BUILDING BRIDGES

Booklet Questions

1. What are the first jobs that need to be done on any bridge?

2. what are pile-drivers?

3. What are abutments?

4. Explain why bridges have to allow for movement.

5. Describe 3 things/forces that could cause movement on a bridge

6. List 4 different kinds of beams

7. How are large concrete beams lifted into place?

(8) In an arch bridge the last stone to be added is what?

(9) How did the Romans lift stoner into place back in the old days?

(10) Which country is the Syndney Harbor Bridge located?

(11) suspension bridges are ideal for what?

(12) The most famous suspension bridge in the world is?

(13) what would people have to do before suspension bridges were built?

(14) How is a suspension bridse like a tent?

(15) How are cable-stayed bridser different then suspension bridges?

BUILDING BRIDGES

Building a large bridge is an enormous job which can take hundreds of people more than five years to finish.

Foundations and piers

what are the first jobs to be done on any bridge?

Digging the foundations and building the **embankments** are the first jobs to be done on any bridge. Each embankment slopes gently up to the bridge so that the road is raised to the same level as the road deck. Powerful earth-moving machines do most of this work. If the ground is soft, the foundations will be dug by huge spinning **pile drivers** until harder rock is felt. If the soft ground goes very deep, concrete slabs will be poured into molds. The slabs act like rafts and will spread the vibration and weight over a larger distance. If you toss a pebble into water, the farther the ripples spread, the less power they have. A concrete slab foundation does a similar thing.

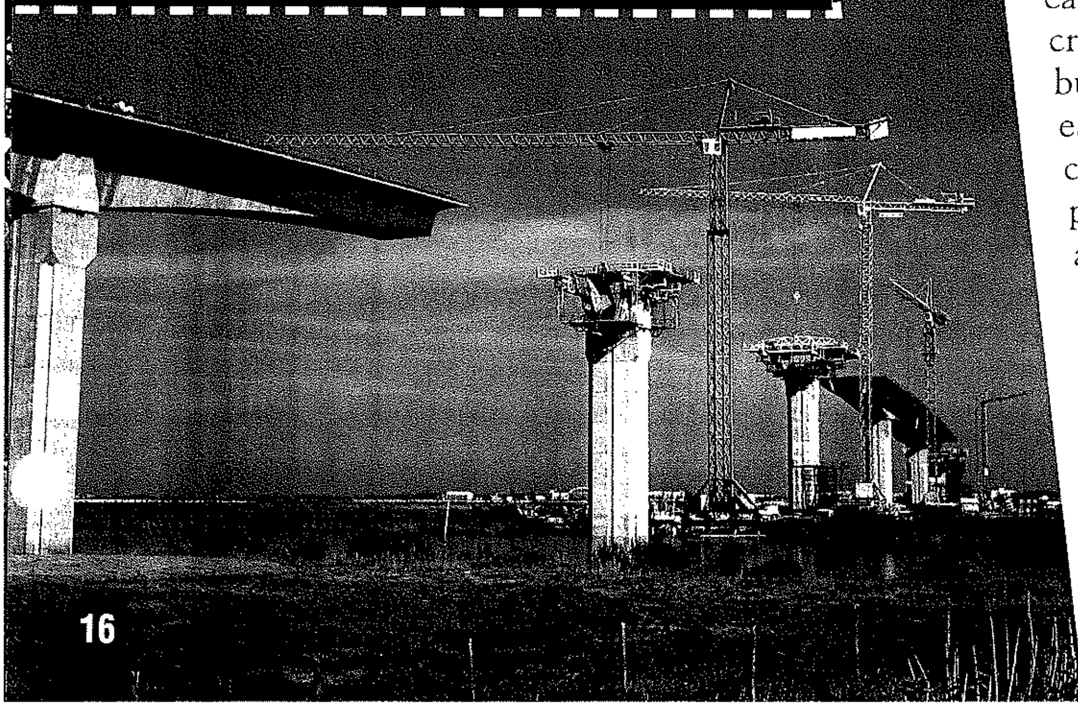
As the piers and **abutments** are built on top of the foundations, another mold is made for the concrete to be poured into. The mold is made from wooden sheets or steel plates, called formwork, and is supported by a special frame called scaffolding. Huge cranes are used to lower bunches of steel wires into each mold to reinforce the concrete. Wet concrete is poured into the mold and allowed to set. The formwork is then moved up and more concrete is poured and allowed to set. This goes on until the pier reaches the right height.

KEY WORDS

embankments mounds of earth made by humans to carry a road or railroad

pile drivers powerful machines that push large metal or concrete poles into the ground like a hammer

