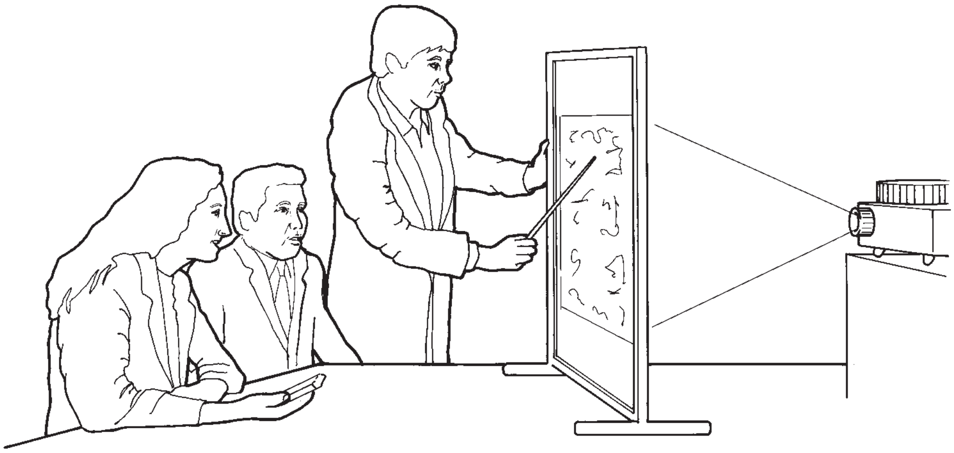
DESIGNING AND MAKING A LIGHTWEIGHT FOLDING PROJECTION SCREEN

Very often a picture can explain something much better than words but as a means of communication it is often taken for granted. When communicating information to a group of people the most important factor is the size of the image. The larger the image, the more people will see it. For this reason a screen is often used, on which a still or moving image is projected.

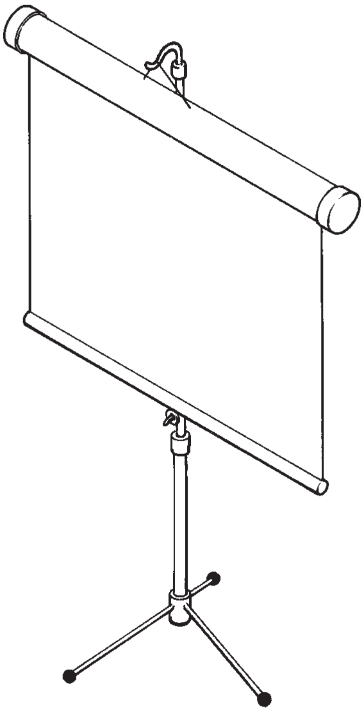
The standard method of projecting either slides or moving images is by a method known as front projection. This requires a projector to transmit the image from a position in front of the screen onto the fabric. It is however becoming more appropriate to use a rear projection method. In this case the fabric of the screen is translucent and allows the image to be viewed through the screen by the audience seated in front. The advantage of this method is that it removes the need for the projection device to be placed on the table in front of the screen and allows it to be situated behind the screen.

For small group presentations such as business meetings, clients expect a high standard of presentation. It is often necessary in this type of meeting to illustrate areas of the screen with a pointer, that with front projection would obscure the image. For ease of viewing it is sometimes more useful to have a small group gathered around the screen. This is also not always possible with front projection as the projector may obscure the clients' view or the clients may themselves obstruct the projected image.



The standard projection screen consists of white fabric wound under spring tension into a tube. The end of the screen is supported by a rigid pole which holds the screen edge straight and stops it from creasing as it is extended. As the screen is returned to the roller in the tube under spring tension, it has to be held open.

A collapsible metal tripod support is usually used to hold the screen open and in the right position. The stand is free standing from the floor which can result in it being rather large. As the stand supports the screen from behind, it also makes it unsuitable for the rear projection method.



