Vocabulary

- solid
- frame
- shell

Lesson 1

Structure Types

Learning Outcomes

After completing this lesson you will be able to

- ❑ classify natural and human-built structures as frame, shell, and solid

Structures Are All Around Us

Structures are everywhere. They're not just buildings, either — chairs, beehives, shoes, and balls are examples of structures.

Structures are built to handle certain loads and stresses. Engineers construct structures a certain way, depending on the type of loads and stresses that the structure may have to withstand.

There are three basic categories of structures: **solid**, **frame**, and **shell**.

Solid structures are made of a solid piece, or solid pieces of strong material. Some examples of solid structures are a stone bridge, a brick wall, and a telephone pole.

Frame structures are made of parts connected into a set arrangement. Some examples of frame structures are the framing for a house, hydro line towers, and a skeleton.

Shell structures are moulded into a shape that provides strength and stability. Some examples of shell structures are a basketball, an egg carton, an igloo, and a clamshell.

Some structures are combinations of two or more of the three basic types. A house is an example of a combined structure — the cement foundation is a solid structure, the two-by-four lumber connected together is a frame structure, and the addition of walls and a roof make the whole house an example of a shell structure (where the inside is hollow).

Learning Activity: Take a "Structure Walk"

Take a walk in your community and look at the structures that surround you. Using a notepad, write down the examples you encounter and identify their structure types (or combination of structure types).

1. Fill in the following chart with examples you saw on the structure walk.

Solid Structure	Frame Structure	Shell Structure

2. Did you observe any structures that were a combination of two types? If so, identify the structures and the types involved in their construction.

3. What type of structure is the human body? Explain your answer.

Notes

- centre of gravity
- force diagrams
- stable
- vectors
- balanced forces
- unbalanced forces

Lesson 2

Centre of Gravity and Keeping Structures Balanced

Learning Outcomes

After completing this lesson you will be able to

- ❑ identify the centre of gravity of a structure
- ❑ demonstrate how changing the location of the centre of gravity can sometimes cause instability
- ❑ recognize how force diagrams can be used to represent direction and size of forces

Learning Activity: Balancing Act

Balance a ruler on one finger, and record where your finger is placed along the length of the ruler. The place where your finger was located when the ruler was balanced is called the **centre of gravity** — it is where the mass of the structure is concentrated.

Next, place your finger toward one end of the ruler and observe what happens. Answer the following questions.

1. Where along the length of the ruler did you place your finger to balance the ruler?

2. What force was pulling on the ruler?

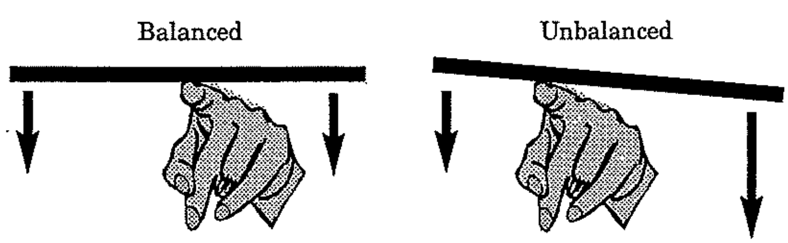
Force Diagrams and Stability

Engineers use **force diagrams** to illustrate how forces act on a structure. This helps them to decide on the design features that are needed to ensure that the structure is **stable** (meaning, it will remain on its base without falling down or breaking into pieces).

Here are some common features of force diagrams:

- The direction and the strength of a force are represented by arrows, called **vectors**. A longer arrow represents a stronger force. The point of the arrow shows the direction in which the force is being applied.
- Pairs of forces are often included in force diagrams. It is possible to predict the overall effect of forces by comparing their relative size. **Balanced forces** will not cause any change, whereas **unbalanced forces** (one greater than the other) will cause a change.
- Force diagrams may not be a true representation of how a force is acting on an object. For example, even though gravity is acting on all parts of a structure, an arrow may be used to illustrate the strength of one force in relation to other forces acting on the structure.

Think back to your ruler experiment and review the diagram below. The "balanced" image on the left shows arrows of equal length to demonstrate that the force of gravity is equally divided on both sides of the ruler. The "unbalanced" ruler on the right shows arrows of different lengths to demonstrate an uneven distribution of gravity. Remember that the finger is what provides the other force, acting in an upward direction.



