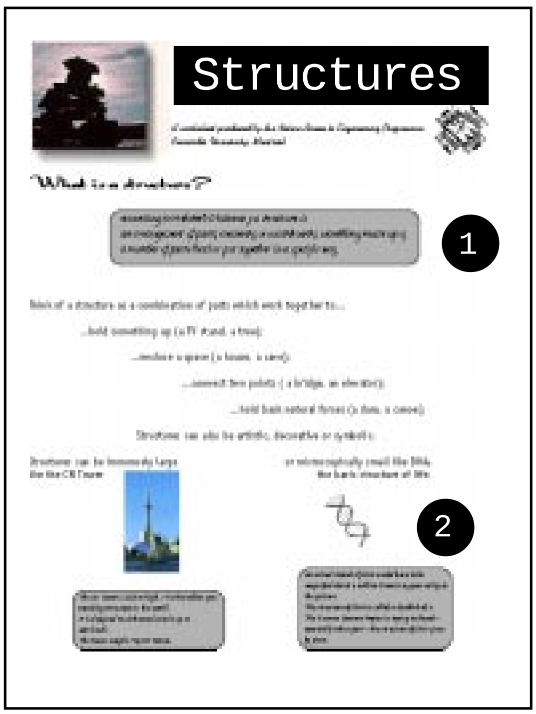
Structures

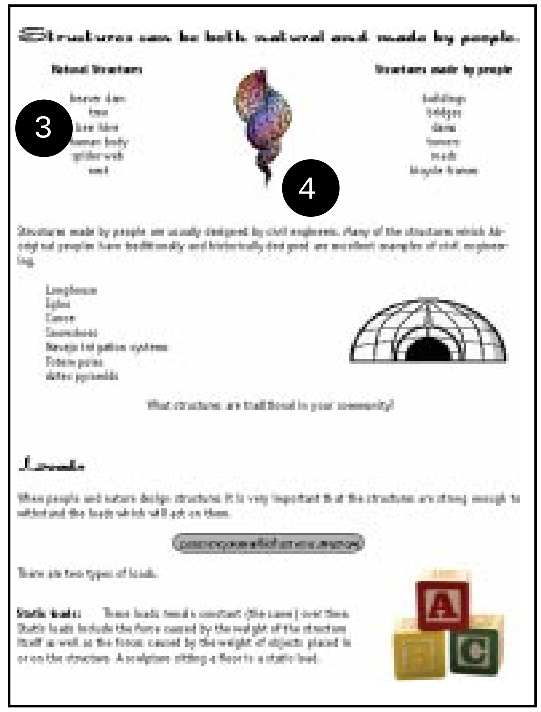


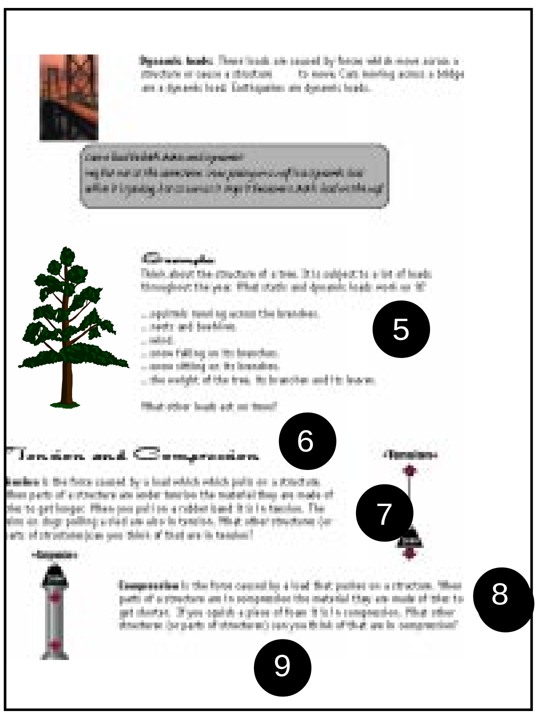
1.Definition.
Ask the students if the definition is clear. Do they understand the terms? Can they name structures based the given definition?

2.Different structures
Explain how structures are not just physical objects we can see. There are chemical structures - the bonds between atoms, for instance, and biological structures - the body’s skeleton.

3. Students can be asked to expand on the given lists.

4. Just like people use math to help them design structures, nature's structures are often very mathematical. The image of the shell structure was produced by a program which graphs mathematical formulae.





