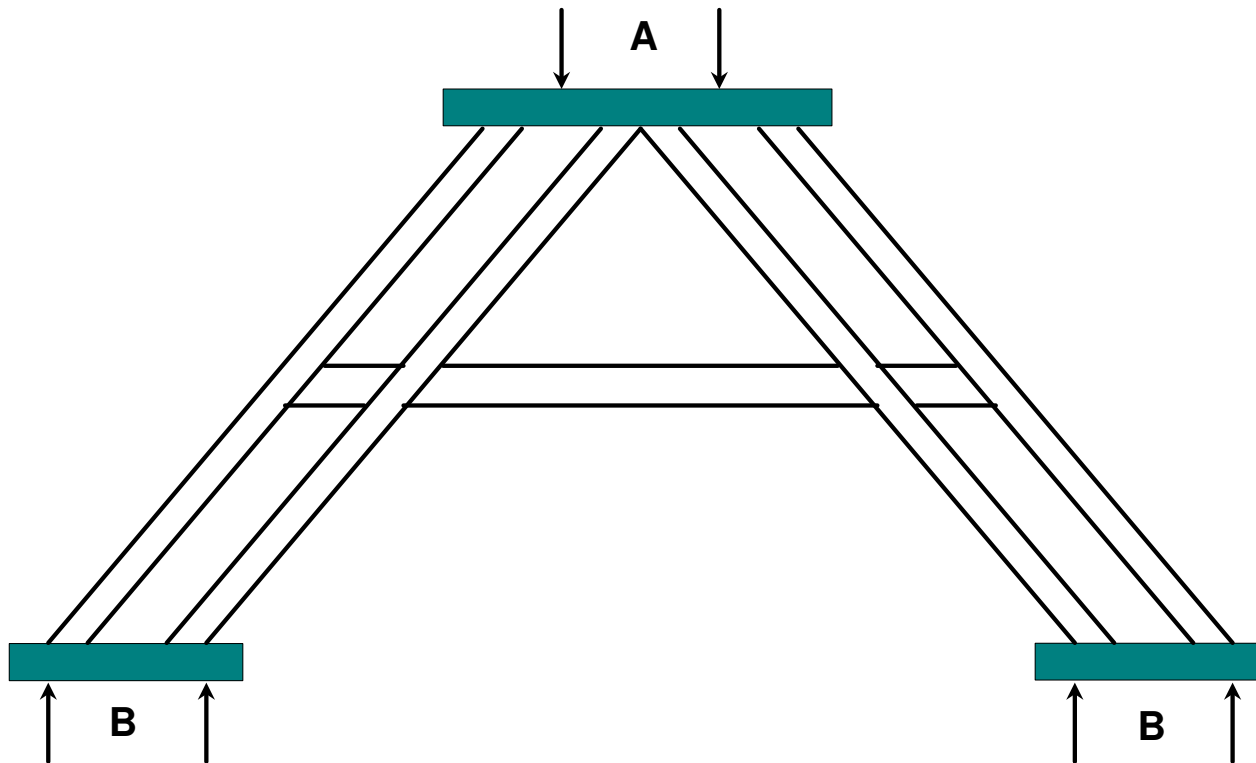# MESA Bridge Design

Basic Engineering Task:
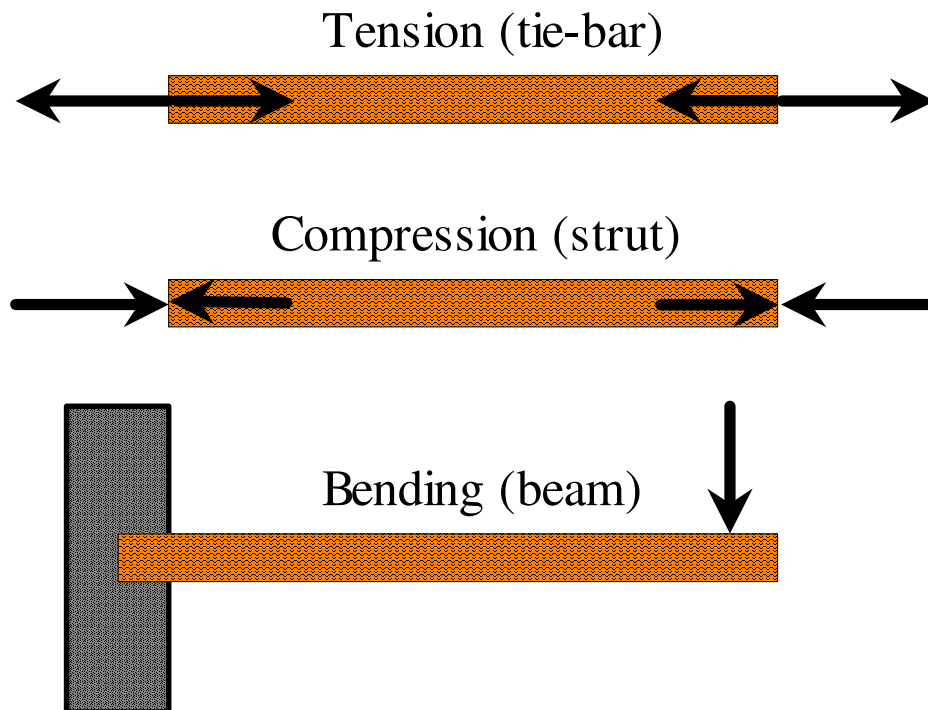
We have to transfer a load A to supports B, using ¼" square balsa, and there has to be clearance under the bridge for vehicles to pass underneath.

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Loads:

Loads in beams can be taken in three simple ways, tension, compression and bending.

Tension (tie-bar)

Compression (strut)

Bending (beam)

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As we are building our bridges from ¼" square material which must not be spliced in any way, we will assume that only tension and compression are applicable.

