9.2 Taller and taller

Towering 818 m over the desert sands of the United Arab Emirates is the Burj Khalifa, current holder of the title 'world's tallest building'. Even taller towers are planned for Dubai and other cities in the Middle East and Asia. Throughout history, humans have built tall towers to impress, intimidate and watch over their surroundings, and in worship. Towers have also helped us communicate with flags, smoke signals, radio and TV.

INQUIRY science 4 fun

Balancing forks

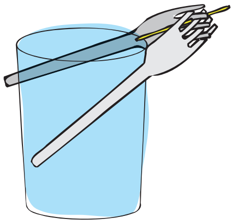
Can you balance two forks on a toothpick?

Yes

Collect this …

- glass of water
- 2 forks
- toothpick
- matches (optional)

Do this …



1. Join two forks by sliding and weaving their prongs together.
2. Slide a toothpick between the prongs so that it is secure and won't come out.
3. Place the other end of the toothpick on the edge of a glass containing water, as shown.
4. Let go. It should balance. If not, then try again. With enough care, it *will* balance!

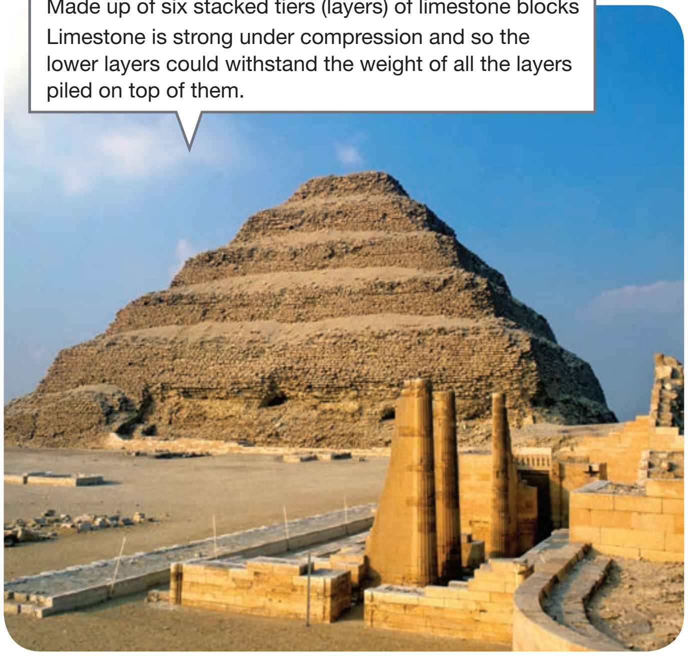
Record this …

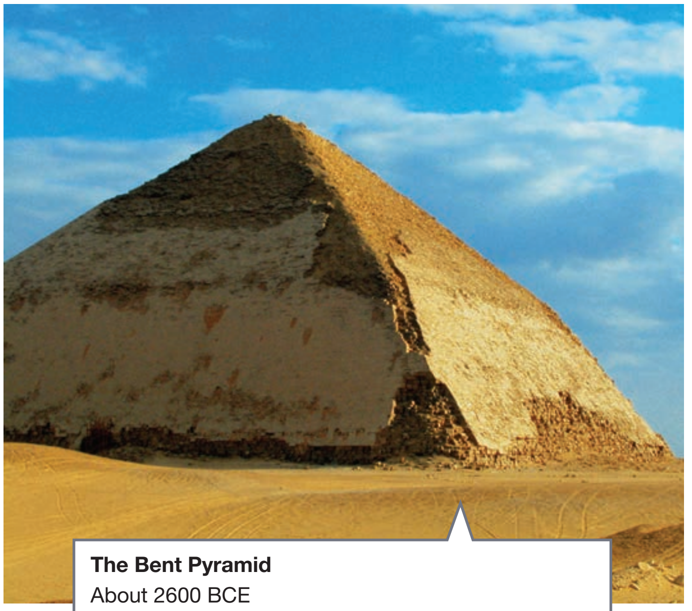
Describe what happened.
Explain why you think this happened.

The pyramids of Egypt

For over 4000 years, the pyramids of Egypt were the world's tallest buildings. Over a period of a hundred years or so, the engineers, builders and architects of ancient Egypt learnt from their past mistakes to make them taller and taller (Figure 9.2.1 on page 304). There are at least 118 ancient pyramids in Egypt. Many are small, and others are just piles of rubble that are buried in the desert sands. The Great Pyramid of Khufu (also known as Cheops) was among the world's tallest buildings until it was overtaken in 1889 by the 300-metre high Eiffel Tower in Paris, France.

The Step Pyramid
2630 to 2611 BCE
62 m high
Built for Pharaoh Djoser
Made up of six stacked tiers (layers) of limestone blocks
Limestone is strong under compression and so the lower layers could withstand the weight of all the layers piled on top of them.





The Bent Pyramid
About 2600 BCE
105 m high
Built for Pharoah Snefru
First attempt at building a smooth-sided pyramid
Made of limestone
45 m up, the angle drops from 55° to 43° to make the completed pyramid lighter so it would not collapse.

Maidum Pyramid
About 2600 BCE
92 m high
Built for Pharaoh Snefru
A step pyramid with its three lower steps filled in to form smooth sides
Upper levels were so steep that they later collapsed.

The Great Pyramid
Built around 2550 BCE
147 m high
Built for Pharaoh Khufu (Cheops)
Among the tallest buildings in the world for over 4000 years
Made of limestone.

SciFile

Pharaoh Snefru

Another theory is sometimes used to explain the shape of the Bent Pyramid: Pharaoh Snefru was nearing death and so the pyramid that was to be his tomb needed to be completed in a hurry! The new angle made it quicker to build.

Figure 9.2.1 The earliest pyramids were piles of rubble or mud brick and most of them collapsed. These four limestone pyramids show how the ancient Egyptians learnt from past mistakes to build taller and taller structures.

1 p310

Towers

The pyramids were not the only tall structures of the ancient world. The ancient peoples also built towers.

Towers were traditionally made from stone, brick or mud. Some are shown in Figures 9.2.2 and 9.2.3. As they got taller, they also got heavier, and so they needed thicker walls at their base to stop them collapsing. They had few openings (such as doors and windows) since openings weakened the walls. This made the rooms inside the towers small and dark, particularly on the lower floors where the walls needed to be thickest. You also needed to climb stairs or ladders to reach the upper levels.

For these reasons, the height of towers was limited to around ten storeys. They were rarely used for accommodation and work but instead were used as lookouts, lighthouses, temples, the spires of cathedrals, and the minarets of mosques.

Figure 9.2.2 San Gimignano in Italy was a wealthy town in the Middle Ages. Rival families in the town built 72 stone towers to impress one another! Fifteen of these towers remain.

Figure 9.2.3 The high-rise apartment blocks in Shibam (Yemen) were built 300 years ago from mud. The tallest has 11 storeys.

Skyscrapers

The weight of a structure (and everything inside it) doesn't need to be held up by the walls when a frame is used. While the walls of many houses in Australia are made of solid brick or stone, many others have a frame of wood or steel that holds up the weight of their roof and upper floors. You can see a typical house frame in Figure 9.2.4. An older version is shown in Figure 9.2.5. Windows and doorways can be placed in gaps in the frame, and lightweight materials such as weatherboards, cement sheeting or a single layer of brick (brick veneer) can be attached to it to disguise and protect the frame and to keep out the weather.

Figure 9.2.4 Wooden or steel frames carry all the weight of the structure.

Figure 9.2.5 In the past, wooden frames were often filled with mud, bricks, or wattle and daub (woven sticks and mud).

Skyscrapers also use a frame (known as a **superstructure**) to support them and to form their basic shape. The frame is made of steel or reinforced concrete (concrete with steel bars or mesh in it). An example is shown in Figure 9.2.6 on page 306. The walls only need to be strong enough to support their own weight. Any lightweight material can be used to fill the gaps and to make the skyscraper weatherproof. In modern skyscrapers, these gaps are most commonly filled with large plates of relatively cheap glass, providing the apartments and offices inside with abundant light and uninterrupted views.

Steel and reinforced concrete perform well when placed under compression and under tension so the frame can withstand the weight of the structure, as well as supporting its floors. The frame can also withstand any twists or stretches that might happen with changes of weather.

Figure 9.2.6 This skyscraper's frame is made of steel and surrounds a solid core occupied by the lift and stairwells.

The height of buildings was naturally limited by how many stairs people were willing to climb. Then, in 1853, American inventor Elisha Otis demonstrated the first **elevator** (lift) with a brake that stopped the elevator from falling if its cable broke. His design provided a safe and easy way of reaching the upper floors, allowing structures to be built higher than ever before.

9.3

Tall, taller, tallest

To measure the height of a building, you first need to know where its top is. The top could be considered to be the:

- very tip of the building
- top of its roof
- highest occupied floor
- highest part of the building but not including 'add-ons' such as TV antennae, radio masts, satellite dishes or flagpoles. Most buildings are measured this way.

The Burj Khalifa is currently the highest building in the world regardless of what criterion is used. In Australia, the Q1 tower (Surfer's Paradise, Queensland) and the Eureka Tower (Melbourne, Victoria) can both be considered to be Australia's tallest building, depending on how you judge where their tops are. The spire of Q1 reaches to a height of 323 m, but its roof only reaches 275 m. The roof of the Eureka Tower is at 297 m but it has no spire. Figure 9.2.7 shows the height of some of the world's tallest buildings.

