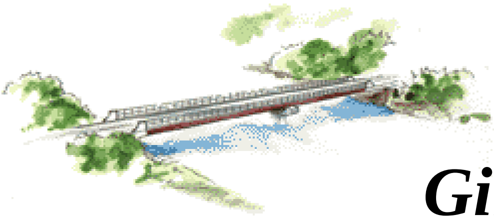
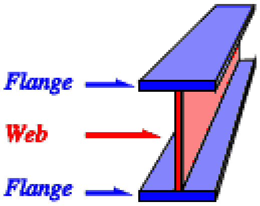


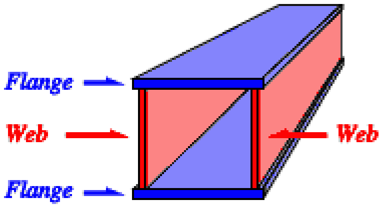
# *Girder Bridge*

A girder bridge is perhaps the most common and most basic bridge. A log across a creek is an example of a girder bridge in its simplest form. In modern steel girder bridges, the two most common girders are I-beam girders and box-girders.



If we look at the cross section of an I-beam girder we can immediately understand why it is called an I-beam (illustration #1.) The cross section of the girder takes the shape of the capital letter I. The vertical plate in the middle is known as the web, and the top and bottom plates are referred to as flanges. To explain why the I shape is an efficient shape for a girder is a long and difficult task so we won't attempt that here.

| | |
|---|---|
| Typical Span Lengths | |
| 10m - 200m | |
| World's Longest | |
| Ponte Costa e Silva, Brazil | |
| Total Length | 700m |
| Center Span | 300m |
| A Matsuo Example | |
| Namihaya Bridge | |

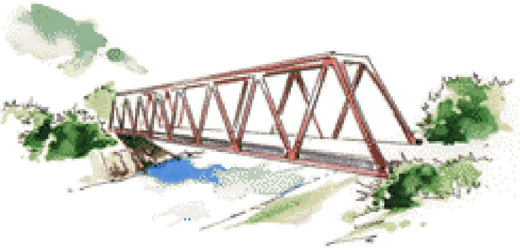


A box girder is much the same as an I-beam girder except that, obviously, it takes the shape of a box. The typical box girder has two webs and two flanges (illustration #2.) However, in some cases there are more than two webs, creating a multiple chamber box girder.

Other examples of simple girders include pi girders, named for their likeness to the mathematical symbol for pi, and T shaped girders. Since the majority of girder bridges these days are built with box or I-beam girders we will skip the specifics of these rarer cases.

Now that we know the basic physical differences between box girders and I-beam girders, let's look at the advantages and disadvantages of each. An I-beam is very simple to design and build and works very well in most cases. However, if the bridge contains any curves, the beams become subject to twisting forces, also known as torque. The added second web in a box girder adds stability and increases resistance to twisting forces. This makes the box girder the ideal choice for bridges with any significant curve in them.

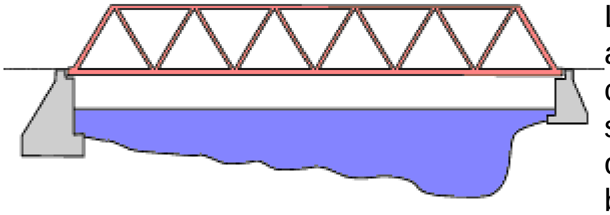
Box girders, being more stable are also able to span greater distances and are often used for longer spans, where I-beams would not be sufficiently strong or stable. However, the design and fabrication of box girders is more difficult than that of I beams. For example, in order to weld the inside seams of a box girder, a human or welding robot must be able to operate inside the box girder.



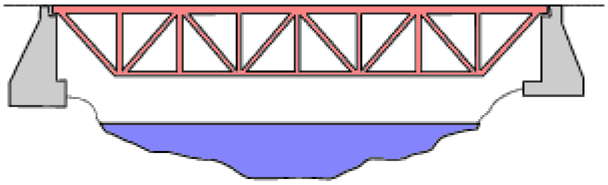
# Truss

The truss is a simple skeletal structure. In design theory, the individual members of a simple truss are only subject to tension and compression forces and not bending forces.
Thus, for the most part, all beams in a truss bridge are straight. Trusses are comprised of many small beams that together can support a large amount of weight and span great distances. In most cases the design, fabrication, and erection of trusses is relatively simple. However, once assembled trusses take up a greater amount of space and, in more complex structures, can serve as a distraction to drivers.