abutments supports at the end of a bridge



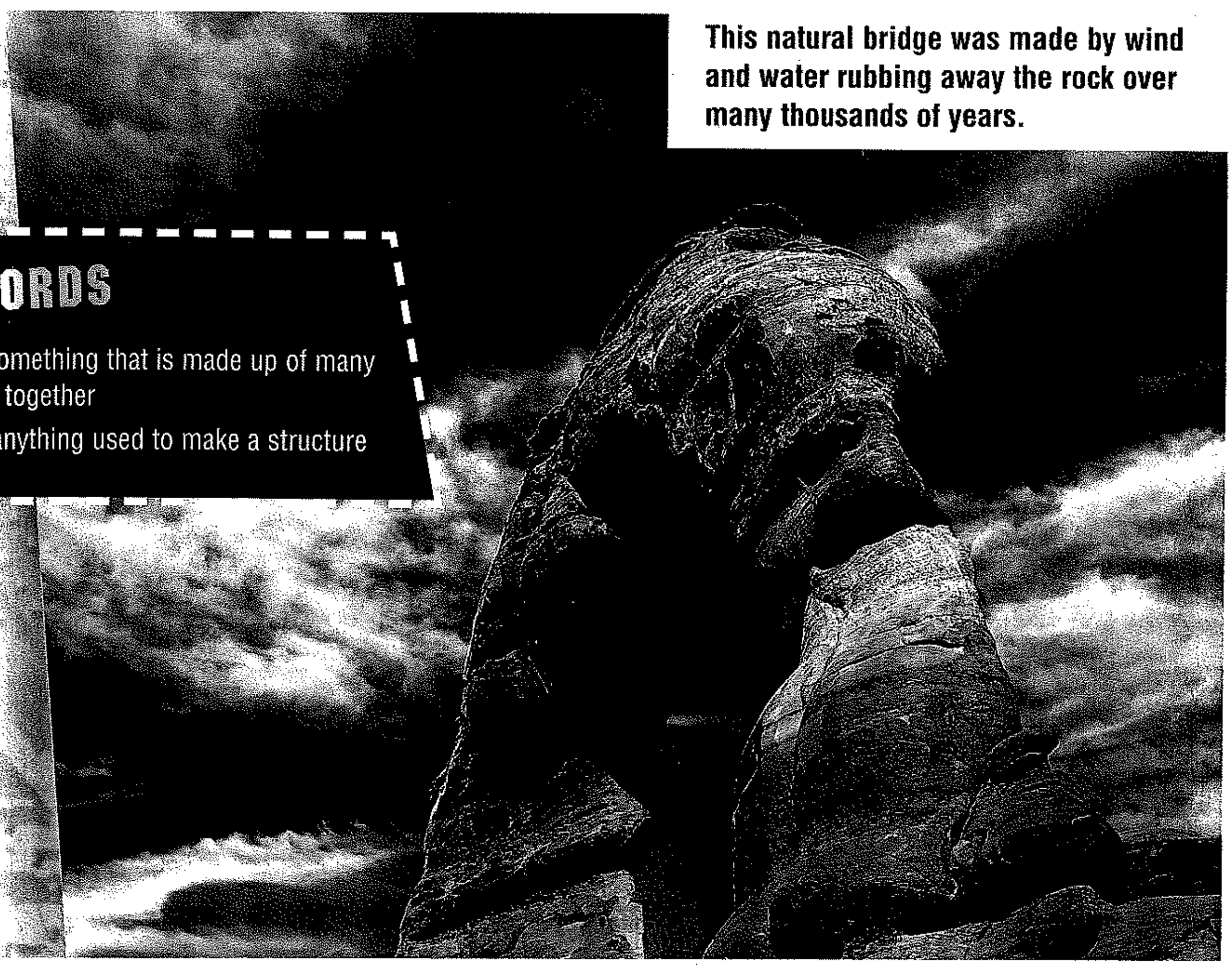
◀ **Long piers are built in stages.**

BRIDGES AS STRUCTURES

A **structure** is made up of many different parts joined together. The shapes of the parts and the way they are joined together help a structure to stand up and do the job for which it has been designed. The **materials** used to make a structure can be made stronger or weaker, depending on their shape and how they are put together.

Bridges are made by humans, but there are also natural bridges. For as long as people have wanted to move from one place to another, they have built bridges. Bridges are built to:

- make journeys for land vehicles and pedestrians shorter, safer, and easier
- carry goods from one place to another as quickly and cheaply as possible
- make journeys across water easier and more comfortable than taking a ferry
- quickly carry traffic away from cities, easing traffic jams and pollution
- cross land that is too rough or not solid enough to support a road.



This natural bridge was made by wind and water rubbing away the rock over many thousands of years.

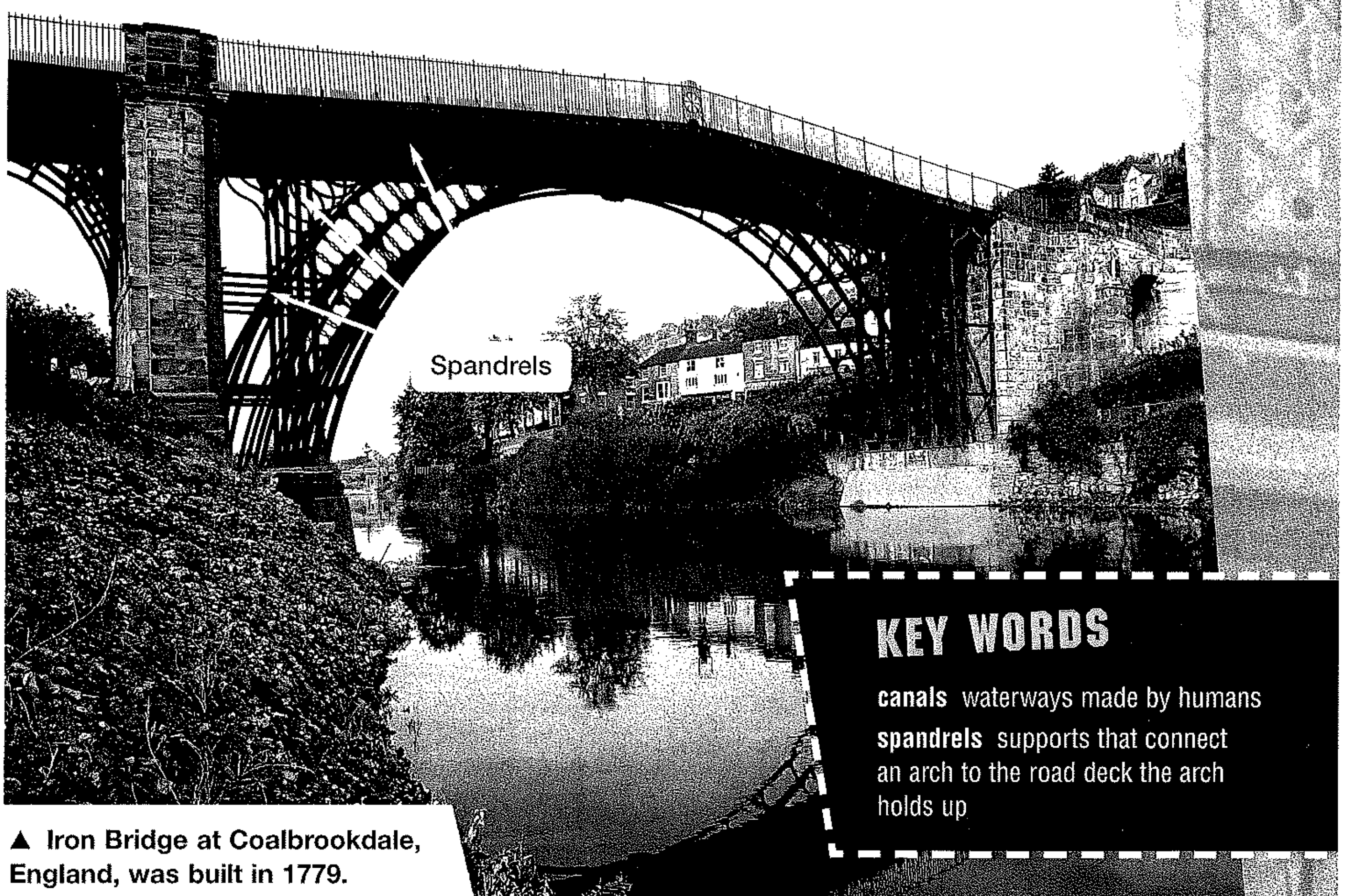
KEY WORDS

structure something that is made up of many parts joined together

materials anything used to make a structure

Arch bridges

Arch bridges are used to carry traffic, railroads, pedestrians, and **canals** over roads, rivers, and steep valleys. Some bridges are thousands of years old. The ancient Romans found that wooden beam bridges could only take a small amount of weight and soon rotted because they were not protected from the weather. Arch bridges built from small stones or bricks were weatherproof and much stronger. The Romans invented a type of cement and found that by joining many arches together, they could span a large gap.



▲ **Iron Bridge at Coalbrookdale, England, was built in 1779.**

KEY WORDS

canals waterways made by humans

spandrels supports that connect an arch to the road deck the arch holds up

Older arch bridges are usually made of solid stone or brick. The first iron-arch bridge ever built was the Iron Bridge across the Severn River at Coalbrookdale, in England. Arch bridges like this have connections called **spandrels**.