2 p310

SciFile

Skyscrapers rise from the ashes

In 1871, 17 500 buildings in Chicago (USA) burnt down in a massive fire. This opened up the centre of America's second largest city for redevelopment with skyscrapers. The first steel-framed skyscraper was built there in 1885. It had ten storeys and was 55 m high.

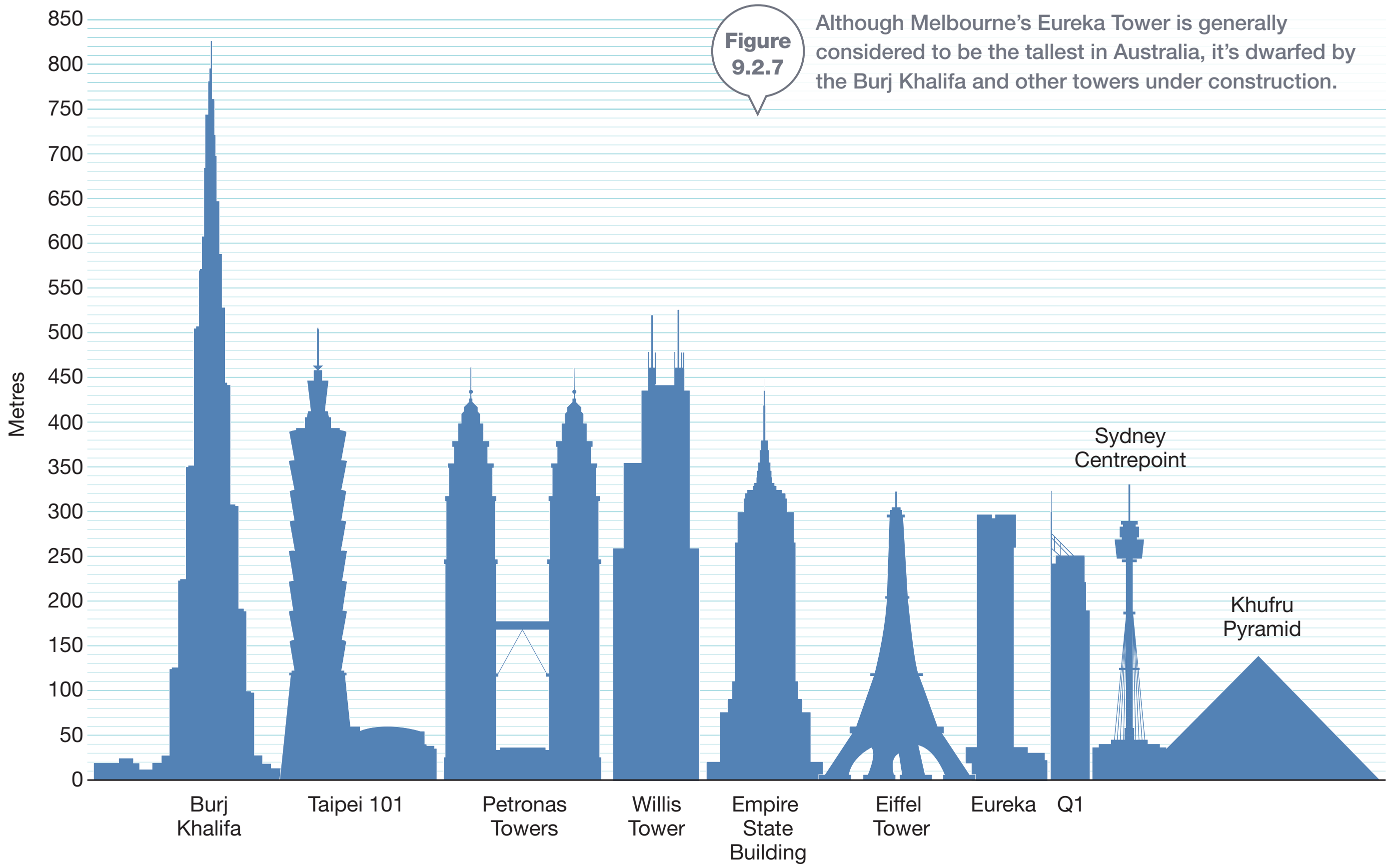


Figure 9.2.7 Although Melbourne's Eureka Tower is generally considered to be the tallest in Australia, it's dwarfed by the Burj Khalifa and other towers under construction.

Stability

Tall, thin structures tend to fall over more easily than short, wide structures because they have a relatively:

- high centre of mass
- small base.

Centre of mass

All objects have a **centre of mass** (sometimes known as their **centre of gravity**). This is the point at which all the mass of the object can be thought to be concentrated. It is also the point through which the object's weight force can be thought to act. For symmetrical objects with a uniform spread of mass, the centre of mass is at with the centre of the object. For example, the centre of a cricket ball is also its centre of mass. Likewise, the centre of mass of this textbook is roughly at its centre. You can find where it is exactly by trying to balance the closed book on the tip of your finger.

Navel gazing

SciFile

When you stand upright, your centre of mass is located a little below and behind your belly button. Lifting your arms spreads your mass over more height and so your centre of mass moves upwards too. As Figure 9.2.8 shows, twisting and bending can shift your centre of mass outside your body.

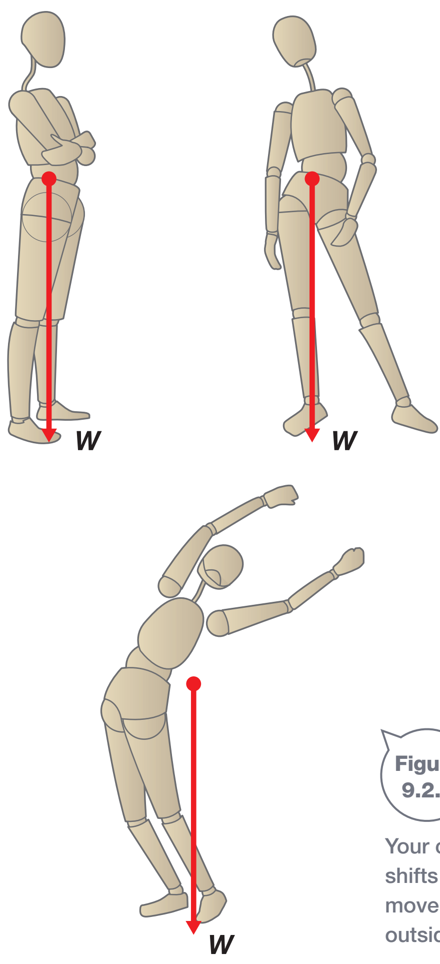


Figure 9.2.8 Your centre of mass shifts around as you move. Sometimes it lies outside of your body!

Size of base

An object is stable and won't fall over if its weight force (drawn as a vertical arrow from its centre of mass) passes through its base. In contrast, an object will topple over if its weight force passes outside its base. This explains why trucks tend to topple over more easily than cars, especially when on a slope or when cornering. You can see this in Figure 9.2.9.

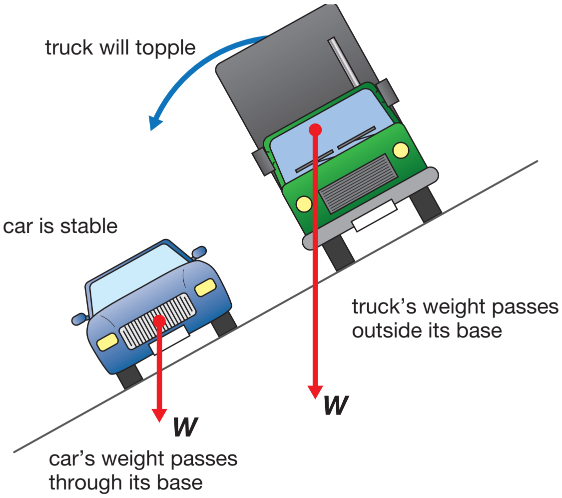


Figure 9.2.9 Tall objects have higher centres of mass than short objects.

Most structures are designed so that they are naturally stable, with their centres of mass directly over their base. Towers and skyscrapers twist and sway in the wind and during unexpected extreme events such as earthquakes and hurricanes. Whatever happens, the base must be wide enough to ensure that the centre of mass is always over it (Figure 9.2.10).

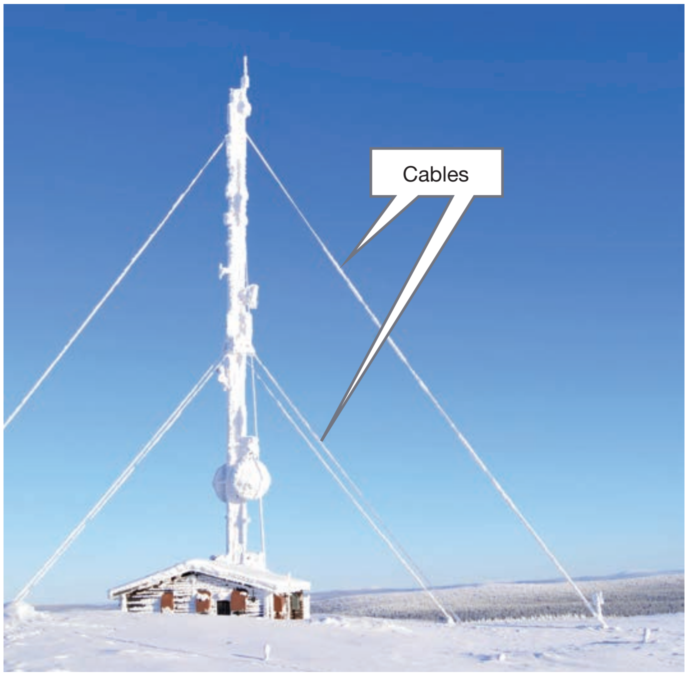


Figure 9.2.10 A high centre of mass and small base make thin radio and TV transmission towers extremely unstable. Cables minimise the twisting and sway of the tower and spread the base of the structure across a greater area, making it more stable.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

The Leaning Tower of Pisa

Figure 9.2.11 The Leaning Tower of Pisa has been leaning for over 800 years because it is not evenly supported by its foundations.