Any member which has forces applied to it will resist those forces with equal and opposite reactions in both magnitude <u>and</u> direction (Isaac Newton). As we are assuming that members do not take bending loads, we can also note that if members form a triangle, the triangle will not distort, and their loads can be resolved in both vertical and horizontal directions.

In this simple symmetrical case, load A will be supported by two equal forces B, each equal to ½ A. The two diagonal struts will transfer the load A by resisting in compression, but at the same time they will push against each other in the horizontal direction. When they reach the supports B, a third horizontal member must be added to prevent the supports being pushed apart. That member will be in tension.
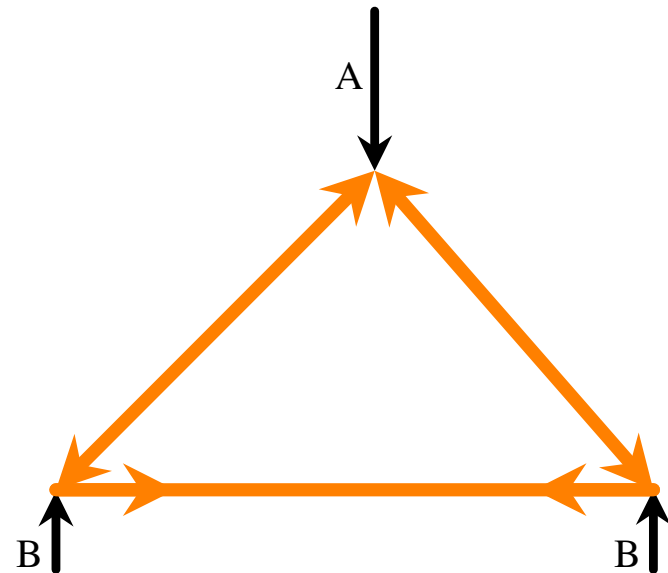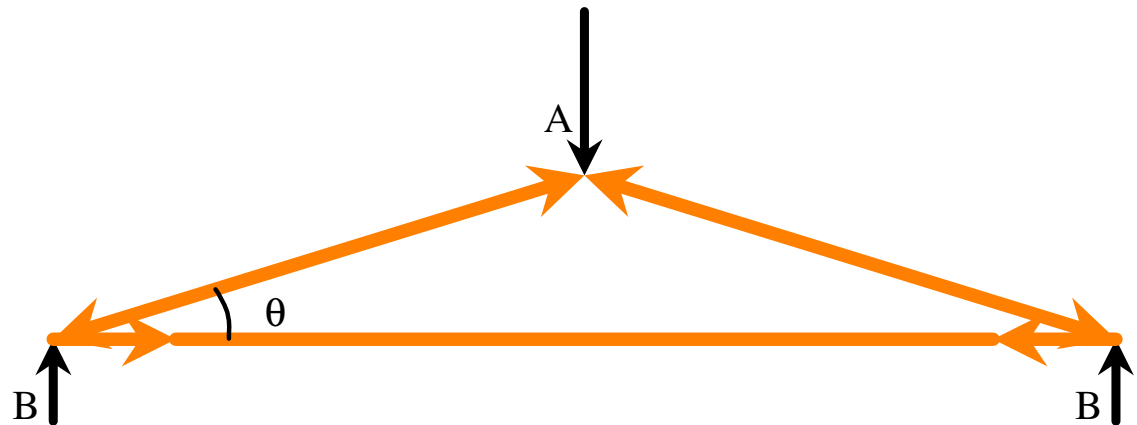
MESA Bridge Design

