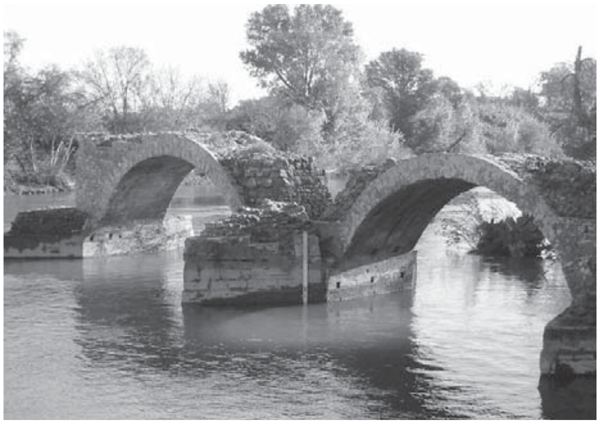
Five Bridge Types

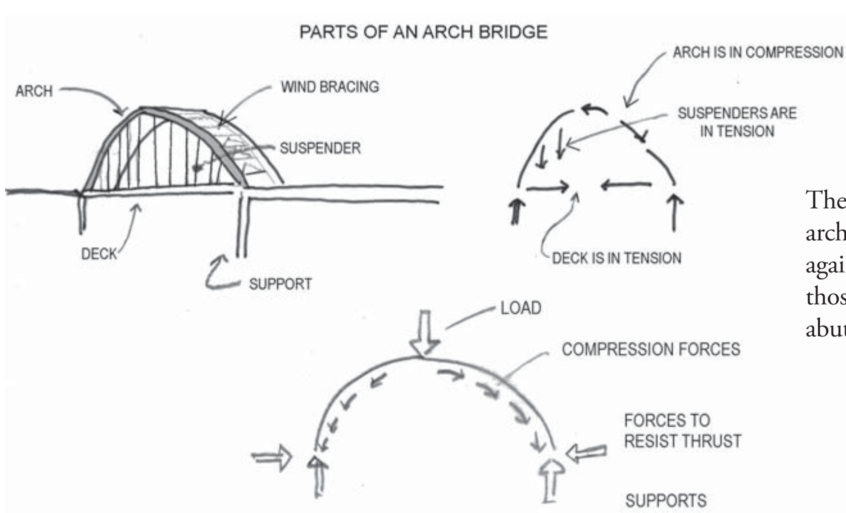
Arch, Suspension, Beam, Truss, Cable-Stayed



Arch Bridge

Ancient arches were made of stone. Arches work by putting the material into compression. Stone (as well as steel and concrete) work well in compression. A material is in compression when its particles are being pushed together. A column holding up a building is a long thin compression element.

A modern example is the Daniel Carter Beard Bridge in Cincinnati. In the roman bridge the weight that the arch carries comes from the stones on top of the arch. In the DCB bridge the weight starts at the road deck, runs up through the vertical cables (tension) and is distributed into the arch.

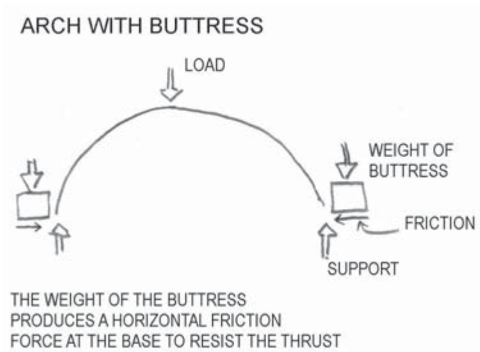


The compression forces in an arch have to press ultimately against the ground. To receive those large forces large abutments have to be created.

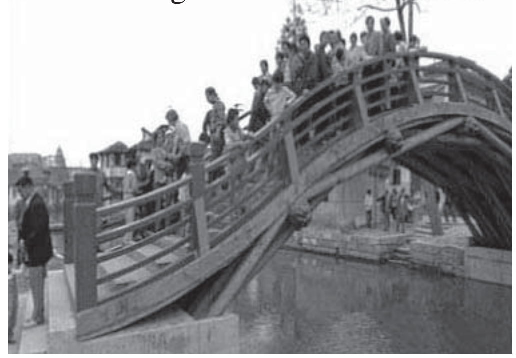
FIVE BRIDGE TYPES

ARCH

On the right you see a concrete abutment at the end of a small wooden bridge built in China. On the left you see a diagram of how the forces will flow from the arch through the abutment into the ground. Look in the picture of the Daniel Carter Beard Bridge shown above. Where are the abutments? Are there some other stiff elements that can work in compression to carry the forces out to the riverbanks? If not, then maybe this is a "tied arch," which means that there are tension forces that allow each end of the arch to pull against the other side. Which explanation do you think best describes how this arch works?