5. dynamic
static
dynamic
dynamic
static
static

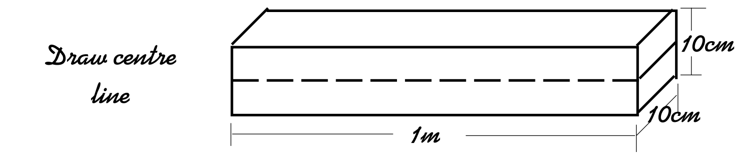
6. To demonstrate tension give each student an elastic band. They will be able to see how the rubber stretches as they apply tension. They can also use a piece of hair - long hair works better! When steel is under tension it stretches too. But as it takes a huge amount of force to stretch steel it is rare for the lengthening to be visible.

7. Rope bridges, telephone wires, guitar strings, tents, suspension bridges, the wire on a bow.

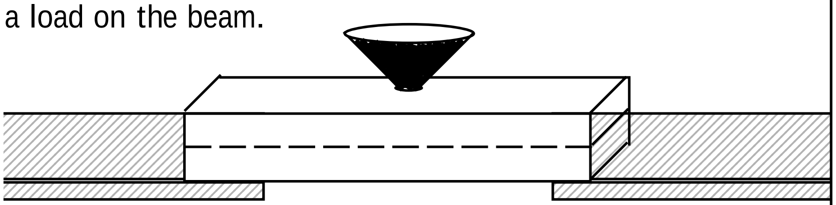
8. Compression can be demonstrated by pushing down on foam rubber, a marshmallow, or anything else which will give and then spring back once the load is removed.

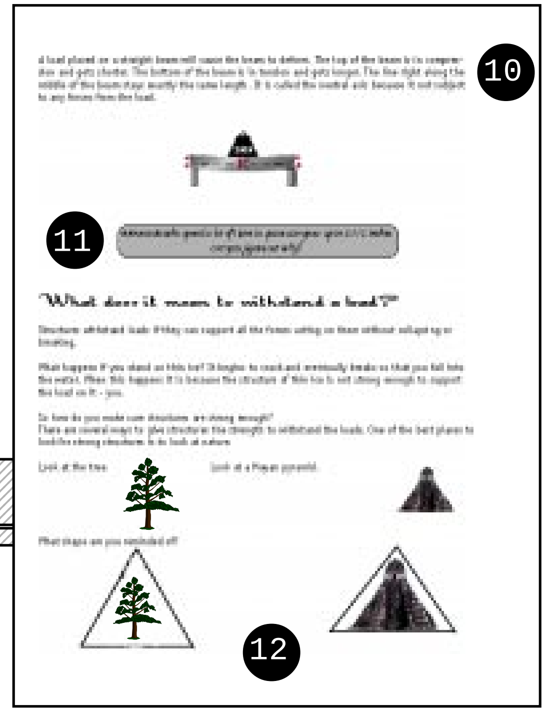
9. Pyramids, totem poles, arches, the legs of an elephant (or any animal), tree trunks etc...

10. If you wish, you can model a simple beam with foam rubber. Use a piece approximately 1m long and 10cm on each side. Draw a line up the middle.



Support the beam by placing the edges on two desks. Place a load on the beam.





Students will be able to see the bending motion which causes the top of the beam to be in compression and the bottom of the beam to be in tension. They can measure the top, bottom and middle lines of the beam to see how they change length under loading.

11. The human body is a structure. Ask students to remember the definition of structure and name some of the parts which make up our own structure (bones, skin, muscles, ligaments). On Earth our bodies a subject to compression (pushing) loads from

- their own weight caused by gravity
- the Earth’s atmosphere (which pushes down on us with a force of 16lb/sq.in. at sea level)

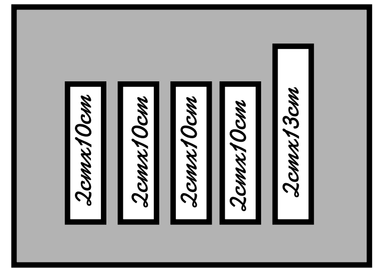
These loads cause the human (and animal) structure to compress on itself (become shorter).

In space there is no atmosphere and the effects of gravity are non-existent or negligible. Astronauts are said to be “weightless”. Because they are no longer subject to the planet’s compressive forces, their structures can stretch out to their full height and so they become taller.