DESIGN OPPORTUNITIES

Design and make a self supporting screen system which could be used for both front or rear projection purposes or both. The screen must be self supporting on the end of a desk or table or standing on the floor. The screen will probably need to fold down for easy transportation and be able to be assembled with the minimum of skill and time.

DESIGN CONSIDERATIONS

The success of your product will depend upon how well it satisfies the factors identified in a design brief and those which you list in your own specification.

Perhaps the three major considerations will be the ability of the structure to maintain tension on the screen, the stability of the screen and the folding mechanism.

STRUCTURE

One of the most obvious ways forward is to utilise a frame structure to support the screen. In its simplest form the frame could be either a square or rectangle.

Both squares and rectangles have a tendency to collapse sideways when compressed, particularly if the corner joints are free to move.

One solution is to place a member diagonally forming two triangles. Triangulation is a common method of increasing the stability of frame structures. By placing just one member in the position shown it is possible for it to act as a strut or a tie depending upon the direction of collapse.

If, as shown in Fig. 1, the frame collapses to the right, the diagonal member will be put under tension and resist the movement. If, as shown in Fig. 2, the frame collapses to the left, the diagonal member will be put under compression and resist the movement.

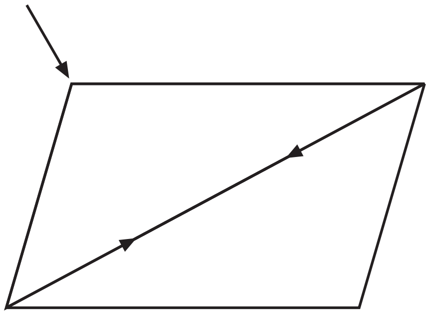


Fig 1

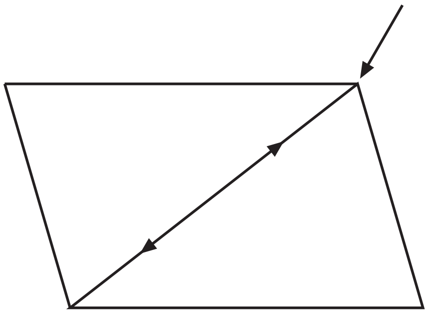
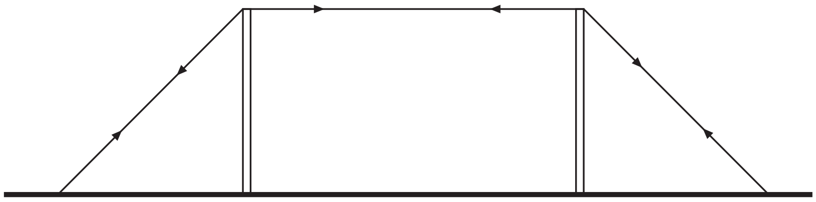


Fig 2

Unfortunately the picture cannot be obstructed by a diagonal member across the screen but the same principles apply to supports placed outside the frame.

It could be useful to look at other design examples where fabric is under tension. Shown here are two examples that use principles which may be applied to your design.

Ridge tents use a very simple frame structure to support the fabric. A side view of a ridge tent shows two poles placed one at either end which act as struts to hold the fabric up. Guy ropes attached to the top of the poles keep them upright and the fabric taut across the top. The fabric of the tent is in tension and acts as a tie to prevent the poles from being pulled apart by the tensile force of the guy ropes. The poles are put under compression by the downward force of the guy ropes. An end view of the tent shows that the guy ropes pull at two different angles in order to keep the poles stable.



This is a principle suitable for screen support. You may however, find it necessary to alter the position of the ties, particularly if you don't want them to come too far forward on the desk.