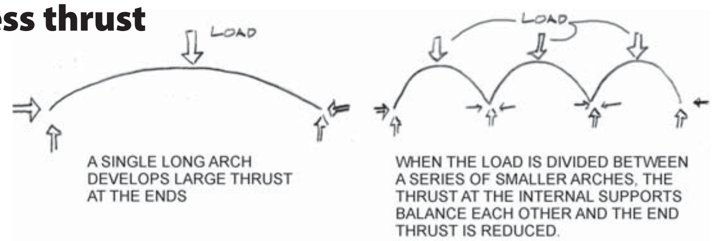
China Bridge



You can view the building of the China Bridge at www.pbs.org type "China Bridge" in the search box.
There are some experiments later in this tutorial that will let you compare the effects of buttresses and ties.

In the Roman arch bridge photo at the top of this section, the thrust on the inner supports balances from one side to the other. The remaining thrust occurs only at the final buttress. The thrust in a series of short arches is less than the amount that would arise in one long arch.

Multiple arches have less thrust



The longest arch bridge in the world (until last year) was the New River Gorge Bridge in West Virginia, built in 1977. It has a central span of 1700 feet and a total length of 4224 feet. The Lupu Bridge in Shanghai now exceeds it by 105 feet. The New River Gorge Bridge is still the highest bridge; it rises 360 feet above the river and weighs 88,000,000 lbs.

New River Gorge Bridge

Arches are often heavy. They can carry more load by getting deeper. With its full length in compression, the material can buckle. One way of overcoming buckling is to use more material, and make the arch heavier. At some point too much of its strength is used to support just its own weight and too little strength is left to carry the superimposed loads of traffic.

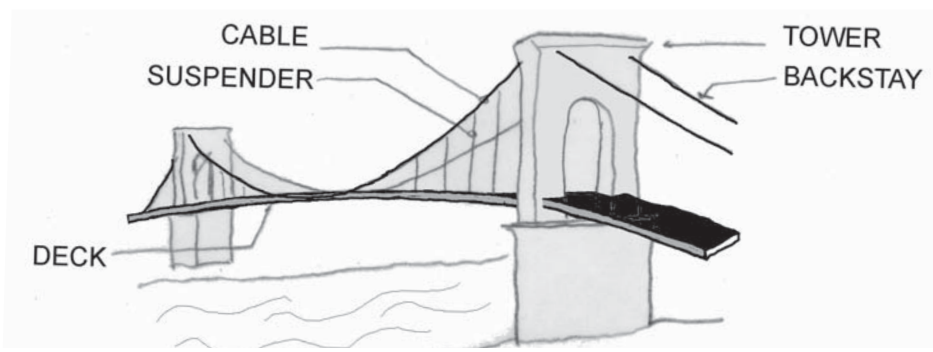
Suspension

Suspension Bridge

Ancient suspension bridges were made of rope, vines or chains.

Newer suspension bridges use steel plates or super-strong steel cables. Cables work by putting the material into tension. Stone and concrete do not work well in tension; they are too brittle and usually too heavy. A material is in tension when its particles are being pulled apart. A rope holding a weight at its end is a long thin tension element, as shown in the picture of the dangling elephant on page 9.

Parts of a suspension bridge



A suspension bridge has a curved tension member. Look back at the diagram of "curved tension" back in the forces section. Examples of suspension bridges include rope bridges like those in ancient China, or the Roebling Bridge in Cincinnati.