Learning Activity: Predicting the Centre of Gravity

The balancing point you found with the ruler is called the centre of gravity, which is the object's most stable point. To experiment more with the centre of gravity, cut out the shapes on the following page. Glue them to pieces of cardboard and trim off the excess.

Predict and then test to determine where the centre of gravity is located for each shape. Your goal is to balance each shape on your fingertip.

Record your observations.

Shape 1 ______________________________

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Shape 2 ______________________________

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Shape 3 ______________________________

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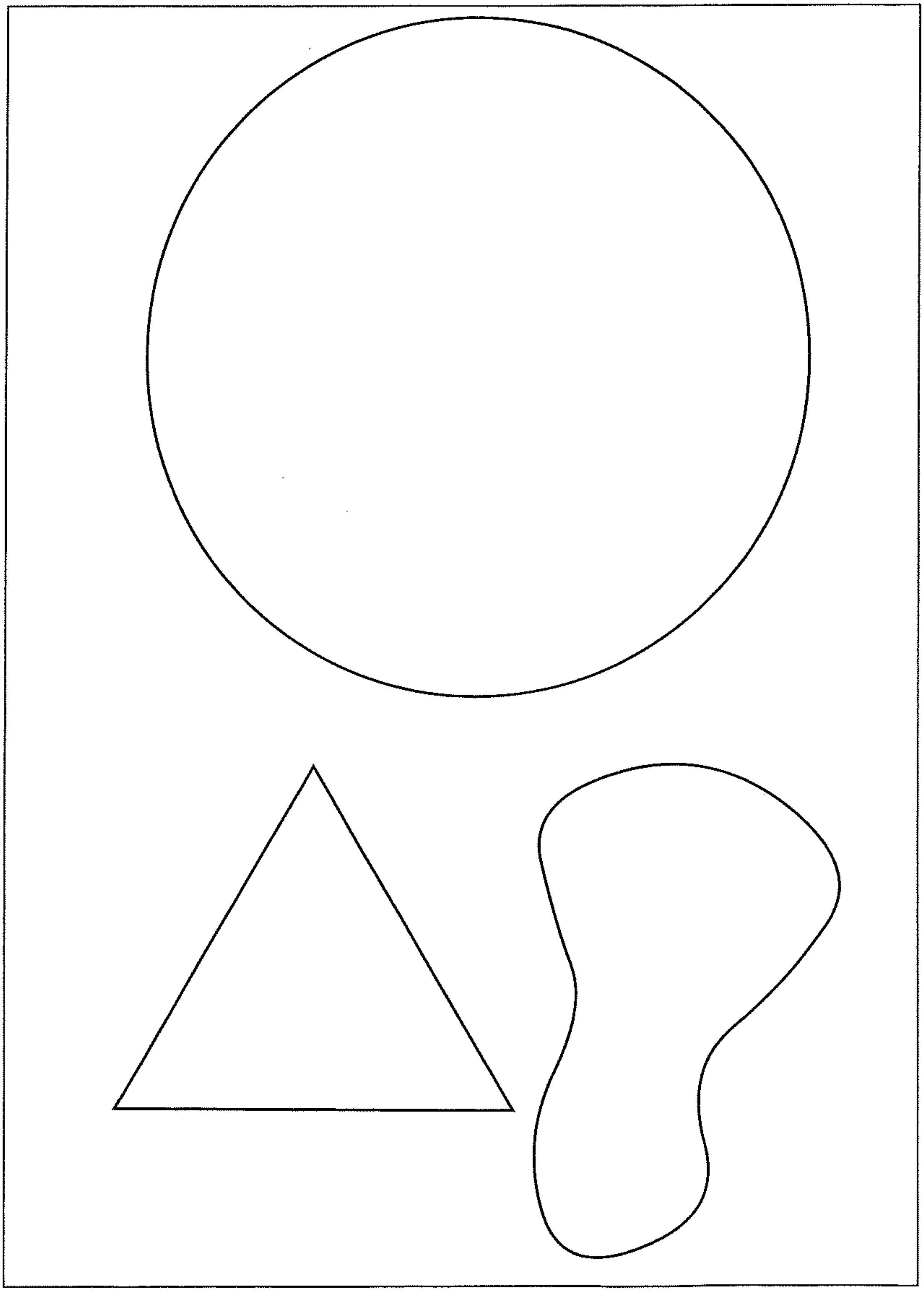


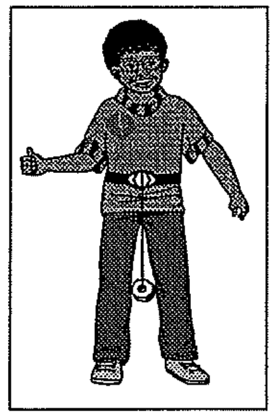
Learning Activity: Where's My Centre of Gravity?