So how do we calculate the loads in the members? In the diagram above, this is quite straightforward. The vertical components of the loads will be equal to the values B, and half that of A. The horizontal components of the loads will be functions of the angle of the struts to the horizontal plane. In the diagram, the struts are at 45 degrees, and so the horizontal components will also be equal to B, for an overall force equal to B x $\sqrt{2}$. The horizontal tie-rod will have a tension force equal to B.

Now imagine that the supports B are moved outwards, so that the struts are at a much shallower angle. The vertical components of the loads in all the members are unchanged, but the horizontal loads are increased by $1/\tan(\theta)$.

We can plot the loads in the slanting and horizontal members as a function of θ, and get the result shown on the next page.
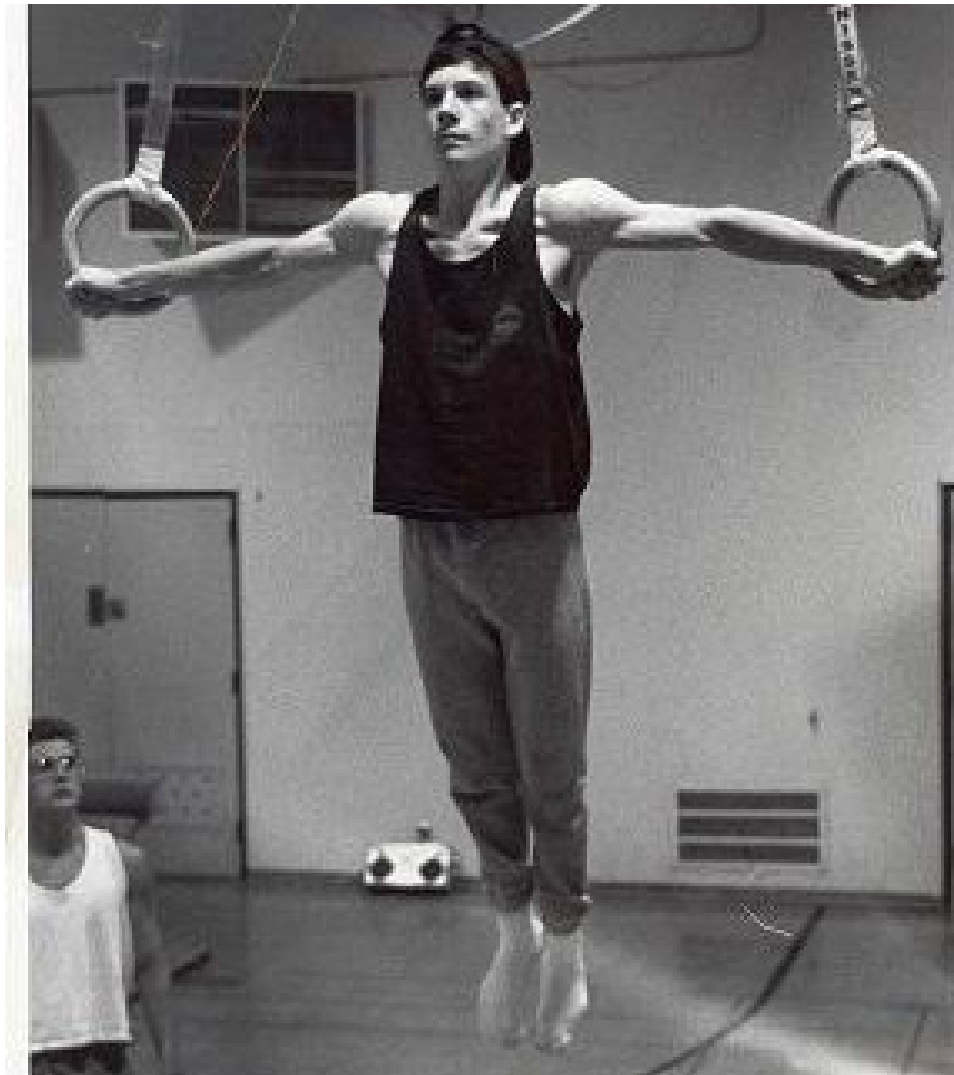
A