Roebling under construction (http://www.cincinnati-transit.net/suspension.html)

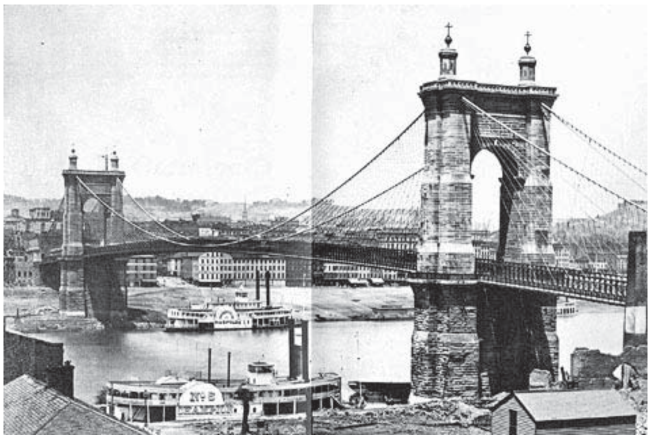
Work on the Roebling Bridge began in 1856. The first parts to be constructed were the two stone towers. Even before they could be started, workers had to build cofferdams that held back the Ohio River water so that they could build the foundations on the dry riverbed. Before the towers were completed work was halted, in part because of the Civil War. In order to transfer troops to Kentucky a temporary pontoon bridge (a bridge built from boat to boat to boat) was built near the site of the Roebling Bridge. By the end of the war, the bridge was finished and it opened in December 1866.

In 1896, after fewer than thirty years in use, the Roebling Bridge was greatly modified to allow it to carry heavier loads. An additional set of cables was added above the original set and the deck was stiffened with a truss.

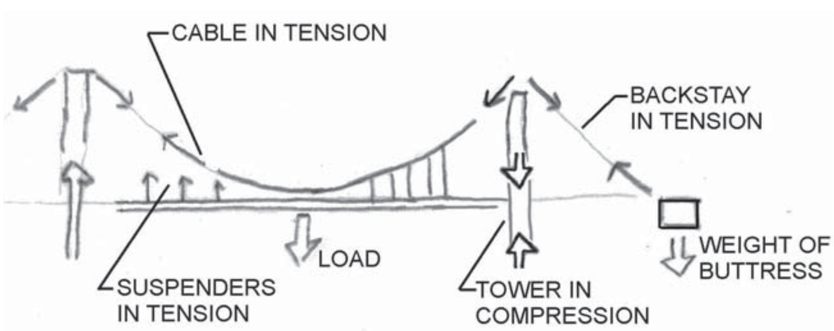
SUSPENSION

Compare these two pictures to see the new cable running over the top of the towers and the new truss along he sides of the road deck.

Original vs. Modern Roebling



Suspension bridges use a combination of tension and compression. The cables can only carry tension loads. By stretching across the towers, they pull down and create compression in the towers.



How a suspension bridge works

The cables that go from the top of the towers down to the ground are the backstays. The backstays are connected to huge rock or concrete piers buried in the ground. The backstays keep the towers from bending in.

There are some experiments later in this tutorial that will let you see what happens if the bridge doesn't have backstays.

Look at the second black and white photo of the Roebling Bridge. Can you see that the cables in the center span curve upward to the towers, but the outer cables, called the backstays, are straight? Can you determine the direction of force on the backstays? It is always in the same direction because the force must run in the same direction of the cable. What is the direction of force on the main cables? What makes them curve?

SUSPENSION

Diagrams

Suspension bridges are very light. This allows them to span very long distances. The longest suspension bridge in the world is the Askashi Kaikyo Bridge in Japan. In addition to the long span, this bridge was designed to resist huge earthquakes (8.5) and hurricane force winds (220 MPH).

Askashi Kaikyo Bridge
www.hsba.go.jp/bridge/e-akasi

Its center span is over a mile long (6531 feet). This is more than six times as long as the Roebling bridge whose span is 1057 feet. Because suspension bridges are very light, they can sometimes be damaged by winds that cause them to sway or gallop. This picture shows the famous collapse of the Tacoma Narrows Bridge (also known as "Galloping Gurdy") in Washington in 1947.

Tacoma Narows failure
http://www.lib.washington.edu/specialcoll/tnb/

A home-movie was made of the collapse by Professor F.B. Farquharson, an engineering professor at the University of Washington, who was studying the dynamic effects of the wind on the bridge. It can be viewed at the first site below. More still photos are available at the second site, below.

http://cee.carleton.ca/Exhibits/Tacoma_Narrows/TacomaNarrowsBridge.mpg
http://cee.carleton.ca/Exhibits/Tacoma_Narrows/DSmith/photos.html

Five Bridge Types

Beam

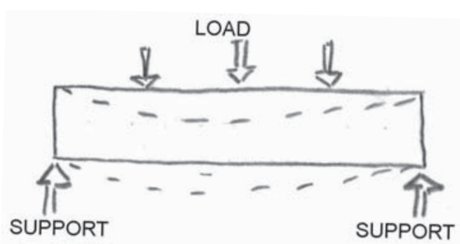
Beam Bridge

Ancient beam bridges were made primarily of wood. Modern beam-type bridges are made wood, iron, steel or concrete. How a beam operates is more complex than a cable or an arch. In the cable all of the material is in tension, but in a beam part of the material is in tension and part of the material is in compression. Look at the example of the Royal Albert Bridge design by I. K. Brunel in England.