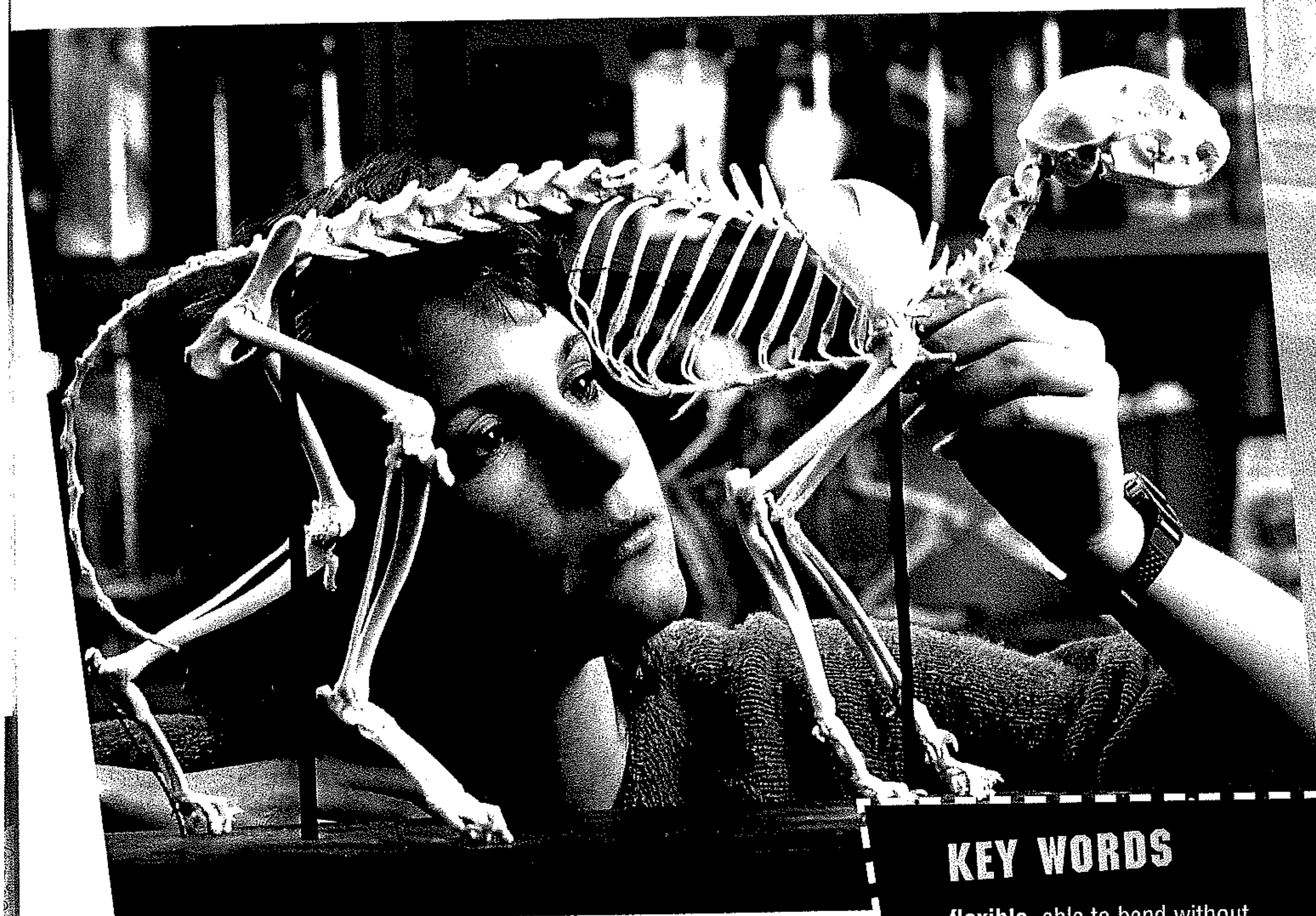
Modern arch bridges are built of steel trusses and concrete. Some of the massive steel truss arches are more than 1,641 feet (500 m) long and as high as a 60-story building! The decks on most modern arch bridges are supported by the arch underneath. The Sydney Harbor Bridge, in Australia, is different—its deck is hung below the giant arch on steel spandrels.

Allowing for movement

The parts used in bridge building must be **flexible**. Some bridges can sway 6 to 10 feet (2–3 m) in strong winds. **Engineers** design bridges so that they can move with the wind, just as a tree does. If a tree did not sway, its trunk would snap.

As heavy traffic rolls across a bridge, the bridge sags slightly. Strong pieces of metal, called bearing plates, sit between beams and piers and allow the beams to slide and twist a little.

Changes in the weather can make parts of a bridge swell or shrink. Bridges have joints made from a special spongy material that can spring back into shape after being stretched or squeezed. These joints are called **expansion** joints. This allows the bridge to move slightly without breaking.



Four-legged animals are like bridges. The four legs act like piers. The weight hangs from the backbone, but is supported by muscles and tendons which move like cables. Engineers get many of their ideas from nature.

KEY WORDS

flexible able to bend without breaking

engineers people who design and build large structures

expansion growing or getting bigger

BRIDGE DESIGN

Engineers do a lot of research to make sure the right type of bridge is designed for the job it has to do. Science has helped engineers find out about stronger bridge designs, lighter building materials, and new tools that do the job faster. Bridge engineers use many of the shapes that are seen in nature. Shapes such as arches and triangles have proved to be extremely strong and stable for bridge building.

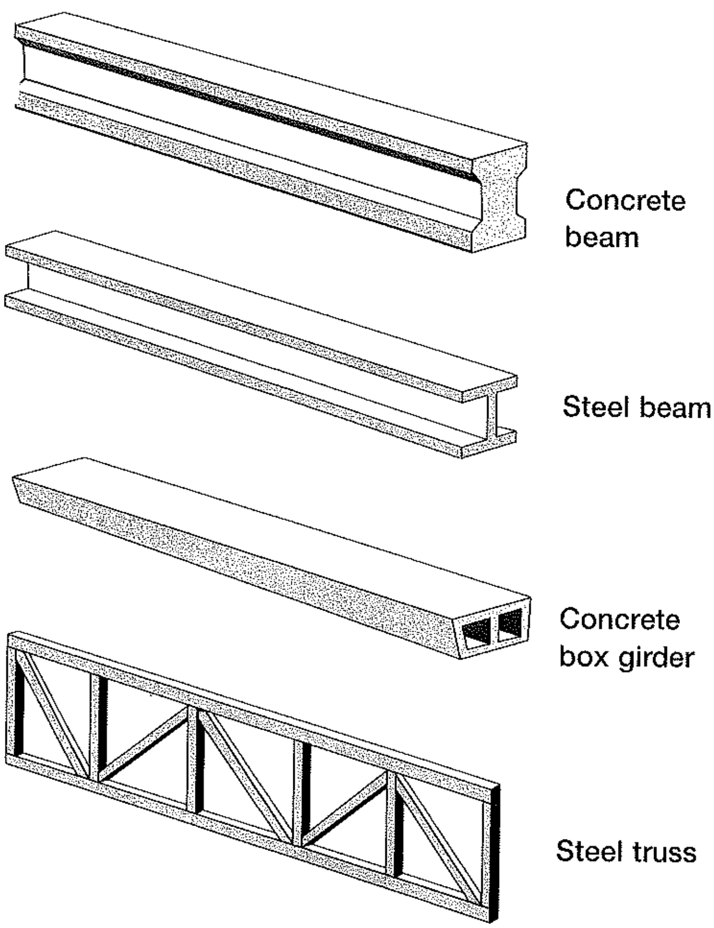
Beam bridges

A beam bridge is the simplest type of bridge. A short beam bridge is a single beam with supports at each end. Beam bridges like this can only span a small gap. Without supports beneath the middle part of the bridge, the beams will collapse under their own weight.