Advances in science allow us to build taller and taller towers like the Burj Khalifa. They also gives us a way of saving old buildings that are at risk of collapse. In this way, science allows us to preserve important monuments like the Leaning Tower of Pisa in Italy.

The Tower of Pisa (Figure 9.2.11) first began to lean in 1178, five years after construction began. It had only got to the third floor and already the weight of its marble was too much for the ground underneath it to support! Work stopped, and began again in 1272 with its new, upper floors being built with one side shorter (and lighter) than the other.

Over the centuries, the angle of the tower increased until it was feared that it would collapse. After several attempts that made the situation worse, scientists and engineers developed a program that would stop the lean and drag it a little more upright (Figure 9.2.12). All this had to be done very slowly since any abrupt movement of the tower could cause it to crumble. Between 1990 and 2001, the program:

- removed the tower's bells to make it lighter (the tower was originally a belltower)
- carefully removed soil from under its raised side
- added lead weights on its raised side to push it down.

The tower now leans about 4° from the vertical, and its top is 3.9 m out of alignment.

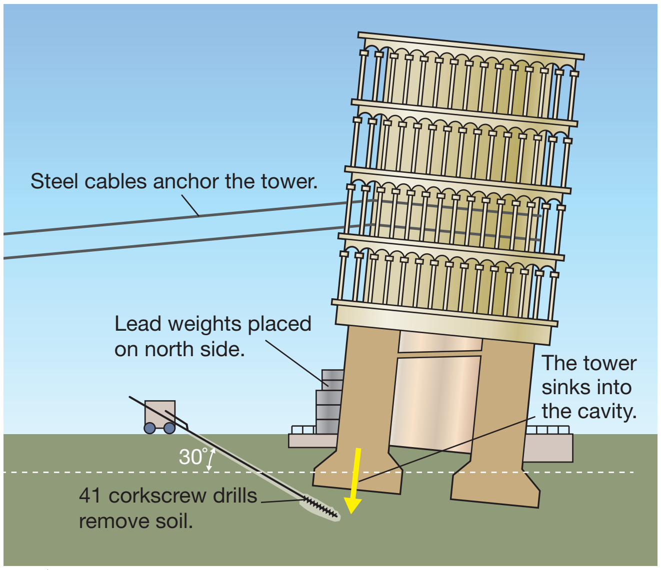


Figure 9.2.12 A restoration program has halted the increasing lean of the Leaning Tower of Pisa.

9.2 Unit review

Remembering

1 **Name** and **specify** the height of the structure that is or was the world's tallest:
  a for over 4000 years
  b in 1889
  c currently.

2 **Name** the event that caused Chicago (USA) to become the home of the skyscraper.

3 The Science4fun activity on page 303 shows how two forks can be balanced on a toothpick hanging off the edge of a glass.
  a **State** whether the forces on the forks are balanced or unbalanced.
  b **State** what the *overall* force on the forks is when they are balanced.

Understanding

4 The later, successful pyramids were made of limestone. **Explain** why this material was ideal for the job.

5 **Explain** why towers made of stone or brick were rarely used for accommodation.

6 **Outline** how the Leaning Tower of Pisa was straightened.

Applying

7 Both the Q1 (Queensland) and Eureka (Victoria) towers can claim the title of 'Australia's tallest'.
  a **Explain** how both can hold the title.
  b **Identify** which one you think should be given the title.

Analysing

8 **Compare** a house frame with a skyscraper superstructure by listing their similarities and differences.

9 **Analyse** Figure 9.2.13 and determine whether the people will topple over or not.

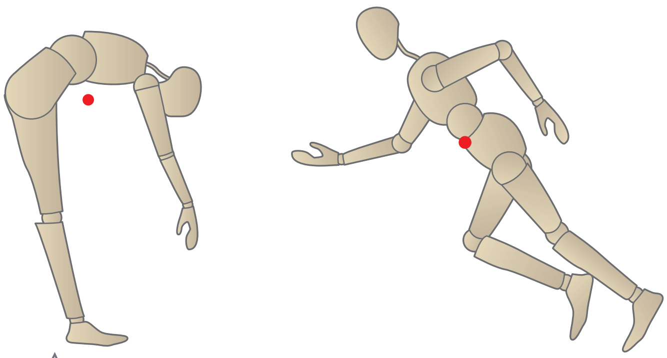


Figure 9.2.13

Evaluating

10 The Great Pyramid is now 10 m shorter than when it was built. **Propose** reasons why.

11 **Propose** what cities would be like now if the elevator (lift) had never been invented.

12 Four-wheel-drive cars are more likely to roll over than normal cars. **Propose** a reason why.

13 Skiers are always encouraged to bend their knees. **Propose** reasons why.

Creating

14 An architect wants to build a structure with the shape shown in Figure 9.2.14 but knows that it will be unstable.
  a **Analyse** the structure and **predict** where its centre of mass would be.
  b **Construct** two diagrams showing different ways the structure might be made stable.

Figure 9.2.14

Inquiring

1 There are plans for a skyscraper with rotating floors in Dubai and another in Moscow. Search the internet to find video of what they will look like and how they will work.

2 Find videos on the internet showing how a skyscraper is planned using computer-assisted design (CAD).

3 Construct a portfolio that contains photos of the following skyscrapers:

- Empire State Building
- Taipei 101
- Sears or Willis Tower
- Shanghai World Financial Centre
- Guangzhou TV Tower
- Abraj Al Bait Towers
- Petronas Towers
- Freedom Tower
- CN Tower
- Burj Khalifa
- Russia Tower
- Pentonium.

Label each photo with its year of construction, height, location and function (such as apartments, offices).

9.2 Practical activities

1 Natural pyramids

A cone is a pyramid with a circular base. When materials pile up into a cone, the angle the side makes with the horizontal is called the angle of repose.

Purpose

To determine the angle of repose of different substances.

Materials

- funnel
- retort stand, bosshead and clamp
- 1 sheet of graph paper
- ruler with millimetre markings
- various substances such as fine sand, coarse sand, flour, fine blue metal screenings

Procedure

1 Set up the funnel as shown in Figure 9.2.15.

2 Place your finger over the end of the funnel and fill it with fine dry sand. Remove your finger quickly and let the sand run out onto the graph paper.

3 Use the ruler to measure the height of the mound and the graph paper to estimate its diameter.

4 Make cones using the other materials, ensuring that the cones are all about 15 cm in diameter.

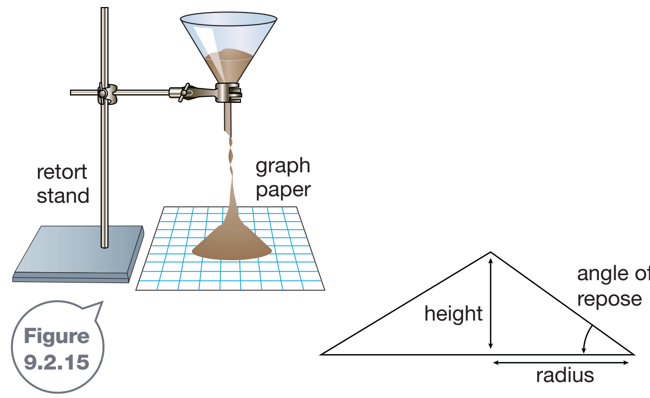


Figure 9.2.15

Results

1 In your workbook, construct a table like the one shown below.

2 To calculate the angle of repose of each material:
- divide the height by the radius. Your answer should be less than 1.
- push the $\tan^{-1}$ button (you may need to push the inverse/shift button first).

Discussion

1 **Propose** a reason why different substances had different angles of repose and made different height cones.

2 The first pyramids were made of rubble and mud bricks loosely piled on top of one another. **Use** the results from this experiment to **propose** why most of them collapsed.

Material	Diameter (mm)	Radius (mm)	Height (mm)	Angle of repose (°)

2 Wonky tower

Purpose

To construct the tallest self-supporting tower possible using straws and pins.

Materials

- 20 plastic or paper drinking straws
- scissors
- pins
- 50 g mass

Procedure

Construct the tallest structure possible using only the materials listed above. You can cut straws and can pin the straws together. Your structure must be able to:

- stand unsupported for at least a minute
- hold a single 50 g mass at its very top.

