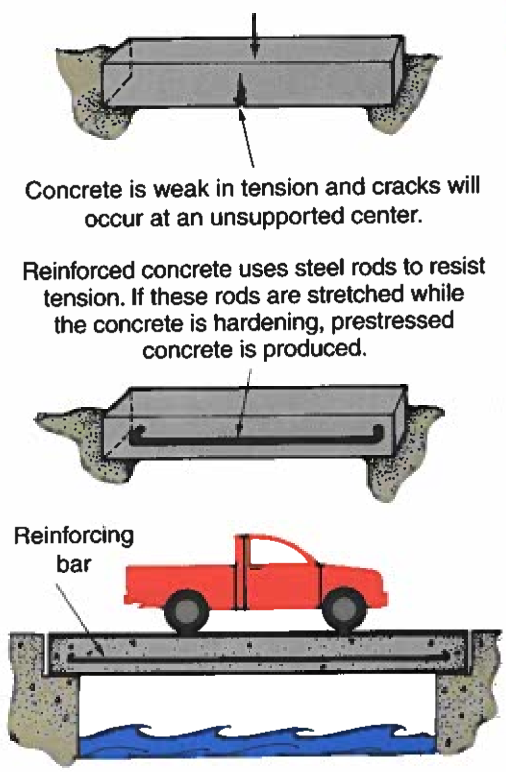


Figure 6-28. Concrete is made stronger by reinforcing it with steel rods.

The substructure of a skyscraper is built underground to give it a firm, solid stance and spread its weight over a larger area. Vertical steel columns are built up from this substructure. Weight from each floor is transferred by horizontal steel girders to the steel columns.

Have you noticed the shape of high-rises? While most of them are square or oblong, others are round, curved, or hexagonal. The structure of many high-rise buildings is quite different from that of houses. Houses have frames on the outside to carry the loads of roof, windows, and doors. Many skyscrapers have a stiff frame near the inner core of the building. In addition to beams and columns, the core has diagonal bars that work in both tension and compression. See **Figure 6-29A**. It supports dead loads (such as the weight of the building) and live loads (including wind). This inner frame also houses elevators and many of the pipes and ducts as they pass from one floor to the next.

If the supporting structure is placed in the center of the building, the outside walls can be made largely of glass, held in place by vertical metal struts. These walls, known as *curtain walls*, are supported by frames of steel or concrete that form part of the structure of the building.