Wherever possible, engineers choose beam bridges with short beams and lots of piers to support them underneath, because they are cheaper and easier to build. The beams can be made of concrete or steel and shaped into girders and trusses.

Beam bridges are used to carry railroad or road traffic. The Forth Railway Bridge, in Scotland, is a type of beam bridge called a cantilever bridge. It has a series of beams that span the Forth River like outstretched arms.

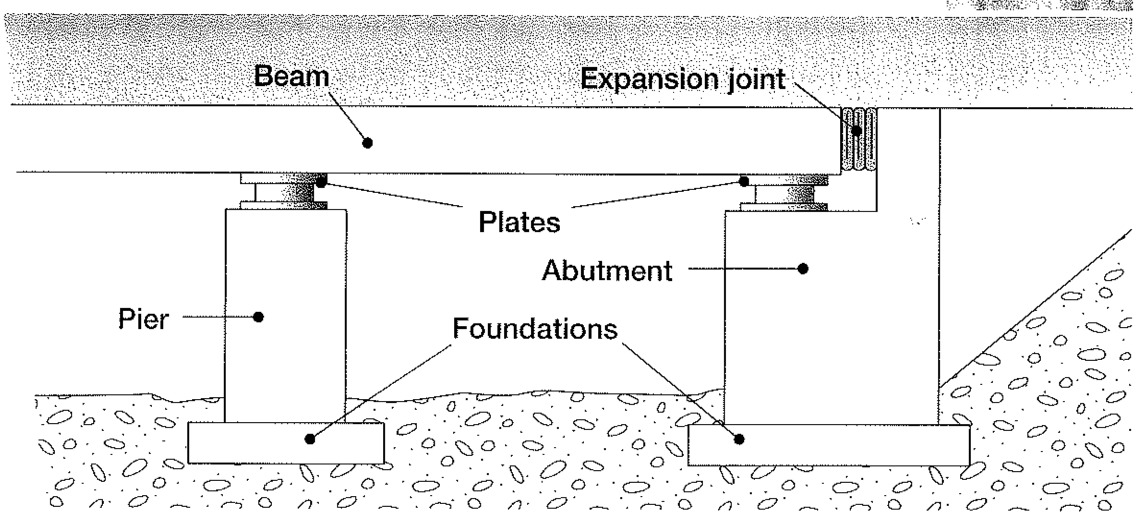
The first railroads used iron-beam bridges to carry trains over rocky or swampy land, across deep valleys, and around hills. This meant that the heavy steam trains did not have to slow down and could reach their destination faster.



◀ **Here are four different kinds of beams.**

Building a beam bridge

The beams for a beam bridge may be made of steel or concrete. If it is a long bridge, the beams are usually made in a factory and brought to the bridge site, where they are lifted into place by a crane. For spans only a few feet long, concrete beams can be poured on the spot, using formwork as a mold. The beams are laid side by side. Bearing plates are placed in between the beams and the piers and abutments. Formwork is built along the sides so that concrete can be poured for the road deck. Finally, expansion joints are placed at the end of the beams.



A beam bridge carries the weight straight down into the ground through its piers and abutments. Special joints and plates allow the bridge to move, adjusting to temperature, wind and Earth movements, and the vibration from traffic rolling across the beams.

Cantilever bridges

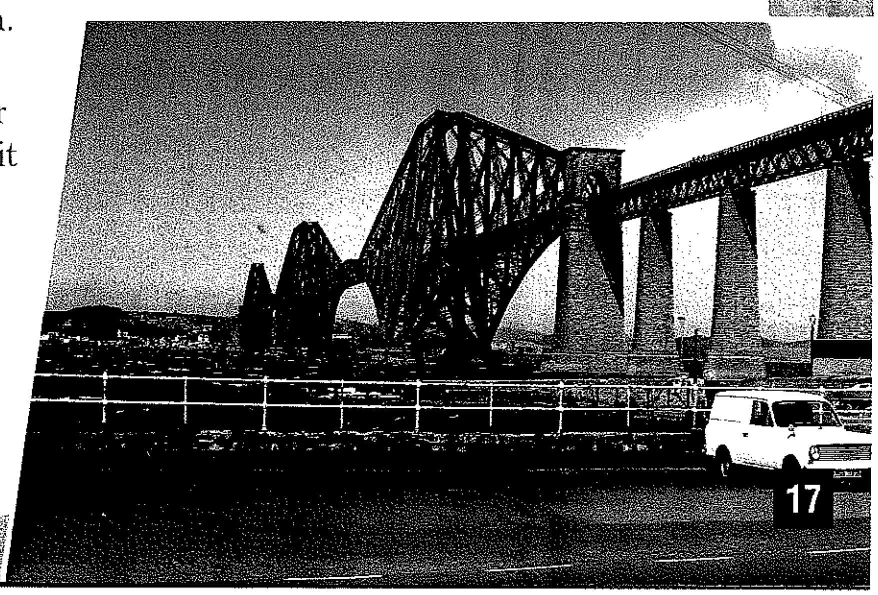
A cantilever is a beam fixed at just one end. A diving board is similar to a cantilever beam. What happens as you walk further down a diving board? It sags under your weight.

A large cantilever bridge needs extra pillars to support its central beams. Each section of a cantilever bridge has a central pillar with a beam sticking out from either side. It looks like a letter "T" or a pair of outstretched arms. A high, arching middle span joins the pillars and allows ships to pass beneath.

The Forth Railway Bridge, in Scotland, is the most famous cantilever bridge in the world. Finished in 1890, it was the first bridge to be made mostly of steel—65,000 tons (59,000 t) of it. Almost seven million **rivets** were needed to fasten the steel tubing and girders together.

KEY WORDS

rivets pins which are used to fasten sheets of metal together



The Forth Railway Bridge, in Scotland ▶

Building an arch bridge

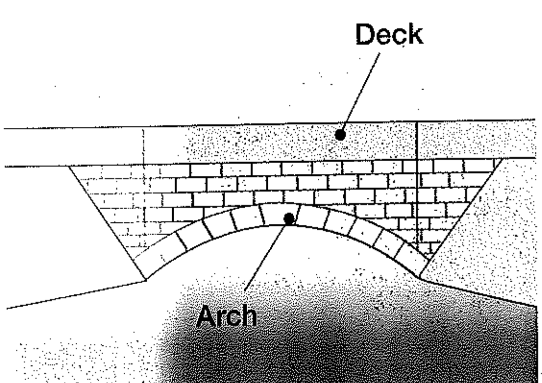
Arch bridges have great natural strength. Most of the bridges you see in nature are still standing because they are arch shaped. The weight of an arch bridge is evenly spread around the arch to its ends, which are firmly anchored in the ground.