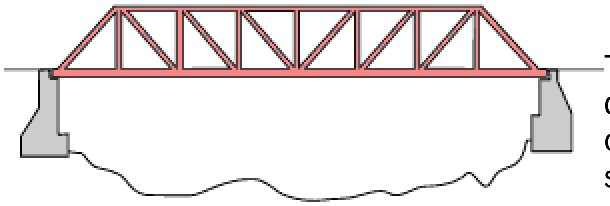
| Typical Span Lengths | |
|---|---|
| 40m - 500m | |
| World's Longest | |
| Pont de Quebec | |
| Total Length | 863m |
| Center Span | 549m |
| A Matsuo Example | |
| 2nd Mameyaki Bridge | |



Like the girder bridges, there are both simple and continuous trusses. The small size of individual parts of a truss make it the ideal bridge for places where large parts or sections cannot be shipped or where large cranes and heavy equipment cannot be used during erection. Because the truss is a hollow skeletal structure, the roadway may pass over (illustration #2) or even through (illustration #1) the structure allowing for clearance below the bridge often not possible with other bridge types.

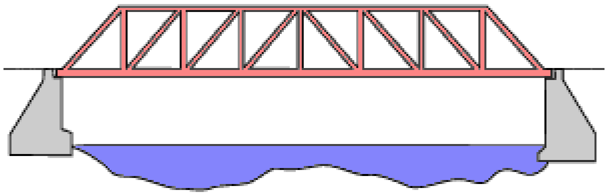


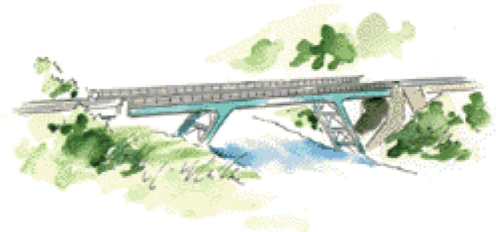
Trusses are also classified by the basic design used. The most representative trusses are the Warren truss, the Pratt truss, and the Howe truss. The Warren truss is perhaps the most common truss for both simple and continuous trusses. For smaller spans, no vertical members are used lending the structure a simple look (illustration #1.) For longer spans vertical members are added providing extra strength (illustration #2.) Warren trusses are typically used in spans of between 50-100m.



The Pratt truss (illustration #3) is identified by its diagonal members which, except for the very end ones, all slant down and in toward the center of the span. Except for those diagonal members near the center, all the diagonal members are subject to tension forces only while the shorter vertical members handle the compressive forces. This allows for thinner diagonal members resulting in a more economic design.

The Howe truss (illustration #4) is the opposite of the Pratt truss. The diagonal members face in the opposite direction and handle compressive forces. This makes it very uneconomic design for steel bridges and its use is rarely seen.



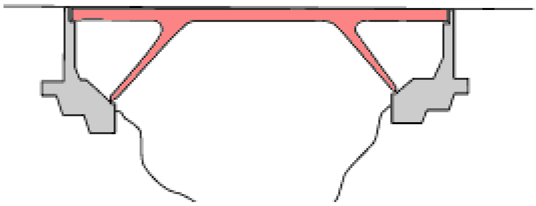


# ***Rigid Frame***

Rigid frame bridges are sometimes also known as Rahmen bridges. In a standard girder bridge, the girder and the piers are separate structures. However, a rigid frame bridge is one in which the piers and girder are one solid structure.

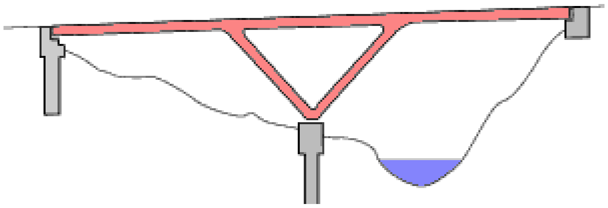
The cross sections of the beams in a rigid frame bridge are usually I shaped or box shaped. Design calculations for rigid frame bridges are more difficult than those of simple girder bridges. The junction of the pier and the girder can be difficult to fabricate and requires accuracy and attention to detail.

