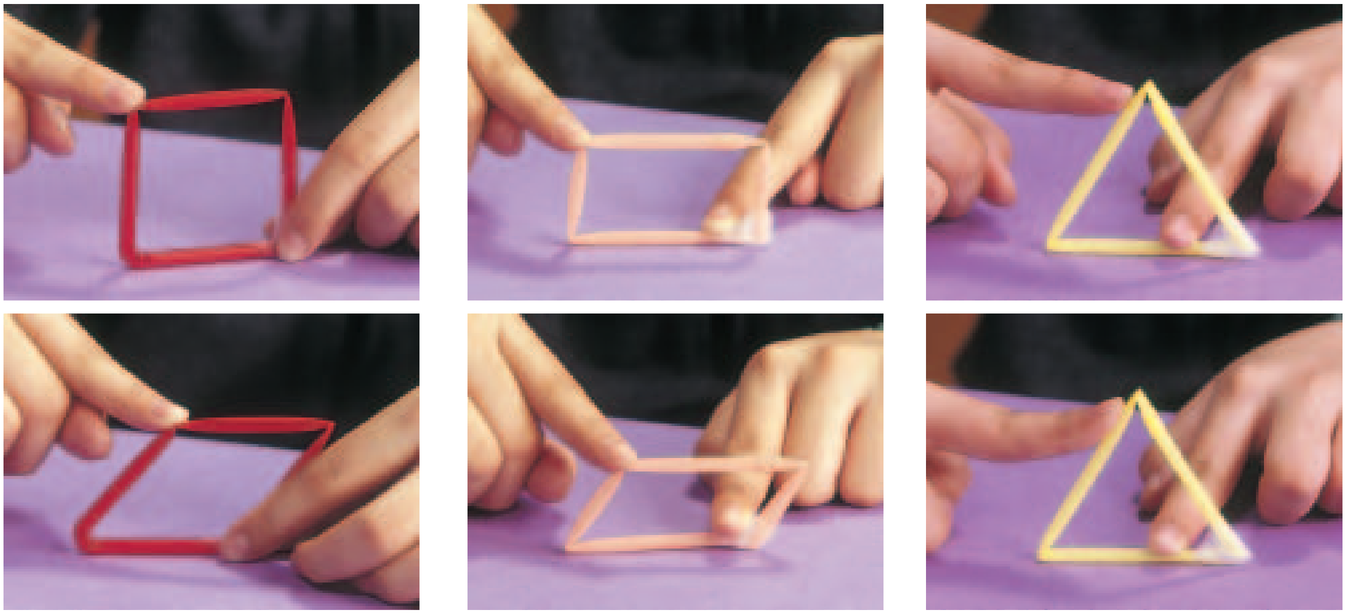
Strong Structural Shapes

You've had several opportunities in this unit to think about how a structure's shape might affect how strong it is. From that knowledge, what do you think the strongest two-dimensional shape is: a triangle, a square, or a rectangle? What is the strongest three-dimensional shape: a triangular prism or a rectangular prism?

If you're not sure about the answer to these two questions, use some straws to try the simple exercise shown in Figure 2.29. What you should notice is that while the square and rectangle will shift their shape slightly, the triangle will not. A triangle is a very strong and rigid shape that cannot be bent easily. In the same way, a triangular prism is stronger than a rectangular prism, a pentagonal prism, or any other multi-sided three-dimensional shape.



A B C

Figure 2.29 Bend one straw into a square (A), one into a rectangle (B), and one into a triangle (C). Tape the ends of each shape together. Lying each structure flat on a table or resting it upright on a table, gently push on an upper corner of the structure (in the same plane as the structure itself).

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Standing the Test of Time

Part of the foundation of the Mausoleum of Halicarnassus can still be seen where it was built in what is now Turkey. Some of its statues are in the British Museum in London. One of the original 127 columns in the Temple of Artemis (located in Ephesus, not far from where Halicarnassus was) also still exists. Longest lasting, however, have been the Pyramids at Giza, near Cairo, Egypt. They still stand much as they were when they were built 4500 years ago.

Structural Components

Have you ever tried to cross a small river or stream by walking on a flat wooden plank laid across it? If the plank was weak, you probably noticed it bending. If you tried bouncing up and down, you probably knew there was a chance you could end up getting wet.

Figures 2.30 to 2.36 show several components that make up structures. Also shown are some of the ways these components can be combined to create strong structures.

Arches

An **arch** is a common shape in structures such as bridges (Figure 2.30). The arch can support a large load because the force of the load is carried down through the arch to the foundation. This spreads out the load.

Figure 2.30 Arch

Beams

Beams are common components in a wide range of structures. A simple **beam** is a flat structure that is supported at each end (Figure 2.31). If too much weight is put on a beam in the middle, it will bend in a U-shape and may even break. Changing the shape of a beam, however, can increase its strength.

The shape of an **I-beam** gives it strength (Figure 2.32). I-beams have less mass than solid beams. **Girders**, or box beams, are long beams in the shape of hollow rectangular prisms (Figure 2.33).

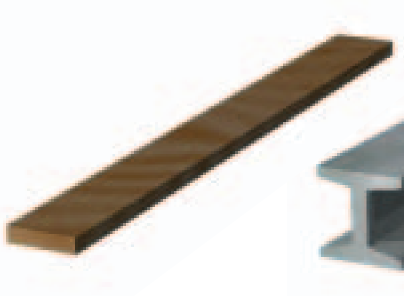


Figure 2.31 Simple beam

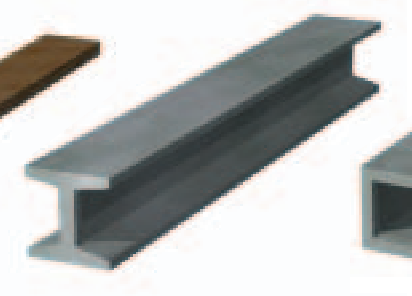


Figure 2.32 I-beam

Figure 2.33 Girder, or box beam

A **truss** is a framework of beams joined together (Figure 2.34). Trusses are usually in the form of interlocking triangles. A **cantilever** is a beam that is supported only at one end (Figure 2.35). When weight is placed on the beam, the beam bends in an N-shape to resist the load.