Older stone-arch bridges were usually built between two thick brick or stone piers around a temporary frame. The last stone to be added was the wedge-shaped keystone. The keystone was always placed at the top of the arch. With the keystone in position, all the blocks beneath pushed on each other and no cement was needed. The frame was removed after the arch was finished.

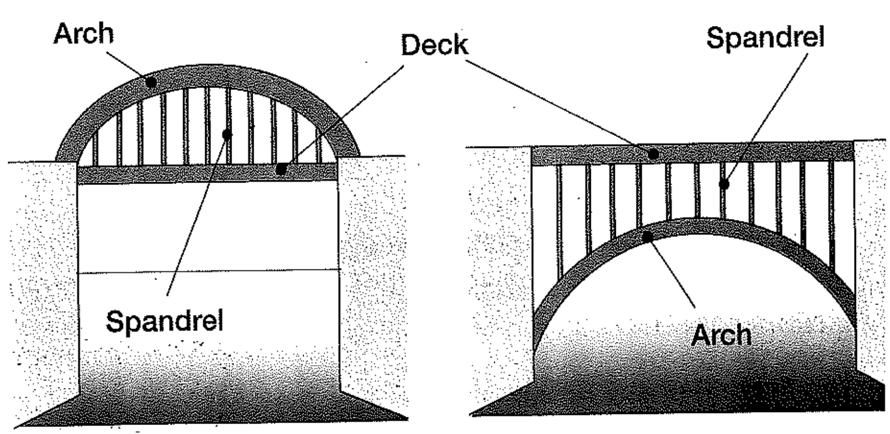
These early arches were high and narrow, and several would be needed to cross a wide river. Strong abutments and piers were needed to prevent the sides of the arch from "doing the splits." Some of the piers were so wide that they blocked most of the river and the water wore away the stonework.

The Trajans Bridge was built across the Danube River, in Europe, by the ancient Romans around A.D. 104. It had 21 arches stretching more than 3,000 feet (914 m) and contained more than a million stones. Each stone weighed about half a ton (450 kg). The Romans used cranes driven by giant wheels to lift the stones into place. Men ran inside the wheels, making them turn, allowing the cranes to work. As the arches reached higher, the builders climbed scaffolding made from wooden poles tied together to reach the top of the bridge. The bridge was destroyed by the Romans 150 years later, as they retreated in battle.

Arch bridges can be filled with stone or brick, or have metal connections, called spandrels.



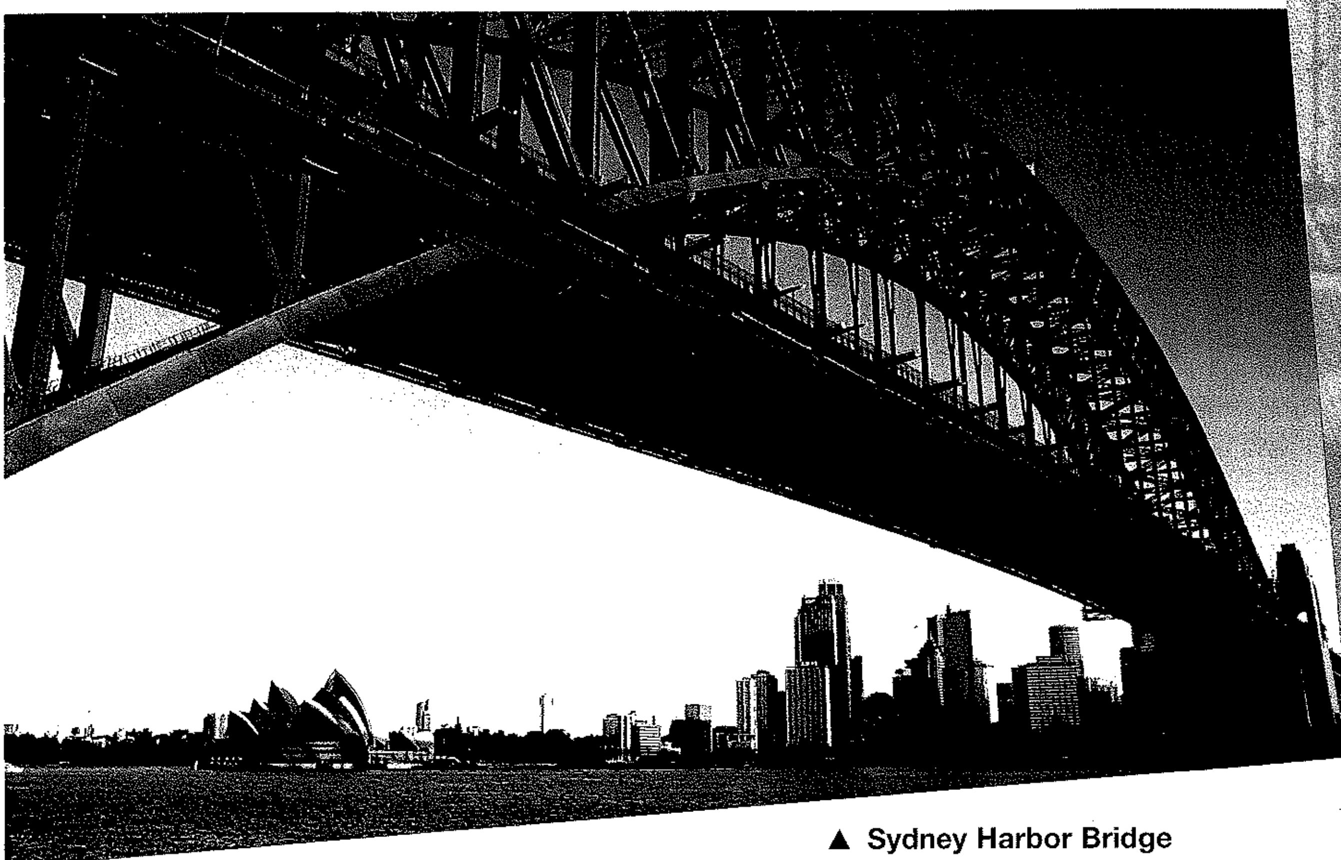
Filled arch



Spandrel arches

Modern arch bridges

With the development of modern building materials such as steel and concrete, engineers found that they could build bigger arches. This meant that they could build an arch bridge over a deep, wide expanse of water without large piers getting in the way of shipping. The Sydney Harbor Bridge in Sydney, Australia, is the world's largest and widest modern steel arch bridge. It spans 1,650 feet (503 m) and carries four railroad lines, eight road-traffic lanes, a sidewalk, and a bicycle path. Most arch bridges have the deck above the arch. The Sydney Harbor Bridge has its deck hung below. The arch may rise or fall seven inches (18 cm) as the steel swells or shrinks during warm or cool weather.



▲ Sydney Harbor Bridge was opened in 1932.