12. Before continuing students could be asked to come up with ideas about what makes structures strong. Things that are important to strength include:

- thickness: thin ice is not strong, thick ice is much stronger;
- shapes;
- the strength of materials used in construction: steel and concrete are very strong, they are used to build heavy skyscrapers, wood is not as strong and cannot be used for such big buildings;
- the method of construction: Ask students if they think spiders webs would be as strong if they were just a series of parallel strings of silk as opposed to a woven web. Because the web is woven together it makes it much stronger, the strands of silk support not only their own weight but the weight of other strands as well.

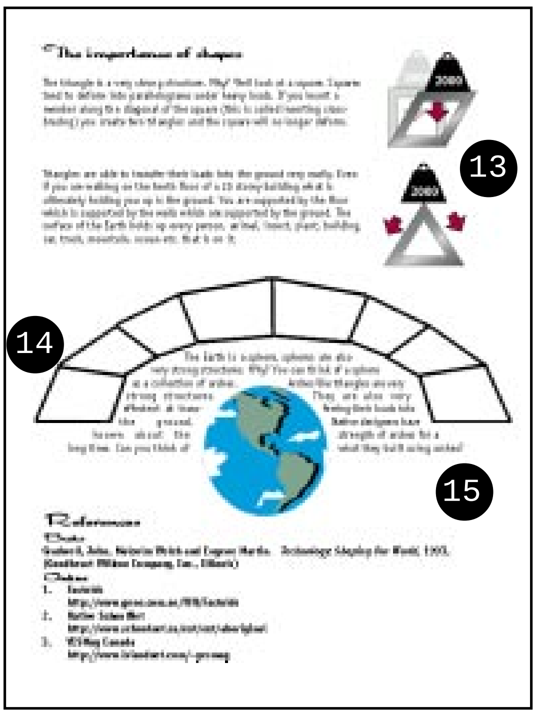
13. You and/or your students can build a model which will demonstrate how triangles are stronger than squares.



You need: scissors
heavy cardboard
4 paper fasteners (the kind with the legs which fold out)
A hole puncher

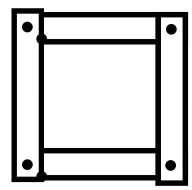
Preparation:

- draw 4, 2cm x 10 cm, rectangles on the cardboard
- draw 1, 2cm x 13 cm rectangle on the cardboard
- cut out the rectangles
- punch holes in the ends of each rectangle approximately as shown. It is important that the holes on the short sides fall in the same place on each.

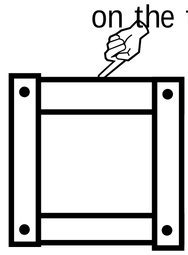


Demonstration:

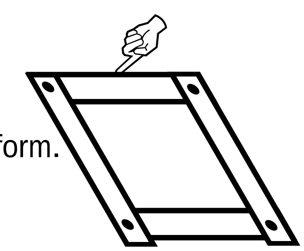
- Assemble the 4 short sides of cardboard in to a square using the paper fasteners to hold the legs together.



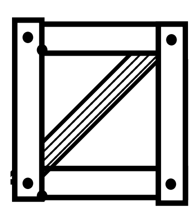
- On a table, hold the square firmly at the base. Push on the top with your finger.



The square should deform.

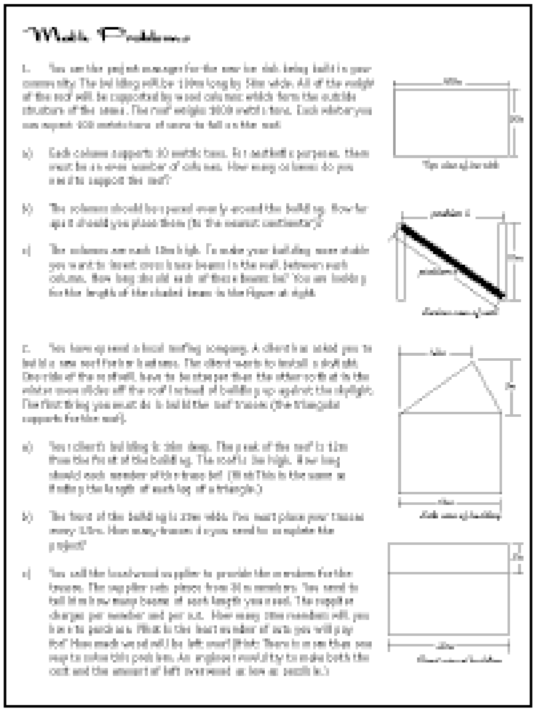


- Open up the paper fasteners on opposite corners of the square. Insert the longer rectangle along the diagonal of the square using the paper fasteners.