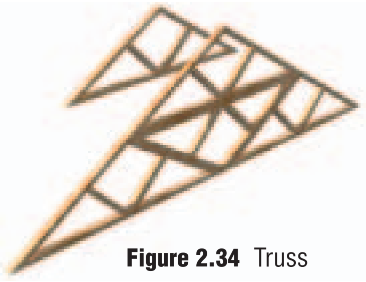


Figure 2.34 Truss

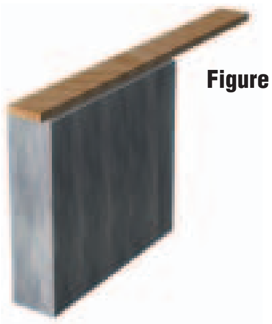


Figure 2.35 Cantilever

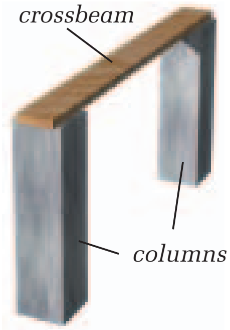


Figure 2.36 Column

Columns

A **column** is a solid structure that can stand by itself (Figure 2.36). Columns can be used to support beams.

Structural Stress, Fatigue, or Failure

Sometimes too great a combination of external and internal forces acting on a structure can weaken it. The result can be **structural stress**.

A strong, stable structure is designed and built to be able to resist stress without any damage happening. However, repeated abnormal use of the structure could cause **structural fatigue**. This is a permanent change in a structure caused by internal forces such as compression, tension, and shear. Cracks, for example, might start appearing in the material. **Structural failure**, such as the collapse of a bridge, occurs when a structure can no longer stand up to the forces acting on it. Failure can also take the form of buckling, shearing, separating of components and deformation, as illustrated in Figure 2.37.

A structure needs strength and stiffness to avoid failure:

- The *strength of a structure* is defined by the load at which it fails. For example, if it takes a load of 100 kg to cause a skateboard to collapse, the strength of the skateboard would be 100 kg.
- The *stiffness of a structure* is its ability to withstand changing its shape under a load. For example, the skateboard must be stiff enough to prevent failure for any load up to about 100 kg.

reSEARCH

Geodesic Domes

Do you know what a geodesic dome is? Find out about these noteworthy structures, how they are built, and what gives them their strength and stability. Use library resources and the Internet in researching these structures.

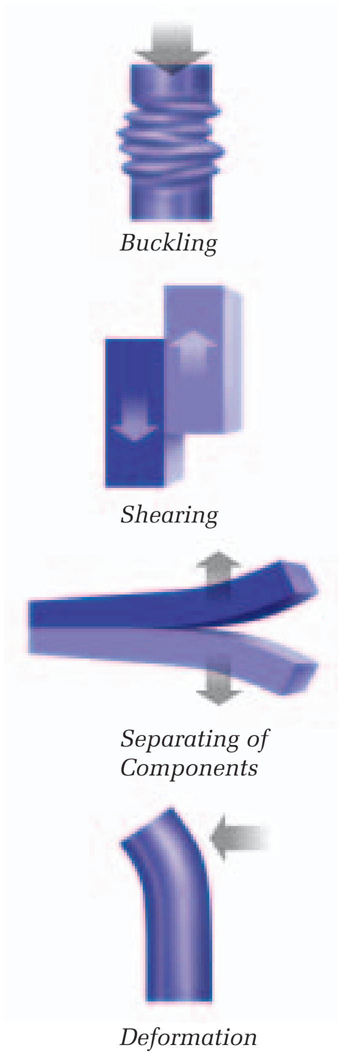


Figure 2.37 Some forms of structural failure

Problem Solving Activity

THE TALLEST TOWER

Materials & Equipment

- newspaper
- uncooked spaghetti
- bamboo skewers
- plastic straws
- plastic interlocking blocks
- masking tape
- cellophane tape
- marshmallows
- a balance
- a ruler
- egg or golf ball
- a fan

Recognize a Need

Several companies are hoping their design will be chosen for the new communications tower. This tower must be the tallest structure in the city so that signals for telephone, television, and radio will be able to pass above all other buildings. The communications company would also like to build a restaurant and observation deck near the top of the tower, so the structure must be able to carry this additional load safely.

The Problem

You and your group have been hired by one of the companies who want to build the new tower. As part of your preliminary work, you must design and build a tall, stable free-standing model of the proposed tower with the materials provided. You will have 20 min to design and build your tower before it is tested. Your teacher will set a timer.

Criteria for Success

- Your structure must be built from at least three of the materials listed.
- Your structure must be the tallest possible free-standing structure that can support an egg or golf ball without structural failure.
- Your structure must be able to withstand the wind from a fan for 60 s.
- You must complete the activity within the time given.

Brainstorm Ideas

1 Discuss and sketch out design ideas for your tower. Keep in mind the function of the tower, the design criteria, and the time limitations. What factors about external and internal forces and loads must your design consider?

2 Consider the materials you have to work with. This may give you some design ideas and options. (Also, in real-life situations, the materials available for a project may be limited. Learning to work with what you've got is all part of the design process!)