Sydney Harbor Bridge was built without a framework, so that ships could still use the harbor. Two steel arches were built out from each bank and were held up by 128 cables anchored underground through U-shaped tunnels. The 250 workers and their families lived in a camp nearby. Three ships were specially built to carry the enormous numbered blocks of rock used in the towers 186 miles (300 km) from where they were cut. Steel girders were made in workshops, placed onto barges, towed into position, and lifted up by two 640-ton (580-t) electrically operated cranes, which built the arches before them as they moved slowly forward. Up to 96 steam railroad engines were driven onto the bridge to test its strength.

BRIDGE DESIGN

Suspension bridges

Suspension bridges are the giants of the bridge world. They can span half a mile (1 km) or more. Their decks hang from thick steel cables draped over enormous concrete and steel towers which are **anchored** to the ground at each end of the bridge. Suspension bridges are ideal for carrying traffic across wide stretches of water.

A suspension bridge does not need lots of piers to support its beams from underneath. This means that large and tall-masted ships can easily pass beneath a suspension bridge without scraping the underside of the bridge's deck or being dragged by fast-flowing water into the piers. Smaller suspension bridges are often used as footbridges across the space between steep cliffs.

KEY WORDS

anchored attached to something heavy to stop moving

The Golden Gate Bridge, in the U.S., is the most famous suspension bridge in the world. Can you see the triangles in its structure?

Before long suspension bridges were built, people would have to take a slow ferryboat across the water or travel a long way up a river before they could find a place narrow enough to support a beam bridge.

The Akashi Kaikyo suspension bridge, which links the small islands of Japan, is the longest suspension bridge in the world. Its longest span is 6,531 feet (1,990 m), or more than a mile (2 km) without a support! It takes 20 minutes to walk from tower to tower on one span.

Building a suspension bridge

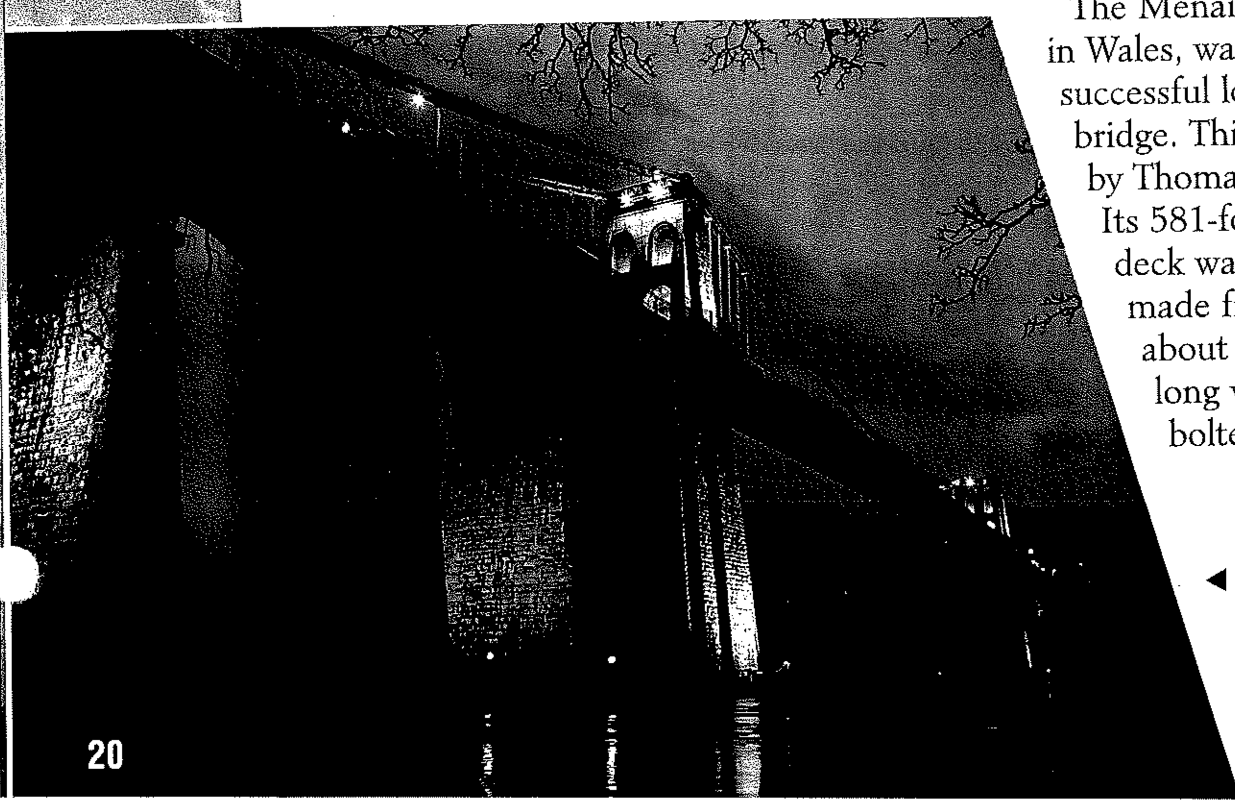
A suspension bridge is a bit like a tent. A tent only stays up if its ropes are stretched equally and attached to pegs pushed deep into firm ground. The stretched ropes pull on the tent from all sides, stopping the tent from collapsing.

The first suspension bridges had cables made of grass or vines. People soon discovered that by plaiting bunches of vines or grass together, they could make a rope strong enough to support the weight of people.

In the Himalaya Mountains, ancient bamboo and woven rattan suspension bridges had a hut at each end filled with stone to help anchor the bridge. The rope cables were wound around tree trunks beneath the huts. Wooden levers or handles extended from the tree trunks. People would hold these and turn the trunk. As the tree trunks were turned, the cables were pulled tighter, keeping the bridge stable. Some of these bridges are more than 229 feet (70 m) long and have been in use for more than 300 years.

Many of these older suspension bridges were quite short. They often swayed so much in windy weather, or under the weight and movement of the people using them, that the people crossing could become seasick.

The Menai Strait Bridge, in Wales, was the first successful long suspension bridge. This bridge was built by Thomas Telford in 1826. Its 581-foot-long (177-m) deck was hung on chains made from iron bars about 10 feet (3 m) long which were bolted together.



◀ **Menai Strait Bridge**

Modern suspension bridges

Modern suspension bridges have concrete towers resting on deep foundations. Steel cables are run across the tops of the towers and fixed into concrete anchors. The anchors have to be very heavy to stop the cables from being pulled out when the bridge deck sags as it carries traffic. One of the anchors for the Humber Bridge, in England, weighs 331,200 tons (300,000 t).

Huge concrete anchors hold the thick, steel cables of the Verrazano Narrows suspension bridge, in the U.S.

Suspension cables

Suspension cables are made by spinning thousands of thin steel wires together. A machine like a bicycle wheel runs up and down, picking up the strands and twisting them tightly together. Some cables are more than three feet (1 m) thick. The spun cables are placed inside steel tubes to protect them from the weather.