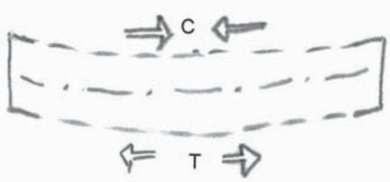
The Royal Albert Bridge, I.K. Brunel in England

(http://www.royal-albert-bridge.co.uk/). The heavy iron tube on top acts like an arch and the smaller wrought iron chains, below, act like cables. The combination of these forces describes what happens in a beam.

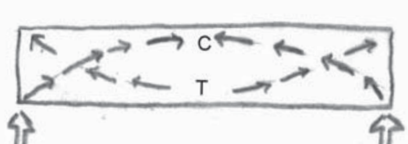
How a beam works



A beam supported at its ends and loaded in the middle deflects downward.



The top edge is in compression. The bottom edge is in tension. there is no stress in a line right through the middle.



C = Compression
T = Tension

The beam develops a compression arch across the top and a tension cable across the bottom.

The top of the beam has compression forces squeezing the material together, and the bottom of the beam has tension forces that stretch the material apart.

FIVE BRIDGE TYPES

BEAM

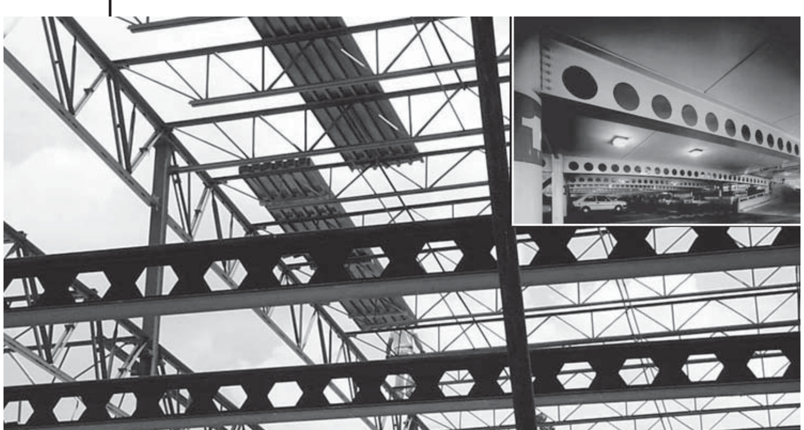
A beam needs to be made of material that can work well under both compression and tension forces. Wood is a good material for this. Stone is not a good material for a beam - it is strong in compression, but weak in tension. That's why it is good for arches but bad for beams. The same is true of concrete. To make a concrete beam, we need to add steel rods or cables at the bottom (in the tension area.) Long-span beams came into great use after 1850 when the production of large batches of steel became possible.

None of the big bridges crossing the Ohio River are beam-types because the span is too long and their weight would be too great. Beams are more often found in shorter spans such as those at many overpasses. Next time you are driving with your parents on the highway, look at the structure beneath the overpasses as you travel beneath them, and you will more often than not see steel wide-flange beams supported by concrete columns.

The new girders in place for the Fort Washington Way overpass at Broadway Street
http://www.cincinnati-transit.net/fww-1999tour3.html

In a wide-flange (or I-shaped) beam supported on each end, the top flange carries large compression forces and the bottom flange carries equally large tension forces. The thin web in the middle separates the two flanges and develops shear forces that usually are much smaller than the forces in the flanges. The excess material in the web can be cut away and a more efficient beam, called a castellated beam, is developed.

Castellated beams
www.buildinggreen.com/products/prod_rev_images/smartbeam.jpg



If enough of the web is removed the castellated beam becomes a truss. In this picture, the large castellated beam will eventually support a series of trusses like those shown above it. The truss is an extreme example of what happens when the beam's web is cut away.