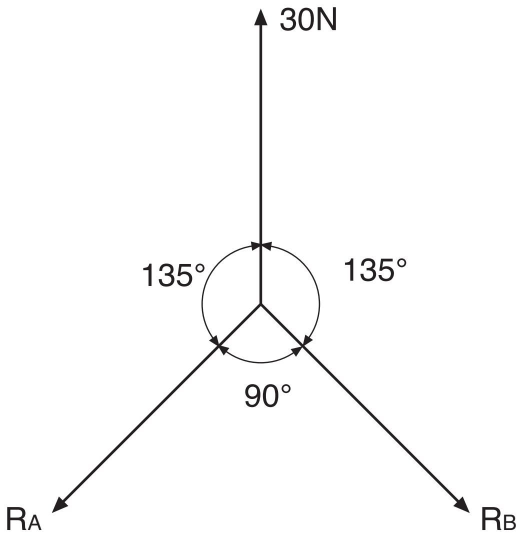
In this type of structure the most important factor is to keep the tension of the screen in equilibrium with the tension of the ties otherwise it would collapse. The combined tie forces must produce a **Resultant Force** which is equal and opposite to the tension force in the screen.

When the angles of the ties are altered the force on each tie will change. The forces on each tie can be calculated using **Lami's Theorem**.

Lami's theorem states that **if three forces in the same plane are in equilibrium, each is proportional to the sine of the angle between the other two.**

By simple experimentation the force needed to maintain tension on the screen can be found. In this case we will take it as being 30N.

By looking at one half of the structure we can calculate the forces present in the two ties. The illustration shows a vector diagram of half of the structure viewed from above. The angle between the two ties is 90°. The two ties are labelled RA and RB.



Using Lami's theorem:

$$\frac{RA}{\text{Sin } 135°} = \frac{RB}{\text{Sin } 135°} = \frac{15}{\text{Sin } 90°}$$

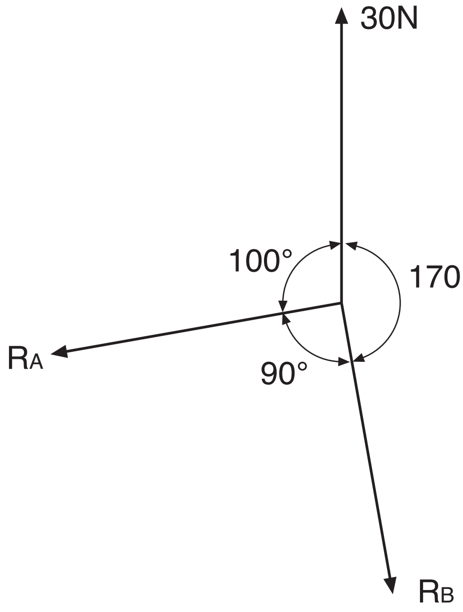
Therefore,

$$RA = 30 \times \frac{\text{Sin } 135°}{\text{Sin } 90°} = 21.2 \text{ N}$$

$$RB = 30 \times \frac{\text{Sin } 135°}{\text{Sin } 90°} = 21.2 \text{ N}$$

For the structure to remain standing each tie must provide a tensile force of 21.2 N.

If the angle between the ties and the structure is altered then the forces in the ties will change. The diagram shows the ties positioned more to the side and back of the screen.



Using Lami's theorem:

$$\frac{RA}{\text{Sin } 170°} = \frac{RB}{\text{Sin } 100°} = \frac{30}{\text{Sin } 90°}$$

