14.3 Forces in Structures

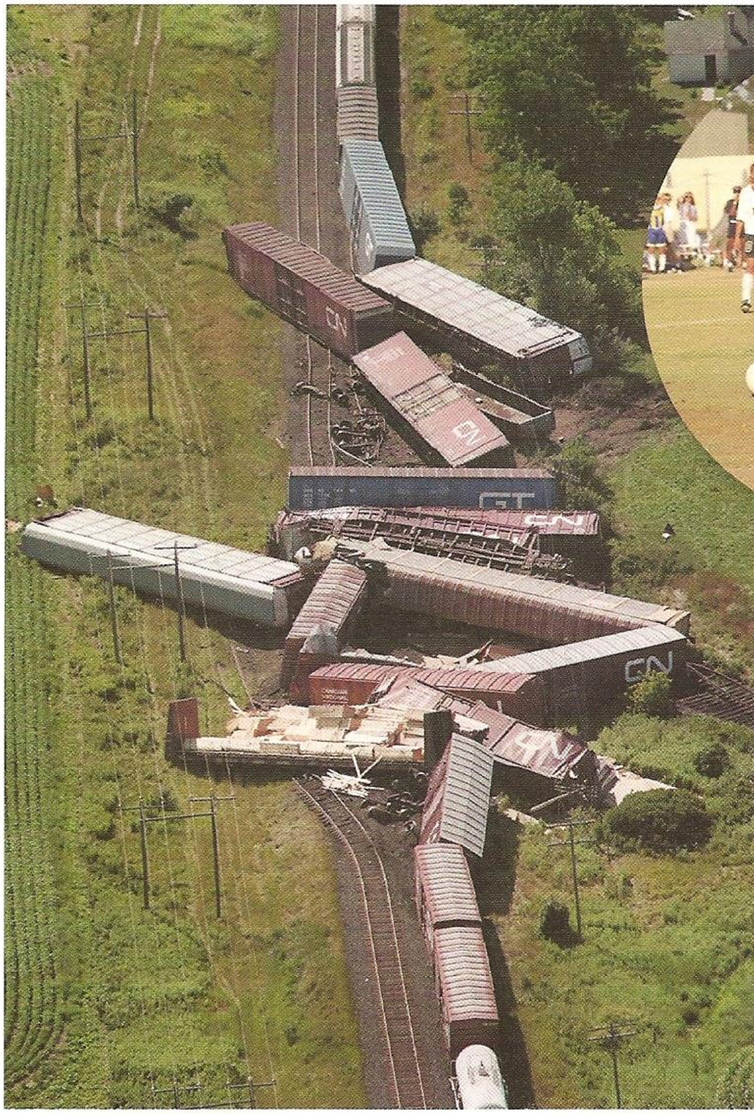


Figure 14.8 A train derailment produces a number of effects on the cars that collide with each other.

You do not have to witness a train crash to know that it creates dangerously large forces. Look closely at Figure 14.8. What effects did the forces in this collision have on the colliding objects? List as many effects as you can.

Now imagine a smaller "collision," such as kicking a soccer ball. When your foot applies a force to the ball, or any small object that is free to move, three things can happen. The object's motion can speed up, slow down, or change direction. When you kick something larger, such as a building, it does not usually move, but the force still has an effect. Your push on the outside of the building (an **external force**) creates forces inside the building material (**internal forces**). If these **stresses** (forces exerted on an object) become large enough, the shape or size of the building may change very suddenly. To design a strong structure, engineers need a good understanding of the different external forces that can act on it and the internal forces that can build up inside it and that may cause parts to fail.

External Forces

Engineers know of many forces that may affect buildings. They divide these forces into two groups.

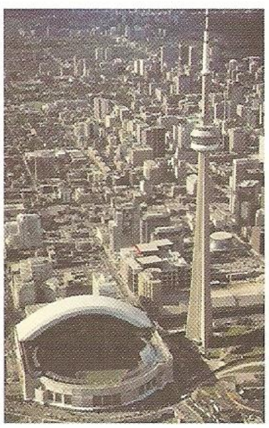
Live load includes the force of the wind and the weight of things that are in or on a structure (people, furniture, and snow and rain on the roof). Impact forces, caused by objects colliding with the structure, are another type of live load. Most structures are designed to withstand forces at least two or three times larger than their expected live load. Sometimes, though, live loads become extremely large for a short time, as in a storm or a collision, and the structure can be damaged.

Dead load is the weight of the structure itself. Over time, this gravitational force can cause the structure to sag, tilt, or pull apart as the ground beneath it shifts or compresses under the load.

When you act as a live load on a teeter-totter, you create forces that spread through the whole apparatus. Your weight pushes down on the seat and the bar to which the seat is fastened, but the opposite seat is lifted up. The centre of the teeter-totter twists around its pivot. One external force (your weight) creates several internal forces. These stresses affect different parts of the structure in different ways. Study Figure 14.9 to learn about four of the most important internal forces.