3 Predict which of your design ideas will best meet the Criteria for Success. Use this design.

Build a Prototype

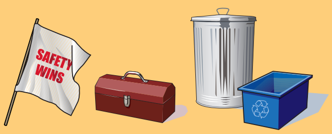
4 Assemble the materials you will need to build your structure.

5 Construct the tower as quickly as possible. As a group, you may wish to assign different members to construct certain components of the structure. These can be assembled when they are ready.

Figure 2.38 Steps 4 and 5

Caution!
Before starting any construction project, be sure you know the answers to these questions:

1. What special safety precautions should you take?
2. Where should you store any tools after using them?
3. How should you dispose of any waste or unused materials?



Test and Evaluate

6 When your tower is complete, test that it can be free-standing. Place the egg or golf ball on top of the model to test the strength of the structure. Make design or construction modifications if there is time.

7 Place the fan about 1 m away from the model and let it blow onto the model for 60 s. Observe how well the model maintains its stability. Again, make design or construction modifications if time allows.

8 Measure the mass of your completed structure and record it.

9 Does your structure meet the design criteria? Explain why it does and/or why it does not.

10 Evaluate your structure along with those of the other groups.

   a) What is the overall range of structure heights? Which structure is the tallest? the shortest?

   b) Why are some structures better able to resist the wind? That is, why are they more stable than others?

   c) How does the mass of your structure compare to that of the other groups' structures? How does the quantity of material you used compare?

11 Compare the area of the bottom of your structure with the area of the top of your structure. Did this ratio prove to be an advantage or a disadvantage in making your structure strong and stable? Explain.

Communicate

12 Compile the results of the activity in a short report:

   a) State the problem you were trying to solve and list the performance requirements of the model.

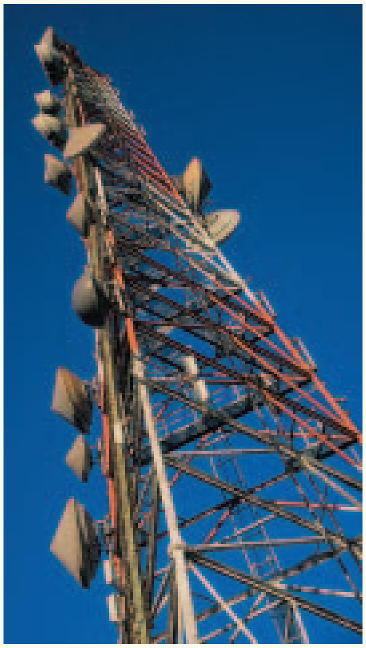
   b) Sketch the design you chose for your prototype and label it with the forces acting on it.

   c) Note the quantity of materials you required to build your structure and what two- and three-dimensional shapes you used most often and least often. Describe any construction difficulties you had.

   d) Summarize your test and evaluation results under the following headings: Strength, Stability, Height (compared to all the designs in the class). Explain whether you think you could have used more or less material than you did to achieve the same strength and stability.

   e) Explain whether your prediction in step 3 was right. Suggest improvements that you would make to your structure.

   f) Write a concluding statement that answers the following questions: To build a structure taller and taller, what must be done to maintain its stability? Is there a limit to how tall a structure can reach and still be free-standing, strong, and stable? Explain.



Communications tower

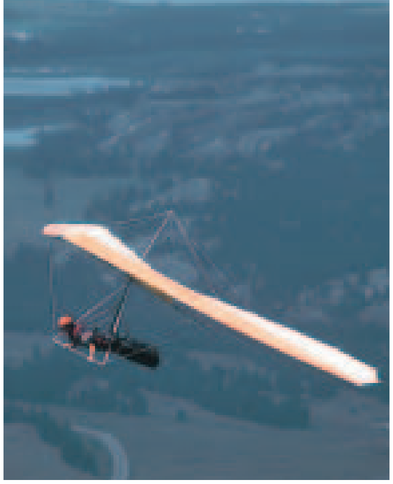


Figure 2.39 What external forces are acting on this hang-glider? what internal forces? What type of design features and materials have been used to make it structurally stable?

Building for Structural Stability

Designing a hang-glider that is stable in the air requires careful analysis of the forces that will be acting on it. It is important that the hang-glider be designed so that it is symmetrical and so that the mass within the structure gets evenly distributed. Distributing the load in that way helps reduce internal forces such as tension, compression, and shear.

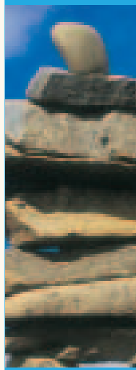
The properties of the materials used for the individual parts of a structure also determine how well the structure will hold together under different loads and forces. Look at the hang-glider in Figure 2.39. The components of the structure are not all made of the same material. Rather, a variety of materials has been used, each for its effectiveness in resisting the applied forces.

Check and Reflect

1. Make a labelled drawing of the three main types of structural components. Answer the following questions:
   a) For each, give an example of a structure in which you would use this component.
   b) For each, what is the advantage of including this component in a structure?
   c) If an arch and a beam were of the same mass, which one would be the strongest? Why?

2. Make a flowchart to connect the following events, beginning with the one that happens first. You can connect more than one event to another. You can use an event in more than one place. (Hint: First, put these events in the correct order.)
   - The bridge structure experiences structural stress.
   - A freight train loaded with iron ore passes over the bridge.
   - The bridge collapses.
   - The beams of the rail bridge bend slowly.
   - The rail bridge carries 10 trains a day over the valley.
   - The beams of the rail bridge give way.
   - The bridge is experiencing structural fatigue.
   - A rail bridge was built here 30 years ago.
   - The bridge is experiencing structural failure.