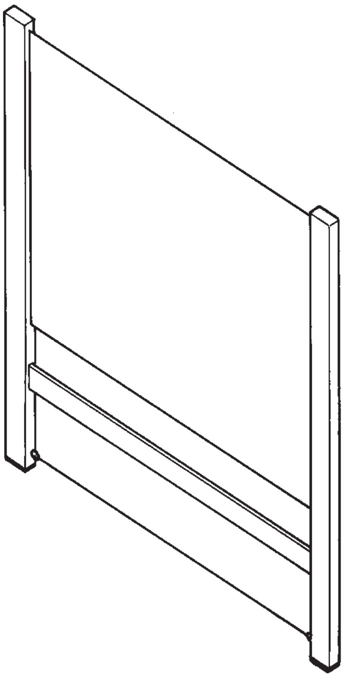
Therefore,

$$RA = 30 \times \frac{\text{Sin } 170°}{\text{Sin } 90°} = 5.22 \text{ N}$$

$$RB = 30 \times \frac{\text{Sin } 100°}{\text{Sin } 90°} = 29.55 \text{ N}$$

The tie R_B is now subjected to a much higher force than R_A and therefore would need to be much stronger.

An alternative method to using ties on either side of the screen would be to use a bracing member between the two struts below the screen and a single tie below that. Using this method the bracing member would be in compression and the two vertical members would be exposed to bending forces.



The tie force would need to be equal to the load on the screen to maintain equilibrium and to keep the screen taut. The tie force can be calculated using moments.

If you assume that the tension force needed to keep the screen taught is 30N, then each side member will need to pull equally with a tensile force of 30N. We will assume that the screen load acts at its centre point.

From the sizes shown you can calculate the force that the tie will be subjected to.