- Now, again holding the base firmly against a table, push down on the top of the square with your finger.

  This time the square should retain its shape. The cross-brace which was inserted transfers the load of your finger onto the table while maintaining the stability of the structure.



Solutions

Problem 1a.

I. What do you know?

- Each column holds 30 tonnes
- The roof weighs 1000 tonnes
- Snow on the roof can weigh up to 100 tonnes
- The columns must support all the weight (or the total load) on the roof.

II. The total load has to take into account the maximum weight of snow that can fall on the roof. If we were to use less than the maximum weight, we wouldn't be able to determine the correct number of columns we need to support the load. If there aren't enough columns to support the load, the roof may collapse.

Total load	= weight of the roof	+ weight of the snow
	= 1000 tonnes	+ 100 tonnes
	= 1100 tonnes	

III. Number of columns required.

If each column supports 30 tonnes, we want to know how many columns it will take to support 1100 tonnes.

$$\text{Number of columns} = \frac{\text{Total load}}{\text{Load per column}} = \frac{1100\ \text{tonnes}}{30\ \text{tonnes/column}} = 36.667\ \text{columns}$$

IV. Aesthetics require an even number of columns. If we round down to 36, there may not be enough columns to support the total load on the roof so we round up to 38 columns. This will give us more than enough columns to support the roof.

Answer = 38 columns

Enrichment:

38 columns will actually hold more weight than will ever fall on the roof. You can ask students to calculate how much each of the columns will support if the full 1100 tonne weight falls on the roof.

$$\text{Each column will support} = \frac{\text{Total load}}{\text{Number of columns}} = \frac{1100\ \text{tonnes}}{38\ \text{columns}} = 28.95\ \text{tonnes/column}$$

You can also ask a question like...

A freak snow storm occurs, there is the potential that more than 100 tonnes of snow will be on the roof of the arena. How much snow can the roof support before you have to worry about it collapsing?

Because we have more columns than we need to support the maximum design load, the roof can actually hold more weight than it theoretically has to.

Total weight that can be supported = # of columns x weight each column can support
= 38 columns x 30 tonnes/column
= 1140 tonnes

We know that 1000 tonnes will always be the weight of the roof, so the columns can support

1140 tonnes - 1000 tonnes = 140 tonnes of extra weight.

So the roof will hold 140 tonnes of snow or 40 more tonnes than the maximum design load.

Problem 1b.

I. What do you know?

- Have 38 columns
- Length of the building is 100m
- The width of the building is 50m

II. Find the perimeter of the building.

The perimeter is the total distance around the outside of the building.

Perimeter = 2(length) + 2(width)
= 2(100m) + 2(50m)
= 200m + 100m
= 300m

III. Distance between the columns.

To find the distance between the columns you assume that you have a 300 m straight line and the first column is at 0 meters.

$$\text{Distance between columns} = \frac{\text{Perimeter}}{\text{\# of columns}} = \frac{300\text{m}}{38 \text{ columns}} = 7.89\text{m}$$

Answer = 7.89m

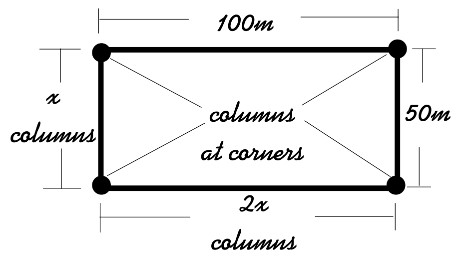
Enrichment:

This problem assumes that the columns are evenly spaced around the buildings perimeter. It also assumes the measurement between columns is from the centre point in one column to the centre point in the next as no dimensions are provided for width or depth of the columns. In reality, an engineer would place a column at each corner of the building. You could have a discussion with the students how they would distribute the remaining 34 columns to support the roof.

There will be many ways to do this, some ways are more sound from an engineering perspective than others.

For instance…

The columns should still be placed as evenly as possible. We know that there will be one column at each corner.