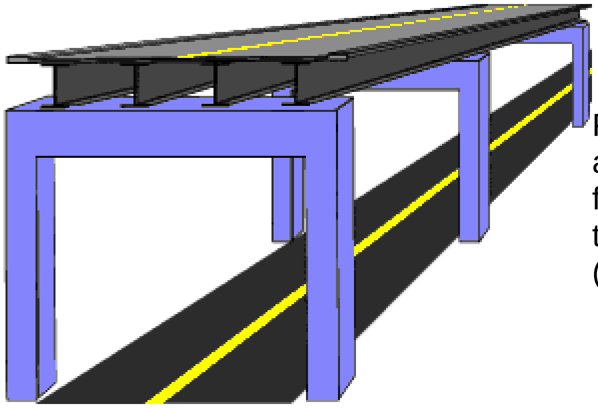
Though there are many possible shapes, the styles used almost exclusively these days are the pi-shaped frame, the batter post frame, and the V shaped frame.



The batter post rigid frame bridge is particularly well suited for river and valley crossings because piers tilted at an angle can straddle the crossing more effectively without requiring the construction of foundations in the middle of the river or piers in deep parts of a valley (illustration #1).

V shaped frames make effective use of foundations. Each V-shaped pier provides two supports to the girder, reducing the number of foundations and creating a less cluttered profile (illustration #3.)





Pi shaped rigid frame structures are used frequently as the piers and supports for inner city highways. The frame supports the raised highway and at the same time allows traffic to run directly under the bridge (illustration #2.)

# ***Arch***

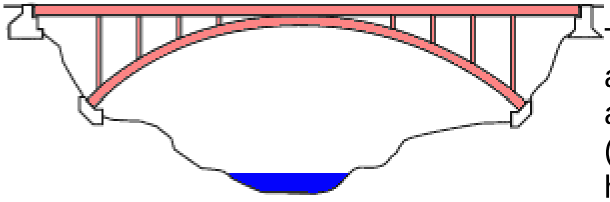
After girders, arches are the second oldest bridge type and a classic structure. Unlike simple girder bridges, arches are well suited to the use of stone. Many ancient and well know examples of stone arches still stand to this day. Arches are good choices for crossing valleys and rivers since the arch doesn't require piers in the center. Arches can be one of the more beautiful bridge types.

| | |
|---|---|
| Typical Span Lengths | |
| 40m - 150m | |
| World's Longest | |
| New River Gorge Bridge, U.S.A. | |
| Total Length | 924m |
| Center Span | 518m |
| A Matsuo Example | |
| Meiwa Bridge | |

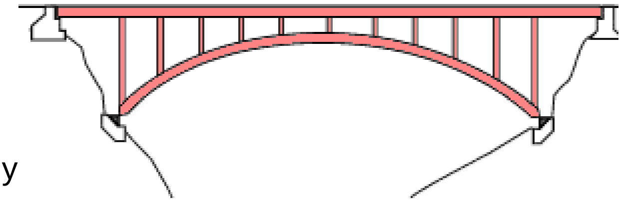
Arches use a curved structure which provides a high resistance to bending forces. Unlike girder and truss bridges, both ends of an arch are fixed in the horizontal direction (i.e. no horizontal movement is allowed in the bearing). Thus when a load is placed on the bridge (e.g. a car passes over it) horizontal forces occur in the bearings of the arch. These horizontal forces are unique to the arch and as a result arches can only be used where the ground or foundation is solid and stable

.

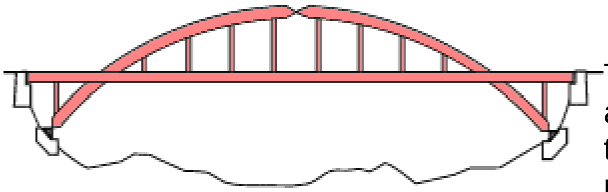
Like the truss, the roadway may pass over (illustration #1) or through an arch (illustration #4) or in some cases both (illustration #3.) Structurally there are four basic arch types: hinge-less, two-hinged, three hinged and tied arches.



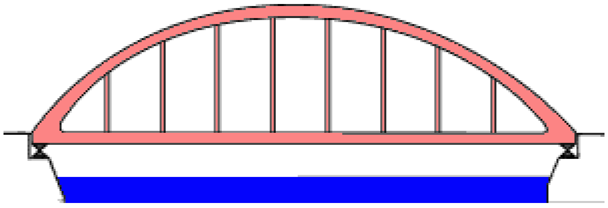
The hinge-less arch (illustration #1) uses no hinges and allows no rotation at the foundations. As a result a great deal of force is generated at the foundation (horizontal, vertical, and bending forces) and the hinge-less arch can only be built where the ground is very stable. However, the hinge-less arch is a very stiff structure and suffers less deflection than other arches.