CWM = 0.3 × 30

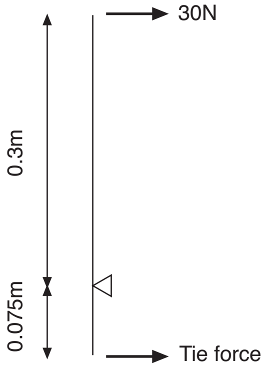
CWM = 9 Nm

ACWM = CWM

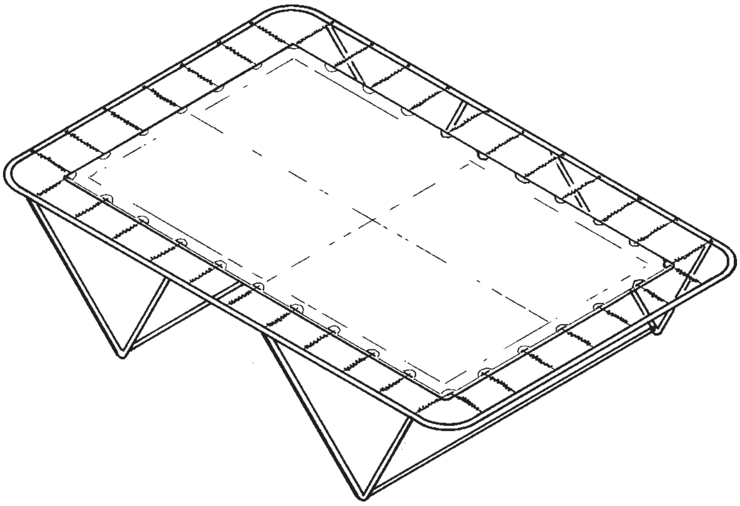
Tie force × 0.075 = 9

Tie force = $\frac{9}{0.075}$

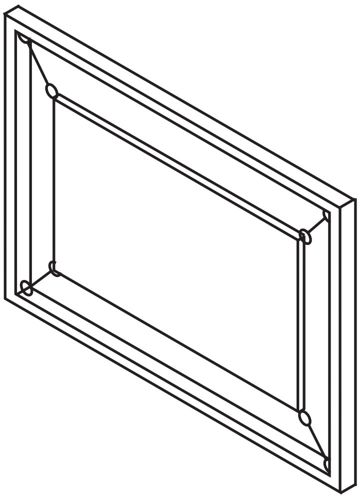
Tie force = 120 N



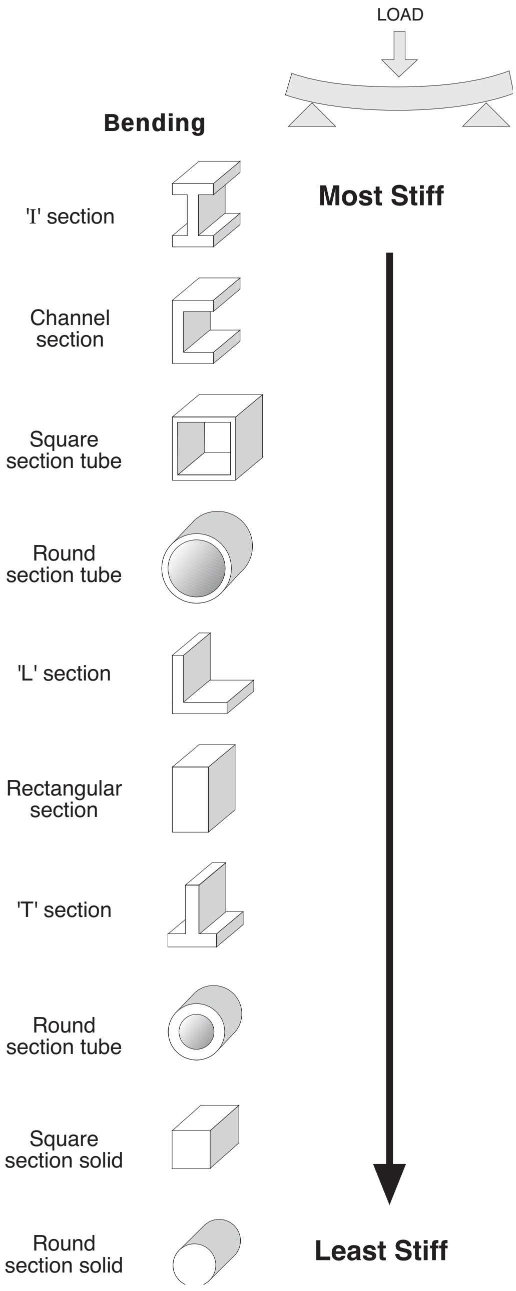
Another method of keeping the fabric taut is used on a trampoline. A rigid frame surrounds the fabric. A large number of ties are connected between the fabric and the frame maintaining the tension on the fabric. A large number of ties are needed because of the dynamic force caused by people bouncing on the fabric.