SECTION REVIEW



Assess Your Learning

1. Think of a symmetrical solid structure and determine its centre of gravity and lines of symmetry. How do you know that your findings make sense?
2. Describe and provide examples of the following structural forces:
   a) compression
   b) tension
   c) shear
3. Explain how compression and tension act together by describing what happens when a diver jumps up and down on a diving board.
4. How can a structure remain standing for several years, then suddenly collapse?
5. What makes many free-standing coat racks so unstable? What design characteristics should you consider when making a coat "tree"?
6. A local marina wants to suspend a sign from a bridge. There are two choices for doing this: it could be hung straight down from cables, or it could be hung between two cables at 45° angles from the bridge. Which arrangement do you recommend? Why?

Focus On SCIENCE AND TECHNOLOGY

Scientific knowledge may lead to the development of new technologies, and new technologies may lead to scientific discovery.

Reflect on what you learned about forces in this section.

1. What forces act on and within structures, and how can they be measured?
2. How can these forces cause structures to fail?
3. Some skiers lost in a snowstorm face the necessity of spending the night on a mountain. They decide to construct an emergency structure out of branches and snow. How could you apply what you have learned about forces to make their structure stable?

3.0 Structural strength and stability depend on the properties of different materials and how they are joined together.

Key Concepts

In this section, you will learn about the following key concepts:

- deformation
- joints
- material strength and flexibility
- structural stability

Learning Outcomes

When you have completed this section, you will be able to:

- compare properties of structural materials, including natural materials and synthetics
- use methods of testing the strength and flexibility of structural materials
- identify examples of frictional forces and their use in structures
- analyze methods of joining used in structures and evaluate their appropriateness for a given structure
- investigate the role of different materials found in plant and animal structures

Figure 3.1 What materials are within your reach? within your sight?

What materials can you see around you? What is holding them together?

With your teacher timing you for one minute, work with a partner to make a list of all the materials you can spot in your classroom. When a minute is up, repeat the exercise, but this time identify examples of fasteners (that is, things that join materials together). Again, you've got one minute. At the end of the allotted time, compare your two lists with those of the other groups.

When everyone has finished the exercise, the class will compile one large list of materials and fasteners. You will use these lists later in this section.

For Web links relating to 3.0, visit **www.pearsoned.ca/scienceinaction**

3.1 Materials and Their Properties

In the past, people constructed shelters out of material they could find, including animal skins, mud, and sticks. Some of these shelters were large and elaborate. Over the years, many more materials were discovered or invented. Today, designers can choose from a wide variety of materials.

Even though there's now so much choice in materials compared to before, how do we know *which* material will be best to use for a particular purpose? Think for a moment about jumping on a skateboard made of nylon or trying to carry a tent made of bricks. You know these materials are poor choices for each of those structures, because you already know a lot about materials. But what else is there to know about their properties?

Classifying Material Properties

The materials used in structures can be evaluated according to many properties. How well the designer, engineer, or builder analyzes those properties determines how well the resulting structures will do what they're supposed to. It also determines how long the structures will last before giving in to the forces acting on them.

Some of the most important properties of materials are listed in Figure 3.2.

Some Properties of Materials	Other Considerations
• **brittleness** (How easily does the material break?) • **ductility** (How easily can the material be made into wire?) • **hardness** • **plasticity** (How easy is the material to shape?) • **resistance to heat** • **resistance to water** • **compression** • **tensile strength**	• **aesthetics** (appearance, texture, etc.) • **consumer demand** • **availability** • **cost** • **effect on the environment** (Can the material be used safely?) • **disposal of waste** (Can the material be recycled or reused? Is there a cost to dispose of it?)

Figure 3.2 Properties of materials and other considerations.

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Letting the Sun Shine In

New materials today allow builders to use the sun to advantage. For example, the windows on the top floors of this home are made of tinted glass that lets light in but keeps ultraviolet radiation out. The solar panels produce electricity, making the home more energy efficient.

Testing Deformation and Flexibility of Materials in Structures

Deformation

Focus for a moment on the property of strength. Any time you have to design and build a structure, you need materials that will have enough strength to resist the forces acting on the structure. You also need materials that won't deform easily. **Deformation** is a change of shape in a structure or any structural component, because the material is unable to resist the load acting on it. When too much deformation occurs, a component or the entire structure might fail.

Figure 3.3 When you apply a very small force to an aluminum can, its sides start to dent, but will return to the original shape when the small force is released. If you apply a greater force, the dent may become permanent, and the can is deformed permanently.

Flexibility

Flexibility is the ability of a material to be bent under force without breaking. How much an object can change shape under a given load without breaking is an indication of how flexible it is.

Structures such as tall buildings must be able to resist the force of the wind. However, being very strong and rigid is not necessarily the best way for a tall building to be designed. Think of a tall tree in the wind. The tree bends a little as the wind pushes against it, and when the wind stops, the tree straightens up again, unharmed. Copying nature, structural engineers have found ways of using materials and combining structural components to make buildings in "high hazard" wind or earthquake zones more flexible.

Figure 3.4 It is their flexibility that allows trees to resist being deformed under strong forces like that applied by the wind.

Inquiry Activity

Material Strength and Stability

The Question

Is it possible to predict what material would be suitable for providing strength and stability to a structure?

Materials & Equipment

- uncooked spaghetti
- newspaper
- plastic straws
- bamboo skewers
- masking tape
- blocks or other small heavy objects
- ruler

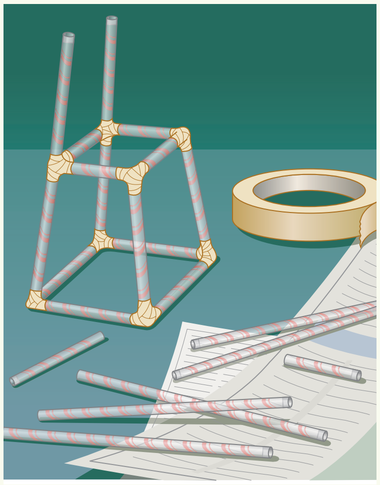


Figure 3.5 Example of a straw model, Step 1

Procedure

1. Organize into groups of three or four. Each group will be assigned a different material to build a model tower as illustrated in Figure 3.5. Predict the suitability of the material for building the tower.
2. Before any building begins, decide as a class how you will test all the materials for strength and stability. Agree on what observations you will record before, during, and after the test to determine the effect of the forces acting on the structures. Include:
   - Qualitative observations: These are changes you observe taking place in the structure as you proceed with your test.
   - Quantitative observations: These are changes you are able to measure in the structure as you proceed with your test.
3. Work with your group to build your model.

