Notes and Guidelines about Bridges – An Educational Resource for Children

Bridges are built to enable people, vehicles, even water at a higher level to cross streams, rivers, valleys. When the bridge is to carry water (and boats etc) at a higher level than the river below, we call it an aqua-duct. Bridges can be as short and simple as logs or planks placed across a ditch or stream such as in these pictures.



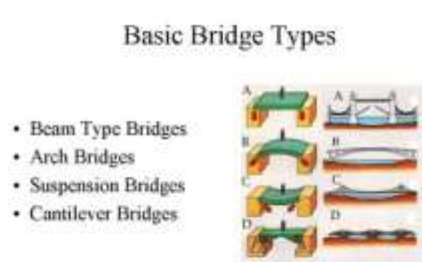
Examples of plank bridges.

They can be as long and complex as the huge steel, and concrete bridges used to cross large rivers or seas.



Bridges can be of different types. To understand the different types, and the forces that act on the parts (engineers call them *members* making up the bridge) of the bridges, we can start with the simple plank bridge. From now onwards we will also call the various parts of the bridge as *members*. In a large bridge the 'plank' is made up of many steel members (beams) joined together to behave as a single structure. In the newer reinforced concrete and pre-stressed concrete bridges you will see it as a large beam structure.

1. If this structure is a straight one, it is called a beam bridge. I am showing the simple plank on the left with a real bridge shape on the right. The forces on the piers and the abutments at the ends are downwards, and they support the weight of the bridge and the loads (cars, trucks, trains etc. on the bridge).



2. If the structure had an upwards curvature forming an arch, it is called an arch bridge. The vertical weight of the bridge and the loads are supported by the inclined compression forces on the abutments pushing them outwards (what is compression forces – we will see later on).

3. If the structure has a downwards curvature so that it seems to hang from the abutments, it is called a suspension bridge. The tension forces on the abutments will be inclined and trying to pull the abutments inwards. (What is a tension force – we will see later on).
4. If the structure is made of two parts entirely supported by the abutments against torsion (we will see what torsion is later on) and other forces, it is called a cantilever bridge.

Forces acting on a bridge and its supports (piers and abutments) and deflection of deck

Forces on the bridge and supports are created by its own weights and the loads that travel on the bridge. In addition there are wind forces (like in a storm) and braking and acceleration forces when the vehicles brake or accelerate on the bridge.

The weight of the bridge itself and the loads on the bridge are the downward forces. Wind forces can be sideways. Engineers use all these forces when they design an actual bridge. The bridge has to be strong enough to withstand all the possible forces that act on them. All these forces have to be withstood by the piers and abutments on which the bridge is supported. Also each part (member) of the bridge has to withstand the highest force acting on it.

To understand how engineers design a bridge, let us start with the single plank bridge example we started with. We can study this on a table using one of the Popsicle stick we use for our bridge.

When we place a stick across two tables, we get a small plank (or beam) bridge. When a load, such as a person or car is placed on the plank, it tends to bend (deflect) downwards. The forces acting on the plank is of bending. The force on the abutments (table) will be vertical. When you increase the load, the beam (the Popsicle stick) bends downwards. We say the stick deflects. If you keep on increasing the load, the deflection also increases, till ultimately the stick breaks or bends so much out of shape it falls down between the tables. Would you like to walk on a plank bridge if the plank deflects a lot, even though it may not break. No! You would feel unsafe. Similarly, the engineers design the bridges, (even the very large ones) so that under the expected largest load, the deflection is only about 1/400 of the span. Which means a 400 metre long bridge should not deflect more than about a metre under the heaviest loads that they design the bridge for!

Taking our Popsicle Bridge, it is 500 mm is span (distance between the supports). This means if the deflection under the highest expected load (cars, trucks and vehicles of that scale) on this bridge should not exceed 1/400 of 500 = 1.25 mm. However for our testing we exert a very large force to see how strong your bridge is. So we allow for larger deflection. By the time the deflection reaches about 50 mm (40 times the designed deflection), most of the bridges would break. Thus it is a destructive test. However some of the bridges we test may be very weak and sags and bends such that even at 50 mm deflection the bridge may not break, but the load it supports is very low. So when the deflection reaches 50 mm we stop the test, as the bridge is considered to have failed.

If the distance between the tables is now increased to be longer than the Popsicle stick the stick cannot be supported. It is like we have to cross a stream wider than a long plank. If we get a longer stick, it may not be strong enough and may sag under its own weight. So what do we do? WE will use many popsicle sticks joined together to form a bridge structure. How do we join the sticks to make this structure?