To conduct this learning activity you'll need some string, a belt, and a large washer (or other small weight).

Connect one end of a string to the buckle of a belt that you are wearing, and the other end of the string to a large washer (any type of small weight can be used) which should hang at knee level.

Stand straight in four positions:

- with your feet together
- with your feet slightly apart
- with your feet shoulder-width apart, and knees bent
- on one foot



Observe where the washer is in relation to your body. Now attempt to reach for something in front of you without moving your feet. Notice the position of the washer at the point at which your balance is lost or almost lost.

Questions: Centre of Gravity

Answer the following questions after completing the washer experiment above.

1. What was the position of the washer in relation to your feet and hips when you lost your balance?

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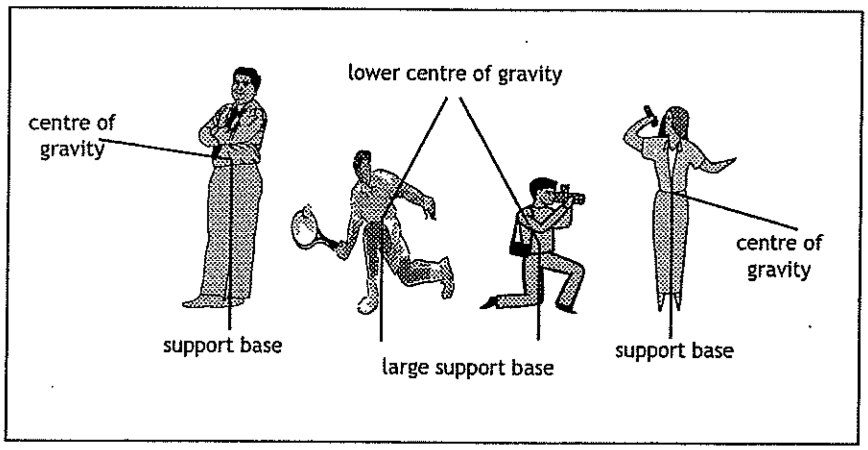
2. The centre of gravity of a person is located in the mid-abdomen region, over the hips. Where must the centre of gravity be in relation to your feet for you to remain balanced while standing?

3. Of the four initial stances/positions you took, which one provided the most stability? Why?



4. Can you identify other examples where stability, balance, and a well-placed centre of gravity are used in sports?

Learning Activity: Build a Free-Standing Tower

Using children's blocks or dominoes, see how high you can build a free-standing tower. Try several different designs, and follow these guidelines:

- Prior to building, draw a plan for your tower.

- During construction, you may not modify the structure once the blocks are in place. However, you may modify your plans for subsequent layers.
- The structure must be stable for a 10-second count, so you may wish to conduct stability checks as you build. You should record the height you achieved at each stability check.

- Draw your final structure and record the height.

- Repeat the process several times, using different designs to see what works best. For each design you should use the same number of blocks or dominoes.

Questions: Free-Standing Tower

After completing several trials of building a free-standing tower, compare diagrams and heights and answer the following questions.

1. What similarities in structure were found among the shortest towers that you built?

2. What was the common characteristic of the taller towers?

Vocabulary

- load force
- compression
- tension
- shear
- torsion
- buoyancy
- structural stress
- structural fatigue
- structural failure

Lesson 3

Internal and External Forces

Learning Outcomes

After completing this lesson you will be able to

- ❑ identify internal and external forces that act on a structure
- ❑ use force diagrams to describe where these forces act on a structure
- ❑ recognize that these forces apply stress to a structure
- ❑ describe examples where this stress has led to structural fatigue or failure

The Effect of Forces

Forces act upon and within a structure. For example, when you place heavy books on a shelf, the books add stress to the shelf by applying what is called a **load force**. The structure of the shelf is affected by this force in several ways. In this lesson you will explore how a load force impacts a structure.