Collecting Data

4 After all towers have been completed, each should be tested in front of the class using the test methods agreed to in step 2.

> Note: If a computer and software are available, you may enter your data into a spreadsheet. This will allow you to produce graphs to show your results and compare them with those for other materials.

Analyzing and Interpreting

5 Which material most resisted the forces acting on the structure? Why do you think that is? Which properties gave the structure that strength and stability? Which material least resisted the forces acting on the structure?

Forming Conclusions

6 Do you agree or disagree that by knowing the properties of given materials, you can accurately choose a material that will provide strength and stability to a structure? Explain, using the results of this investigation.

7 What material properties do you think are the most important in real life for building tall, free-standing structures that can support the greatest mass? Why?

Give it a TRY — ACTIVITY

MEASURING DEFORMATION

Deformation of a structure can be measured.

- Weigh the masses and record the amounts.
- Measure the height of your foam cube and record the height in a table.
- Add the smallest mass to the top of the cube.
- Measure the height of the foam and record it.
- Repeat the procedure using each of the different masses.

Observations and Analysis

TOOLBOX

- What internal force is acting in this activity?
- Plot a line graph of your results. (Refer to Toolbox 7 if you need help drawing a graph.)

Materials & Equipment

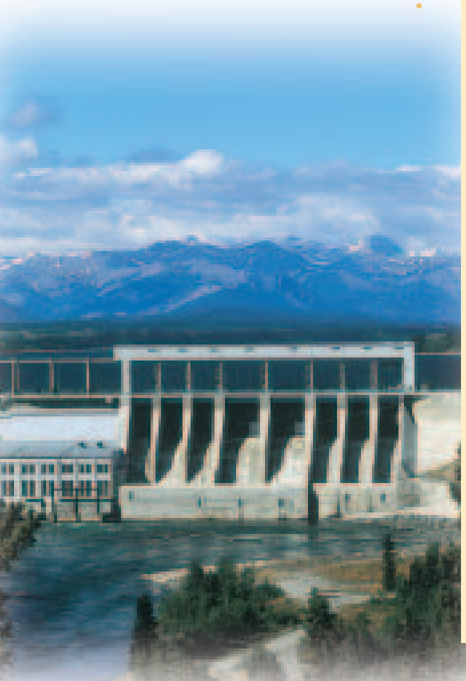
- polyester foam cube
- ruler
- 3–4 small heavy masses

CHECK AND REFLECT

reSEARCH

Wasp Nests

Research how wasps build their nests. What materials do they use to make their nests? What is the advantage of these materials?



1. Explain why it is important to match structural material and structural function.
2. Do you agree or disagree with the statement, "Almost any material can be used to build any structure"? In a paragraph, explain your answer.
3. The hydro-electric dam in your area is beginning to need expensive repairs. The building of a new dam is being proposed. Several people have been asked to provide advice to the designers of the new dam, including
   - the manager of the marina upstream from the dam
   - a freshwater ecologist
   - a drinking water expert from the city downstream
   - a person representing the hydro-electric power company
   - a person representing a local group wishing to open a biking trail and to use the new dam as a bridge

   a) In your notebook, list the people above. In turn, put yourself in the position of each person. Note what structural characteristics of a dam would be important to you, and how those characteristics would affect the choice of building materials you would recommend.

   b) Choose to be one of the individuals above. Compare your ideas for material choice with those of a classmate who is being a different individual. How could both of your needs be met in the new design?

3.2 Joining Structural Components

Figure 3.6 What is happening when the design and materials of a structure are just right, but the structural components don't stay connected?

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Expansion Joints
Outdoor structures such as bridges get very cold in winter and very hot in summer. Because their components contract and expand at different rates with these temperature changes, the joints connecting them must be able to move a little bit, too. Next time you're crossing a large bridge, watch for these "expansion joints."

Have you ever taped the broken frame of a pair of glasses together only to have the pieces work their way apart again? Have you ever struggled with a locker or cupboard door when one of the hinges has broken off?

The problem is that the components are not properly joined. Just as design and materials are important to a structure's strength and stability, so is how the parts of the structure are fastened together. The place at which structural parts are joined is called the **joint**. Some joints need to be rigid, or fixed, for the structure to work as intended. Others need to be flexible, or movable.

Joints That Rely on Friction

Think of pulling your desk across the floor. The drag or resistance you feel is the result of the **friction** that is occurring between the floor and the legs of the desk. Friction is the force that results when the surface of one object moves against the surface of another object. You may be able to overcome the force of friction easily when you are moving just the desk by itself. But what if a friend sat on the desk while you were pulling? You would have to work harder to move it. Can you explain why, using the terms *gravity*, *mass*, and *force*?

The strength of the force of friction also depends on the roughness or smoothness of the two surfaces in contact with each other. It is easier to move a desk across a freshly waxed linoleum floor than across a rough concrete floor. Why do you think that is?