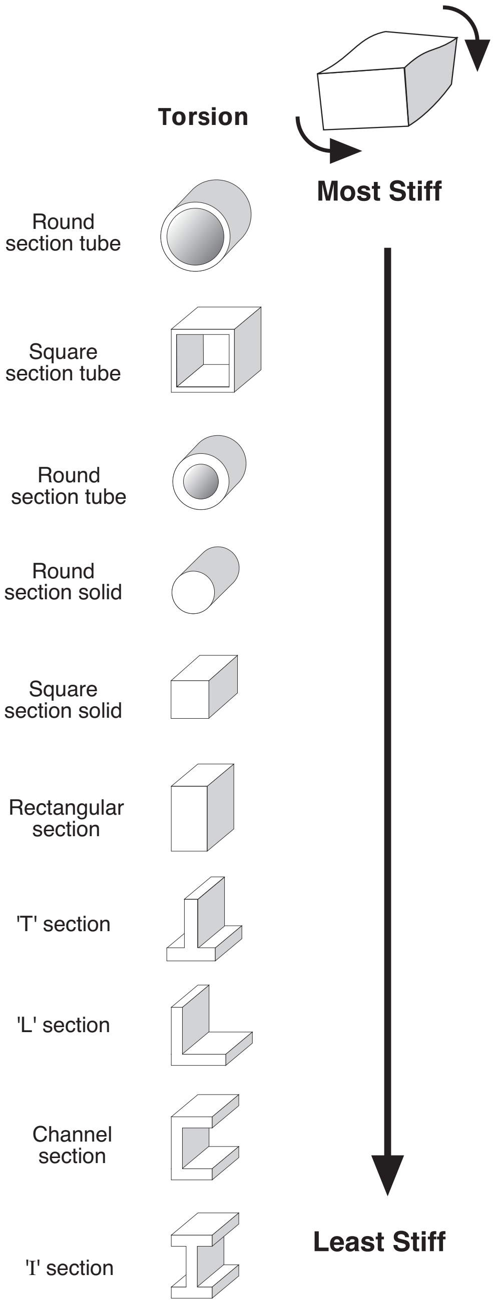


If this method of support were to be used for a projector screen then the number of ties could be greatly reduced. To provide overall tension on a square screen only four ties are needed. If one tie was placed at each corner and acted at an angle of 45° then the screen would be pulled taut. By using this method the frame could be hinged at the four corners as the tension created by the opposing ties and the fabric of the screen acts as the diagonal members.



The success of this method would rely on the rigidity of the frame. With tension being applied diagonally there will be a tendency for the frame to twist causing torsion in the frame members and corner joints. Unless this can be prevented the screen will not remain flat. The table shown is useful for selecting different cross-sections of materials by their resistance to torsional and bending forces for the same cross sectional area.

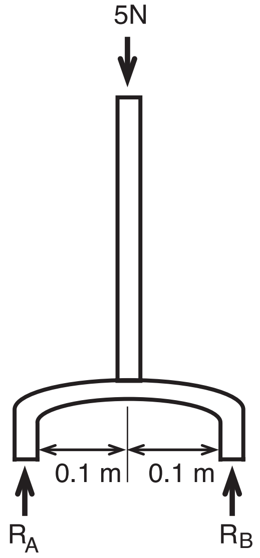




STABILITY

Your solution may require a separate stand to support the screen frame. With any stand one of the most important considerations must be stability. Depending upon the design of the stand, the centre of gravity of the screen may alter as its angle is adjusted. The weight of the screen will produce a downward force on the desk.

Fig.1. shows the side view of a simple screen and stand with the screen in the vertical position. The legs of the stand provide the reaction points with the table (labelled R_A and R_B). In this position the force will be divided equally between the two reaction points. We can prove this by calculation.



Assume that the load of the screen and stand is 5N

Imagine that R_A has been removed. The member will have an anti-clockwise moment of:

5N × 0.1m = 0.5 Nm

R_A needs to oppose this moment.

$R_A \times 0.2 = 0.5$ Nm

$R_A = \frac{0.5}{0.2} = 2.5$ N

An alternative way to calculate R_A and R_B which is useful when there are more than three forces is as follows:

Take moments about R_B:

$R_A \times 0.2 = 5 \times 0.1$

$R_A = \frac{5 \times 0.1}{0.2} = 2.5$ N

Take moments about R_A:

$R_B \times 0.2 = 5 \times 0.1$

$R_B = \frac{5 \times 0.1}{0.2} = 2.5$ N

The total reaction force must be equal and opposite to the force applied by the screen and the stand.

Therefore:

$R_A + R_B = 5$ N

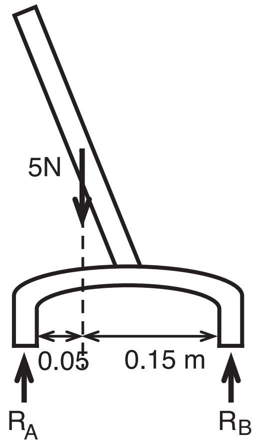
$R_B = 5 - R_A$

$R_B = 5 - 2.5$

$R_B = 2.5$ N

R_A and R_B oppose the force of the screen and stand equally.

If the angle of the screen is altered the centre of gravity moves more towards R_A.



When we repeat the calculation:

$R_B = 5 \times 0.15 = 0.75$ Nm

R_A needs to oppose this movement.