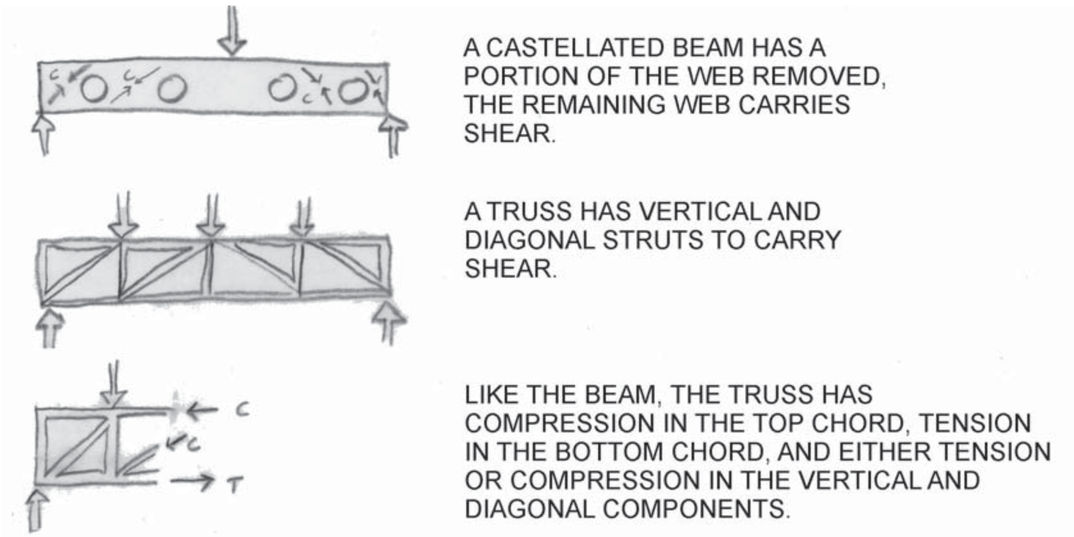
FIVE BRIDGE TYPES

TRUSS

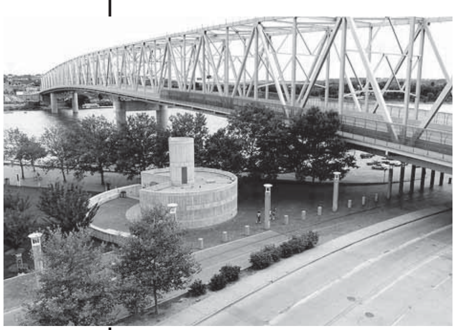
Truss Bridge

Trusses work much like beams: they carry a combination of compression and tension forces. The main difference is that trusses are less bulky (heavy) than beams. Beams use extra material in some areas; these areas don't use the full strength available to them. Engineers and builders can determine which portions of beams can be removed. The resulting truss concentrates the forces into many smaller members and eliminates the under-stressed areas of beams.

How a truss works

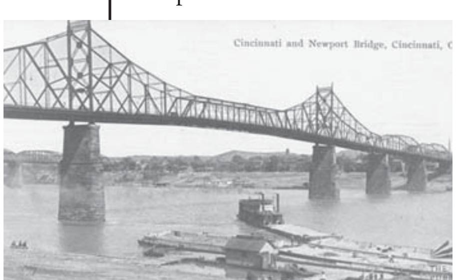


Taylor - Southgate bridge in Cincinnati
http://www.cincinnati-transit.net/taylorsg.html



The Taylor-Southgate is a modern example (1995) of a truss bridge over the Ohio River in Cincinnati. It replaced the Central Bridge built in 1890.

Central Bridge - opened in 1890, demolished in 1992.
http://www.cincinnati-transit.net/central.html



Compare the differences. The Taylor-Southgate uses fewer, longer spans than the Central Bridge. These longer spans produce much larger forces in the Taylor-Southgate, yet this bridge is not as deep as the Central Bridge. The tubes in the Taylor-Southgate Bridge must carry much higher stress, but they can do so, primarily, because they use a stronger type of steel than the types available in 1890.