We will see what are the forces that can act on a single popsicle stick (or member of a bridge). They are:

1. Tension
2. Compression
3. bending
4. Twisting (or torsion)
5. Shear

1. Tension

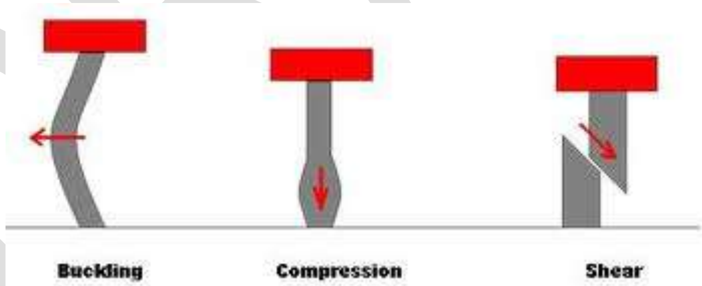
Tension is the force acting on a stick if you pull it outwards or hang a weight from it. The stick tends to stretch or get longer. This is the same force acting on a string or rope, an elastic band, or a spring. You can easily see the elastic band stretching. Even the string, rope or the stick do stretch, but it is so small an amount that you cannot see or measure it with normal methods.

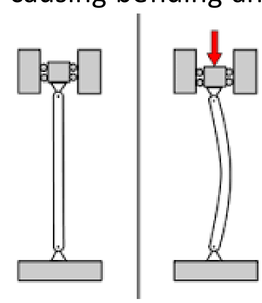



The spring on the left can be stretched by pulling the ends outwards. Then the spring will be under tension and will get stretched. You can therefore see that members of a bridge which are always under tension can be replaced by a thin strong enough rod, cable or wire.

2. Compression

Compression is the force acting on a stick when you push it inwards. It is the type of force acting on the legs of a stool or chair when you it on them. Compression tends to make the members shorter, and crush the member. Can there be compression on a string or wire? No! String or wire can take tension but not compression. Also if the force of compression is large and the member is long and slender, it can buckle under compression. The member can buckle if the force is not exactly centred on the member causing bending and

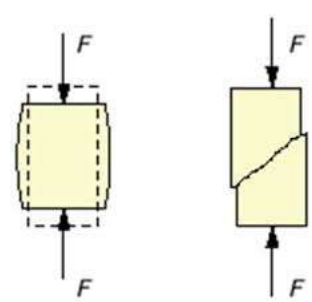





thus buckling.

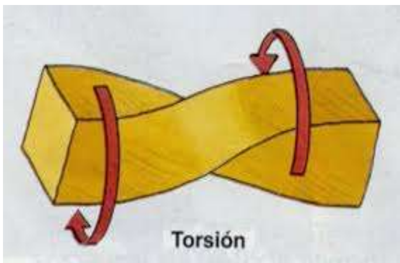
3. Bending

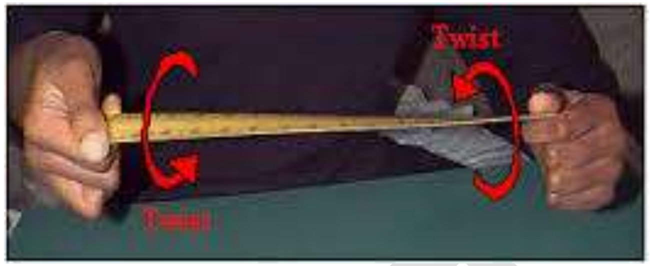
Bending forces act on a member when the force acts at an angle on the member, such as a weight on a horizontal plank. It is also a type of buckling, but bending can be well designed and controlled, while buckling can be damaging, and not desirable. Only some short members are designed to withstand bending. The whole bridge is allowed to bend as mentioned earlier, so that under the maximum designed loading it deflects only about 1/400 of the span.

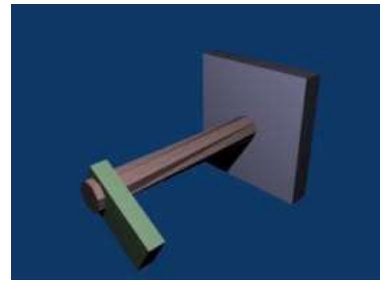


4. Twisting (or torsion)

Twisting is what happens to a member when you apply a rotational (torsional) force at its ends. Torsion in a member is not desirable, unless the engineer designs a member to withstand the torsion. Usually in a bridge member we avoid torsion. The whole bridge may experience torsion during heavy gusts of wind and cyclones etc. The engineers have to design the bridge to withstand such torsion.