The two hinged arch (illustration #2) uses hinged bearings which allow rotation. The only forces generated at the bearings are horizontal and vertical forces. This is perhaps the most commonly used variation for steel arches and is generally a very economical design.



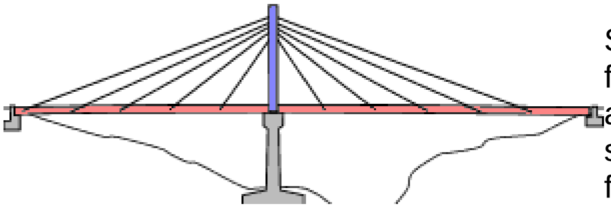
The three-hinged arch (illustration #3) adds an additional hinge at the top or crown of the arch. The three-hinged arch suffers very little if there is movement in either foundation (due to earthquakes, sinking, etc.) However, the three-hinged arch experiences much more deflection and the hinges are complex and can be difficult to fabricate. The three-hinged arch is rarely used anymore.



The tied arch (illustration #4) is a variation on the arch which allows construction even if the ground is not solid enough to deal with the horizontal forces. Rather than relying on the foundation to restrain the horizontal forces, the girder itself "ties" both ends of the arch together, thus the name "tied arch."

# ***Cable Stayed***

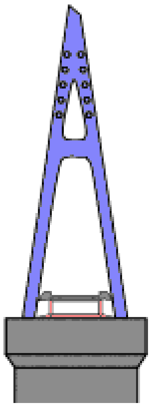
A typical cable stayed bridge (illustration #1 & 2) is a continuous girder with one or more towers erected above piers in the middle of the span. From these towers, cables stretch down diagonally (usually to both sides) and support the girder.



Steel cables are extremely strong but very flexible. Cables are very economical as they allow a slender and lighter structure which is still able to span great distances. Though only a few cables are strong enough to support the entire bridge, their flexibility makes them weak to a force we rarely consider: the wind.

For longer span cable-stayed bridges, careful studies must be made to guarantee the stability of the cables and the bridge in the wind.

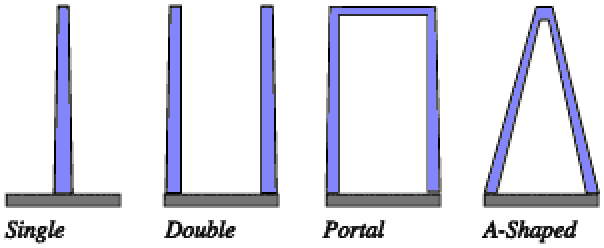
| Typical Span Lengths | |
|---|---|
| 110m - 480m | |
| World's Longest | |
| Tatara Bridge, Japan | |
| Total Length | 1,480m |
| Center Span | 890m |
| A Matsuo Example | |
| Tsurumi Tsubasa Bridge | |

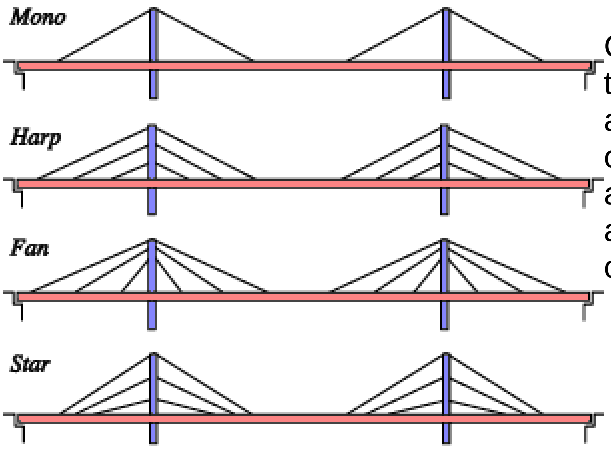


The lighter weight of the bridge, though a disadvantage in a heavy wind, is an advantage during an earthquake. However, should uneven settling of the foundations occur during an earthquake or over time, the cable-stayed bridge can suffer damage so care must be taken in planning the foundations. The modern yet simple appearance of the cable-stayed bridge makes it an attractive and distinct landmark.