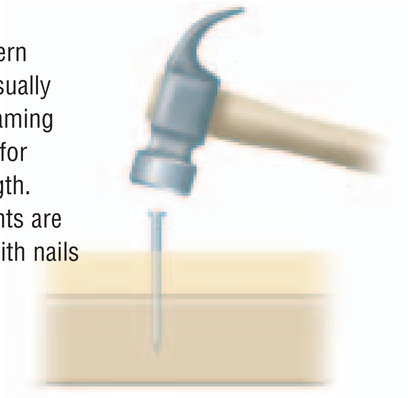
To create strong joints between parts of a structure, the force of friction can be used to prevent the individual components from slipping apart.

Figure 3.7 What force is helping this rock climber's foot stay joined to the rock? Is this the same force that is keeping the pitons (metal spikes) firmly in the cracks where they were hammered?

Nails, Screws, Rivets, Tacks, Staples

When a nail, screw, rivet, tack, or staple is used to hold components together, it is the friction between the metal and the material surrounding it that does the job. This is the most common type of joining used in modern construction (Figure 3.8). One advantage of screws, tacks, and staples is that they can be easily removed to dismantle a structure if necessary.

Figure 3.8 Modern structures are usually made of steel framing riveted together for maximum strength. Wood components are often fastened with nails and screws.



Interlocking Pieces

Since friction is the force as two surfaces rub against one another, you can increase the amount of friction by increasing the area in contact. As Figure 3.9 shows, this method is used, for example, to join wood together in interlocking pieces (without screws or nails).

Figure 3.9 The notches cut into these logs ensure that the parts in this structure will remain tightly interlocked. Furniture uses notches for strong joints.

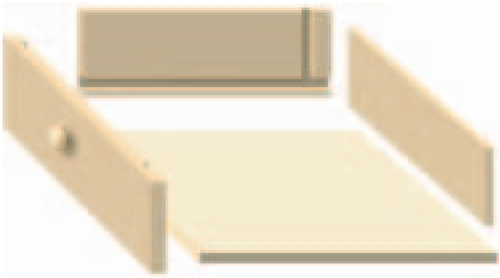
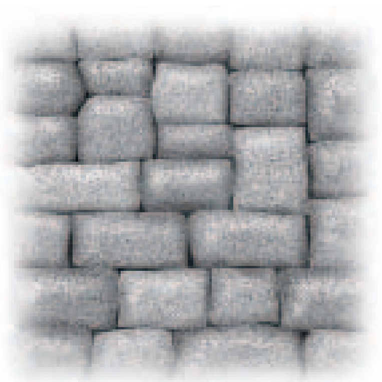


Figure 3.10 Landscape architects often use this "mass" method of joining to design stone retaining walls and split-rail fences.

Mass

The friction between the base of the block shown in Figure 3.10 and the surface underneath is enough to keep the block in place. The blocks forming the Pyramids of Giza are joined together only by the force of friction.



Joints That Rely on Bonding

Another form of joining actually changes the two surfaces being joined so that they are connected by a common material—whatever bonding substance is spread on them.

Glue, Tape, Cement, Welds

Adhesive glue and tape (which has glue on one side), cement, and welds act to bond the surfaces of two materials. Some types of glue, for example, dissolve the surfaces on which they're spread, creating a chemical change. The two new surfaces mix and harden together into one solid mass. Figure 3.11 shows an example of glue being used as a means of joining.

Figure 3.11 The joints in wooden furniture can be strengthened using glue.

Fixed or Movable? Which Joint for Which Structure?

All of the methods of joining just described can be combined in different ways to create fixed joints or movable joints.

Fixed joints are rigid to prevent any movement. They result, for example, from welding, cementing, gluing, or nailing parts firmly together. Which of these methods works best in any given structure depends on the material of the components, how the structure is to be used, and where it is to be located. Why would gluing to hold a fence together or welding to assemble a kite not be appropriate?

Movable joints are flexible or mobile so that parts of the structure can move as required. Hinges, pin joints, and flexible rubber tubing are examples of movable joints. So are your knees, elbows, and shoulders. Even though they are mobile, movable joints must still be able to withstand a load and the stress of repeated movements.

Figure 3.12 No matter how good a structure's design is on the drawing board, the ultimate strength and stability of that structure depend on the right materials and method of joining being used.

Problem Solving Activity

A Home for Time

Recognize a Need

Your school has decided to do a unique project to mark its upcoming anniversary. Each class will put together a message for students of the future, as well as small objects that may have special meaning in 100 years. The messages and objects will be put into a metal time capsule. The school is asking students to submit designs for a small structure to protect the box until a century has passed. The structure will be built by a local contractor who has volunteered time and materials.

Materials & Equipment

Suggested modelling materials. Use other materials if you prefer.

- Plasticine or modelling clay
- cardboard or foam board
- Popsicle sticks
- tape
- glue

The Problem

You and a small group of fellow students have decided to submit a design to the contractor. Your group will come up with an overall shape for the structure, as well as make suggestions for the materials and how they should be fastened. You will present your design as a combination of a scale model and a written list of materials for the real structure.

Figure 3.13 How would you build a structure to protect a time capsule?

Criteria for Success

The contractor who has volunteered to build the structure to hold the time capsule has set the following criteria for the student designs:

- There must be a door in the structure that can be opened when the time comes (in 100 years), but which would be locked until then.
- The material for the real structure must be able to withstand the climate found at your school over time.
- The material must be easily obtained.
- Preference will be given to a design that uses a material that is easily obtained, not expensive, and attractive looking.
- There has to be some way people in the future will be able to identify the function of the structure, so they know there is a time capsule inside.

Brainstorm Ideas

1 Brainstorm how you want the structure to look. Make sketches to show possible structures from different views, such as from the top and from the side. Keep in mind the structure will be outside and visible to the public.

2 When you're ready, make a scale drawing of your design. Include any features such as doors or other moving parts, as well as any signs or ornamentation you wish to use.