Learning Activity: Forces Acting Upon Licorice

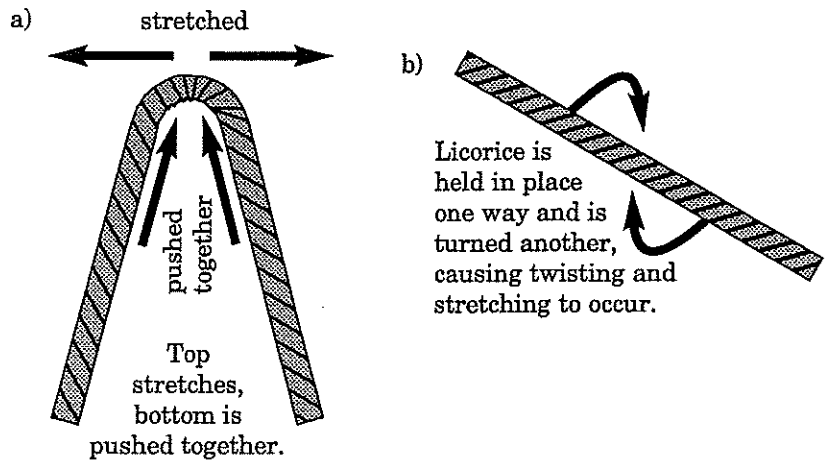
For this experiment, you'll need a couple of licorice strips. Follow these directions:

1. a) Bend a licorice strip in half and observe where the bend occurs.

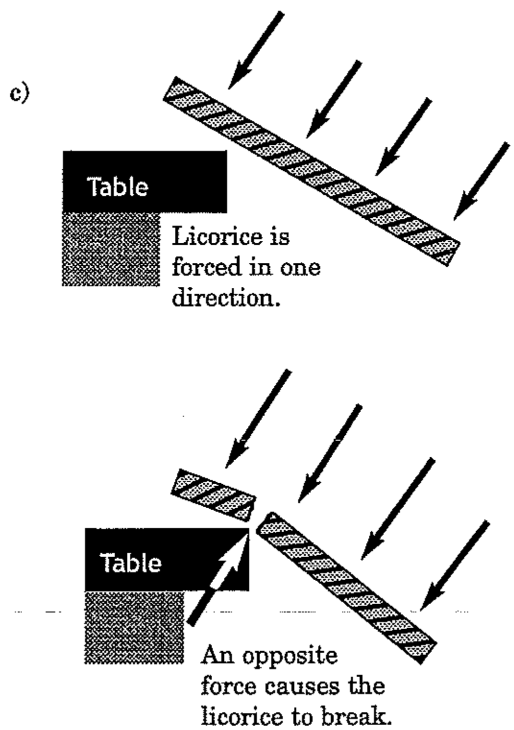
   b) Straighten the licorice and, holding one end steady, turn the other end of the licorice.

   The following diagrams use force arrows to illustrate what is happening in each case.

3. Using the terms *stability* and *centre of gravity*, describe what is needed to ensure that a tall tower is stable.



c) The following diagram illustrates what happens when frozen licorice is broken against the edge of a table. (Note: If you want to try this at home, wear safety goggles.)



2. Scientists use special terms to describe different forces. Beside each description, indicate which diagram (a, b, or c) from the previous page illustrates the type of force described.

   Compression is a squeezing or pressing force.

   Example: ____________________

   Tension is a force that stretches or pulls.

   Example: ____________________

   Shear is two forces acting in opposite directions along the same line or plane.

   Example: ____________________

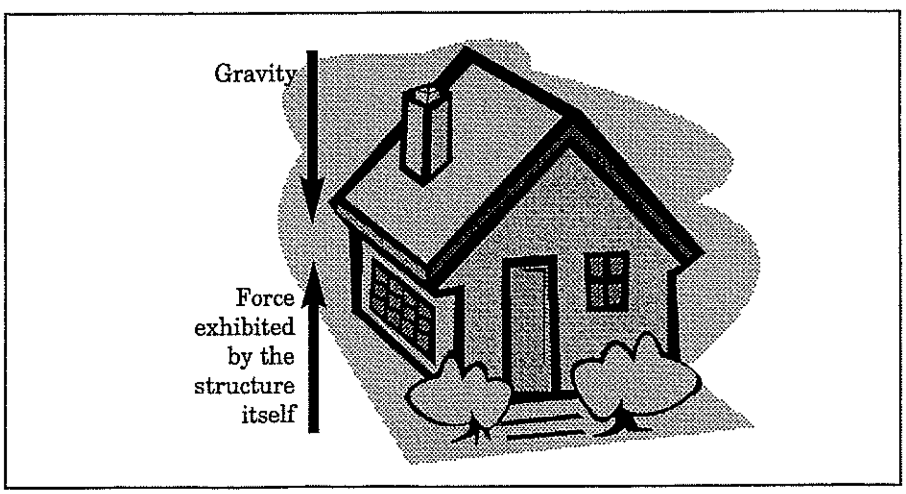
   Torsion is a twisting force.