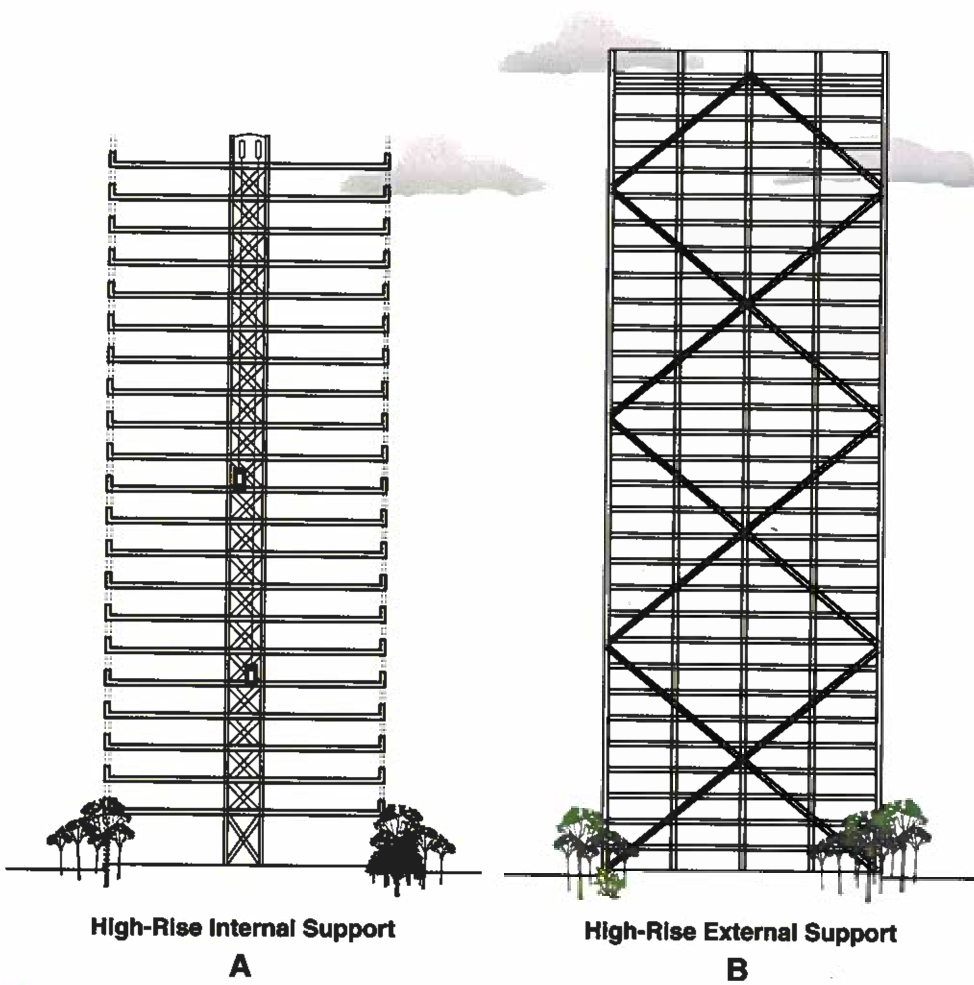


Figure 6-29. A—A central core provides the support in this high-rise. B—The exterior walls of this high-rise provide a supporting frame.

Another type of high-rise construction is shown by the John Hancock Building in Chicago. See **Figure 6-29B**. It uses the same principle of diagonal, X-shaped bracing. However, the bracing is on the outside walls of the building, making the entire building into a huge hollow tube anchored to its foundation. The Burj Khalifa, the world's tallest building with more than 160 stories, also uses this principle of construction.

Think **Green**

Green Roofs

One interesting way to make a building eco-friendly is to include a "green roof." More than just a rooftop garden, a green roof provides several advantages. It can improve both the energy performance of the building and the air quality around the building. It also provides habitat for birds and other small animals. Visually, it provides relief from the gray concrete surfaces that make up many cities.

Some green roofs include pathways for people to walk on, so the space can be used as a park or a place to grow vegetables. Others are completely covered with native grasses and plants and are designed to avoid the need for irrigation.

A good design for a green roof must take many structural factors into consideration. The weight of the soil, plants, and water or moisture must be taken into account. Drainage is also a structural issue. How will excess water be handled? The soil mix and types of plants to be used should be chosen carefully to minimize maintenance and irrigation.

More and more cities are incorporating green roofs into their municipal buildings. Check to see if any buildings in your city or county have a green roof. If not, can you identify any buildings that would be good candidates for a green roof?

End Note

Two types of loads are present in structures: static and dynamic. These loads create the forces of compression, tension, and shear. Structures must be designed to minimize the effects of these forces. The members are then connected together in a design that minimizes bending.

The iron and concrete bridges and the towering skyscrapers are the great structures of the nineteenth and twentieth centuries. They provide examples of how structures are designed to resist forces.

As new materials and processes are developed, we can build taller skyscrapers, longer bridges, and other complex structures. Engineers and designers working on the Burj Khalifa in Dubai, for example, faced many new challenges. For example, how does one wash the windows on the 160th floor of a building in an area known for high winds? Meeting these challenges and designing structures to meet the needs of people living in the 21st century are tasks for the designers and engineers of today and tomorrow.

Summary

- The two types of loads on a structure are static and dynamic loads.
- Forces that act on structures include compression, tension, and shear forces.
- Structures must be designed to withstand both static and dynamic loads.
- Bridges are designed to support the weight of the actual roadway, as well as the weight of traffic that uses the bridge and weather elements, such as snow.
- High-rise buildings can have either internal or external supports. The same triangle shape used to reinforce bridges can be used to strengthen high-rise structures.

Reading Target

Creating an Outline

Use the following graphic organizer to create an outline. Write your outline on a separate sheet of paper. The first section of the chapter has been outlined for you as an example. Notice that the main idea of the first section has been placed next to the Roman numeral I. The major details from that section are placed on the indented lines with letters (A, B, C, and so on). Using the first section as a pattern, outline the rest of the chapter. Try to supply at least two supporting details for each main section. Add more detail lines if necessary to describe all of a section's important details.

I. One important job of all structures is to support a load.
  A. A load is the weight or force placed on a structure.
  B. Static loads either do not change or change slowly.
  C. Dynamic loads are always moving and changing.

II.
  A.
  B.

III.
  A.
  B.

IV.
  A.
  B.

V.
  A.
  B.

Test Your Knowledge

Write your answers to these review questions on a separate sheet of paper.

1. Name three natural structures and three structures made by humans.
2. Briefly explain why all structures must be built to withstand a load.
3. Name two types of loads acting on structures. Give one example of each.
4. What forces act on the top and bottom surfaces of a beam loaded from above?
5. Where should a beam be reinforced to strengthen its ability to handle a load on its top surface?
6. Why does a triangle give greater rigidity to a structure than a rectangle?
7. What is a tie?
8. What is the difference between a tie and a strut?
9. What type of bridge uses a series of triangular frames to support the roadbed?
10. Using notes and diagrams, explain how an arch bridge resists loads.
11. Using notes and diagrams, explain the principle of a cantilever bridge.
12. From what two materials are bridges most commonly built?
13. Concrete is weak in tension. How is this problem overcome?
14. What is the purpose of the substructure of a high-rise building?
15. List two types of framing that are commonly used on high-rise buildings.