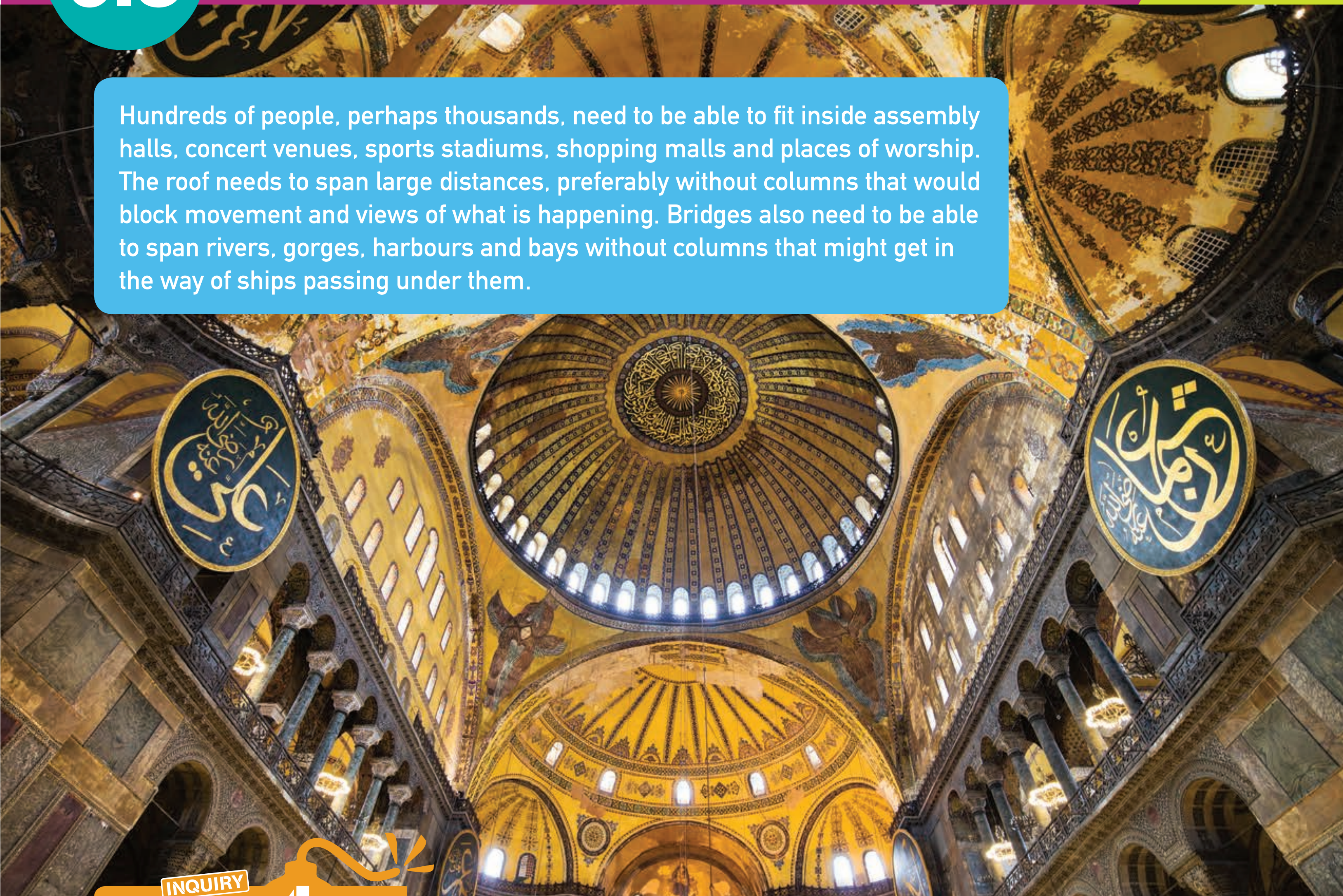
Discussion

1 **List** the features you used to ensure that your tower kept its shape and did not topple over.

2 **Compare** your tower with the tallest one in the class.

3 **Assess** how your tower could have been made stronger.

9.3 Bridging the gap



Hundreds of people, perhaps thousands, need to be able to fit inside assembly halls, concert venues, sports stadiums, shopping malls and places of worship. The roof needs to span large distances, preferably without columns that would block movement and views of what is happening. Bridges also need to be able to span rivers, gorges, harbours and bays without columns that might get in the way of ships passing under them.

INQUIRY science 4 fun

Arching bodies

Can you model the forces in an arch with your body?

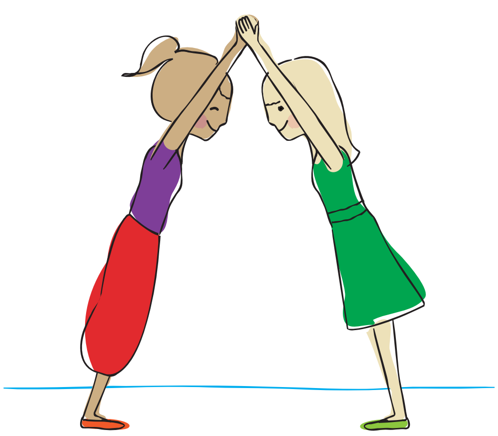
Yes

Collect this …

- No equipment is needed for this activity but a soft ground surface (such as grass or carpet) is suggested in case you fall.

Do this …

1. Pair off against a person of roughly the same size and weight as you.
2. Stand a little apart, facing each other.
3. Grip each other's hands over your heads and lean all your weight into your partner so that you form an arch.
4. Test if you can both stay upright.
5. Once you have done this, move a little further apart and repeat.
6. Keep moving apart until your arch 'fails'.
7. Repeat, but now use other people to help stop your feet sliding. What happens now?



Record this …

Describe what happened.
Explain why you think this happened.

Buildings

Wooden buildings rarely last more than a few centuries because they eventually rot or are eaten by insects such as termites. Steel and reinforced concrete are relatively recent materials, and so any buildings containing them are less than 150 years old. The buildings that remain from the ancient world are made of stone, brick or mud. Three different methods were used to build them.

Post and beam

The easiest way of support a roof is to place a **beam** (also known as a **lintel**) horizontally across two columns or vertical posts.

The columns or posts hold up the roof and are in compression. Timber, steel, concrete, brick, marble and granite perform well under compression and so are good materials to construct columns from.

However, the weight of the beam and the roof on top can cause the beam to sag a little. As Figure 9.3.1 shows, when a beam sags, the:

- lower side of the beam is stretched and so it is in tension
- upper side of the beam squashed and so it is in compression.

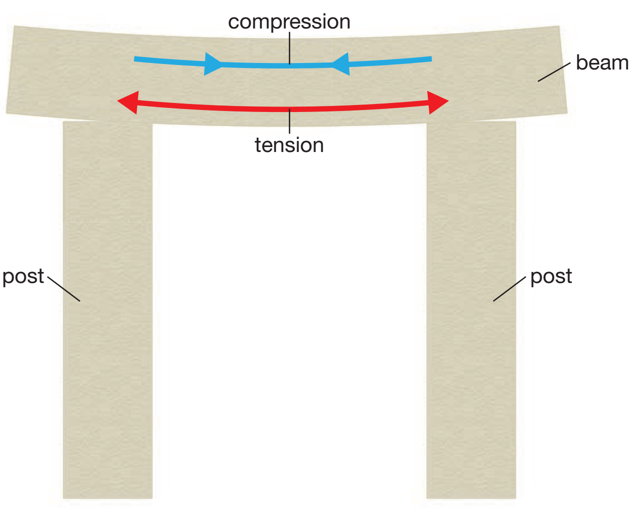


Figure 9.3.1 A horizontal beam sags under its own weight. As a result, the materials used must perform well under both compression and tension.

Timber and steel perform well under compression *and* tension and so both are good materials to construct beams and lintels from (as well as the columns holding them up). For this reason, timber and steel are commonly used over doorways and windows in homes to hold up the wall and roof above them. A steel lintel is shown in Figure 9.3.2.

Figure 9.3.2 Doorways and windows need lintels so that the weight of the wall and roof above them doesn't come crashing down. This steel lintel holds up the wall above the door.

Concrete, brick, marble and granite are strong under compression but quickly crack when placed under tension. Therefore, when used as beams they need a lot of columns to support them so they don't sag and crack. All these columns leave very little room in the building and block any views through it. This is obvious in the Parthenon, shown in Figure 9.3.3.

Figure 9.3.3 Post and beam construction was used to construct the Parthenon of ancient Greece (built around 440 BCE).

Reinforced concrete is concrete poured over steel mesh or steel rods. This is shown in Figure 9.3.4. Concrete is relatively cheap and performs well under compression. Steel is more expensive and heavier, but performs well under both compression and tension. In combining concrete with some steel, reinforced concrete provides a relatively cheap and light material that performs well under compression *and* tension. This makes it the ideal material for use in beams *and* columns.

Figure 9.3.4 Reinforced concrete is strong under both compression and tension because it combines the properties of both concrete and steel.

Roman arch

While the ancient Greeks used the post and beam method to build their temples and monuments, the ancient Romans used a simple semicircular arch like that shown in Figure 9.3.5. All the materials in a **Roman arch** are under compression. This allowed the arch to be constructed from marble, granite, concrete, bricks or mud. Buildings like the church in Figure 9.3.6 could be constructed from many arches.

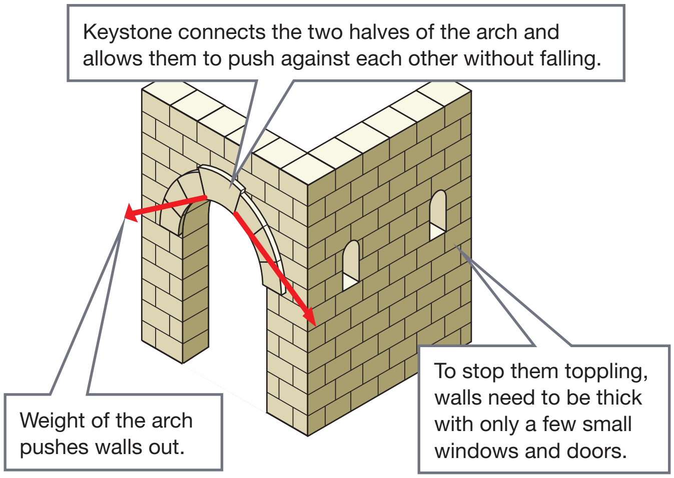


Figure 9.3.5 A Roman arch is semicircular. It needs thick walls to support it.