The Akashi Kaikyo Bridge, in Japan, is so long that its cables could circle Earth more than seven times! A groove in the tower stops the cable from slipping off. **Hangers** join the deck to the cables. The builders hang wire walkways between the towers so that they can hang the cables and fix the hangers. The deck is added one piece at a time. It is attached to cables, lifted on a hoist, and pulled along rails and into position. Once all the deck pieces are in place, some of the builders climb inside the hollow pieces and join them together by **welding**.

KEY WORDS

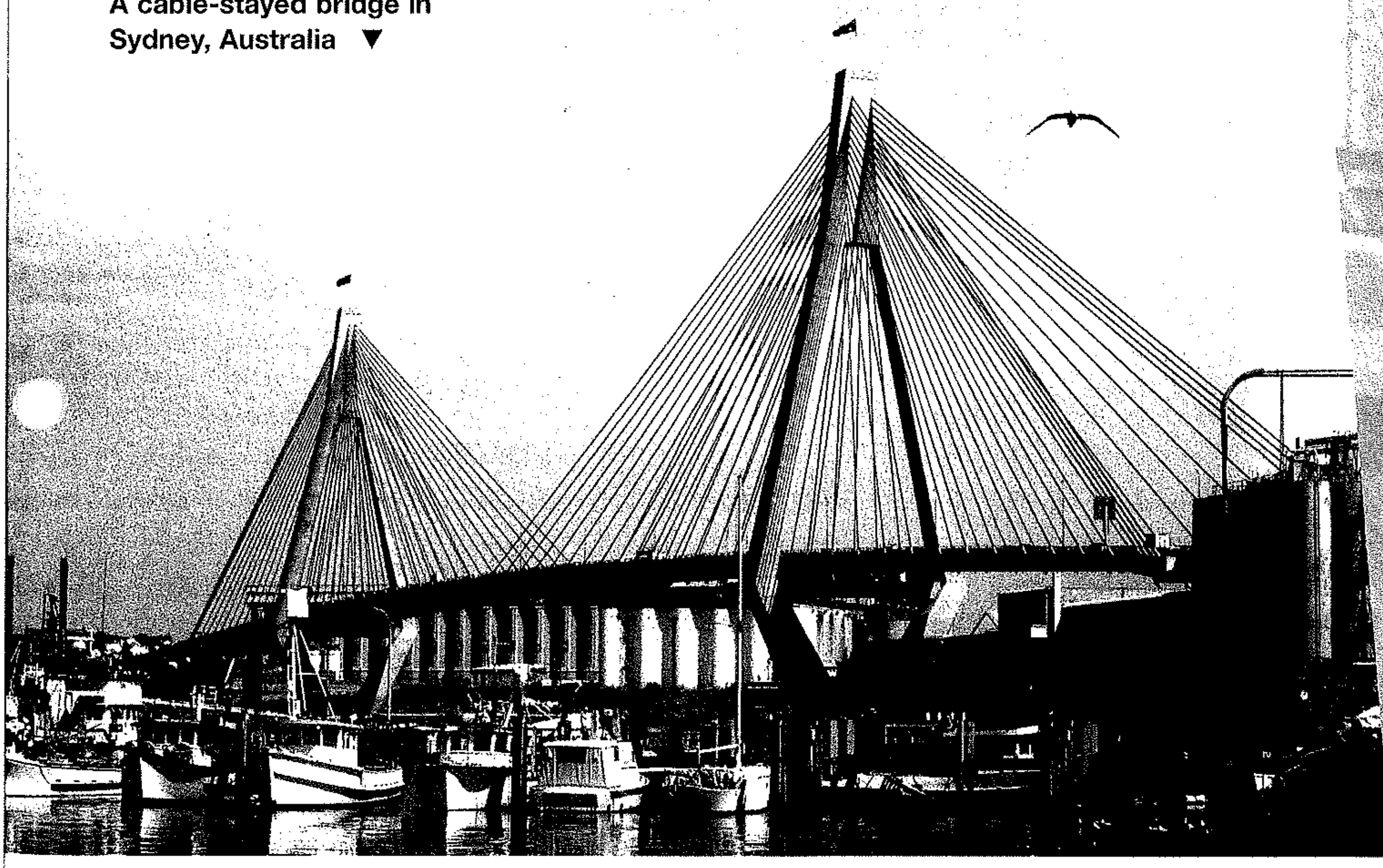
hangers pieces of metal that join the vertical steel cables to the horizontal cables on a suspension bridge

welding joining pieces of metal together by heating their edges until they melt into one

Cable-stayed bridges

A cable-stayed bridge is like a suspension bridge because strong, steel cables support its deck. The cables that support the deck of a suspension bridge are draped over the towers at each end and fixed in the ground. A cable-stayed bridge is different. Its cables are attached to the towers themselves and fan out along the deck. This makes a cable-stayed bridge easier and cheaper to build, because it uses fewer materials. However, without deep ground anchors, a cable-stayed bridge cannot have spans as long as a suspension bridge. The tower of a suspension or cable-stayed bridge can be as high as a skyscraper. The deck is shaped so that the air flows around it. Otherwise the deck would vibrate like a plucked guitar string when it was windy.

A cable-stayed bridge in Sydney, Australia ▼



Choosing the right bridge design

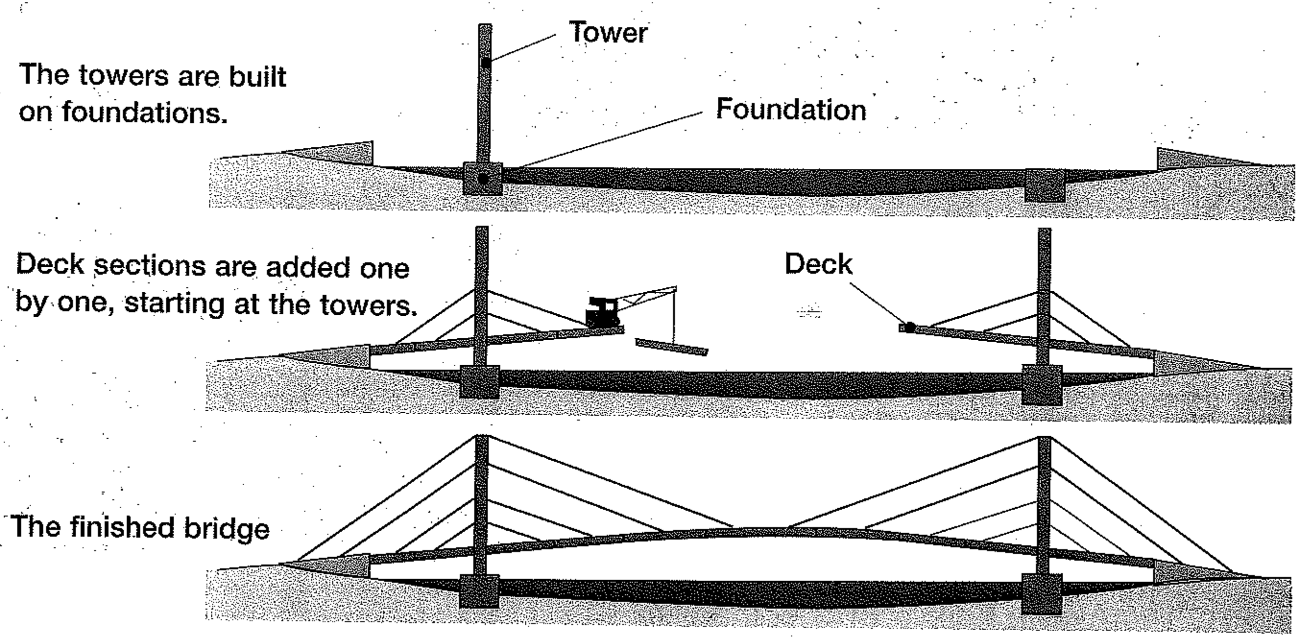
Choosing a bridge design depends on different things. Engineers decide what sort of foundations are needed and how deep they should be after geologists test samples of rock and soil in a laboratory to discover if there are any weaknesses in the ground. Next, the engineers will work out how much the bridge will weigh and how much extra weight it will carry when it is in use. This tells the engineers how strong the bridge parts need to be. They must try and keep the bridge as light as possible without making it weak.