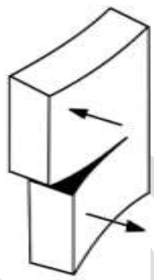
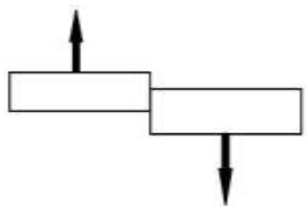
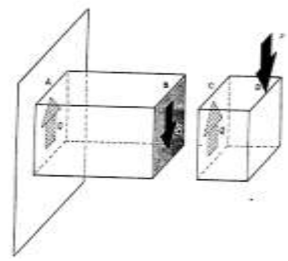






5. Shear

Shear is the force on a member which tends to 'Shear' it. That is slide on part across the other. Normally when designing the bridge the engineers have to take into account the shear forces on the whole bridge. When they design the members they try to avoid shear forces in the in the members.

Summary of Forces on Bridges

The engineers have to design the whole bridge to take up all the different types of forces acting on the bridge and abutments and piers: Tension, Compression, Bending, Twisting, and Shear. However they design the individual members of the bridges to take up only tension and compression. They design the members to avoid bending, torsion, and shear. Only some members such as the members directly supporting the loads etc. are designed for Bending and other forces also.

How do they design the members having to take up only tension and compression?

Design of Bridge members

The first question that arises is why not make the whole bridge out of one large welded unit instead of pieces of steel. Of-course when it comes to the modern pre-stressed or reinforced concrete bridges, which is more or less how it is designed. But they design them to be so slim and elegant that they use a minimum of materials (and weight) with maximum of strength.

We will only consider the bridges made of wood or steel beams. If we make the bridge using large blocks of wood or steel, they will so heavy that they will sag or break under its own weight. Also the cost will be prohibitive. The intent of the design is to make the bridge as light as possible with the maximum of strength. That is why in our Popsicle Stick Bridges we use a bridge efficiency which is the Maximum load divided by the bridge weight. Thus the lighter bridge will give a higher efficiency.

So let us try to build some members for our bridge. Let us join a few flat steel pieces together to form a frame for our bridge.

Let us try to join say 2 members to start with. How do we join them? Available methods are 1) Use a pin/bolt/rivets to join them. 2) Use many pins/bolts/rivets 3) Weld them together.

Engineers have to calculate all the forces that are acting on the members as accurate as possible. Then only they can design the correct size of member to withstand the forces. If you use method 2) or 3) you get a very rigid and strong joint. That's very good! No, but there is a problem!! When you join many members together, there can be bending and other forces in addition to tension or compression. So what? Well, all the forces cannot be easily calculated or determined. If you use only 1 pin, then all the forces have to go through that pin. Then any member will have only tension or compression going through the one pin or bolt at each end. This makes for easy calculations.

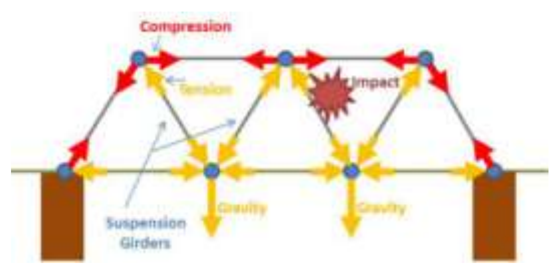
Remember that most of the large and famous bridges were built in 1940s and earlier. There were no calculators or computers then. The engineers and technicians had to do the calculations manually (with some help from slide rules). So they did not have the wonderful tool of computers for rapid and accurate calculations available to the modern engineers.
Even with such modern tools, most engineers would not take the risk of designing with bending and torsional forces on members especially for very large structures. It is too risky as during construction unexpected forces can come to be introduced by rigid joints. So pin joints have come to stay for most designs even now.

Eiffel Tower: The famous Eiffel Tower in France is made of steel beams arranged in triangles. It is said by some that even if one member breaks or is removed, the tower will collapse.

When we build various frames using members with only pins at each end, we find that triangular shape is very rigid and stable. If you make a rectangle with 4 members, it can change shape.

So bridges, towers and other structures were made of members arranged in triangular shapes. When you really look at the joints in the members of a real bridge, you will see that there are many rivets, bolts and many are welded. That is because if you try to hold the members with one bolt only at the end of the member, the bolt has to be impossibly large. So the force has to be spread over a number of bolts/rivets. However, the design engineer assumes it to be only one pin. Any bending force etc. that is introduced by using many bolts or welds is small compared to the tension or compression forces and can be ignored or taken up by the stiffness of the member.

In our Popsicle Bridges the bridge can be very strong if the specifications allow the use of pins (of the same materials as the popsicle stick. Also by sticking them together with school glue in a proper manner you can have very high strengths. Of-course you will not be doing and calculations as how engineers do for real brides, but if you follow proper design principles your bridge will be a winner. The glue gives some rigidity and increased strength. If you can study your design carefully and determine the tension and compression members, and adequately strengthen them as an I beam, it would prevent buckling of the compression members, thus adding to the strength.



In a suspension bridge, the bridge deck is suspended from the main cable using cables/rods. These cables take up only tension.