θ

B

B

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The loads increase very rapidly as theta goes below forty degrees.

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This is why a gymnast on the rings needs very strong arms. Note the angles of his arms and the angles of the supporting ropes.

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So far we have dealt with fairly simple layouts. But how do we calculate the loads in a more complicated structure? We can do this graphically by following the rule that every force must have an equal and opposite resisting force. We will also suppose that each joint can be represented by a simple pin which has no intrinsic bending resistance. Represent each area of the structure by a letter covering the space between one load and another, in this case, A,B,C,D. Then select an intersection of no more than three loads or members, let's say where the 100 lb. load is supported by the two struts.

Structure
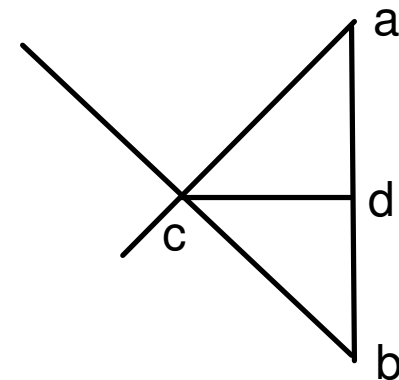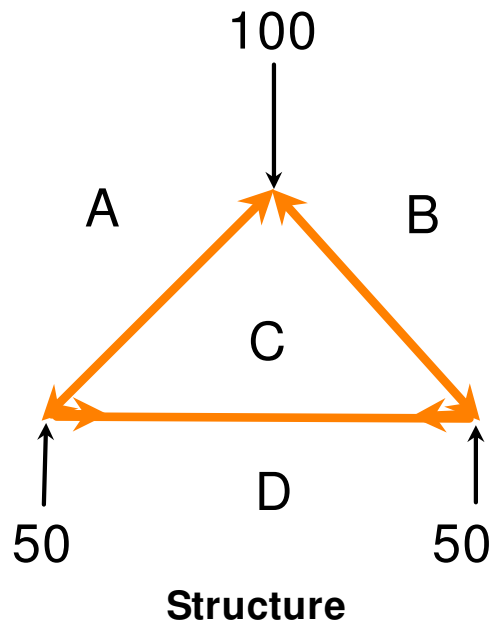
Force diagram