Figure 9.3.6 A series of arches can be used to construct a building such as this church.

The weight of any arch is transferred through its supporting walls to the ground. The weight of a Roman arch pushes the walls of the arch outwards, and so the walls need to be very thick to stop them toppling over. Openings weaken the walls, and so any doors or windows need to be small and few (Figure 9.3.7). This makes the interiors of buildings using Roman arches extremely dark.

Figure 9.3.7 Domes made from three-dimensional Roman arches need thick walls with few openings. An igloo is an example of a dome.

INQUIRY science 4 fun

Egg domes

How strong is the dome formed by an eggshell?

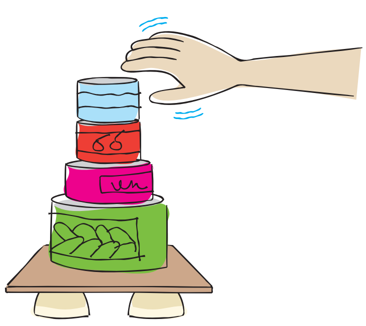
Yes

Collect this ...

- 2 eggs
- strong sticky tape (e.g. masking tape or gaffer tape)
- fine-tipped scissors (e.g. fingernail scissors)
- stiff cardboard (e.g. cut from a cereal packet)
- masses or packets and cans from the kitchen cupboard
- kitchen scales or electronic balance

Do this ...

1. Stick a strip of tape around the 'waist' of each egg so that the ends don't quite meet.
2. In the gap between the ends of the tape, make a small hole with the end of the scissors. Take care!
3. Use this hole to pour out the contents of the eggs. (Wash your hands thoroughly afterwards.)
4. Starting at the hole, carefully cut along the tape around the 'waist' of the eggs. This will give you four half-eggshells.
5. Place the four half-eggshells on a flat bench and place the sheet of stiff cardboard on them.
6. Slowly add masses or packets and cans, stacking them up on the cardboard.
7. Stop when one or more of the eggshells develops cracks.



Record this ...

Describe what happened.

Explain why eggshells arranged like this are so strong.

Gothic arches

Gothic arches are pointed arches. They were invented in 12th century Europe, where they were first used to hold up the roofs of the cathedrals and churches.

All the materials used in a Gothic arch are in compression, so they too can be built from stone, concrete or brick.

As shown in Figure 9.3.8, the weight of a Gothic arch pushes down more vertically on its walls than a Roman arch does. This means the walls are less likely to topple over and so can be made thinner, and with larger windows. **Flying buttresses** are stone struts (supports) that give the walls any extra support they need. The huge stained glass windows and flying buttresses of Gothic buildings make them much brighter than earlier buildings constructed with Roman arches.

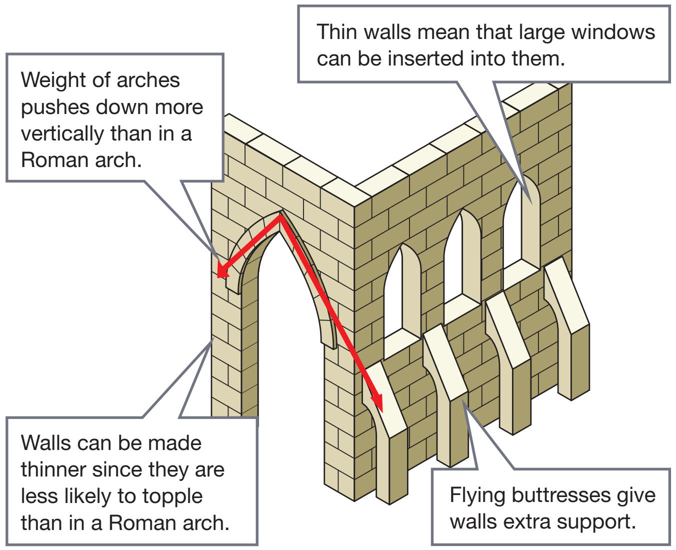


Figure 9.3.8 Gothic arches have pointed tops. They don't need thick walls to keep them toppling over but sometimes use flying buttresses to keep them upright.

Bridges

A simple bridge can be made by placing a log across a gap, but the length of a simple bridge is limited by the length of the log. Stone and brick can be used to form a beam, but (as in buildings) they tend to crack and fail and so need multiple columns to support them.

Roman or Gothic arches can be used to support the weight of a bridge. However, these also need multiple columns to support their arches. This gets in the way of any traffic such as people, cars and ships that must pass under them. An example is shown in Figure 9.3.9.

Figure 9.3.9 Old stone bridges were built using much the same methods as stone buildings. This is Richmond Bridge in Tasmania. It is Australia's oldest surviving bridge and was built in 1829.

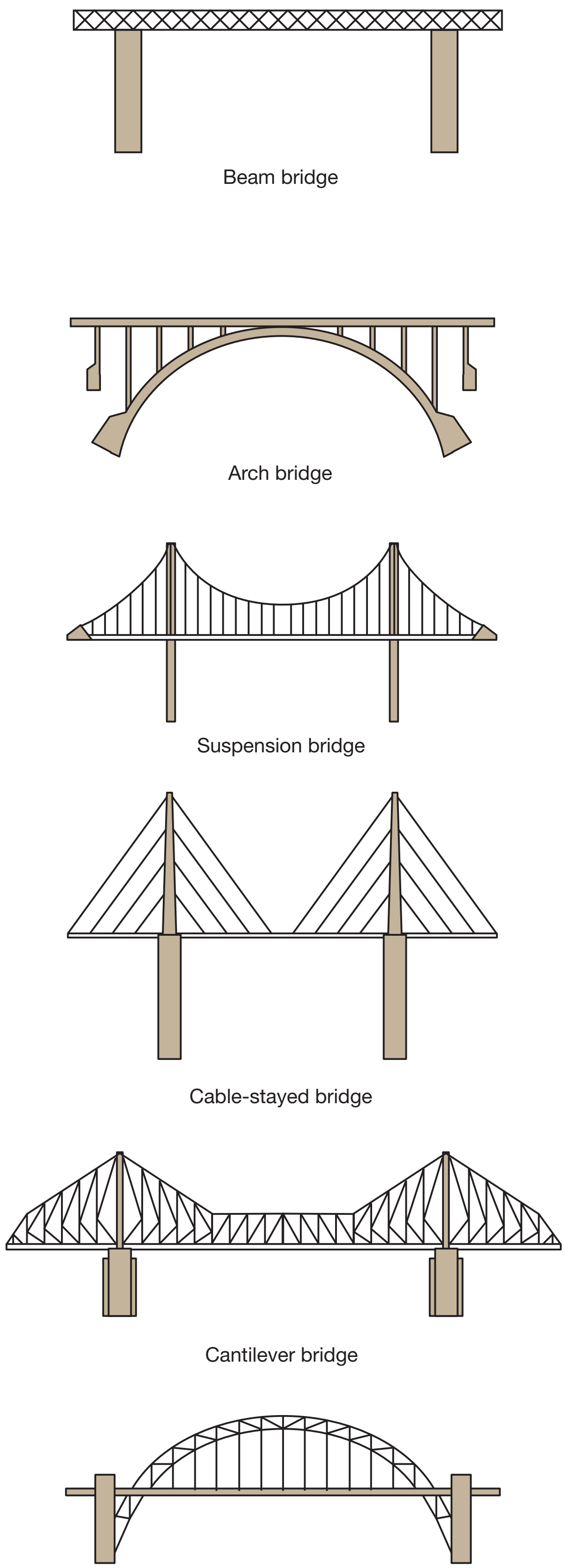


Figure 9.3.10 Steel is an extremely versatile material and can form the uprights, deck and cables of a bridge. For this reason, modern bridges are commonly made of steel and/or reinforced concrete.

Modern bridges

Modern bridges need to span large distances without multiple columns or supports. Modern bridges are commonly made from steel and/or reinforced concrete because these materials act well under both compression and tension. This means steel and reinforced concrete can be used to construct the columns and pylons needed to support the structure's weight and to construct the long decks that form the base of the road or path across the bridge. Steel can also be used to construct cables that can hold the structure in place by pulling upwards against the force of gravity.

Modern bridges commonly use one of the designs shown in Figure 9.3.10.

9.4 9.5

Trusses

The structure of a bridge can be made far lighter and stronger if the beams and supports are not solid but are arranged instead into trusses. A **truss** is an open structure made up of a series of triangles. You can see trusses in use in Figure 9.3.11. Triangles are particularly strong as that they don't twist or distort their shape when weight is applied.

Figure 9.3.11 The trusses on Brisbane's Storey Bridge give it strength but make it relatively light. Trusses use triangles to help them retain their shape.

1 p318 2 p319 3 p320

9.3 Unit review

Remembering

1 **List** the disadvantages of building a bridge:
 a as a post and beam
 b with arches.

2 **Name** each of the structures in Figure 9.3.12.

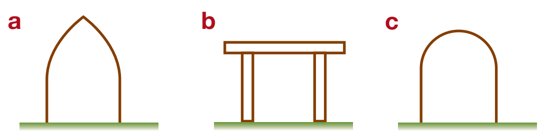


Figure 9.3.12

3 **List** two materials that would be suitable to build a:
 a column
 b beam.