   Example: ____________________

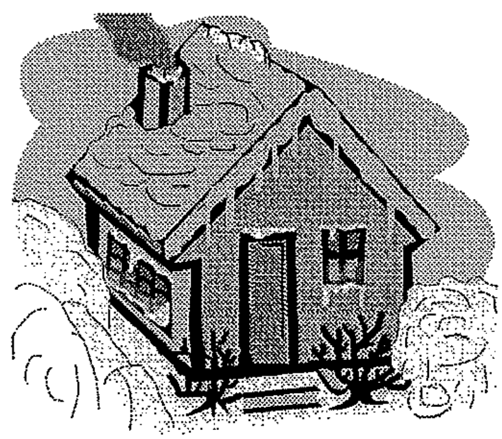
External Forces

Besides the internal forces acting within a structure (as seen in the previous learning activity), there are also external forces that act on a structure. Forces always act in pairs. In the example of a house, gravity is the force that acts upon the structure, and the house itself exerts a force that counteracts the force of gravity.

If the opposing forces are equal and balanced, the structure is stable. The following diagram illustrates those forces:



What if the scenario changed slightly, and a large amount of snow fell on the roof of the house? Using vectors (arrows), illustrate how the gravitational force on the house would change with the addition of the weight of the heavy snowfall. Remember, force diagrams usually show pairs of forces, so you'll want to draw two vectors.



Points to Ponder

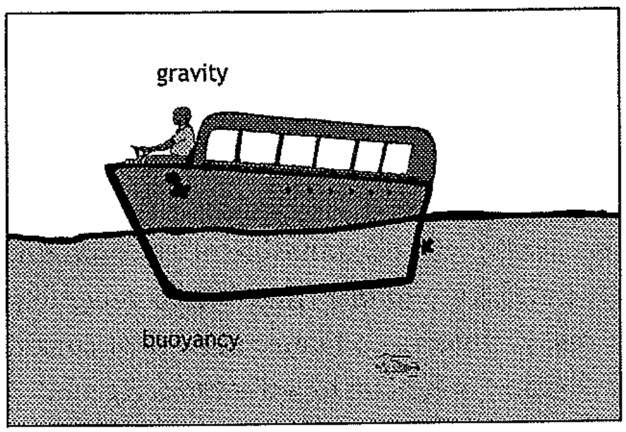
Think about the following questions before continuing this lesson.

- If the snow-covered house in the second diagram were to remain standing, what would the force exhibited by the structure of the house have to be in relation to the force of gravity?
- What would happen if there was too much snow on the house? How would you picture this using a force diagram?
- Why do engineers have to take the concepts of force into consideration when designing and building a structure?

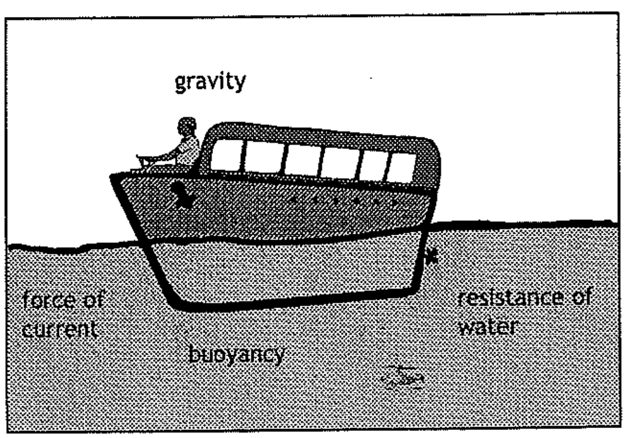
Learning Activity: May the Force Be With You

Boats are structures that have forces acting upon them. For example, the force that keeps the boat up in the water is called **buoyancy**. Using vectors, illustrate the forces acting on the boats in the following situations. There should be one vector beside each label on the diagrams. (**Note:** Remember that the length of the arrow represents the strength of the force.)