3 Brainstorm possible materials and their pros and cons. Once your group has decided on the materials you want for the structure, modify your design if necessary. Make note of any properties of your materials that will be especially valuable for this structure.

4 Build a model of your structure using any modelling material you wish. Your model should include a scale model of the time capsule so you can demonstrate how the capsule fits inside. Make any modifications you need to during the building process.

Test and Evaluate

5 Your teacher will, if possible, invite a local contractor to help assess the various designs. Alternatively, a class selection committee can be formed to choose the design that best fits all of the criteria.

Communicate

6 In a short assessment report, summarize:

a) the most difficult aspect of this challenge that you had to overcome in your design

b) how you overcame that difficulty

c) how you might have tested your design for strength and stability

7 Which features of the chosen design were considered most important by the contractor or selection committee? Discuss how the other designs could be improved using some or all of these features. Often one design will be just as good as another, and a final choice is made based on personal opinions about appearance. If this was the case in your class, hold a vote to see which design would receive the most support.

8 This could be a project that your school or a community group would be interested in doing. Discuss how you might get such a project started.

St. Paul, Alberta, is home to the world's first UFO landing pad. Built in 1967 (the year this picture was taken), this imaginative structure also contains a time capsule.

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When Friction Is a Problem

When structural parts are joined together, friction can cause wear in one or both of the surfaces rubbing together. Friction also generates heat where the two surfaces rub. Neither of these is a good thing when it comes to keeping structures strong and stable. Think of an example in which wear and heat generation between structural parts pose a problem. Research how the problem is being dealt with.

Designing Joints to Last

If a structure is to last any reasonable length of time, it must be designed to withstand the forces acting on it year after year.

For some structures, such as a monument, the main forces acting on them are extremes in weather (such as extreme heat or cold).

For structures with moving parts, "building for time" is also a challenge. The joints used in them must be able to survive the force of repeated movement. Consider your refrigerator at home. How many times a day does its door get open and shut? How many times a week is that? How many times a year? An inappropriate type of joint for the job will eventually experience fatigue and then breakage, even though other parts of the structure remain strong.

Figure 3.14 A structure's basic shape may be stable and its materials strong, but if its joints are not suited to how and where it is used, it won't be useful for long.

Check and Reflect

1. Remember the list of fasteners, or joints, you made at the start of subsection 3.1? Which ones function based on friction? How does friction help those joints do the job they are supposed to do—that is, not slip apart?
2. Given what you now know about friction, read the statements below and correct the three that are incorrect (one is right!):
   - A camper spreads rubber tarp on slightly sloping ground, then puts a backpack on top of the tarp. When the camper returns a moment later, the backpack has slid several centimetres down the slope.
   - It is easier to open a jar lid if your hands are dry than if they are wet.
   - A hockey skater reduces speed by digging in the tip of each skate when striding forward.
   - A very thin film of water on a road is less slippery to a moving car or truck than a dry road.
3. Identify four structures found in the natural environment that have fixed joints and four that have movable joints.

3.3 Properties of Materials in Plant and Animal Structures

As you have studied, structure and function go together. The living world is no exception. Have you ever seen a Venus flytrap catch an insect? If you have, you would have been amazed at how fast the leaves that have been modified to form a trap can move. The unsuspecting insect triggers this reaction when it touches the small hairs located on the inside of the trap. The human body is built to move quickly as well.

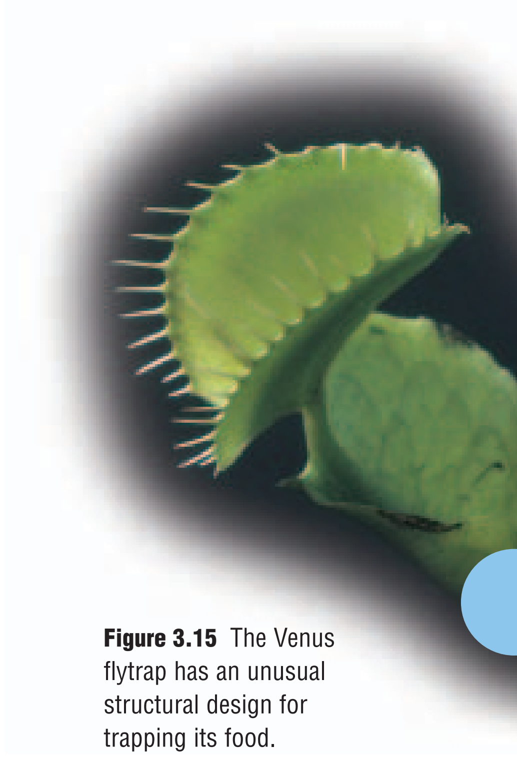

Figure 3.15 The Venus flytrap has an unusual structural design for trapping its food.

Materials in the Human Structure

Think about your body as a structure. Each of the components in the human body is a unique material with special properties suited to the function of that part.

Bones, Ligaments, and Cartilage of the Frame Structure

Bones in the human adult are hard and rigid. They form a structural frame that is strong enough to support and protect other parts of the body. The thigh bone is connected to the shin bone by ligaments. These are bands of strong, flexible connective tissue. Cartilage that is found at the ends of some bones reduces friction and provides a smooth surface for movement. When you fall off your bicycle, the cartilage helps to absorb the shock of your bones being bumped together.