$R_A \times 0.2 = 0.75$ Nm

$$R_A = \frac{0.75}{0.2} = 3.75 \text{ N}$$

Therefore:

$R_A + R_B = 5$ N

$R_B = 5 - R_A$

$R_B = 5 - 3.75$

$R_B = 1.25$ N

It can now be seen that reaction point R_A is exposed to a much higher force than R_B.

The screen becomes less stable as the centre of gravity gets closer to either of the reaction points. If the centre of gravity is taken outside of the reaction points the structure will become unstable.

Technical fact
A general rule: The resultant of all the forces acting on a structure (including its own weight) must pass through the base of the structure if the structure is to be stable

JOINING MATERIALS

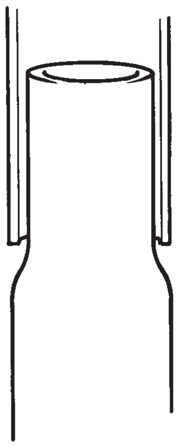
Another important design consideration is the method by which the members of a frame structure will be joined together. This will obviously depend upon the material that you have chosen but there are three broad categories:

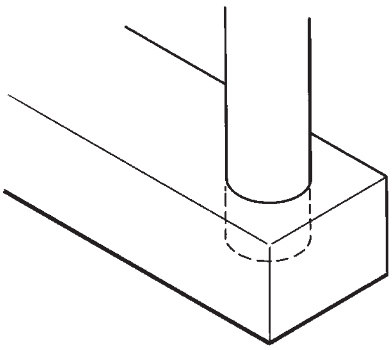
1. Permanent fixing
If two members are to be joined together so that they will not move or come apart, we have a permanent fixing. The possible methods are too numerous to mention here but there are many text books that deal with suitable methods for particular materials.

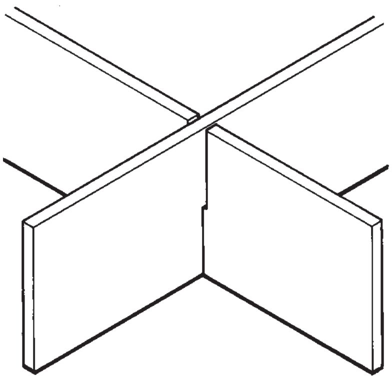
2. Rigid fixing
When two members are joined together so that they will not move but may be taken apart, we have a rigid fixing. There are many examples of this in use. A tent pole is usually made from a number of sections which have been tapered at one end to allow the top of one pole to be inserted into the bottom of the next.

A horizontal member of suitable depth could have a hole drilled into it to allow a round section tube to slot in and stand vertical. The sides of the hole would support the vertical member without the need for permanent fixing.

Flat sheet material is often slotted together by cutting halfway through the width of the material and interlocking the two pieces. This allows relatively thin sheet material to be stable when standing on its edge.