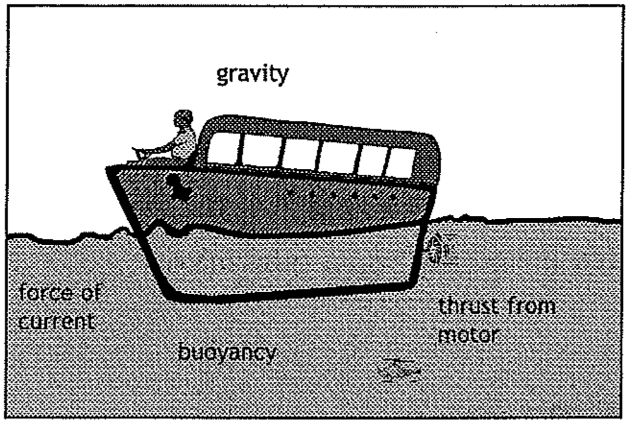
1. The boat is floating in one place on a calm lake.



2. The boat gets caught in a current of water that begins to move it backwards.



3. The driver starts the motor and moves ahead against the current.



Unbalanced Forces

Structural stress occurs when a combination of external and internal forces act on a structure at one time. When designing and building structures, architects and engineers must consider the stresses that a structure will have to withstand. Special modifications sometimes have to be made to ensure that structures are stable and safe.

For example, buildings that are situated in an earthquake zone have to be able to withstand the shaking movement of the earth, and buildings built along a shoreline have to be able to withstand the stress of the pounding waves. In each of these instances, engineers have to make special adaptations to their designs to ensure that their structures can withstand the stress.

Sometimes, when a structure is exposed to a combination of external and internal forces for a long period of time, its components begin to weaken. This is called **structural fatigue**. Structural fatigue can occur in the concrete or the beams that make up the structure.

If the structure is exposed to unexpectedly strong forces that it was not built to withstand and/or has suffered structural fatigue, **structural failure** or collapse may occur.

A Tower on the Brink of Structural Failure

Read the following case study to learn more about structural fatigue and structural failure. Answer the questions on the page provided following the case study.

Stabilizing the Tower of Pisa

The Leaning Tower of Pisa in Italy (**Figure 1**) is one of the wonders of the Middle Ages. The structure is known as a *campanile*, a kind of bell tower. Eight storeys high, the tower reaches 55.9 m into the air. The structure is made of stone—white marble—and the foundation walls are 4.0 m thick. The tower is strong and it has stood for centuries, but it is not stable.

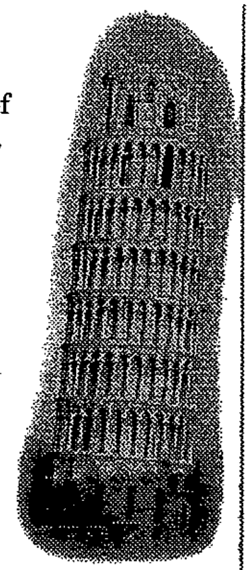


Figure 1

The Leaning Tower of Pisa. Engineers are working to reduce the tower's lean so it will not fall.

Building the Tower

Construction of the tower started in 1173. In 1178, when the base and three more storeys had been built, construction was interrupted by a war. Even then, it was obvious that the tower was leaning to the south. After the war, the people of Pisa decided to continue construction, but with a slightly changed plan—they built the next two levels on a slight curve, opposite the direction of the lean. They hoped this would allow them to make the bell chamber at the top.

(a) The lean of the tower was a problem. The people of Pisa decided to solve it by curving the tower. Was this the best solution? What other solutions can you think of?

Completing the Tower

The curve didn't work. As the tower grew taller, it began to lean even more. Construction was interrupted several times, but the tower was finally completed in 1350, almost 200 years after the start of the project. At that point, the lean, measured from the seventh storey to the ground (Figure 2), was about 1.5 m. It was visible, but not dangerous. However, the lean has increased since then, as you can see from Table 1.

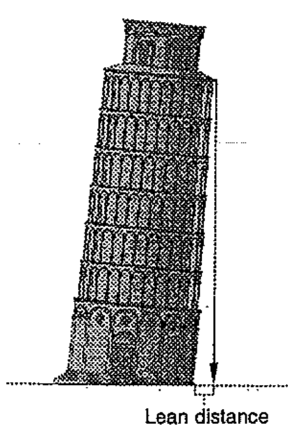


Figure 2

(b) Speculate on the position of the tower's centre of gravity. What happens to the stability of the tower as its lean increases?