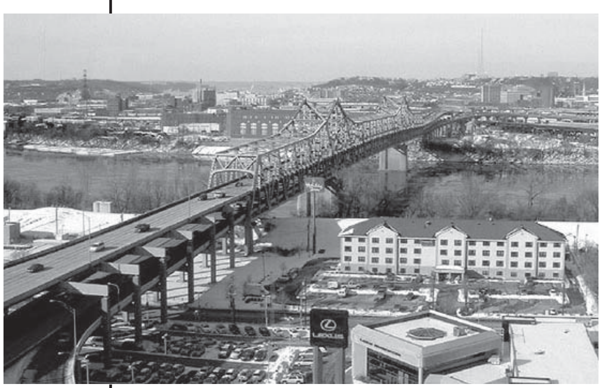
FIVE BRIDGE TYPES

TRUSS

The Central Bridge was an early example of a type of bridge called a cantilever truss bridge. In the center of the main span you see a small trapezoidal truss that is actually supported by the two large cantilever trusses. These tall trusses, one on each end, sit on the stone piers in the middle of the river. This construction type was very popular at the time these bridges were built.

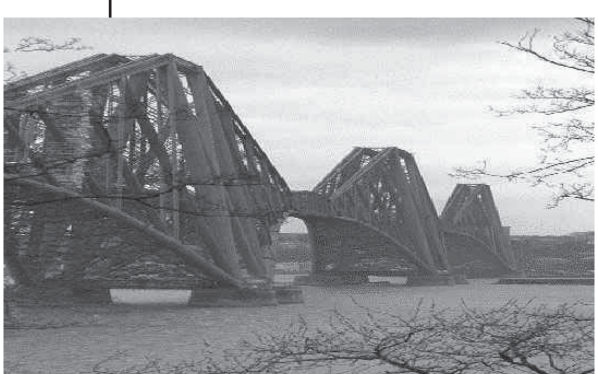
There are two more cantilever truss bridges over the Ohio River in Cincinnati: The C&O Railway Bridge (1929) and Clay-Wade-Bailey Bridge (1974) are side-by-side just downstream from the suspension bridge and the Brent Spence (I-75, I-71) bridge built in 1963.

The C&O Railway Bridge and Clay-Wade-Bailey Bridge
http://www.cincinnati-transit.net/claywade.html(1974



Brent Spence (I-75, I-71)
http://www.cincinnati-transit.net/brentspence.html

The Brent-Spence Bridge carrying I-71 and I-75 traffic across the Ohio is also a cantilever truss bridge.



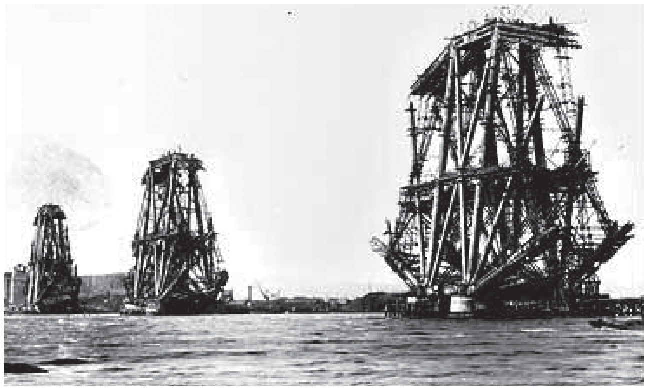
The Firth of Forth Bridge in Scotland
http://bridgepros.com/projects/FirthofForth/FirthofForth.htm

One of the longest and earliest cantilever truss bridges in the world is the Firth of Forth Bridge in Scotland. It is also the first truly large structure that used steel instead of iron. Its total span is 2520 meters or 8276 feet. Its center spans are each about 107 meters (350 feet). It took 7 years to build and was completed in 1890. It was designed following the disaster in which a nearby railway bridge at the Firth of Tay collapsed in a huge windstorm. When the Firth of Forth bridge was designed the engineers, Benjamin Baker and John Fowler, wanted to be very cautious so they used wind loads eight times larger than those that destroyed the Tay Bridge.