Critical Thinking

1. Search the Internet to find what you consider to be the 20 greatest engineering achievements of the 20th century. Place them in order from most important to least important, and explain your reasoning.
2. Why is the middle of a beam bridge the point most likely to break?
3. New building construction is good in many ways. For example, it allows us to incorporate new, more environmentally friendly processes and materials, and it provides employment for many people. However, current construction practices also have disadvantages, such as deforesting rainforests and contributing to global climate change. Write an essay on the ethical aspects of new construction. Should it be allowed to continue without limits or controls? Explain the role of trade-offs and compromise in this issue.

Apply Your Knowledge

1. Use books, magazines, and other sources to find illustrations of natural structures. Then find structures made by humans that closely resembles each natural structure. Create a display that compares each natural structure with a human-made structure that resembles it. Share the display with your class or school.
2. List five different types of structures. For each structure, list the loads to which it is subjected. State whether each load is static or dynamic.
3. Draw a diagram of a plank bridge with a load on it. Label the diagram to show the forces on the bridge.
4. Research one career related to the information you have studied in this chapter. Create a report that states the following:
   - The occupation you selected
   - The education requirements to enter this occupation
   - The possibilities for promotion to a higher level
   - What someone with this career does on a daily basis
   - The earning potential for someone with this career

   You might find this information on the Internet or in your library. If possible, interview a person who already works in this field to answer the five points. Finally, state why you might or might not be interested in pursuing this occupation when you finish school.

STEM Applications

1. **ENGINEERING** Using only one sheet of newspaper and 4 inches (10 cm) of clear tape, construct the tallest freestanding tower possible. Document your designing process and include the documentation in your portfolio.
2. **ENGINEERING** Using drinking straws and pins, construct a bridge to span a gap of 20 inches (508 mm) and support the largest mass possible at midpoint. Document your designing process and include the documentation in your portfolio.
3. **MATH** Explain why the triangle is one of the strongest shapes for supporting static and dynamic loads. Use sketches to show basic geometric principles in your answer.

Adrian Smith, the architect who designed the Burj Khalifa, was inspired by the hymenocallis flower. Search the Internet to find out what this flower looks like. What features of the flower provided inspiration?

CHAPTER 7

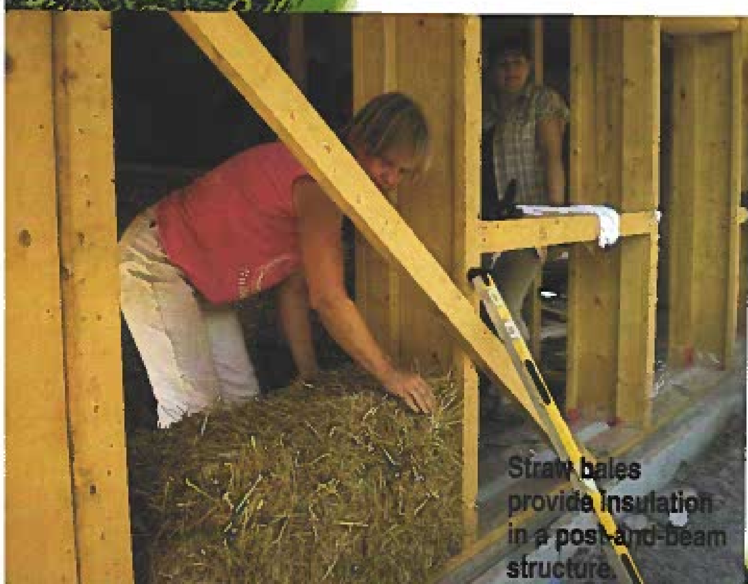
Construction

Better by Design

Two coats of mud plaster are applied to the straw.

Rena Upitis designs and builds sustainable buildings

Rena Upitis is a Canadian educator, architect, artist, and environmentalist. She believes that people must become committed to sustainable building and environmentally respectful practices. To explore this idea, Rena designed and built Wintergreen Studios, a straw-bale building that uses recycled barn beams in its structure and locally grown straw for its walls. One wing of the building is sheltered with an earth-covered living roof. In straw-bale construction, baled straw from barley, wheat, rice, flax, rye, or oats is used to build the exterior walls. The bales are then covered with mesh that is stitched on with giant bale needles. On top of the mesh, two or three coats of plaster are applied. This construction technique provides a high insulation value, so houses are warm in the winter and cool in the summer. The house is ***off-grid***. In other words, electricity is generated at the site, and the house is not connected to an electric utility.



Straw bales provide insulation in a post-and-beam structure.

"Everything I have read about energy consumption and global warming tells me that we do not have the privilege of another fifty years to think about these issues."—Rena Upitis