MESA Bridge Design
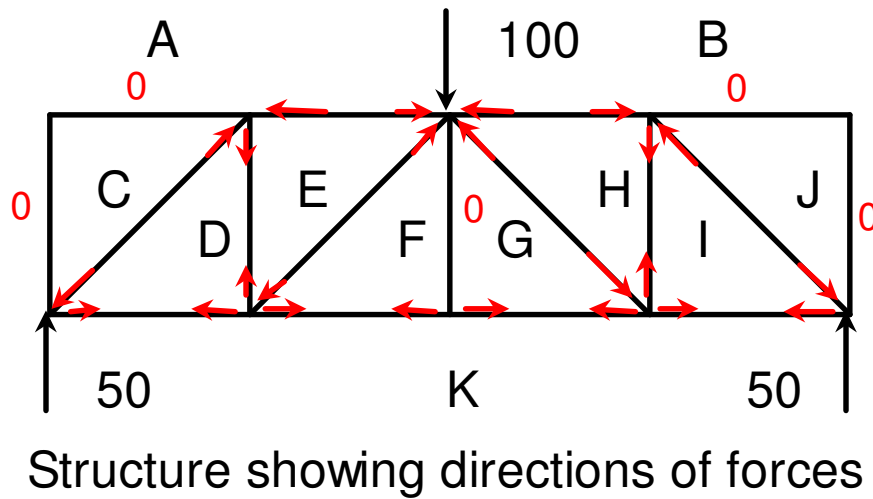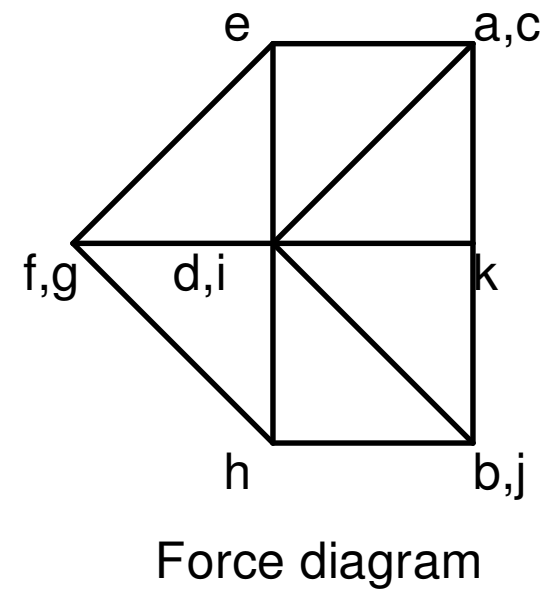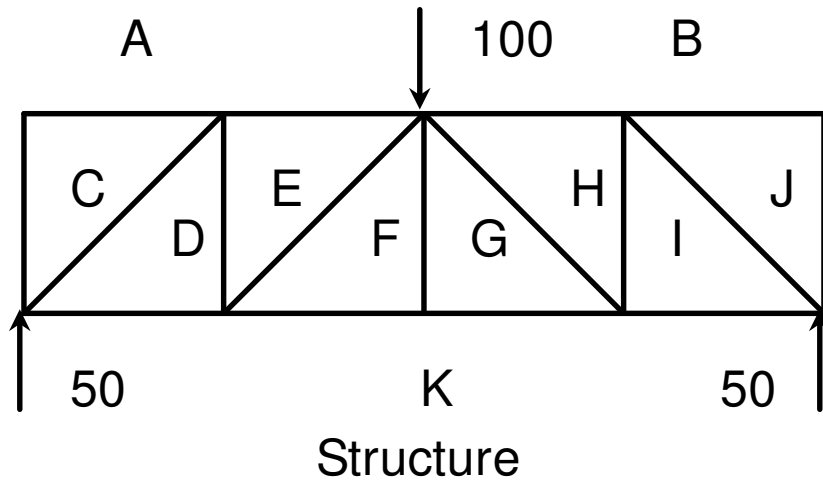
Each load or member will be represented by the two letters on either side of it. Start by drawing ab parallel to the load AB and equal to 100 lb. Note that the direction a to b is in the same direction as the load applied. Now draw a line bc parallel to the strut BC. At present, you don't know where c will be, it's just somewhere on that line. Now draw a line ac from point a and parallel to the strut AC, intersecting the line bc uniquely at c. If you walk round the triangle abc, all the arrows will automatically come out in the correct direction, and the lengths of the lines equal the loads in those members.