The remaining 34 columns should be spaced in some logical fashion. The length of the building is twice the width of the building. By logical extension we can assume that twice as much weight will be supported by the columns along the length of the building as by those along the width. We can preserve the two to one ratio so that we place x of the remaining columns along each 50m side and 2x columns along each 100m side. The total number of columns is still 38, so we can solve the problem through an algebraic equation…

$$
\begin{aligned}
38 &= 2(2x) + 2(x) + 4 \\
&= 4x + 2x + 4 \\
&= 6x + 4 \\
38 - 4 &= 6x \\
34 &= 6x \\
x &= 5.67
\end{aligned}
$$

there are 5.67 columns along each 50m side and 11.34 columns along each 100m side. (In real life you would choose to put 5 or 6 columns on each 50m side and adjust the number of columns on the 100m sides accordingly.)

The spacing of these columns would be

for the 100m sides $\frac{100m}{11.34 \text{ columns}} = 8.82m$

for the 50m sides $\frac{50m}{5.67 \text{ columns}} = 8.82m$

Problem 1c.

I. What do you know?

- The column (a) is 10m high
- The distance between columns (b) is 7.89 m
- You want to find the diagonal distance between the top of one column and the bottom of adjacent column. The diagonal is the hypotenuse of a triangle.

II. Length of cross bracing

Pythagorean theorum:

$$
\begin{aligned}
c^2 &= a^2 + b^2 \\
&= (10)^2 + (7.89)^2 \\
&= 100 + 62.25 \\
&= 162.25 \\
c &= \sqrt{162.25} \\
&= 12.74\text{m}
\end{aligned}
$$

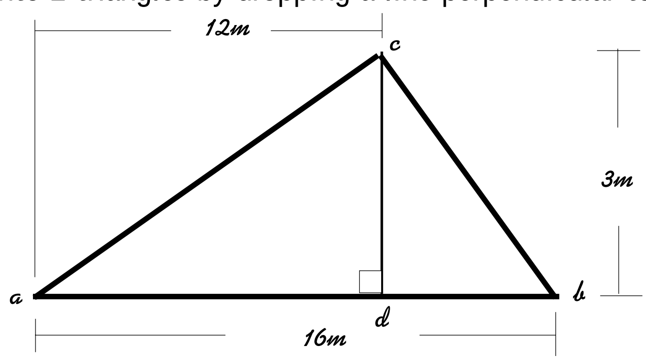
Answer = 12.74m

Problem 2a

I. What do you know?

- The roof truss is a triangle, call it Δabc
- The lengths are as given.

II. **Δabc** can be split into 2 triangles by dropping a line perpendicular to line ab from point c. Call the point where the perpendicular hits line $\overline{ab}$, d.



We now know $\overline{ab} = 16\text{m}$, $\overline{ad} = 12\text{m}$, $\overline{cd} = 3\text{m}$

$$
\begin{aligned}
\overline{db} &= \overline{ab} - \overline{ad} \\
&= 16\text{m} - 12\text{m} \\
&= 4\text{m}
\end{aligned}
$$

III. **You now have two right triangles** in which the length of two sides is known in each. The remaining sides can be determined by Pythagorean theorum.

$$\overline{ac}^2 = \overline{ad}^2 + \overline{cd}^2 = (12)^2 + (3)^2 = 144 + 9 = 153$$

$$\overline{ac} = \sqrt{153} = 12.37m$$

$$\overline{cb}^2 = \overline{db}^2 + \overline{cd}^2 = (4)^2 + (3)^2 = 16 + 9 = 25$$

$$\overline{cb} = \sqrt{25} = 5m$$

Answer
ab = 16m
ac = 12.37m
cb = 5m

Problem 2b.

I. **What do you know?**

- The front of the building is 20m long
- The trusses are placed every 1.5m.

II. **Number of trusses**

$$\text{Number of trusses required} = \frac{\text{building width}}{\text{Spacing of trusses}} = \frac{20m}{1.5m/truss} = 30 \text{ trusses}$$

Answer = 30 trusses

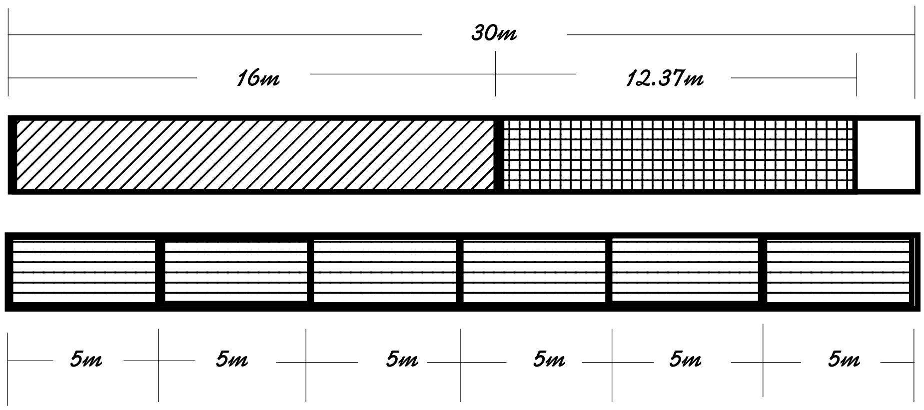
Problem 2c. (Note there are many solutions to this problem.)