4 **State** whether the stones used to build Roman and Gothic arches are in compression or tension.

Understanding

5 **Predict** what would happen in the following situations.
 a Two people lean into each other as shown on page 311.
 b They then push their legs out and lean into each other more.
 c Someone else uses a foot to stop them from slipping.

6 **Explain** why the Parthenon in Figure 9.3.3 on page 312 needed so many columns.

7 a **Define** the term *lintel*.
 b **Describe** where lintels are found in a house.

8 **Explain** why timber and steel are good materials to make a beam out of.

9 a **Describe** what reinforced concrete is.
 b **Describe** the advantages of reinforced concrete over normal concrete.

10 A historic church was built using a series of Roman arches. **Explain** why its:
 a walls needed to be very thick
 b windows were very small.

11 **Explain** why stone is an ideal material from which to construct arches.

12 **Explain** the purpose of flying buttresses.

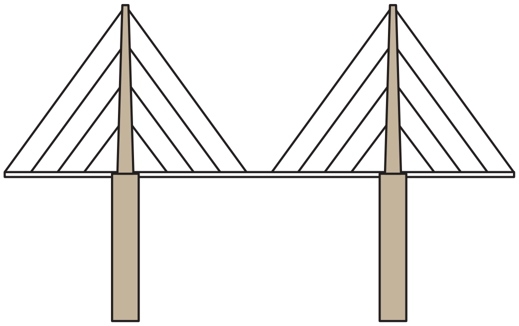
13 Windows weaken a wall. Even so, Gothic churches generally have large stained-glass windows. **Explain** why they don't collapse under the weight of their upper walls and roof.

Applying

14 **Identify** the structures labelled A and B in Figure 9.3.13.

Figure 9.3.13

15 Below is a cable-stayed bridge.
 a Copy the diagram and **identify** where you expect materials to be under compression.
 b **Identify** where you expect materials to be under tension.



16 **Identify** the type of arch used to support Richmond Bridge in Figure 9.3.9 on page 314.

Analysing

17 **Contrast** a:
- **a** Roman arch with a Gothic arch
- **b** suspension bridge with a cable-stayed bridge.

Evaluating

18 The Romanesque was a period of European architecture. **Propose** what architectural feature it used.

Creating

19 **Construct** a diagram showing the compression and tension forces in a beam that sags.

20 **a** **Construct** a diagram showing what would happen to the truss in Figure 9.3.14 (made from a series of squares) if the truss was pushed as shown.

b **Use** your answer to part a to **describe** the advantage of using triangles and not squares in a truss.

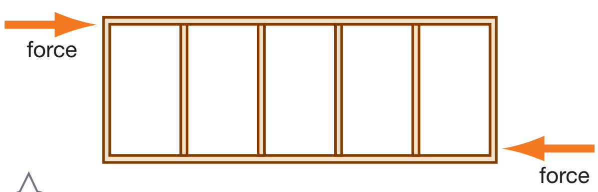


Figure 9.3.14

Inquiring

1 Search the internet for videos showing the wild vibrations of the Tacoma Narrows Bridge before it collapsed.

2 Research the collapse of the Westgate Bridge (Melbourne, Victoria) or the Tasman Bridge (Hobart, Tasmania).

3 Construct a portfolio that contains photos of the following Australian and international bridges:
- Kurilpa (Queensland)
- Merivale (Queensland)
- ANZAC (New South Wales)
- Gladesville (New South Wales)
- Studley Park (Victoria)
- Westgate (Victoria)
- Batman (Tasmania)
- Golden Gate (USA)
- Millau Viaduct (France)
- Puente de Alamillo (Spain)
- Bridge of the Americas (Panama)
- Brooklyn (USA).

Label each photo with its:
- **a** year of construction
- **b** height
- **c** location
- **d** purpose (for cars, rail or pedestrians)
- **e** bridge type (refer to Figure 9.3.10) on page 315.

4 Construct a portfolio that contains photos of the following historic buildings:
- Hagia Sofia (Turkey)
- Notre Dame (France)
- Pantheon (Italy)
- Pont du Gard (France)
- Stonehenge (UK).

Label each photo with its:
- **a** year of construction
- **b** height
- **c** location
- **d** purpose (such as accommodation, worship, offices)
- **e** basic structure (such as post and beam, Roman arch, Gothic arch, dome).

5 Construct a portfolio that contains photos of domed buildings such as the Taj Mahal (Agra, India), St Basils (Moscow, Russia), the Dome of the Rock (Jerusalem, Israel), the Pantheon (Rome, Italy) and the Great Stupa (Sanchi, India). Label each of the photos with the type of material the dome is made from.

6 Design a bridge that can span a 20 cm gap. You can only use one sheet of A3 paper and enough sticky tape to hold it together. You cannot use the sticky tape to reinforce your bridge. Load your bridge up with 50 g masses and determine how many it can support before it collapses.

SciFile

Troops … break march!

Wind can make a bridge swing higher and higher (a bit like when you push a playground swing) until it breaks. The effect is called resonance. The rhythm of the steps of troops passing over a bridge can also cause resonance. For this reason, troops crossing a bridge need to 'break step', deliberately walking so that their steps were not all at the same time.

1 Building bridges

Purpose
To build and compare the strength of different types of bridges.

Materials
- 4 long strips of cardboard (about 30 cm × 10 cm)
- short strip of cardboard (about 20 cm × 10 cm)
- sticky tape
- scissors
- 2 retort stands and bossheads
- string
- 50 g masses

SAFETY

Keep your feet clear of any masses that may fall. Place padding underneath the bridge to soften its fall.

Procedure
1 Shift two tables or desks about 20 cm apart. Once you have this gap, do not change it.

Part A: Post and beam bridge
2 Construct the post and beam bridge shown in Figure 9.3.15 by simply resting a long piece of cardboard across the gap.

3 Add 50 g masses to the centre of the bridge until it 'fails'. Record your mass in a table similar to the one in the results section.

Part B: Arch bridge
4 Construct an arch bridge by bending another long piece of cardboard to form an arch. Tape it to the legs or side of the table or desk as shown in Figure 9.3.15.

5 Secure the arch to the horizontal strip of cardboard with another piece of sticky tape.

6 Once again, add 50 g masses to the centre until the arch bridge fails.

Part C: Cantilever bridge
7 Construct a cantilever bridge by arranging two long strips of cardboard hanging from the desks as shown in Figure 9.3.15. Do not overlap them but add a retort stand at each end to stop them falling.

8 Place a short strip of cardboard on top to form the 'road'.

9 Add 50 g masses again to find what will cause the cantilever bridge to fail.

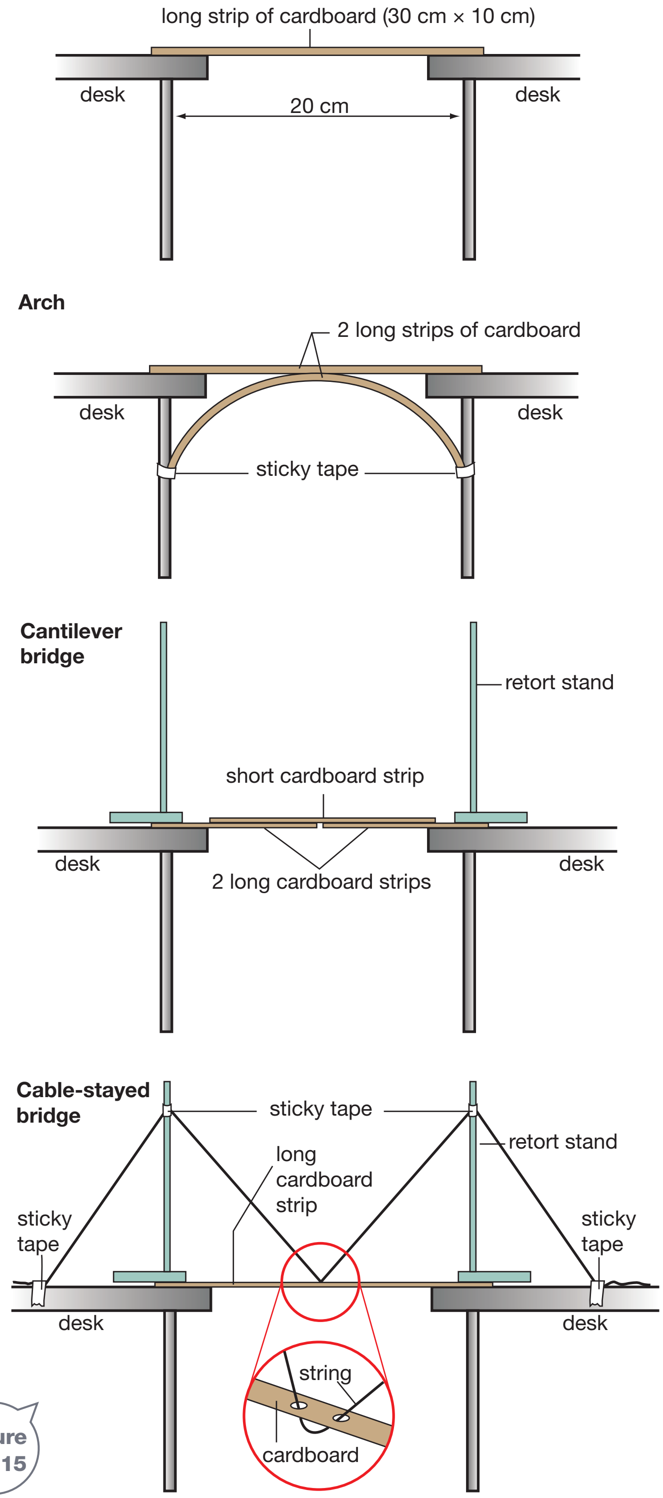


Figure 9.3.15

Part D: Cable-stayed bridge

10 Construct a cable-stayed bridge by placing a long piece of cardboard across the gap and weighing it down at each end with a retort stand as shown in Figure 9.3.15.