Now we'll go to the next junction, cbd. The line cb is already in place. We can move vertically upwards from b 50 lb. to give point d, which automatically comes out to give a horizontal line going to point c, representing the load in tie-rod CD, in this simple case also equal to 50 lb.

This approach can be used for more complicated structures. Now we'll show a structure which demonstrates a bad design, just to illustrate that the force diagram approach makes intuitive sense.

MESA Bridge Design

A   100   B

C

E   H   J

D   F   G   I

50   K   50

Structure

e   a,c

f,g   d,i   k

h   b,j

Force diagram

A   100   B

0   0

0

C

E   H   J

D   F   G   I

0

0

50   K   50

Structure showing directions of forces
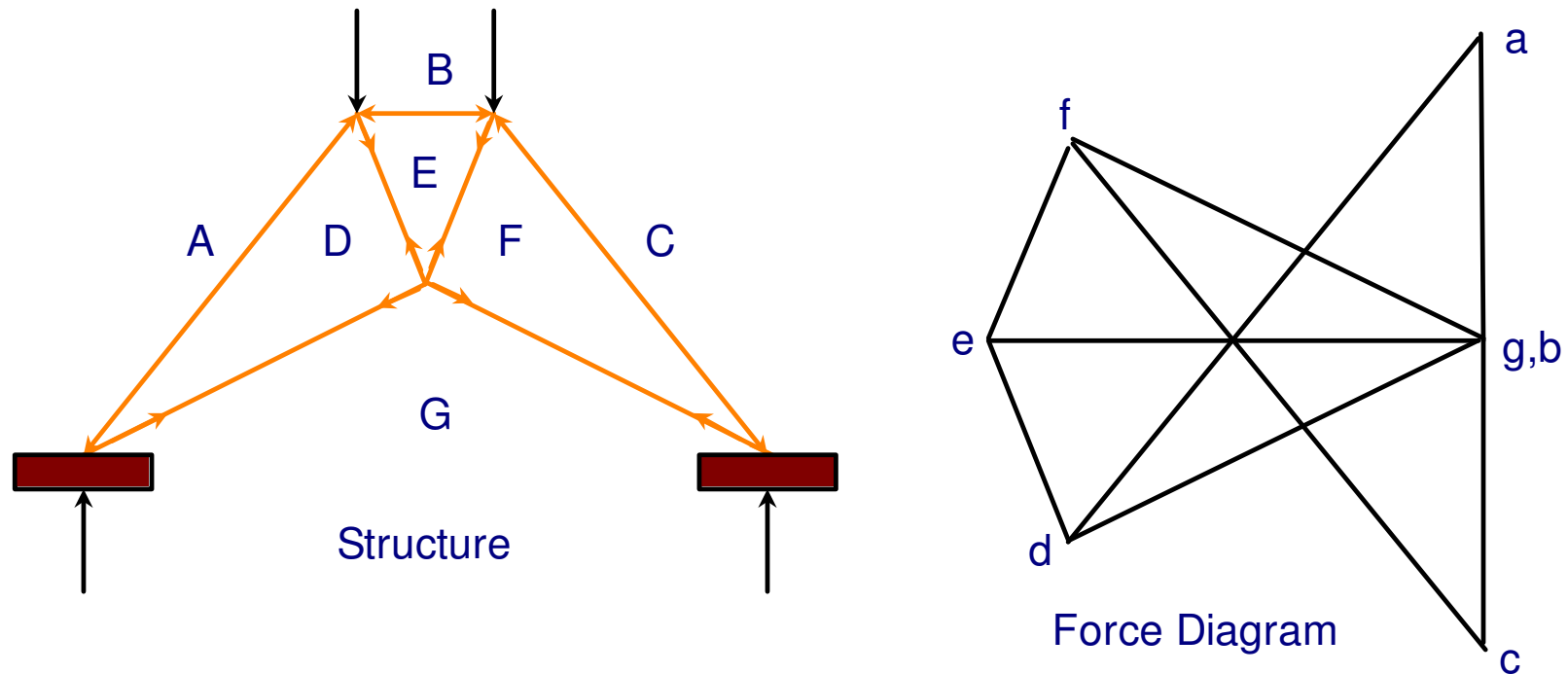
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Here is a very simple bridge design which meets the requirements of the competition, showing the forces in the members.