Building a cable-stayed bridge

A cable-stayed bridge is a newer type of suspension bridge which has been built since the 1950s. The difference between a cable-stayed bridge and a suspension bridge is how the deck pieces are joined and where the cables are placed.

In a cable-stayed bridge, the cables are anchored, or stayed, to the towers and fan out along the deck. The deck pieces are concrete. They are raised into position and pulled together on tight steel cables. The stretched cables pull and the vibration and weight of the traffic travels through them to the towers and down into the ground.

If you have ever been in a tug-of-war where the other team is as strong as your team, you can see how the pulling action of a cable-stayed or suspension bridge works. The steel cables are like spider-web silk—light, but tough, and spun in tight spirals for extra strength. Just as a spider's web is anchored firmly to another structure, so the cables are anchored to the bridge towers.



▲ **This is how a cable-stayed bridge is built.**

Sometimes, there are two different types of ground where the foundations of a bridge are to be built. The Tamar River in Tasmania, Australia, has hard rock on one side and soft clay on the other. So, a half-suspension, half-cable-stayed bridge was designed, which supports nearly all the weight of the Batman Bridge from the rocky side.

Building across water

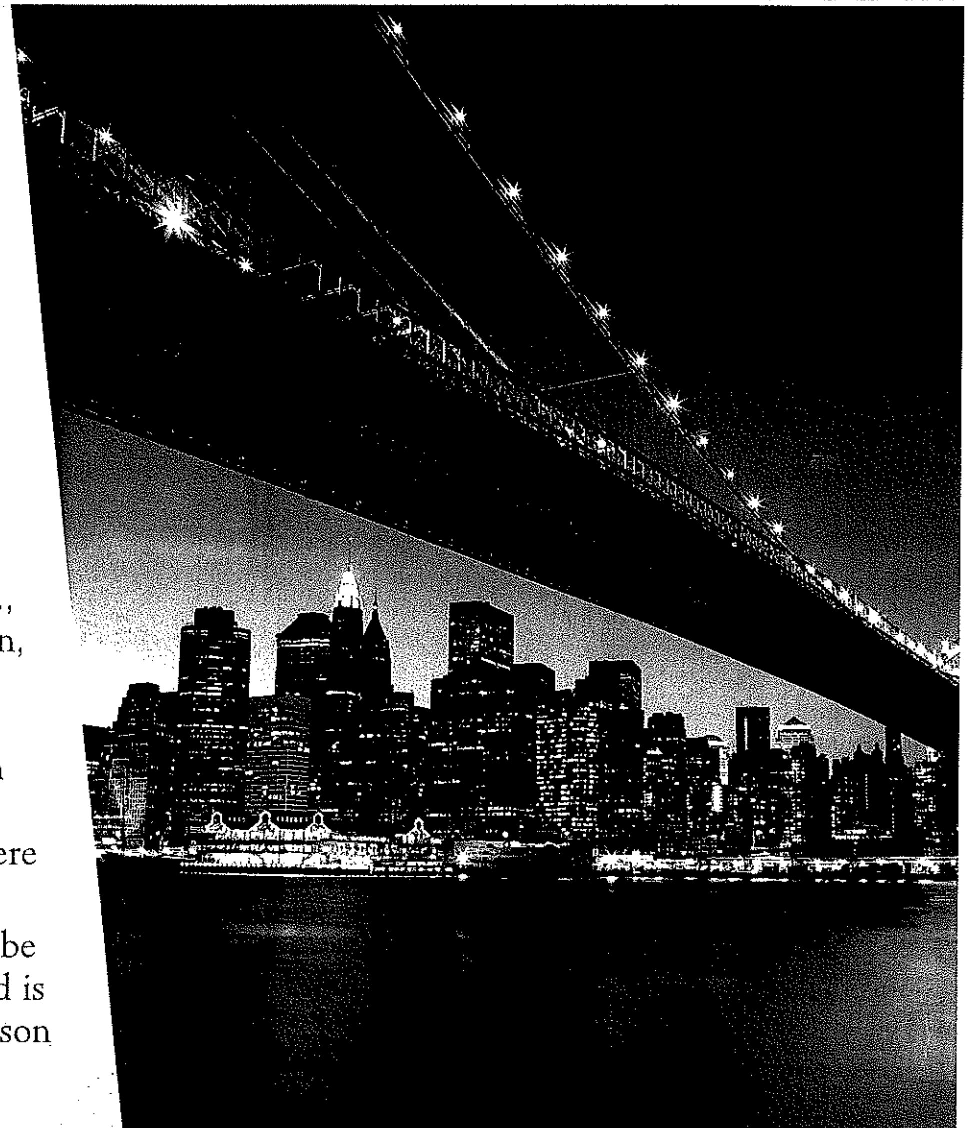
Suspension and cable-stayed bridges are usually built across wide rivers or bays, with their towers standing in water.

Staying dry

Keeping the work area dry and free of mud while foundations are dug and towers are built can be a problem. If the water is shallow, a temporary circular dam called a cofferdam is built in the river. The water is pumped out and the soft river mud is dug away until harder ground is felt. The bottom is lined with concrete.

One of the piers for the Golden Gate Bridge, in the U.S., had to be built in the open ocean, 1,000 feet (305 m) below the surface. The engineer built a cofferdam that was large enough to enclose a playing field. Hundreds of tons of concrete were pumped in.

In deeper water, a concrete tube called a caisson is used. The mud is dug out from inside and the caisson sinks until it reaches solid rock. Concrete is pumped in and the caisson becomes the foundation for the tower.



The Brooklyn Bridge, in New York, was the first bridge where explosives were used inside a caisson to break up rock.

Decks and cables

When a bridge is built across a river, the deck pieces are floated on barges until they are in position beneath the bridge. Floating cranes lift deck pieces and equipment up to the deck height. The cranes pull a special rope into place so that a walkway can be built for the workers who will attach the cables. The water around the Akashi Kaikyo Bridge is crowded with shipping and flows so fast that a helicopter was used to pull the rope into position.