(c) In 1990, the tower was closed to the public. Why do you think this was done?

Why the Tower Leans

The reason for the tower's instability is the sandy soil under the foundation. This soil is gradually shifting from under the great weight of the tower. There is a layer of more solid clay 10 m below the surface. If the original architects had considered the soil, they could have compensated by building the foundation deep into the ground. However, the foundation is only 3.0 m deep—not nearly enough to stabilize the tower against shifting soil!

(d) If there were a way to straighten the tower, is there any reason to believe it would stay straight? Explain.

Table 1 A Growing Lean

Year	Lean (m)
1298	1.43
1550	3.79
1787	3.79
1817	3.84
1911	4.04
1935	4.80
1997	5.20

(continued)

Reducing the Lean

The first commission to deal with the problem of the leaning tower was established in 1298. There have been 17 more commissions since then. Most have done nothing that helps, and a few have done harm. The attempts to inject concrete under the tower in 1934 and to freeze the soil around the foundation in 1995 both made the lean significantly worse.

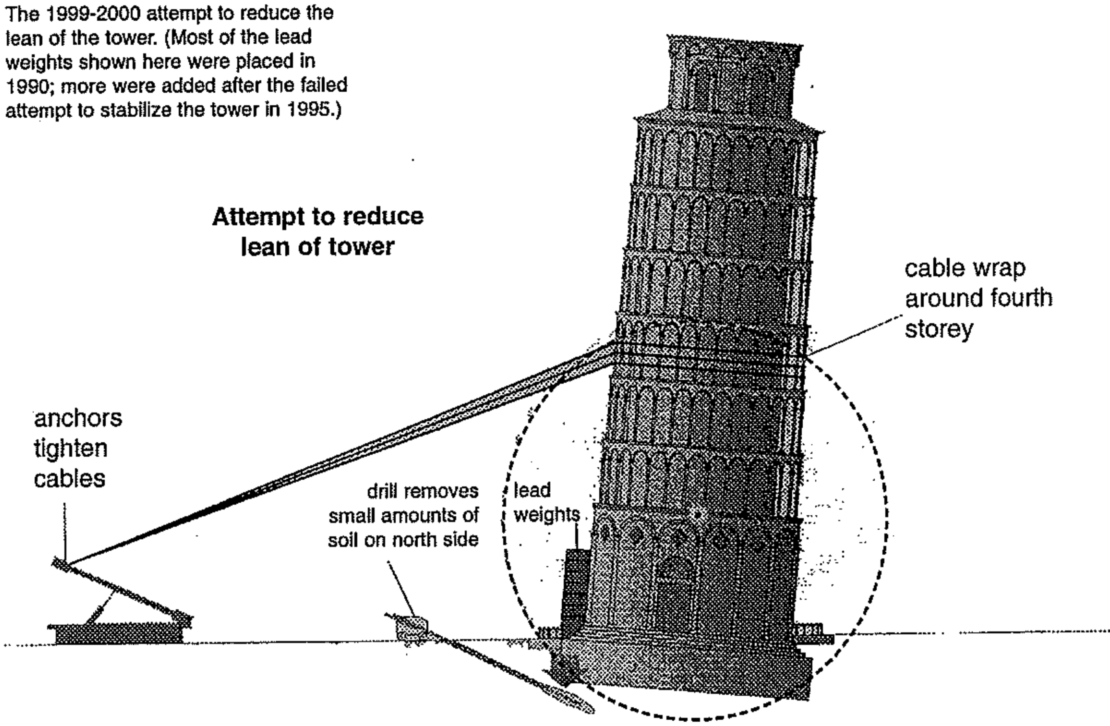
A new plan, scheduled for 1999 and 2000, involves bracing the tower with cables and removing some of the soil from under the north side of the foundation (Figure 3). The plan is to reduce the lean by only a small amount, about 0.4 m, enough to make the structure safe for visitors.

(e) Why would removing some of the soil from under the north side of the tower reduce the lean?

(f) No one wants to completely straighten the tower, especially the people of Pisa. Suggest some reasons why.

Figure 3

The 1999-2000 attempt to reduce the lean of the tower. (Most of the lead weights shown here were placed in 1990; more were added after the failed attempt to stabilize the tower in 1995.)



Stabilizing the Tower of Pisa

a) ______________________________

b) ______________________________

c) ______________________________

Notes

d) ____

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e) ____

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f) ____

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