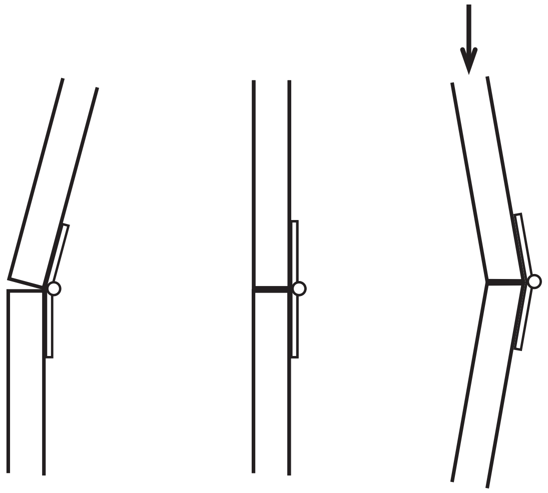




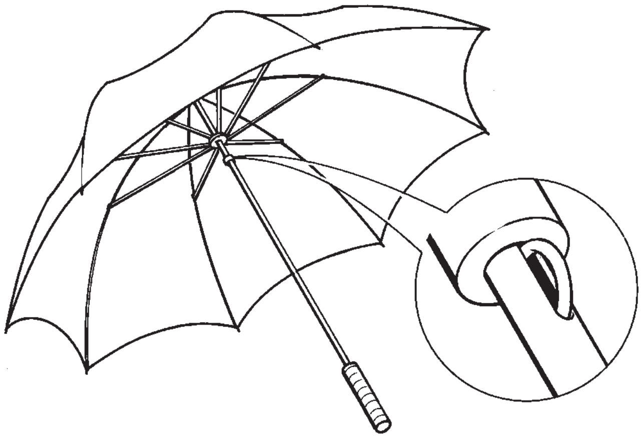


3. Flexible Joints

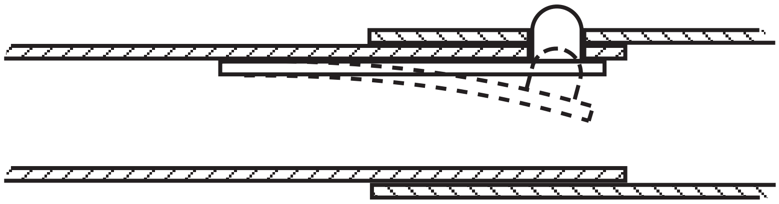
When two members are joined together to allow movement we have a flexible joint. If your screen is to be portable, the use of flexible joints may be necessary for part of the structure. Hinges are probably the most common form of flexible joint with many variations available. If a hinge is carefully positioned it will allow the member to be folded but when unfolded it will form a rigid member. It may be necessary to make a hinged joint in a vertical member pass just beyond the vertical to prevent compression forces pushing the joint open again.



Simple locking devices are often used to allow folding or collapse of members. An umbrella has a simple spring clip on either end of its main support. As the spring is pressed it allows the sliding part to ride over the clip and hold the required position.

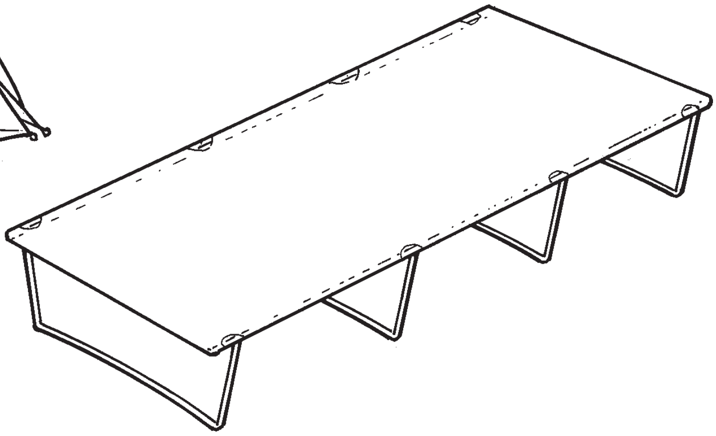


Spring-loaded buttons are used in telescopic poles where a precise location is required. Holes are drilled in the outer tube and a spring loaded button is mounted on the inner tube. When the hole lines up with the button it springs into place, preventing the poles from sliding. To be released the button needs to be pressed below the surface of the tube and the holes misaligned.



The type of folding mechanism that you choose will depend upon the materials you are using and arrangement of your structure. Remember, it needs to fold to a convenient size for easy storage and transportation and also needs to be stable when in use.

It may be worth investigating products which use frames and fabrics in tension but that are designed to fold. The traditional camp bed and the modern dome tent are two examples of structures which are designed to be relatively easy to dismantle but stable and strong when in use.



The success of your product will depend upon how well you can satisfy the needs of the design brief and your own specification. The most successful products will be as light as possible, as structurally strong as is necessary, fold and unfold easily and be both ergonomically sound and aesthetically pleasing.