FIVE BRIDGE TYPES

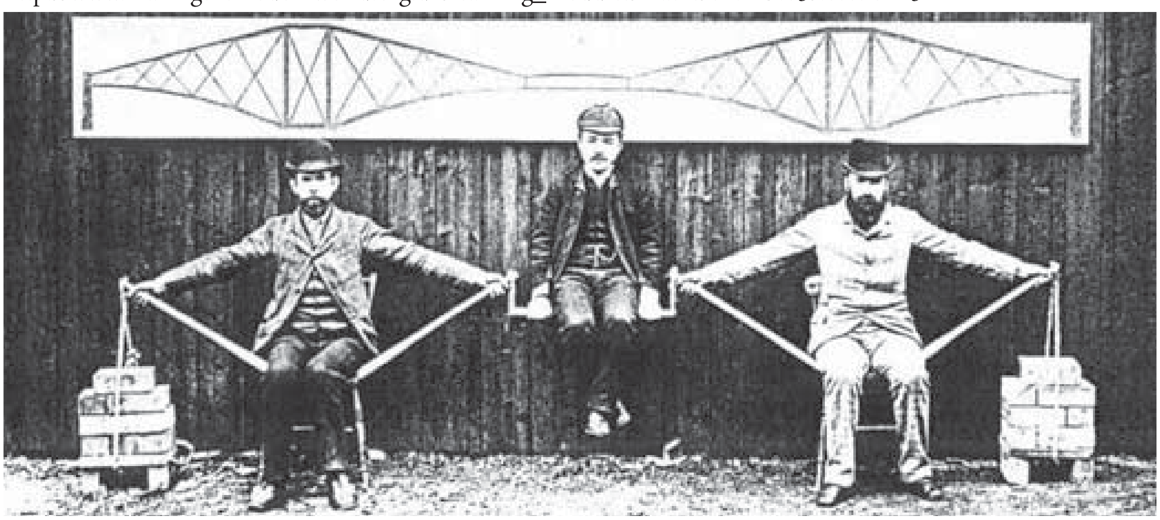
TRUSS

The Firth of Forth Bridge in Scotland (construction)
http://www.makingthemodernworld.org.uk/learning_modules/maths/02.TU.03/?section=3



In the construction photo you can see that the three main towers were built first and then the smaller inner bridges were hung in the gaps left over. The main towers have arms that reach out on either side. These arms are the cantilevers that give this bridge type its name.

The Firth of Forth Bridge in Scotland (model)
http://www.makingthemodernworld.org.uk/learning_modules/maths/02.TU.03/?section=3



In this photo you see a very famous demonstration that the engineers performed to demonstrate the principle behind the bridge's action. The two men in the chairs represent the outer towers. They support the man in the middle (an associate engineer on the project named Mr. Watanabe.) How do the men's arm feel - stretched or squashed? If the arms are in tension (stretched) what parts carry the compression forces? Do you see the sticks that are pushing against the chair? Those are in compression. What is the function of the heavy bricks at the outside edges? What do you think would happen if the bricks were not there or the ropes holding them were cut? We have seen the need for other elements like these bricks in other bridges; what were they called there and which bridges used them?

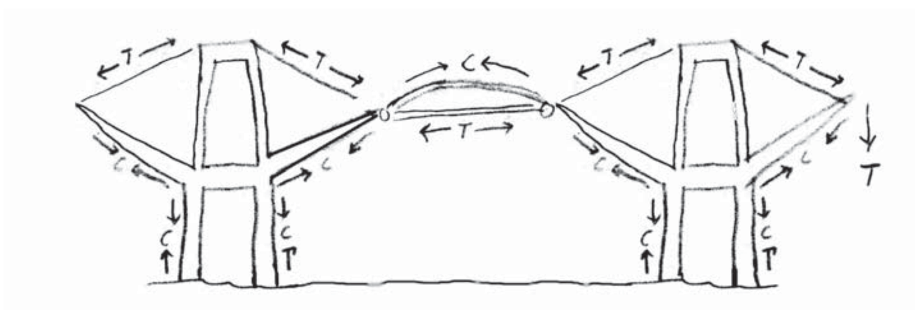
FIVE BRIDGE TYPES

TRUSS

The Firth of Forth Bridge in Scotland (color overview) photo: Klaus Föhl

Compare the picture of the men holding up Mr. Watanabe and the picture of the Firth of Forth Bridge. Can you find all of the same parts in the real bridge?

Forces in the Firth of Forth Bridge



The Firth of Forth Bridge in Scotland (color close-up) photo: Klaus Föhl

Notice that the bottom pieces are huge steel tubes and the top are much lighter, thin pieces. If you know that compression members need to be bigger to resist buckling, can you determine which parts of the bridge are in compression?

Notice that the middle suspended trusses are not nearly as deep as the towers. Why is that? Does it have anything to do with their shorter span?

FIVE BRIDGE TYPES

CABLE-STAYED

The newest type of bridge to be developed is the cable-stayed bridge. They have gained great popularity in recent years because of their great beauty and economy. They cannot be used for truly large spans like a suspension bridge, but they are very good for the more moderate spans that trusses have been used for.