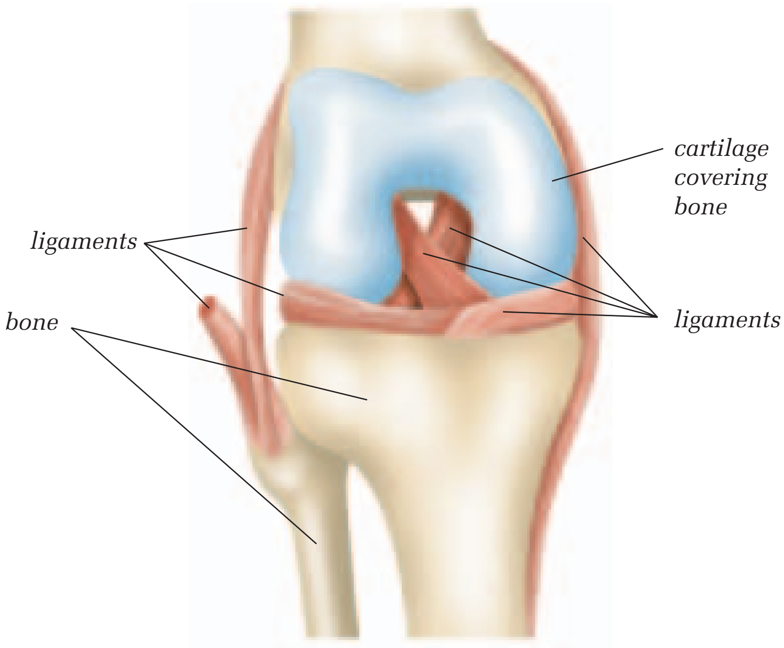

Figure 3.16 The seven ligaments that hold your leg bones together meet at your knee.

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Synthetic Muscles

Scientists have discovered that a glue commonly used for such jobs as holding road signs up over highways may create the perfect "muscles" for robots and artificial limbs. The glue, an *acrylic elastomer*, can take strain better than human muscle can. It also creates as much force as human muscle does. Other advantages are its light weight and the fact that it goes back to its original shape even after it has been stretched.

Muscles and Tendons

The muscles of your body, 656 of them, allow your skeletal frame to move. Muscles are made of semi-solid fibrous tissue that functions by contracting (shortening) and relaxing. They are attached to bones by tendons. Like ligaments, tendons are strong and flexible. A tendon will often hold together even when the bone to which it is connected breaks. When a skeletal muscle contracts, a bone moves. Muscles also are located in your internal organs. Heart muscle contracts and pumps blood. Digestive tract muscles contract and move food along.

Joints

The joints in your body are specialized for various functions. Ball-and-socket joints in your shoulders and hips permit movement in many directions. Elbows and knees function with hinge joints. There are pivot joints in your spinal column and gliding joints in your wrists. All of these allow movement. However, there are joints in the body that don't allow movement at all. They are found between the bones of your skull. What do you think the function of the skull is? Do immovable joints make it suited for that function?

Give it a **TRY** ACTIVITY

MATERIALS IN PLANTS AND ANIMALS

You've just learned a little about the role of different materials found in the human body. You've also seen how the functions of the body's various components are made possible by a range of methods of joining. The role of different materials in plant and animal structures is just as fascinating.

- Using the library or Internet, research the material composition of a plant or animal of your choice. Find out what properties the main materials have and what advantages these give the structure in terms of how it functions. Also note how the parts of the structure in your chosen plant or animal are joined.
- Write a summary of your findings, and include drawings to illustrate the materials and joints.

Skin, the Human Shell

Skin, along with the bones, joints and connective tissue, form a shell and frame structure. Skin is a tough, flexible material. It provides the ultimate structural shelter. It waterproofs your body and protects it from harmful bacteria. As well, it helps to regulate your body's temperature through such actions as perspiration and shivering.

Materials in a Tree's Structure

A tree trunk may seem to be made of just one material ("wood"), but in fact, it is a structure composed of several layers of different materials. As Figure 3.17 shows, each layer of material has a specific job to do to maintain the strength and stability of the tree.

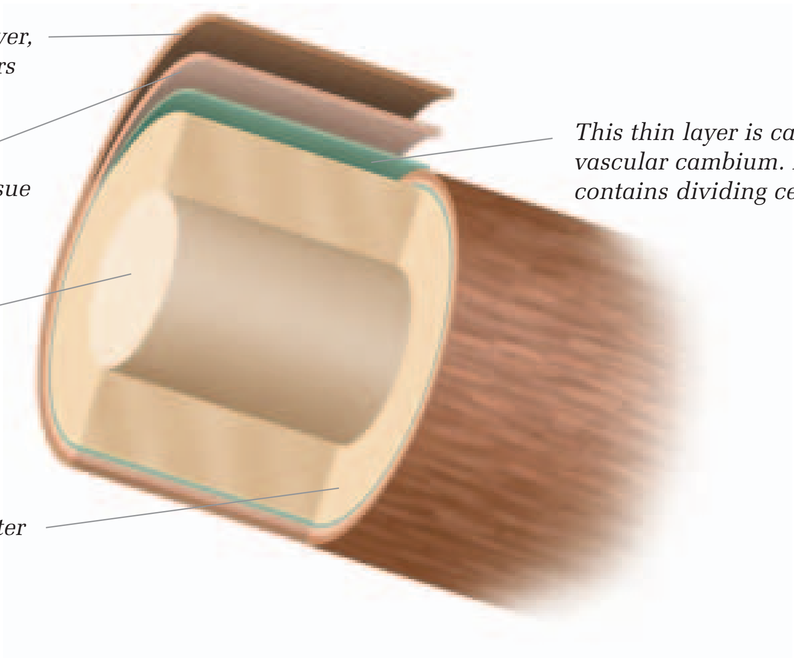

Figure 3.17 Each layer of material in this tree plays a role in keeping the tree strong, stable, and healthy.

Check and Reflect

1. What would happen if ligament material in the human body were replaced by bone material?
2. Most sports injuries involve damage to joints such as ankles, knees, and wrists. Why do you think this is so?
3. True or false? The different layers of materials found in plants are needed only to make the plants strong. Explain your answer.