I. **What do you know?**

- Need 30 trusses
- Each truss has 3 members lengths, 16m, 12.37m, 5m, therefore need 30 of each size member to make the trusses.
- The supplier cuts from members which are 30m long.

II. **Try to fit** the required lengths into the 30m members.

If the members were to be cut as follows you would need to cut 30 pieces of wood to get enough 16m and 12.37m lengths and 5 pieces of wood to get enough 5m lengths. So in total you would need 35 pieces of wood.



III. **# cuts you pay for**

(2 cuts for each 1x16m/12.37m length)30 members +(5 cuts in each 6x5m length)5 members
= 60 + 25
= 85 cuts

IV. **Left over wood.**
There is only extra wood in the members used for the 16m/12.37m lengths.

leftover wood per 30m member =
Total length of the member - length to be used in trusses
= 30m - (16m + 12.37m)
= 30m - 28.37
= 1.63m

You need 30 members so,
Total leftover wood = 30(leftover wood per 30m member)
= 30(1.63)
= 48.90m

Answer (for this particular solution)
 # 30m members required = 35 members
 # Cuts required = 85 cuts
Extra wood = 48.90m

14. You can also demonstrate the strength of an arch. (The following can also be set up as a small group exercise in class.)

You need: A piece of paper
two heavy books
a few 1 or 2 dollar coins

Demonstration/Exercise

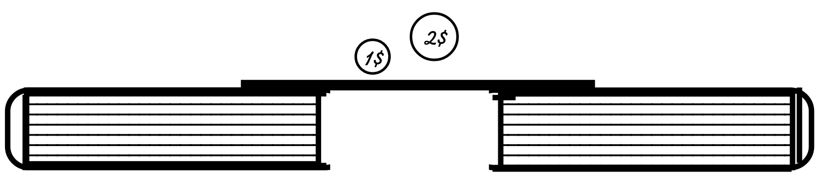
- Place or have the students place the books about 6 inches apart on a table.

- Tell the students that the books represent two mountains, the space between them a gorge or a river, the piece of paper a bridge, and the coins cars or people who need to cross the river. The people need to get over the river safely. If you are doing this as an exercise ask them to try different methods up setting up the bridge so that the people can get across.

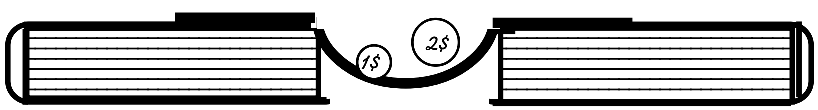
  If you are doing a demonstration, follow these steps.

- Put the piece of paper across the top of the two books.

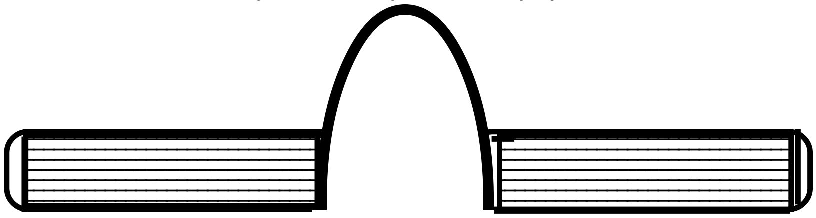
- Place one or two coins on the paper over the space between the books.



- The paper should (if you are putting enough weight on it) sag into the space between the books. The sagging occurs because nothing is really supporting the ends of the bridge (piece of paper). A much better bridge would be one in which the bridge was better supported by the ground.



- Now, leave the books as they are, but place the paper between them in an arch.



- Again, place the coins on the paper.

- This time, the paper should hold up the coins. Because the bridge (paper) is supported by the ground (books) the load of the people (coins) on the bridge is also supported by the ground.

15. Igloos are also made of a series of arches.