The closest cable-stayed bridge near Cincinnati is the William H. Harsha Bridge near Maysville, KY. It has a main span of 320 meters, or about 1,050 feet. It was completed in October 2000.

The William H. Harsha Bridge near Maysville, KY

Though the cable-stayed bridges look a lot like a suspension bridges, their function is quite different. Compare the profile of the William H. Harsha bridge in the top photo, with the suspension bridge in the middle photo.

Suspension bridge Maysville, KY

Compare this photo of the older Maysville suspension bridge. Can you see the difference between the curved cables of the older bridge with the straight cables of the new bridge?

Constructing the William H. Harsha Bridge Maysville, KY

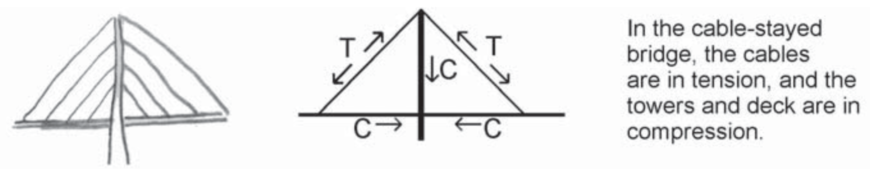
This photo shows a barge crane lifting a deck section into place. You can see the cables supporting the deck sections that were raised earlier. Once the new deck section is secured, cables will support it from the tower and then the barge crane can let go. Visit the web page, http://www.ace-plc.com/maysvillepg.htm for more images of this bridge during construction.

FIVE BRIDGE TYPES

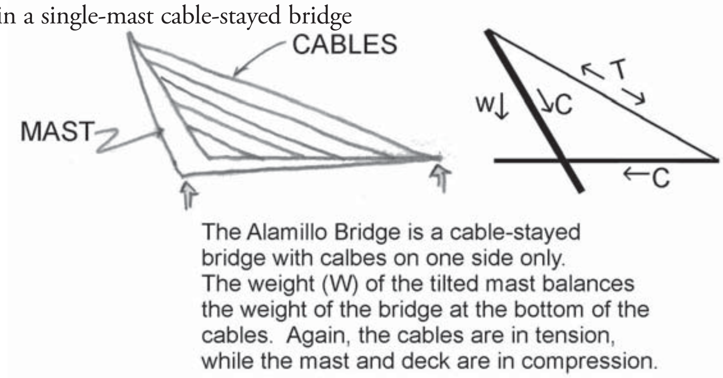
CABLE-STAYED

A cable-stayed bridge could be constructed using just one tower. It would be placed in the middle of the river as shown in the first diagram above. The weight of one side of the bridge would balance the weight of the other side. When two towers are used the cables do not run from one tower to the other. Instead they run from the tower to the road deck. Each side works independently. Look at the photo below of the construction of the William H. Harsha Bridge. You will see that one tower and the roadway it supports are almost complete, while the cables and roadway of the other tower have not been started.

Forces in a cable-stayed bridge



Forces in a single-mast cable-stayed bridge

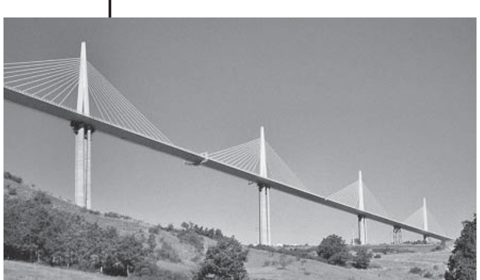


The single-mast cable-stayed bridge sketch shows how this bridge "balances" its weight. This principle is used in a body building exercise outlined in the Body Building section of this packet.

Alamillo Bridge in Spain

In the photo above you see a different type of cable-stayed bridge. It uses one tower, but rather than having a harp of cables on each side of a central tower, it has the cables on one side only. To balance the horizontal pull of the cables to the right, the tower must lean to the left. The angle of the tower and its weight were carefully designed to keep the bridge balanced. This bridge was built between 1987 and 1992 in Seville, Spain over the Guadalquivir River. Its total length is 250 meters (or 820 feet) and the span between supports is 200 meters (656 feet.)

Millau Viaduct in France



The tallest bridge in the world, the Millau Viaduct was completed in 2004. Over a series of 5 huge pylons, a continuous road deck was constructed on the ground at either end of the valley, and slid into place over an innovative system of synchronized mechanical sliders controlled by a central computer system. See the details at http://www.structurae.net/structures/data/index.cfm?ID=s0000351 .