Did You Know?

Although the mass of the CN Tower in Toronto is over 130 000 t, this hollow concrete structure is still flexible. In 190 km/h winds, which are thought to occur only once or twice every 100 years in Toronto, the glass-floored observation deck near the top of the tower would move 0.46 m (about the width of this open textbook) off centre. Instead of making the tower unstable, this movement would press the specially shaped foundation even more firmly into the ground.



INTERNET CONNECT

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Find out more about the Leaning Tower of Pisa by going to the web site above. Go to the **Science Resources**, then to **SCIENCEPOWER 7** to know where to go next. Or submit **"Pisa"** to an Internet search engine.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

For information about how the CN Tower was designed and built, and some of the records it has set, go to the web site above. Go to the **Science Resources**, then to **SCIENCEPOWER 7** to know where to go next. Or submit **"CN Tower"** to an Internet search engine.

Did You Know?

The Leaning Tower was designed to be a beautiful bell tower for a church in the Italian town of Pisa. Construction began in 1173, but after the first three storeys were built, the ground beneath the heavy stone building began to sink unevenly. Even before the 55 m tower was completed (around 1370), it had developed a noticeable tilt. By 1990, when the tower was closed to the public, the edge of the top storey was about 4.4 m outside the edge of the foundation and the tilt was increasing by about 1.3 mm each year. There have been many attempts to stop or reverse the leaning to keep the tower from collapsing. Recently, engineers have been able to straighten it about 10 mm — still not safe enough to be reopened.

Internal Forces

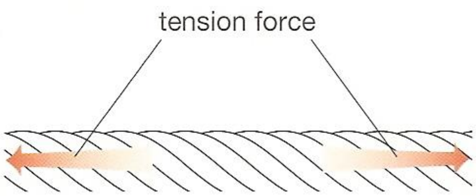

Figure 14.9A

Tension forces stretch a material by pulling its ends apart. **Tensile strength** measures the largest tension force the material can stand before breaking.

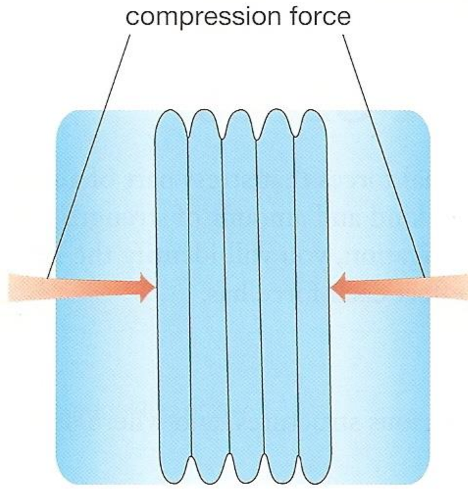

Figure 14.9B

Compression forces crush a material by squeezing it together. **Compressive strength** measures the largest compression force the material can stand before losing its shape or breaking into pieces.

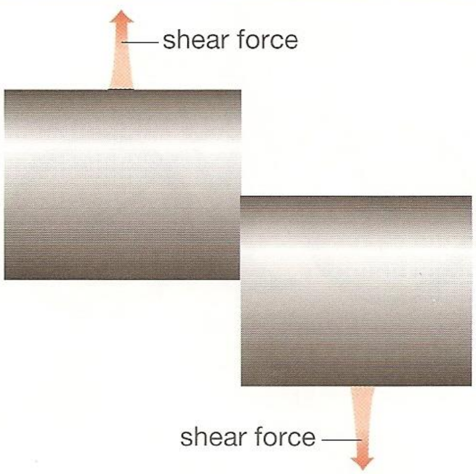

Figure 14.9C

Shear forces bend or tear a material by pressing different parts in opposite directions at the same time. **Shear strength** measures the largest shear force the material can stand before ripping apart.

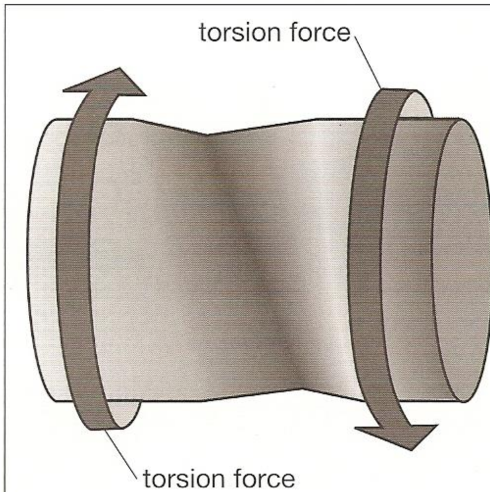

Figure 14.9D

Torsion forces twist a material by turning the ends in opposite directions. **Torsion strength** measures the largest torsion force the material can stand and still spring back to its original shape.

Pause& Reflect

In your Science Log, write a short paragraph explaining the difference between external forces and internal forces. To illustrate your explanation, give an example of each type of force when a strong wind blows on a flag.