11 Tape or tie a length of string as shown.

12 Test the strength of the cable-stayed bridge by adding 50 g masses until it fails.

Results

In your workbook, construct a table like the one shown below in which you will record all your results.

Type of bridge	Mass that caused the bridge to 'fail' (g)
Beam	
Arch	
Cantilever	

Discussion

1 **Rank** the bridges in order from strongest to weakest.

2 Cantilever bridges are easier to build over large gaps than beam (like the one in Figure 9.3.16), arch or cable-stayed bridges. **Propose** reasons why.

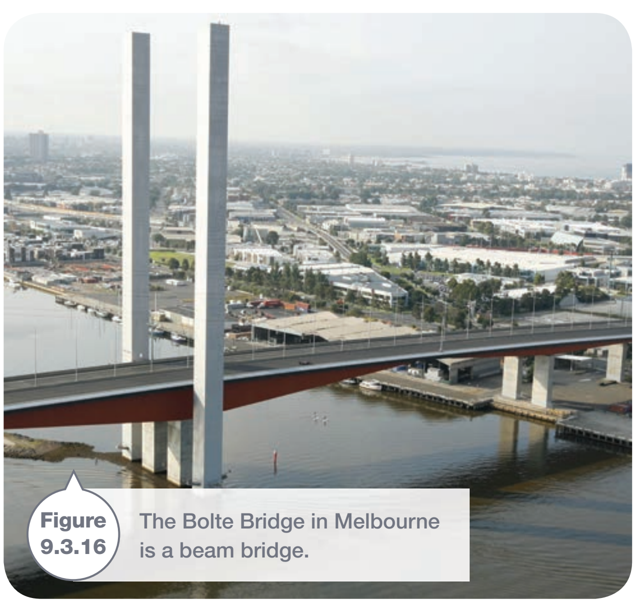


Figure 9.3.16 The Bolte Bridge in Melbourne is a beam bridge.

2 Design your own bridge

Purpose

To design and construct your own bridge.

Materials

- 1 pack of satay sticks
- 1 m string
- wood glue or access to hot glue gun
- metre ruler
- access to various masses

SAFETY

Do not touch the tip of the hot glue gun.

Procedure

1 The task of your prac team is to design and construct a bridge that:
   - spans a gap of 60 cm
   - is able to hold as high a mass as possible without failing
   - uses only the satay sticks (these can be used whole or broken or cut into smaller lengths) and string provided
   - uses only the glue provided
   - uses only sufficient glue to hold the sticks together and to glue string in place (you cannot coat the sticks in glue).

2 When all bridges are complete, the class will test how much each bridge can hold before it fails.

Discussion

1 **List** the features that you used in your bridge (such as cantilever or truss) to make it stronger.

2 **Compare** your bridge with the one in the class that was most successful. Assess how your bridge could be made even stronger.

3 The bridge you designed yourself was probably stronger than many of the simple bridges you tested in Prac 1. **Explain** why.

9.3 Practical activities

3 Trusses

Purpose
To compare the strength of different trusses.

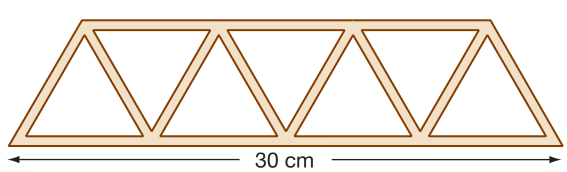
Materials
- icy-pole sticks
- wood glue or access to hot glue gun
- long strip of cardboard (30 cm × 5 cm)
- drawing pins
- newspaper
- 50 g masses

SAFETY

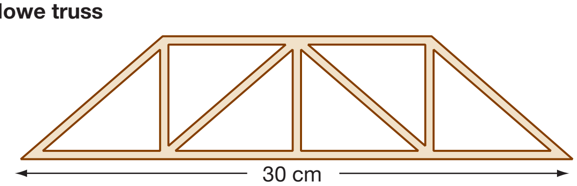
Do not touch the tip of the hot glue gun.

Procedure
1 Each practical team in the class will be given one of three designs of trusses, which they are to build. These are shown in Figure 9.3.17.

Warren truss



Howe truss



Pratt truss

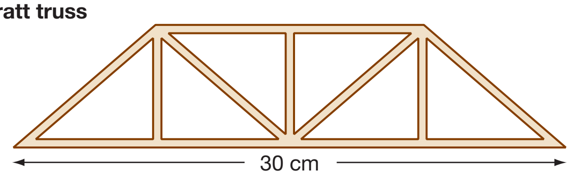


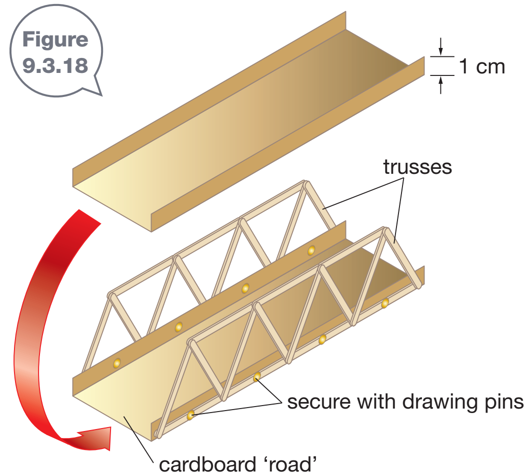
Figure 9.3.17

2 Use icy-pole sticks and wood glue or hot glue gun to construct two trusses of the design that you have been assigned. Build the trusses flat on sheets of newspaper and make sure that both are around 30 cm long. Leave both to dry in a place where they won't be disturbed.

3 Fold each side of the cardboard strip up to form walls 1 cm high.

4 Construct a bridge by pinning one truss on either side of the folded cardboard walls as shown in Figure 9.3.18.

Figure 9.3.18



5 Shift two desks or tables apart and place the truss bridge over the gap.

6 Add 50 g masses to the cardboard 'road' until it fails. Stop if the bridge still hasn't broken when 1.5 kg has been added to it.

7 Collect the results for other truss designs from the other prac teams. Enter all results in a table like the one shown in the results section.

Results
Copy and complete the following table.

Truss type	Mass that caused the bridge to fail
Warren truss	
Howe truss	
Pratt truss	

Discussion
1 **Rank** the truss bridges in order from strongest to weakest.

2 Many older railway bridges are truss bridges, with the truss made of steel. **Propose** one advantage and two disadvantages of these steel truss bridges.

Chapter review 9

Remembering

1 **List** three changes in structures around the home that indicates that the forces in the structure may have become unbalanced.

2 **State** what might happen if the forces on one part of a building become seriously unbalanced because of a cyclone.

Understanding

3 **Explain** why the following materials are ideal for their purpose.
  a timber used to construct a house frame
  b steel used to construct the frame (superstructure) of a skyscraper

4 Sails of ocean-going and racing yachts are often made of Kevlar. **Describe** the advantages Kevlar has over other synthetic materials such as nylon when used for the sails of ocean-going and racing yachts.

5 **Outline** two theories that explain why the builders of the Bent Pyramid changed its angle 45 m from its base.

6 **Outline** the four ways used to determine the top of a skyscraper.

7 **Explain** why most towers made of brick or stone are rarely higher than ten storeys.

8 **Describe** what you need to do to carry out a successful handstand.

9 **Explain** why the Parthenon (Figure 9.3.3, page 312) needs a lot of supporting columns to hold its roof up.

Applying

10 **Identify** a suitable material to use to make a:
  a Roman arch
  b bulletproof vest
  c floor of a skyscraper
  d cable to hold a roof up.

11 **Use** diagrams to **explain** why walls can be thinner with more windows when using Gothic arches than when using Roman arches.

Analysing

12 **Contrast**:
  a compression with tension
  b the characteristics of steel and concrete.

13 **Use** Figure 9.3.10 on page 315 to **classify** the:
  a Sydney Harbour Bridge (Figure 9.1.6 on page 296)
  b Storey Bridge (Figure 9.3.11 on page 315).

Evaluating

14 Mudbricks are made of mud reinforced with plant material such as straw or grass. **Propose** reasons why they are among the oldest building materials ever used.

15 You are more likely to cut your foot if you stand on a broken glass bottle than on a bottle that is intact. **Propose** a reason why.

16 **Propose** advantages and disadvantages of living in a very tall skyscraper.

17 Figure 9.2.7 on page 306 seems to indicate that Willis Tower in Chicago is taller than Petronas Towers in Kuala Lumpur. Yet most records state that Petronas is taller than Willis. **Use** the different ways building heights are measured to **propose** reasons why.

18 Steel framed buildings rarely went higher than 15 storeys until the early twentieth century. **Propose** a reason why.

19 Skyscrapers often have revolving doors at their base. Consider the air flow through a tall building and **propose** a reason why revolving doors are used.