Structure

Force Diagram

Note how the forces are distributed. ad and cf take the main compressive loads, which are much greater than the initial weights ab and bc. be, the top cross member, is also in compression, while the other members are all in tension.

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Here are two more complicated bridges showing the loads in compression (C) and tension (T).

MESA Bridge Design

200 200

237C

345C 80T

110T

125C ----- 170C 120T

80T

100 100 100 100
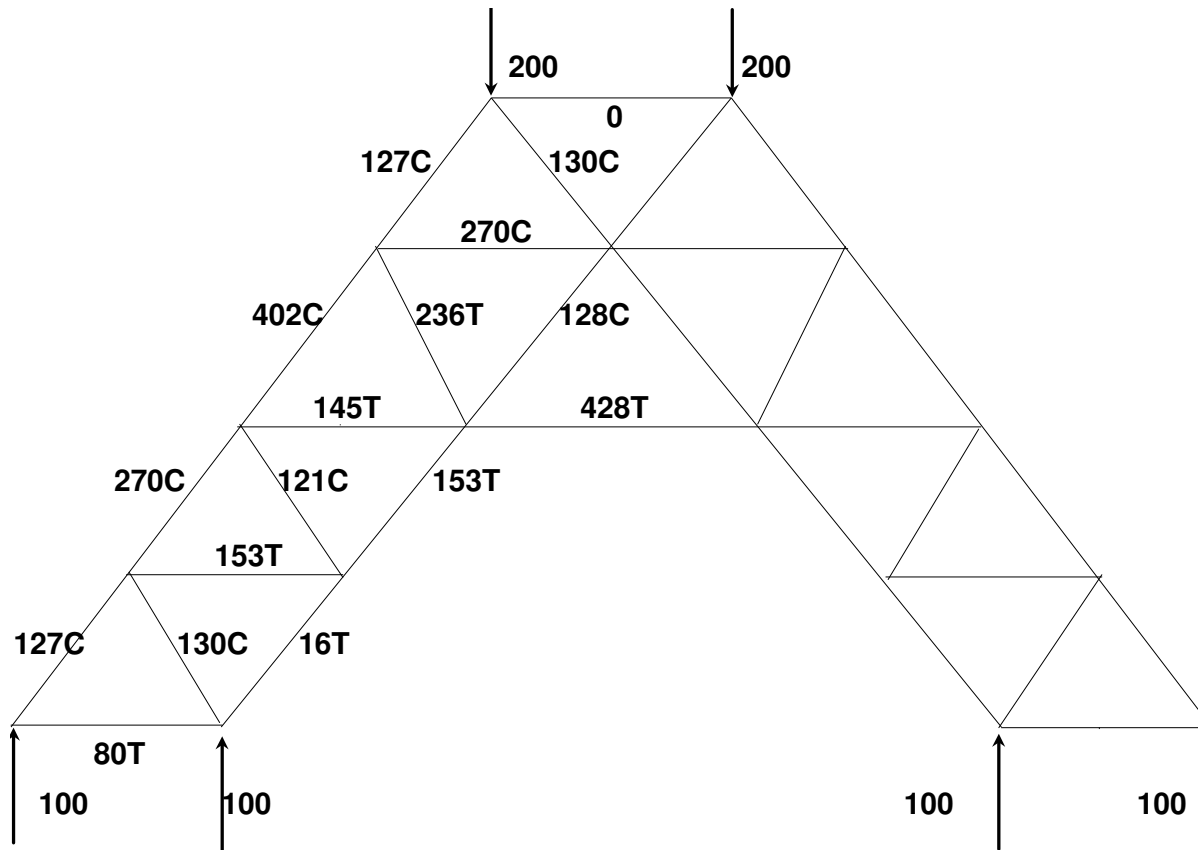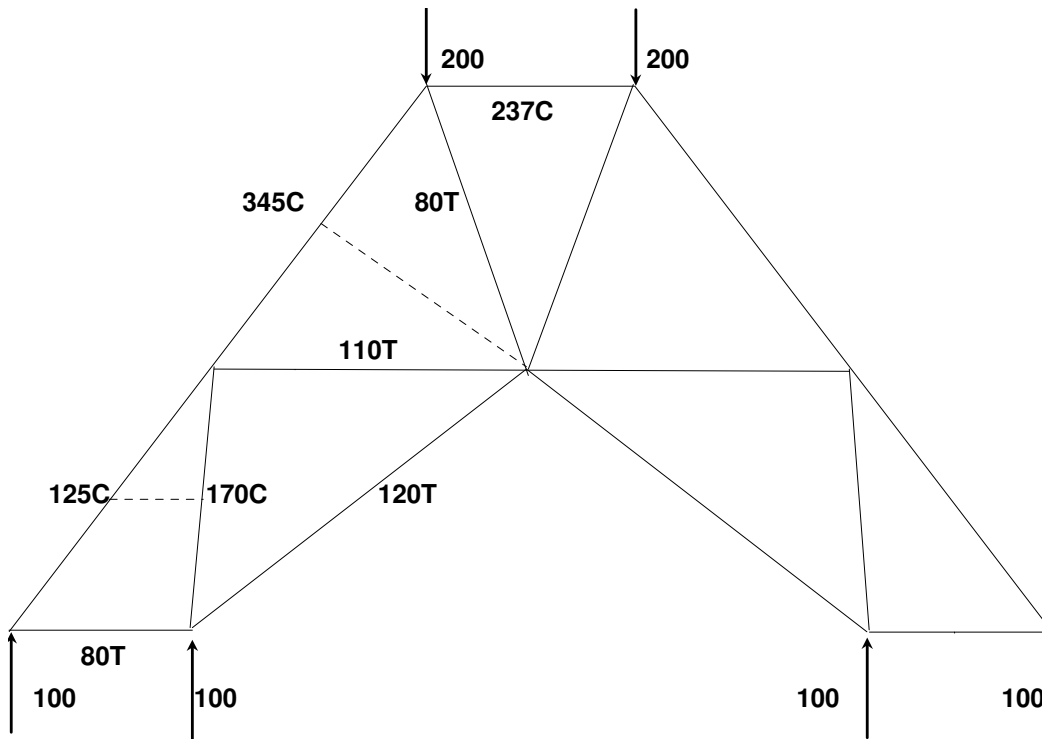
Note the very large tension loads running across the first bridge at its maximum height above the roadway. We probably want to make these pieces continuous across the bridge. The dotted lines represent members with small loads designed to prevent extreme bending of the long compression members.

MESA Bridge Design

So much for determining forces in the structure. Now what do we need to know about detail design?

The blue plate represents the applied distributed load, and the structure below carries the load. The first picture has the struts spread far apart with the load tending to bend the beam in the middle. The next structure is very bad. It will fail at the edges of the applied load. The last structure is very good. The struts carry the applied load fairly evenly. It is no coincidence that most tables, chairs and desks are designed like this.

MESA Bridge Design

All the previous illustrations show just one side of the bridge. These sides have to be joined together in parallel to form a three-dimensional structure. It is extremely important that each part of the structure takes its share of the load. We shouldn't have one leg not touching the ground, and three others doing all the work, for example. So good workmanship is crucial.

Also, note that struts which are in compression are liable to bend if they are long compared to their width. So for those members in compression, we may need to add members whose main purpose is to add rigidity. If we are clever, they will also contribute usefully to the strength of the bridge.

Also note that glue joints are strong in compression and in shear, but less so in tension. However, a shear joint does introduce slightly eccentric loading.

Good luck with your bridges!

← Glue

← Glue

Glue

Compression joint (good)

Tension joint (not so good)

Shear joint (good for tension and compression)