Word CONNECT

The same words that name internal forces are used in other situations.

- How is a metal pair of cutting *shears* similar to a *shear* force?
- How is a *tension* headache similar to a *tension* force?
- How is a *compressed* computer file similar to a *compressive* force?

Strengthening Structures

DidYouKnow?

Symmetrical shapes can be turned or folded to fit exactly on top of themselves. Most people's faces are quite symmetrical, as are many other natural and manufactured structures. Because symmetry looks very pleasing, it is a powerful element of good design. Symmetrical parts, braces, and decorations on an object help it look attractive. If you start watching for symmetry in structures you observe every day, you might find ways to use this principle in your next design project. Can you find the axis of symmetry — the line that divides the butterfly into two parts with almost identical shapes?

In science fiction stories, you can read about wonderful imaginary materials that stand up to almost any force. Real materials are more limited. As you saw in Chapter 13, concrete and mortar have very high compressive strength if they are made according to the correct recipe. Concrete is quite weak if it is pulled or sheared, however. Similarly, most other materials have one kind of strength but not another. That is why engineers must analyze structures in great detail to find what types of internal forces are stressing each part. They can then choose materials and shapes with the strength to withstand each force. Even a simple swing needs to be designed in this way (see Figure 14.11).

Shear forces were a big problem for early railways. Tiny cracks inside the rails often weakened them enough that the weight of a loaded train would shear a rail in half, causing a serious accident. But the cracks could be detected only after the rails broke. In 1932 a Canadian metallurgist, J. Cameron Mackie, discovered that the cracks formed when the rails cooled too quickly during the manufacturing process. Mackie tried putting red-hot rails in a covered steel box where they could cool more slowly. He found that this eliminated the cracks completely. Within ten years, Mackie's process was being used by steel companies all over the world to produce strong, crack-free rails.

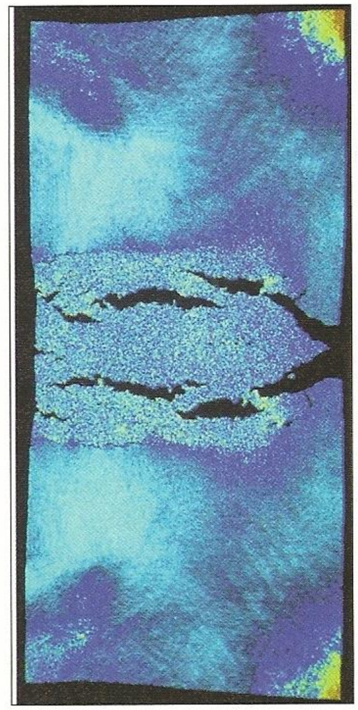

Figure 14.10 Stress cracks in metal can lead to structural failure.

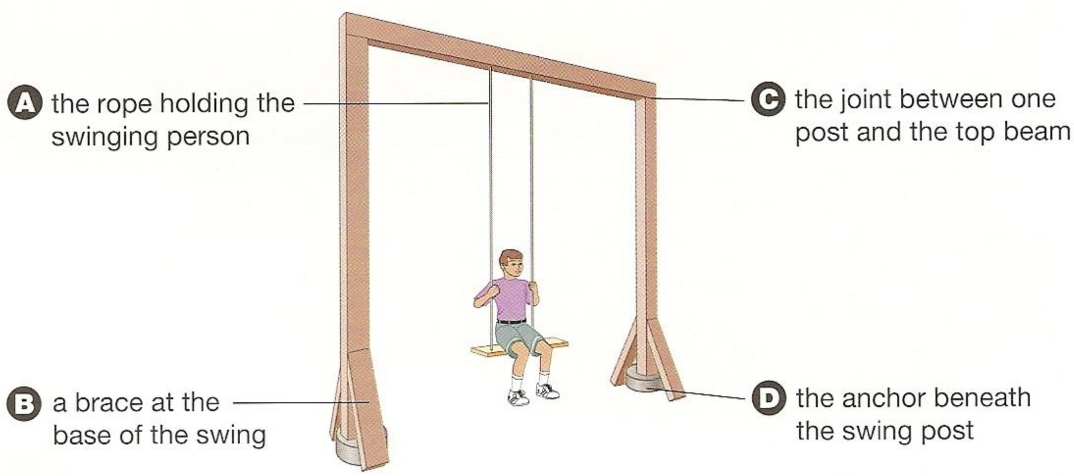

Figure 14.11 Different structural stresses in a garden swing

A Lots of tension here. Use rope or chain for high tensile strength.

B Brace gets pushed and pulled if the frame wiggles. It needs high tensile and compressive strength. Use wood or steel.

C Joint gets twisted as the swinger moves back and forth. Make sure it has high torsion strength and it is not brittle.

D Anchor needs compressive strength to hold the weight of the apparatus. Concrete is good, and it will not rot if the ground is wet.