20 Skiing and snowboarding are difficult sports to master and adult beginners are far more likely to fall than children just starting. **Propose** a reason why.

Creating

21 **Construct** a diagram showing what a truss is.

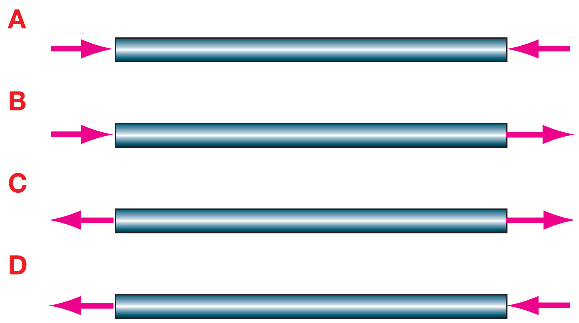
22 **Use** the following ten terms to **construct** a visual summary of the information presented in this chapter.

force	tension
compression	squash
stretch	weight
balanced	unbalanced
structure	failure

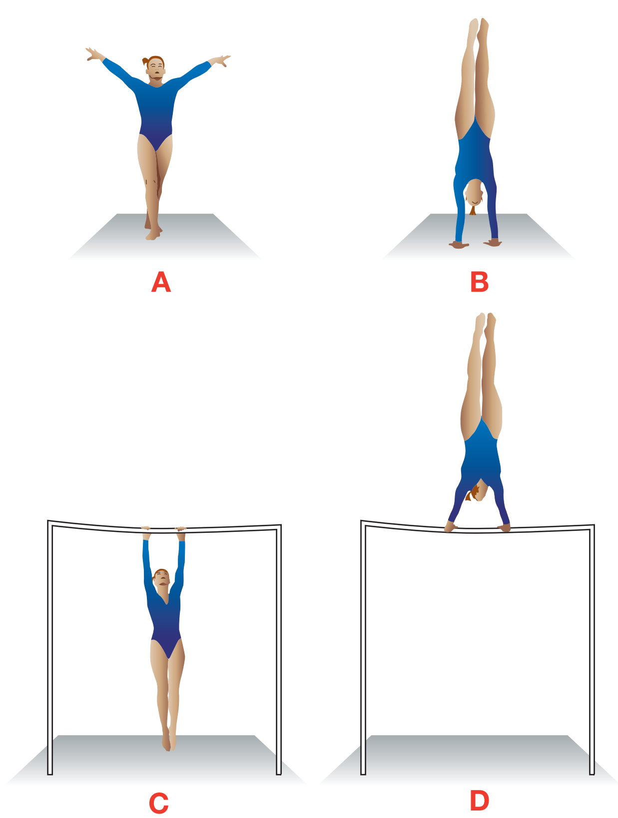
9.6

Thinking scientifically

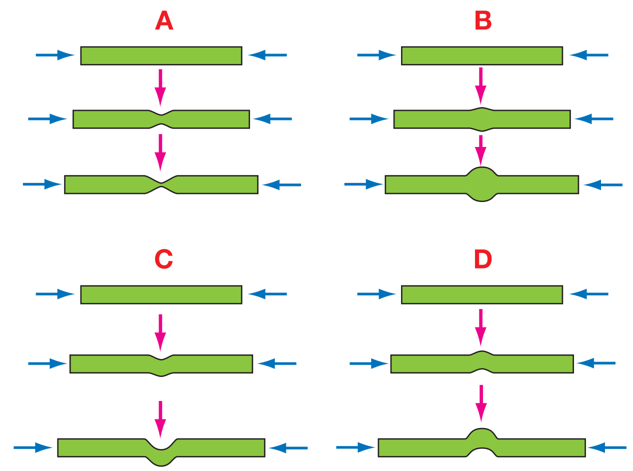
Q1 Tension forces stretch a material while compression forces squash it. State which of the following diagrams most accurately shows compression forces on a material.



Q2 Elaine is a gymnast. The four diagrams below show part of her routine. Identify in which part(s) of the routine her arms are under tension.



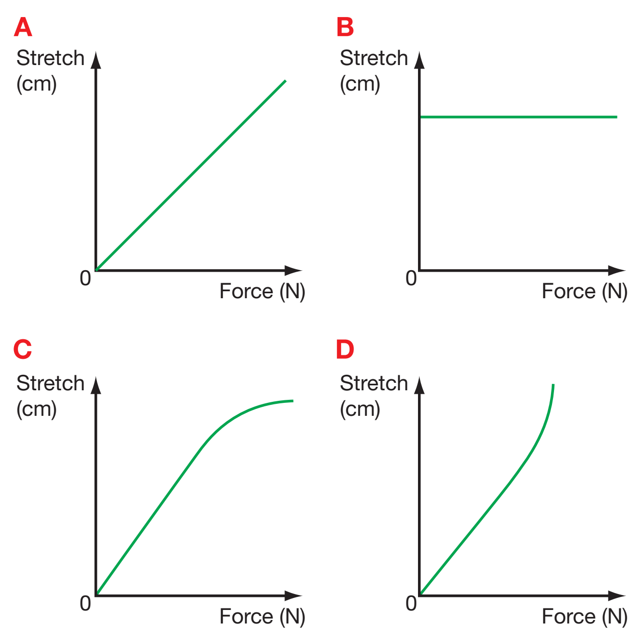
Q3 Increasing the compression on a material will squash it more and more. Eventually it will break. The diagrams show a material placed under so much compression that it eventually snaps. Identify which set of diagrams best shows what would happen just before it broke.



Q4 A practical team measured how much a material stretched when tension was applied to it. Their results are shown below.

Force (N)	0	10	20	30	40	50
Stretch (cm)	0	10	20	30	35	37.5

Identify which of the following sketch graphs best describes these measurements.



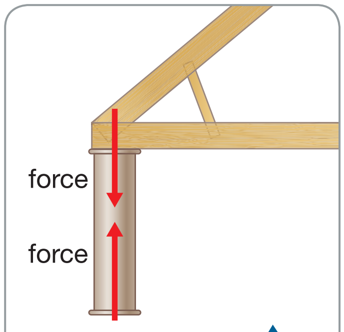
Glossary

Unit 9.1

Accelerates: speeds up

Balanced: all forces cancel each other out, zero overall force; no change will result

Compression: forces attempting to squash a material



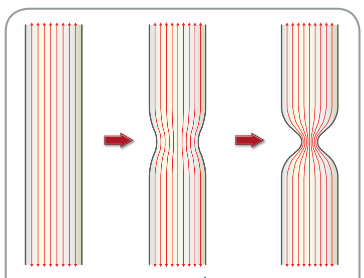
Compression

Decelerates: slows down

Failure: breaking, snapping, crumbling of a material

Force: push, pull or twist; unit, N

Necking: thinning of a material just before it snaps



Necking

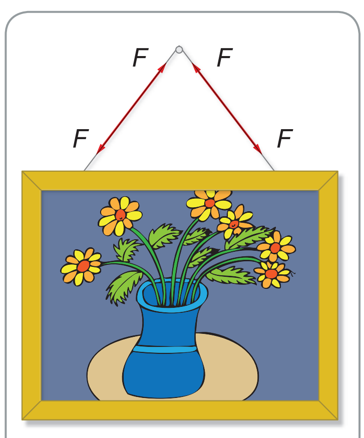
Newton's first law: the motion of an object will not change if all the forces acting on it are balanced

Newton's second law: an object will accelerate if an unbalanced force is acting on it

Newton's third law: for every force in a structure, there is an equal and opposite force acting on the structure

Stress: measure of how concentrated a force is on a material: stress = $\frac{\text{force}}{\text{area}} = \frac{F}{A}$

Tension: forces attempting to stretch a material



Tension

Unbalanced: forces do not cancel each other completely; an overall force exists, causing a change

Weight: gravitational force on a mass; unit, N

Unit 9.2

Centre of gravity: point in an object in which all of the mass the object can be thought to be concentrated; the object's weight can be thought to act through here

Centre of mass: point in an object in which all of the mass the object can be thought to be concentrated; the object's weight can be thought to act through here

Elevator: lift, used to go up and down a skyscraper

Superstructure: frame of a skyscraper

Superstructure

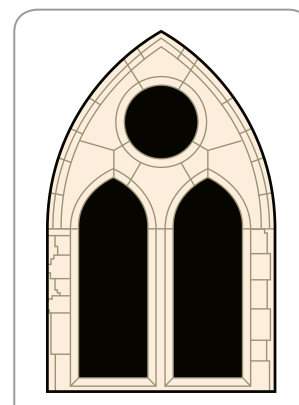
Unit 9.3

Beam: lintel, used over windows and doors to hold up the weight of the wall above it

Flying buttress: a structure that provides extra support for walls, used with Gothic arches

Gothic arch: pointed arch

Lintel: beam used over windows and doors to support the weight of the wall above it



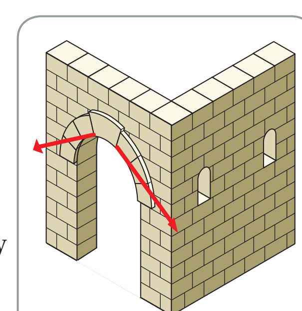
Gothic arch

Lintel

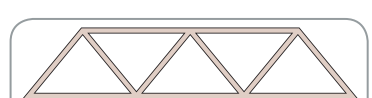
Reinforced concrete: concrete with steel rods and/or mesh within it

Roman arch: semicircular arch

Truss: lightweight structure made from triangles, commonly used in bridges



Roman arch



Truss