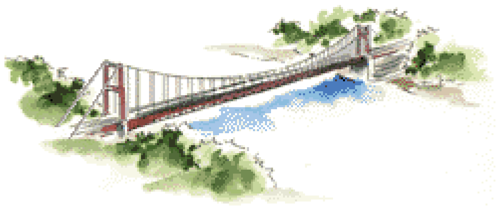
The unique properties of cables, and the structure as a whole, make the design of the bridge a very complex task. For longer spans where winds and temperatures must be considered, the calculations are extremely complex and would be virtually impossible without the aid of computers and computer analysis. The fabrication of cable stay bridges is also relatively difficult. The cable routing and attachments for the girders and towers are complex structures requiring precision fabrication.

There are no distinct classifications for cable-stayed bridges. However, they can distinguished by the number of spans, number of towers, girder type, number of cables, etc. There are many variations in the number and type of towers, as well as the number and arrangement of cables. Typical towers used are single, double, portal, or even A-shaped towers (illustration #2 & 3.)





Cable arrangements also vary greatly. Some typical varieties are mono, harp, fan, and star arrangements (illustration #4.) In some cases, only the cables on one side of the tower are attached to the girder, the other side being anchored to a foundation or other counterweight.



## Suspension

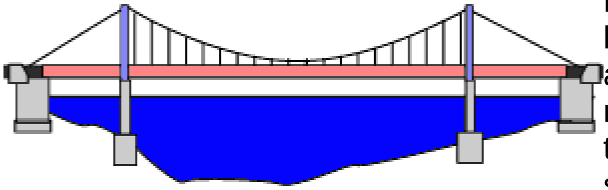
Of all the bridge types in use today, the suspension bridge allows for the longest spans. At first glance the suspension and cable-stayed bridges may look similar, but they are quite different. Though suspension bridges are leading long span technology today, they are in fact a very old form of bridge. Some primitive examples of suspension bridges use vines and ropes for cables.

The development of metals brought the use of linked iron bars and chains. But it was the introduction of steel wire ropes that allowed spans of over 500m to become a reality. Today the Akashi Kaikyo bridge boasts the world's longest center span of any bridge at 1,991 meters.

| Typical Span Lengths | |
|---|---|
| 70m - 1,000m+ | |
| World's Longest | |
| Akashi Kaikyo Bridge, Japan | |
| Total Length | 3,911m |
| Center Span | 1,991m |
| A Matsuo Example | |
| Hakucho Bridge<br>Ohnaruto Bridge | |

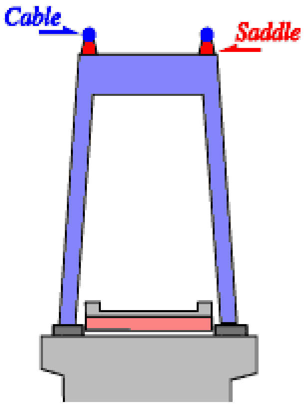
A typical suspension bridge (illustration #1) is a continuous girder with one or more towers erected above piers in the middle of the span. The girder itself it usually a truss or box girder though in shorter spans, plate girders are not uncommon. At both ends of the bridge large anchors or counter weights are placed to hold the ends of the cables.

The main cables are stretched from one anchor over the tops of the tower(s) and attached to the opposite anchor. The cables pass over a special structure known as a saddle (illustration #2.) The saddle allows the cables to slide as loads pull from one side or the other and to smoothly transfer the load from the cables to the tower.



From the main cables, smaller cables known as hanger cables or hanger ropes are hung down and attached to the girder. Some suspension bridges do not use anchors, but instead attach the main cables to the ends of the girder. These self-anchoring suspension bridges rely on the weight of the end spans to balance the center span and anchor the cable.

Thus, unlike normal bridges which rest on piers and abutments, the girder or roadway is actually hanging suspended from the main cables. The majority of the weight of the bridge and any vehicles on it are suspended from the cables. In turn the cables are held up only by the tower(s), there is an incredible amount of weight that the towers must be able to support.



As explained in the cable stayed bridge section, steel cables are extremely strong yet flexible. Like a very strong piece of string, it is good for hanging or pulling something, but it is useless for trying to push something. Long span suspension bridges, though strong under normal traffic loads, are vulnerable to the forces of winds. Special measures are taken to assure that the bridge does not vibrate or sway excessively under heavy winds.

The most famous example of an aerodynamically unstable bridge is the Tacoma Narrows Bridge in Washington state, USA. This page on the Tacoma Narrows Bridge Disaster at the University of Bristol has some excellent photos and short movies showing why aerodynamic stability is important.